UNIT 3:

Relational DBMS and Relational Algebra and Calculus

What is RDBMS (Relational Database Management System)

RDBMS stands for *Relational Database Management System*.

All modern database management systems like SQL, MS SQL Server, IBM DB2, ORACLE, My-SQL, and Microsoft Access are based on RDBMS.

It is called Relational Database Management System (RDBMS) because it is based on the relational model introduced by E.F. Codd.

How it works

Data is represented in terms of tuples (rows) in RDBMS.

A relational database is the most commonly used database. It contains several tables, and each table has its primary key.

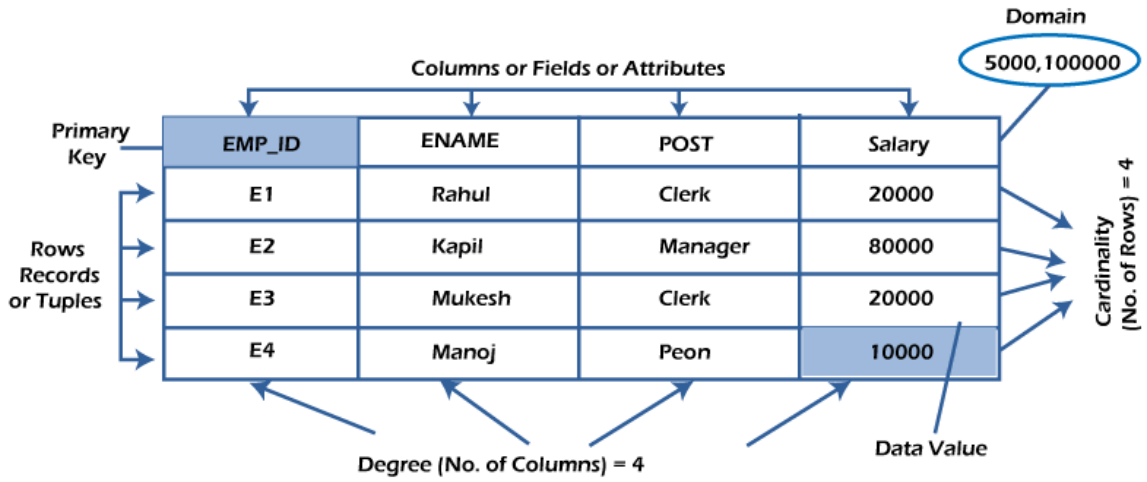
Due to a collection of an organized set of tables, data can be accessed easily in RDBMS.

Brief History of RDBMS

From 1970 to 1972, E.F. Codd published a paper to propose using a relational database model.

RDBMS is originally based on E.F. Codd's relational model invention.

Following are the various terminologies of RDBMS:



What is table/Relation?

Everything in a relational database is stored in the form of relations. The RDBMS database uses tables to store data. A table is a collection of related data entries and contains rows and columns to store data. Each table represents some real-world objects such as person, place, or event about which information is collected. The organized collection of data into a relational table is known as the logical view of the database.

Properties of a Relation:

- Each relation has a unique name by which it is identified in the database.
- Relation does not contain duplicate tuples.
- The tuples of a relation have no specific order.
- All attributes in a relation are atomic, i.e., each cell of a relation contains exactly one value.

A table is the simplest example of data stored in RDBMS.

Let's see the example of the student table.

ID	Name	AGE	COURSE
1	Ajeet	24	B.Tech
2	aryan	20	C.A

3	Mahesh	21	BCA
4	Ratan	22	MCA
5	Vimal	26	BSC

What is a row or record?

A row of a table is also called a record or tuple. It contains the specific information of each entry in the table. It is a horizontal entity in the table. For example, The above table contains 5 records.

Properties of a row:

- No two tuples are identical to each other in all their entries.
- All tuples of the relation have the same format and the same number of entries.
- The order of the tuple is irrelevant. They are identified by their content, not by their position.

Let's see one record/row in the table.

ID	Name	AGE	COURSE
1	Ajeet	24	B.Tech

What is a column/attribute?

A column is a vertical entity in the table which contains all information associated with a specific field in a table. For example, "name" is a column in the above table which contains all information about a student's name.

Properties of an Attribute:

- Every attribute of a relation must have a name.
- Null values are permitted for the attributes.
- Default values can be specified for an attribute automatically inserted if no other value is specified for an attribute.

