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Database Technologies

Master of Computer Applications (MCA)
Semester - 1

SELF LEARNING MATERIAL

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Master of Computer Applications

MCA-103

Database Technologies

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COURSE INTRODUCTION

Databases play a crucial role in managing, storing, and retrieving structured information efficiently. This course provides a comprehensive understanding of database management systems (DBMS), covering fundamental concepts, relational modeling, SQL, transaction management, and object-oriented databases.

Module1: Introduction to Database Management System

This Module lays the foundation by introducing database management systems, their evolution, key characteristics, advantages, and real-world applications. It explores different types of DBMS and their significance in modern computing environments.

Module2: Relational Data Modeling and Database Design

A well-structured database starts with a robust design. This Module covers relational data modeling, entity-relationship (ER) diagrams, normalization techniques, and schema design principles to ensure data consistency and integrity.

Module 3: SQL and Procedural SQL

Structured Query Language (SQL) is the backbone of database interaction. This Module introduces fundamental SQL commands and extends into procedural SQL, covering stored procedures, triggers, and functions to enhance database operations.

Module 4: Transaction Management and Concurrency

Data consistency and reliability are essential in multi-user environments. This Module discusses ACID properties, transaction processing, concurrency control techniques, and recovery mechanisms to ensure data integrity in database systems.

Module 5: Object-Oriented Database

The evolution of data storage has led to object-oriented databases (OODB), which integrate object-oriented principles with database management. This Module explores OODB concepts, advantages, and their application in complex data structures.

By the end of this course, learners will have a strong grasp of database concepts, design methodologies, and practical SQL skills to manage and optimize databases efficiently.

MODULE 1
INTRODUCTION TO DATABASE MANAGEMENT SYSTEM

LEARNING OUTCOMES

By the end of this Unit, students will be able to:

- Understand the purpose of database systems, including data management, integrity, and security.
- Explain data abstraction, data models (relational, E-R, object-based, semi-structured), and database languages.
- Describe database architecture, data storage, indexing, and query processing for efficient retrieval.
- Identify the roles of database users and administrators, focusing on database security, maintenance, and management.

Unit 1: Purpose of Database Systems

1.1 Purpose of Database Systems

It is software used to manage the efficient storage, retrieval, and manipulation of data. Its A2F architecture guarantees data integrity, security, and accessibility for all users and applications.

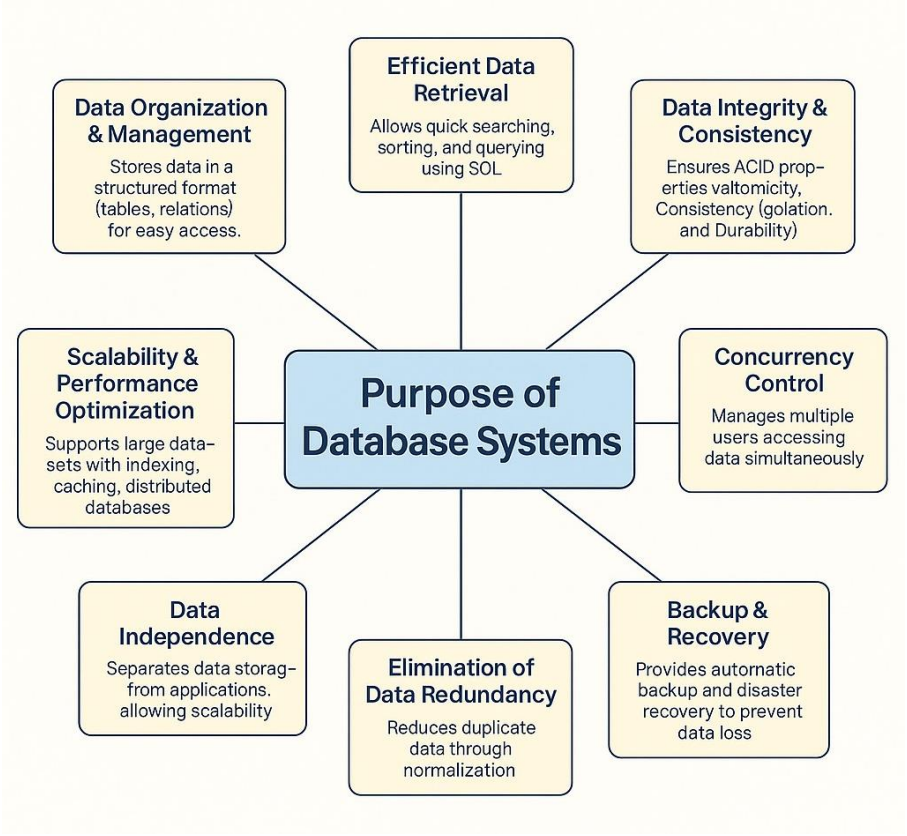


Fig.1.1: Purpose of Database Systems

Purpose of Database Systems

Purpose	Description
Data Organization & Management	Stores data in a structured format (tables, relations) for easy access.
Efficient Data Retrieval	Allows quick searching, sorting, and querying using SQL.
Data Integrity & Consistency	Ensures ACID properties (Atomicity, Consistency, Isolation, and Durability).
Data Security & Access Control	Restricts access using authentication & authorization (user roles, permissions).
Concurrency Control	Manages multiple users accessing data simultaneously.

Backup & Recovery	Provides automatic backup and disaster recovery to prevent data loss.
7. Data Independence	Separates data storage from applications, allowing scalability.
8. Elimination of Data Redundancy	Reduces duplicate data through normalization.
9. Scalability & Performance Optimization	Supports large datasets with indexing, caching, and distributed databases.

3. Example: Database Management System (DBMS)

A DBMS (e.g., MySQL, PostgreSQL, and MongoDB) helps in:

- Storing customer records in an e-commerce site.
- Managing bank transactions securely.
- Handling real-time analytics in businesses.

Modern applications such as banking, healthcare, e-commerce, and cloud computing demand efficient, secure, and scalable data management and that is where Database Systems comes into the picture**.**

1.2 View of Data: Data Abstraction, Instances and Schemas

A DBMS (database management system) is a software used for storing, retrieving and managing data. Databases utilize data abstraction, instances, and schemas to efficiently manage complex data and to organize and present data in the most effective way.

Data Abstraction

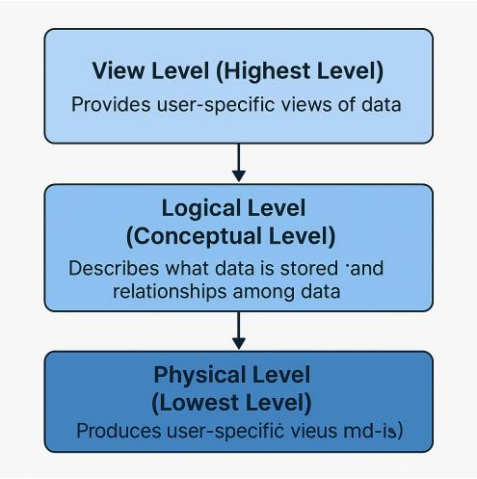


Fig.1.2: Levels of Data Abstraction

Data Abstraction means displaying only the relevant data while hiding the background details about how the data is stored and maintained. It

contributes in handling large data bases effectively by dividing the data representation into three levels.

2.2 Levels of Data Abstraction

Level	Description	Example
1. Physical Level (Lowest Level)	Describes how data is stored in memory (files, indexes, pointers).	Data stored as B-trees, Hash Tables, Blocks on Disk.
2. Logical Level (Conceptual Level)	Describes what data is stored and relationships among data.	Tables: Students (ID, Name, Course, Age)
3. View Level (Highest Level)	Provides user-specific views of the data.	A university student can see only his/her records, while an admin can access all student details.

Example: In a banking system:

- Physical Level: Data is stored as indexed files on a disk.
- Logical Level: Tables store account details like Account_No, Name, Balance.
- View Level: A customer sees only their transactions, but the manager sees all accounts.

3. Instances and Schemas

Instance:

• Eg: The current state of the database at a specific point in time.

• Database keeps updating the instances as the data keeps changing.

Example:

A Students table contains:

- ID Name Age Course
- 101 Alex 21 CS
- 102 Emma 22 IT

• The Students table above is a snapshot of the Students table at this time.

• The instance changes when a new student joins.

Schema (Structure of the Database)

• Schema is the architecture of the database is stable.
• Describes tables, attributes, relationships, constraints.

For example: A schema for Students table:

```
CREATE TABLE Students (
ID INT PRIMARY KEY,
Name VARCHAR(50),
Age INT,
Course VARCHAR(50)
);
```

• All records share the same schema, even though we can add/delete records

Types of Schemas:

Schema Type	Description
Physical Schema	Defines storage details (indexes, partitioning).
Logical Schema	Defines tables, relationships, constraints.

4. Difference Between Instance and Schema

Feature	Instance	Schema
Definition	Snapshot of data at a given moment	Blueprint or structure of the database
Changes	Frequently changes	Fixed unless modified by DBA
Example	Current rows in Students table	Table design (ID, Name, Age, Course)

- Data Abstraction facilitates easier management of database, separates data storage, structure and how user view.
- Instances contain the most current data, which changes continuously.
- Schemas dictate the architecture of a database, ownership and accessibility

1.3 Data Models: Relational Model, Entity-Relationship Model, Object-Based Data Model, semi structured Data Model, Database Languages

Data models are abstract models that organize the elements of data and how they relate to one another and to the properties of real-world entities. Here's a snapshot of the data models and database languages you listed:

Data Models

1. **Relational Model:**
   - **Description:** In contrast, the relational model stores data in one or more tables (or 'relations') that consist of rows and columns, where each row is uniquely identified by a key. Rows are referred to as records or tuples, and columns as attributes or fields.
     - Tables, Rows (Tuples), Columns (Attributes)
     - Primary Keys and Foreign Keys
     - Relationships between tables
     - Normalization (removing redundancy and ensuring consistency)
   - **Pros:**
     - **Easy to use** – simple table structure.
     - **Reliable** – strong data integrity with keys and constraints.
     - **Flexible** – supports a wide variety of queries.
     - **Powerful** – can handle complex joins and operations.
   - **Examples:** MySQL, PostgreSQL, Oracle.

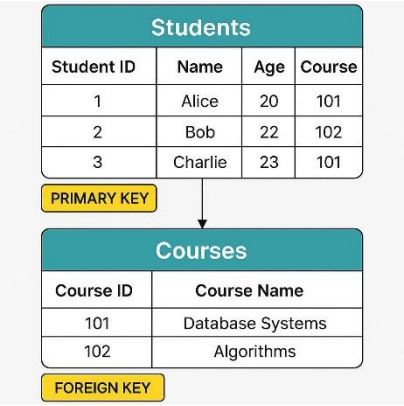


Fig.2.1.: Relational Model Example

2. **Entity-Relationship Model (ER Model):**
   - **Definition:** The ER model is a high-level data model that provides a conceptual representation of the data structure of a database. This use ER diagrams for representation of your entities (tables), attributes (columns), and associations.
   - **Keywords:** Entities, attributes, relationships, cardinality and participation constraints.

     - **Entities** – Real-world objects or concepts (e.g., Student, Course).
     - **Attributes** – Properties or fields of an entity (e.g., Student Name, CourseID).
     - **Relationships** – Connections between entities (e.g., *enrolled in*).
     - **Cardinality** – The number of instances in a relationship (e.g., one-to-many).
     - **Participation Constraints** – Whether all or some entity instances participate in a relationship (total or partial participation).

   - **Strengths**: Simple to comprehend and picture, benefits database design.
     - **Easy to visualize** – Simple diagrams for complex systems.
     - **Great for design** – Helps in planning before implementation.
     - **Improves communication** – Everyone (even non-technical users) can understand the database structure.
   - **Example(s)--** Usually you will use this during the design phase before creating a relational database, you might design an ER diagram:

     - **Entity:** `Student` with attributes (StudentID, Name, Age)
     - **Entity:** `Course` with attributes (CourseID, CourseName)
     - **Relationship:** `EnrolledIn` (Student ↔ Course) with cardinality (many students can enroll in many courses).

3. **Object-Based Data Model:**

   - **Description:**
     The Object-Based Data Model is an extension of the relational

model that incorporates object-oriented concepts. It supports complex data types, encapsulation, inheritance, and polymorphism—making it ideal for representing real-world objects in a database.

- **Key Concepts:**
  - **Objects** – Real-world entities represented as objects with state and behaviours.
  - **Classes** – Blueprints that define the structure and behaviours of objects.
  - **Inheritance** – Classes can inherit attributes and methods from parent classes.
  - **Encapsulation** – Data and methods are bundled together.
  - **Polymorphism** – Same method or operation can behave differently based on the object.
- **Benefits:**
  - **Handles complex data schemas** easily (multimedia, spatial, or hierarchical data).
  - **Better compatibility** with object-oriented programming languages like Java, C++, or Python.
  - **Reusability and modularity** thanks to inheritance and encapsulation.
- **Examples:**
  - **PostgreSQL** (supports object-relational features like custom types and inheritance)
  - **Oracle Database** (supports object types and methods)

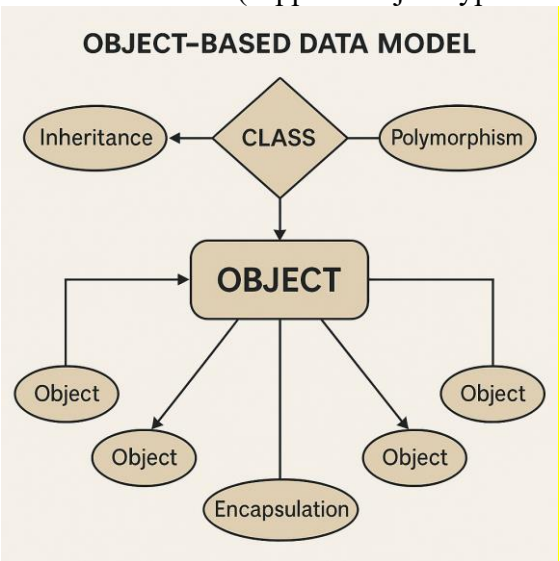


Fig.2.2: Objecct Based Data Model

4. Semi-Structured Data Model:

- **Definition:**
  The semi-structured data model is used when data cannot be arranged into rigid tables like in relational databases. It has no fixed schema and supports nesting of data elements,

making it highly flexible for representing irregular or evolving data structures.

- **Keywords:**
  - **Tags** – Markers (like in XML or JSON) to identify elements.
  - **Elements** – Data items within tags or keys.
  - **Nesting** – Data structures can contain other data structures.
  - **Flexible** – Schema-less or self-describing data.
- **Pros:**
  - **Flexible management** of heterogeneous (mixed) data.
  - **Easy integration** with web-based or semi-structured sources (APIs, documents).
  - **Ideal for rapidly changing requirements** (no need to redesign schemas).
- **Examples:**
  - **MongoDB** (stores data as JSON-like documents)
  - **Couchbase**
  - **Any NoSQL database**
  - **XML** and **JSON** files commonly used in web services.

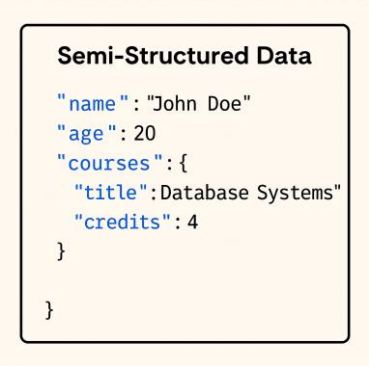


Fig.2.3 Semi-Structured Data

Database Languages

1. **Data Definition Language (DDL):**
   - **Description:**

     DDL (Data Definition Language) is used to define, modify, or remove the structure of database objects. It deals with the schema and structural changes in a database rather than the data itself. You can use DDL commands to create new tables or other objects, alter their definitions, or remove them entirely.
   - **Main operations:**
     - **Create** database objects (tables, indexes, schemas, views, etc.)
     - **Alter** existing database objects (add/remove columns, change data types)
     - **Drop** or delete objects

- **Truncate** tables (remove all rows quickly while keeping structure)

- **Examples of DDL commands:**
  - **CREATE** – Creates new objects (e.g., CREATE TABLE students (...);)
  - **ALTER** – Modifies an existing object's structure (e.g., ALTER TABLE students ADD age INT;)
  - **DROP** – Deletes an object completely (e.g., DROP TABLE students;)
  - **TRUNCATE** – Removes all data from a table but keeps its structure (e.g., TRUNCATE TABLE students;)

2. **Data Manipulation Language (DML):**
   - **Description:**
     DML (Data Manipulation Language) is used to manage and interact with the data stored in database objects (like tables). It allows you to insert new data, update existing data, delete unwanted data, and retrieve data as needed. Unlike DDL, which affects the structure, DML works on the actual records inside the structure.
   - **Main operations:**
     - **Insert** new records into a table
     - **Update** existing records in a table
     - **Delete** records from a table
     - **Select** (retrieve) records from one or more tables
   - **Examples of DML commands:**
     - **SELECT** – Retrieves data (e.g., SELECT * FROM employees;)
     - **INSERT** – Adds new rows (e.g., INSERT INTO employees (id, name) VALUES (1, 'John');)
     - **UPDATE** – Modifies existing rows (e.g., UPDATE employees SET name = 'John Doe' WHERE id = 1;)
     - **DELETE** – Removes rows (e.g., DELETE FROM employees WHERE id = 1;)
3. **Data Control Language (DCL):**
   - **Definition**: DCL is a language used to control accessibility of the data in the database. It has commands to add and remove permissions

- **Definition:**
  DCL (Data Control Language) is used to control access to data stored in the database. It allows database administrators to grant or revoke permissions on database objects, ensuring only authorized users can perform certain actions.
- **Main operations:**
  - **Grant** permissions to users or roles
  - **Revoke** permissions from users or roles
- **Examples of DCL commands:**
  - **GRANT** – Gives specific privileges to a user or role *(e.g., GRANT SELECT, INSERT ON employees TO user1;)*
  - **REVOKE** – Removes previously granted privileges *(e.g., REVOKE INSERT ON employees FROM user1;)*

4. **Transaction Control Language (TCL):**
   - **Description:**
     TCL (Transaction Control Language) is used to manage transactions in a database. It works closely with DML operations to control how changes are saved or undone, ensuring data integrity and consistency. TCL commands help you confirm, cancel, or temporarily mark points within a transaction.
   - **Main operations:**
     - **Commit** a transaction (save changes permanently)
     - **Rollback** a transaction (undo changes since the last commit)
     - **Savepoint** within a transaction (set a point to which you can roll back later)
   - **Examples of TCL commands:**
     - **COMMIT** – Makes all changes in the current transaction permanent *(e.g., COMMIT;)*
     - **ROLLBACK** – Undoes changes made in the current transaction *(e.g., ROLLBACK;)*
     - **SAVEPOINT** – Creates a named savepoint to roll back to if needed *(e.g., SAVEPOINT sp1; then later ROLLBACK TO sp1;)*

5. **Query Language:**
   - A query language is a data access language used to make queries in databases and information systems.
     It enables users to retrieve, filter, and organize data according to specific conditions. SQL (Structured Query Language) is the most widely used query language in relational database systems.
   - **Examples of SQL Clauses (used in queries):**
     - SELECT – Specify the columns to retrieve
     - FROM – Specify the table(s) to query
     - WHERE – Apply conditions to filter records
     - GROUP BY – Group rows sharing a property
     - HAVING – Filter groups based on conditions
     - ORDER BY – Sort the result set
   - **Data Models supported by Query Languages:**
     - **Relational Model:** Data is organized in **tables** with rows and columns, and relationships between them.
     - **Object-Based Data Model:** Incorporates **object-oriented features** (objects, classes, inheritance).
     - **Semi-Structured Data Model:** Supports flexible, schema-less representation, such as JSON or XML.
   - **Database Languages include:**
     - **Data Definition Language (DDL)** – Define and modify structure
     - **Data Manipulation Language (DML)** – Manage data in tables
     - **Data Control Language (DCL)** – Control access and permissions
     - **Transaction Control Language (TCL)** – Manage transactions and changes

Unit 3: Database Architecture, Storage, and Administration

1.4 Data Storage and Querying, Database Architecture

1. Data Storage and Querying

Data Storage

In order to access and obtain data quickly, data is stored efficiently on various storage structures in a database. The two most commons types of storage are:

Storage Type	Description	Examples
Primary Storage (Main Memory)	Stores frequently accessed data in RAM for quick access.	Cache memory, Buffer pool
Secondary Storage (Disk Storage)	Stores large amounts of data persistently.	Hard Disk (HDD), SSD
Tertiary Storage	Used for long-term backups and archival data.	Magnetic tapes, Cloud storage

How Databases Store Data?

- Heap Storage – Stores unordered records (slow for searches).
- Indexed Storage – Uses B-Trees, Hash Indexes for fast lookup.
- Clustered Storage – Groups related data together for efficiency.

Querying in Databases

A query is a request to retrieve, insert, update, or delete data. Queries are written using SQL (Structured Query Language).

Example SQL Queries:

```
-- Retrieve all students older than 20
SELECT * FROM Students WHERE Age > 20;
-- Insert a new student record
INSERT INTO Students (ID, Name, Age, Course) VALUES (103,
'John', 21, 'CS');
-- Update a student's course
UPDATE Students SET Course = 'AI' WHERE ID = 103;
-- Delete a student record
DELETE FROM Students WHERE ID = 103;
```

Query Optimization:

- Query optimization is the process of improving the performance of database queries so they run faster and use fewer resources.

- **Key Techniques in Query Optimization:**
  - **Use of Indexes:**
  - Speeds up data retrieval by avoiding full table scans. *(e.g., creating B-Tree or Hash indexes on frequently searched columns)*
  - **Query Rewriting:**
    Rewriting a query into an equivalent but more efficient form.
    (e.g., replacing subqueries with joins, simplifying conditions)
  - **Execution Plans:**
    The database's query optimizer evaluates multiple plans and chooses the most efficient one.

2. Database Architecture

Databases are designed based on different architectures, which define how users, applications, and database systems interact.

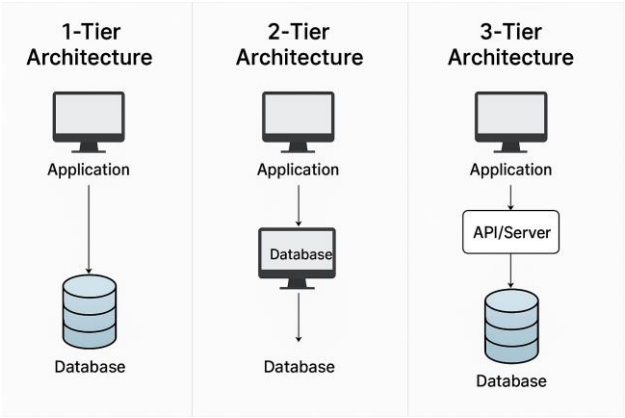


Fig.3.1: 3-Tier Architecture

Architecture Type	Description	Examples
1-Tier Architecture	The database is directly accessed by the application.	Local file databases (MS Access)
2-Tier Architecture	Application connects to a central database (client-server model).	MySQL, PostgreSQL
3-Tier Architecture	Uses an intermediate layer (API/Server) between user and database.	Web applications (MySQL + Django/Node.js)

2.2 Components of Database Architecture

Component	Function
Database	Stores data in structured format.
DBMS (Database Management System)	Manages data, queries, and transactions.
Query Processor	Converts SQL queries into execution plans.
Storage Manager	Handles data retrieval, indexing, and optimization.
Transaction Manager	Ensures ACID properties (Atomicity, Consistency, Isolation, Durability).

Example: 3-Tier Web Application Architecture

1. Presentation Layer – Web UI (HTML, React)
2. Application Layer – Backend (Python, Java, Node.js)
3. Database Layer – DBMS (MySQL, MongoDB)

- **Data Storage**:
    - Databases are designed with indexing**,** sharding**,** replication, and caching strategies to handle large-scale data efficiently.
    - Proper storage design ensures:
    - **High performance** (faster queries)
    - **Scalability** (handles growth in users/data)
    - **Security** (controlled access, encrypted storage)

- For querying, we use SQL (statement for retrieving the data in SQL)
- Database Architecture that is highly secure, scalable, and efficient.

Designing a high performance application require a proper understanding of these concepts

1.5 Database Users and Administrators

In line with the database system, there are two kinds of roles, Users, and Administrators. On that note, here are five types of database users and administrators along with their responsibilities:

1. Database Administrators (DBAs)

• Responsibilities: Database Administrators (DBAs) oversee the database system's administration, upkeep, and performance.

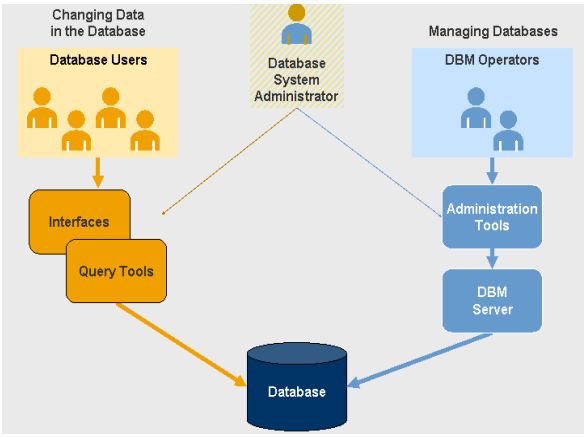


Fig.3.2: Database Administrator
(Source: https://maxdb.sap.com)

• Responsibilities:

- Installation and upgrades of the database software
- Database configuration and optimization tuning
- User access and security management (such as granting or revoking permissions).
- Failing speed with backup and recovery of data.
- Performance monitoring of database and fix the issues.
- Providing appropriate access controls.

• For example, a DBA may utilize tools such as Oracle Enterprise Manager or SQL Server Management Studio (SSMS) to monitor and manage databases:

2. Database Designers

• Role: Also referred to as the database architect, the database designer is responsible for designing the database structure and schema.

• **Responsibilities**:

- Identifying user needs and converting them into a database schema.
- Develop ER diagrams and their corresponding relational schemas.
- Normalizing the database to avoid redundancy and make it more efficient.
- Establishing tables, links, conditions and indexes.
- **Example**: ER Diagrams and DB Schema Sophia (damn every time I use Sophia feels so real to me) is a database designer, she

can use ERwin or Lucidchart to create ER Diagram and Design DB Schema

3. End Users

Role: The End users are system users who enter into the database using different applications to retrieve, insert, update, or delete data.

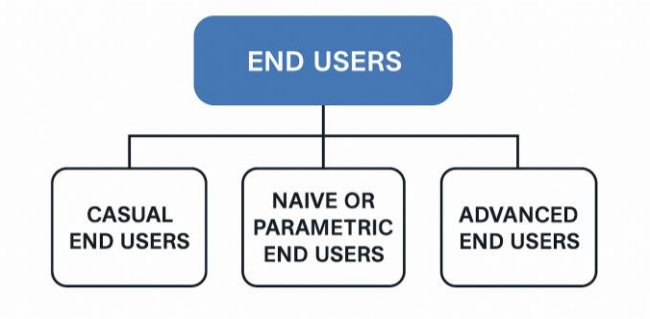


Fig.3.3: End User

• Types of End Users:

- Casual End Users: Use query languages (for example, SQL) to access the database on an occasional basis.
- Naive or Parametric End Users: Use existing applications or forms to access the database (e.g. ATMs, online shopping carts).
- Advanced End Users: Use specialized tools such as data analysis software or craft sophisticated queries.

• Responsibilities:

- Platforms that utilize the database for their work (e.g., interrogating data,c producing reports).
- Ensuring that data the data inputted into the system is accurate and complete.

• BOT: AN EXAMPLE We have a sales manager querying the database to generate a sales report.

4. Application Programmers

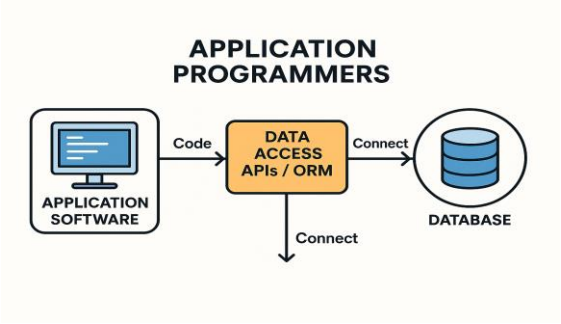


Fig.3.4: Application Programmer

• Role: Application programmers design and create software applications that will communicate with the database.

• Responsibilities:

- Coding into applications to enable the database.
- Connect to the database using Data Access APIs (e.g., JDBC, ODBC, etcSimple API) or ORM (Object-Relational Mapping) tools
- Application logic ensuring data consistency and security.
- {Debugging and optimizing database queries in application.

• For instance, a programmer could use SQLAlchemy within a Python script to pull data from a PostgreSQL database

5. System Analysts

Role: Systems analysts are the link between end users and the database system. They understand what the user needs and optimize the database accordingly.

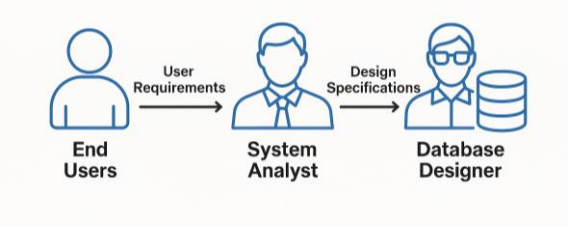


Fig.3.5: System Analysts

• Responsibilities:

- Collecting and Evaluating User Requirements
- Collaborating with database designers to confirm that the design aligns with user applications.
- Audit of the DB system to validate the functional & performance requirements.
- Preparing system specifications and user manuals.

• example: A system analyst helps a healthcare provider design a database for patient records.

Role	**Primary Responsibility**
Database Administrator	Manages and maintains the database system (e.g., performance, security, backups).
Database Designer	Designs the database schema and structure (e.g., ER diagrams, normalization).

End Users	Interact with the database to perform tasks (e.g., querying, updating data).
Application Programmers	Develop applications that interact with the database (e.g., APIs, ORM tools).
System Analysts	Analyze user requirements and ensure the database meets those needs.

Summary of Roles

All the above roles together provide an efficient and secure way of storing, accessing and managing data in a database system.

Summary

Database systems serve as vital tools for organizing, storing, retrieving, and managing data efficiently in modern applications. Their primary purpose is to reduce data redundancy, maintain consistency, and support multi-user environments with controlled access and concurrency. They provide secure and reliable data management by offering features such as transaction control, data integrity enforcement, and backup and recovery mechanisms. By abstracting complex storage details and offering simplified user views, database systems help streamline operations and facilitate informed decision-making across organizations.

