Introduction

Data is nothing but facts and statistics stored or free flowing over a network, generally it's raw and unprocessed. For example: When you visit any website, they might store you IP address, that is data, in return they might add a cookie in your browser, marking you that you visited the website, that is data, your name, it's data, your age, it's data.

Data becomes **information** when it is processed, turning it into something meaningful. Like, based on the cookie data saved on user's browser, if a website can analyse that generally men of age 20-25 visit us more, that is information, derived from the data collected.

A **Database** is a collection of related data organised in a way that data can be easily accessed, managed and updated. Database can be software based or hardware based, with one sole purpose, storing data.

During early computer days, data was collected and stored on tapes, which were mostly write-only, which means once data is stored on it, it can never be read again. They were slow and bulky, and soon computer scientists realised that they needed a better solution to this problem.

Larry Ellison, the co-founder of **Oracle** was amongst the first few, who realised the need for a software based Database Management System.

DBMS

A **DBMS** is a software that allows creation, definition and manipulation of database, allowing users to store, process and analyse data easily. DBMS provides us with an interface or a tool, to perform various operations like creating database, storing data in it, updating data, creating tables in the database and a lot more.

DBMS also provides protection and security to the databases. It also maintains data consistency in case of multiple users.

Here are some examples of popular DBMS used these days:

- MySql
- Oracle
- SQL Server
- IBM DB2
- PostgreSQL
- Amazon SimpleDB (cloud based) etc.

Characteristics of Database Management System

A database management system has following characteristics:

1. **Data stored into Tables:** Data is never directly stored into the database. Data is stored into tables, created inside the database. DBMS also allows to have relationships between tables which makes the data more meaningful and connected. You can easily understand what type of data is stored where by looking at all the tables created in a database.
2. **Reduced Redundancy:** In the modern world hard drives are very cheap, but earlier when hard drives were too expensive, unnecessary repetition of data in database was a big problem. But DBMS follows **Normalisation** which divides the data in such a way that repetition is minimum.
3. **Data Consistency:** On Live data, i.e. data that is being continuosly updated and added, maintaining the consistency of data can become a challenge. But DBMS handles it all by itself.
4. **Support Multiple user and Concurrent Access:** DBMS allows multiple users to work on it(update, insert, delete data) at the same time and still manages to maintain the data consistency.
5. **Query Language:** DBMS provides users with a simple Query language, using which data can be easily fetched, inserted, deleted and updated in a database.
6. **Security:** The DBMS also takes care of the security of data, protecting the data from un-authorised access. In a typical DBMS, we can create user accounts with different access permissions, using which we can easily secure our data by restricting user access.
7. DBMS supports **transactions**, which allows us to better handle and manage data integrity in real world applications where multi-threading is extensively used.

Advantages of DBMS

- Segregation of applicaion program.
- Minimal data duplicacy or data redundancy.
- Easy retrieval of data using the Query Language.
- Reduced development time and maintainance need.
- With Cloud Datacenters, we now have Database Management Systems capable of storing almost infinite data.
- Seamless integration into the application programming languages which makes it very easier to add a database to almost any application or website.

Disadvantages of DBMS

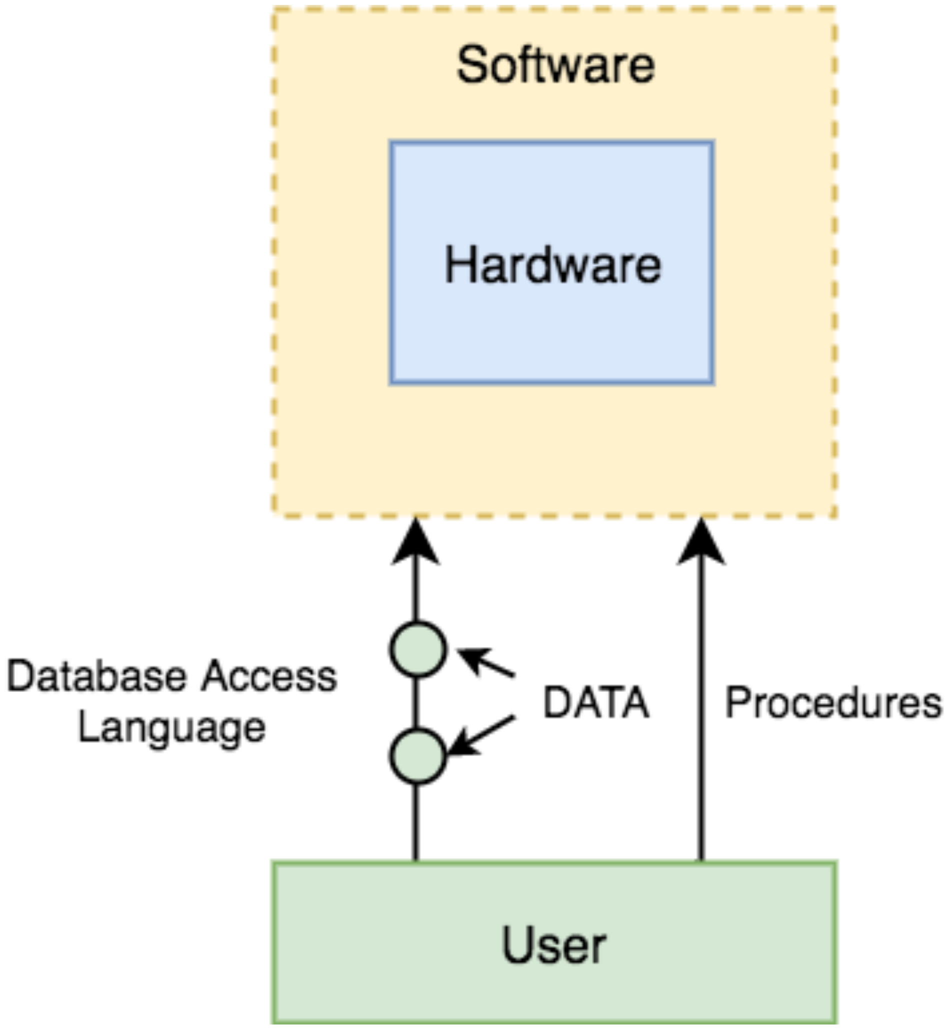
- It's Complexity
- Except MySQL, which is open source, licensed DBMSs are generally costly.
- They are large in size.

Components of DBMS

The database management system can be divided into five major components, they are:

1. Hardware
2. Software
3. Data
4. Procedures
5. Database Access Language

Let's have a simple diagram to see how they all fit together to form a database management system.



DBMS Components: Hardware

When we say Hardware, we mean computer, hard disks, I/O channels for data, and any other physical component involved before any data is successfully stored into the memory.

When we run Oracle or MySQL on our personal computer, then our computer's Hard Disk, our Keyboard using which we type in all the commands, our computer's RAM, ROM all become a part of the DBMS hardware.

DBMS Components: Software

This is the main component, as this is the program which controls everything. The DBMS software is more like a wrapper around the physical database, which provides us with an easy-to-use interface to store, access and update data.

The DBMS software is capable of understanding the Database Access Language and intrepret it into actual database commands to execute them on the DB.

DBMS Components: Data

Data is that resource, for which DBMS was designed. The motive behind the creation of DBMS was to store and utilise data.

In a typical Database, the user saved Data is present and **meta data** is stored.

Metadata is data about the data. This is information stored by the DBMS to better understand the data stored in it.

For example: When I store my **Name** in a database, the DBMS will store when the name was stored in the database, what is the size of the name, is it stored as related data to some other data, or is it independent, all this information is metadata.

DBMS Components: Procedures

Procedures refer to general instructions to use a database management system. This includes procedures to setup and install a DBMS, To login and logout of DBMS software, to manage databases, to take backups, generating reports etc.

DBMS Components: Database Access Language

Database Access Language is a simple language designed to write commands to access, insert, update and delete data stored in any database.

A user can write commands in the Database Access Language and submit it to the DBMS for execution, which is then translated and executed by the DBMS.

User can create new databases, tables, insert data, fetch stored data, update data and delete the data using the access language.

Users

- **Database Administrators:** Database Administrator or DBA is the one who manages the complete database management system. DBA takes care of the security of the DBMS, it's availability, managing the license keys, managing user accounts and access etc.
- **Application Programmer or Software Developer:** This user group is involved in developing and desiging the parts of DBMS.
- **End User:** These days all the modern applications, web or mobile, store user data. How do you think they do it? Yes, applications are programmed in such a way that they collect user data and store the data on DBMS systems running on their server. End users are the one who store, retrieve, update and delete data.

DBMS Architecture

A Database Management system is not always directly available for users and applications to access and store data in it. A Database Management system can be **centralised**(all the data stored at one location), **decentralised**(multiple copies of database at different locations) or **hierarchical**, depending upon its architecture.

1-tier DBMS architecture also exist, this is when the database is directly available to the user for using it to store data. Generally such a setup is used for local application development, where programmers communicate directly with the database for quick response.

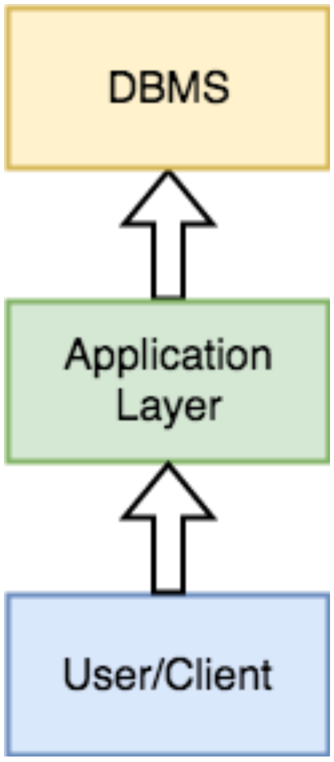
Database Architecture is logically of two types:

1. 2-tier DBMS architecture
2. 3-tier DBMS architecture

2-tier DBMS Architecture

2-tier DBMS architecture includes an **Application layer** between the user and the DBMS, which is responsible to communicate the user's request to the database management system and then send the response from the DBMS to the user.