- Attributes that uniquely identify each tuple of a relation are the primary key.

Name
Ajeet
Aryan
Mahesh
Ratan
Vimal

What is data item/Cells?

The smallest unit of data in the table is the individual data item. It is stored at the intersection of tuples and attributes.

Properties of data items:

- Data items are atomic.
- The data items for an attribute should be drawn from the same domain.

In the below example, the data item in the student table consists of Ajeet, 24 and Btech, etc.

ID	Name	AGE	COURSE
1	Ajeet	24	B.Tech

Degree:

The total number of attributes that comprise a relation is known as the degree of the table.

For example, the student table has 4 attributes, and its degree is 4.

ID	Name	AGE	COURSE
1	Ajeet	24	B.Tech
2	aryan	20	C.A
3	Mahesh	21	BCA
4	Ratan	22	MCA
5	Vimal	26	BSC

Cardinality:

The total number of tuples at any one time in a relation is known as the table's cardinality. The relation whose cardinality is 0 is called an empty table.

For example, the student table has 5 rows, and its cardinality is 5.

ID	Name	AGE	COURSE
1	Ajeet	24	B.Tech
2	aryan	20	C.A
3	Mahesh	21	BCA
4	Ratan	22	MCA
5	Vimal	26	BSC

Domain:

The domain refers to the possible values each attribute can contain. It can be specified using standard data types such as integers, floating numbers, etc. For example, An attribute entitled Marital_Status may be limited to married or unmarried values.

NULL Values

The NULL value of the table specifies that the field has been left blank during record creation. It is different from the value filled with zero or a field that contains space.

Data Integrity

There are the following categories of data integrity exist with each RDBMS:

Entity integrity: It specifies that there should be no duplicate rows in a table.

Domain integrity: It enforces valid entries for a given column by restricting the type, the format, or the range of values.

Referential integrity specifies that rows cannot be deleted, which are used by other records.

User-defined integrity: It enforces some specific business rules defined by users. These rules are different from the entity, domain, or referential integrity.

Normalization

A large database defined as a single relation may result in data duplication. This repetition of data may result in:

- Making relations very large.
- It isn't easy to maintain and update data as it would involve searching many records in relation.
- Wastage and poor utilization of disk space and resources.
- The likelihood of errors and inconsistencies increases.

So to handle these problems, we should analyze and decompose the relations with redundant data into smaller, simpler, and well-structured relations that are satisfy desirable properties. Normalization is a process of decomposing the relations into relations with fewer attributes.

What is Normalization?

- Normalization is the process of organizing the data in the database.
- Normalization is used to minimize the redundancy from a relation or set of relations. It is also used to eliminate undesirable characteristics like Insertion, Update, and Deletion Anomalies.
- Normalization divides the larger table into smaller and links them using relationships.
- The normal form is used to reduce redundancy from the database table.

Why do we need Normalization?

The main reason for normalizing the relations is removing these anomalies. Failure to eliminate anomalies leads to data redundancy and can cause data integrity and other problems as the database grows. Normalization consists of a series of guidelines that helps to guide you in creating a good database structure.

Data modification anomalies can be categorized into three types:

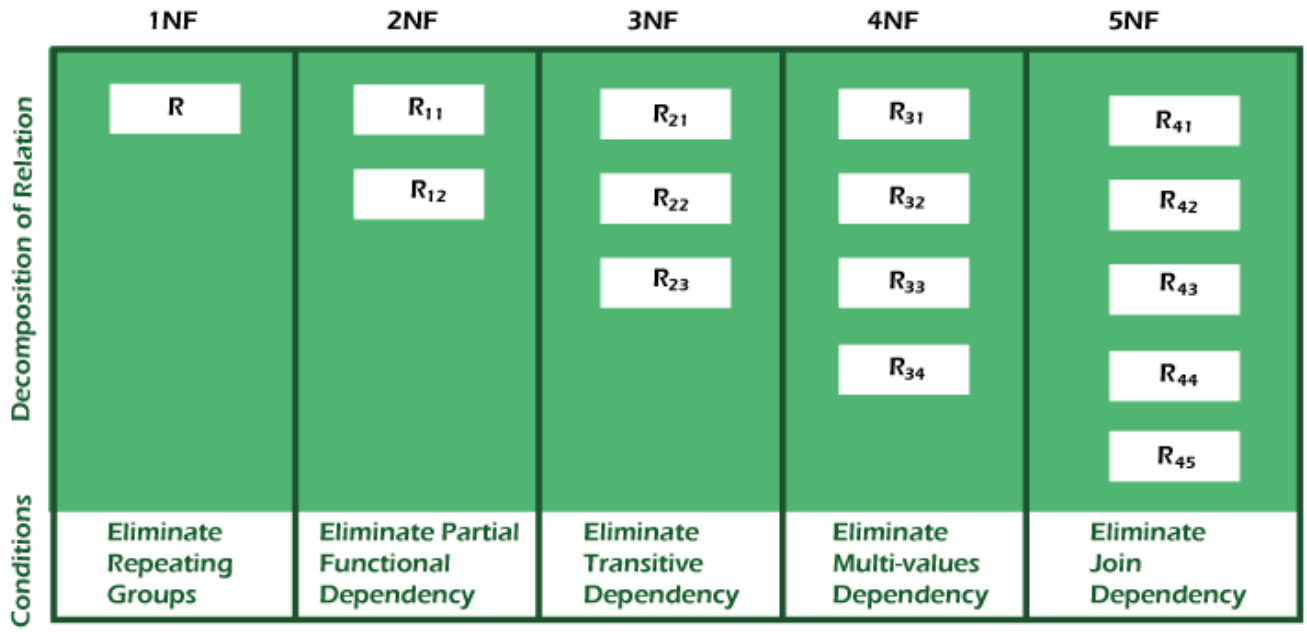
- Insertion Anomaly: Insertion Anomaly refers to when one cannot insert a new tuple into a relationship due to lack of data.
- Deletion Anomaly: The delete anomaly refers to the situation where the deletion of data results in the unintended loss of some other important data.

- Updatation Anomaly: The update anomaly is when an update of a single data value requires multiple rows of data to be updated.

Types of Normal Forms:

Normalization works through a series of stages called Normal forms. The normal forms apply to individual relations. The relation is said to be in particular normal form if it satisfies constraints.

Following are the various types of Normal forms:



Normal Form	Description
1NF	A relation is in 1NF if it contains an atomic value.
2NF	A relation will be in 2NF if it is in 1NF and all non-key attributes are fully functional dependent on the primary key.
3NF	A relation will be in 3NF if it is in 2NF and no transition dependency exists.

BCNF	A stronger definition of 3NF is known as Boyce Codd's normal form.
4NF	A relation will be in 4NF if it is in Boyce Codd's normal form and has no multi-valued dependency.
5NF	A relation is in 5NF. If it is in 4NF and does not contain any join dependency, joining should be lossless.

Advantages of Normalization

- Normalization helps to minimize data redundancy.
- Greater overall database organization.
- Data consistency within the database.
- Much more flexible database design.
- Enforces the concept of relational integrity.

Disadvantages of Normalization

- You cannot start building the database before knowing what the user needs.
- The performance degrades when normalizing the relations to higher normal forms, i.e., 4NF, 5NF.
- It is very time-consuming and difficult to normalize relations of a higher degree.
- Careless decomposition may lead to a bad database design, leading to serious problems.

Functional Dependency

Functional dependency (FD) is a set of constraints between two attributes in a relation. Functional dependency says that if two tuples have same values for attributes A1, A2,..., An, then those two tuples must have to have same values for attributes B1, B2, ..., Bn.

Functional dependency is represented by an arrow sign (→) that is, X→Y, where X functionally determines Y. The left-hand side attributes determine the values of attributes on the right-hand side.

Armstrong's Axioms

If F is a set of functional dependencies then the closure of F, denoted as F^+, is the set of all functional dependencies logically implied by F. Armstrong's Axioms are a set of rules, that when applied repeatedly, generates a closure of functional dependencies.

- **Reflexive rule** − If alpha is a set of attributes and beta is_subset_of alpha, then alpha holds beta.
- **Augmentation rule** − If a → b holds and y is attribute set, then ay → by also holds. That is adding attributes in dependencies, does not change the basic dependencies.
- **Transitivity rule** − Same as transitive rule in algebra, if a → b holds and b → c holds, then a → c also holds. a → b is called as a functionally that determines b.