To structure and interpret data meaningfully, database systems rely on various data models. The relational model is the most widely used, representing data in tables with rows and columns. Other models like hierarchical, network, object-oriented, and NoSQL cater to specific needs such as complex relationships, multimedia storage, or unstructured data. Underlying these systems is a layered architecture that ensures separation of concerns—typically including client, application, and data tiers. Database storage involves managing data physically on disk with efficient indexing, buffering, and logging mechanisms for speed and reliability. Database administration ensures optimal performance and security, involving tasks like user access control, system monitoring, and query optimization. Altogether, database systems form the backbone of digital data ecosystems, supporting everything from daily operations to advanced analytics.

Multiple-Choice Questions (MCQs)

1. Which of the following best describes a database?
    a) A collection of files stored on a hard drive
    b) A systematic collection of data that allows easy access and management

c) A set of interconnected spreadsheets
d) A software program used for designing web pages

(Answer: b)

2. What is the purpose of data abstraction in databases?
   a) To provide a physical representation of data
   b) To hide complex details from users and provide a simplified view
   c) To store data in encrypted format only
   d) To ensure data is always in a graphical format

   (Answer: b)
3. Which of the following is NOT a type of database schema?
   a) Logical schema
   b) Conceptual schema
   c) Flat schema
   d) Physical schema

   (Answer: c)
4. What is DDL in databases?
   a) Data Derivation Language
   b) Data Definition Language
   c) Database Deployment Language
   d) Dynamic Data Language

   (Answer: b)
5. The three-tier database architecture consists of:
   a) Client, Application Server, Database Server
   b) Front-end, Back-end, Middleware
   c) Data Layer, Business Logic Layer, Presentation Layer
   d) All of the above

   (Answer: d)

6. Which of the following database users is responsible for managing access control?
   a) End users
   b) Database Administrator (DBA)
   c) System Analyst
   d) Data Scientist

   (Answer: b)
7. Data mining is used for:
   a) Discovering patterns and relationships in large datasets

b) Cleaning redundant data from a database
c) Encrypting sensitive information in a database
d) Physically storing data in warehouses

(Answer: a)

8. What is the primary function of a data warehouse?
    a) To store current transactional data
    b) To process online transactions in real-time
    c) To store historical data for analysis and decision-making
    d) To replace traditional relational databases

(Answer: c)

9. Big Data typically involves:
    a) Small-scale structured datasets
    b) Large volumes of unstructured or semi-structured data
    c) Only relational databases
    d) Only cloud-based data storage

(Answer: b)

10. Which of the following is a key feature of Data Analytics?
    a) Predicting future trends based on historical data
    b) Encrypting databases for security
    c) Deleting unnecessary data from databases
    d) Creating web pages for data visualization

(Answer: a)

Short Questions

1. Define a database and its primary purpose.
2. What is data abstraction in a database system?
3. Differentiate between schema and instance in databases.
4. What are the two main types of database languages?
5. Define DML and provide one example.
6. What is the difference between two-tier and three-tier database architecture?
7. Name two key responsibilities of a Database Administrator (DBA).
8. What is data mining and how is it useful?
9. Explain the concept of a data warehouse.
10. What are the four key characteristics of Big Data?

Long Questions

Notes

1. Explain the purpose of a database and its advantages over traditional file systems.
2. Discuss the three levels of data abstraction with examples.
3. Differentiate between different types of database schemas with proper explanations.
4. Explain the differences between DDL and DML with appropriate SQL examples.
5. Describe the components of a three-tier database architecture and how they interact.
6. Discuss the different types of database users and their roles in a database system.
7. What is data mining? Explain the various techniques used in data mining.
8. Define data warehousing and discuss its architecture and benefits.
9. Explain the concept of Big Data, its challenges, and how it differs from traditional databases.
10. What is Data Analytics? Discuss its types, importance, and applications in real-world scenarios.

MODULE 2
RELATIONAL DATA MODELING AND DATABASE DESIGN

LEARNING OUTCOMES

By the end of this Unit, students will be able to:

- Understand relational model concepts and different types of keys (Super Key, Candidate Key, Primary Key).
- Explain integrity constraints, E.F. Codd's rules, and functional dependencies in relational databases.
- Learn decomposition techniques ensuring lossless join and dependency preservation.
- Apply normalization (1NF, 2NF, 3NF, BCNF, PJNF) to eliminate redundancy and enhance database efficiency.

Unit 4: Relational Model and Constraints

2.1Relational Model Concepts, Super Key, Candidate Key and

In the Relational Model, data is organized in tables (relations) consisting of tuples (rows) and attributes (columns). Each table represents an entity, and relationships among entities are established through keys.

Primary Key

A Primary Key is an attribute (or a combination of attributes) that uniquely identifies each tuple **(row)** in a table.

- No two rows can have the same primary key value.
- A primary key cannot contain NULL values.

Role in the Relational Model:

- **Ensures data integrity:** Each row is uniquely identifiable.
- **Reduces redundancy:** Prevents duplicate records.
- **Enables relationships:** Used as a reference by foreign keys in other tables.
- **Supports efficient storage & retrieval:** SQL queries rely on keys for quick lookups and joins.

Example:

StudentID (PK)	Name	Course
101	Sophia	DBMS
102	Alex	Networks

Here, **StudentID** is the **Primary Key**, ensuring each student record is unique.

Super Key

A Super Key is any set of one or more attributes (columns) that can uniquely identify a tuple (row) in a relation (table).

- It may consist of a single attribute or a combination of attributes.
- Every table must have at least one super key.
- A primary key is always a super key, but not every super key is a primary key (some may contain extra attributes that are not necessary for uniqueness).

Key points about Super Keys:

- **Uniqueness**: No two rows can have the same values for a super key.

- **Minimality not required**: Unlike a candidate key or primary key, a super key can have redundant attributes and still be unique.

Example:

Consider a Student table with attributes:

{StudentID, Email, Name, Phone}

Possible Super Keys:

{StudentID} (uniquely identifies each student)

{Email} (assuming each email is unique)

{StudentID, Name} (still unique, but not minimal)

{StudentID, Phone} (also unique, but includes extra attribute)

Candidate Key

A Candidate Key is a minimal set of one or more attributes that uniquely identifies each tuple (row) in a table.

- **Minimality:** A candidate key has no redundant attributes—if you remove any attribute from it, it will no longer uniquely identify rows.
- **Uniqueness:** No two rows can share the same values for a candidate key.
- **Multiple Candidate Keys:** A table can have more than one candidate key.

Among all candidate keys, one is chosen as the Primary Key, while others remain as alternate keys.

Example:

Consider a Student table with attributes:

{StudentID, Email, Name, Phone}

Possible Candidate Keys (assuming uniqueness):

{StudentID} (unique and minimal)

{Email} (unique and minimal)

Non-Candidate Example:

{StudentID, Email} (still unique but not minimal, because StudentID alone is enough)

Foreign Key

A Foreign Key is an attribute (or a set of attributes) in one table that refers to the Primary Key (or a unique key) in another table.

It is used to establish and enforce a link between the data in the two tables.

Key Characteristics:

- **Maintains referential integrity:** Every value in the foreign key column must either match a value in the referenced primary key column or be NULL.
- **Defines relationships between tables:** One-to-many or many-to-one relationships are often implemented using foreign keys.
- **Restricts invalid data:** The database will prevent inserting or updating a foreign key value that doesn't exist in the referenced table.

Example:

Suppose you have two tables:

Students Table

StudentID (PK)	Name
101	Sophia
102	Alex

Enrollments Table

EnrollmentID (PK)	StudentID (FK)	Course
1	101	DBMS
2	102	Networks

Here, StudentID in Enrollments is a Foreign Key that references StudentID in Students.

It ensures every enrollment record belongs to a valid student.

2.2 Constraints: Domain, Key, Entity and Referential Integrity constraints

Types of Integrity Constraints in RDBMS: Entity, Referential, Domain, and Key Integrity Constraints This include basically rules that are used by tables in relational databases in order to verify if the data inserted to these tables have a sense, when they are updated, deleted, etc. They limit the values that can be placed within tables and disallow bad values being entered. The main types of Constraints in a relational

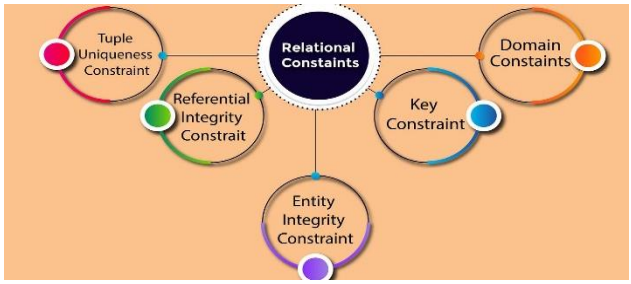


Figure 4.1: Relational Model and Constraints

model areDomain ConstraintsKey ConstraintsEntity Integrity ConstraintsReferential Integrity Constraints

1. Domain Constraints

Domain Constraints restrict the values that a column (attribute) can take in a table. It validates that it stores only valid data types and values in the database.

Example: Assuming you have "Student" table with the following schema (Student_ID, Name, Age, and Email).

- Age is an example of a domain constraint, suppose Age is integer and Age is allowed only from 18 to 60 that is Age =17 or Age = 65 would violate the domain constraint.
- As another example, if Email is defined as a string that matches the format "@domain. i.e., student_email.@school. com" would be rejected

2. Key Constraints

Table: Key Constraint Ensures Each Row is Unique This implies that two rows cannot possess the same value in a key attribute. Super Keys Candidate Keys Primary Keys

Example: Consider an "Employee" table having attributes (Employee_ID, Name, Email) and it is having Employee_ID as the Primary Key.

- If we attempt to add duplicate Employee_ID (like two employees with Employee_ID = 101), the Therewould be no insertion due to key constraint.

3. Entity Integrity Constraint

The Entity Integrity constraint ensures that the primary key of a table will never have NULL values. This Rule keeps each row in the table unique and into its own entity.

Example: In a “Product” table with attributes (Product_ID, Name, Price), the Product_ID is the Primary Key.

- The new product cannot be inserted with NULL as Product_ID, the entry will be rejected by database system, as primary key can be NULL.

4. Referential Integrity Constraint

A Referential Integrity Constraint is a set of rules that ensures that relationships between tables remain consistent. Foreign keys in one table must reference an existing primary key in another table or be NULL.

• **Definition:** A foreign key is a column whose data must match a primary key in another table **Example:** Two Tables, Orders, Customers.

Primary-foreign key relationship constraints (also known as referential integrity constraint) maintain the consistency between the two tables. It either has to refer to an existing primary key or NULL.

For example, imagine two tables, "Orders" and "Customers".

- **"Customers" Table:**

Customer_ID	Name	Email
C101	Alice	alice@email.com
C102	Bob	bob@email.com

- **"Orders" Table:**

Order_ID	Customer_ID	Product
O201	C101	Laptop
O202	C102	Phone
O203	C105	Tablet

- The *Customer_ID* column in the "Orders" table is a Foreign Key referencing the *Customer_ID* in the "Customers" table. If an order is placed with *Customer_ID = C105*, but no such customer exists in the "Customers" table, the database system will prevent the insertion to maintain referential integrity.

Constraints ensure data consistency and reliability within a relational database.

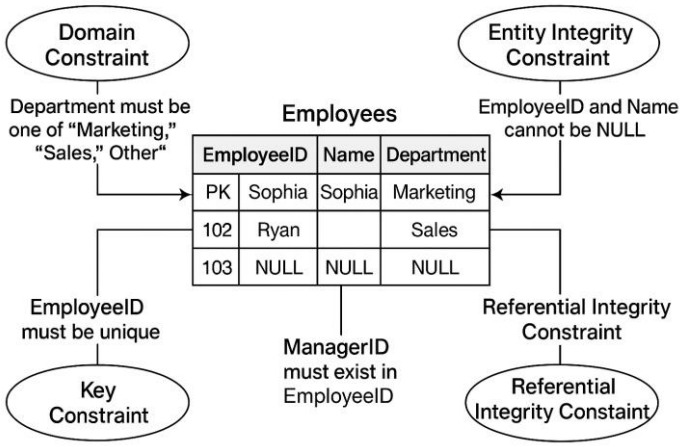


Fig.4.2: Constraints in Database

• Domain Constraints Maintain Proper Data Types & Values
• Key Constraints are used to uniquely identify records.
• Primary keys are subject to Entity integrity Constraints would not allow NULL values.
• Referential Integrity Constraints enforce valid relationships between tables.

These constraints ensure that data anomalies are avoided and data integrity is maintained, thus enforcing the stoof reliable data which is consistent and meaningful.

2.3 E.F. Codd's Rule

In the context of relational databases, Dr. Edgar F. Codd, the father of the relational database model, defined 12 rules (actually 13, including Rule 0) to qualify a system as a true relational database management system (RDBMS) of 1985. In relational databases these rules help keep data integrity, data consistency and help organize data for better management.

Rule 0: Foundation Rule

Else, an application can be called RDBMS if it manages data completely based on relational capabilities. It is actually support for relational structures (tables, rows and columns), and agree with all other rules.

Rule 1: Information Rule

Every data in a relational database can only be stored in tables as rows and columns.

For Example: A "Student" table storing data in structured rows and columns.

Violation: Unstructured file-based data storage (e.g., text documents and spreadsheets)..

Rule 2: Guaranteed Access Rule

All data (value) needs to be retrievable by a combination of the table name, primary key, and the column name.

For instance in order to get a student email, you can do:

SQL

SQL Query: SELECT Email FROM Students WHERE Student_ID = 101;

Violation: When we have access to some data using physical addresses or pointers but not using SQL queries.

Rule 3: Systematic Treatment of NULL Values

NULL values should be handled consistently across the database as to indicate missing, unknown, or inapplicable data.

For instance: Suppose a student's phone number is not known, then the database must permit NULL in the "Phone" column.

Violation: Replacing NULL with arbitrary negativity (i.e. -1 or 99999).

Rule 4: Dynamic Online Catalog (Metadata Rule)

A relational database must use tables (SQL) to access metadata (schema, constraints, data types).

Sample: Fetching table structure with Inserting/fetching Create table: SQL

PARSE_NO_STD_ERRORS_074001=095BD429L2+045C06%BQ+018F+0B6=2_SELECT * FROM INFORMATION_SCHEMA. TABLES;

Incorrect: When metadata is part of external files or system logs rather than tables..

Rule 5: Comprehensive Data Sub-language Rule

At least one complete language (SQL, for example) for data access, manipulation, and control must be provided by the system.

e.g.: SQL can insert, delete, update, and retrieve data.

Not even a devil (Can database that have different languages for different operation, one for query other for updates, etc.)

Rule 6: View Updating Rule

In case a view (virtual table) is constructed from base tables it should be updatable.

Example:

SQL

CREATE VIEW StudentEmails AS

-- 2. Retrieving specific columns (SELECT): SELECT Student_ID, Email FROM Students;

The underlying table must change if we change the StudentEmails view.

Violation: When views are read only and don't provide updates.

Rule 7: High-Level Insert, Update, Delete

Since inserts, updates, and deletes are performed on RDBMS using set-based operations and not row-based operations.

Example Updating Multiple Rows in One Query

SQL

Break: The update will excessive looping through each row

Rule 8: Physical Data Independence

We should be able to change our physical storage (where on disk, the way we handle indexing, etc.) but this should not affect our ability to access our data with an SQL query.

e.g Moving data from a disk to another disk should not break SQL queries

Violation: Moving data means re-writing application code.

Rule 9: Logical Data Independence

Logical structure change (adding/removing columns) should not affect the exist applications

Adding a column like Date_of_Birth — should not break existing queries that do not use it.

Violation: When applications break due to schema changes.

Have you watched "The Fall of the House of Usher"?

Rule 10: Integrity Independence

The integrity constraints (e.g., the primary key, the foreign key, NOT NULL) must be stored directly in the database and not in application code.

Example: Primary key constraint in SQL:

SQL

ALTER TABLE Employees ADD CONSTRAINT pk_emp PRIMARY KEY (Emp_ID);

Violation: When you enforce uniqueness in your application logic instead of letting the DB do it.

Rule 11: Distribution Independence

A characteristic requirement of RDBMS is support for distributed databases without changing of SQL statements.

For example, a query should be functional regardless if your data lives in one server or is sharded across multiple servers.

Violation: If you need to rewrite queries every time you move data between different locations.

Rule 12: Non-Subversion Rule

No mechanism to access the data (e.g., system-level commands) is allowed that bypasses relational security and integrity constraints.

For example: Direct database access through scripts must still respect constraints (such as NOT NULL, FOREIGN KEY)

Violation: When backend scripts allow a user to enter invalid data.

E.F. Codd's 12 rules guarantee a database adheres to the relational model. Most modern relational databases (e.g., MySQL, PostgreSQL, SQL Server, Oracle) follow most of these rules, though some systems (e.g., NoSQL databases) do not abide by all of them. With these very rules the relational databases became reliable and efficient for

structured data management, as they allow the database management system (DBMS) to maintain the well defined integrity rules that guarantees the correctness of data as well as independent from all applications and usable format of data.

2.4 Functional dependency, Armstrong's Inference rules

1. Functional Dependency (FD) in Relational Databases

What is Functional Dependency? Functional Dependency (FD) in a relational database design is an important concept as it describes the relationship between attributes in a relation. 3NF (TEACHER, HEAD_DEPARTMENT, HEAD_DEPARTMENT) or 3NF: A functional dependency from attributes X to attributes Y in a relation R is a possibility that X can functionally determine Y. Understanding this model is essential for maintaining data integrity to prevent redundancy as well as database normalization.

What Functional Dependency means

Functional Dependency is denoted as:

X→YX \rightarrow YX→Y

where:

• X (determinant): one or more set of attributes.

• Y (dependent) would be another (or group of) attribute.

• There is exactly one Y for every unique value of X.Example of Functional Dependency

Consider a "Student" table:

Student_ID	Name	Course	Department
101	Alice	DBMS	CS
102	Bob	OS	CS
103	Charlie	DBMS	IT
104	David	OS	CS

Functional Dependencies in this relation:

1. Student_ID → Name, Course, Department
    - If we know the Student_ID, we can determine Name, Course, and Department.
2. Course → Department
    - If we know the Course, we can determine the Department.

Types of Functional Dependencies

1. Trivial Functional Dependency
    - If X→YX \rightarrow YX→Y, and Y⊆XY \subseteq XY⊆X, it is called trivial.
    - Example: {Student_ID, Name} → Name (Here, Name is already part of the left-hand side).
2. Non-Trivial Functional Dependency
    - If X→YX \rightarrow YX→Y, and YYY is not a subset of XXX, it is non-trivial.
    - Example: Student_ID → Name (Name is not part of Student_ID).
3. Completely Non-Trivial Dependency
    - If X→YX \rightarrow YX→Y, and X and Y do not overlap, it is completely non-trivial.
    - Example: Course → Department.

Importance of Functional Dependency in Normalization

- Used to identify candidate keys.
- Helps in decomposing tables while preserving dependencies.
- Essential for eliminating anomalies in database design.

Functional Dependencies in this relation:

Student_ID → Name | Course | Department

o We can find out Name, Course & Department if we know the Student_ID.

Course → Department

o We can even find out the Department if we have the Course

Functional Dependencies Types

Trivial Functional Dependency

If X→YX \rightarrow YX→Y, and Y⊆XY \subseteq XY⊆X, it is trivial.

o For instance: {Student_ID, Name} → Name (Where Name is already included in the LEFT SIDE).

Non-Trivial Functional Dependency

o That is, if X→YX \rightarrow YX→Y is non-trivial, and Y is not (a subset of) X (here: YXYXYXYY⊆XXX)

o Example: Student_ID → Name (Name does not lie in Student_ID).

Non-Trivial Dependency You ban the initial k elements.

o If X→YX \rightarrow YX→Y and not-overlapping X and Y then it's completely non-trivial.

o E.g., Course → Department.

Role of Functional Dependency in Normalization

• It is used to identify the candidate keys.

• Assists decomposition of tables such that dependencies are preserved.

• Crucial for removing anomalies from the design of the database.

2. Armstrong's Axioms (Inference Rules for Functional Dependencies)

Armstrong's Axioms (proposed by William W. Armstrong in 1974) are a set of inference rules used to derive all functional dependencies in a relational schema. These axioms form the basis for closure computation and normalization in relational databases.

Armstrong's Inference Rules

1. Reflexivity (Trivial Dependency Rule)
    - If Y is a subset of X, then X → Y holds.
    - Example: {Student_ID, Name} → Name (since Name is part of {Student_ID, Name}).
2. Augmentation Rule
    - If X → Y, then XZ → YZ (Adding more attributes does not affect dependency).
    - Example: If Student_ID → Name, then (Student_ID, Course) → (Name, Course).
3. Transitivity Rule
    - If X → Y and Y → Z, then X → Z.
    - Example: If Student_ID → Course and Course → Department, then Student_ID → Department.

Additional Derived Rules (Based on Armstrong's Axioms)

4. Union Rule
    - If X → Y and X → Z, then X → YZ.
    - Example: If Student_ID → Name and Student_ID → Course, then Student_ID → (Name, Course).
5. Decomposition Rule
    - If X → YZ, then X → Y and X → Z separately.
    - Example: If Employee_ID → (Employee_Name, Salary), then:
        - Employee_ID → Employee_Name
        - Employee_ID → Salary.
6. Pseudotransitivity Rule
    - If X → Y and WY → Z, then WX → Z.

- Example: If Student_ID → Course and (Course, Department) → Professor, then (Student_ID, Department) → Professor.

Closure of Functional Dependencies (F+)

The closure of a set of functional dependencies is the complete set of dependencies that can be derived using Armstrong's Axioms.

- Given F = {A → B, B → C}, the closure F+ includes:
  1. A → B (Given)
  2. B → C (Given)
  3. A → C (By Transitivity)

Example of Computing Closure of an Attribute Set

Given: F = {A → B, B → C, C → D}, find A+ (Closure of A).

1. Start with A+ = {A}.
2. Since A → B, add B → A+ = {A, B}.
3. Since B → C, add C → A+ = {A, B, C}.
4. Since C → D, add D → A+ = {A, B, C, D}.
5. Final result: A+ = {A, B, C, D}.

Finding Candidate Keys Using Closure

- If A+ = All Attributes in Relation, then A is a candidate key.

Example: In R(Student_ID, Name, Course, Department) with FDs: Student_ID → Name, Course → Department,

- Closure of Student_ID: {Student_ID, Name, Course, Department} → Student_ID is a Candidate Key.

• Functional Dependency It specifies how attributes relate to maintain the integrity of the database.

• Using Armstrong's Axioms, one can derive all the dependencies and use this for schema normalization.

• \Database design\ : FD Closures and Candidate Key identification

In this article, we present the basic ideas, examples, and application for Functional Dependencies and Armstrong's Rules. If you want me to elaborate on certain parts (for example: more real world examples, more mathematical proofs or more step by step derivations) just tell me!

2.5 Decomposition of Relations: Lossless Join and Dependency Preservation property

1. Decomposition of Relations

Decomposition is necessary in database design to address issues such as:

- Data Redundancy(duplicating the same data several times).
- Anomalies of Insertion, Deletion and Update (inconsistencies when we modify data).
- Integrity of Data (avoid the inconsistency in data).

Normalization is the process of organizing the columns (attributes) and tables (relations) of a database to minimize data redundancy and improve data integrity, and 1NF, 2NF, 3NF, and BCNF normalization techniques involve decomposing a relation into smaller relations so that functional dependencies are preserved, and joins are lossless..

Example:

Let us assume the relation R(Student_ID, Name, Course, Instructor, Department) with the following functional dependencies:

- Student_ID → Name, Course
- Course → Instructor, Department

Here Course → Instructor,Department is BCNF violating, so we decompose R into:

1. R1(Student_ID, Name, Course)
2. R2(Cours e, In structor, De part ment)

2. Lossless Join Property

Also, when relations decomposed, they can be combined back to the original collection of tuples without any loss of information: A Lossless Join Decomposition.

Definition:

A decomposition of a relation RRR into R1,R2,...,RnR1, R2,..., RnR1,R2,...,Rn is lossless join if:

RR1 \bowtie R2 \bowtie... \bowtie Rn = R R R 1 ⋈ R 2 ⋈... ⋈ R n = R.Strings are based on the way they are built or arranged.

So it had to not introduce any false (additional) tuples, and not lose any source data either.

Lossless Join Condition:

A lossless decomposition R1R1R1 and R2R2R2 of relation RRR is said to be lossless if:

More formally, the common attributes need to be a key for at least one of the newly generated relations.

Example of Lossless Join Decomposition

Let us consider a relation R(Employee_ID, Name, Department, Manager) with the following functional dependencies:

- Employee_ID | Name | Department
- Department → Manager

In order to comply with BCNF we break it into:

- R1(Employee ID, Name, Department))
- R2(Department, Manager)

Note that the common attribute Department in R1∩R2R1 \cap R2R1∩R2 is a key in R2, so this gives us lossless join.

R1⋈R2=R(No information is lost)R1 \bowtie R2 = R \quad \text{(No information is lost)}R1⋈R2=R(No information is lost)

But what if our decomposition is wrong and we write, for example:

• R1(Employee_ID, Name)

• R2(Employee_ID, Department, Manager)

The join between Department and Manager becomes lossy as we lose the mapping between them.

3. Dependency Preservation Property

We say a decomposition is dependency preserving, if all functional dependencies of the original relation are enforceable in the decomposed relations (without doing joins).

Definition:

A decomposition R1,R2,...,RnR1, R2,..., RnR1,R2,...,Rn of RRR is said to be dependency preserving if:

(F1∪F2∪...∪Fn)+=F+(F1∪F2∪...∪Fn)+

=(F1∪F2∪...∪Fn)+=F+(F1∪F2∪...∪Fn)+=F+

where:

- FFF is the initial set of functional dependencies.
- F1, F2,... Fn F1,F2,...FnF1,F2,...Fn are functional dependencies in decomposing relation
- F+F^{+}F+ is the closure of FFF, that is, all derived dependencies.

Why is Dependency Preservation Important?

• It provides a way to enforce integrity constraints (functional dependencies) in specific tables without the need for potentially expensive joins.

• If a decomposition loses dependencies, we may have to enforce some constraints by joins, resulting in loss of efficiency.

Checking for Dependency Preservation

To determine whether decomposition is dependency preserving, we find the closure of the union of the dependencies in decomposed relations and check if it is equal to the original closure.

Example of Dependency Preservation

Let's assume you have the relation R(A, B, C) and with the dependencies

1. A → B
2. B → C

Decomposing into:

• R1(A, B)

• R2(B, C)

Checking closures:

• F1 = {A → B}

• F2 = {B → C}

• Closure (F1 ∪ F2) + (F1 ∪ F2)^{+}(F1 ∪ F2) + contains A → B → C, hence all dependencies preserved.

Dependency preserved

Non-Dependency Preservation Example

Assuming we decompose R(A, B, C) into:

• R1(A, B)

• R2(A, C)

Since B → C is lost here, we need to perform joins to uphold this.

Not dependency preserving

4. Combining Lossless Join and Dependency Preservation

Ideal Decomposition

A good decomposition should satisfy both properties:

1. No Loss → Should not lose any data or add extra tuples.
2. Dependency Preservation → The functional dependencies must enforceable without costly joins.

However, in some cases, achieving both simultaneously may not be possible.

Trade-Off Example

Suppose we have a relation R(A, B, C, D, E) Functional Dependencies:

• A → B

• B → C

• C → D, E

The BCNF decomposition would yield:

• R1(A, B)

• R2(B, C)

• R3(C, D, E)

The first option is lossless but not dependency preserving (because C → D, E spans multiple tables).

• Normalizations of database and removal of duplicate is only possible by means of decomposition.

• Lossless Join means no information is lost if relations are rejoined.

• Dependency Preservation assumes that the functional dependencies can be enforced without computing joins.

• The ideal decomposition preserves both properties, but compromises are sometimes necessary.

These tools serve as important checks for not only the viability of the proposed database schema but also for its performance: by ensuring that a schema maintains lossless join and dependency preservation, database designers are able to implement an optimal, normalized, high-performing database schema.

2.6 Normalization: First, Second, Third, BCNF, PJNF

This means normalization is a systematic approach that organizes an RDBMS into the tables and columns. The objective of the first one is mainly to normalize relations (i.e. tables) into smaller, well-structured relations only such that integrity and dependency of data are met. This process happens through a set of stages referred to as Normal Forms (NF), where each stage addresses certain types of anomalies in the data structure. 1st, 2nd, 3rd, Boyce-Codd Normal Form (BCNF), and Projection-Join Normal Form (PJNF or 5NF). Normalization leads to a well-organized data structure which in turn provides the benefit of:

• Consistency of data (reduces redundant storage of same data)

• Data integrity (through constraints, it ensures accuracy).

• Query performance (decreases data redundancy and anomalies)

1. First Normal Form (1NF)

A relation is in 1NF(First Normal Form) if:

1. They all contain atomic (or indivisible) values for each attribute.
2. No multi valued attributes: Each column holds a single value for each row.
3. This is a primary key requirement as each row must be uniquely identifiable.

Example of a Non-1NF Table:

Student_ID	Name	Courses	Phone Numbers
101	Alice	DBMS, OS	9876543210, 1234
102	Bob	OS, Networks	5556677889

Issues in Non-1NF Table:

• Multi-valued attributes: "Courses" and "Phone Numbers" have multiple values in a single column.

• Repeating groups: Some students have multiple phone numbers in a single field

Converting to 1NF (Atomic Values & Unique Rows):

Student_ID	Name	Course	Phone Number
101	Alice	DBMS	9876543210
101	Alice	OS	1234
102	Bob	OS	5556677889
102	Bob	Networks	5556677889

Now:

- Each column contains atomic values.
- No multi-valued attributes.
- Every single row can be uniquely identified.

2. Second Normal Form (2NF)

Definition:

Second Normal Form (2NF) if − A relation is in

1. It is already in 1NF.
2. partial dependencies). All non-primary attributes are fully functionally dependent on the primary key (no

Example of a Non-2NF Table:

Order_ID	Product_ID	Product_Name	Quantity	Order_Date
O101	P01	Laptop	2	2024-01-01
O102	P02	Mouse	5	2024-01-02

Issues in Non-2NF Table:

- Primary Key = (Order_ID, Product_ID) (Composite Key).
- Partial Dependency:
  - Product_Name functionally depends on Product_ID, but not on Order_ID

Converting to 2NF (Eliminating Partial Dependencies):

Order Table:

Order_ID	Order_Date
O101	2024-01-01
O102	2024-01-02

Product Table:

Product_ID	Product_Name
P01	Laptop
P02	Mouse

Order_Details Table:

Order_ID	Product_ID	Quantity
O101	P01	2
O102	P02	5

Now:

No partial dependency (all non-key attributes depend on its primary key, fully).

Data is form correctly into lower tables.

