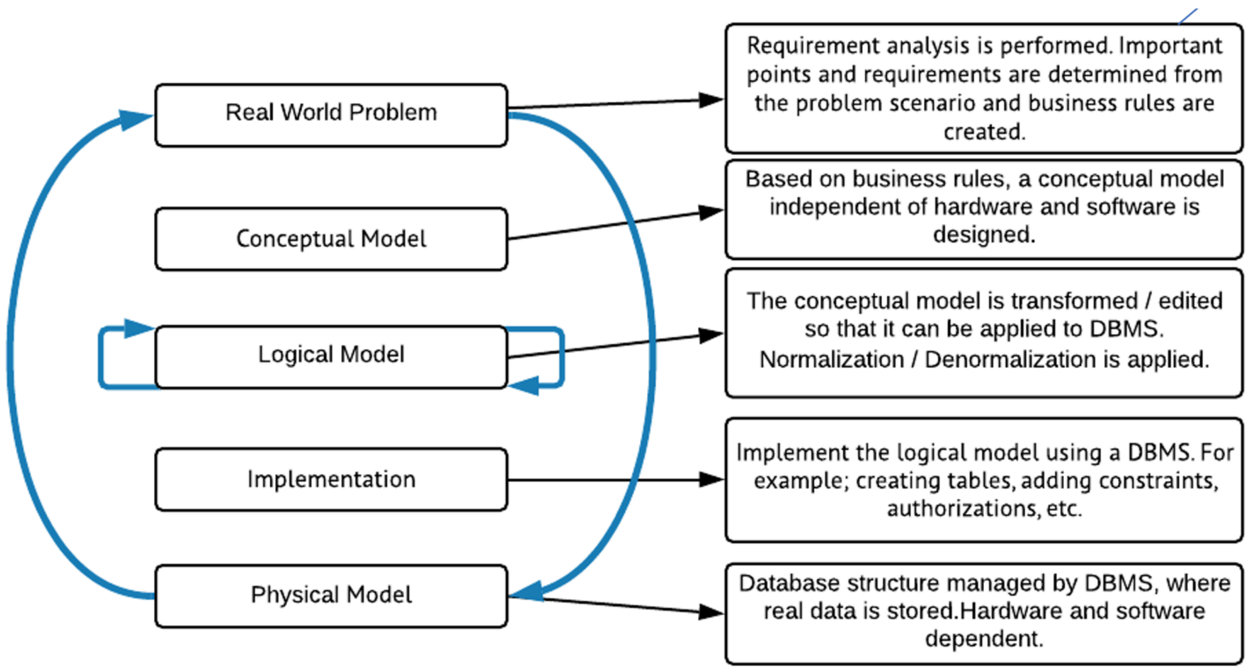
Module 3: Relational Database Model

Database Development Lifecycle

When developing databases, we need to adhere to the **Database Development Lifecycle.** It consists of several stages to build a well-structured database:



- **Requirements Analysis**: Understanding business needs and defining **business rules**.
- **Conceptual Design**: Designing high-level Entity-Relationship (ER) models.
- **Logical Design**: Transforming ER models into relational schemas.
- **Implementation**: Building and configuring the database using SQL

1. Fundamentals of the Relational Model

The relational model organizes data into tables (relations) consisting of rows (tuples) and columns (attributes).

- **Relation**: A table with rows and columns.
- **Tuple**: A single row in a table representing a record.
- **Attribute**: A column in a table representing a specific data field.
- **Domain**: The set of valid values for an attribute.

- **Relation Schema**: Describes the structure of a table, including the names and data types of attributes, PK, and FK .
  Product Table Relational Schema:
  Product
  ProductID: INT, **PRIMARY KEY**, Unique identifier for each product.
  ProductName: VARCHAR(255), **NOT NULL**, The name of the product.
  Price: DECIMAL(10, 2), **NOT NULL**, The cost of the product.
  StockQuantity: INT, **NOT NULL**, The number of products available in stock.

Why Relational Model?