Trivial Functional Dependency

- **Trivial** − If a functional dependency (FD) X → Y holds, where Y is a subset of X, then it is called a trivial FD. Trivial FDs always hold.
- **Non-trivial** − If an FD X → Y holds, where Y is not a subset of X, then it is called a non-trivial FD.
- **Completely non-trivial** − If an FD X → Y holds, where x intersect Y = Φ, it is said to be a completely non-trivial FD.

Normalization

If a database design is not perfect, it may contain anomalies, which are like a bad dream for any database administrator. Managing a database with anomalies is next to impossible.

- **Update anomalies** − If data items are scattered and are not linked to each other properly, then it could lead to strange situations. For example, when we try to update one data item having its copies scattered over several places, a few instances get updated properly while a few others are left with old values. Such instances leave the database in an inconsistent state.
- **Deletion anomalies** − We tried to delete a record, but parts of it was left undeleted because of unawareness, the data is also saved somewhere else.
- **Insert anomalies** − We tried to insert data in a record that does not exist at all.

Normalization is a method to remove all these anomalies and bring the database to a consistent state.

First Normal Form

First Normal Form is defined in the definition of relations (tables) itself. This rule defines that all the attributes in a relation must have atomic domains. The values in an atomic domain are indivisible units.

Course	Content
Programming	Java, c++
Web	HTML, PHP, ASP

We re-arrange the relation (table) as below, to convert it to First Normal Form.

Course	Content
Programming	Java
Programming	c++
Web	HTML
Web	PHP
Web	ASP

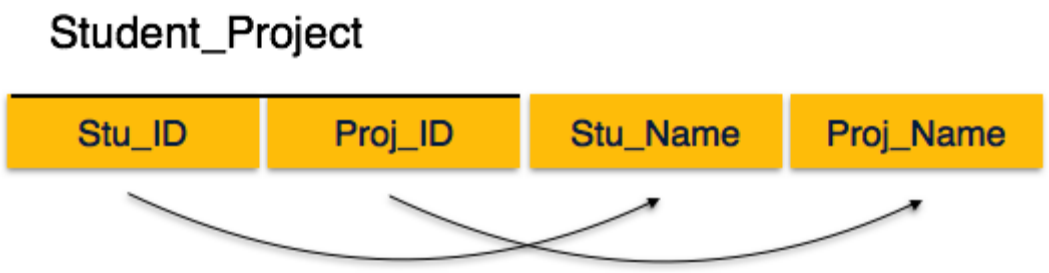
Each attribute must contain only a single value from its pre-defined domain.

Second Normal Form

Before we learn about the second normal form, we need to understand the following −

- **Prime attribute** − An attribute, which is a part of the candidate-key, is known as a prime attribute.
- **Non-prime attribute** − An attribute, which is not a part of the prime-key, is said to be a non-prime attribute.

If we follow second normal form, then every non-prime attribute should be fully functionally dependent on prime key attribute. That is, if X → A holds, then there should not be any proper subset Y of X, for which Y → A also holds true.



We see here in Student_Project relation that the prime key attributes are Stu_ID and Proj_ID. According to the rule, non-key attributes, i.e. Stu_Name and Proj_Name must be dependent upon

both and not on any of the prime key attribute individually. But we find that Stu_Name can be identified by Stu_ID and Proj_Name can be identified by Proj_ID independently. This is called **partial dependency**, which is not allowed in Second Normal Form.

We broke the relation in two as depicted in the above picture. So there exists no partial dependency.

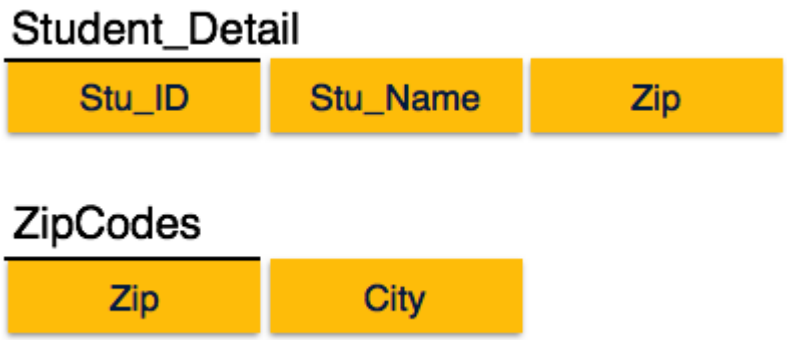
Third Normal Form

For a relation to be in Third Normal Form, it must be in Second Normal form and the following must satisfy −

- No non-prime attribute is transitively dependent on prime key attribute.
- For any non-trivial functional dependency, X → A, then either −
    - X is a superkey or,
    - A is prime attribute.