3. Third Normal Form (3NF)

Definition:

A relation is in Third Normal Form(3NF) if:

1. It is already in 2NF.
2. No transitive dependency (a non-key attribute must not dependent on other non-key attributes).

Example of a Non-3NF Table:

Student_ID	Name	Course	Instructor	Instructor_Phone
101	Alice	DBMS	Dr. John	9876543210
102	Bob	OS	Dr. Smith	5556677889

Issues in Non-3NF Table:

- Transitive Dependency:
  - Instructor_Phone depends on Instructor, not on Student_ID.

Converting to 3NF (Eliminating Transitive Dependency):

Student Table:

Student_ID	Name	Course	Instructor
101	Alice	DBMS	Dr. John
102	Bob	OS	Dr. Smith

Instructor Table:

Instructor	Instructor_Phone
Dr. John	9876543210
Dr. Smith	5556677889

Now:

No transitive dependency.

colspan="2" Attributes are directly dependent on the primary key.

4. Boyce-Codd Normal Form (BCNF)

Definition:

A relation is in BCNF if:

1. It is already in 3NF.
2. All determinants would be candidate key (We have no partial or transitive dependency now

Example of a Non-BCNF Table:

Employee_ID	Department	Manager
101	IT	John
102	HR	Sarah
103	IT	John

Issues in Non-BCNF Table:

- Manager depends on Department, not on Employee_ID (violating BCNF).

Converting to BCNF:

Department Table:

Department	Manager
IT	John
HR	Sarah

Employee Table:

Employee_ID	Department
101	IT
102	HR

None of the functional dependencies violates BCNF..

5. Projection-Join Normal Form (PJNF or 5NF)

Definition:

A relation is in 5NF (PJNF) if and only if:

1. It is already in BCNF.
2. There is no join dependency that cannot be enforced by decomposition of the relation

Example:

Consider a Supplier-Parts-Project relation:

Supplier_ID	Part_ID	Project_ID
S1	P1	J1
S1	P2	J2
S2	P1	J1

If we decompose into:

- Supplier-Part
- Part-Project
- Supplier-Project

We must ensure that recombining these tables retains all original data. PJNF eliminates join dependencies and guarantees that there's no more lossless decomposition to be had.

• 1NF → No multivalues attributes.

• 2NF → No partial dependency.

• 3NF → No transitive dependency.

• BCNF → Each determinant is a candidate key.

• PJNF (5NF) → All join dependencies.

The process of normalization adheres to a set of specific criteria, resulting in efficient databases that are scalable and free from logical conflicts.

Summary

The relational model forms the core of modern database systems by representing data in structured tables known as relations, where each row corresponds to a record and each column represents an attribute. It uses keys—such as primary keys and foreign keys—to uniquely identify records and establish relationships between tables. Constraints like entity integrity, referential integrity, and domain constraints help maintain data accuracy, consistency, and validity across relational databases. These rules ensure that the data remains meaningful and reliable, preventing anomalies and enforcing structured relationships.

The theoretical foundations of relational databases are grounded in formal logic and set theory, particularly in relational algebra and relational calculus. These mathematical models enable precise querying, optimization, and manipulation of data. To enhance database design and eliminate redundancy, techniques like decomposition and normalization are employed. Decomposition involves breaking down complex tables into simpler ones without losing data integrity, while normalization restructures data into well-formed tables through various normal forms (1NF, 2NF, 3NF, BCNF). This minimizes duplication, improves data integrity, and ensures scalability. Together, the relational model, its theoretical underpinnings, and normalization principles provide a solid framework for designing efficient, reliable, and logically sound database systems.

MCQs:

1. What is the first step in database design?

a) Creating tables

b) Identifying requirements and data modeling

c) Writing SQL queries

d) Normalization

(Answer: b)

2. What does an E-R model primarily represent?

a) Data processing speed

b) Database structure using entities and relationships

c) SQL Queries

d) File management

(Answer: b)

3. Which symbol is used to represent an entity in an E-R diagram?

a) Circle

b) Rectangle

c) Diamond

d) Triangle

(Answer: b)

4. Which of the following is a type of constraint in databases?

a) Logical Constraint

b) Primary Key Constraint

c) Software Constraint

d) Physical Constraint

(Answer: b)

5. In an E-R diagram, relationships are represented using:

a) Ovals

b) Rectangles

c) Diamonds

d) Lines

(Answer: c)

6. A weak entity set is an entity that:

a) Does not have any attributes

b) Depends on a strong entity and lacks a primary key

c) Has multiple primary keys

d) Cannot participate in a relationship

(Answer: b)

7. Which of the following is NOT a type of relationship in an E-R model?

a) One-to-One

b) One-to-Many

c) Many-to-Many

d) Fixed-to-Variable

(Answer: d)

8. Which constraint ensures that all values in a column are unique?

a) Primary Key

b) Foreign Key

c) NOT NULL

d) DEFAULT

(Answer: a)

9. A strong entity set is an entity that:
a) Requires a foreign key
b) Does not have sufficient attributes
c) Has a primary key and can exist independently
d) Cannot store any data
(Answer: c)
10. Which of the following helps in improving database efficiency?
a) Adding redundant data
b) Proper database design using E-R models
c) Using only one large table for all data
d) Avoiding constraints
(Answer: b)

Short Questions:

1. What is the database design process?
2. Define E-R Model and its purpose.
3. What are the key components of an E-R diagram?
4. Explain the difference between a strong entity and a weak entity.
5. What are cardinalities in an E-R model?
6. Define constraints in a database and provide examples.
7. What is the role of primary and foreign keys in database design?
8. How do one-to-one, one-to-many, and many-to-many relationships differ?
9. Explain the significance of entity sets in a relational database.
10. What is referential integrity, and why is it important?

Long Questions:

1. Explain the database design process in detail with steps.
2. What is an E-R Model, and how is it used in database design?
3. Describe the different types of relationships in an E-R model with examples.
4. Discuss the importance of constraints in a relational database.
5. How does an E-R diagram help in designing a database structure?
6. Compare weak entity sets and strong entity sets with examples.
7. Explain the importance of cardinality and participation constraints.
8. Discuss different types of constraints (Primary Key, Foreign Key, NOT NULL, UNIQUE).

9. Describe the steps involved in converting an E-R model into a relational model.
10. How does a well-designed E-R model improve database performance?

MODULE 3

SQL AND PROCEDURAL SQL

LEARNING OUTCOMES

- By the end of this Unit, students will be able to:
- Use conditional and iterative statements to control the flow of SQL execution.
- Create and implement user-defined functions for modular and reusable SQL code.
- Develop stored procedures with different parameter types (IN, OUT, INOUT) for efficient database operations.
- Understand and apply triggers, including before and after triggers, to enforce business rules and maintain data integrity.

3.1 Conditional statements and Iterative statements

Conditional statements

Conditional statements in PL/SQL allow your block to make decisions and execute different code paths depending on conditions.

Types of Conditional Statements:

- IF…THEN

Executes a block only if a condition is true.

```
IF <condition> THEN
-- statements
END IF;
```

- IF…THEN…ELSE

Chooses between two paths.

```
IF <condition> THEN
-- statements if true
ELSE
-- statements if false
END IF;
```

- IF…THEN…ELSIF…ELSE

Chooses among multiple conditions.

```
IF condition1 THEN
-- statements
ELSIF condition2 THEN
-- statements
ELSE
-- statements if none are true
END IF;
```

- CASE Statement

Used to evaluate expressions and choose one path:

```
CASE v_grade
WHEN 'A' THEN DBMS_OUTPUT.PUT_LINE('Excellent');
WHEN 'B' THEN DBMS_OUTPUT.PUT_LINE('Good');
ELSE DBMS_OUTPUT.PUT_LINE('Needs Improvement');
END CASE;
```

Example:

```
DECLARE
salary NUMBER := 60000;
```

```
BEGIN
IF salary > 50000 THEN
DBMS_OUTPUT.PUT_LINE('High Salary');
ELSE
DBMS_OUTPUT.PUT_LINE('Normal Salary');
END IF;
END;
```

2. Iterative Statements (Loops for Repetition)

Iterative Statements in PL/SQL

Iterative statements (loops) are used to repeat execution of a block of statements as long as a condition holds or for a fixed number of iterations.

Types of Loops:

- **LOOP…EXIT**

  A basic loop that repeats until you explicitly EXIT.

  ```
  LOOP
    -- statements
    EXIT WHEN condition;
  END LOOP;
  ```

- **WHILE Loop**

  Repeats while a condition remains true

  ```
  WHILE condition LOOP
    -- statements
  END LOOP;
  ```

- **WHILE Loop**

  Repeats while a condition remains true.

  ```
  WHILE condition LOOP
    -- statements
  END LOOP;
  ```

- **FOR Loop**

  Repeats for a known range

  ```
  FOR counter IN start..end LOOP
    -- statements
  END LOOP;
  ```

Example:

```
DECLARE
  i NUMBER := 1;
BEGIN
```

```
  WHILE i <= 5 LOOP
    IF MOD(i,2)=0 THEN
      DBMS_OUTPUT.PUT_LINE('Even Number: ' || i);
    ELSE
      DBMS_OUTPUT.PUT_LINE('Odd Number: ' || i);
    END IF;
    i := i + 1;
  END LOOP;
END;
```

Output:

Odd Number: 1
Even Number: 2
Odd Number: 3
Even Number: 4
Odd Number: 5

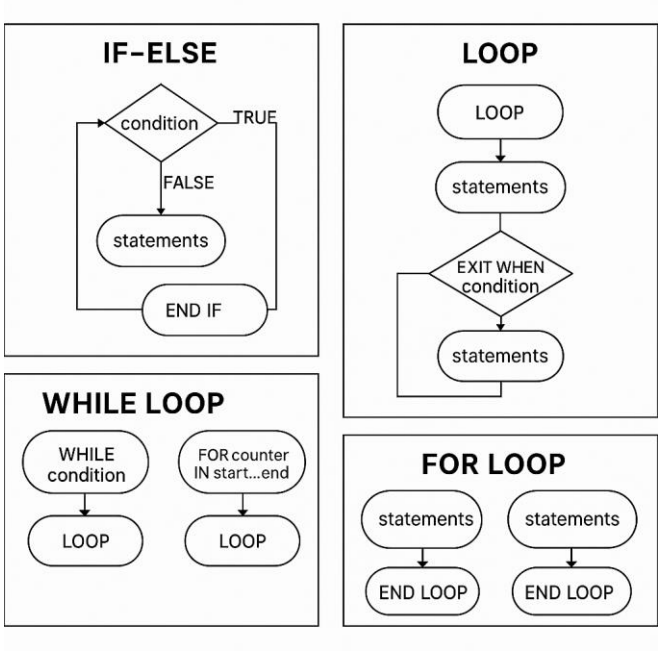


Fig.7.1: Conditional statements and Iterative statements

Unit 8: User-Defined Functions and Stored Procedures

3.2 User-defined functions

A function in PL/SQL is a named block of code that performs a task and returns a single value. It can be called in SQL queries, PL/SQL blocks, or other functions/procedures.

Key Features:

- Must return exactly one value using RETURN.
- Can have parameters.
- Can be used in SELECT, WHERE, or HAVING clauses.

Syntax:

```
CREATE OR REPLACE FUNCTION function_name (param1
datatype, param2 datatype)
RETURN return_datatype
IS
  -- variable declarations
BEGIN
  -- function body
  RETURN value;   -- must return a value
END;
```

Example:

```
CREATE OR REPLACE FUNCTION get_bonus(salary NUMBER)
RETURN NUMBER
IS
BEGIN
  RETURN salary * 0.1;
END;
/
-- Calling the function
DECLARE
  bonus NUMBER;
BEGIN
  bonus := get_bonus(50000);
  DBMS_OUTPUT.PUT_LINE('Bonus: ' || bonus);
END;
/
```

Output:

Bonus: 5000

Types of User-Defined Functions in PL/SQL

In PL/SQL, user-defined functions are generally categorized based on how they are used in SQL statements.

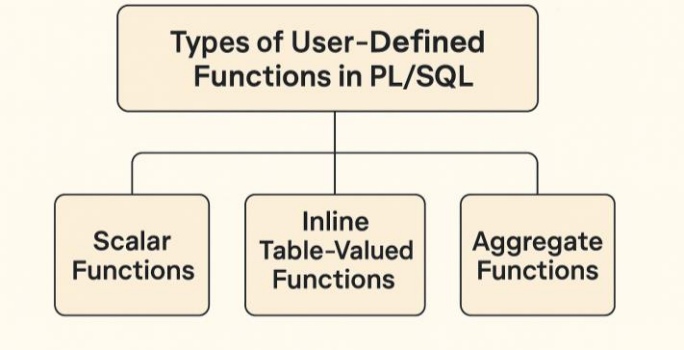


Fig.8.1: statements and Iterative statements

According to the SQL/PLSQL standards, there are three main types:

1. Scalar Functions

Return a single value for each call.

Typically used in SELECT, WHERE, HAVING, or in calculations.

Example:

```
CREATE OR REPLACE FUNCTION get_bonus (salary NUMBER)
RETURN NUMBER
IS
BEGIN
  RETURN salary * 0.1;
END;
/
 --Usage
SELECT employee_name, get_bonus(salary) AS bonus
FROM employees;
```

When to use:

- To compute and return a single value (like bonus, tax, percentage, etc.).

2. Inline Table-Valued Functions (Pipelined Table Functions in Oracle)

Return a **set of rows** (a table) instead of a single value.

In Oracle PL/SQL, these are implemented as pipelined table functions.

Example (simplified):

```
-- First, define a collection type
CREATE OR REPLACE TYPE emp_obj AS OBJECT (
  emp_id NUMBER,
  emp_name VARCHAR2(50)
);
/
CREATE OR REPLACE TYPE emp_table AS TABLE OF emp_obj;
/
-- Then create the function
CREATE OR REPLACE FUNCTION get_emp_list
RETURN emp_table PIPELINED
IS
BEGIN
   FOR r IN (SELECT employee_id, first_name FROM employees)
LOOP
     PIPE ROW(emp_obj(r.employee_id, r.first_name));
   END LOOP;
   RETURN;
END;
/
--Usage
SELECT * FROM TABLE(get_emp_list());
```

When to use:

- When you want to return a **virtual table** from a function and use it like a normal table in SELECT.

3. Aggregate Functions (User-Defined)

Perform calculations on a set of values and **return a single aggregated result**.

Oracle allows creation of **user-defined aggregate functions** by implementing object types with specific methods (advanced topic).

Example (conceptual):

```
-- Create an object type implementing ODCIAggregate interface
-- (complex steps: implement ODCIAggregateInitialize,
ODCIAggregateIterate, etc.)
```

-- Then register as a user-defined aggregate function.

When to use:

- To create custom aggregates beyond built-in ones like SUM, AVG, COUNT.

3.3 Stored Procedures, Parameter types: IN, OUT and INOUT

Introduction to Stored Procedures

A Stored Procedure is a compiled SQL statement collection stored in the database that can be reused. Adan also helps in performing complex queries and operation efficiently and enhances performance, security and code reusability.

Why Use Stored Procedures?

Better performance – The SQL statements are compiled once and then executed multiple times.

Code Reusability – Means no need to write SQL queries again and again.

Security – Enforcement of access control can restrict changes to underlying tables.

Less Network Traffic – You send a procedure call instead of multiple SQL queries.

2. Creating a Stored Procedure

Basic Syntax (MySQL Example):

```
DELIMITER //
CREATE  PROCEDURE procedure_name(
BEGIN
-- SQL Statements
END //
DELIMITER;
```

• DELIMITER // sets a new statement terminator (because the procedure contains;).

• CREATE PROCEDURE defines (creates) the procedure.

• SQL logic is within BEGIN... END

• DELIMITER; resets the default terminator

3. Calling a Stored Procedure

Syntax:

```
CALL procedure_name();
```

Example:

```
DELIMITER //
CREATE PROCEDURE  GetEmployees()
```

```
BEGIN
SELECT * FROM Employees;
END //
DELIMITER;
CALL GetEmployees();
```

Explanation:

• When you execute this procedure, it retrieves all the records from the Employees table.

• Call GetEmployees(); statement runs the procedure.

4. Parameter Types in Stored Procedures

We can also pass parameters to the stored routines.

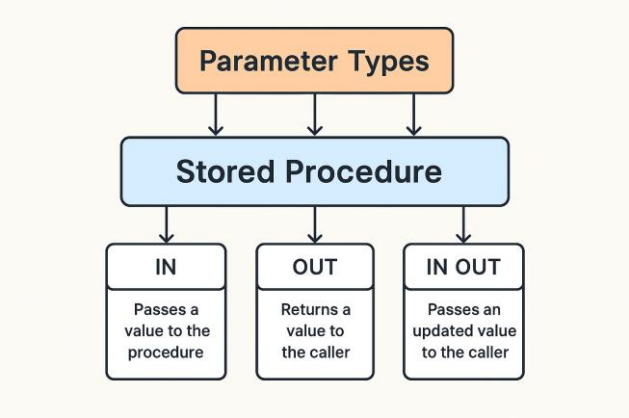


Fig.8.2: Parameter Types in Stored Procedures

Types of parameters are 3 types.

1. IN – For passing input values to the procedure.
2. OUT − Used for returning values from the procedure.
3. INOUT – Input and Output.

IN Parameter (Passing Input to Procedure)

• An IN parameter passes a value into the stored procedure.

• An IN parameter cannot be modified by the procedure.

Syntax:

```
DELIMITER //
CREATE PROCEDURE GetEmployeeByID(IN emp_id INT)
BEGIN
```

Roughly, if you were to be running SQL commands, your prompt input would be something like:

```
END //
DELIMITER;
```

Calling the Procedure:

```
CALL GetEmployeeByID(101);
```

Explanation:

• IN emp_id INT → Takes in an integer (Employee_ID) as input.

• Fetches employee information for a specific employee ID.

OUT Parameter (Returning a Value)

- OUT parameter returns a value.
- THE PROCEDURE CHANGES THE VALUE OF OUT PARAMETER

For Example: Number Of Employees Rehired

```
DELIMITER //
DELIMITER $$ CREATE PROCEDURE GetEmployeeCount(OUT
total INT)$$ DELIMITER;
BEGIN
SELECT COUNT(*) INTO total FROM Employees;
END //
DELIMITER;
```

Calling the Procedure:

```
CALL GetEmployeeCount(@count);
SELECT @count; -- Show the value returned
```

Explanation:

• OUT total INT stores total employees.

• SELECT COUNT(*) INTO total saves the result to total.

• The CALL GetEmployeeCount(@count); saves the result to @count.

4.3 INOUT Parameter (Both Input and Output)

- The INOUT modifier is for directly changing value and returning.

Example: Modify Salary and Retrun updated Value

```
DELIMITER //
CREATE PROCEDURE UpdateSalary( INOUT emp_salary
DECIMAL(10,2), IN emp_id int)
BEGIN
UPDATE Employees SET Salary = emp_salary WHERE
Employee_ID = emp_id;
SELECT Salary INTO emp_salary FROM Employees WHERE
Employee_ID=emp_id
END //
DELIMITER;
```

Calling the Procedure:

```
SET @salary = 50000;
CALL UpdateSalary(101, @salary);
SELECT @salary; -- Updated salary
```

Explanation:

• INOUT emp_salary → input and output salary value

• Modifies the salary, and then reads back the new value.

• SET @salary = 50000; initializes the value

• The new salary is returned and stored in @salary.

5. Dropping a Stored Procedure

- To remove a procedure you are no longer interested in, use:

```
DROP PROCEDURE procedure_name IF EXISTS;
```

Example:

```
DROP PROCEDURE IF EXISTS GetEmployeeByID;
```

They optimized database operations by efficiency, security, and reusability.

- IN Parameters → Get input but cannot be changed.
- OUT Parameters ⇒ Return from procedures
- INOUT Parameters → Re-route values by modifying and returning.

Stored procedures help manage the database more quickly and securely in an effective and structural way, thus making them one of the key functions of all modern RDBMS systems.

3.4 Triggers: Introduction, Needs, Before trigger and After trigger

1. Introduction to Triggers

Triggers are special types of stored procedures in a database that are automatically executed when an event occurs on a table. The events can be INSERT, UPDATE, or DELETE operations.

Business rules, data integrity, automation, and security controls are all uses of triggers. Triggers are similar to stored procedures in that you cannot call them manually; they run automatically in response to the event with which they are associated.

Features of Triggers:

Automatic Execution – Automatically fires on occurrence of referenced Event.

Event-Driven – Triggers on INSERT, UPDATE, or DELETE.

Validates Business Rules – Prevents Invalid Data Churn

Data Integrity – Ensures consistent data across tables.

Makes Unauthorized Changes Impossible – Data Access and Validation

2. Need for Triggers

We will use triggers in the database. Triggers are very important in removing data constraints, audit log creation, or enforce a business rule automatically. Some key use cases include:

Enforcing Business Rules

Example: Ensuring employees don't pay salaries under minimum wage.

Maintaining Data Integrity

Example: automatically updating child records if any parent record is updated to maintain a foreign key constraint.

Auditing and Logging Changes

Example: Audit trail for changes to sensitive tables like financial transactions.

Preventing Invalid Transactions

Example: Not allowing account balance updates for negative amounts.

Automating Actions

Example: Send an email notification every time a new user is added to the system.

3. Types of Triggers

Triggers are classified based on when they execute relative to the event:

Type	Executes Before/After	Applies to INSERT, UPDATE, DELETE	Use Case
BEFORE Trigger	Before the event	YES	Validation & Prevention
AFTER Trigger	After the event	YES	Logging &Post-processing

4. BEFORE Triggers

Definition:

A BEFORE Trigger runs before an INSERT, UPDATE, or DELETE operation. Its common on use is to verify data and prevent incorrect alterations.

Example 1: BEFORE INSERT Trigger (Preventing Invalid Salary Entry)

```
DELIMITER //
The order of the two is the subject of this post.CREATE TRIGGER
Before_Insert_Employee
BEFORE INSERT ON Employees
FOR EACH ROW
BEGIN
IF NEW. Salary= 30000) THEN SET MESSAGE_TEXT = 'Salary
should be atleast 30000';
END IF;
END //
DELIMITER;
```

Explanation:

- BEFORE INSERT – Executes before inserting data into the Employees table.
- NEW.Salary – Refers to the salary value being inserted.
- SIGNAL SQLSTATE '45000' – Throws an error if salary is less than 30,000.

Calling the Trigger:

```
INSERT INTO Employees (Employee_ID, Name, Salary)VALUES
(101, 'Alice', 25000);
```

Output:

ERROR Salary Must be Greater Than 30,000

To ensure no invalid salary can be inserted the trigger can be used.

Example 2: BEFORE UPDATE Trigger (Restricting Price Reduction by More Than 50%)

```
DELIMITER //
< ` CREATE TRIGGER Before_Update_Product
BEFORE UPDATE ON Products
FOR EACH ROW
BEGIN
IF NEW. Price< (OLD. Price * 0.5) THEN
SIGNAL SQLSTATE '45000'
SET MESSAGE_TEXT = 'Reduced price can't be more than 50%';
END IF;
END //
DELIMITER;
```

Explanation:

• BEFORE UPDATE – Executes before product prices are updated.

• OLD. Price – Refers to the current price.

• NEW. Price – The new price that is being updated

• The trigger throws an error if the new price is less than 50% of the old price.

Calling the Trigger:

```
UPDATE Products SET Price = 20 WHERE Product_ID = 1; --
Previous price 100
```

Output:

vbnet

The trigger saves us from having to make a drastic price cut.

5. AFTER Triggers

Definition:

An AFTER Trigger runs after INSERT, UPDATE, or DELETE statement. It is often used to log, audit, and update reference tables.

Example 1: AFTER INSERT Trigger (Logging New Employee Addition)

```
DELIMITER //
SQL -- CREATE TRIGGER After_Insert_Employee
AFTER INSERT ON Employees
FOR EACH ROW
```

```
BEGIN
"INSERT INTO  Employee_Log (Employee_ID, Action, Timestamp)
VALUES (NEW. Insert into  Table (Employee_ID, 'Inserted',
NOW());
END //
DELIMITER;
```

Explanation:

• AFTER INSERT – Trigger works after inserting an employee.

• NEW. Employee_ID – Gets the new employee's Identification.

• NOW() – Saves the current date and time.

• Outputs log entry into Employee_Log table

Calling the Trigger:

INSERT INTO Employees VALUES (102, 'Bob', 50000);

Employee_Log Table (Post Trigger Execution):

Log_ID Employee_ID Action Timestamp

Row Status | ID | Data | Date/Time | 1 Inserted | 2024-03-09 12:30:00 |

The trigger logs the new joins automatically.

Example 2: AFTER DELETE Trigger (Archiving Deleted Orders)

```
DELIMITER //
CREATE  TRIGGER After_Delete_Order
AFTER DELETE ON Orders
FOR EACH ROW
BEGIN
INSERT  INTO Order_Archive (Order_ID, Customer_ID,
Order_Date) VALUES
VALUES (OLD. Order_ID, OLD. Customer_ID, OLD. Order_Date);
END //
DELIMITER;
```

Explanation:

• AFTER DELETE – Triggered post deletion of the order.

• OLD. Order_ID – The Order which has been deleted.

• Deletes orders into an archive table (Order_Archive).

Calling the Trigger:

The trigger also keeps deleted orders in the archive table.

6. Dropping a Trigger

To drop a trigger, which may be, no longer needed:

```
DROP TRIGGER IF EXISTS  trigger_name;
```

Example:

DROP TRIGGER IF EXISTS Before_Insert_Employee;

Triggers increase database automation, security, and integrity by enforcing business rules at the database level.

• Triggers BEFORE → Validate on execution (BEFORE INSERT/UPDATE/DELETE).

• AFTER Triggers → Execute after the execution of actions (AFTER INSERT/UPDATE/DELETE).

Triggers are a major component of data management in relational databases, allowing automated checks on data, logging, fraud prevention, and ensuring data consistency.

Summary

Control flow in SQL enables decision-making and repetition within procedural extensions of SQL, such as PL/SQL or T-SQL. Using constructs like IF-THEN-ELSE, CASE statements, and loops (WHILE, FOR), SQL scripts can perform complex logic and automate processes within the database. These structures allow SQL to not only query data but also to react dynamically based on conditions, improving the ability to handle business logic directly within the database environment.

User-defined functions and stored procedures further enhance SQL's capabilities. A stored procedure is a precompiled block of SQL code that performs specific tasks and can be reused across applications, while user-defined functions return values and are often used in queries for calculations or formatting. These programmable components reduce redundancy, improve maintainability, and enhance performance by encapsulating logic at the database level. Triggers are special procedures that automatically execute in response to specific database events such as INSERT, UPDATE, or DELETE. They enforce rules, audit changes, and automate responses, ensuring data integrity and consistency without manual intervention. Together, control flow mechanisms, functions, procedures, and triggers offer a powerful toolkit for managing logic and automation directly within the database.

MCQs:

1. Generalization in a database is the process of:

a) Combining multiple entities into a higher-level entity

b) Splitting one entity into multiple sub-entities

c) Creating foreign keys

d) Deleting redundant data

(Answer: a)

2. Specialization in an E-R model refers to:

a) Merging two entities into one
b) Creating sub-entities from a higher-level entity
c) Removing attributes from a table
d) Encrypting a database
(Answer: b)
3. A Super Key is:
a) A key that uniquely identifies a tuple but may have extra attributes
b) A key used for indexing
c) A key with duplicate values
d) A key used only for foreign relations
(Answer: a)
4. Which of the following is a Candidate Key?
a) A key that can be used as a Primary Key
b) A key that contains duplicate values
c) A foreign key
d) A key that cannot be unique
(Answer: a)
5. The Primary Key in a relational database:
a) Uniquely identifies each record
b) Can have NULL values
c) Is always a foreign key
d) Must contain duplicate values
(Answer: a)
6. A Foreign Key is used to:
a) Uniquely identify a record in a table
b) Enforce referential integrity between two tables
c) Store encrypted data
d) Improve query performance
(Answer: b)
7. Which diagram is used to represent the structure of a relational database?
a) Flowchart
b) Schema Diagram
c) E-R Diagram
d) UML Diagram
(Answer: b)
8. What does E-R to Relational Model Conversion involve?
a) Mapping entities and relationships to tables

b) Writing SQL queries
c) Creating indexes for tables
d) Deleting duplicate records
(Answer: a)
9. Which of the following constraints ensures referential integrity in a database?
a) Primary Key
b) Foreign Key
c) NOT NULL
d) CHECK
(Answer: b)
10. The Relational Model consists of:
a) Tables with rows and columns
b) Images and videos
c) Hierarchical data storage
d) Graph-based relationships
(Answer: a)

Short Questions:

1. What is the difference between Generalization and Specialization?
2. Define Super Key, Candidate Key, and Primary Key.
3. Explain the Relational Model Structure in databases.
4. What are the different types of keys in a relational database?
5. How does a Foreign Key maintain referential integrity?
6. What are the constraints on Specialization in E-R models?
7. Explain how an E-R model is converted into a relational model.
8. What is the role of a Schema Diagram in database design?
9. Define Database Schema and its types.
10. What is the importance of constraints in relational databases?

Long Questions:

1. Explain Generalization and Specialization in the E-R model with examples.
2. Discuss the role of constraints on Specialization in database design.
3. What is a Relational Model? Explain its structure with examples.
4. Describe the different types of keys and their importance in a relational database.

5. Explain the concept of Foreign Keys and how they enforce referential integrity.
6. What is a Schema Diagram, and how does it help in database design?
7. Describe the process of converting an E-R model into a relational model.
8. Explain the importance of normalization in relational databases.
9. Compare and contrast Primary Key and Foreign Key.
10. How does a well-designed relational model improve database efficiency?

- To understand the fundamental concepts of Data Warehousing.
- To explore the architecture of Data Warehouses, including the three-tier architecture.
- To analyze multidimensional data models such as Data Cubes.
- To examine different schemas used in Data Warehousing.
- To learn about Concept Hierarchies and OLAP operations.

MODULE 4

TRANSACTION MANAGEMENT AND CONCURRENCY

LEARNING OUTCOMES

- Understand transactions, their properties, and different transaction models in database systems.
- Analyze transaction isolation and scheduling techniques (serial and non-serial schedules) to ensure consistency.
- Learn serializability concepts (conflict serializability) and their role in maintaining correctness.
- Implement concurrency control protocols (lock-based and timestamp-based) and deadlock handling techniques for efficient database performance.

4.1 Transaction: Introduction, Transaction Model

A transaction is a series of one or more SQL operation from a database that is executed as one logical unit of work. Transactions help maintain database consistency and reliability in the case of system crashes or power failures, as well as concurrent user operations. In multi-user database environments, when several users at the same time perform operations, data integrity has to be maintained. If transactions were not handled correctly, partial operations could corrupt or render data inconsistent. In banking systems, if a customer transfers money from one account to another, both the debit and the credit operation has to be successful. If the debit is successful but the credit fails the money will be lost. Transactions allow you to group both operations so they either both complete or both fail to prevent this from happening.