- Simple and intuitive structure.
- Ensures data integrity and reduces redundancy.
- Supports powerful querying using SQL.

2. Table (Relation) Structure

- **Table Name**: Unique identifier for the table.
- **Columns**: Define the attributes (e.g., `StudentID`, `Name`, `Age`).
- **Rows**: Represent individual records.

- **Product** Table

ProductID (PK)	ProductName	Price	StockQuantity
1	SSD 512GB	60	120
2	16GB DDR4 RAM	75	150
3	Intel i7 CPU	300	80
4	1TB HDD	50	200
5	750W PSU	85	100

- **ProductID (Primary Key)**: A unique identifier for each product.
- **ProductName**: The name of the product.
- **Price**: The cost of the product.
- **StockQuantity**: The number of products available in stock.

3. Integrity Rules (Constraints)

Integrity rules help maintain data accuracy and consistency.

- **Primary Key (PK)**:
  - Uniquely identifies each row in a table.
  - Cannot be **NULL**.
  - Examples: ProductId in the Product table, StudentID in the Students table.
- **Foreign Key (FK)**:
  - Establishes a relationship between two tables.
  - Ensures referential integrity.
- **Unique Constraint**:
  - Ensures all values in a column are unique.
  - Example: Email in the Users table.
- **Not Null Constraint**:
  - Ensures a column cannot have NULL values.
  - Example: Name in the Course table.

Referential Integrity and FK

Category Table

CategoryID (PK)	CategoryName
1	Storage Devices
2	Memory
3	Processors
4	Power Supplies

Products Table

ProductID (PK)	ProductName	Price	StockQuantity	CategoryID (FK)
1	SSD 512GB	60	120	1
2	16GB DDR4 RAM	75	150	2
3	Intel i7 CPU	300	80	3
4	1TB HDD	50	200	1
5	750W PSU	85	100	4

- **Referential Integrity** ensures that the relationship between tables remains consistent.
- **CategoryID** in the **Products** table is a **Foreign Key** that refers to **CategoryID** in the **Category** table.
    - This means every value in the **Products.CategoryID** column must exist in the **Category.CategoryID** column. It can also be **NULL**.
    - For example, the product **SSD 512GB** has a CategoryID = 1, which corresponds to **Storage Devices** in the **Category** table.

What Happens Without Referential Integrity?

1. **Inserting Invalid Data**: If you try to add a product with `CategoryID = 5`, it will fail because `CategoryID = 5` doesn't exist in the **Category** table.
2. **Deleting a Category**: If you delete the **Storage Devices** category, the database will prevent it because products like **SSD 512GB** and **1TB HDD** depend on that category.

Best Practices:

When designing databases, always use foreign keys to enforce referential integrity.

This prevents orphaned records and ensures the data remains **reliable** and **consistent**.

4. Best Practices for Primary Keys

- Use **surrogate keys** (e.g., auto-incremented integers like **id**) instead of natural keys (e.g., SSN, StudentNumber,etc.).
- Keep primary keys **compact** and **simple** to increase database performance(search and constraint enforcement). Prefer **integer** types.
    - For example; Instead of using a string-based primary key like `ProductCode = "SSD512GB"`, use a compact integer key: `ProductID = 1`. This makes operations more efficient and scalable.
- Avoid using meaningful data (e.g., names) as primary keys.
- Ensure primary keys are **immutable** (do not change over time).
- Avoid using **business data** (e.g., SSNs) as primary keys to ensure data privacy.

5. Indexes and Their Importance

Index in a table is a data structure that **improves the speed of data retrieval operations** on a database table. Indexes can speed up SELECT queries and improve performance for complex queries involving joins or WHERE clauses, but this is not always the case.

Indexes can result in **slower INSERT, UPDATE, and DELETE operations** due to the need for index maintenance..