We find that in the above Student_detail relation, Stu_ID is the key and only prime key attribute. We find that City can be identified by Stu_ID as well as Zip itself. Neither Zip is a superkey nor is City a prime attribute. Additionally, Stu_ID → Zip → City, so there exists **transitive dependency**.

To bring this relation into third normal form, we break the relation into two relations as follows −



Boyce-Codd Normal Form

Boyce-Codd Normal Form (BCNF) is an extension of Third Normal Form on strict terms. BCNF states that −

- For any non-trivial functional dependency, X → A, X must be a super-key.

In the above image, Stu_ID is the super-key in the relation Student_Detail and Zip is the super-key in the relation ZipCodes. So,

Stu_ID → Stu_Name, Zip

and

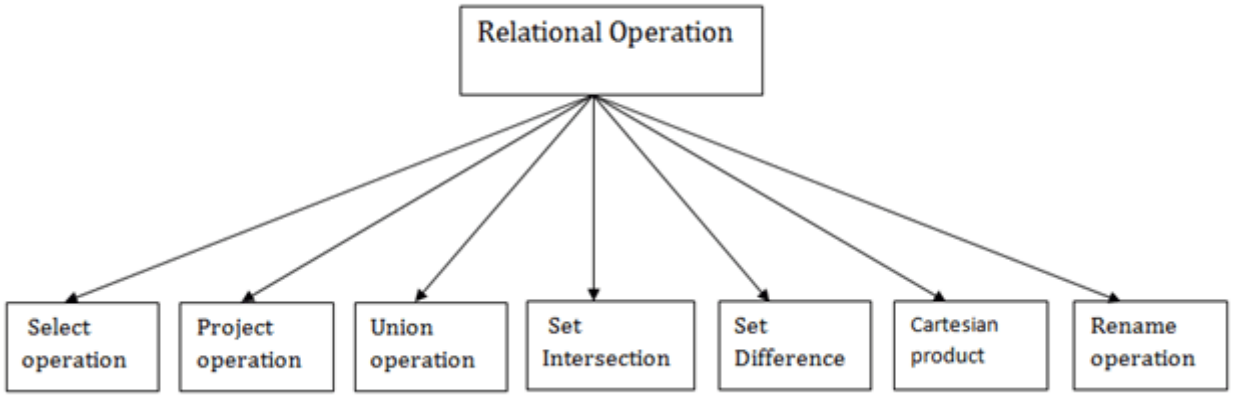
Zip → City

Which confirms that both the relations are in BCNF.

Relational Algebra

Relational algebra is a procedural query language. It gives a step by step process to obtain the result of the query. It uses operators to perform queries.

Types of Relational operation



1. Select Operation:

- The select operation selects tuples that satisfy a given predicate.
- It is denoted by sigma (σ).

1. Notation: σ p(r)
   Where:

   σ is used for selection prediction
   r is used for relation
   p is used as a propositional logic formula which may use connectors like: AND OR and NOT. These relational can use as relational operators like =, ≠, ≥, <, >, ≤.

   For example: LOAN Relation

BRANCH_NAME	LOAN_NO	AMOUNT
Downtown	L-17	1000
Redwood	L-23	2000

Perryride	L-15	1500
Downtown	L-14	1500
Mianus	L-13	500
Roundhill	L-11	900
Perryride	L-16	1300

Input:

1. σ BRANCH_NAME="perryride" (LOAN)

Output:

BRANCH_NAME	LOAN_NO	AMOUNT
Perryride	L-15	1500
Perryride	L-16	1300

2. Project Operation:

- This operation shows the list of those attributes that we wish to appear in the result. Rest of the attributes are eliminated from the table.
- It is denoted by ∏.

1. Notation: ∏ A1, A2, An (r)

Where

A1, A2, A3 is used as an attribute name of relation r.