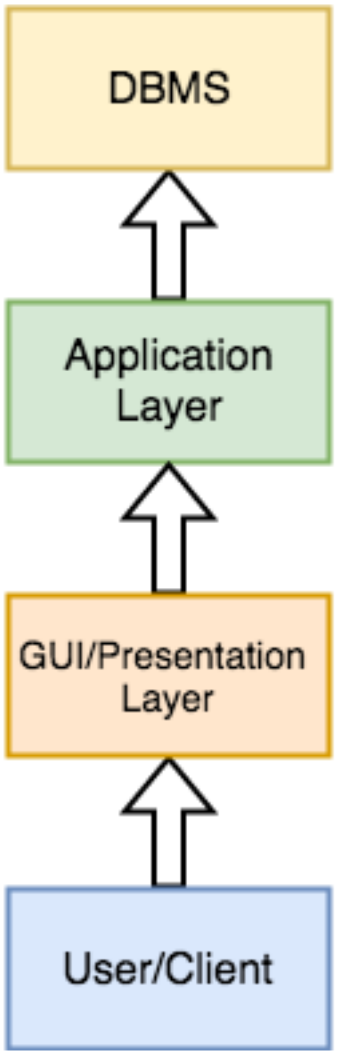
An application interface known as **ODBC**(Open Database Connectivity) provides an API that allow client side program to call the DBMS. Most DBMS vendors provide ODBC drivers for their DBMS.



Such an architecture provides the DBMS extra security as it is not exposed to the End User directly. Also, security can be improved by adding security and authentication checks in the Application layer too.

3-tier DBMS Architecture

3-tier DBMS architecture is the most commonly used architecture for web applications.



It is an extension of the 2-tier architecture. In the 2-tier architecture, we have an application layer which can be accessed programatically to perform various operations on the DBMS. The application generally understands the Database Access Language and processes end users requests to the DBMS.

In 3-tier architecture, an additional Presentation or GUI Layer is added, which provides a graphical user interface for the End user to interact with the DBMS.

For the end user, the GUI layer is the Database System, and the end user has no idea about the application layer and the DBMS system.

If you have used **MySQL**, then you must have seen **PHPMyAdmin**, it is the best example of a 3-tier DBMS architecture.

DBMS Database Models

A Database model defines the logical design and structure of a database and defines how data will be stored, accessed and updated in a database management system. While the **Relational Model** is the most widely used database model, there are other models too:

- Hierarchical Model
- Network Model
- Entity-relationship Model
- Relational Model

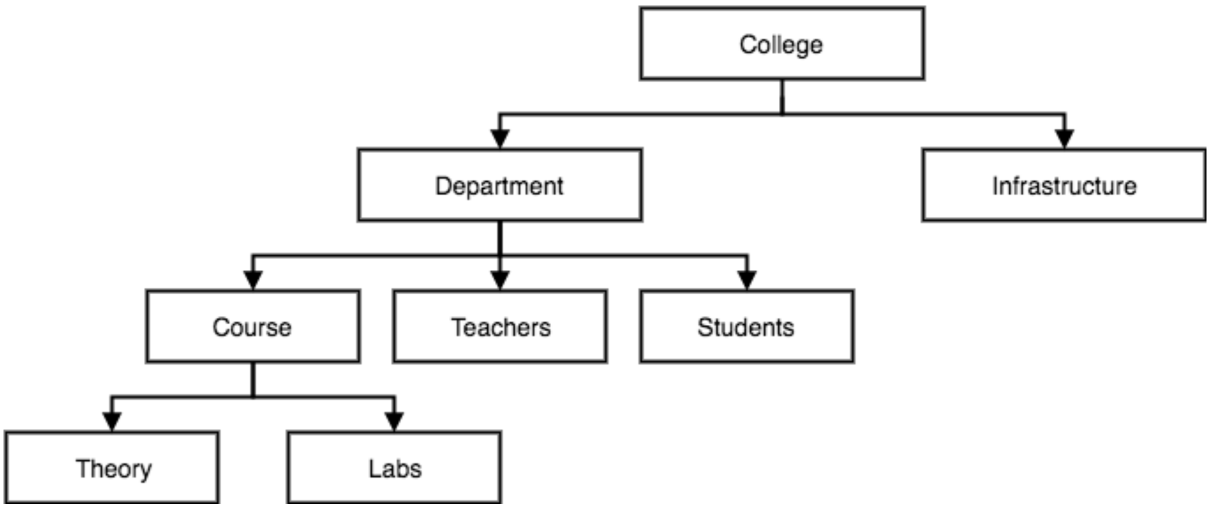
Hierarchical Model

This database model organises data into a tree-like-structure, with a single root, to which all the other data is linked. The heirarchy starts from the **Root** data, and expands like a tree, adding child nodes to the parent nodes.

In this model, a child node will only have a single parent node.

This model efficiently describes many real-world relationships like index of a book, recipes etc.

In hierarchical model, data is organised into tree-like structure with one one-to-many relationship between two different types of data, for example, one department can have many courses, many professors and of-course many students.

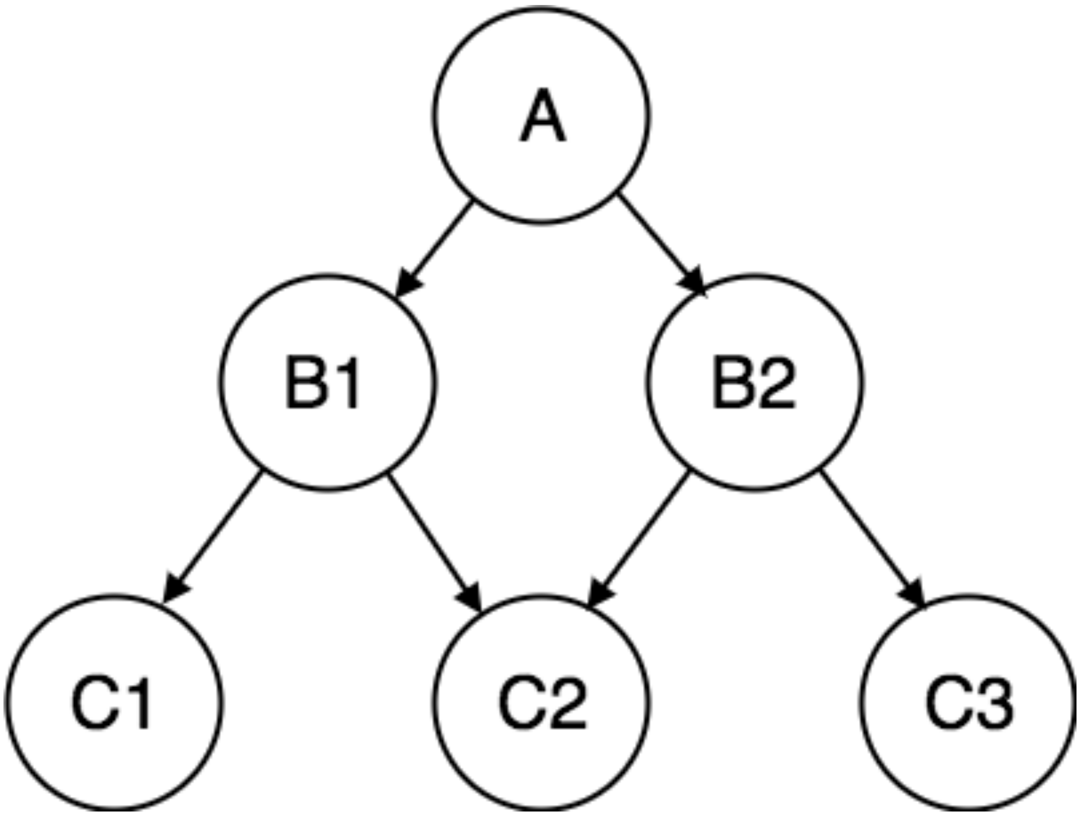


Network Model

This is an extension of the Hierarchical model. In this model data is organised more like a graph, and are allowed to have more than one parent node.

In this database model data is more related as more relationships are established in this database model. Also, as the data is more related, hence accessing the data is also easier and fast. This database model was used to map many-to-many data relationships.

This was the most widely used database model, before Relational Model was introduced.



Entity-relationship Model

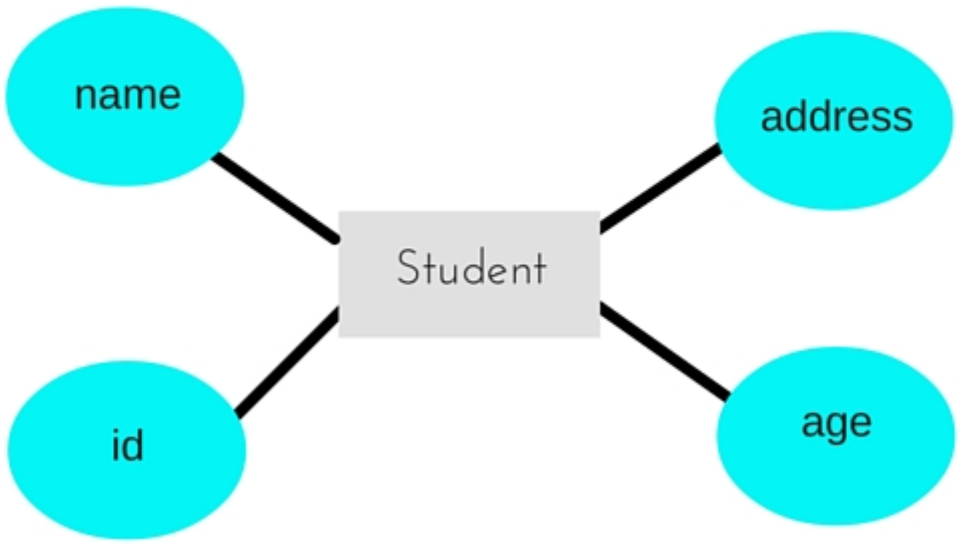
In this database model, relationships are created by dividing object of interest into entity and its characteristics into attributes.

Different entities are related using relationships.

E-R Models are defined to represent the relationships into pictorial form to make it easier for different stakeholders to understand.

This model is good to design a database, which can then be turned into tables in relational model(explained below).

Let's take an example, If we have to design a School Database, then **Student** will be an **entity** with **attributes** name, age, address etc. As **Address** is generally complex, it can be another **entity** with **attributes** street name, pincode, city etc, and there will be a relationship between them.