Real-Life Example of a Transaction

For instance let's say a bank customer transfers $500 from Account A to Account B. The transaction involves two operations:

1. Update Accounts Set Balance = Balance - 500 Where Account_ID = 1; Deduct $500 from Account A.
2. Update Accounts: Add $500 in Account B (UPDATE Accounts SET Balance = Balance + 500 WHERE Account_ID = 2;).

For consistency, the rollback should be performed in case the second operation fails, so that no operation will have to revert back

2. Understanding the ACID Properties of Transactions

A transaction must follow four key properties, known as the ACID properties:

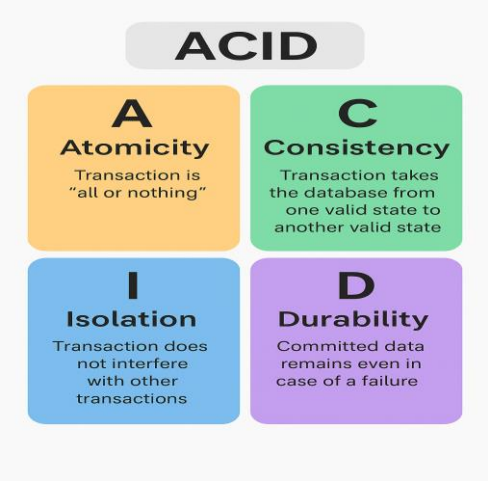


Fig. 10.1-ACID Properties

Atomicity (All or Nothing Rule)

- A transaction is either successfully completed or aborted.
- • All changes made in a transaction must either be completed successfully or rolled back if an error occurs.
- For example, if a payment fails after taking money out from an account, the amount has to be refunded.

Consistency (Maintaining Database Validity)

- Every transaction should transform the database from one valid state to another.
- Any changes made need to comply with the database constraints, rules, and integrity checks
- For example, if an order is placed in an e-commerce system, then the stock count must be decreased accordingly.

Isolation (Preventing Concurrent Transaction Interference)

- Concurrent transactions must not interfere with one another's execution.
- All transactions are executed sequentially and the final outcome must look like transactions were executed sequentially.
- Illustration: When two users book the last ticket to a movie, both should fail, but one should succeed.

Durability (Permanent Storage of Committed Data)

- Once a transaction commits, its changes have to be persisted even in case of a system crash.
- Example: After conducting an online banking transaction, new balance should not be lost after server crash

3. Transaction Lifecycle and States

A transaction progresses through multiple states during its execution:

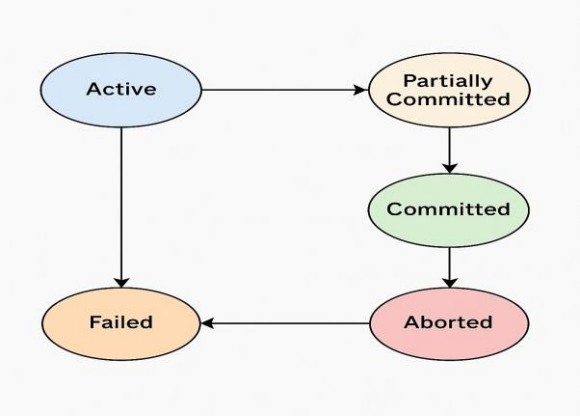


Fig. 10.2- Transaction Lifecycle and States

Transaction State	Description
Active	The transaction has started and is currently executing.
Partially Committed	All SQL operations are completed, but not yet permanently saved.
Committed	Changes are successfully stored in the database.
Failed	An error occurred, causing the transaction to fail.
Aborted (Rollback)	The transaction is undone, restoring the database to its previous state.

State Transitions in a Transaction

1. Execution of a transaction starts in the ACTIVE state.
2. If all operations succeed, changes to PARTIALLY COMMITTED.
3. Once the COMMIT statement is executed, the transaction is CONVERTED to COMMITTED, which saves the changes permanently.
4. If any step fails, the transaction will enter into FAILED state.
5. In the event of a failure, a ROLLBACK command restores the database, transitioning it to the ABORTED state.

Example of Transaction Lifecycle in SQL

```
ROLLBACK;  -- Undo all changes
START TRANSACTION;
UPDATE Accounts Set Balance  = Balance-500 WHERE Account_ID
= 1; -- Decrease money
UPDATE Accounts SET Balance = Balance - 500 WHERE
Account_ID =  1; -- Withdraw money
COMMIT; # Make changes  permanent
If any error occurs before the  COMMIT, we can roll it back
```

4. Transaction Models in Database Management Systems (DBMS)

A transaction model specifies the functioning of transactions in a database system with guarantee of ACID properties. They assist in managing transactions, concurrency, and failure recovery efficiently.

Flat Transactions (Simple Transactions)

- An abstract model for the simplest transaction in which a series of operations are performed as a single unit.

- Strictly follows ACID properties: Thus if there is a failure in a part of transaction, the complete transaction will be rolled back.
- for instance: Moving currency between bank accounts.

Nested Transactions (Transactions Inside Transactions)

• Sub-transactions which are executed independently within the main transaction.

• Supports rolling back a single part of a compound transaction if it is a sub-transaction and the parent transaction can still succeed.

• Example: In case of an online shopping system placing an order is:

1. Minusing money from the customer account (Sub-transaction 1)
2. Stock levels update (Sub-transaction 2)
3. Sending a confirmation mail (Sub-Transaction 3)

Whether Sub-transaction 3 fails or succeeds, the payment and update of stock will still be valid.

Long-Duration Transactions (Used in Batch Processing & Cloud Systems)

- Long-running transactions (hours or days)
- Used extensively in scientific computing, cloud applications, and batch data processing.
- Sample: Month-end for payroll processing for thousands of employees

5. Concurrency Control in Transactions

Data inconsistencies arise when two or more transactions access the same data and try to change it at the same time. Concurrency control mechanisms must be implemented in database systems to avoid conflicts.

Problems Caused by Concurrent Transactions

- lost update → two transactions updating the same data; one update gets lost.
- Dirty Read → This occurs in case if one transaction reads data that another transaction has not yet committed.
- Non-Repeatable Read → A transaction is read multiple times but value change from another transaction.

Techniques for Concurrency Control

- Locking Mechanisms (Shared & Exclusive Locks) → Avoid two transactions modifying the same data at the same time.

- Timestamp Ordering→ Guarantees the correct sequence of executing transactions.
- Optimistic Concurrency Control →Freely allows transactions to execute, checks for conflicts before committing.

6. Handling Failures and Recovery in Transactions

Transaction Failures can be attributed to:

System Crashes → Power failures, OS crashes.

Deadlock → Transaction(s) waiting infinitely for each other.

Concurrency Issues → when multiple transactions conflict with one another.

Recovery Mechanisms:

1. Undo (Rollback) – Reverts uncommitted changes to ensure data consistency
2. Redo (Reapply Changes) – it guarantees that committed transactions are recovered after a system crash.
3. Transaction ambiguity rules – Ensures only valid transactions are considered, managing rollback overhead.

• Transactions are guaranteed to execute reliably because of ACID properties.

• Transaction – states and models define the way transactions work.

• Concurrency control provides protection against concurrency conflicts (e.g., in a multi-user environment).

• Ensure atomicity of transactions even in case of system failures through failure recovery mechanisms.

Transaction handling is a critical aspect of any modern Database Management System (DBMS), ensuring that operations within a database are secure, efficient, and free from errors.

4.2 Properties of Transactions

A transaction, in a database, is a series of operations executed as one work unit. Transactions executed must adhere to ACID properties to ensure that they have data integrity, consistency, and reliability. These Properties guarantee that, even during power failures, crashes and concurrent transactions, the database could be returned to some previous valid state. The four fundamental properties of a transaction are:

1. Atomicity – Ensures that all operations in a transaction are executed completely or not at all.

2. Consistency – Ensures a transaction takes the database from one valid state to another.
3. Isolation – Guarantees that transactions do not disturb one another.
4. Durability – Guarantees that once a transaction has been committed, it will remain so, regardless of what may happen.

These properties together make the ACID model, which is the basis of a reliable Database Management System (DBMS).

1. Atomicity (All or Nothing Rule)

Atomicity guarantees that a transaction is treated as a single, indivisible unit. So, either all the operations of the transaction are performed successfully or none of them are performed at all. Any failure of any of these operations must trigger a rollback of the entire transaction to avoid partial updates.

Why is Atomicity Important?

In the absence of atomicity, a transaction may leave data half-completed in the database, creating corrupted and inconsistent data.

Example of Atomicity

Consider a bank transfer where Alice transfers $500 to Bob. The transaction consists of:

1. Deduct $500 from Alice's account
2. Add $500 to Bob's account

SQL Example:

```
START TRANSACTION;
UPDATE Accounts SET Balance = Balance + 500 WHERE
Account_ID = 1; -- Add money
UPDATE Accounts SET Balance = Balance - 50 WHERE
Account_ID = 1; -- Withdraw money
COMMIT;  -- Commit changes
```

If the second operation fails (say due to a database crash), atomicity guarantees the first operation will be undone by rolling back the transaction:

```
ROLLBACK;  -- undo everything
```

Effect: It is either fully committed or fully rolled back so no partial transfer.

2. Consistency (Maintaining Database Validity)

Consistency means that a transaction is valid with respect to any database constraint before and after running. The database must meet all conditions, rules, and relationships.

Why is Consistency Important?

To prevent creating corrupt or invalid data that breaks business rules and constraints through transactions, consistency is important.

Example of Consistency

Consider an e-commerce system where a customer places an order:

1. Deduct stock quantity from inventory
2. Generate an invoice for the order

The order should not be processed if the stock is not available, so the database should be consistent.

SQL Example (Consistency in Order Placing):

START TRANSACTION;

This SQL query deducts one stock for a product with Product_ID of 101, if there is stock available, Sequelize would be Genetrating a query similar to the one below.

INSERT INTO Orders (Order_ID, Product_ID, Customer_ID)
VALUES (5001, 101, 2001);
COMMIT;

If the stock quantity is zero, the transaction fails and does not place the order, maintaining consistency.

The consequence is that the database is always in a valid state during and after the transaction.

3. Isolation (Ensuring Independent Execution of Transactions)

Definition:

Isolation is what makes sure that when transactions are being processed, they do so without stepping on one another. Changes made by a transaction may not be visible to other transactions until the transaction is committed.

Why is Isolation Important?

Without isolation, concurrent transactions can lead to issues such as:

- Lost updates – One transaction overwrites changes made by another.
- Dirty reads – A transaction reads uncommitted data from another transaction.
- Non-repeatable reads – A transaction sees different results for the same query due to another transaction's modifications.

Example of Isolation

Consider two customers trying to book the last available flight seat at the same time:

1. Customer A initiates booking.
2. Customer B initiates booking at the same time.

If the database does not implement isolation, both customers can be assigned to the same seat, which will cause a conflic.

SQL Example (Using Isolation to Prevent Booking Conflicts):

SQL Example (Utilising Isolation to Avoid Overbooking)---

START TRANSACTION;

SELECT Seats_Available FROM Flights WHERE Flight_ID = 301 FOR UPDATE; // Locks the row

UPDATE Flights SET Seats_Available = Seats_Available - 1 WHERE Flight_ID = 301

COMMIT;

- The seat availability is locked due to the FOR UPDATE statement until that transaction is done.
- Then no other user will be able to access the seat until the transaction is committed.

Outcome: A single customer gets the seat, no conflicts.

4. Durability (Permanent Data Storage After Transaction Completion)

Definition:

Durability: Once some transaction has been committed, the updates made by that transaction should be permanent.

Why is Durability Important?

In the absence of durability, there could be a potential loss of committed transactions in the event of a power outage or a system crash/abrupt shutdown, resulting in data loss.

How is Durability Ensured?

• Write-Ahead Logging (WAL): This mechanism ensures that the database can recover after a crash by writing transaction logs before applying any changes.

• Commit Operation: Changes are available in persistent storage (disk, SSD, or cloud storage) after they are committed.

Example of Durability

Let us consider a customer who placed an order online, for instance:

1. Fill stock inventory by reducing stock quantity

2. An order with 'Confirmed' status

Persist the order once it is confirmed, the order should be stored permanently, even if the system crashes.

SQL Example (Ensuring Durability in Order Confirmation):

START TRANSACTION;

UPDATE Products SET Stock = Stock - 1 WHERE Product_ID = 102;

INSERT INTO Orders (Order ID, Product ID, Customer ID, Status) VALUES (6001, 102, 3001, 'Confirmed')INSERT INTO Orders (Order_ID, Product_ID, Customer_ID, Status) VALUES (6001, 102, 3001, 'Confirmed');

COMMIT;

• If the system fails after the COMMIT statement, the order will still be confirmed (when the system restarts).

• Committed changes are sustainable, even after failures, through database logging.

OUTPUT: the order is stored permanently (Durability).

These four properties, Atomicity the A, Consistency the C, Isolation the I, and Durability the D, ensure the reliability, integrity, and consistency of the database.

ACID Property	Ensures That...	Example
Atomicity	A transaction is fully completed or fully rolled back	Money transfer: Debit and credit both succeed or both fail
Consistency	The database remains valid before and after transactions	Preventing orders if stock is unavailable
Isolation	Transactions do not interfere with each other	Preventing two customers from booking the same flight seat
Durability	Committed transactions remain permanent	Orders stay confirmed even after a system crash

Databases ensure that applications like business applications, financial systems, e-commerce platforms, etc., work correctly without errors or inconsistencies.

4.3 Transaction isolation, Schedules: Serial, Non-Serial Schedules

1. Transaction Isolation in Databases

Transaction isolation prevents interference from concurrent transactions, preserving the database's consistency and integrity. Multiple versions of a row is a core concept in concurrency control, which avoids issues like dirty reads, lost updates, and inconsistent reading. A multi-user database allows multiple transactions to overlap in time. Promiscuous interaction may lead to corrupt, out-of-sync, or missing data. Isolation guarantees the correct outcome of each transaction as if it executed in isolation.

Example of Transaction Isolation

Consider two customers booking the last available train ticket simultaneously:

1. Transaction A queries availability and sees 1 seat available.
2. Transaction B, which checks availability at the same time, also sees 1 seat left.
3. Both the transactions book the seat.
4. Now they have two customers with the same seat and, hence, a conflict.

Transaction isolation mechanisms prevent both incorrect updates and ensure the consistency of data to avoid this situation.

2. Isolation Levels in Database Systems

The level of isolation between one transaction and other concurrent transactions is defined by different isolation levels. The more isolation you have, the more accurate (but slower) you will be, the less isolation, the faster (but potentially inaccurate) you will be.

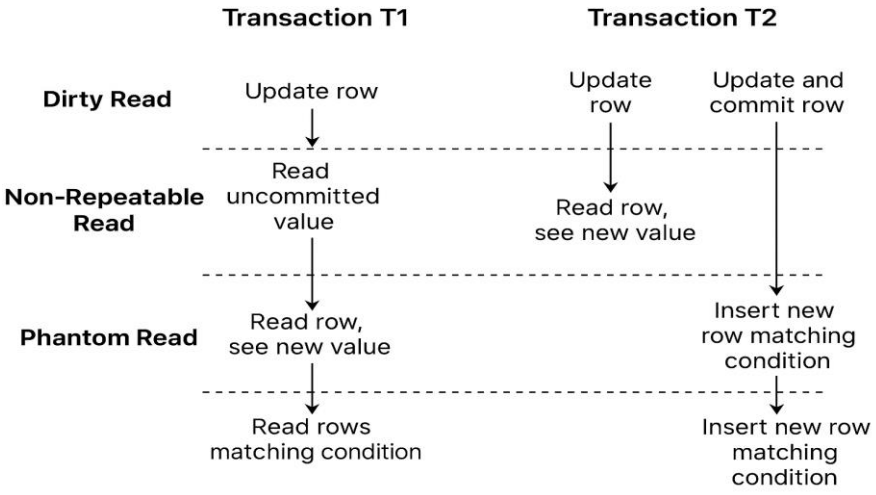


Fig. 10.3 : Diagram illustrating transaction anomalies

Isolation Level	Dirty Read	Non-Repeatable Read	Phantom Read	Use Case
Read Uncommitted	Allowed	Allowed	Allowed	Fastest, but least safe
Read Committed	Prevented	Allowed	Allowed	Standard for many databases
Repeatable Read	Prevented	Prevented	Allowed	Ensures consistent reads
Serializable	Prevented	Prevented	Prevented	Highest safety, but slowest

Common Problems in Isolation Levels

1. Dirty Read (Reading Uncommitted Data)

This happens when a transaction reads data that has been modified by yet another transaction but has not yet been committed

Example:

- Transaction A: Increase salary, not yet committed.
- Transaction B: Fetches the new salary.
- Transaction A: Rollback, reverting change.
- Transaction B: Is now corrupt and has the wrong data.

2. Non-Repeatable Read (Different Results in the Same Transaction)

When transaction reads the same row twice but gets different values due to another transaction updating it in between.

Example:

- Transaction A: Reads a product price to be $100.
- Transaction B: Changes the price to $120 and commits.
- Transaction A: Reads the price again: $120 instead of $100.

3. Phantom Read (New Rows Appearing in Subsequent Reads)

This happens when an inserted/deleted row is returned in a new read through the same transaction.

Example:

Transaction A : Get All Orders for Customer 101(5 records)

• Transaction B: Create new ORD for Customer 101 and commit.

• Transaction A: Reads again, there are 6 records now.

3. Transaction Schedules: Serial and Non-Serial Schedules

Scheduler is a way of executing multiple transaction in a database in a serial manner. This order of execution affects the consistency and correctness of the data.

Serial Schedule (Fully Isolated Transactions)

A serial schedule is one where transactions are executed one after another, with no overlaps.

Slow but certain — every transaction must wait for the previous one to complete.

Example:

Let us consider two transactions, T1 and T2:

• T1: Account balance update.

• T2: Reads account balance.

Serial Execution:

T1: Read Balance

T1: Update Balance

T1: Commit

T2: Read Updated Balance

T2: Commit

Pro: Guarantees consistency and free from concurrency issues.

X Drawback: Slow, because transactions do not overlap

Non-Serial Schedule (Concurrent Transactions)

In contrast, a non-serial schedule permits transactions to run concurrently, interleaving their operations.

Works great and boost performance but might create inconsistency.

Example:

T1: Read Balance

T2: Read Balance

T1: Update Balance

T2: Update Balance

T1: Commit

T2: Commit

Problem: Lost updates—T2 reading before T1 commits will overwrite T1's changes.

4. Types of Non-Serial Schedules

However, not all non-serial schedules are of concern. Others are accurate but perform worse.

Conflict Serializable Schedule

• Concurrent execution of transactions but final result matches a serial execution.
• Correctness is preserved and permits parallel execution.
• Utilized for optimistic concurrency control.

Example:

T1: Read Balance
T1: Update Balance
T2: Read Balance
T2: Update Balance
T1: Commit
T2: Commit

Since T1 finishes before the effects of T2's changes are seen, the outcome is the same as that of a serial schedule.

View Serializable Schedule

- Transaction produces a final result as in serial execution, although operations may differ.
- Much more permissive than conflict serializability.

Example:

For example, two transactions update a price list, but their final effect is correct: the operations are reordered.

5. Ensuring Correct Schedules: Concurrency Control

Databases use the following concurrency control techniques to avoid errors in non-serial schedules:

1. Two-Phase Locking (2PL) → Set locks earlier than accessing resources and eventuates in serializability.
2. Timestamp Ordering → Each transaction is assigned a timestamp, and according to their timestamp, transactions are executed.
3. Optimistic Concurrency Control (OCC) → No lock mechanism, transactions run freely then checked before committing. Transaction isolation means transactions execute properly without interfering with each other.

- READ_COMMITTED is Isolation levels (Read Uncommitted, Read Committed, Repeatable Read, Serializable) (if we want to allow how much concurrency?)
- A schedule is the order of execution of transactions, which has an impact on consistency.

- Serial schedules are always accurate, but slow, and non-serial schedules optimize the speed, but expect for conflicts.
- Concurrency control methods maintain data integrity in non-serialized schedules.

With a sound grasp of isolation levels and transaction schedules, database administrators can achieve a good balance of performance and consistency, enabling reliable database operations in multi-user settings.

4.4 Serializability, Conflict Serializability

1. Introduction to Serializability

Millions of transaction attempts are submitted to the database concurrently every second, and a vital concept you need to be aware of is something called serializability. If the effect of a schedule (the order in which transactions operations are carried out) is equivalent to the effect of some serial schedule then it is called as serializable schedule.

Why is Serializability Important?

- In multi-user databases, several transactions may be working concurrently to enhance performance.
- Inconsistent data, lost updates, or incorrect results may happen when transactions are not adequately controlled.
- Sequentializability guarantees correctness under concurrency and prevents execution at the same time conflicting

Example: Serial vs. Non-Serial Execution

Consider two transactions, T1 and T2:

- T1: Withdraws $100 from a bank account.
- T2: Checks the balance.

Serial Execution (Correct & Safe)

T1: Read Balance ($1000)
T1: Update Balance ($900)
T1: Commit
T2: Read Balance ($900)
T2: Commit
T2 sees the correct updated balance of $900.

Non-Serial Execution (Unsafe)

T1: Read Balance ($1000)
T2: Read Balance ($1000)
T1: Update Balance ($900)
T1: Commit
T2: Commit
T2 reads an incorrect balance of $1000 instead of $900!

Serializability defines a contract to ensure that, despite running concurrently, transactions will execute such that they are equivalent to a serial execution order, preventing this type of inconsistency.

2. Types of Serializability

. Conflict Serializability

- Ensures that transactions can be reordered into a serial schedule by checking for conflicts.
- Conflict serializability is verified using a precedence graph (or dependency graph).

View Serializability

- Ensures that final results of transactions match those of a serial execution, even if operations are reordered.
- More relaxed than conflict serializability.

3. Conflict Serializability

What is Conflict Serializability?

What is conflict serializable: A schedule is conflict serializable if it is possible to convert it into a serial one by exchanging non-conflicting operations without modifying the final outcome.

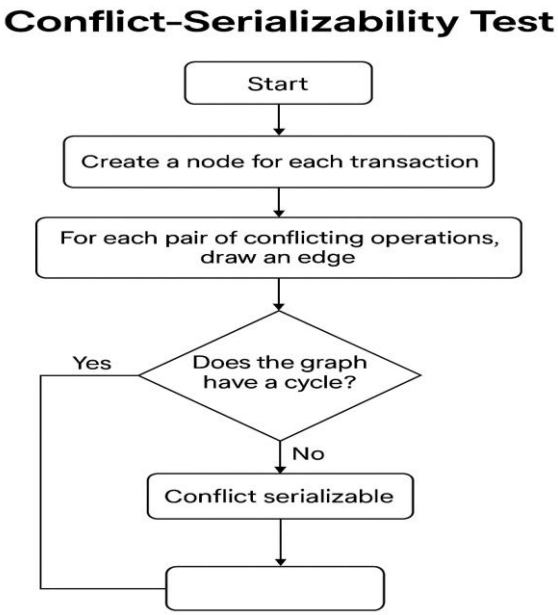


Fig. 11.1 : flowchart illustrating the conflict-serializability test

What Causes a Conflict?

Two operations conflict if they:

1. Belong to different transactions (T1 and T2).
2. Operate on the same data item (e.g., X).
3. At least one of them is a WRITE operation.

Types of Conflicting Operations

Operation 1	Operation 2	Same Transaction?	Same Data Item?	At Least One WRITE?	Conflict?
Read(X)	Read(X)	No	Yes	No	No
Read(X)	Write(X)	No	Yes	Yes	Yes
Write(X)	Read(X)	No	Yes	Yes	Yes
Write(X)	Write(X)	No	Yes	Yes	Yes

Checking Conflict Serializability Using a Precedence Graph

A Precedence Graph (or Dependency Graph) is used to show if a schedule is conflict serializable.

Steps to Check Conflict Serializability:

1. Create a directed graph with transactions as nodes.
2. Add a directed edge from Ti to Tj if Ti performs an operation before Tj that conflicts.
3. Check for cycles in the graph:
    - If the graph has NO cycles, the schedule is conflict serializable.
    - If the graph has a cycle, the schedule is not conflict serializable.

4. Example of Conflict Serializability

Example 1: Conflict Serializable Schedule

Consider the following schedule:

Time	Transaction	Operation
1	T1	Read(X)
2	T2	Read(X)
3	T1	Write(X)
4	T2	Write(X)

Step 1: Identify Conflicts

- T1: Read(X) vs. T2: Read(X) → No conflict
- T1: Write(X) vs. T2: Read(X) → Conflict (T1 → T2)
- T1: Write(X) vs. T2: Write(X) → Conflict (T1 → T2)

Step 2: Build Precedence Graph

T1 → T2

- No cycle exists → The schedule is conflict serializable.

Step 3: Equivalent Serial Schedule

The transactions can be executed in the order T1 → T2.

The schedule is conflict serializable (and equivalent to the serial execution of T1 followed by T2).

Example 2: Non-Conflict Serializable Schedule

Consider this schedule:

Time	Transaction	Operation
1	T1	Read(X)
2	T2	Write(X)
3	T1	Write(X)

Step 1: Identify Conflicts

- T1: Read(X) vs. T2: Write(X) → Conflict (T1 → T2)
- T2: Write(X) vs. T1: Write(X) → Conflict (T2 → T1)

Step 2: Build Precedence Graph

T1 → T2

T2 → T1 (Cycle detected)

- A cycle exists → The schedule is not conflict serializable.

The schedule is not conflict serializable because T1 and T2 cannot be reordered into a serial sequence.

5. Conflict Serializability vs. View Serializability

Feature	**Conflict Serializability**	**View Serializability**
Definition	Transactions can be reordered into a serial schedule using conflict rules	Transactions produce the same final result as a serial execution
Check Method	Precedence Graph (Check for cycles)	Compare final results
More Restrictive?	Yes (Stronger condition)	No (More relaxed)
Practical Use	Most databases enforce conflict serializability	View serializability is rarely used

• Serializability verifies correct result of concurrent transaction is equivalent to that of serial execution.

- The conflict serializability is the most popular method that is used to ensure the safe concurrent executions.
- Conflict serializability of a schedule can be tested through Precedence Graphs.
- If a schedule has a cycle, it is NOT conflict serializable.
- Conflict serializability is stricter than view serializability, but simpler to implement.

Conflict serializability is a key concept in database management systems that ensures transactions are executed in a manner that preserves the desired properties of the database.

4.5 Concurrency Control

1. Introduction to Concurrency Control

Concurrency control refers to the methods used by a DBMS to ensure the correct operation of simultaneous transactions. It handles dirty read, lost update, and inconsistency problems when multiple users are trying to access the database at the same time.

Why is Concurrency Control Important?

In a multi-user database system, multiple transactions may execute concurrently, leading to potential conflicts. Concurrency control ensures that:

Data integrity is maintained despite concurrent operations.

ACID properties (Atomicity, Consistency, Isolation, Durability) are preserved.

Correct execution order of transactions is maintained.

Performance and throughput are optimized without sacrificing correctness.

Example Without Concurrency Control (Lost Update Problem)

Consider two transactions, T1 and T2, updating the same data item (bank balance = $1000):

Without Concurrency Control:

T1: Read Balance ($1000)

T2: Read Balance ($1000)

T1: Update Balance to ($900)

T2: Update Balance to ($950)

T1: Commit

T2: Commit

Final Balance = $950 instead of $900 (T1's update is lost).

With Concurrency Control:

T1: Read Balance ($1000)

T1: Update Balance ($900)

T1: Commit

T2: Read Balance ($900)

T2: Update Balance ($950)

T2: Commit

Final Balance = $950 (Correct result achieved).

2. Problems Due to Lack of Concurrency Control

Problem	Description	Example
Dirty Read	A transaction reads uncommitted changes made by another transaction.	T1 updates salary, T2 reads new salary before T1 commits, but T1 rolls back. T2 now has incorrect data.
Lost Update	One transaction overwrites another transaction's changes.	T1 and T2 read the same balance, T1 updates it, then T2 updates it, ignoring T1's change.
Non-Repeatable Read	A transaction reads the same row twice but gets different values due to another transaction's update.	T1 reads product price, T2 updates the price, T1 reads again and gets a different value.
Phantom Read	A transaction reads a set of rows, but another transaction inserts/deletes rows in between.	T1 counts total employees, T2 inserts a new employee, T1 re-executes and gets a different count.

3. Concurrency Control Techniques

To prevent the above problems, DBMSs implement concurrency control mechanisms that ensure correct transaction execution. The most widely used techniques are:

1. Lock-Based Protocols (Pessimistic Concurrency Control)
2. Timestamp-Based Protocols
3. Optimistic Concurrency Control (OCC)
4. Multiversion Concurrency Control (MVCC)

4. Lock-Based Concurrency Control (Using Locks)

What are Locks?

Locks mechanisms that prevent concurrent access to the same data by multiple transactions. Locks guarantee that a transaction has to relinquish a lock before another transaction can use the data item.

Types of Locks

Lock Type	Purpose	Example
Shared Lock (S-Lock)	Allows multiple transactions to read but not write.	T1 and T2 both read the same row at the same time.
Exclusive Lock (X-Lock)	Allows only one transaction to read and write at a time.	T1 updates a row, preventing T2 from accessing it.

Two-Phase Locking (2PL) Protocol

The Two-Phase Locking (2PL) protocol ensures conflict serializability by dividing transactions into two phases:

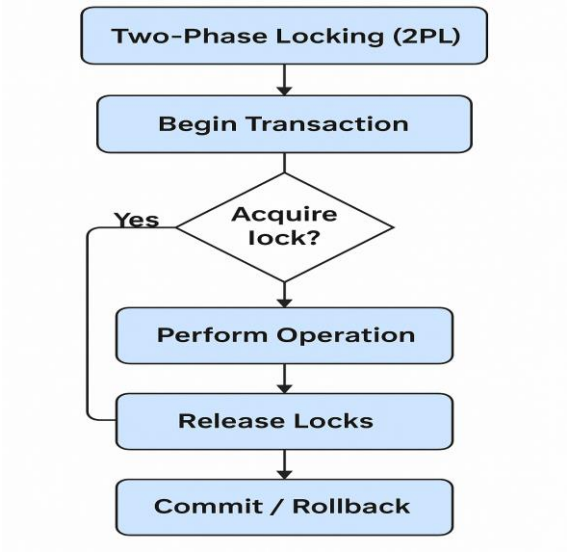


Fig.12.1: flowchart of the Two-Phase Locking (2PL) protocol

1. Growing Phase:
    - A transaction acquires locks but does not release any locks.
2. Shrinking Phase:
    - A transaction releases locks but does not acquire any new locks.