Example: CUSTOMER RELATION

NAME	STREET	CITY

Jones	Main	Harrison
Smith	North	Rye
Hays	Main	Harrison
Curry	North	Rye
Johnson	Alma	Brooklyn
Brooks	Senator	Brooklyn

Input:

1. ∏ NAME, CITY (CUSTOMER)

Output:

NAME	CITY
Jones	Harrison
Smith	Rye
Hays	Harrison
Curry	Rye
Johnson	Brooklyn
Brooks	Brooklyn

3. Union Operation:

- Suppose there are two tuples R and S. The union operation contains all the tuples that are either in R or S or both in R & S.
- It eliminates the duplicate tuples. It is denoted by ∪.

1. Notation: R ∪ S
   A union operation must hold the following condition:

   - R and S must have the attribute of the same number.
   - Duplicate tuples are eliminated automatically.

Example:

DEPOSITOR RELATION

CUSTOMER_NAME	ACCOUNT_NO
Johnson	A-101
Smith	A-121
Mayes	A-321
Turner	A-176
Johnson	A-273
Jones	A-472
Lindsay	A-284

BORROW RELATION

CUSTOMER_NAME	LOAN_NO

Jones	L-17
Smith	L-23
Hayes	L-15
Jackson	L-14
Curry	L-93
Smith	L-11
Williams	L-17

Input:

1. ∏ CUSTOMER_NAME (BORROW) ∪ ∏ CUSTOMER_NAME (DEPOSITOR)

Output:

CUSTOMER_NAME
Johnson
Smith
Hayes
Turner
Jones
Lindsay

Jackson
Curry
Williams
Mayes

4. Set Intersection:

- Suppose there are two tuples R and S. The set intersection operation contains all tuples that are in both R & S.
- It is denoted by intersection ∩.

1. Notation: R ∩ S
   Example: Using the above DEPOSITOR table and BORROW table

   Input:

1. ∏ CUSTOMER_NAME (BORROW) ∩ ∏ CUSTOMER_NAME (DEPOSITOR)
   Output:

CUSTOMER_NAME
Smith
Jones

5. Set Difference:

- Suppose there are two tuples R and S. The set intersection operation contains all tuples that are in R but not in S.
- It is denoted by intersection minus (-).

1. Notation: R - S

Example: Using the above DEPOSITOR table and BORROW table

Input:

1. ∏ CUSTOMER_NAME (BORROW) - ∏ CUSTOMER_NAME (DEPOSITOR)

Output:

CUSTOMER_NAME
Jackson
Hayes
Willians
Curry

6. Cartesian product

- The Cartesian product is used to combine each row in one table with each row in the other table. It is also known as a cross product.
- It is denoted by X.

1. Notation: E X D

Example:

EMPLOYEE

EMP_ID	EMP_NAME	EMP_DEPT

1	Smith	A
2	Harry	C
3	John	B

DEPARTMENT

DEPT_NO	DEPT_NAME
A	Marketing
B	Sales
C	Legal

Input:

1. EMPLOYEE X DEPARTMENT

Output:

EMP_ID	EMP_NAME	EMP_DEPT	DEPT_NO	DEPT_NAME
1	Smith	A	A	Marketing
1	Smith	A	B	Sales
1	Smith	A	C	Legal
2	Harry	C	A	Marketing
2	Harry	C	B	Sales

2	Harry	C	C	Legal
3	John	B	A	Marketing
3	John	B	B	Sales
3	John	B	C	Legal

7. Rename Operation:

The rename operation is used to rename the output relation. It is denoted by rho (ρ).

Example: We can use the rename operator to rename STUDENT relation to STUDENT1.

1. ρ(STUDENT1, STUDENT)

Note: Apart from these common operations Relational algebra can be used in Join operations.

Tuple Relational Calculus (TRC) in DBMS

Tuple Relational Calculus (TRC) is a non-procedural query language used in relational database management systems (RDBMS) to retrieve data from tables. TRC is based on the concept of tuples, which are ordered sets of attribute values that represent a single row or record in a database table.

TRC is a declarative language, meaning that it specifies what data is required from the *database*, rather than how to retrieve it. TRC queries are expressed as logical formulas that describe the desired tuples.

Syntax: The basic syntax of TRC is as follows:

{ t | P(t) }

where t is a tuple variable and P(t) is a logical formula that describes the conditions that the tuples in the result must satisfy. The curly braces {} are used to indicate that the expression is a set of tuples.