Relational Model

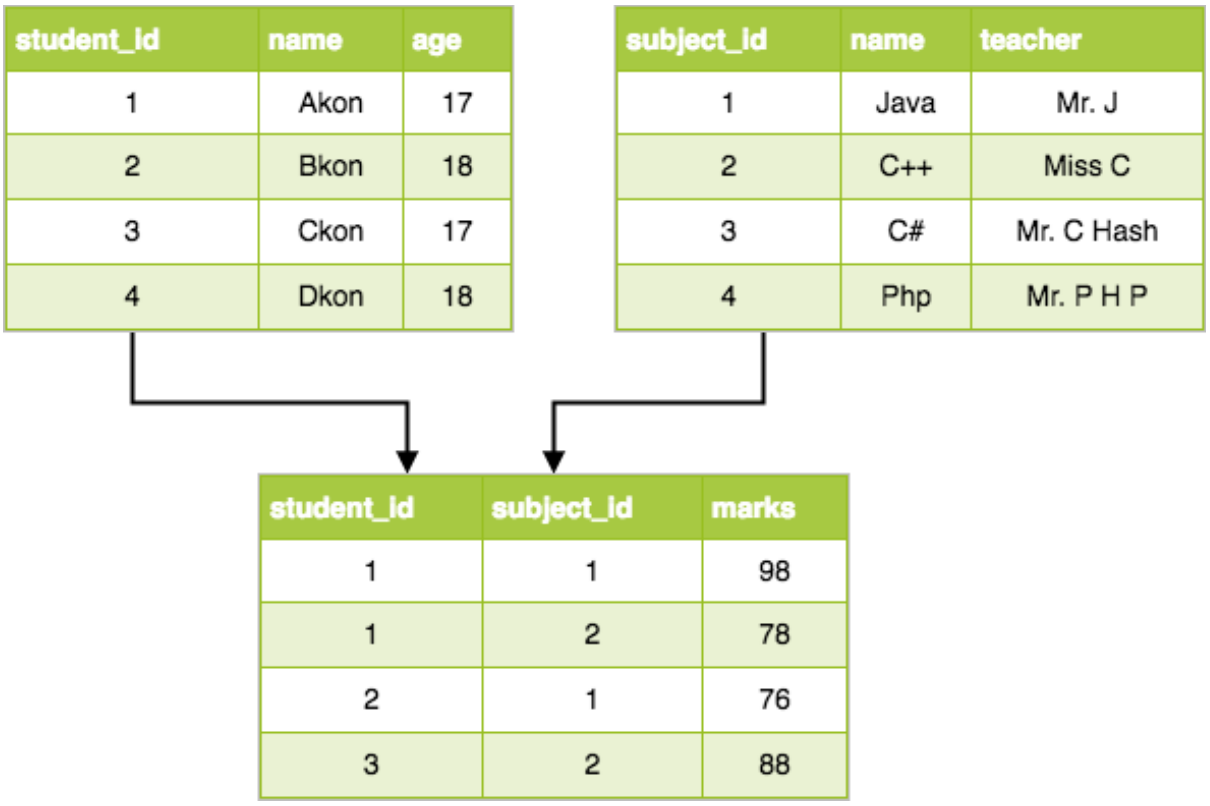
In this model, data is organised in two-dimensional **tables** and the relationship is maintained by storing a common field.

This model was introduced by E.F Codd in 1970, and since then it has been the most widely used database model, infact, we can say the only database model used around the world.

The basic structure of data in the relational model is tables. All the information related to a particular type is stored in rows of that table.

Hence, tables are also known as **relations** in relational model.

In the coming tutorials we will learn how to design tables, normalize them to reduce data redundancy and how to use Structured Query language to access data from tables.



student_Id	name	age
1	Akon	17
2	Bkon	18
3	Ckon	17
4	Dkon	18

subject_Id	name	teacher
1	Java	Mr. J
2	C++	Miss C
3	C#	Mr. C Hash
4	Php	Mr. P H P

student_Id	subject_Id	marks
1	1	98
1	2	78
2	1	76
3	2	88

Basic Concepts of ER Model in DBMS

As we described in the tutorial Database models, Entity-relationship model is a model used for design and representation of relationships between data.

The main data objects are termed as Entities, with their details defined as attributes, some of these attributes are important and are used to identity the entity, and different entities are related using relationships.

In short, to understand about the ER Model, we must understand about:

- Entity and Entity Set
- What are Attributes? And Types of Attributes.
- Keys
- Relationships

ER Model: Entity and Entity Set

Considering the above example, **Student** is an entity, **Teacher** is an entity, similarly, **Class**, **Subject**etc are also entities.

An Entity is generally a real-world object which has characteristics and holds relationships in a DBMS.

If a Student is an Entity, then the complete dataset of all the students will be the **Entity Set**

Let's take an example to explain everything. For a **School Management Software**, we will have to store **Student** information, **Teacher** information, **Classes**, **Subjects** taught in each class etc.

ER Model: Attributes

If a Student is an Entity, then student's **roll no.**, student's **name**, student's **age**, student's **gender** etc will be its attributes.

An attribute can be of many types, here are different types of attributes defined in ER database model:

1. **Simple attribute:** The attributes with values that are atomic and cannot be broken down further are simple attributes. For example, student's **age**.
2. **Composite attribute:** A composite attribute is made up of more than one simple attribute. For example, student's **address** will contain, **house no.**, **street name**, **pincode** etc.
3. **Derived attribute:** These are the attributes which are not present in the whole database management system, but are derived using other attributes. For example, *average age of students in a class*.
4. **Single-valued attribute:** As the name suggests, they have a single value.
5. **Multi-valued attribute:** And, they can have multiple values.

ER Model: Keys

If the attribute **roll no.** can uniquely identify a student entity, amongst all the students, then the attribute **roll no.** will be said to be a key.

Following are the types of Keys:

1. Super Key
2. Candidate Key
3. Primary Key

ER Model: Relationships

When an Entity is related to another Entity, they are said to have a relationship. For example, A **Class**Entity is related to **Student** entity, becasue students study in classes, hence this is a relationship.

Depending upon the number of entities involved, a **degree** is assigned to relationships.

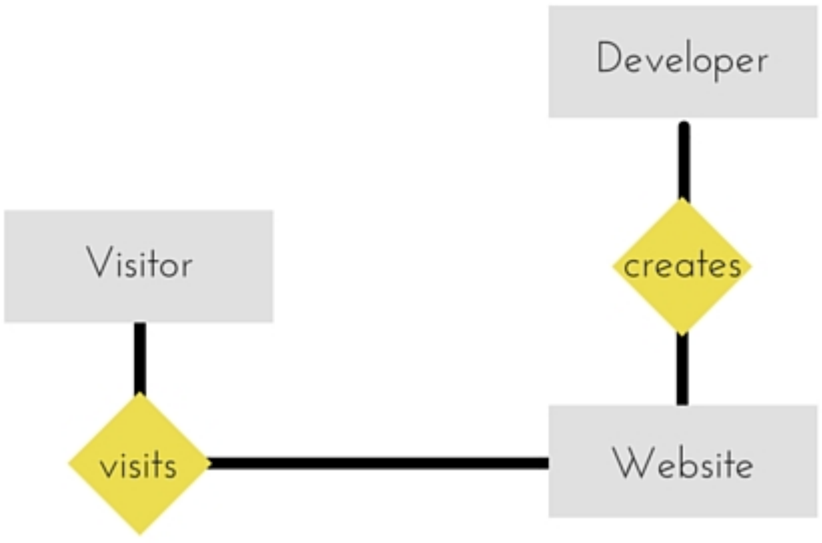
For example, if 2 entities are involved, it is said to be **Binary relationship**, if 3 entities are involved, it is said to be **Ternary** relationship, and so on.

In the next tutorial, we will learn how to create ER diagrams and design databases using ER diagrams.

Working with ER Diagrams

ER Diagram is a visual representation of data that describes how data is related to each other. In ER Model, we disintegrate data into entities, attributes and setup relationships between entities, all this can be represented visually using the ER diagram.

For example, in the below diagram, anyone can see and understand what the diagram wants to convey: *Developer develops a website, whereas a Visitor visits a website*.



Components of ER Diagram

Entitiy, Attributes, Relationships etc form the components of ER Diagram and there are defined symbols and shapes to represent each one of them.

Let's see how we can represent these in our ER Diagram.

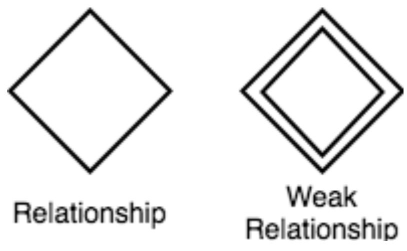
Entity

Simple rectangular box represents an Entity.

Student
Subject

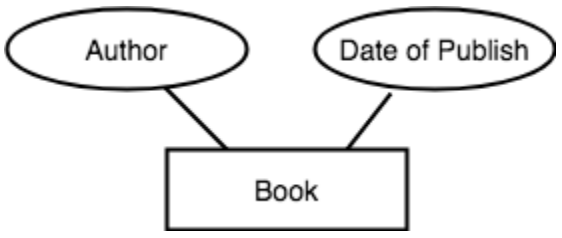
Relationships between Entities - Weak and Strong

Rhombus is used to setup relationships between two or more entities.



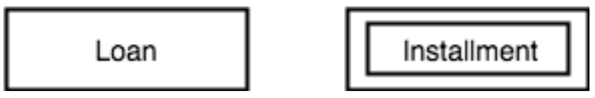
Attributes for any Entity

Ellipse is used to represent attributes of any entity. It is connected to the entity.



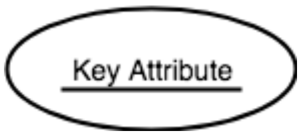
Weak Entity

A weak Entity is represented using double rectangular boxes. It is generally connected to another entity.



Key Attribute for any Entity

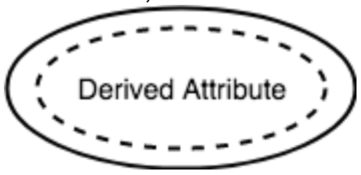
To represent a Key attribute, the attribute name inside the Ellipse is underlined.



Derived Attribute for any Entity

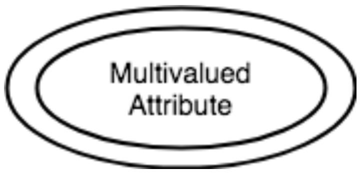
Derived attributes are those which are derived based on other attributes, for example, age can be derived from date of birth.

To represent a derived attribute, another dotted ellipse is created inside the main ellipse.



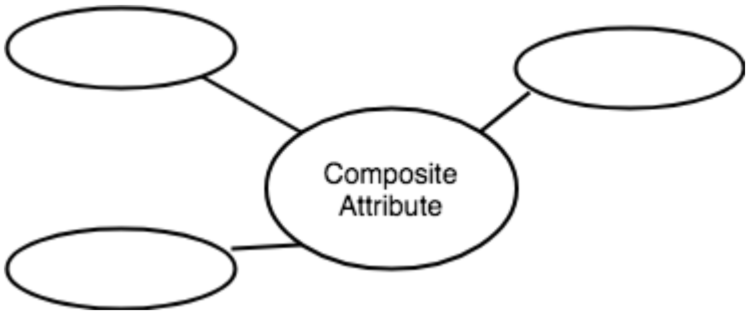
Multivalued Attribute for any Entity

Double Ellipse, one inside another, represents the attribute which can have multiple values.