Advantage: Ensures serializability.

Disadvantage: Can lead to deadlocks (two transactions waiting indefinitely for each other's locks).

Example of Two-Phase Locking

T1: Lock(X)

T1: Read(X)

T1: Lock(Y)

T1: Read(Y)

T1: Unlock(X)

T1: Update(Y)

T1: Unlock(Y)

Ensures correct execution by preventing lost updates and dirty reads.

5. Timestamp-Based Concurrency Control

What is Timestamp Ordering?

- Every transaction is assigned a unique timestamp when it starts.
- Transactions execute in order of their timestamps.

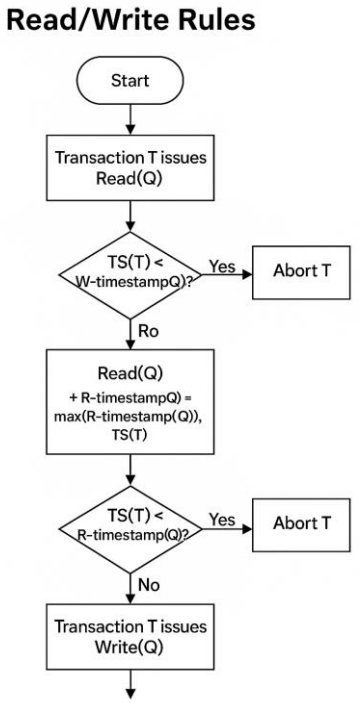


Fig.12.2: flowchart for the read/write rules in Timestamp-Based Concurrency Control

How Timestamp-Based Concurrency Control Works

Each data item has:

1. Read Timestamp (RTS): The largest timestamp of any transaction that has read the item.
2. Write Timestamp (WTS): The largest timestamp of any transaction that has written the item.

If a newer transaction tries to access an older version of data, it is aborted and restarted.

Advantage: Prevents deadlocks.

Disadvantage: Transactions may be aborted frequently, reducing performance.

6. Optimistic Concurrency Control (OCC)

What is OCC?

- OCC assumes transactions rarely conflict and allows them to execute freely.
- Before commit, the system checks if conflicts occurred.
- If a conflict is found, the transaction is aborted and restarted.

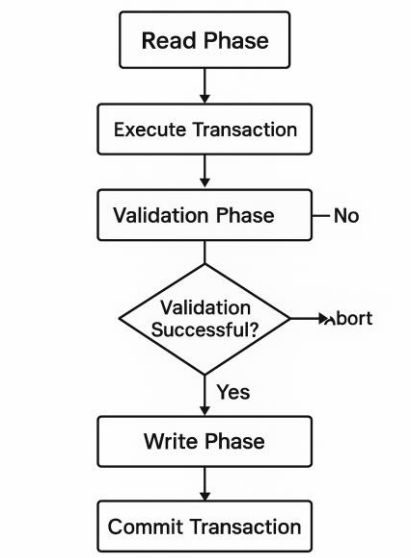


Fig.12.3: flowchart of Optimistic Concurrency Control process

Phases in OCC

1. Read Phase: Transaction reads data without locking.
2. Validation Phase: Before committing, checks if another transaction modified the data.
3. Write Phase: If no conflict, changes are written to the database.

Advantage: Faster in systems with low conflicts.

Disadvantage: Rollback may happen frequently in high-concurrency environments.

7. Multiversion Concurrency Control (MVCC)

What is MVCC?

- MVCC stores multiple versions of data instead of locking it.
- Each transaction gets a consistent snapshot of the database at the time it starts.
- Readers don't block writers, and writers don't block readers.

How MVCC Works:

1. Read transactions get a snapshot of old data (ensuring consistent reads).
2. Write transactions create a new version of the data instead of modifying the old one.

3. Older versions are removed when no transactions need them.

Advantage: Eliminates locking overhead and increases performance.
Disadvantage: Uses more storage because multiple versions of data are kept.

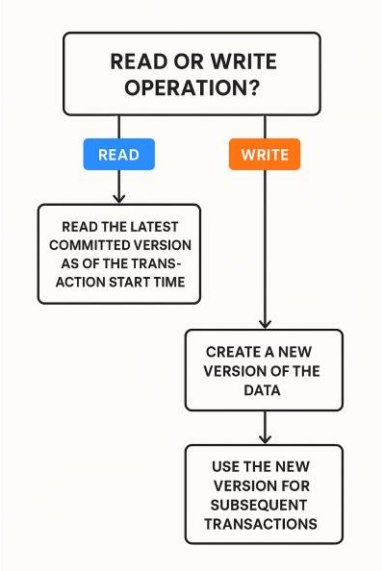


Fig.12.4: flowchart showing how MVCC handles reads and writes

8. Deadlock Handling in Concurrency Control

Deadlock happens when two or more transactions are keeping each other waiting indefinitely for each other to release locks The two most common ones are.

Deadlock Prevention Strategies:

1. Timeout: If a transaction waits too long, it is aborted.
2. Wait-Die Scheme: Older transactions wait; younger transactions restart.
3. Wound-Wait Scheme: Older transactions force younger ones to restart.

Deadlock handling ensures transactions do not block indefinitely. Concurrency control is necessary to ensure the correct, consistent, and efficient execution of transactions in a multi-user database.

Technique	Advantage	Disadvantage
Lock-Based Protocols (2PL)	Prevents lost updates & dirty reads	Can cause deadlocks
Timestamp Ordering	Ensures transactions execute in correct order	May abort transactions frequently

Optimistic Concurrency Control (OCC)	Best for low-conflict environments	Rollbacks may be frequent in high concurrency
MVCC	Improves performance (no blocking)	Uses more storage

Features of databases:[/heading]Through effective concurrency control, databases maintain a balance between consistency, isolation and performance, ensuring that multiple users can work on them simultaneously, without corrupting data.

4.6 Concurrency Control Protocols: Lock based and Timestamp based

Concurrency Control Protocols: Lock-Based and Timestamp-Based

1. Introduction to Concurrency Control Protocols

In Database Management Systems (DBMS), concurrency control is the process of managing simultaneous operations without conflicting with each other. They guarantee that the operations execute correctly and comply with isolation, consistency, and serializability.

Why Are Concurrency Control Protocols Needed?

In multi-user databases, several transactions execute simultaneously to enhance performance. Without adequate concurrency management, read anomalies return, which include dirty reads, lost updates, and inconsistent data reads.

Concurrency control protocols prevent conflicts by ensuring that transactions execute in a controlled manner.

Types of Concurrency Control Protocols

The two most commonly used concurrency control protocols are:

1. Lock-Based Protocols – Transactions acquire locks to control data access.
2. Timestamp-Based Protocols – Transactions are ordered using timestamps to ensure serial execution.

2. Lock-Based Concurrency Control Protocols

. What Are Lock-Based Protocols?

Lock-based protocols use locks to restrict multiple transactions from accessing the same data simultaneously.

2.2. Types of Locks

Lock Type	Description	Example

Shared Lock (S-Lock)	Allows multiple transactions to read the same data but prevents writes.	Multiple users can view a bank balance at the same time.
Exclusive Lock (X-Lock)	Allows only one transaction to read and write the data.	A user transferring money should prevent others from modifying the same account.

Shared Locks allow reading but prevent writing.

Exclusive Locks prevent all access except for the locking transaction.

2.3. Two-Phase Locking (2PL) Protocol

What is 2PL?

The Two Phase Locking (2PL) protocol is one of the most common methods to achieve serializability; it does so by separating the transaction into two distinct phases:

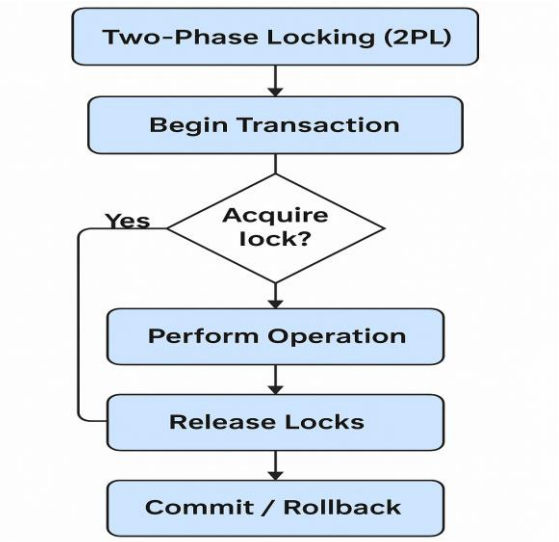


Fig.12.5: flowchart of the Two-Phase Locking (2PL) protocol

1. Growing Phase: A transaction acquires locks but does not release any.
2. Shrinking Phase: A transaction releases locks but does not acquire any new ones.

Guarantees serializability.

Can lead to deadlocks if transactions wait indefinitely for each other's locks.

Example of Two-Phase Locking (2PL)

T1: Lock(A)
T1: Read(A)
T1: Lock(B)
T1: Read(B)
T1: Unlock(A)
T1: Write(B)
T1: Unlock(B)

Correct execution: Ensures consistent transaction execution.

Strict Two-Phase Locking (Strict 2PL)

- Locks are held until the transaction commits or aborts.
- Prevents cascading rollbacks (when an aborted transaction forces multiple rollbacks).

  Safer than basic 2PL because transactions only release locks after committing.

Deadlock and Starvation in Lock-Based Protocols

Problem	Description	Solution
Deadlock	Two or more transactions wait indefinitely for each other's locks.	Timeouts, Wait-Die, Wound-Wait schemes
Starvation	A transaction never gets a lock because other transactions always get priority.	Fair scheduling policies

Deadlocks occur when transactions form a circular wait.

Starvation happens when low-priority transactions never execute.

3. Timestamp-Based Concurrency Control Protocols

What Are Timestamp-Based Protocols?

Timestamp-based protocols order transactions based on their timestamps to ensure serializability.

How It Works

- Each transaction T is assigned a unique timestamp (TS) when it starts.
- Each data item has:
  1. Read Timestamp (RTS): Latest timestamp of a transaction that read the data.
  2. Write Timestamp (WTS): Latest timestamp of a transaction that wrote to the data.

Ensures that older transactions execute before newer ones.

3.3. Basic Timestamp Ordering Protocol

- If a transaction T wants to read X:
  - If TS(T) < WTS(X) → T is aborted (because a newer transaction already updated X).
  - Else, T reads X, and RTS(X) is updated.
- If a transaction T wants to write X:
  - If TS(T) < RTS(X) or WTS(X) → T is aborted (because older reads or writes exist).
  - Else, T writes X, and WTS(X) is updated.

Prevents dirty reads and lost updates.

Transactions may be aborted frequently, reducing performance.

3.4. Thomas's Write Rule (Optimized Timestamp Protocol)

- If TS(T) < WTS(X), ignore the write instead of aborting T.

  Reduces unnecessary transaction rollbacks.

4. Comparison: Lock-Based vs. Timestamp-Based Protocols

Feature	Lock-Based Protocols	Timestamp-Based Protocols
How It Works	Uses locks to control access	Uses timestamps to order transactions
Handling Concurrency	Prevents conflicts by locking resources	Allows transactions to execute but aborts if conflicts occur
Risk of Deadlock?	Yes	No
Risk of Starvation?	Yes	Yes (Frequent rollbacks)
Performance	Slower due to locks	Faster but can lead to frequent restarts
Best Used For	Systems with high contention (e.g., banking, ticketing)	Systems with high read-to-write ratio (e.g., analytics, reporting)

Lock-based protocols prevent conflicts but can cause deadlocks.

Timestamp-based protocols avoid deadlocks but may require frequent transaction rollbacks.

Concurrency control protocols are used for the correct execution of transactions in multi-user databases.

- Lock-based methods (2PL, Strict 2PL) avoid conflict and deadlock issues.
- Timestamp-based protocols (Basic Timestamp Ordering, Thomas's Write Rule) make serializability guarantee without deadlocks but may result in frequent rollbacks.
- Selecting appropriate protocols will be aligned with specific performance requirements as per transaction type.

Database systems are then able to efficiently leverage efficient concurrency control protocols to strike a balance between isolation, consistency, and performance, as multiple transactions are able to execute concurrently and safely.

4.7 Deadlock Handling: Detection and Prevention

This leads to a situation of circular dependency, in which processes cannot continue execution, and thus, parts of the system come to a halt. Deadlocks are one of the hardest problems in operating systems, database management systems, and distributed computing environments. Therefore, it is critical to understand, identify and resolve deadlocks because they may cause a noticeable drop in system performance, useless resource consumption or even system deadlocks that require manual restart of the system. This guide will explore the key principles behind deadlocks, the conditions that result in them, how they can be detected, prevented, avoided, and recovered from. We will also link to practical implementations in different contexts of computing, analyze the trade-offs of proposed solutions, and explore research directions for the evolution of deadlock avoidance/avoidance in modern paradigms of computing.

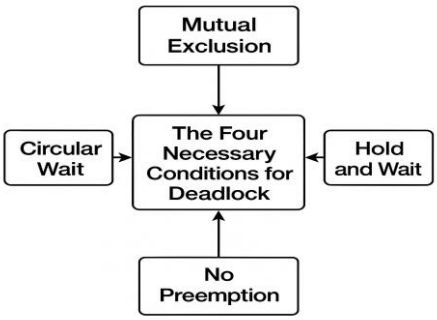
Fundamental Concepts of Deadlocks

Deadlock is a particular state in concurrent programming in which processes are forever blocked in their wait for resources, so it is a condition where, without outside intervention, the system enters a state it cannot recover from. The resource allocation systems where deadlocks happen need to be understood to fully comprehend this phenomenon. In these systems, processes request resources, use them to calculate and then release them to other processes. Resources can either be preemptable (can be taken away from a process) or non-preemptable (the holding process must explicitly release it). Deadlocks are mainly because of non-preemptable resources because pre-emptable resources can hardly lead to deadlock conditions. Resource

Allocation Graphs The Resource allocation graph is another data structure that visually depicts resource allocation and requests in a system. In this directed graph, we have processes and resources as nodes, and the edges are allocated resources or requests. Haven't heard of deadlock detection? This description should give a better idea about the format of resource allocation graph and how swill be interpreted.

Fig.12.6:diagram illustrating the Four Necessary Conditions for Deadlock

The Four Necessary Conditions for Deadlock



The Coffman conditionsE. G. Coffman: A look at Deadlock are four conditions that must hold for a deadlock to occur, they form the basis of understanding a deadlock situation and E. G. Coffman formalized this concept. The first condition for mutual exclusion states that at least one resource should be held in a non-sharable mode such that only one process can be using it at any specific interval. Deadlocks could never occur if every resource in the system could be shared among all processes at the same time. The other condition, hold and wait (or resource holding) arises when a process that is holding at least one resource is waiting to attain additional resources that are held by other processes. This provides a scenario where processes will wait for other processes to release resources while already holding resources, thereby potentially paving the way for circular dependencies. The third condition, no preemption, says that resources cannot be forcibly removed from a process; the process that has the resource must explicitly give it up. The system could preempt resources to prevent deadlocks by reallocating them from a waiting process. The fourth condition, circular wait, occurs when there is a set of processes such that every process is waiting for a resource held by another process in the set, forming a circle of processes. A deadlock can occur when all four of the following conditions hold simultaneously. Alternatively, if all of these conditions are precluded the system can avoid deadlock completely. These insights lay the groundwork for a class of deadlock

prevention schemes all of which attempt to eliminate one of the four conditions that are needed to allow deadlocks to occur within the system.

Resource Allocation Graphs and Deadlock Representation

A visual model to explain optimal resource allocation in based on resource allocation graphs (RAG) in a powerful way. A representational element of a resource allocation graph contains two kinds of nodes (circles, process nodes and squares or rectangles, resource nodes). Directed edges link these nodes, indicating resource requests or allocations. The edge from a process to a resource indicates that the process has requested that resource, but not yet been granted it. An edge from a resource to a process means that the resource has been allocated to that process. Abstract resources(0): In systems where there are several instances of a single resource type, the representation is complex, for example it may to have to be notated the number of instances requested or allocated. Resource allocation graphs are not so much useful for detecting deadlock: a cycle in a resource allocation graph with only one instance of each resource type means a deadlock has occurred. But cycles are an essential yet not sufficient condition for deadlocks in most resource arrangement models.

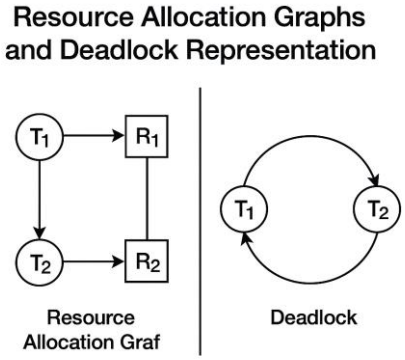


Fig.12.7: Diagram showing Resource Allocation Graphs

In such systems, special algorithms must be applied to determine whether a cycle actually represents a deadlock. Additionally, these resource allocation graphs can be dynamic since processes are able to request new allocations and release resources as needed. By tracking these changes and examining the structure of the resulting graph, systems can detect impending deadlocks before they completely manifest or can discover full deadlocks for resolution. Resource allocation graphs are especially helpful in visualizing and explaining

deadlock states, making them a tool for understanding as well as education in concurrent systems.

Deadlock Detection Mechanisms

Deadlock detection describes algorithms and techniques allowing systems to detect when a deadlock has occurred. These will be required in systems where deadlock prevention or avoidance strategies are not implemented, or as a backup to fallback strategies that fail. Detection algorithms commonly check resource allocation state and process requests to search for circular wait states. If we consider a single-instance resource type, detection can be simple — it is equivalent to searching for cycles within the resource allocation graph. (N) To avoid deadlock in multi-instance resource systems, more complex methods needed, such as the banker's algorithm or derivatives thereof, exploring possible resource allocation paths to determine if safe sequences exist. Deadlock detection is done periodically or when certain events occur such as a resource is requested or allocation failed. Detections happen relatively infrequently; there is always a trade-off: with more frequent detections you get more overhead but an earlier detection and response, whereas with less frequent detections you get less overhead but potentially longer deadlocks.

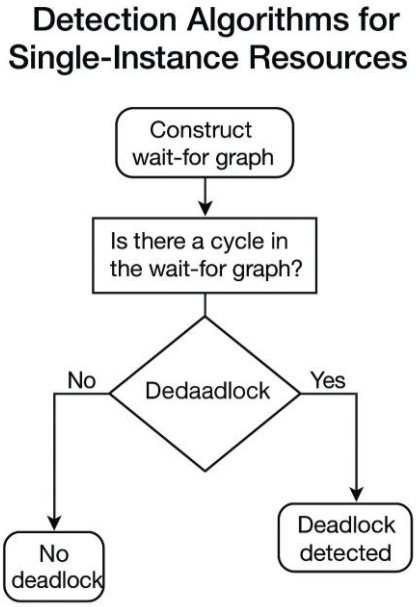
As soon as a deadlock is detected, the system needs to follow recovery procedures that it has in place to break the deadlock and allow those processes involved in the deadlock to continue. Approaches such as those used by operating systems and database systems involve advanced detection methods that minimize false positives and negatives while providing timely responses that do not unduly degrade system performance.

Algorithms for Single-Instance Resource Deadlock Detection

Detecting deadlocks can be done with graph-based algorithms, comparatively easy, in systems in which every resource has a single instance. The typical method is to create and examine what is called a wait-for graph which is a simplified version of the resource allocation graph where the process nodes are connected directly by edges denoting wait relationships. This graph edge from process P1 to process P2 means that process P1 is waiting for a resource that is currently held by process P2. Detecting deadlocks subsequently boils down to cycle detection in this directed graph which can be done using classical graph algorithms e.g., depth-first search (DFS) or breadth-first search

(BFS).The detection algorithm usually works in three steps: First, build the wait-for graph from the current resource allocation and request; Second, check if the graph has cycle either with DFS or BFS;

Fig.12.8: Diagram illustrating Detection Algorithms for Single-Instance Resources



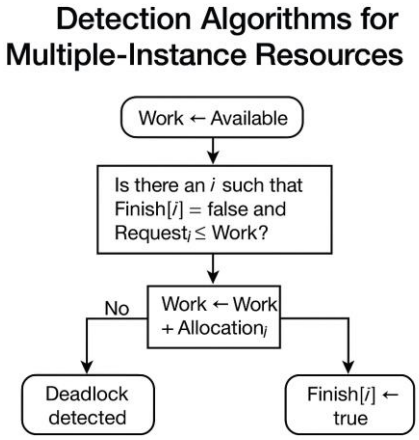
And thirdly, if any cycle has found, Then declare a dead-lock involving the processes in the cycle. The time complexity is generally $O(n^2)$ (where n is the number of processes that need to be executed) making this approach computational efficient and suitable for normal execution, for instance in a small system with no more than 60 processes. A single-instance detection algorithm can also be applied at the resource type level instead of the add instance level, grouping similar resources together. Further optimization: we can do so less frequently, based on system activity patterns (e.g. detecting when two processes cycle back on holding resources), and further focus detection on when deadlocks are more likely, e.g. within the periods after sequences of resource requests and when processes claim to be waiting past a threshold period of time.

Detection Algorithms for Multiple-Instance Resources

We have already said that deadlocks in systems where multiple instances of resources exist are more complex than with systems with a single instance. So from what it follows: Not having cycles in a resource allocation graph no longer implies that there are no deadlocks, because it may be the case that there are other types of instances of a

resource that have not yet been allocated, making at least one process to finish and freeing some resources. There are multiple algorithms

Fig.12.9: Diagram illustrating Detection Algorithms for Multiple-Instance Resources



developed for this purpose, of which, the most notable ones are - the banker's algorithm and deadlock detection algorithm. The multiple-instance resources deadlock detection algorithm generally checks for the possibility of some sequence of resource acquisitions enabling all the processes to execute. This means keeping data structures that keep track of: available resources (ones that are not currently allocated to any process), allocated resources (ones that are currently held by each process), and requested resources (ones that each process is waiting to get). The algorithm then tries to find a hypothetical execution sequence, repeatedly finding processes whose resource requests can be satisfied with the current available resources. If such processes are discovered, the algorithm simulates such processes starting and releasing the resources they had, putting their allocated resources back into the pool. This is repeated until we are either out of processes (no deadlock) or we run out of eligible processes (indicating a deadlock involving the remaining processes). Since m is the number of resource types and n is the number of processes, this algorithm has $O(m \times n^2)$ time complexity which is usually more computationally intensive than single-instance detection. Such overhead can be minimized using several optimizations like incremental detection with processes and resources their state has changed since last detection cycle or priority-based approaches that considers process that are more likely to cause deadlocks before others.

Distributed Deadlock Detection

The problem of deadlock detection in distributed systems has its own complexity that doesn't appear in centralized systems. A distributed system is one in which resources and processes are spread across multiple nodes or sites, and no single entity has complete knowledge of the global state of the system. This distributed nature makes it challenging to build an overall resource allocation graph and requires specific algorithms for effective deadlock detection. Three general types of methods have been proposed for the distributed detection of deadlocks: path-pushing, edge-chasing, and global state detection methods. Similarly, path-pushing algorithms propagate the dependencies between the processes along the paths in the wait-for graph, with the eventual goal of being able to tolerate cycles that span multiple nodes. Edge chasing algorithms employ special "probe" messages that move along the edges of the wait-for graph, which return to their originators to signal a cycle. Global state detection methods try to make a global view of the system state at all nodes and analyze the global state for deadlocks with the help of centralized algorithms. Such distributed detection algorithms face additional complexities like message delays, partial failures, false positives or false negatives owing to dynamic nature of system. Additionally, they should incur little communication overhead; even small amounts of message passing to perform deadlock detection can be detrimental to system performance. Indeed, many distributed systems operate with hierarchical strategies that integrate local detection among nodes with global coordination across nodes, thereby balancing detection accuracy and communication efficiency.

Deadlock Prevention Strategies

Deadlock prevention involves designing a system with resource allocation policies that prevent at least one of the four necessary conditions for deadlock. These strategies ensure that deadlocks are structurally impossible in the system by guaranteeing at least one condition cannot occur. Prevention strategies are conservative by nature and involve placing restrictions on the ways processes are allowed to request and hold onto resources. In most resources question of mutual exclusion prevention is very rare, however minimum number of resources should be made non-shareable by the system designers. Preventing hold and wait generally leads processes to either have to request for all resources required by them before they can proceed, or to release all of the resources they hold before they can request more. This means that these systems may need to take away resources from a process when it runs out of other options, in what is called forced reclaiming. Circular wait can typically be prevented by defining a total

ordering for resource types and forcing processes to request resources in that order. Although prevention strategies offer the strongest guarantee against deadlocks, they often incur a significant cost in terms of resource utilization, system performance, and programming complexity. This composite of trade-offs is what makes prevention strategies well-suited for critical systems in which deadlocks are simply unacceptable under any conditions, but less so for the general-purpose computing environments where more well-rounded approaches may be preferred.

Eliminating Mutual Exclusion

One of the base yet difficult methods for deadlock prevention is to remove the mutual exclusion condition. This strategy is designed from the perspective of systems approach, and aims to design systems where resources can be simultaneously shared among two or more processes, hence breaking the contention that creates the basis of deadlocks. In practice, completely avoiding mutual exclusion is not possible for many types of resources that are inherently non-shareable (e.g. printers, tape drives, database locks). Yet, some strategies can mitigate this impact by designing systems such as spooling where resource-executing processes interact with processes running on virtual resources instead of the actual resources themselves. Print spooling, for instance, enables multiple processes to send data to a print job queue as opposed to needing direct access to the printer hardware. In much the same way, virtualization technologies allow multiple virtual machines to share the same physical hardware, de-stabilizing exclusive resources for shared ones at a higher level of abstraction. Another response is to redesign resources or the patterns in which they are accessed to allow concurrent usage, for instance through reader-writer locks in which multiple processes can read the data concurrently whilst still allowing exclusive access for writing. Asynchronous data structure, lock-free and wait-free -- Among the ways to decrease mutual exclusion is the devel- opment of lock-free and wait-free data structures. Although it is impossible to eliminate mutual exclusion for every type of resource, it is possible to look at some resources and determine if they can be made into shareable resources and reduce the potential deadlocks in a system.

Preventing Hold and Wait

Hold and Wait − In this condition, a process holds a resource while waiting to acquire additional ones. To prevent this condition, we need

to design resource allocation policies that guarantee that processes will never concurrently possess some resources while it is waiting for others. There are two common methodologies in pursuing this end. This way all resources required by each process should be requested at the beginning of execution. This means that when a process requests resources, the system will give either all resources or nothing, in this way, it does not allow a process to hold some resources while in wait for others. Although conceptually simple, this strategy requires processes to specify all of their resource needs ahead of time, something that may not always be realistic for practical applications that can develop dynamic resource requirements. It can further cause the waste of resources since resources that are reserved at a very early point in a process lifecycle can go unused for a long time. The second approach allows processes to request resources incrementally but forces them to relinquish all currently held resources upon a denied request. Then, the process tries to grab all necessary resources at once in a next request. This is more flexible, but leads to complexities including the potential for starvation (if a process repeatedly fails to acquire all the resources it needs) and the extra cost of repeatedly releasing & reacquiring resources. Both strategies can be improved upon, such as using resource reservation in which processes inform the system in advance of their expected future demands for resources without actually requesting the resources, allowing the system to plan allocations and reduce waiting whenever possible. Furthermore, pooling of resources together can be used where similar resources are grouped, and operations are less, again reducing the chances of hold and wait condition occurring.

Allowing Resource Preemption

No-preemption: The system should be designed in such a way that resources cannot be forcibly taken away from the processes holding them, which is one of the necessary conditions for deadlocks. In the context of preemption, if a process requests a resource that it cannot yet access, the system checks whether preempting resources from other processes might help to avoid a potential deadlock. If we identify any of our resources on which a suitable candidate for preemption would be found, we can release it and grant the requesting process the resource, breaking the formation of a deadlock before it can even materialize. There are a number of approaches to making preemption

work. These include process priority schemes, where higher-priority processes can preempt one or more resources from lower-priority processes. A second approach uses resource age or holding time as its criteria and preempts resources holding for a while. This is not a bad description of a one-shot preemption/cancel paradigm, checkpoint-based preemption is a better fit because a process periodically saves its execution check pointed state, allowing it to be rolled back to a sort of consistent state after preemption of its resources. This makes preemption a complex topic that requires careful design of the system implementing it. Such a system must ensure the safe aspects of the process context saving, the performance costs of saving process state when preempting processes, and starvation policies to stop processes from being repeatedly preempted in to sensibly afford a system which ensures progress in userspace. The system also needs some policies on how to choose which resources to preempt, where there are multiple candidates, e.g. the system should try to minimize the disruption to the processes, should provide fairness and let the processes make progress.) Indeed, many modern operating systems employ some forms of resource preemption, and for some resource types—especially memory, CPU time, and some I/O resources—there are practical ways to implement this process, even if it is not easy.

Avoiding Circular Wait

Out of the deadlock prevention strategies, preventing circular wait is one of the most commonly used strategies since it is easier to implement than removing other necessary conditions. The basic method is to develop a total ordering of all classes of resources and require processes to request resources in this order. This phone work eliminating circular dependencies between processes at the level structure. By never requesting resources except in order. To implement this strategy, however, the following steps are required: (1) assign a unique numerical identifier to each resource type; (2) require that processes request resources strictly in increasing (or decreasing) order of identifiers; (3) enforce this ordering in system calls or middleware that validates resource request sequences. For instance, if there are resource R1, R2, and R3 with identifiers 1, 2, and 3, a process must ask for them in the order R1, R2, R3 This avoids creating cycles within the resource allocation graph ensuring that processes can only wait on resources than have identifiers greater than those that they currently

possess. While simple in principle, this technique can be difficult in practice. The processes in the system must be designed or modified to acquire the resources in the specified sequence, which may conflict with their actual operational order. It also needs to find a logical ordering of resources such that processes do not have to request resources out-of-order. By deciding hierarchies of related resources to work with can ease some of these problems, where stabilization can be at a classification level rather than a direct resource. There are dynamic resource hierarchies of resources that dynamically adjust the ordering of resource accesses based on observed usage patterns, hopefully matching the application requirements better while still avoiding circular wait conditions.