For example, let's say we have a table called "Employees" with the following *attributes*:

Employee ID
Name
Salary
Department ID

To retrieve the names of all employees who earn more than $50,000 per year, we can use the following TRC query:

{ t | Employees(t) ∧ t.Salary > 50000 }

In this query, the "Employees(t)" expression specifies that the tuple variable t represents a row in the "Employees" table. The "∧" symbol is the logical AND operator, which is used to combine the condition "t.Salary > 50000" with the table selection.

The result of this query will be a set of tuples, where each tuple contains the Name attribute of an employee who earns more than $50,000 per year.

TRC can also be used to perform more complex queries, such as joins and nested queries, by using additional logical operators and expressions.

While TRC is a powerful query language, it can be more difficult to write and understand than other SQL-based query languages, such as *Structured Query Language (SQL)*. However, it is useful in certain applications, such as in the formal verification of database schemas and in academic research.

Tuple Relational Calculus is a non-procedural query language, unlike relational algebra. Tuple Calculus provides only the description of the query but it does not provide the methods to solve it. Thus, it explains what to do but not how to do it.

Tuple Relational Query

In Tuple Calculus, a query is expressed as

{t| P(t)}

where t = resulting tuples, P(t) = known as Predicate and these are the conditions that are used to fetch t. Thus, it generates a set of all tuples t, such that Predicate P(t) is true for t.

P(t) may have various conditions logically combined with OR (∨), AND (∧), NOT(¬). It also uses quantifiers:
∃ t ∈ r (Q(t)) = ”there exists” a tuple in t in relation r such that predicate Q(t) is true.
∀ t ∈ r (Q(t)) = Q(t) is true “for all” tuples in relation r.

Domain Relational Calculus (DRC)

Domain Relational Calculus is similar to Tuple Relational Calculus, where it makes a list of the attributes that are to be chosen from the relations as per the conditions.
{<a1,a2,a3,.....an> | P(a1,a2,a3,.....an)}

where a1,a2,…an are the attributes of the relation and P is the condition.

Tuple Relational Calculus Examples

Table Customer

Customer name	Street	City
Saurabh	A7	Patiala
Mehak	B6	Jalandhar
Sumiti	D9	Ludhiana
Ria	A5	Patiala

Table Branch

Branch name	Branch City
ABC	Patiala

Branch name	Branch City
DEF	Ludhiana
GHI	Jalandhar

Table Account

Account number	Branch name	Balance
1111	ABC	50000
1112	DEF	10000
1113	GHI	9000
1114	ABC	7000

Table Loan

Loan number	Branch name	Amount
L33	ABC	10000
L35	DEF	15000
L49	GHI	9000

Loan number	Branch name	Amount
L98	DEF	65000

Table Borrower

Customer name	Loan number
Saurabh	L33
Mehak	L49
Ria	L98

Table Depositor

Customer name	Account number
Saurabh	1111
Mehak	1113
Suniti	1114

Example 1: Find the loan number, branch, and amount of loans greater than or equal to 10000 amount.

$\{t \mid t \in loan \ \wedge t[amount] >= 10000\}$

Resulting relation:

Loan number	Branch name	Amount
L33	ABC	10000
L35	DEF	15000
L98	DEF	65000

In the above query, t[amount] is known as a tuple variable.

Example 2: Find the loan number for each loan of an amount greater or equal to 10000.

{t| ∃ s ∈ loan(t[loan number] = s[loan number]

∧ s[amount]>=10000)}

Resulting relation:

Loan number
L33
L35
L98

Example 3: Find the names of all customers who have a loan and an account at the bank.

{t | ∃ s ∈ borrower(t[customer-name] = s[customer-name])

∧ ∃ u ∈ depositor(t[customer-name] = u[customer-name])}

Resulting relation:

Customer name
Saurabh
Mehak

Example 4: Find the names of all customers having a loan at the “ABC” branch.

{t | ∃ s ∈ borrower(t[customer-name] = s[customer-name]

∧ ∃ u ∈ loan(u[branch-name] = “ABC” ∧ u[loan-number] = s[loan-number]))}

Resulting relation:

Customer name
Saurabh

Relational Calculus

There is an alternate way of formulating queries known as Relational Calculus. Relational calculus is a non-procedural query language. In the non-procedural query language, the user is concerned with the details of how to obtain the end results. The relational calculus tells what to do but never explains how to do. Most commercial relational languages are based on aspects of relational calculus including SQL-QBE and QUEL.

Why it is called Relational Calculus?