Student Table

RowNumber	StudentID (PK)	FirstName	LastName	Age	Major
1	1	John	Doe	20	Computer Sci
2	2	Jane	Smith	21	Business
3	3	John	Doe	22	Engineering
4	4	Alice	Brown	19	Mathematics
5	5	John	Doe	23	Physics
6	6	Jane	Smith	24	Economics

Index Table for FirstName (with Unique First Names and Row Numbers)

FirstName	Location
John	1, 3, 5
Jane	2, 6
Alice	4

An **index scan** is a process where the database uses an **index** to quickly locate data in a table without having to scan the entire table. It is especially useful for speeding up query performance, especially when searching for specific values or ranges in indexed columns.

A **non-index scan**, often referred to as a **sequential scan**, is a process where the database scans **all rows in a table** to satisfy a query, rather than using an index to directly locate specific rows. In a **sequential scan**, the database reads the entire **table** row by row and checks each row to see if it matches the query conditions.

Types of Indexes:

1. Primary Index

- Constructed automatically for the **Primary Key**.
- Ensures **unique and non-null** values for the primary key column.
- Example: **`ProductID`** in a **Products** table.

2. Unique Index

- Ensures that all values in the indexed column are **unique**.
- Unlike the primary index, it allows **one NULL value** (depending on the database).
- It can be applied to any column to enforce uniqueness without making it a primary key.
- **Use Case:** Email addresses in a **Users** table, where each email must be unique.

3. Secondary Index (Non-unique Index)

- An additional index defined on non-primary key columns to improve query performance.
- It allows **duplicate values**.
- **Use Case:** Defining an index on the ProductName column in the Products table to speed up searches by product name.

4. Full-text Index (full text search)

- Specialized index for searching text data efficiently (supported in databases like PostgreSQL, MySQL, etc.).
- **Use Case:** Searching keywords in a **blog posts** table.
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- **Benefits**:
    - Faster **SELECT** queries.
    - Improved performance for complex queries involving joins or WHERE clauses.

6. System Catalog and Metadata

- **System Catalog**: A collection of tables that store metadata (data about data). It provides information about database objects like tables, views, indexes, and users.
- Managed by the Database Management System.
- Metadata (tables, table fields, field types, value ranges, keys, indexes, relationships, constraints, etc.) for all databases are stored here.
- It is queryable by the user.

Hands-on Exercise 1: E-Commerce System – Business Rules to ER Model with Crow's Foot Notation to Relational Model

Objective

In this exercise, you will practice database modeling by converting business rules into an Entity-Relationship (ER) model using Crow's Foot notation, and then constructing a relational model.

Task 1: Analyze Business Rules

Below are several business rules describing the structure of an e-commerce database. Carefully analyze them and identify the necessary entities, attributes, and relationships:

1. A **customer** can place **many orders**, but each order is placed by **one customer**.
2. Each **customer** has a **unique customer ID**, **name**, **email**, **phone number**, and **shipping address**.
3. An **order** has a **unique order ID**, an **order date**, a **total amount**, and a **status** (e.g., pending, shipped, delivered).
4. An **order** can contain **multiple products**, and a **product** can be part of multiple orders. The quantity of each product in an order must be recorded.
5. Each **product** has a **unique product ID**, **name**, **description**, **price**, and **stock quantity**.
6. A **product** belongs to **one or more categories**, and each **category** can have multiple products.
7. The system tracks **payments** made by customers. A **payment** is associated with **one order**, and an order can have **only one payment**.
8. Each **payment** has a **unique payment ID**, **payment date**, **amount paid**, and **payment method** (e.g., credit card, PayPal).
9. Customers can leave **reviews** for products. A **review** belongs to **one customer** and **one product**.
10. Each **review** has a **review ID**, a **rating** (1 to 5), **review text**, and a **date**.

Task 2: Convert Business Rules into an ER Model

Using Crow's Foot notation, design an ER model that represents the above business rules. Your model should include:

- Entities and their attributes
- Relationships between entities
- Relationship types (cardinalities) (one-to-one, one-to-many, many-to-many)

Task 3: Transform the ER Model into a Relational Model and obtain the relational schema.

Additional Challenges (Optional)

These tasks are for students to implement at home:

- Investigate and propose potential index definitions for the fields of the table.