Deadlock Avoidance Algorithms

Deadlock avoidance is a halfway house between the very restrictive prevention and the more reactive detection and recovery. These algorithms adopt an approach where processes can make incremental resource requests, without taking the system to an unsafe state that might independently bring about deadlock. They work based on extra information about the resources needed for processes, usually expressed as predetermined maximum resource demands. Based on this information, the system can decide on each resource request whether it can grant it or might place the system in a potential deadlock state in the future. The banker's algorithm, one of the most popular deadlock avoidance algorithms, designed by Edsger Dijkstra, simulates a tentative allocation of resources to find out if, there is a sequence of processes that can be executed without deadlock. This solution is safe because all processes can finish even if they request their maximum remaining resources right away. A request is denied if after the allocation there is no safe sequence and the requesting process blocks until resources can be granted. The main contribution of this paper is an alternative model to the banker's algorithm, called the resource-trajectory approach, in which the sequence of resource allocations and deallocations is modeled as a trajectory through a multidimensional space, that is, the resource space, and a safe resource allocation is one that never allows the trajectory to enter unsafe regions. Avoidance algorithms offer stronger correctness guarantees than detection and recovery with much less severe restrictions than prevention strategies, but present their own challenges such as the overhead of safety

checking to ensure avoidance, the need to know beforehand how much of a resource is needed, and, potentially, less than optimal use of resources due to conservative allocation policies.

The Banker's Algorithm and its Variants

Deadlock avoidance The single most important approach to deadlock avoidance is the banker's algorithm that was originally formulated by Edsger Dijkstra and is so named because of its analogy to banking systems. This algorithm uses a few data structures to maintain the state of resources that are allocated: the maximum resources still needed by each process — the resources currently allocated to each process — and the missing resources needed by each process. The algorithm simulates the allocation of processes' requests and looks for a "safe sequence" of process executions that would allow all processes to finish

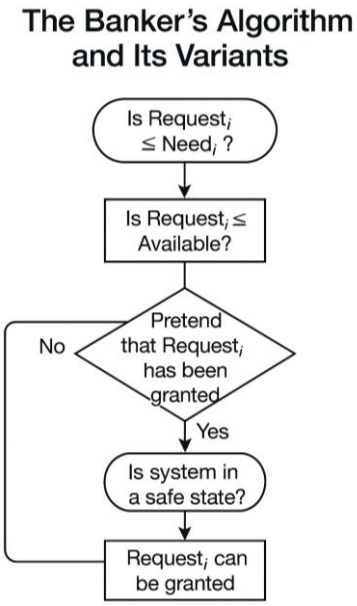


Fig.12.9: Diagram The Banker's Algorithm and its Variants.

running without a deadlock. If an such a sequence, does exist the state is said to be safe and the request is granted; otherwise the request is denied and the process that made the request has to wait. The banker's algorithm forms the basis of several extended and optimized variants tailored to specific system needs. We can simplify the original Handle Algorithm into its single-resource version for the case of only one resource type, which reduces the computational complexity. Instead posing the bankers algorithm to hierarchal resources system, as in tree (parent-child) hierarchy. The distributed banker algorithm works similar in nature as the banker's algorithm but it does not work with the centralized method, instead it uses a distributed matter to prevent

deadlock, The process of allocation takes place in a distributed manner. There are also variants of the banker's algorithm that are dynamic, meaning they take resource requests that come up during execution of a process into consideration, thus avoiding one of the main problems of the original algorithm. Therefore, with a theoretically sound approach proposed with the banker's algorithm, the practical implementation can be difficult due to the safety need to be checked for every resource request, processes should declare their maximum needs in advance (which in many cases may be difficult to evaluate), resources may remain underutilized due to conservative allocation policies. These constraints have driven many general-purpose operating systems to prefer different strategies for deadlock management, but it provides a useful way in very specific contexts, where resource requests are measurable ahead of time and a high reliability is fundamental.

Resource Trajectory Methods

An alternative to deadlock avoidance are resource trajectory methods, which model resource allocation as a path through a multi-dimensional resource space. The axes in this model represent different types of resources, while a point in space reflects how many of those resources are currently dedicated to a process. The system moves through this space along a trajectory as processes request and release resources. Some areas of the space correspond to unsafe allocations that can cause deadlocks, and others represent safe allocations. For resource trajectory methods, the key ideas are to keep the state trajectory in a safe region. A key aspect of this approach is identifying the critical boundaries that delineate the safe from the unsafe regions in resource space. This is when a process requests resources and the system assesses whether granting the request would cross a dangerous threshold into an unsafe space. If so the request is denied, if not the request is granted. There have been various mathematical formulations proposed for defining such critical boundaries, as well as for more efficient identifications of these boundaries. The first-run single-resource trajectory approach streamlines the analysis, applying to systems with a single resource type. The claim-and-release trajectory method utilizes knowledge of future resource releases to model a tighter safe region. The process-interaction trajectory approach focuses directly on interactions between specific processes, as opposed to the global system state, which could enable more concurrency for resource allocation. In some cases,

resource trajectory approaches can be more advantageous for certain situations than the banker's algorithm, particularly potentially displaying a more accurate representation of safe and unsafe conditions, lower computational complexity for specific configurations of the system, and more intuitive visualization of safety of the system. Nonetheless, they suffer from similar limitations to other avoidance strategies (Table 2): They require prior knowledge of resource needs, and conservative allocation will underutilize resources (catch recovery too late).

Deadlock Recovery Techniques

In cases where deadlock prevention, avoidance, and detection mechanisms fail or are not applied, systems must instead rely on recovery strategies to address deadlocks once they have manifested. Deadlock recovery is where the system detects the deadlock and takes action to break it, e.g. by killing a process. Process termination techniques choose one or more competing processes in a deadlock to abort, freeing them of their held resources, and allowing potential continuation with other processes. For mustering process termination candidates, priority (w/o) process execution time, resources held and

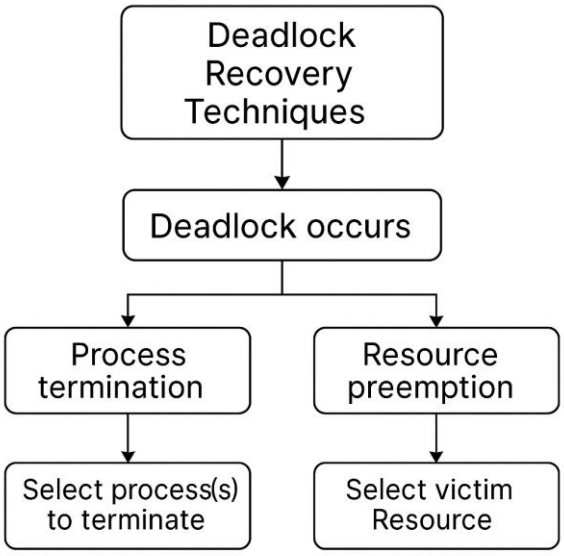


Fig.12.11: Diagram for Deadlock Recovery Techniques

remaining work, may provide selection criteria. Resource preemption typically requires saving the state of the processes being preempted, identifying which resources to preempt, and dealing with the possible cascading effect. Since partial execution is an issue, both approaches need to cater for recovery, since aborted or preempted processes might have been state-changing and therefore need to be undone or

compensated. Transaction rollback mechanisms in database systems offer a systematic way to reverse the effects of partially completed operations in the event of deadlock recovery. Current systems use hybrid recovery strategies that involve a combination of process termination and resource preemption, which chooses the appropriate strategy given a certain deadlock condition. Recovering from the deadlock allows systems to continue, but these techniques tend to have high penalties of lost work, degraded performance, and the prospect of data inconsistency, making recovery techniques sometimes a preferred strategy, but more often a strategy of last resort.

Process Termination Strategies

One of the most straightforward strategies for deadlock recovery is the termination of processes, in which one or more processes in the deadlock is/are chosen and aborted. These processes once terminated release all the resources they have if they were not previously finished, thus eliminating the circular wait condition and enabling other processes to make progress. There are several strategies for deciding which processes to kill when a deadlock is detected. Selection of victims tends to balance several elements so as to minimize the impact on the overall system. This strategy -known as the minimum disruption strategy- consists of terminate the minimum number of processes that is necessary to break the deadlock and generally reports a set of processes that, by terminating them, will release the resources needed to satisfy the needs of the remaining processes involved in the deadlock. In a cost-based approach, processes are assigned a termination cost based on dispatching priority, the amount of computation they have performed to date, resources they hold, and even the amount of work left to do. It then picks the processes that are cheapest to terminate. The resource utilization method aims at processes that hold many resources, specifically the ones that are used by several other processes, because killing them anyway unblocks more processes. Clearly, this kind of framework is quite conservative, as it terminates only the victims one-by-one and checks if the deadlock has been cleared before going after more victims: Incremental termination. For a system to achieve clean termination, things can get complex, since it needs to make sure to free up all previously allocated resources, correctly handle any shared data structures between the affected processes, inform dependent software, and potentially even hang onto some data to support restart. In systems

that have transactional semantics, like databases, the termination of processes relies on the transaction undo mechanism to recover the system from operations that only partially execute, preventing the system from becoming inconsistent. Though terminating processes will resolve deadlock, this results in substantial loss of computation and the potential of user created frustration especially if the process in question is interactive. As such, its cost means it is most appropriate as a last resort in systems where other deadlock management mechanisms have been unsuccessful or are not feasible.

Resource Preemption Methods

One technique of deadlock recovery that would fall under this method is resource preemption. This provides a more fine-grained way to intervene than terminating processes (which may lose more work and be more disruptive). There are several key challenges that need to be addressed for effective resource preemption. First, it must decide which resources to preempt, most often choosing those that will end the deadlock without a significant cost. The importance of the resource, the length of time it has been retained, progress in the holding process, and how many processes could be enabled by releasing it are among possible criteria. Second, the system must have means of saving the state of processes that have their resources preempted, so that they can resume execution later when the resources are available again. Third, the system has to deal with the complications of rolling back any partially executed operations that relied on the preempted resources in order to keep the data consistent. Different types of resource preemption strategies have been developed for different computing environment. Checkpoint-based preemption utilizes process checkpointing protocols to capture the execution state before preempting resources, enabling a clean restoration when the resources are reallocated. In priority-based preemption, processes with higher importance are preferred, and each resource is preempted from lower-priority processes to meet the demands of higher-priority ones. Cost-minimization preemption aims to characterize the cost of preempting various resources and chooses those with the lowest aggregate system cost. Preemption is a practical construct that can be applied for some types of resources such as memory pages, CPU time slices and some locks which are eligible for a clean preemption and being less applicable for resources that cannot be restored easily like open

network connections or exclusive device controls. Resource preemption is effective mainly in systems capable of adequately capturing, and restoring process state, which makes it a more feasible solution in systems that provide rich facilities for checkpoint-restore.

Handling Partial Execution and Rollback

In many systems in which deadlocks are solved by killing processes, or by preempting their resources, the system faces the problem of partially executed operations. In scenarios of deadlocks, processes involved might have previously finished some parts of their work, modifying state of system, data structures or external systems in ways which need to be handled in the process of recovery. Transaction Rollback Mechanisms Some systems, especially database systems and systems with transactional semantics, implement transaction rollback

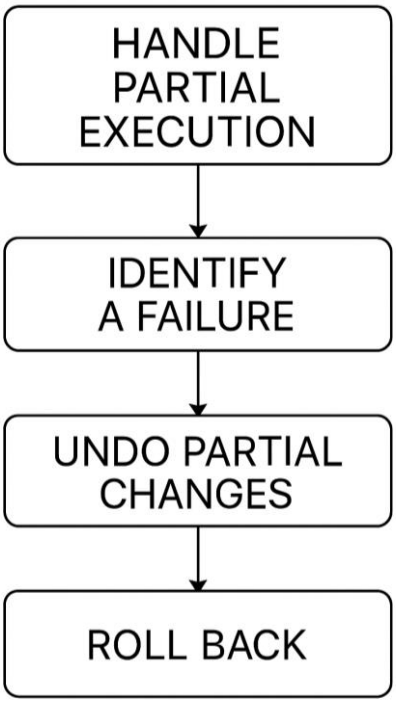


Fig.12.12: Diagram for Handling Partial Execution and Rollback

mechanisms that logically associate a series of operations with a transaction. These systems log enough information about commands to be able to cancel them, usually using write-ahead logging, shadow paging or journaling techniques. Since, during a deadlock recovery action, when a process is terminated or preempted, the transaction associated with it would need to be rolled back and thus restoring the system to a consistent state, as if the transaction had not started at all. In systems not supporting a fully-fledged transaction interface, compensating actions can be needed to cancel the effects of partial

operations. These might be application-specific cleanup procedures, restoring modified data to their original values, releasing resources consumed and notifying dependent services of the failed operation. Checkpointing is another solution to the partial-execution problem, and involves processes periodically storing their state such that it is possible to return to that point (but note that checkpointing solutions often only deal with the data space of the processes). It can shrink the amount of work lost during deadlock recovery as well as improve deadlock recovery cleanliness relative to a crash/restart of the whole process. Some systems use speculative execution in systems where they allow an operation to proceed on an optimistic basis, but preserve enough information so they can back out the changes if there is contention for those changes, or a dead-lock occurs. The overall cost of deadlock recovery is heavily affected by the handling of partially executed actions. Rollback capabilities: Well extolled systems can roll back more gracefully from deadlocks, and poorly–designed ones may create data inconsistency, resource leakes or other side effects that must be cleaned up manually — which itself may lead to cascading failures.

Practical Implementations in Operating Systems

Deadlocks can be handled in many different ways by many different operating systems (OS), and some OS don't even bother trying to prevent a deadlock. Unix-like systems like Linux tend to be minimalist in nature, relying on timeouts and human rescues instead of robust deadlock prevention or detection tools. Most of these systems use closet timeout-based resolution for some resource types and provide administrative tooling to help identify and resolve deadlocks manually. In Windows operating systems, deadlocks are handled in a more structured approach, especially for synchronization objects like mutexes or semaphores, including wait chains traversal to detect cycles of dependency. Strict deadlock prevention is commonly introduced in real-time operating systems as they are time critical and this is typically done using priority inheritance protocols and resource reservation to eliminate priority inversion/deadlock conditions. Custom deadlock handling strategies tailored to specific hardware and application domains may be implemented by specialized embedded operating systems. Internal deadlock prevention mechanisms for services that are critical to operating system kernels typically use hierarchical locking, lock-free algorithms or careful ordering of resource acquisition. There

are some specific problems for deadlock handling at the file system level, where contemporary designs employ things like delayed allocation, intent logging and non-blocking algorithms to limit deadlock risk. It is the responsibility of low-level memory management subsystems — via paging, virtual memory and the like — to prevent deadlock by treating physical memory as a preemptable resource. As you learn the approaches to implement this rather theoretical topic, you get to understand what happens at system design perspective when you are forced to go with a solution that constructs a trade-off between theory and logistics.

Unix and Linux Approaches

As for Linux and other Unix-like operating systems, historically they use a relatively minimalist policy when it comes to deadlock detection and resolution compared to more elaborate policies explored in theory. They provide a time out and other features from careful system design and user level intervention, rather than avoiding, detecting or recovering from deadlock through complex system level mechanisms. Another way of saying this, and one that is very Unix systems-like, is to "give me a lever and a place to stand" — offer hooks and ways to do things instead of trying to synthesize the thing you want right out of the core of the OS; this also fits with other Unix design principles: offer mechanisms, not policies, minimize overhead for common we-do-an-operating-and-a-some users operations, and — where it is at all possible — push complexity out into user space. Unix systems generally implement prevention strategies for specific classes of internal resources at the kernel level through careful lock ordering and acquisition protocols. Kernel synchronization primitives such as mutexes, semaphores and reader-writer locks are generally designed for deadlock prevention, using hierarchical locking schemas or lock dependency checkers to ensure consistent acquisition order. Unix systems also provide timeouts on many resource acquisition operations for user-level processes, allowing processes to detect when they are waiting too long for resources and to initiate appropriate recovery. Signal mechanisms allow blocked system calls to be interrupted, enabling applications to perform their own timeout-based recovery strategies. Resource limits and quotas ensure no single process can monopolise the system resources in such a way as to create a widespread deadlock. Linux itself has also built on top of this,

introducing additional deadlock features including pthread mutexes that detect deadlocks, a kernel lock validator called "lockdep" that seeks to guarantee that no deadlocks can occur, and process monitors to determine which processes might be competing for shared resources. The watchdog facility in systemd is a promising feature since modern Linux distributions ship with it, and if it detects that an application is hung, it tries to restart it which can also bring the system out of deadlock by terminating and restarting affected processes. The practical concurrency model of Unix, with its ad-hoc approach to deadlock, captures both the challenge of implementing full deadlock detection and recovery in a general-purpose operating system and the Unix ethos to give application developers freedom — and responsibility — to design suitable deadlock strategies for their own use cases

Windows Operating System Deadlock Management

Differences in deadlock handling – The Windows OS uses a slightly more structured approach to deadlock management than any of the Unix-like OS systems, particularly with regards to synchronization objects and system resources. Similar to e.g. POSIX, Windows has a rich set of synchronization primitives (all with built-in timeout-based acquisition support), so that applications do not have to block indefinitely waiting for resources. Operating systems include timeout parameters as part of their wait functions, allowing processes to specify how long they will wait for a resource and thus provide a mechanism to detect and recover from potential deadlock situations.

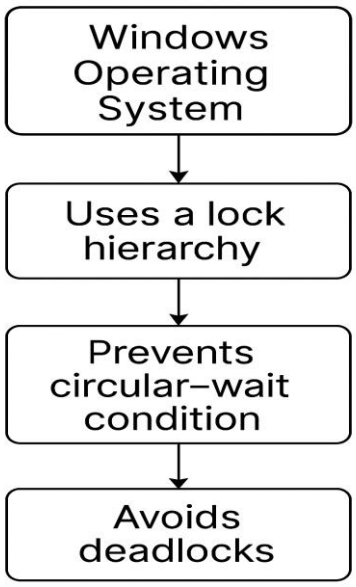


Fig.12.11: Diagram for Windows Operating System Deadlock

Windows has a sophisticated wait chain transverser, capable of detecting circular dependencies in threads waiting on synchronization objects. This functionality is also exposed through programmatic interfaces and administrative tool such as Resource Monitor, allowing developers and system administrators to identify deadlocks involving Windows synchronization primitives. Windows applies internal deadlock prevention mechanisms for critical system resources: Kernel code is written to acquire locks in a consistent order and to follow hierarchical access patterns. The Windows memory management and process scheduling subsystems use resource reservation and preemption techniques to decisively limit the potential for system-wide resource deadlocks and to ensure that deadlocks can never take the entire system down. They offer a complementary technique to the timeout-based resource acquisition within an application, making the application capable of achieving graceful degradation thanks to structured exception handling implemented by the OS. Deadlock detection and resolution capabilities for distributed transactions across multiple resource managers are built into Windows via the Microsoft Distributed Transaction Coordinator (MS DTC), which integrates with database applications. With features like fair share CPU scheduling and resource metering, Windows Server editions provide additional resource governance to prevent resource monopolization that could cause deadlocks. Windows does not enforce global deadlock avoidance algorithms like banker's algorithm but its strategy of limiting resource access to short time frames, traversing wait chains, and providing administrative tools offer the system a practical approach to deadlock management that balances performance overhead with system reliability requirements.

Real-Time Operating Systems (RTOS)

The subject of this article is deadlock handling in real-time operating systems. Contrarily, in an RTOS environment, deadlocks can severely disrupt system functionality and directly encroach upon time constraints, causing disaster scenarios in critical applications (aerospace systems, medical devices, automotive control units, etc.). Thus, RTOS implementations tend to use stricter deadlock prevention techniques compared to general-purpose operating systems. One of the fundamental deadlock prevention mechanisms implemented in many

RTOS is priority inheritance protocols that prevent priority inversion problems. The dynamic priority of a process holding a resource, therefore it would be adjusted to be equal to the highest priority of any process waiting for a resource. The priority ceiling protocol generalizes this idea by associating with every resource its priority ceiling (the highest priority of any process that may request the resource), and temporarily raising the priority of the process that successfully acquires the resource to its ceiling. Another common feature in RTOS environments is deterministic resource allocation policies where resources are allocated in fixed predictable patterns as opposed to dynamic decisions that could potentially lead to deadlock. No dynamic resource allocation means that the system is more rigid, with all resources being assigned to processes when the system is created, and thus many forms of deadlock are avoided at the expense of flexibility. Another RTOS paradigm is time-bounded resource acquisition; that is, every resource acquisition must finish within a fixed time limit, and timeout-based failure recovery mechanisms ensure that processes do not stall indefinitely. Commercial implementations such as VxWorks, QNX and FreeRTOS have these mechanisms as well as other specialized features such as deterministic scheduling, memory protection, and fault isolation to preserve system integrity in the event that part of the system fails. Due to the influence of time constraints on real-time systems, the potential consequence of uncontrolled deadlock may justify the overhead and increased complexity incurred by more extensive deadlock prevention, making them an interesting avenue for practical deadlock prevention and handling evaluation.

Summary

Transactions in a database system are sequences of operations performed as a single logical unit of work. They follow the ACID properties—Atomicity, Consistency, Isolation, and Durability—which ensure that either all operations within a transaction are completed successfully or none are, thus maintaining data integrity. A transaction guarantees that the database remains in a valid state before and after the execution, even in the event of system failures or concurrent access by multiple users.

Serializability is a key concept in ensuring the correctness of concurrent transactions. It ensures that the final outcome of concurrently executed transactions is the same as if they were executed one after the other in

some order. This forms the theoretical foundation for concurrency control mechanisms. To manage multiple transactions simultaneously without conflicts, the database uses concurrency control techniques such as locking, timestamp ordering, and multiversion control. However, concurrency can lead to issues like deadlocks, where two or more transactions wait indefinitely for each other to release resources. Deadlock handling involves detection, prevention, or resolution strategies to maintain smooth operation and data consistency. Together, these mechanisms allow modern databases to support high levels of concurrent user activity while ensuring reliable, predictable outcomes.

MCQs:

1. Which SQL command is used to create a new database?
a) MAKE DATABASE
b) CREATE DATABASE
c) NEW DATABASE
d) ADD DATABASE
(Answer: b)

2. Which command is used to delete an entire database permanently?
a) DROP DATABASE
b) DELETE DATABASE
c) REMOVE DATABASE
d) TRUNCATE DATABASE
(Answer: a)

3. Which SQL command is used to remove all records from a table but keep the
structure?
a) DELETE
b) DROP
c) TRUNCATE
d) ALTER
(Answer: c)

4. Which of the following is a valid SQL data type?
a) STRING
b) TEXT
c) CHAR
d) NUMERIC
(Answer: c)

5. Which command is used to change the structure of an existing table?

a) MODIFY TABLE
b) CHANGE TABLE
c) ALTER TABLE
d) EDIT TABLE
(Answer: c)
6. What does the NOT NULL constraint do?
a) Ensures that a column does not contain duplicate values
b) Prevents a column from having NULL values
c) Sets a default value for the column
d) Creates a new table
(Answer: b)
7. Which of the following statements about PRIMARY KEY is true?
a) A table can have multiple primary keys
b) A primary key column can contain duplicate values
c) A primary key ensures uniqueness and cannot be NULL
d) A primary key can be removed using DELETE
(Answer: c)
8. Which SQL command is used to modify existing records in a table?
a) MODIFY
b) CHANGE
c) UPDATE
d) ALTER
(Answer: c)
9. What does the CHECK constraint do?
a) Ensures values in a column meet a specific condition
b) Automatically fills a column with a default value
c) Allows NULL values in a column
d) Creates a new table
(Answer: a)
10. Which command is used to remove a table completely, including its structure?
a) DROP TABLE
b) DELETE TABLE
c) REMOVE TABLE
d) TRUNCATE TABLE
(Answer: a)

Short Questions:

1. What is the purpose of the CREATE DATABASE command?
2. How does the DROP DATABASE command work?
3. What is the difference between DELETE, DROP, and TRUNCATE?
4. What are the different data types available in SQL?
5. Explain the difference between CHAR and VARCHAR.
6. How does the ALTER TABLE command work?
7. What is the function of NOT NULL and UNIQUE constraints?
8. How can we update records in a table using SQL?
9. What is the purpose of the CHECK constraint?
10. How does the DEFAULT constraint work in SQL?

Long Questions:

1. Explain the process of creating and deleting a database in SQL.
2. Discuss the different SQL commands used to manage tables.
3. What are SQL data types, and how are they used in table creation?
4. Explain the differences between DELETE, DROP, and TRUNCATE with examples.
5. How does the ALTER TABLE command modify table structures?
6. Describe the different types of constraints used in database design.
7. Explain how the PRIMARY KEY and FOREIGN KEY constraints enforce data integrity.
8. What is the purpose of the CHECK constraint, and how is it implemented?
9. Write SQL queries to insert, update, and delete records from a table.
10. Discuss the importance of constraints in database security and integrity.

MODULE 5

OBJECT-ORIENTED DATABASE

LEARNING OUTCOMES

- Identify the limitations of RDBMS and the need for Object-Oriented Database Management Systems (OODBMS).
- Differentiate between OODBMS and ORDBMS and their applications in modern databases.
- Understand techniques for storing and accessing objects in relational databases.
- Learn the principles of Object-Oriented Database Design and how they enhance data modeling.
- Explore Object-Oriented Data Models and their advantages in handling complex data structures.

Unit 13: Limitations of RDBMS and Introduction to Advanced Databases

5.1 Limitations of RDBMS

For several decades, structured data storage and retrieval have relied on Relational Database Management Systems (RDBMS). They provide many advantages like ACID (Atomicity, Consistency, Isolation, Durability) compatibility, SQL Sizes, and data integrity properties. However, despite widespread adoption and capability, there are a few downsides to RDBMSS. With advances in technology, new problems have arisen that highlight the limitations of traditional relational databases. Some of these constraints affect the performance, scalability, flexibility, and usability especially in the modern applications where massive data. These limitations are important for database architects, developers, and organizations to consider when making data management strategies. Scalability is one of the major limitations of RDBMS. Traditional relational databases were built for vertical scaling, which refers to increasing the strength of a single server by provisioning additional CPU, memory, or storage. This technique works great for moderate workloads but becomes very expensive and illogical as data volume starts to increase exponentially. Since RDBMS relies on strict table structure and complex joins to access data organized into related tables, horizontal scaling—i.e. spreading data over many machines—is fundamentally difficult. As a result, distributed systems and NoSQL databases gained notoriety as an alternative, since they can scale out well across clusters of low-cost hardware. RDBMS solutions, on the other hand, need extensive architectural changes like sharding and partitioning to scale to this level, leading to added complexity and maintenance costs. Another critical problem of RDBMS that pinpoints its ineffectiveness especially in high-throughput environments is performance. Since the Regular databases query execution involves joins, indexes, transactions, etc. Although indexes can enhance read performance, they can also increase the time taken for write operations because of the overhead of maintaining multiple indexes. Query performance over a growing dataset can degrade considerably, giving longer response times and less effective operation. Furthermore, real-time data processing requirements are challenging for RDBMSs, which are designed for

transactional consistency instead of speed and live analytics. RDBMS usually are not able to provide the low-latency requirements of applications like recommendation engines, financial trading engines, and IoT applications. On the other hand, NoSQL is focused on optimizing performance for certain use cases like key-value stores for fast lookups, or columnar databases for analytical workloads. This is another place where RDBMS is lacking, flexibility. RDBMSs enforce strict schema, which means that you need to define the structure of tables (columns and their types) before you store any data. While this rigidity guarantees well-defined measures of data consistency and integrity, it can be a massive limitation in the use case of changing data requirements. Changing an existing schema may be a painful process and need downtime and long data migrations. Another very important aspect is being able to adapt to changing business requirements. Designed to cater to the needs of big data and cloud storage, NoSQL databases are schema-less, which provides developers with the ability to store unstructured or semi-structured content without needing to define a schema beforehand.

RDBMS have another biggest disadvantage that it cannot store unstructured data in enough wide scale. Common applications in modern systems generate a variety of data types: text, images, videos, logs, sensors. RDBMSs are optimized for structured data with well-defined relationships, making storing and processing such data inefficient in a relational database. Although some relational databases offer a special field type called Binary Large Objects (or BLOBs) to store unstructured data, querying and accessing them can be slow and resource-consuming. Key features: NoSQL databases, including document stores and graph databases, are structured to handle unstructured and semi-structured information more rapidly, ideal for applications such as content management systems (CMS), big data analytics, or a machine learning workload. One more major drawback of RDBMS is the difficulty in managing relationships, and keeping data consistent. Though the performance is good, maintaining data integrity which is very important in transactional applications is achieved with relational databases utilizing foreign keys and normalization techniques. As the database grows and the behind-the-scenes maintenance of these relationships can become complex, which can cause performance bottlenecks. Joins are a necessary part of why

relational databases are so powerful, but they can be computationally heavy, especially at scale. As a result, queries that perform multiple joins can become slow and inefficient, affecting application performance. On the other hand, graph databases and NoSQL databses are able to accommodate highly connected data, making them useful in scenarios like social networks, recommendation engines, and fraud detection systems. One more major limitation of RDBMS is its high maintenance and admin cost. Maintaining a relational database effectively takes an understanding of database design, indexing techniques, query optimization, and performance mitigation — and, honestly, this is a full-time job in itself. This increases operational costs and SQL database administrators (DBAs) have a vital role in keeping the database performing smoothly. Database management systems, or RDBMS, require thoughtful planning and execution of backup and recovery, replication, and security management. Scaling an RDBMS solution across many nodes multiplies these administrative challenges

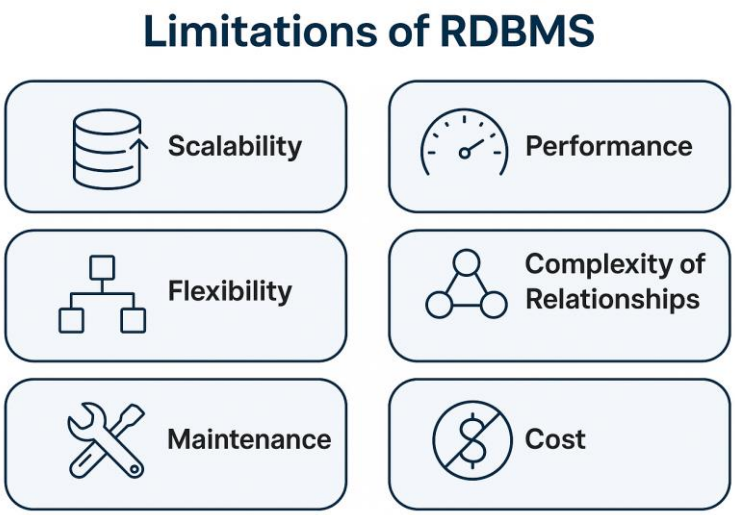


Fig. 13.1- Limitation of RDBMS

and necessitates Replication / Sharding, challenges that have their own complexity. On the other hand, spherical NoSQL databases listen to availability and scalability by automating the process of scaling with auto-scaling, automated replication and replication recovery mechanisms.