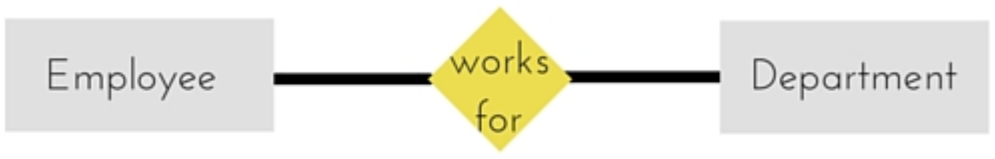
Composite Attribute for any Entity

A composite attribute is the attribute, which also has attributes.



ER Diagram: Entity

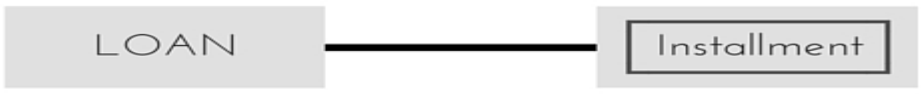
An **Entity** can be any object, place, person or class. In ER Diagram, an **entity** is represented using rectangles. Consider an example of an Organisation- Employee, Manager, Department, Product and many more can be taken as entities in an Organisation.



The yellow rhombus in between represents a relationship.

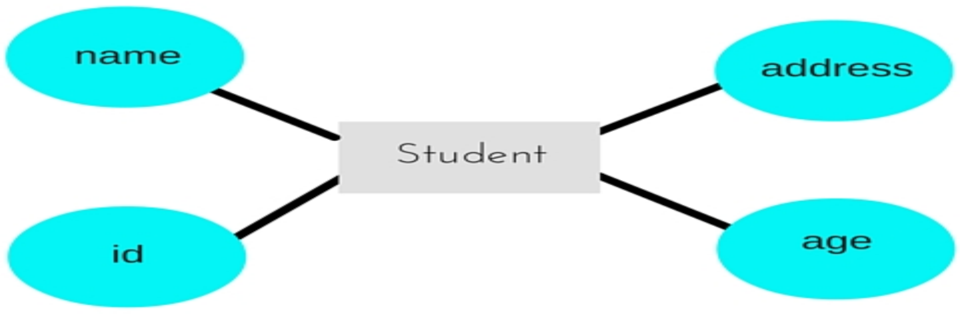
ER Diagram: Weak Entity

Weak entity is an entity that depends on another entity. Weak entity doesn't have anay key attribute of its own. Double rectangle is used to represent a weak entity.



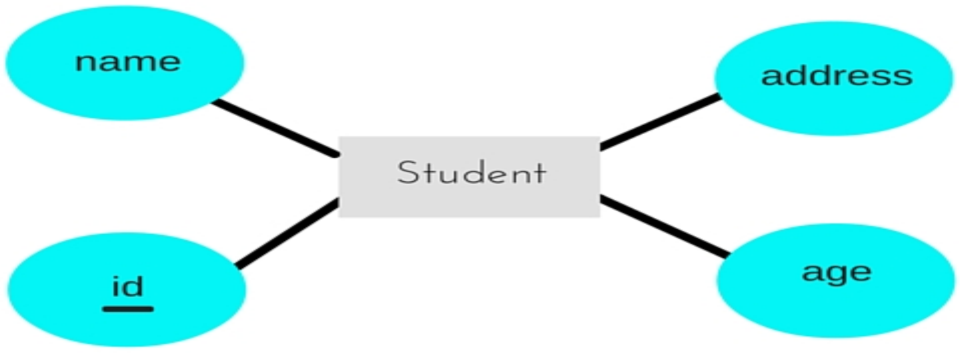
ER Diagram: Attribute

An **Attribute** describes a property or characterstic of an entity. For example, **Name**, **Age**, **Address** etc can be attributes of a **Student**. An attribute is represented using eclipse.



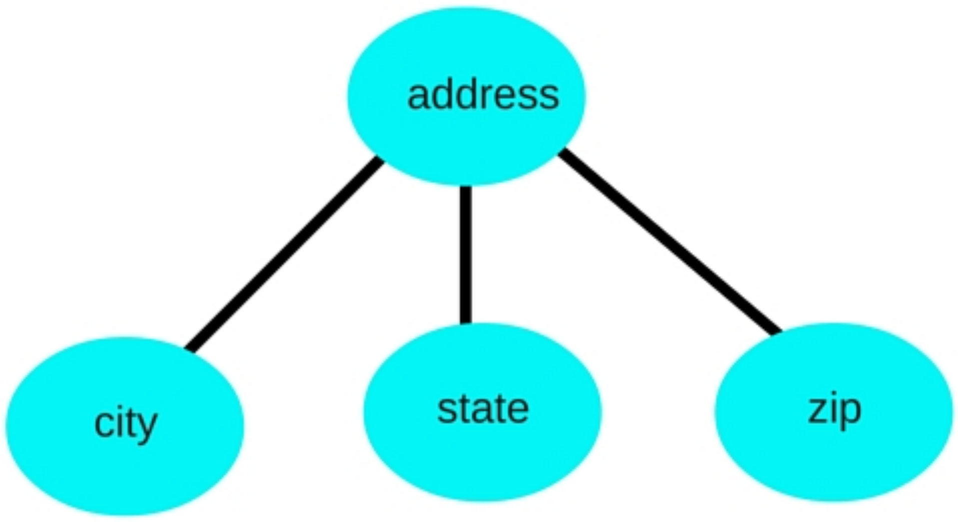
ER Diagram: Key Attribute

Key attribute represents the main characterstic of an Entity. It is used to represent a Primary key. Ellipse with the text underlined, represents Key Attribute.



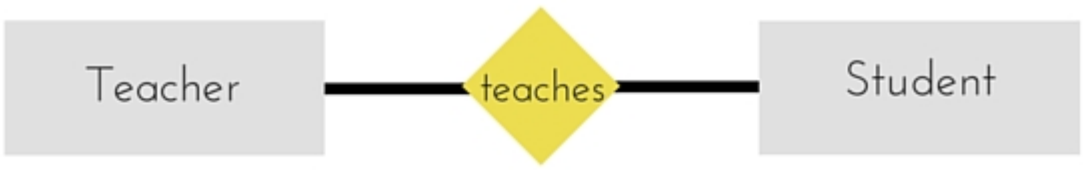
ER Diagram: Composite Attribute

An attribute can also have their own attributes. These attributes are known as **Composite** attributes.



ER Diagram: Relationship

A Relationship describes relation between **entities**. Relationship is represented using diamonds or rhombus.



There are three types of relationship that exist between Entities.

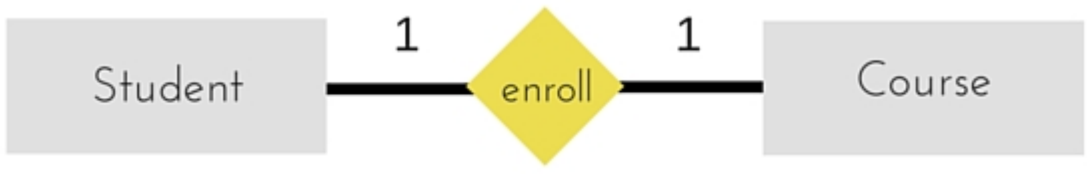
1. Binary Relationship
2. Recursive Relationship
3. Ternary Relationship

ER Diagram: Binary Relationship

Binary Relationship means relation between two Entities. This is further divided into three types.

One to One Relationship

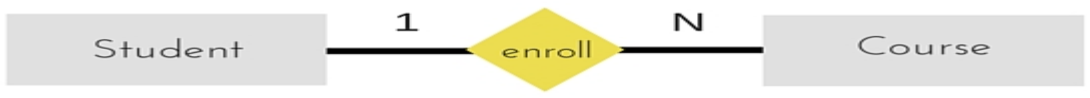
This type of relationship is rarely seen in real world.



The above example describes that one student can enroll only for one course and a course will also have only one Student. This is not what you will usually see in real-world relationships.

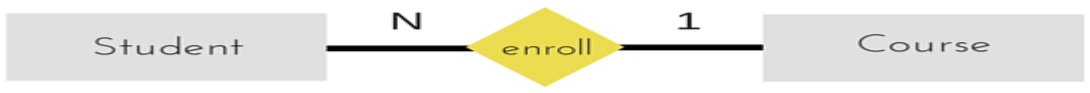
One to Many Relationship

The below example showcases this relationship, which means that 1 student can opt for many courses, but a course can only have 1 student. Sounds weird! This is how it is.

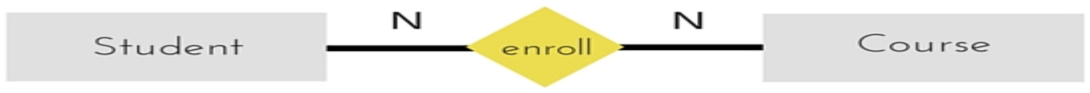


Many to One Relationship

It reflects business rule that many entities can be associated with just one entity. For example, Student enrolls for only one Course but a Course can have many Students.



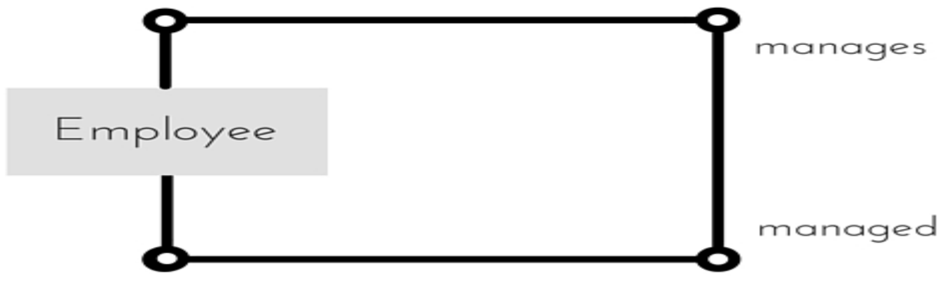
Many to Many Relationship



The above diagram represents that one student can enroll for more than one courses. And a course can have more than 1 student enrolled in it.

