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RELATIONAL ALGEBRA AND RELATIONAL CALCULUS ELEMENTS

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Annotation. *In relational databases, relationships define how data in one table is associated with data in other tables. These relationships are fundamental for ensuring data integrity, reducing redundancy, and enabling complex queries. The three primary types of relationships in relational databases are one-to-one, one-to-many, and many-to-many, each of which serves to link records in different tables based on common attributes. Relationships are established through keys, such as primary keys and foreign keys, which ensure the consistency and accuracy of data. Understanding and implementing these relationships is essential for effective database design, as they help maintain a logical structure and improve the efficiency of data retrieval. This article explores the different types of relationships in relational databases, their role in database design, and their applications across various industries, including e-commerce, healthcare, and education.*

Keywords: *Relational Databases, Data Relationships, One-to-One, One-to-Many, Many-to-Many, Primary Keys, Foreign Keys, Data Integrity, Database Design, SQL, Data Management.*

Аннотация. *В реляционных базах данных отношения определяют, как данные в одной таблице связаны с данными в других таблицах. Эти отношения имеют основополагающее значение для обеспечения целостности данных, снижения избыточности и обеспечения сложных запросов. Три основных типа отношений в реляционных базах данных — это «один к одному», «один ко многим» и «многие ко многим», каждый из которых служит для связывания записей в разных таблицах на основе общих атрибутов. Отношения устанавливаются с помощью ключей, таких как первичные ключи и внешние*

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ключи, которые обеспечивают согласованность и точность данных. Понимание и реализация этих отношений необходимы для эффективного проектирования баз данных, поскольку они помогают поддерживать логическую структуру и повышать эффективность поиска данных. В этой статье рассматриваются различные типы отношений в реляционных базах данных, их роль в проектировании баз данных и их применение в различных отраслях, включая электронную коммерцию, здравоохранение и образование.

Ключевые слова. *реляционные базы данных, связи данных, «один к одному», «один ко многим», «многие ко многим», первичные ключи, внешние ключи, целостность данных, проектирование баз данных, SQL, управление данными.*

Relational databases rely on mathematical foundations to structure and manage data efficiently. Two key components that underpin the querying and manipulation of data in relational databases are **Relational Algebra** and **Relational Calculus**. These are formal systems used to represent and compute queries on relational databases. While they are rooted in the same underlying principles, they differ in their approach to querying data. Relational algebra is procedural, focusing on the steps to retrieve data, while relational calculus is non-procedural, specifying what data to retrieve without describing how to retrieve it. Together, these two elements provide the foundation for Structured Query Language (SQL), the most widely used language for querying relational databases.

This article delves into the fundamental elements of relational algebra and relational calculus, their differences, and their applications in the realm of database management.

Overview of Relational Algebra

Relational algebra is a formal query language that is procedural in nature. It consists of a set of operations that take one or more relations as input and produce a new relation as output. Relational algebra focuses on the "how" of data manipulation, specifying the operations that should be performed to obtain the desired result. These

operations can be combined to form complex queries, and they serve as the basis for SQL queries.

The primary operations in relational algebra are:

Basic Operations in Relational Algebra

Selection (σ):

Selection is an operation that retrieves rows (tuples) from a relation that satisfy a given condition. It is similar to the "WHERE" clause in SQL.

Syntax:

σ(condition)(Relation)

Example:

σ(age > 30)(Employees)

This operation selects all rows from the Employees table where the age is greater than 30.

Projection (π):

Projection selects specific columns from a relation. It is used to eliminate unnecessary attributes and focus only on the desired columns, much like the "SELECT" clause in SQL.

Syntax:

π(attribute1, attribute2,...)(Relation)

Example:

π(name, age)(Employees)

This operation selects only the name and age columns from the Employees table.

Union (∪):

The union operation combines the results of two relations and returns all unique tuples from both relations. The relations involved must have the same set of attributes.

Syntax:

Relation1 ∪ Relation2

Example:

Employees ∪ Contractors

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This operation combines the Employees and Contractors relations, returning all unique rows from both tables.

Difference (−):

The difference operation returns the tuples that exist in one relation but not in another. It is similar to the "EXCEPT" or "MINUS" clause in SQL.

Syntax:

Relation1 − Relation2

Employees − Contractors

This operation returns the rows from the Employees table that do not appear in the Contractors table.

Cartesian Product (×):

The Cartesian product operation returns all possible combinations of rows between two relations. Each tuple from the first relation is paired with each tuple from the second relation.

Syntax:

Relation1 × Relation2

Example:

Employees × Departments

This operation produces a relation containing every possible combination of Employee and Department.