RDBMS also has challenges with concurrency control and transaction management. Although the ACID properties guarantee the integrity of the data, they can also come with performance overhead, especially in

situations involving high transaction concurrency. By using locking mechanisms to maintain consistency, contention issues can occur since several transactions try to grab the same resources, resulting in bottlenecks and reduced throughput. This is especially problematic in distributed systems where one may have multiple nodes, maintaining strong consistency can lead to higher latency. NoSQL databases typically follow an eventual consistency model, trading off full ACID compliance for better performance and scalability. Not all applications are suited for this, but it certainly provides many benefits for anything with high availability and fault tolerance requirements. Another important aspect that needs to be taken care of by organizations is the cost of implementing and maintaining an RDBMS. Commercial relational database solutions like Oracle, Microsoft SQL Server, and IBM Db2 are costly due to hefty licensing fees; this proves to be too expensive for small and medium-sized businesses. Even open-source alternatives come with a hefty investment in infrastructure, expertise, and ongoing maintenance, with potential pitfalls similar to those of DynamoDB for scaling products. Moreover, scaling an RDBMS solution becomes more and more costly, as data volume increases, as it requires a high-performance hardware, storage, and networking resources in the most sense. On the other hand NoSQL databases are generally more economical because of their distributed architectures which let organizations take advantage of commodity hardware and cloud-based resources to scale effectively. RDBMSs also have limitations in terms of security and compliance. However, relational databases offer solid security features, such as authentication, authorization, and encryption, but configuring and managing them is not a trivial task. Ensuring compliance with industry regulations like GDPR, HIPAA, and PCI-DSS is necessitating stringent access controls, audit logging, and data encryption mechanisms. In an RDBMS environment, enforcing compliance can be difficult because distributed architectures are increasingly common. And for big data analysis, traditional relational databases are more prone to SQL injection, which is an attack when attackers can manipulate poorly designed queries. NoSQL databases are not without their own security risks, but can offer alternative security models to address specific threats. To sum up, even though RDBMSs are an initial basic part of big data management, their scopes have revealed themselves due to the

new data paradigms. All the issues mentioned in terms of scalability, performance, flexibility, unstructured data handling, administrative complexity, concurrency control, cost, and security have created more need for alternative database solutions. As a result, NoSQL databases, cloud-based storage solutions, and distributed data architectures have developed as valid options and provide more scalability, performance, and flexibility for modern applications. So, you know you must consider their particular use cases and needs when deciding whether an RDBMS has the best fit, or some of alternative database technologies offers the best solution for the organization. Knowing these constraints allows businesses to make informed decisions to streamline their data management strategies, helping them cope better with their evolving data requirements.

Unit 14: Object-Oriented Features in Relational Databases

5.2 Introduction: OODBMS and ORDBMS

OODBMS and ORDBMS

Database management systems have made great strides in recent years and two of the most notable evolutions beyond RDBMS are Object-Oriented Database Management Systems and Object-relational Database Management Systems. The RDBMS was not without its limitations, particularly when it came to dealing with complex data structures, multimedia applications, and systems that required a tight coupling between the object-oriented programming language used for application development and the underlying database technology.

Object-Oriented Database Management System (OODBMS)

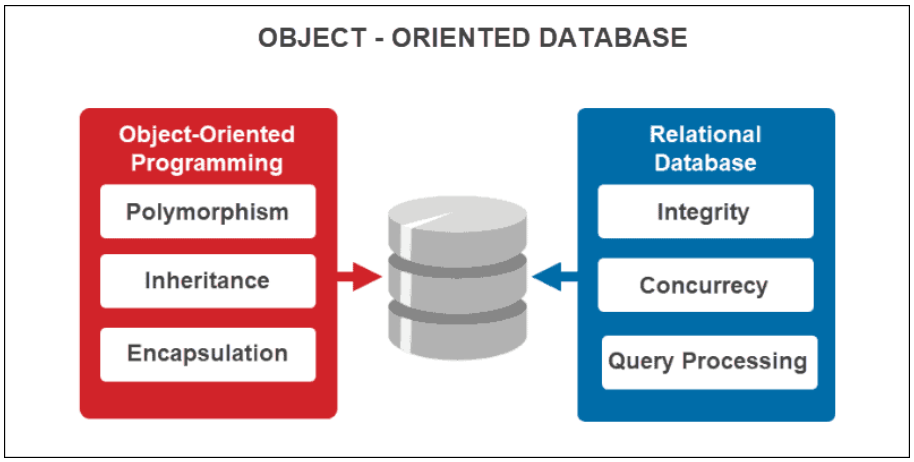


Figure14.1: Object Oriented Database

An Object-Oriented Database Management System (OODBMS) is a database management system that supports the modeling and creation of data as objects. This is in contrast to RDBMS architecture where data is structured in the form of rows and columns in tables, OODBMS stores data in the form of objects in a similar way just like data is represented in object-oriented programming languages like Java, C++, and Python. It provides a better way of dealing with complex data like images, audio-visual data, and nested structures, as they support object-oriented features. Suitable for CAD, multimedia database, real-time system, and AI applications. OODBMS supports inheritance, encapsulation and polymorphism, allowing developers to directly

work with objects without being forced to convert them to relational tables. This eliminates the O/R Mapping (which is needed when using RDBMS over any OO language). Yet OODBMS is not as widely used as RDBMS because of compatibility issues, a lack of standards, and a steep learning curve for many developers who are used to working in traditional relational models.

Object-Relational Database Management System (ORDBMS)

ORDBMS (Object Relational Database Management System): It is a combination of RDBMS and OODBMS. It preserves the traditional SQL and ACID (Atomicity, Consistency, Isolation, Durability) aspects of relational databases, while also allowing for the use of object-oriented techniques, such as user-defined types (UDTs), inheritance, and complex data types.

ORDBMS provides the ability to store and manipulate complex objects such as array, multimedia, geographical data, and application-defined data types without having to convert these into normal relational types. This makes well suited for applications such as geographic information systems (GIS), data warehousing, and scientific computing. Widely used ORDBMS systems include PostgreSQL, Oracle and IBM Db2 that provide object-oriented features while maintaining the performance and familiarity of SQL-like relational databases.

While both OODBMS and which are O/R DBMS exist to handle for all those complex data that the regular RDBMS simply do not work for. OODBMS would be best suited where there is a need to integrate a lot with an object-oriented programming environment, while ORDBMS can be used as a middle ground between the relational and object-oriented paradigms, which is useful for enterprises looking to extend their existing relational databases. Organizations can determine the best database system for their needs by examining the complexity and scalability of their data and the purpose of their application through these database models.

5.3 Storing and Accessing Objects in a Relational Database

Relational database management systems (RDBMS) follow the table structure, making it look difficult to store and access objects since generally the objects are directly used in object-oriented programming. Nonetheless, as object-oriented programming languages like Java, Python and C++ became more widely used, the definition of an

RDBMS changed, as most modern RDBMSs now support object storage and retrieval in one way or the other. Object-Relational Mapping (ORM), serialization, and structured storage techniques are

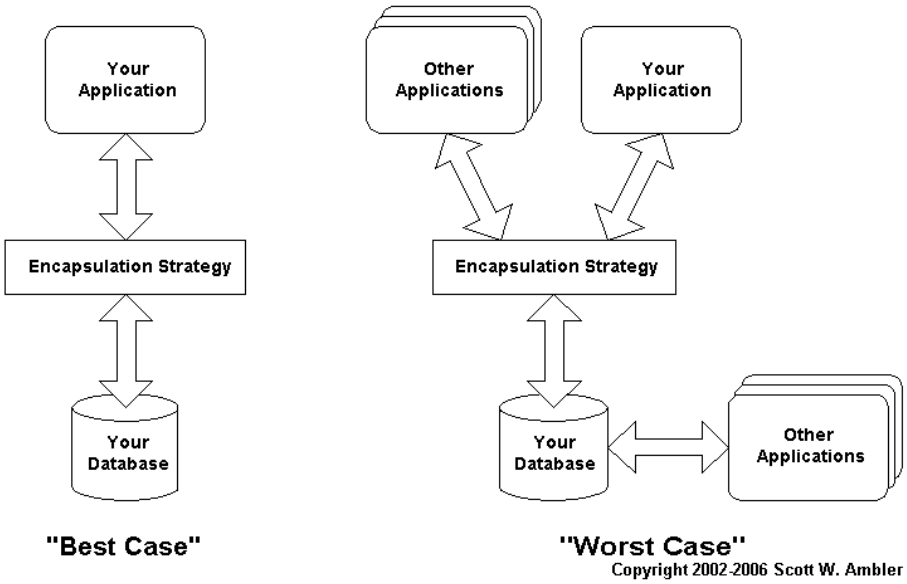


Figure 14.2: Storing and Accessing Objects in a Relational Database

commonly used for storing and accessing objects in a relational database.

1. Object-Relational Mapping (ORM)

Object-Relational Mapping (ORM) is a common technique that maps objects to their corresponding records in relational databases. ORM tools (Object Relational Mapping tools) are used to create mapping between objects in programming languages and relational database tables.

• In ORM-based approaches, each class of the object-oriented language corresponds to a table in the database, and each instance of that class corresponds to a row in that table.

• ORM Libraries: Hibernate (java), SQLAlchemy (python), Entity Framework (. In.NET, Hibernate (Java), and Django ORM (Python), the conversion between objects and database records is handled automatically.

• By avoiding manual SQL query writing, this method increases productivity and lowers the risk of SQL injection attacks.

• While ORMs provide significant development benefits, they also come with a performance trade-off related to the necessity for query

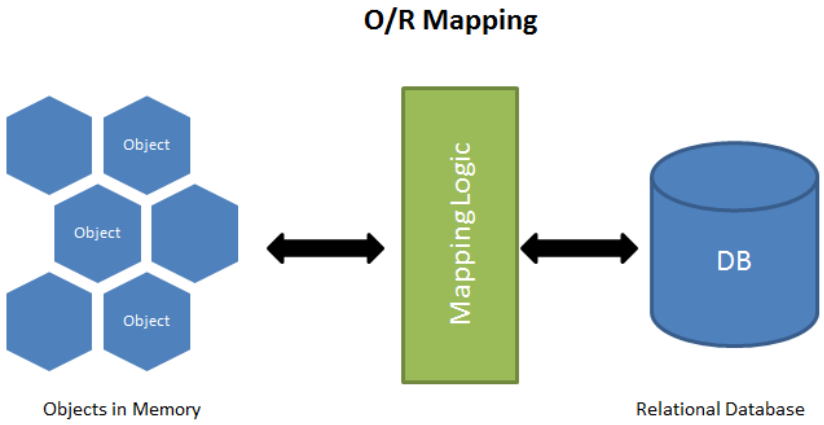


Figure 14.3 O/R Mapping

translation, affecting the efficiency of complex queries and large scale data operations.

2. Storing Objects as Serialized Data

Alternative ways of persisting objects in a relational database can be achieved through serialization, which involves transforming the objects into a format that can be persisted in a database column and reconstructed when pulled from the database.

- Serialization format: JSON, XML, YAML, or binary formats (e.g., Protocol Buffers, Avro)
- Usually the serialized object is stored in a BLOB (Binary Large Object) or TEXT field in the database.
- JSON and XML formats enable semi-structured storage and simplify retrieval using built-in database functions like PostgreSQL's JSONB type or MySQL's JSON functions.
- Even though serialization provides flexible storage, the serialized data is not efficient to query since relational databases are optimized for structured tabular data not embedded hierarchical structures.

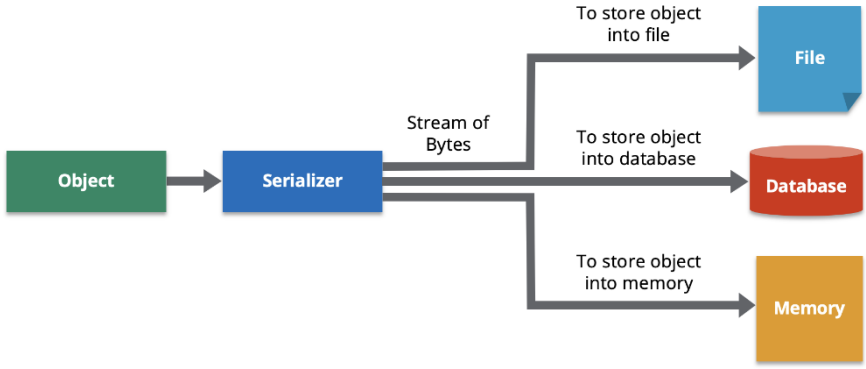


Figure14.4: Storing Objects as Serialized Data

3. Storing Objects in Relational Tables

Objects can be persisted through a normalized relational structure for performance, storage or data integrity. In this method:

- Normalized — these are complex objects that are broken into 2+ relational tables and result in foreign key relationships.
- Objects are kept associated through primary or foreign keys, ensuring referential integrity.
- For example, an embedded Address object in an object Person will have a separate Address table with a foreign key reference from Address to Person.
- Using this approach allows for fast querying and consistency, though retrieving the object will require JOIN operations to restore it.

4. Using Object-Relational Features in ORDBMS

Some Object-Relational Database Management Systems (ORDBMS), such as PostgreSQL, Oracle, and IBM Db2, offer built-in support for storing objects with object-oriented features like:

- User-Defined Data Types (UDTs): Allow defining custom data structures in the database.
- Nested Tables and Arrays: Support for multi-valued attributes within relational tables.
- Inheritance: Enables table hierarchies similar to object-oriented class inheritance.
- Table Functions: Allow querying objects as structured entities instead of flat tables.

These features allow for more natural object storage while maintaining the advantages of relational databases, such as data consistency and ACID compliance.

Accessing Stored Objects in a Relational Database

Once objects are stored, they must be accessed efficiently for retrieval and manipulation. Common methods include:

1. **Using SQL Queries:**
    - Standard SQL queries (SELECT, JOIN, WHERE) are used to retrieve object-related data from multiple tables.
    - Indexed queries improve performance when retrieving objects with complex relationships.
2. **ORM Query Methods:**

- ORM frameworks provide high-level query abstractions such as find(), filter(), or get() methods to fetch objects without writing SQL manually.
- Example using SQLAlchemy in Python:

```
person = session.query(Person).filter_by(id=1).first()
print(person.name)
```

3. **Deserialization for Stored Objects:**
   - Serialized objects stored as JSON/XML/BLOB need to be deserialized before being used in the application.
   - Example of JSON deserialization in Python:

```
import json
data = json.loads(json_string)
print(data["name"])
```

4. **Querying JSON/XML Fields in Modern RDBMS:**
   - Databases like PostgreSQL and MySQL allow direct querying within JSON fields using SQL functions:

```
SELECT data->>'name' FROM person_table WHERE id = 1;
```

Storing and accessing objects in relational databases requires a combination of ORM techniques, serialization, relational structuring, or object-relational extensions. While relational databases are optimized for structured data, modern enhancements like JSON support and ORM frameworks have made it easier to handle objects efficiently. The choice of method depends on application requirements, performance considerations, and scalability needs.

5.4 Object-Oriented Database Design

Object-Oriented Database Design (OODD) is a methodology for designing databases that align with the principles of Object-Oriented Programming (OOP). Unlike traditional relational database design, which relies on tables, rows, and columns, object-oriented database design structures data as objects, encapsulating both attributes (data) and behaviors (methods). This approach is particularly beneficial for applications that handle complex data types, multimedia content, real-time processing, and hierarchical relationships.

Object-Oriented Database Management Systems (OODBMS) such as ObjectDB, db, Versant, and GemStone/S support this design paradigm, enabling direct storage and retrieval of objects without the need for Object-Relational Mapping (ORM). Additionally, Object-Relational Database Management Systems (ORDBMS) like PostgreSQL and

Oracle provide hybrid solutions that integrate object-oriented features into relational models.

Key Concepts of Object-Oriented Database Design

1. Objects and Classes

In OODD, data is modeled as objects, which are instances of classes.

- Objects store both data (attributes) and methods (behavior) in a single entity.
- Classes define a blueprint for objects, specifying attributes and behaviors.
- Objects persist in the database in the same way they exist in object-oriented programming, reducing the need for transformation.

Example of an Object in OODBMS

```
class Employee {
   String name;
   int employeeID;
   Address address; // Reference to another object
   void calculateSalary() {
      // Method logic
   }
}
```

Here, the Employee object contains attributes (name, employeeID) and a method (calculateSalary). It also contains a reference to another object (Address), demonstrating object composition.

2. Encapsulation

Encapsulation ensures that data is bundled with methods that operate on it, preventing unauthorized access.

- In an OODBMS, objects maintain their own states and behaviors, allowing operations to be performed directly on them rather than using SQL queries.
- This reduces complexity by allowing direct object manipulation instead of translating objects into relational data structures.

3. Inheritance

Inheritance allows new classes to derive properties and behaviors from existing classes, promoting code reusability.

- OODD supports hierarchical data modeling, where subclasses inherit attributes and methods from a parent class.

- This eliminates data redundancy and enables efficient data organization in the database.

Example of Inheritance in OODD

```
class Person {
   String name;
   int age;
}
class Employee extends Person {
   int employeeID;
   double salary;
}
```

Here, Employee inherits properties (name, age) from Person, reducing redundancy.

4. Polymorphism

Polymorphism allows objects of different types to be treated uniformly through method overriding or overloading.

- In an OODBMS, polymorphism ensures that queries and operations can be applied to objects of different subclasses seamlessly.
- This makes applications more adaptable to changing requirements.

Example of Polymorphism in OODD

```
class Shape {
   void draw() {
System.out.println("Drawing a shape");
   }
}

class Circle extends Shape {
   void draw() {
System.out.println("Drawing a circle");
   }
}
```

A draw() method can be called on any Shape object, whether it is a Circle or another shape, demonstrating polymorphism.

5. Object Identity (OID) and Relationships

Each object in an OODBMS has a unique Object Identifier (OID), which is independent of the object's data.

- OID is used instead of primary keys (as in relational databases) to maintain object uniqueness.
- Objects can be related using one-to-one, one-to-many, or many-to-many relationships.

Example of Object Relationships

- An Order object may contain multiple Product objects, forming a one-to-many relationship.
- Unlike relational databases, these relationships are maintained via direct object references rather than foreign keys, improving retrieval efficiency.

Steps in Object-Oriented Database Design

Step 1: Requirement Analysis

- Identify the entities (objects) that need to be stored in the database.
- Define the behaviors associated with each entity.
- Understand data relationships and constraints.

Step 2: Identify Classes and Attributes

- Define classes corresponding to real-world objects.
- Identify attributes and categorize them as simple types (integers, strings) or complex types (nested objects).
- Specify methods that belong to each class.

Step 3: Define Inheritance Hierarchies

- Identify common properties among classes and define superclasses.
- Establish subclass relationships to minimize redundancy.

Step 4: Establish Associations and Aggregations

- Define relationships between objects.
- Use aggregation (whole-part relationships) and composition (strong association) where necessary.

Step 5: Assign Object Identifiers (OIDs)

- Ensure each object has a unique identifier.
- OIDs remain constant even if object attributes change, unlike primary keys in relational databases.

Step 6: Normalize the Object Schema

- Avoid redundant attributes by following object normalization techniques similar to database normalization.
- Convert redundant objects into reusable components.

Step 7: Implement Methods and Constraints

- Define object methods that enforce business logic.
- Implement constraints (e.g., salary cannot be negative) at the object level.

Step 8: Optimize for Performance

- Use indexing techniques for efficient retrieval.
- Apply caching to store frequently accessed objects in memory.
- Consider partitioning large object collections.

Advantages of Object-Oriented Database Design

Better Handling of Complex Data

OODBMS efficiently stores multimedia, CAD models, XML, and hierarchical data, which is difficult in relational databases.

No Impedance Mismatch

Since objects are stored directly, there is no need for Object-Relational Mapping (ORM), reducing overhead.

Encapsulation and Reusability

Encapsulation keeps data and behavior together, while inheritance promotes code reuse.

Efficient Query Performance

Objects are retrieved using direct references (OIDs) rather than expensive JOIN operations in relational databases.

Scalability and Flexibility

OODBMS allows schema evolution, making it easier to accommodate changes without restructuring entire tables.

Challenges of Object-Oriented Database Design

Lack of Standardization

Unlike SQL-based relational databases, OODBMS lacks a universally accepted query language.

Steep Learning Curve

OODD requires familiarity with object-oriented programming concepts, making it difficult for traditional database administrators.

Limited Adoption

Due to wide enterprise reliance on RDBMS, many applications still require Object-Relational Mapping (ORM) rather than a full switch to OODBMS.

Object-Oriented Database Design (OODD) provides an efficient, flexible, and scalable approach to managing complex data structures by aligning with object-oriented programming principles. It overcomes

limitations of relational databases, such as impedance mismatch and rigid schema structures, making it ideal for applications involving multimedia, CAD, IoT, and real-time systems. However, challenges such as lack of standardization, steep learning curve, and limited industry adoption must be considered before choosing an OODBMS over traditional RDBMS or ORDBMS solutions. As software development continues to embrace object-oriented paradigms, the demand for integrated object-oriented database systems is expected to grow.

5.5 Introduction to Object-Oriented Data Models

The Object-Oriented Data Model (OODM) represents a significant evolution in database management systems, integrating the principles of object-oriented programming (OOP) with data storage and retrieval. Unlike traditional Relational Database Management Systems (RDBMS), which organize data into structured tables of rows and columns, the object-oriented model structures data as objects, similar to those used in programming languages such as Java, C++, and Python. These objects encapsulate both data attributes and behavioral methods, facilitating a more natural representation of real-world entities. The Object-Oriented Database Management System (OODBMS) extends this model by enabling direct storage and retrieval of objects without requiring conversion into relational tables. This approach eliminates the need for Object-Relational Mapping (ORM), which is necessary when using an RDBMS with object-oriented programming. As a result, OODM offers a more seamless integration between applications and databases, making it particularly suitable for complex data structures, multimedia applications, hierarchical data, and real-time systems.

Key Features of the Object-Oriented Data Model

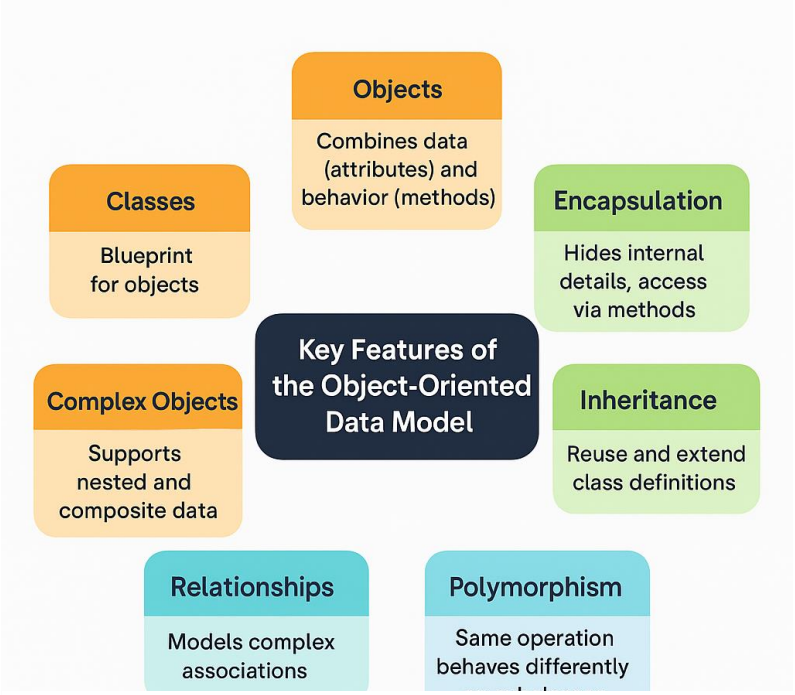


Figure 15.1 ; Key Features of the Object-Oriented Data Model

1. Objects as Fundamental Data Units

In an Object-Oriented Data Model, data is represented as objects, which are instances of classes. These objects store both attributes (data) and methods (functions), encapsulating behavior alongside data storage. This design facilitates a more intuitive and flexible representation of entities within a system. For example, an Employee object may contain attributes such as name, employeeID, and salary, along with methods such as calculateBonus(). Unlike relational databases, where attributes and behavior are separated, OODM allows objects to self-manage their behavior and state, enhancing modularity and reusability.

2. Classes and Object Instances

The class serves as a blueprint for creating objects, defining their attributes and behaviors. Each instance of a class represents an individual object containing specific data values. For instance, a Car class may define attributes such as model, color, and speed. An instance of this class could be a Tesla Model S, characterized by a red color and a top speed of 200 km/h.

3. Encapsulation and Data Integrity

Encapsulation is a key principle of the object-oriented model, ensuring that data is bundled with its associated methods and protected from unauthorized access. Objects expose data through controlled interfaces, typically via getter and setter methods.

For example, in Java:

```
class Student {
   private String name;
   public String getName() { return name; }
   public void setName(String n) { name = n; }
}
```

Here, the name attribute is private, ensuring that it can only be accessed or modified through controlled methods. This design enhances data security, integrity, and modularity.

4. Inheritance and Code Reusability

The Object-Oriented Data Model supports inheritance, a mechanism that enables new classes to derive attributes and methods from existing classes. This feature promotes code reusability and hierarchical organization, reducing redundancy and improving maintainability. For example, a Manager class may inherit common properties from an Employee class, eliminating the need for redundant definitions.

```
class Employee {
   String name;
   int employeeID;
}
class Manager extends Employee {
   double bonus;
}
```

Here, the Manager class automatically inherits attributes from Employee, extending functionality without redefining common properties.

5. Polymorphism and Dynamic Behavior

Polymorphism allows different objects to respond to the same function call in multiple ways, enhancing flexibility and adaptability. This is particularly useful in object-oriented queries and dynamic data processing.

For instance, a draw() method can be applied to different shapes (Circle, Rectangle), each implementing its own version of the method:

```
class Shape {
   void draw() { System.out.println("Drawing a shape"); }
}

class Circle extends Shape {
   void draw() { System.out.println("Drawing a circle"); }
}
```

Here, invoking draw() on a Shape object may execute different behaviors based on the actual object type, demonstrating method overriding in polymorphism.

6. Object Identity (OID) and Unique Identification

Every object in an OODBMS is assigned a unique Object Identifier (OID), which remains constant throughout the object's lifecycle, even if attribute values change. Unlike primary keys in relational databases, OIDs provide efficient object retrieval and referencing without relying on external keys. For instance, a Customer object with OID C123 may reference an Order object with OID O456, creating a direct object relationship without foreign keys.

7. Relationships and Data Associations

Objects in an object-oriented database can be related through various associations:

- One-to-One: A Student object is linked to a LibraryCard object.
- One-to-Many: A Department contains multiple Employees.
- Many-to-Many: A Student can enroll in multiple Courses, and a Course can have multiple students.

Unlike relational databases, where relationships require foreign key constraints, OODBMS maintains direct references between objects, improving data retrieval efficiency.

Advantages of Object-Oriented Data Models

1. **Enhanced Representation of Complex Data:**
    - Supports multimedia, CAD models, hierarchical data, and real-world relationships.
2. **Seamless Integration with Object-Oriented Programming:**
    - Eliminates the need for Object-Relational Mapping (ORM), reducing conversion overhead.
3. **Reusability and Maintainability:**
    - Inheritance, encapsulation, and polymorphism facilitate efficient system design.
4. **Efficient Data Retrieval:**
    - Direct object references and OID-based indexing improve query performance compared to relational joins.
5. **Flexibility and Scalability:**
    - Objects can evolve dynamically, supporting schema evolution without requiring major restructuring.

Challenges and Limitations

1. **Lack of Standard Query Language:**
    - Unlike SQL, there is no universally accepted query language for OODBMS, making it less standardized.
2. **Steeper Learning Curve:**
    - Requires expertise in object-oriented programming and database management.
3. **Limited Enterprise Adoption:**
    - Many businesses rely on RDBMS solutions due to their mature ecosystem and widespread support.
4. **Complex Implementation:**

- Object-oriented databases require efficient indexing and caching strategies to handle large datasets effectively.

The Object-Oriented Data Model (OODM) represents a paradigm shift in database management, offering a natural and intuitive approach to data storage by aligning with object-oriented programming principles. By encapsulating data and behavior within objects, it provides a flexible, scalable, and efficient solution for applications that require complex data modeling and hierarchical relationships. However, despite its advantages, the lack of standardization and the dominance of relational databases have limited its widespread adoption. Nonetheless, as modern applications increasingly demand dynamic and flexible data storage, OODBMS and hybrid Object-Relational Database Systems (ORDBMS) continue to gain traction, paving the way for next-generation data management solutions.

Summary

Relational Database Management Systems (RDBMS) have long been foundational in structured data management, offering reliable ACID-compliant transactions and strong integrity. However, they face significant limitations in the context of modern, large-scale, and dynamic applications. Their rigidity in schema design, challenges with horizontal scalability, inefficiency in handling unstructured or semi-structured data, and the high cost of maintenance and performance tuning make them less ideal for rapidly evolving use cases like big data analytics, IoT, and real-time applications. These shortcomings have led to the emergence of advanced database technologies, including NoSQL and object-oriented databases, which offer greater flexibility, scalability, and performance for modern workloads.

To bridge the gap between object-oriented programming and traditional relational storage, object-oriented features have been incorporated into relational systems, resulting in Object-Relational Database Management Systems (ORDBMS). These systems support user-defined types, inheritance, and complex data structures, while retaining relational features and SQL compatibility. Meanwhile, Object-Oriented Database Management Systems (OODBMS) offer a more natural and seamless integration with object-oriented applications by storing data as persistent objects. The object-oriented data model encapsulates both data and behavior, supporting concepts like inheritance, encapsulation,

polymorphism, and object identity. This model enables the representation of complex, hierarchical, and multimedia data, and is particularly well-suited for applications in scientific computing, CAD, and multimedia systems. Though challenges like lack of standardization and limited adoption persist, the object-oriented approach addresses key limitations of RDBMS and supports evolving data management needs.

MCQs:

1. Which SQL statement is used to retrieve data from a database?
a) FETCH
b) GET
c) SELECT
d) RETRIEVE
(Answer: c)
2. Which SQL clause is used to sort records in ascending or descending order?
a) SORT
b) ORDER BY
c) ARRANGE
d) GROUP BY
(Answer: b)
3. Which SQL operator is used to filter results based on a range of values?
a) IN
b) BETWEEN
c) LIKE
d) OR
(Answer: b)
4. Which function is used to find the highest value in a column?
a) COUNT()
b) MAX()
c) SUM()
d) AVG()
(Answer: b)
5. What type of JOIN returns only matching records from both tables?
a) LEFT JOIN
b) RIGHT JOIN

c) INNER JOIN
d) FULL JOIN
(Answer: c)
6. Which SQL function is used to count the number of records in a table?
a) COUNT()
b) TOTAL()
c) NUMBER()
d) RECORDS()
(Answer: a)
7. What does the WHERE clause do in SQL?
a) Sorts data
b) Filters records based on a condition
c) Deletes records
d) Modifies table structure
(Answer: b)
8. Which SQL operator is used to search for a pattern in a column?
a) LIKE
b) IN
c) IS NULL
d) AND
(Answer: a)
9. A subquery is:
a) A query inside another query
b) A duplicate query
c) A function call
d) A SQL join
(Answer: a)
10. Which clause is used to filter records after grouping them?
a) GROUP BY
b) WHERE
c) HAVING
d) ORDER BY
(Answer: c)

Short Questions:

1. What is the purpose of the SELECT statement in SQL?
2. Explain the ORDER BY clause and how it works.

3. What is the difference between WHERE and HAVING clauses?
4. How do you filter records using BETWEEN and IN operators?
5. Define numeric functions in SQL with examples.
6. What are string functions? Give examples.
7. How do joins work in SQL? Explain different types.
8. What are aggregate functions, and how are they used?
9. Explain the difference between INNER JOIN and LEFT JOIN.
10. What is a subquery, and when is it used?