ER Diagram: Recursive Relationship

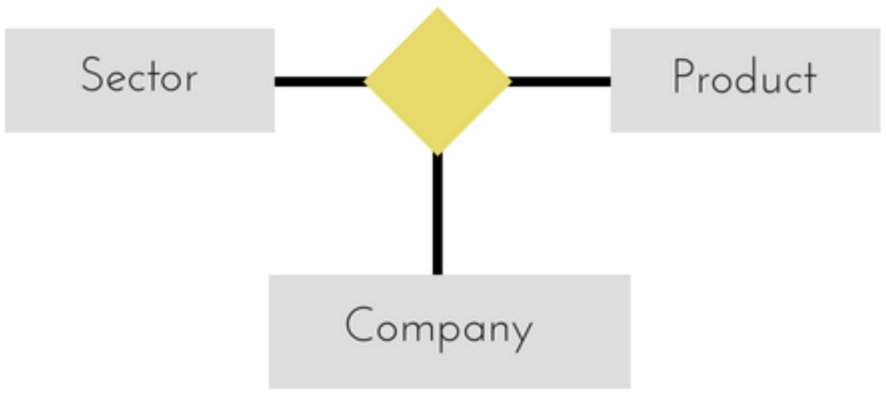
When an Entity is related with itself it is known as **Recursive** Relationship.



ER Diagram: Ternary Relationship

Relationship of degree three is called Ternary relationship.

A Ternary relationship involves three entities. In such relationships we always consider two entites together and then look upon the third.



- The above relationship involves 3 entities.
- Company operates in Sector, producing some Products.

For example, in the diagram above, we have three related entities, **Company**, **Product** and **Sector**. To understand the relationship better or to define rules around the model, we should relate two entities and then derive the third one.

A **Company** produces many **Products**/ each product is produced by exactly one company.

A **Company** operates in only one **Sector** / each sector has many companies operating in it.

Considering the above two rules or relationships, we see that although the complete relationship involves three entities, but we are looking at two entities at a time.

The Enhanced ER Model

As the complexity of data increased in the late 1980s, it became more and more difficult to use the traditional ER Model for database modelling. Hence some improvements or enhancements were made to the existing ER Model to make it able to handle the complex applications better.

Hence, as part of the **Enhanced ER Model**, along with other improvements, three new concepts were added to the existing ER Model, they were:

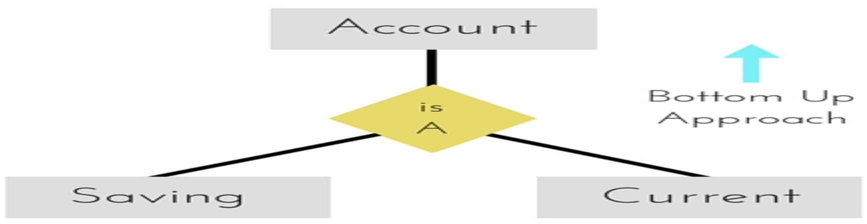
1. Generalization
2. Specialization
3. Aggregration

Let's understand what they are, and why were they added to the existing ER Model.

Generalization

Generalization is a bottom-up approach in which two lower level entities combine to form a higher level entity. In generalization, the higher level entity can also combine with other lower level entities to make further higher level entity.

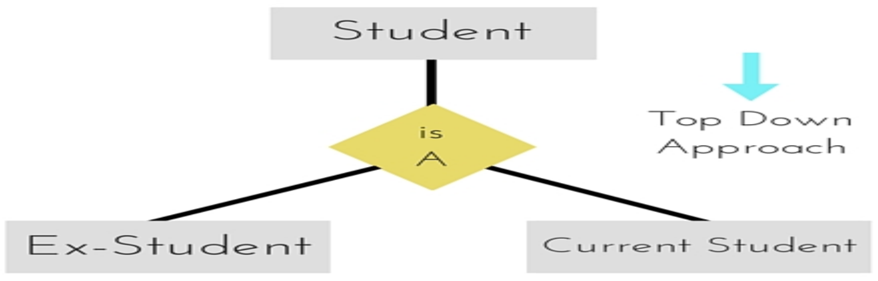
It's more like Superclass and Subclass system, but the only difference is the approach, which is bottom-up. Hence, entities are combined to form a more generalised entity, in other words, sub-classes are combined to form a super-class.



For example, **Saving** and **Current** account types entities can be generalised and an entity with name **Account** can be created, which covers both.

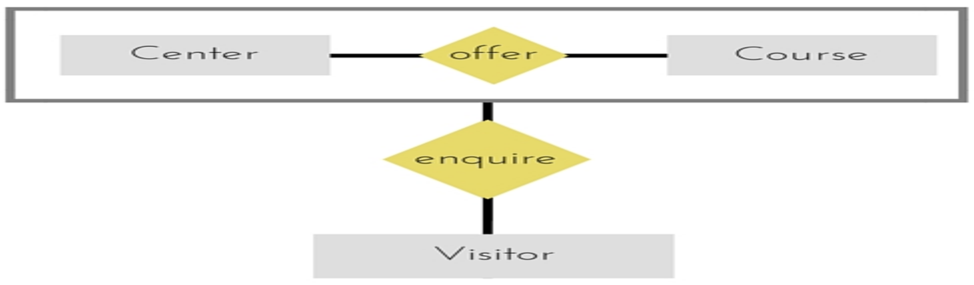
Specialization

Specialization is opposite to Generalization. It is a top-down approach in which one higher level entity can be broken down into two lower level entity. In specialization, a higher level entity may not have any lower-level entity sets, it's possible.



Aggregration

Aggregration is a process when relation between two entities is treated as a **single entity**.



In the diagram above, the relationship between **Center** and **Course** together, is acting as an Entity, which is in relationship with another entity **Visitor**. Now in real world, if a Visitor or a Student visits a Coaching Center, he/she will never enquire about the center only or just about the course, rather he/she will ask enquire about both.

Codd's Rule for Relational DBMS

E.F Codd was a Computer Scientist who invented the **Relational model** for Database management. Based on relational model, the **Relational database** was created. Codd proposed 13 rules popularly known as **Codd's 12 rules** to test DBMS's concept against his relational model. Codd's rule actualy define what quality a DBMS requires in order to become a Relational Database Management System(RDBMS). Till now, there is hardly any commercial product that follows all the 13 Codd's rules. Even **Oracle** follows only eight and half(8.5) out of 13. The Codd's 12 rules are as follows.

Rule zero

This rule states that for a system to qualify as an **RDBMS**, it must be able to manage database entirely through the relational capabilities.

Rule 1: Information rule

All information(including metadata) is to be represented as stored data in cells of tables. The rows and columns have to be strictly unordered.

Rule 2: Guaranted Access

Each unique piece of data(atomic value) should be accesible by : **Table Name + Primary Key(Row) + Attribute(column)**.

NOTE: Ability to directly access via POINTER is a violation of this rule.

Rule 3: Systematic treatment of NULL

`Null` has several meanings, it can mean missing data, not applicable or no value. It should be handled consistently. Also, Primary key must not be null, ever. Expression on `NULL` must give null.

Rule 4: Active Online Catalog

Database dictionary(catalog) is the structure description of the complete **Database** and it must be stored online. The Catalog must be governed by same rules as rest of the database. The same query language should be used on catalog as used to query database.

Rule 5: Powerful and Well-Structured Language

One well structured language must be there to provide all manners of access to the data stored in the database. Example: **SQL**, etc. If the database allows access to the data without the use of this language, then that is a violation.

Rule 6: View Updation Rule

All the view that are theoretically updatable should be updatable by the system as well.

Rule 7: Relational Level Operation

There must be Insert, Delete, Update operations at each level of relations. Set operation like Union, Intersection and minus should also be supported.

Rule 8: Physical Data Independence

The physical storage of data should not matter to the system. If say, some file supporting table is renamed or moved from one disk to another, it should not effect the application.

Rule 9: Logical Data Independence

If there is change in the logical structure(table structures) of the database the user view of data should not change. Say, if a table is split into two tables, a new view should give result as the join of the two tables. This rule is most difficult to satisfy.

Rule 10: Integrity Independence

The database should be able to enforce its own integrity rather than using other programs. Key and Check constraints, trigger etc, should be stored in Data Dictionary. This also make **RDBMS**independent of front-end.

Rule 11: Distribution Independence

A database should work properly regardless of its distribution across a network. Even if a database is geographically distributed, with data stored in pieces, the end user should get an impression that it is stored at the same place. This lays the foundation of **distributed database**.

Rule 12: Nonsubversion Rule

If low level access is allowed to a system it should not be able to subvert or bypass integrity rules to change the data. This can be achieved by some sort of looking or encryption.

Basic Relational DBMS Concepts

A **Relational Database management System**(RDBMS) is a database management system based on the relational model introduced by E.F Codd. In relational model, data is stored in **relations**(tables) and is represented in form of **tuples**(rows).

RDBMS is used to manage Relational database. **Relational database** is a collection of organized set of tables related to each other, and from which data can be accessed easily. Relational Database is the most commonly used database these days.

RDBMS: What is Table ?

In Relational database model, a **table** is a collection of data elements organised in terms of rows and columns. A table is also considered as a convenient representation of **relations**. But a table can have duplicate row of data while a true **relation** cannot have duplicate data. Table is the most simplest form of data storage. Below is an example of an Employee table.

ID	**Name**	**Age**	**Salary**
1	Adam	34	13000
2	Alex	28	15000
3	Stuart	20	18000
4	Ross	42	19020

RDBMS: What is a Tuple?

A single entry in a table is called a **Tuple** or **Record** or **Row**. A **tuple** in a table represents a set of related data. For example, the above **Employee** table has 4 tuples/records/rows.

Following is an example of single record or tuple.

1	Adam	34	13000

RDBMS: What is an Attribute?

A table consists of several records(row), each record can be broken down into several smaller parts of data known as **Attributes**. The above **Employee** table consist of four attributes, **ID**, **Name**, **Age** and **Salary**.

Attribute Domain

When an attribute is defined in a relation(table), it is defined to hold only a certain type of values, which is known as **Attribute Domain**.

Hence, the attribute **Name** will hold the name of employee for every tuple. If we save employee's address there, it will be violation of the Relational database model.

Name
Adam
Alex
Stuart - 9/401, OC Street, Amsterdam
Ross

What is a Relation Schema?

A relation schema describes the structure of the relation, with the name of the relation(name of table), its attributes and their names and type.

What is a Relation Key?

A relation key is an attribute which can uniquely identify a particular tuple(row) in a relation(table)

Relational Integrity Constraints

Every relation in a relational database model should abide by or follow a few constraints to be a valid relation, these constraints are called as **Relational Integrity Constraints**.

The three main Integrity Constraints are:

1. Key Constraints
2. Domain Constraints
3. Referential integrity Constraints

Key Constraints

We store data in tables, to later access it whenever required. In every table one or more than one attributes together are used to fetch data from tables. The **Key Constraint** specifies that there should be such an attribute(column) in a relation(table), which can be used to fetch data for any tuple(row).