1. **Rename (ρ):**

The rename operation is used to rename a relation or its attributes, allowing for more clarity or preventing ambiguity when performing operations like joins.

Syntax:

ρ(new_relation_name)(Relation)

ρ(Emp)(Employees)

This operation renames the Employees relation to Emp.

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Join Operation in Relational Algebra

One of the most important operations in relational algebra is **join**, which combines two relations based on a related attribute. There are several types of joins, but the most common are:

- **Natural Join (⋈):** A natural join combines two relations by matching all attributes with the same name, eliminating duplicates.
- **Theta Join (⋈θ):** A theta join combines two relations based on a condition or predicate (not necessarily equality).
- **Equi Join:** This is a specific case of a theta join where the condition is equality between attributes.

Suppose we have two relations: Employees(EmployeeID, Name, DepartmentID) and Departments(DepartmentID, DepartmentName). To retrieve the names of employees and their departments, we would perform an equi join based on the DepartmentID attribute:

Employees ⋈θ(Employees.DepartmentID = Departments.DepartmentID) Departments

This operation combines the Employees and Departments relations, matching tuples where DepartmentID is equal in both relations.

Relational calculus, unlike relational algebra, is a non-procedural query language. It focuses on specifying *what* data is required without describing the steps to retrieve it. The user expresses the desired results in terms of logical formulas, and the system determines the most efficient way to compute the results. Relational calculus is based on mathematical logic and set theory.

There are two main types of relational calculus:

2.1. Tuple Relational Calculus (TRC)

Tuple relational calculus allows users to describe queries using variables that range over tuples (rows). A query is expressed as a formula, which is essentially a condition on the tuples in a relation. The tuple variables are bound by the relation name.

Syntax:

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{ T | P(T) }

Where:

- **T** is a tuple variable,
- **P(T)** is a predicate or condition on the tuple.

To retrieve the names of employees who work in the "HR" department, the query in tuple relational calculus would be:

{ T.Name | ∃ D (Employees(T) ∧ Departments(D) ∧ T.DepartmentID = D.DepartmentID ∧ D.DepartmentName = "HR") }

In this example, the formula specifies that for each tuple T in the Employees relation, there must exist a tuple D in the Departments relation such that the DepartmentID matches and the DepartmentName is "HR."

2.2. Domain Relational Calculus (DRC)

Domain relational calculus operates on individual attributes or domains, rather than entire tuples. A domain variable is used to specify values from particular attributes in the relation.

Syntax:

{ D1, D2,..., Dn | P(D1, D2,..., Dn) }

Where:

- **D1, D2,..., Dn** are domain variables representing attributes in the relation,
- **P(D1, D2,..., Dn)** is a predicate or condition on the domain variables.

To retrieve the names of employees who work in the "HR" department, the query in domain relational calculus would be:

{ Name | ∃ EmployeeID, DepartmentID (Employees(EmployeeID, Name, DepartmentID) ∧ DepartmentName = "HR" ∧ Employees.DepartmentID = Departments.DepartmentID) }

Here, the query specifies that the Name of employees is retrieved where the DepartmentName is "HR," and a valid DepartmentID relationship exists between the Employees and Departments tables.

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Although relational algebra and relational calculus serve similar purposes, their approaches differ significantly:

Procedural and focuses on the steps or operations needed to retrieve data. It is more direct in terms of operations, such as selections, projections, and joins.

Non-procedural and focuses on the description of the result of a query, specifying what is to be retrieved rather than how to retrieve it. It is more expressive and closer to SQL's declarative style.

While relational algebra has a more operational focus, relational calculus is more flexible and formal, allowing for a more expressive specification of queries.

Both relational algebra and relational calculus form the theoretical foundation of SQL, the most widely used language for managing relational databases. SQL incorporates operations derived from relational algebra, such as SELECT, JOIN, and WHERE, but also incorporates elements of relational calculus, such as declarative query syntax.

SQL's set of operations, such as SELECT, JOIN, UNION, and INTERSECT, corresponds closely to relational algebra operations. Understanding relational algebra can improve one’s ability to optimize SQL queries and design efficient databases.

The declarative nature of SQL is based on relational calculus. SQL queries specify what data is needed (like relational calculus) and leave the optimization and execution details to the database management system.

Relational algebra and relational calculus are both critical in understanding the theory behind relational database management systems. They provide the foundation for querying data, with relational algebra focusing on the procedural aspects and relational calculus offering a more declarative approach. These two elements together have influenced the development of SQL, which has become the standard language for managing relational databases. A deep understanding of relational algebra and calculus is essential for anyone looking to become proficient in relational database design and optimization.

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