Long Questions:

1. Explain the SELECT statement with multiple examples.
2. Discuss the different SQL operators and their uses.
3. How do numeric, string, and date functions work in SQL? Provide examples.
4. Explain different types of joins with real-world examples.
5. How do aggregate functions work? Explain GROUP BY, HAVING, MIN(), MAX(), AVG(),
SUM(), COUNT().
6. What is the difference between WHERE and HAVING clauses?
7. Explain ORDER BY and LIMIT in SQL.
8. Discuss subqueries and how they can be used to filter data.
9. Write SQL queries to demonstrate different JOIN operations.
10. Explain how data manipulation queries improve database performance.

SCENARIO BASED PRACTICAL PEOBLEM

Exp. #	Objective	Remarks
	Unit1	
1.	To demonstrate a simple conditional IF statement in MySQL stored procedure.	Book availability in library
2.	To demonstrate how to use conditional statements in MySQL stored procedure. (If then else structure)	Customer's categorization on their payment history
3.	Demonstrates the use of IN, OUT, and INOUT parameters in MySQL stored procedure.	Bank account transactions (Balance, Deposit, Withdraw)
4.	To demonstrate how to use conditional statements in MySQL stored procedure. (Searched CASE structure)	Student Grading System
5.	To demonstrate how to use conditional statements in MySQL stored procedure. (Simple CASE structure)	Department Management System
6.	To demonstrate how to use iterative statements in MySQL stored procedure. (WHILE loop)	Salary Increment System
7.	To demonstrate how to use iterative statements in MySQL stored procedure. (WHILE loop)	Online Store Management System

Experiment 1

Objective: To demonstrate a simple conditional IF statement in MySQL stored procedure.

Scenario:

You are managing a small library system where users can borrow books. To ensure that the borrowing process is efficient, the library wants to implement a stored procedure that checks if a book is available before a user can borrow it. If the book is available (i.e., not already borrowed), the procedure should mark the book as borrowed. If the book is unavailable, it should return a message indicating the unavailability.

Your task is to create a stored procedure that uses a conditional statement to check the availability of a book before allowing it to be borrowed.

Problem Statement:

Write a MySQL stored procedure named BorrowBook that uses a conditional (IF) statement to check if a book is available. The procedure should:

1. Accept p_book_id and p_user_id as input parameters to identify the book and the user.
2. Check whether the book is available (i.e., its is_borrowed flag is set to 0 in the Books table).
3. If the book is available, update the is_borrowed flag to 1 to mark it as borrowed and insert a record into the Borrowings table.
4. If the book is unavailable, return a message indicating that the book is already borrowed.

Table Structure:

Assume you have the following Books and Borrowings tables:

```
CREATE TABLE Books (
   book_id INT PRIMARY KEY,
   title VARCHAR(100),
   is_borrowed BOOLEAN DEFAULT 0
);
INSERT INTO Books (book_id, title, is_borrowed) VALUES (101, 'Transforming India', 0);
```

INSERT INTO Books (book_id, title, is_borrowed) VALUES (102, 'Vision 2047', 1);

```
CREATE TABLE Borrowings (
   borrowing_id INT AUTO_INCREMENT PRIMARY KEY,
   user_id INT,
   book_id INT,
   borrow_date DATE,
   FOREIGN KEY (book_id) REFERENCES Books(book_id)
);
```

Steps:

1. Create a stored procedure named BorrowBook that:
    - Takes p_book_id (INT) and p_user_id (INT) as IN parameters.
    - Uses a conditional IF statement to check if the book is available by checking the is_borrowed column in the Books table.
    - If the book is available, updates the is_borrowed column and inserts a record into the Borrowings table.
    - If the book is unavailable, returns a message indicating that the book is already borrowed.

Sample SQL Stored Procedure:

```
DELIMITER //

CREATE PROCEDURE BorrowBook(IN p_book_id INT, IN p_user_id INT)
BEGIN
   DECLARE book_status BOOLEAN;

   -- Check if the book is available
   SELECT is_borrowed INTO book_status
   FROM Books
   WHERE book_id = p_book_id;
```

```
    -- Conditional logic to check book availability
    IF book_status = 0 THEN
        -- If the book is available, mark it as borrowed
        UPDATE Books
        SET is_borrowed = 1
        WHERE book_id = p_book_id;

        -- Insert a record into the Borrowings table
        INSERT INTO Borrowings (user_id, book_id, borrow_date)
        VALUES (p_user_id, p_book_id, CURDATE());

        SELECT CONCAT('Book ID ', p_book_id, ' has been successfully
borrowed by User ID ', p_user_id) AS message;
    ELSE
        -- If the book is already borrowed, return a message
        SELECT CONCAT('Book ID ', p_book_id, ' is already borrowed.')
AS message;
    END IF;

END//

DELIMITER ;
```

Test Cases:

1. **For a book that is available:**

Assume book 101 is available for borrowing.

CALL BorrowBook(101, 1);

Expected Output:

Book ID 101 has been successfully borrowed by User ID 1

2. **For a book that is already borrowed:**

Assume book 102 is already borrowed.

CALL BorrowBook(102, 2);

Expected Output:

Book ID 102 is already borrowed.

Experiment 2

Objective: To demonstrates how to use conditional statements in MySQL stored procedure.

Scenario:

You are working as a database administrator for a company that offers subscription-based services. The company wants a system to automatically categorize customers based on their payment history. A stored procedure needs to be created that categorizes customers as **Active**, **Inactive**, or **Delinquent** based on the number of days since their last payment. The categorization will help customer service and marketing teams manage customer relationships more effectively.

The conditions for categorization are as follows:

- **Active**: Last payment was made within the last 30 days.
- **Inactive**: Last payment was made between 31 and 60 days ago.
- **Delinquent**: Last payment was made more than 60 days ago.

Your task is to create a stored procedure in MySQL that categorizes a customer based on their payment history using conditional statements.

Problem Statement:

Write a MySQL stored procedure named CategorizeCustomer that uses conditional statements (IF) to categorize a customer based on the number of days since their last payment. The procedure should:

1. Accept p_customer_id as an input parameter to identify the customer.
2. Retrieve the number of days since the customer's last payment from the Payments table.
3. Use conditional logic to categorize the customer as **Active**, **Inactive**, or **Delinquent** based on the number of days since the last payment.
4. Return the customer's category as output.

Table Structure:

Assume you have the following Customers and Payments tables:

CREATE TABLE Customers (

```
    customer_id INT PRIMARY KEY,
    customer_name VARCHAR(100)
);

CREATE TABLE Payments (
    payment_id INT PRIMARY KEY,
    customer_id INT,
    payment_date DATE,
    FOREIGN KEY (customer_id) REFERENCES
Customers(customer_id)
);
insert into customers  values(101, 'Ajay');
insert into payments values(1, 101, '2024/01/01');
insert into customers  values(102, 'Vijay');
insert into payments values(4, 102, '2024/10/01');
insert into customers  values(103, 'Vijay');
insert into payments values(5, 103, '2024/09/01');
```

Steps:

1. Create a stored procedure named CategorizeCustomer that:
    - Takes p_customer_id as an IN parameter.
    - Retrieves the number of days since the customer's last payment using the DATEDIFF function.
    - Uses an IF statement to categorize the customer as **Active**, **Inactive**, or **Delinquent** based on the number of days.
    - Returns the category as an output.

Sample SQL Stored Procedure:

```
DELIMITER //

CREATE PROCEDURE CategorizeCustomer(IN p_customer_id INT,
OUT p_category VARCHAR(20))
BEGIN
```

```
    DECLARE days_since_last_payment INT;

    -- Retrieve the number of days since the last payment for the customer
    SELECT DATEDIFF(CURDATE(), MAX(payment_date)) INTO days_since_last_payment
    FROM Payments
    WHERE customer_id = p_customer_id;

    -- Check if any payments are found
    IF days_since_last_payment IS NULL THEN
        SET p_category = 'No Payment History';
    ELSE
        -- Conditional logic to categorize the customer
        IF days_since_last_payment <= 30 THEN
            SET p_category = 'Active';
        ELSEIF days_since_last_payment BETWEEN 31 AND 60 THEN
            SET p_category = 'Inactive';
        ELSEIF days_since_last_payment > 60 THEN
            SET p_category = 'Delinquent';
        END IF;
    END IF;

END//

DELIMITER ;
```

Explanation of Conditional Statements:

- The IF and ELSEIF statements are used to apply conditional logic for categorizing the customer based on the value of days_since_last_payment.
- The IF checks if the customer is **Active**, **Inactive**, or **Delinquent**, and assigns the appropriate value to the p_category output parameter.

- An additional condition checks if there is no payment history for the customer (NULL value), categorizing them as "No Payment History."

Test Cases:

1. **For a customer with recent payments (Active):**

Assume customer 101 made a payment 10 days ago.

```
SET @category := '';

CALL CategorizeCustomer(101, @category);

SELECT @category AS Customer_Category;
```

Expected Output:
Customer_Category: Active

2. **For a customer with older payments (Inactive):**

Assume customer 102 made a payment 45 days ago.

```
SET @category := '';

CALL CategorizeCustomer(102, @category);

SELECT @category AS Customer_Category;
```

Expected Output:
Customer_Category: Inactive

3. **For a customer with long overdue payments (Delinquent):**

Assume customer 103 made a payment 75 days ago.

```
SET @category := '';

CALL CategorizeCustomer(103, @category);
```

SELECT @category AS Customer_Category;

Expected Output:

Customer_Category: Delinquent

4. **For a customer with no payment history:**

Assume customer 104 has no payment history.

SET @category := '';

CALL CategorizeCustomer(104, @category);

SELECT @category AS Customer_Category;

Expected Output:

Customer_Category: No Payment History

Experiment 3

Objective: Demonstrates the use of IN, OUT, and INOUT parameters in MySQL stored procedure.

Scenario:

You are working for a banking system, and you need to implement a stored procedure that performs multiple tasks related to a customer's bank account. The stored procedure should be able to:

1. **Accept** the account number as input (IN parameter).
2. **Return** the current balance of the account (OUT parameter).
3. **Adjust** the balance by adding or deducting a specified amount (INOUT parameter).

This will allow the bank staff to easily view the current balance of an account, adjust the balance for transactions like deposits or withdrawals, and return the updated balance all in one step.

Problem Statement:

Write a MySQL stored procedure named ManageAccountBalance that demonstrates the use of IN, OUT, and INOUT parameters. The procedure should:

1. Take an IN parameter p_account_number to identify the customer's account.
2. Use an OUT parameter p_current_balance to return the current balance of the account.
3. Use an INOUT parameter p_adjustment to adjust the balance by adding (for deposits) or deducting (for withdrawals) a specified amount, and then return the updated balance.

Table Structure:

```
CREATE TABLE Accounts (
   account_number INT PRIMARY KEY,
   account_holder VARCHAR(100),
   balance DECIMAL(10, 2)
);
```

Steps:

1. Create a stored procedure named ManageAccountBalance that:
    - Takes p_account_number (INT) as an IN parameter to identify the account.
    - Takes p_current_balance (DECIMAL) as an OUT parameter to return the current balance of the account.
    - Takes p_adjustment (DECIMAL) as an INOUT parameter to adjust the balance by the specified amount and then return the updated balance.
2. Inside the procedure:
    - Check if the account no p_account_number exists.
    - Retrieve the current balance based on p_account_number.

- If the account exists, return the current balance using the OUT parameter and apply the adjustment (either deposit or withdrawal) using the INOUT parameter.
- If the account does not exist, return an appropriate message.

Sample SQL Stored Procedure:

```
DELIMITER //

CREATE PROCEDURE ManageAccountBalance(
   IN p_account_number INT,
   OUT p_current_balance DECIMAL(10, 2),
   INOUT p_adjustment DECIMAL(10, 2)
)
BEGIN
   DECLARE account_exists INT;

   -- Check if the account exists
   SELECT COUNT(*) INTO account_exists
   FROM Accounts
   WHERE account_number = p_account_number;

   -- If the account exists, retrieve the balance and apply the adjustment
   IF account_exists > 0 THEN
      -- Get the current balance
      SELECT balance INTO p_current_balance
      FROM Accounts
      WHERE account_number = p_account_number;

      -- Adjust the balance by the given p_adjustment (deposit or withdrawal)
      SET p_current_balance = p_current_balance + p_adjustment;

      -- Update the balance in the Accounts table
```

```
    UPDATE Accounts
    SET balance = p_current_balance
    WHERE account_number = p_account_number;

    -- Return the updated balance through the INOUT parameter
    SET p_adjustment = p_current_balance;
  ELSE
    -- If account does not exist, set the current balance to NULL and return an error message
    SET p_current_balance = NULL;
    SET p_adjustment = NULL;
    SELECT CONCAT('Account with number ', p_account_number, ' does not exist.') AS message;
  END IF;

END//

DELIMITER ;
```

Explanation of Parameters:

- IN p_account_number: Used to input the account number to identify which account's balance needs to be checked and updated.
- OUT p_current_balance: Used to output the current balance of the specified account.
- INOUT p_adjustment: Used to input the amount to be added or subtracted from the current balance and then return the updated balance after the adjustment.

Test Cases:

1. **For an account that exists (deposit example):**

Assume there is an account with account_number = 101 and balance = 1000.00.

```
SET @balance := 0;
```

```
SET @adjustment := 200.00; -- Deposit amount
CALL ManageAccountBalance(101, @balance, @adjustment);
SELECT @balance AS Current_Balance, @adjustment AS Updated_Balance;
```

Expected Output:

Current_Balance: 1000.00

Updated_Balance: 1200.00

2. **For an account that exists (withdrawal example):**

Assume there is an account with account_number = 101 and balance = 1000.00.

```
SET @balance := 0;
SET @adjustment := -300.00; -- Withdrawal amount
CALL ManageAccountBalance(101, @balance, @adjustment);
SELECT @balance AS Current_Balance, @adjustment AS Updated_Balance;
```

Expected Output:

Current_Balance: 1000.00

Updated_Balance: 700.00

3. **For an account that does not exist:**

```
SET @balance := 0;
SET @adjustment := 100.00;
CALL ManageAccountBalance(999, @balance, @adjustment);
SELECT @balance AS Current_Balance, @adjustment AS Updated_Balance;
```

Expected Output:

Account with number 999 does not exist.

Current_Balance: NULL

Updated_Balance: NULL

Experiment 4

Objective: To demonstrate how to use conditional statements in MySQL stored procedure. (Searched CASE structure)

Scenario:

You are developing a **Student Grading System** for a university. The system needs to categorize students' performance based on their marks using a stored procedure. The grades should be assigned according to the following criteria:

- **Grade 'A'**: Marks >= 85
- **Grade 'B'**: Marks between 70 and 84
- **Grade 'C'**: Marks between 50 and 69
- **Grade 'F'**: Marks below 50

To efficiently assign grades, you will use the CASE statement inside a MySQL stored procedure to determine the grade based on the student's marks.

Problem Statement:

Write a MySQL stored procedure that accepts a student's marks as an **input parameter** and returns the corresponding grade using a **CASE** conditional statement. The procedure should perform the following tasks:

1. Accept the student's marks as an input parameter.
2. Use a CASE statement to evaluate the marks and assign a grade:
    - A for marks 85 and above.
    - B for marks between 70 and 84.
    - C for marks between 50 and 69.
    - F for marks below 50.
3. Return the calculated grade as the output.

Example Operation:

1. **Input Marks**: The student’s marks will be provided as input to the stored procedure.
2. **Grade Assignment**: Based on the marks, the appropriate grade is assigned using the CASE statement.
3. **Return Grade**: The grade is returned to the user.

SQL Code:

Step 1: Creating the Stored Procedure

```
DELIMITER //

CREATE PROCEDURE CalculateGrade(IN student_marks INT,
OUT student_grade CHAR(1))
BEGIN
   CASE
      WHEN student_marks >= 85 THEN
         SET student_grade = 'A';
      WHEN student_marks >= 70 AND student_marks < 85 THEN
         SET student_grade = 'B';
      WHEN student_marks >= 50 AND student_marks < 70 THEN
         SET student_grade = 'C';
      ELSE
         SET student_grade = 'F';
   END CASE;
END //

DELIMITER ;
```

Step 2: Calling the Stored Procedure

To call the procedure and get the grade for a specific student, use the following SQL code:

```
-- Declare a variable to store the grade
SET @grade = '';

-- Call the stored procedure with 92 marks
CALL CalculateGrade(92, @grade);

-- Output the grade
SELECT @grade AS Grade;
```

Example Outputs:

1. **For marks = 92**:

   CALL CalculateGrade(92, @grade);

   SELECT @grade AS Grade;

   Output:

   Grade

   A

2. **For marks = 75**:

   CALL CalculateGrade(75, @grade);

   SELECT @grade AS Grade;

   Output:

   Grade

   B

3. **For marks = 58**:

   CALL CalculateGrade(58, @grade);

   SELECT @grade AS Grade;

   Output:

   Grade

   C

4. **For marks = 40**:

   CALL CalculateGrade(40, @grade);

   SELECT @grade AS Grade;

   Output:

   Grade

   F

Experiment 5

Objective: To demonstrate how to use conditional statements in MySQL stored procedure. (Simple CASE structure))

Scenario:

You are tasked with developing a **Department Management System** for a university. Each department is identified by a unique department code, and based on the code, you need to display the corresponding department name.

Here are the department codes and names:

- **1**: Computer Science
- **2**: Electrical Engineering
- **3**: Mechanical Engineering
- **4**: Civil Engineering
- **5**: Mathematics

You will use a **SIMPLE CASE** statement in MySQL to match these codes with the department names.

Problem Statement:

Write a MySQL stored procedure that accepts a department code as an **input parameter** and returns the corresponding department name using a **SIMPLE CASE** statement. The procedure should perform the following tasks:

1. Accept the department code as an input parameter.
2. Use a **SIMPLE CASE** statement to return the corresponding department name based on the department code.
3. If the department code does not match any of the predefined values, return "Unknown Department".

Example Operations:

1. **Input Department Code**: The department code will be provided as input to the stored procedure.
2. **Return Department Name**: The corresponding department name is returned based on the input department code using a SIMPLE CASE statement.

SQL Code:

Step 1: Creating the Stored Procedure

```
DELIMITER //

CREATE PROCEDURE GetDepartmentName(IN dept_code INT,
OUT dept_name VARCHAR(50))
BEGIN
   CASE dept_code
      WHEN 1 THEN
         SET dept_name = 'Computer Science';
      WHEN 2 THEN
         SET dept_name = 'Electrical Engineering';
      WHEN 3 THEN
         SET dept_name = 'Mechanical Engineering';
      WHEN 4 THEN
         SET dept_name = 'Civil Engineering';
      WHEN 5 THEN
         SET dept_name = 'Mathematics';
      ELSE
         SET dept_name = 'Unknown Department';
   END CASE;
END //

DELIMITER ;
```

Step 2: Calling the Stored Procedure

To call the procedure and get the department name for a specific department code, use the following SQL code:

```
-- Declare a variable to store the department name
SET @dept_name = '';

-- Call the stored procedure with department code 1
CALL GetDepartmentName(1, @dept_name);
```

```
-- Output the department name
SELECT @dept_name AS Department;
```

Example Outputs:

1. **For department code = 1**:

   ```
   CALL GetDepartmentName(1, @dept_name);
   SELECT @dept_name AS Department;
   ```

   Output:

   ```
   Department
   ----------
   Computer Science
   ```

2. **For department code = 3**:

   ```
   CALL GetDepartmentName(3, @dept_name);
   SELECT @dept_name AS Department;
   ```

   Output:

   ```
   Department
   ----------
   Mechanical Engineering
   ```

3. **For department code = 5**:

   ```
   CALL GetDepartmentName(5, @dept_name);
   SELECT @dept_name AS Department;
   ```

   Output:

   ```
   Department
   ----------
   Mathematics
   ```

4. **For an invalid department code = 10**:

   ```
   CALL GetDepartmentName(10, @dept_name);
   SELECT @dept_name AS Department;
   ```

   Output:

   ```
   Department
   ----------
   Unknown Department
   ```

Experiment 6

Objective: To demonstrate how to use iterative statements in MySQL stored procedure. (WHILE loop)

Scenario:

You are developing a **Salary Increment System** for a company's HR department. The company offers a yearly salary increment to employees. The system needs to simulate the process of incrementing the salary by 5% each year until the employee's salary reaches or exceeds a specified target salary.

Problem Statement:

Write a MySQL stored procedure that accepts an employee's current salary and a target salary as **input parameters** and returns:

1. The final salary (which will be equal to or greater than the target).
2. The number of years it takes to reach or exceed the target salary by incrementing the salary by 5% each year.

The procedure should perform the following tasks:

1. Accept the employee's current salary and the target salary as input parameters.
2. Use a **WHILE loop** to increase the salary by 5% each year.
3. Count the number of years it takes for the salary to reach or exceed the target.
4. Return the final salary and the number of years required.

Example Operation:

1. **Input**:
    - Current Salary: 50,000
    - Target Salary: 60,000
2. **Output**:
    - Final Salary: 60,000 (or more)
    - Years Taken: 4 years

SQL Code:

Step 1: Creating the Stored Procedure

```
DELIMITER //

CREATE PROCEDURE CalculateSalaryIncrement(IN current_salary
DECIMAL(10,2), IN target_salary DECIMAL(10,2), OUT
final_salary DECIMAL(10,2), OUT years_taken INT)
BEGIN
   -- Declare a variable to keep track of the number of years
   DECLARE years INT DEFAULT 0;

   -- Initialize the final salary with the current salary
   SET final_salary = current_salary;

   -- Use a WHILE loop to keep incrementing the salary by 5% until
the target is reached
   WHILE final_salary < target_salary DO
      -- Increment the salary by 5%
      SET final_salary = final_salary * 1.05;

      -- Increment the year counter
      SET years = years + 1;
   END WHILE;

   -- Set the output variable for the number of years taken
   SET years_taken = years;
END //

DELIMITER ;
```

Step 2: Calling the Stored Procedure

To call the procedure and calculate how many years it will take to reach the target salary, use the following SQL code:

```
-- Declare variables to store the final salary and years taken
```

```
SET @final_salary = 0.00;
SET @years_taken = 0;

-- Call the stored procedure with a current salary of 50,000 and a
target salary of 60,000
CALL CalculateSalaryIncrement(50000, 60000, @final_salary,
@years_taken);

-- Output the final salary and years taken
SELECT @final_salary AS FinalSalary, @years_taken AS
YearsTaken;
```

Example Outputs:

1. **For current salary = 50,000 and target salary = 60,000**:

   ```
   CALL CalculateSalaryIncrement(50000, 60000,
   @final_salary, @years_taken);
   SELECT @final_salary AS FinalSalary, @years_taken AS
   YearsTaken;
   ```

   Output:

   ```
   FinalSalary   | YearsTaken
   --------------|------------
   60,775.31     | 4
   ```

2. **For current salary = 70,000 and target salary = 100,000**:

   ```
   CALL CalculateSalaryIncrement(70000, 100000,
   @final_salary, @years_taken);
   SELECT @final_salary AS FinalSalary, @years_taken AS
   YearsTaken;
   ```

   Output:

   ```
   FinalSalary   | YearsTaken
   --------------|------------
   100,579.96    | 7
   ```

Experiment 7

Objective: To demonstrate the working of loop.

Scenario:

You are managing an online store, and you want to create a stored procedure that counts how many times a product has been ordered in a given month. The Orders table keeps track of all orders, and your goal is to loop through each day of the month and count how many orders were made for a specific product.

Problem Statement:

Write a MySQL stored procedure named **CountProductOrders** that demonstrates the use of a simple loop. The procedure should:

1. Accept p_product_id, p_start_date, and p_end_date as input parameters to identify the product and the date range.
2. Use a loop to iterate through each day in the range from p_start_date to p_end_date.
3. For each day, check whether there were orders for the specified product in the Orders table and count them.
4. Return the total number of orders for the product within the given date range.

Table Structure:

Assume you have the following Orders table:

```
CREATE TABLE Orders (
   order_id INT PRIMARY KEY,
   product_id INT,
```

```
    order_date DATE
);
```

Steps:

1. Create a stored procedure named CountProductOrders that:
    - Takes p_product_id (INT), p_start_date (DATE), and p_end_date (DATE) as IN parameters.
    - Initializes a counter to track the total number of orders for the product.
    - Uses a loop to iterate through each day in the date range, checking for each day if an order was placed for the product.
    - Returns the total number of orders.

Sample SQL Stored Procedure:

```
DELIMITER //

CREATE PROCEDURE CountProductOrders(
    IN p_product_id INT,          -- Input parameter for product ID
    IN p_start_date DATE,         -- Input parameter for the start date of the range
    IN p_end_date DATE,           -- Input parameter for the end date of the range
    OUT total_orders INT          -- Output parameter to return the total number of orders
)
BEGIN
    -- Declare variables
    DECLARE current_date DATE;       -- To store the current date in the loop
```

```
    DECLARE order_count INT DEFAULT 0;  -- To keep track of the number of orders for each day

    -- Initialize the total_orders variable
    SET total_orders = 0;

    -- Initialize the current date to the start date
    SET current_date = p_start_date;

    -- Loop through each day in the date range
    WHILE current_date <= p_end_date DO

        -- Count the number of orders for the given product on the current date
        SELECT COUNT(*)
        INTO order_count
        FROM Orders
        WHERE product_id = p_product_id
        AND order_date = current_date;

        -- Add the count to the total number of orders
        SET total_orders = total_orders + order_count;

        -- Move to the next day
        SET current_date = DATE_ADD(current_date, INTERVAL 1 DAY);

    END WHILE;
END //

DELIMITER ;



-- Declare a variable to store the total number of orders
```

```
SET @total_orders = 0;

-- Call the stored procedure
CALL CountProductOrders(101, '2024-10-01', '2024-10-04',
@total_orders);

-- Output the total number of orders
SELECT @total_orders AS TotalOrders;
```

Glossary

- ACID Properties: Set of principles (Atomicity, Consistency, Isolation, Durability) ensuring reliable transactions in a database.
- Application Layer: The middle tier in 3-tier architecture where application logic runs (e.g., Java, Python).
- Backup & Recovery: Mechanisms to restore data in case of failure or corruption.
- Big Data: Large and complex datasets characterized by Volume, Velocity, Variety, and Veracity.
- Clustered Storage: Storage method that groups related data physically close to improve performance.
- Concurrency Control: Ensures correct execution of transactions by multiple users at the same time.
- CREATE (DDL): SQL command to create a new object such as a table.
- Data Abstraction: Hiding complex storage details while presenting a user-friendly view of data.
- Data Definition Language (DDL): SQL language subset used to define or alter database schema (e.g., CREATE, ALTER).
- Data Independence: Ability to change storage structure without affecting applications.
- Data Manipulation Language (DML): SQL commands used to manage data in tables (e.g., SELECT, INSERT).
- Data Mining: Process of discovering patterns and knowledge from large datasets.
- Data Model: Framework for organizing data and defining relationships (e.g., Relational, ER, Object-Based).
- Data Warehouse: A central repository that stores historical data for analytical purposes.
- Database Administrator (DBA): Person responsible for database installation, security, tuning, and backups.
- Database Designer: Professional who defines the structure and schema of a database.
- Database Management System (DBMS): Software used to store, retrieve, and manage data in databases.

- Entity: An object or thing in the real world that is distinguishable from other objects (e.g., Student, Course).
- Entity-Relationship (ER) Model: Conceptual model used for database design showing entities, attributes, and relationships.
- Execution Plan: Optimized sequence of operations for executing a database query.
- Foreign Key: A key in one table that refers to the primary key in another table to establish relationships.
- FROM (SQL): Clause used to specify the table in a SQL query.
- GRANT (DCL): SQL command to give privileges to a user or role.
- GROUP BY: SQL clause used to group rows with the same values in specified columns.
- HAVING: Clause used to filter groups created by GROUP BY.
- Index: Database object that speeds up data retrieval operations.
- Instance: The current state or snapshot of the data in a database at a specific moment.
- INSERT (DML): SQL command used to add new records to a table.
- JOIN: SQL operation used to combine rows from two or more tables based on a related column.
- Logical Level: Middle level of data abstraction showing what data is stored and how it relates.
- LIKE: SQL operator used for pattern matching.
- MongoDB: A NoSQL database that stores data in JSON-like documents.
- MySQL: Popular open-source relational database management system.
- Normalization: Process of organizing data to reduce redundancy and improve integrity.
- NoSQL: Type of database that handles semi-structured or unstructured data (e.g., MongoDB, Couchbase).

- Object-Based Model: A data model that represents real-world entities as objects with attributes and methods.

- ORDER BY: SQL clause used to sort query results in ascending or descending order.
- Physical Level: The lowest level of data abstraction detailing how data is physically stored.
- Primary Key: A field (or combination of fields) that uniquely identifies each record in a table.
- PostgreSQL: Open-source object-relational database system.
- Query: A command used to retrieve or manipulate data from a database.
- Query Optimization: Process to enhance SQL query performance using indexes, execution plans, and rewriting.
- Relational Model: Data model that organizes data into tables with rows and columns.
- REVOKE (DCL): Removes access privileges from users or roles.
- ROLLBACK (TCL): Reverses changes made in a transaction since the last COMMIT.
- Schema: The overall design or blueprint of a database, including tables, attributes, and constraints.
- SELECT (DML): SQL command to retrieve data from a table.
- Semi-Structured Model: Data model used for loosely organized data like JSON or XML.
- System Analyst: User who connects system requirements with database implementation.
- TCL (Transaction Control Language): SQL subset to control transactions (e.g., COMMIT, ROLLBACK).
- TRUNCATE (DDL): Removes all records from a table while preserving its structure.
- Transaction: A sequence of database operations treated as a single logical unit.
- UPDATE (DML): SQL command to modify existing records in a table.
- User Roles: Defined set of permissions assigned to users to control database access.
- View Level: Highest level of abstraction, showing user-specific perspectives of data.

- WHERE Clause: SQL condition to filter query results.
- Weak Entity: An entity that cannot exist without a related strong entity and does not have a primary key.

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