The Key attribute should never be **NULL** or same for two different row of data.

For example, in the **Employee** table we can use the attribute `ID` to fetch data for each of the employee. No value of `ID` is null and it is unique for every row, hence it can be our **Key attribute**.

Domain Constraint

Domain constraints refers to the rules defined for the values that can be stored for a certain attribute.

Like we explained above, we cannot store **Address** of employee in the column for **Name**.

Similarly, a mobile number cannot exceed 10 digits.

Referential Integrity Constraint

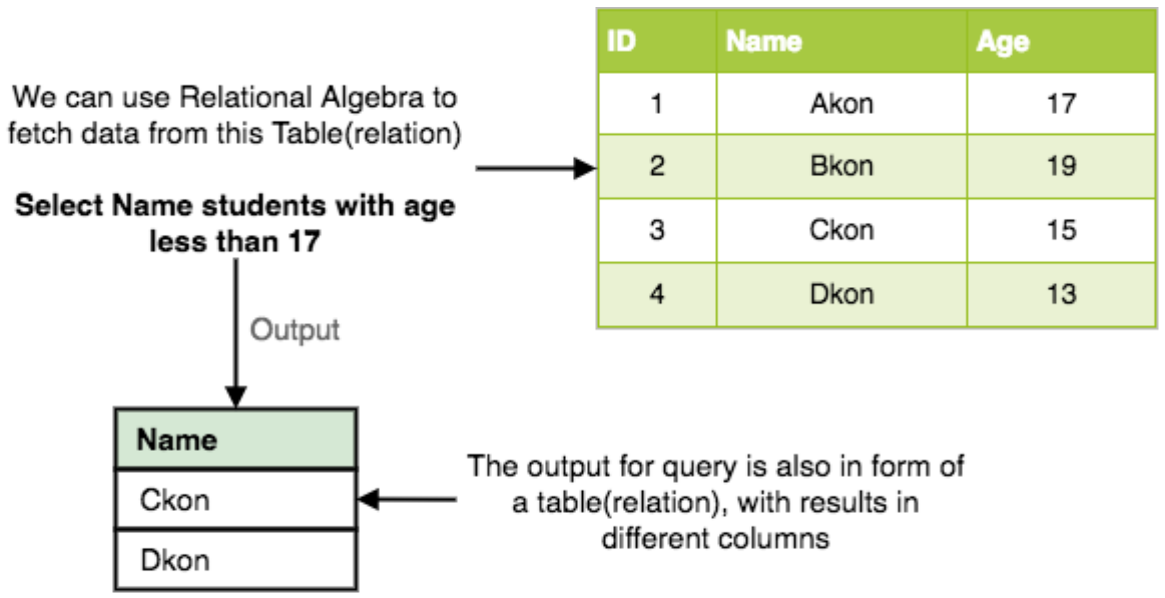
We will study about this in detail later. For now remember this example, if I say **Supriya** is my girlfriend, then a girl with name Supriya should also exist for that relationship to be present.

If a table reference to some data from another table, then that table and that data should be present for referential integrity constraint to hold true.

Relational Algebra

Every database management system must define a query language to allow users to access the data stored in the database. **Relational Algebra** is a procedural query language used to query the database tables to access data in different ways.

In relational algebra, input is a relation(table from which data has to be accessed) and output is also a relation(a temporary table holding the data asked for by the user).


We can use Relational Algebra to fetch data from this Table(relation)
Select Name students with age less than 17
Output
The output for query is also in form of a table(relation), with results in different columns

ID	Name	Age
1	Akon	17
2	Bkon	19
3	Ckon	15
4	Dkon	13

Name
Ckon
Dkon

Relational Algebra works on the whole table at once, so we do not have to use loops etc to iterate over all the rows(tuples) of data one by one. All we have to do is specify the table name from which we need the data, and in a single line of command, relational algebra will traverse the entire given table to fetch data for you.

The primary operations that we can perform using relational algebra are:

1. Select
2. Project
3. Union
4. Set Different
5. Cartesian product
6. Rename

Select Operation (σ)

This is used to fetch rows(tuples) from table(relation) which satisfies a given condition.

Syntax: $\sigma_p(r)$

Where, σ represents the Select Predicate, r is the name of relation(table name in which you want to look for data), and p is the prepositional logic, where we specify the conditions that must be satisfied by the data. In prepositional logic, one can use **unary** and **binary** operators like =, <, > etc, to specify the conditions.

Let's take an example of the Student table we specified above in the Introduction of relational algebra, and fetch data for **students** with **age** more than 17.

$\sigma_{age > 17}$ (Student)

This will fetch the tuples(rows) from table **Student**, for which **age** will be greater than **17**.

You can also use, and, or etc operators, to specify two conditions, for example,

$\sigma_{age > 17 \text{ and } gender = 'Male'}$ (Student)

This will return tuples(rows) from table **Student** with information of male students, of age more than 17.(Consider the Student table has an attribute Gender too.)

Project Operation (∏)

Project operation is used to project only a certain set of attributes of a relation. In simple words, If you want to see only the **names** all of the students in the **Student** table, then you can use Project Operation.

It will only project or show the columns or attributes asked for, and will also remove duplicate data from the columns.

Syntax: $\prod_{A1,\ A2...}(r)$

where A1, A2 etc are attribute names(column names).

For example,

$\prod_{Name,\ Age}$(Student)

Above statement will show us only the **Name** and **Age** columns for all the rows of data in **Student**table.

Union Operation (∪)

This operation is used to fetch data from two relations(tables) or temporary relation(result of another operation).

For this operation to work, the relations(tables) specified should have same number of attributes(columns) and same attribute domain. Also the duplicate tuples are autamatically eliminated from the result.

Syntax: $A \cup B$

where A and B are relations.

For example, if we have two tables **RegularClass** and **ExtraClass**, both have a column **student** to save name of student, then,

$\prod_{Student}$(RegularClass) ∪ $\prod_{Student}$(ExtraClass)

Above operation will give us name of **Students** who are attending both regular classes and extra classes, eliminating repetition.

Set Difference (-)

This operation is used to find data present in one relation and not present in the second relation. This operation is also applicable on two relations, just like Union operation.

Syntax: `A - B`

where A and B are relations.

For example, if we want to find name of students who attend the regular class but not the extra class, then, we can use the below operation:

$\prod_{Student}$(RegularClass) - $\prod_{Student}$(ExtraClass)

Cartesian Product (X)

This is used to combine data from two different relations(tables) into one and fetch data from the combined relation.

Syntax: `A X B`

For example, if we want to find the information for Regular Class and Extra Class which are conducted during morning, then, we can use the following operation:

$\sigma_{time\ =\ 'morning'}$ (RegularClass X ExtraClass)

For the above query to work, both **RegularClass** and **ExtraClass** should have the attribute **time**.

Rename Operation (ρ)

This operation is used to rename the output relation for any query operation which returns result like Select, Project etc. Or to simply rename a relation(table)

Syntax: `ρ(RelationNew, RelationOld)`

Apart from these common operations Relational Algebra is also used for **Join** operations like,

- Natural Join
- Outer Join
- Theta join etc.

Relational Calculus

Contrary to Relational Algebra which is a procedural query language to fetch data and which also explains how it is done, **Relational Calculus** in non-procedural query language and has no description about how the query will work or the data will b fetched. It only focusses on what to do, and not on how to do it.

Relational Calculus exists in two forms:

1. Tuple Relational Calculus (TRC)
2. Domain Relational Calculus (DRC)

Tuple Relational Calculus (TRC)

In tuple relational calculus, we work on filtering tuples based on the given condition.

Syntax: `{ T | Condition }`

In this form of relational calculus, we define a tuple variable, specify the table(relation) name in which the tuple is to be searched for, along with a condition.

We can also specify column name using a `.` dot operator, with the tuple variable to only get a certain attribute(column) in result.

A lot of informtion, right! Give it some time to sink in.

A tuple variable is nothing but a name, can be anything, generally we use a single alphabet for this, so let's say `T` is a tuple variable.

To specify the name of the relation(table) in which we want to look for data, we do the following:

`Relation(T)`, where `T` is our tuple variable.

For example if our table is **Student**, we would put it as `Student(T)`

Then comes the condition part, to specify a condition applicable for a particluar attribute(column), we can use the `.` dot variable with the tuple variable to specify it, like in table **Student**, if we want to get data for students with age greater than 17, then, we can write it as,

`T.age > 17`, where `T` is our tuple variable.

Putting it all together, if we want to use Tuple Relational Calculus to fetch names of students, from table **Student**, with age greater than **17**, then, for `T` being our tuple variable,

`T.name | Student(T) AND T.age > 17`

Domain Relational Calculus (DRC)

In domain relational calculus, filtering is done based on the domain of the attributes and not based on the tuple values.

Syntax: `{ c1, c2, c3, ..., cn | F(c1, c2, c3, ... ,cn)}`

where, c1, c2... etc represents domain of attributes(columns) and `F` defines the formula including the condition for fetching the data.

For example,

`{< name, age > | ∈ Student ∧ age > 17}`

Again, the above query will return the names and ages of the students in the table **Student** who are older than 17.

Introduction to Database Keys

Keys are very important part of Relational database model. They are used to establish and identify relationships between tables and also to uniquely identify any record or row of data inside a table.

A Key can be a single attribute or a group of attributes, where the combination may act as a key.

Why we need a Key?

In real world applications, number of tables required for storing the data is huge, and the different tables are related to each other as well.

Also, tables store a lot of data in them. Tables generally extends to thousands of records stored in them, unsorted and unorganised.

Now to fetch any particular record from such dataset, you will have to apply some conditions, but what if there is duplicate data present and every time you try to fetch some data by applying certain condition, you get the wrong data. How many trials before you get the right data?

To avoid all this, **Keys** are defined to easily identify any row of data in a table.

Let's try to understand about all the keys using a simple example.

student_id	**name**	**phone**	**age**
1	Akon	9876723452	17
2	Akon	9991165674	19
3	Bkon	7898756543	18
4	Ckon	8987867898	19
5	Dkon	9990080080	17

Let's take a simple **Student** table, with fields `student_id`, `name`, `phone` and `age`.

Super Key

Super Key is defined as a set of attributes within a table that can uniquely identify each record within a table. Super Key is a superset of Candidate key.

In the table defined above super key would include `student_id`, `(student_id, name)`, `phone` etc.
Confused? The first one is pretty simple as `student_id` is unique for every row of data, hence it can be used to identity each row uniquely.

Next comes, `(student_id, name)`, now name of two students can be same, but their `student_id`can't be same hence this combination can also be a key.