It is based on Predicate calculus, a name derived from branch of symbolic language. A predicate is a truth-valued function with arguments. On substituting values for the arguments, the function

result in an expression called a proposition. It can be either true or false. It is a tailored version of a subset of the Predicate Calculus to communicate with the relational database.

Many of the calculus expressions involves the use of Quantifiers. There are two types of quantifiers:

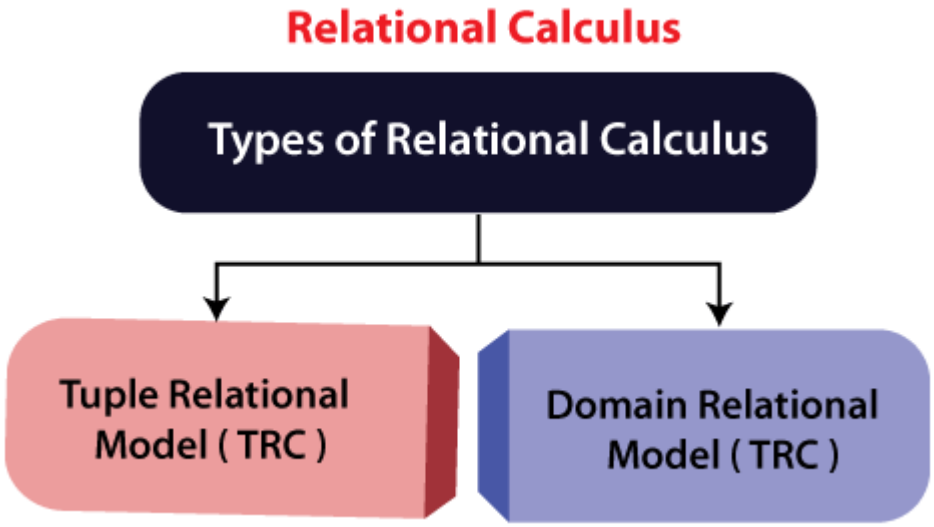
- Universal Quantifiers: The universal quantifier denoted by ∀ is read as for all which means that in a given set of tuples exactly all tuples satisfy a given condition.
- Existential Quantifiers: The existential quantifier denoted by ∃ is read as for all which means that in a given set of tuples there is at least one occurrences whose value satisfy a given condition.

Before using the concept of quantifiers in formulas, we need to know the concept of Free and Bound Variables.

A tuple variable t is bound if it is quantified which means that if it appears in any occurrences a variable that is not bound is said to be free.

Free and bound variables may be compared with global and local variable of programming languages.

Types of Relational calculus:



1. Tuple Relational Calculus (TRC)

It is a non-procedural query language which is based on finding a number of tuple variables also known as range variable for which predicate holds true. It describes the desired information

without giving a specific procedure for obtaining that information. The tuple relational calculus is specified to select the tuples in a relation. In TRC, filtering variable uses the tuples of a relation. The result of the relation can have one or more tuples.

Notation:

A Query in the tuple relational calculus is expressed as following notation

1. {T | P (T)} or {T | Condition (T)}
   Where

   T is the resulting tuples

   P(T) is the condition used to fetch T.

   For example:

1. { T.name | Author(T) AND T.article = 'database' }
   Output: This query selects the tuples from the AUTHOR relation. It returns a tuple with 'name' from Author who has written an article on 'database'.

   TRC (tuple relation calculus) can be quantified. In TRC, we can use Existential (∃) and Universal Quantifiers (∀).

   For example:

1. { R| ∃T ∈ Authors(T.article='database' AND R.name=T.name)}
   Output: This query will yield the same result as the previous one.

2. Domain Relational Calculus (DRC)

The second form of relation is known as Domain relational calculus. In domain relational calculus, filtering variable uses the domain of attributes. Domain relational calculus uses the same operators as tuple calculus. It uses logical connectives ∧ (and), ∨ (or) and ¬ (not). It uses Existential (∃) and Universal Quantifiers (∀) to bind the variable. The QBE or Query by example is a query language related to domain relational calculus.

Notation:

1. { a1, a2, a3, ..., an | P (a1, a2, a3, ... ,an)}
   Where

   a1, a2 are attributes

   P stands for formula built by inner attributes

For example:

1. {< article, page, subject > | ∈ javatpoint ∧ subject = 'database'}
   Output: This query will yield the article, page, and subject from the relational javatpoint, where the subject is a database.