Similarly, phone number for every student will be unique, hence again, `phone` can also be a key.

So they all are super keys.

Candidate Key

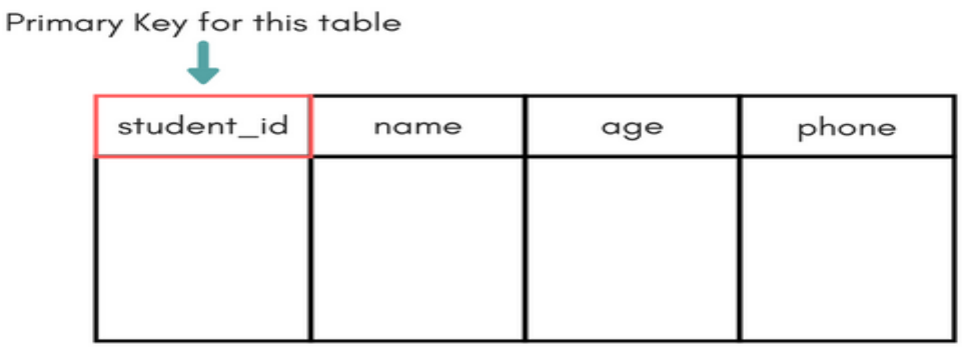
Candidate keys are defined as the minimal set of fields which can uniquely identify each record in a table. It is an attribute or a set of attributes that can act as a Primary Key for a table to uniquely identify each record in that table. There can be more than one candidate key.

In our example, `student_id` and `phone` both are candidate keys for table **Student**.

- A candiate key can never be NULL or empty. And its value should be unique.
- There can be more than one candidate keys for a table.
- A candidate key can be a combination of more than one columns(attributes).

Primary Key

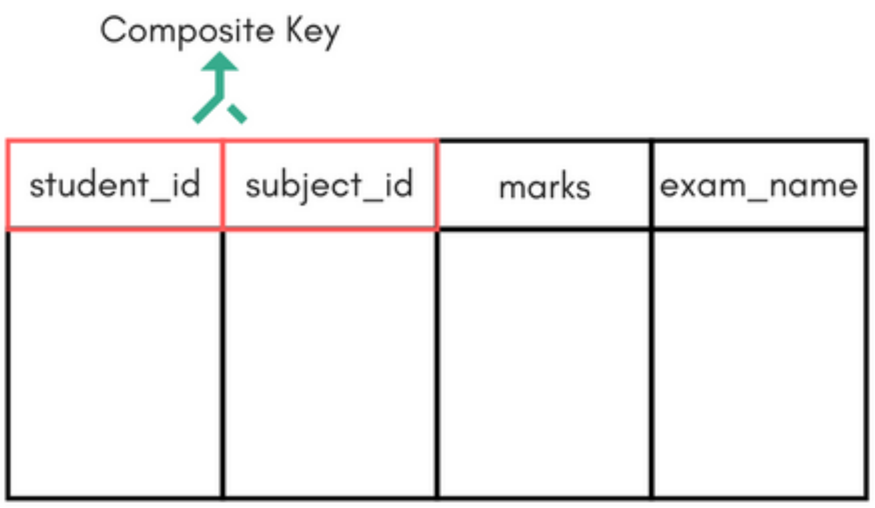
Primary key is a candidate key that is most appropriate to become the main key for any table. It is a key that can uniquely identify each record in a table.



For the table **Student** we can make the `student_id` column as the primary key

Composite Key

Key that consists of two or more attributes that uniquely identify any record in a table is called **Composite key**. But the attributes which together form the **Composite key** are not a key independentely or individually.



Score Table - To save scores of the student for various subjects.

In the above picture we have a **Score** table which stores the marks scored by a student in a particular subject.

In this table `student_id` and `subject_id` together will form the primary key, hence it is a composite key.

Secondary or Alternative key

The candidate key which are not selected as primary key are known as secondary keys or alternative keys.

Non-key Attributes

Non-key attributes are the attributes or fields of a table, other than **candidate key** attributes/fields in a table.

Non-prime Attributes

Non-prime Attributes are attributes other than **Primary Key attribute(s)**..

Normalization of Database

Database Normalization is a technique of organizing the data in the database. Normalization is a systematic approach of decomposing tables to eliminate data redundancy(repetition) and undesirable characteristics like Insertion, Update and Deletion Anamolies. It is a multi-step process that puts data into tabular form, removing duplicated data from the relation tables.

Normalization is used for mainly two purposes,

- Eliminating reduntant(useless) data.
- Ensuring data dependencies make sense i.e data is logically stored.

Problems Without Normalization

If a table is not properly normalized and have data redundancy then it will not only eat up extra memory space but will also make it difficult to handle and update the database, without facing data loss. Insertion, Updation and Deletion Anamolies are very frequent if database is not normalized. To understand these anomalies let us take an example of a **Student** table.

rollno	name	branch	hod	office_tel
401	Akon	CSE	Mr. X	53337
402	Bkon	CSE	Mr. X	53337
403	Ckon	CSE	Mr. X	53337
404	Dkon	CSE	Mr. X	53337

In the table above, we have data of 4 Computer Sci. students. As we can see, data for the fields `branch`, `hod`(Head of Department) and `office_tel` is repeated for the students who are in the same branch in the college, this is **Data Redundancy**.

Insertion Anomaly

Suppose for a new admission, until and unless a student opts for a branch, data of the student cannot be inserted, or else we will have to set the branch information as **NULL**.

Also, if we have to insert data of 100 students of same branch, then the branch information will be repeated for all those 100 students.

These scenarios are nothing but **Insertion anomalies**.

Updation Anomaly

What if Mr. X leaves the college? or is no longer the HOD of computer science department? In that case all the student records will have to be updated, and if by mistake we miss any record, it will lead to data inconsistency. This is Updation anomaly.

Deletion Anomaly

In our **Student** table, two different informations are kept together, Student information and Branch information. Hence, at the end of the academic year, if student records are deleted, we will also lose the branch information. This is Deletion anomaly.

Normalization Rule

Normalization rules are divided into the following normal forms:

1. First Normal Form
2. Second Normal Form
3. Third Normal Form
4. BCNF
5. Fourth Normal Form

First Normal Form (1NF)

For a table to be in the First Normal Form, it should follow the following 4 rules:

1. It should only have single(atomic) valued attributes/columns.
2. Values stored in a column should be of the same domain
3. All the columns in a table should have unique names.
4. And the order in which data is stored, does not matter.

Second Normal Form (2NF)

For a table to be in the Second Normal Form,

1. It should be in the First Normal form.
2. And, it should not have Partial Dependency.

Third Normal Form (3NF)

A table is said to be in the Third Normal Form when,

1. It is in the Second Normal form.

2. And, it doesn't have Transitive Dependency.

Boyce and Codd Normal Form (BCNF)

Boyce and Codd Normal Form is a higher version of the Third Normal form. This form deals with certain type of anomaly that is not handled by 3NF. A 3NF table which does not have multiple overlapping candidate keys is said to be in BCNF. For a table to be in BCNF, following conditions must be satisfied:

- R must be in 3rd Normal Form
- and, for each functional dependency ($X \rightarrow Y$), X should be a super Key.

Fourth Normal Form (4NF)

A table is said to be in the Fourth Normal Form when,

1. It is in the Boyce-Codd Normal Form.
2. And, it doesn't have Multi-Valued Dependency.

First Normal Form (1NF)

In our last Chapter we learned and understood how data redundancy or repetition can lead to several issues like Insertion, Deletion and Updation anomalies and how **Normalization** can reduce data redundancy and make the data more meaningful.

In this tutorial we will learn about the 1st Normal Form which is more like the Step 1 of the Normalization process. The 1st Normal form expects you to design your table in such a way that it can easily be extended and it is easier for you to retrieve data from it whenever required.

If tables in a database are not even in the 1st Normal Form, it is considered as **bad database design**.

Rules for First Normal Form

The first normal form expects you to follow a few simple rules while designing your database, and they are:

Rule 1: Single Valued Attributes

Each column of your table should be single valued which means they should not contain multiple values. We will explain this with help of an example later, let's see the other rules for now.

Rule 2: Attribute Domain should not change

This is more of a "Common Sense" rule. In each column the values stored must be of the same kind or type.

For example: If you have a column `dob` to save date of births of a set of people, then you cannot or you must not save 'names' of some of them in that column along with 'date of birth' of others in that column. It should hold only 'date of birth' for all the records/rows.

Rule 3: Unique name for Attributes/Columns

This rule expects that each column in a table should have a unique name. This is to avoid confusion at the time of retrieving data or performing any other operation on the stored data.

If one or more columns have same name, then the DBMS system will be left confused.

Rule 4: Order doesn't matters

This rule says that the order in which you store the data in your table doesn't matter.

Example

Although all the rules are self explanatory still let's take an example where we will create a table to store student data which will have student's roll no., their name and the name of subjects they have opted for.

Here is our table, with some sample data added to it.

roll_no	**name**	**subject**
101	Akon	OS, CN
103	Ckon	Java
102	Bkon	C, C++

Our table already satisfies 3 rules out of the 4 rules, as all our column names are unique, we have stored data in the order we wanted to and we have not inter-mixed different type of data in columns.

But out of the 3 different students in our table, 2 have opted for more than 1 subject. And we have stored the subject names in a single column. But as per the 1st Normal form each column must contain atomic value.

How to solve this Problem

It's very simple, because all we have to do is break the values into atomic values.

Here is our updated table and it now satisfies the First Normal Form.

roll_no	**name**	**subject**
101	Akon	OS
101	Akon	CN
103	Ckon	Java

102	Bkon	C
102	Bkon	C++

By doing so, although a few values are getting repeated but values for the `subject` column are now atomic for each record/row.

Using the First Normal Form, data redundancy increases, as there will be many columns with same data in multiple rows but each row as a whole will be unique.

Second Normal Form (2NF)

For a table to be in the Second Normal Form, it must satisfy two conditions:

1. The table should be in the First Normal Form.
2. There should be no Partial Dependency.

What is **Partial Dependency**? Do not worry about it. First let's understand what is **Dependency** in a table?

What is Dependency?

Let's take an example of a **Student** table with columns `student_id`, `name`, `reg_no`(registration number), `branch` and `address`(student's home address).

student_id	name	reg_no	branch	address

In this table, `student_id` is the primary key and will be unique for every row, hence we can use `student_id` to fetch any row of data from this table

Even for a case, where student names are same, if we know the `student_id` we can easily fetch the correct record.

student_id	name	reg_no	branch	address
10	Akon	07-WY	CSE	Kerala
11	Akon	08-WY	IT	Gujarat

Hence we can say a **Primary Key** for a table is the column or a group of columns(composite key) which can uniquely identify each record in the table.

I can ask from branch name of student with `student_id` **10**, and I can get it. Similarly, if I ask for name of student with `student_id` **10** or **11**, I will get it. So all I need is `student_id` and every other column **depends** on it, or can be fetched using it.

This is **Dependency** and we also call it **Functional Dependency**.

What is Partial Dependency?

Now that we know what dependency is, we are in a better state to understand what partial dependency is.

For a simple table like Student, a single column like `student_id` can uniquely identfy all the records in a table.

But this is not true all the time. So now let's extend our example to see if more than 1 column together can act as a primary key.

Let's create another table for **Subject**, which will have `subject_id` and `subject_name` fields and `subject_id` will be the primary key.

subject_id	subject_name
1	Java
2	C++
3	Php

Now we have a **Student** table with student information and another table **Subject** for storing subject information.

Let's create another table **Score**, to store the **marks** obtained by students in the respective subjects. We will also be saving **name of the teacher** who teaches that subject along with marks.

score_id	student_id	subject_id	marks	teacher
1	10	1	70	Java_Teacher

2	10	2	75	C++_Teacher
3	11	1	80	Java_Teacher

In the score table we are saving the **student_id** to know which student's marks are these and **subject_id** to know for which subject the marks are.

Together, `student_id + subject_id` form a **Candidate Key** for this table, which can be the **Primary key**.

Confused, How this combination can be a primary key?

See, if I ask you to get me marks of student with `student_id` 10, can you get it from this table? No, because you don't know for which subject. And if I give you `subject_id`, you would not know for which student. Hence we need `student_id + subject_id` to uniquely identify any row.

But where is Partial Dependency?

Now if you look at the **Score** table, we have a column names `teacher` which is only dependent on the subject, for Java it's Java Teacher and for C++ it's C++ Teacher & so on.

Now as we just discussed that the primary key for this table is a composition of two columns which is `student_id` & `subject_id` but the teacher's name only depends on subject, hence the `subject_id`, and has nothing to do with `student_id`.

This is **Partial Dependency**, where an attribute in a table depends on only a part of the primary key and not on the whole key.

How to remove Partial Dependency?

There can be many different solutions for this, but out objective is to remove teacher's name from Score table.

The simplest solution is to remove columns `teacher` from Score table and add it to the Subject table. Hence, the Subject table will become:

subject_id	**subject_name**	**teacher**
1	Java	Java Teacher
2	C++	C++ Teacher

3	Php	Php Teacher

And our Score table is now in the second normal form, with no partial dependency.

score_id	student_id	subject_id	marks
1	10	1	70
2	10	2	75
3	11	1	80

Quick Recap

1. For a table to be in the Second Normal form, it should be in the First Normal form and it should not have Partial Dependency.
2. Partial Dependency exists, when for a composite primary key, any attribute in the table depends only on a part of the primary key and not on the complete primary key.
3. To remove Partial dependency, we can divide the table, remove the attribute which is causing partial dependency, and move it to some other table where it fits in well.

Third Normal Form (3NF)

In our last Chapter, we learned about the Second Normal Form and even normalized our **Score** table into the 2nd Normal Form.
So let's use the same example, where we have 3 tables, **Student**, **Subject** and **Score**.

Student Table

student_id	name	reg_no	branch	address
10	Akon	07-WY	CSE	Kerala
11	Akon	08-WY	IT	Gujarat
12	Bkon	09-WY	IT	Rajasthan

Subject Table

subject_id	subject_name	teacher
1	Java	Java Teacher
2	C++	C++ Teacher
3	Php	Php Teacher

Score Table

score_id	student_id	subject_id	marks
1	10	1	70
2	10	2	75

3	11	1	80

In the Score table, we need to store some more information, which is the exam name and total marks, so let's add 2 more columns to the Score table.

score_id	student_id	subject_id	marks	exam_name	total_marks

Requirements for Third Normal Form

For a table to be in the third normal form,

1. It should be in the Second Normal form.
2. And it should not have Transitive Dependency.

What is Transitive Dependency?

With `exam_name` and `total_marks` added to our Score table, it saves more data now. Primary key for our Score table is a composite key, which means it's made up of two attributes or columns → **student_id + subject_id**.

Our new column `exam_name` depends on both student and subject. For example, a mechanical engineering student will have Workshop exam but a computer science student won't. And for some subjects you have Prctical exams and for some you don't. So we can say that `exam_name` is dependent on both `student_id` and `subject_id`.

And what about our second new column `total_marks`? Does it depend on our Score table's primary key?

Well, the column `total_marks` depends on `exam_name` as with exam type the total score changes. For example, practicals are of less marks while theory exams are of more marks.

But, `exam_name` is just another column in the score table. It is not a primary key or even a part of the primary key, and `total_marks` depends on it.

This is **Transitive Dependency**. When a non-prime attribute depends on other non-prime attributes rather than depending upon the prime attributes or primary key.

How to remove Transitive Dependency?

Again the solution is very simple. Take out the columns `exam_name` and `total_marks` from Score table and put them in an **Exam** table and use the `exam_id` wherever required.

Score Table: In 3rd Normal Form

score_id	student_id	subject_id	marks	exam_id

The new Exam table

exam_id	exam_name	total_marks
1	Workshop	200
2	Mains	70
3	Practicals	30

Advantage of removing Transitive Dependency

The advantage of removing transitive dependency is,

- Amount of data duplication is reduced.
- Data integrity achieved.

Boyce-Codd Normal Form (BCNF)

Boyce-Codd Normal Form or BCNF is an extension to the Third Normal Form, and is also known as 3.5 Normal Form.

In our last tutorial, we learned about the third normal form and we also learned how to remove **transitive dependency** from a table, we suggest you to follow the last tutorial before this one.

Rules for BCNF

For a table to satisfy the Boyce-Codd Normal Form, it should satisfy the following two conditions:

1. It should be in the **Third Normal Form**.
2. And, for any dependency A → B, A should be a **super key**.

The second point sounds a bit tricky, right? In simple words, it means, that for a dependency A → B, A cannot be a **non-prime attribute**, if B is a **prime attribute**.

Time for an Example

Below we have a college enrolment table with columns `student_id`, `subject` and `professor`.

student_id	**subject**	**professor**
101	Java	P.Java
101	C++	P.Cpp
102	Java	P.Java2
103	C#	P.Chash
104	Java	P.Java

As you can see, we have also added some sample data to the table.

In the table above:

- One student can enrol for multiple subjects. For example, student with **student_id** 101, has opted for subjects - Java & C++
- For each subject, a professor is assigned to the student.
- And, there can be multiple professors teaching one subject like we have for Java.

What do you think should be the **Primary Key**?

Well, in the table above `student_id, subject` together form the primary key, because using `student_id` and `subject`, we can find all the columns of the table.

One more important point to note here is, one professor teaches only one subject, but one subject may have two different professors.

Hence, there is a dependency between `subject` and `professor` here, where `subject` depends on the professor name.

This table satisfies the **1st Normal form** because all the values are atomic, column names are unique and all the values stored in a particular column are of same domain.

This table also satisfies the **2nd Normal Form** as their is no **Partial Dependency**.

And, there is no **Transitive Dependency**, hence the table also satisfies the **3rd Normal Form**.

But this table is not in **Boyce-Codd Normal Form**.

Why this table is not in BCNF?

In the table above, `student_id, subject` form primary key, which means `subject` column is a **prime attribute**.

But, there is one more dependency, `professor` → `subject`.

And while `subject` is a prime attribute, `professor` is a **non-prime attribute**, which is not allowed by BCNF.

How to satisfy BCNF?

To make this relation(table) satisfy BCNF, we will decompose this table into two tables, **student** table and **professor** table.

Below we have the structure for both the tables.

Student Table

student_id	**p_id**
101	1
101	2
and so on...	

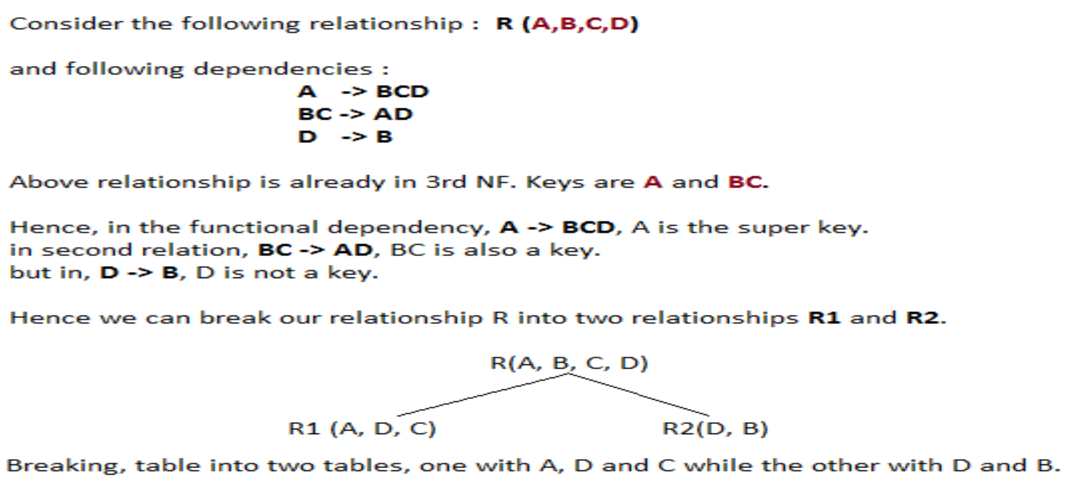
And, **Professor Table**

p_id	**professor**	**subject**
1	P.Java	Java
2	P.Cpp	C++
and so on...		

And now, this relation satisfy Boyce-Codd Normal Form. In the next tutorial we will learn about the **Fourth Normal Form**.

A more Generic Explanation

In the picture below, we have tried to explain BCNF in terms of relations.



Consider the following relationship : **R (A,B,C,D)**

and following dependencies :

A -> BCD
BC -> AD
D -> B

Above relationship is already in 3rd NF. Keys are **A** and **BC**.

Hence, in the functional dependency, **A -> BCD**, A is the super key.
in second relation, **BC -> AD**, BC is also a key.
but in, **D -> B**, D is not a key.

Hence we can break our relationship R into two relationships **R1** and **R2**.

$$\begin{tikzcd}
 & R(A, B, C, D) \arrow[dl, dash] \arrow[dr, dash] & \\
R1 (A, D, C) & & R2(D, B)
\end{tikzcd}$$

Breaking, table into two tables, one with A, D and C while the other with D and B.