

Foundations of Computer Science - SQL

1 Relational Databases

1.1 Introduction

The relational DBs are organized in tables that can be linked together. A table in the relational model represents, itself, a relation. For example in the following database each row describes a single book:

ISBN	Title
978-1-449-30321-1	Scaling MongoDB
978-1-491-93200-1	Graph Databases
978-1-449-39041-9	Cassandra: The Definitive Guide
007-709500-6	Database Systems

Table 1: Some sample books

The data in a relational model are organized into columns and each entry(cell) contains a **SINGLE** piece of data, so the main problem of relational model is to handle data with multiple elements in a single column for example a book with two authors.

The solution proposed by the relational model is to link two tables and to do so we need an identifier ID for each row. Here is an example of two linked tables.

book_id	ISBN	Title
1	978-1-449-30321-1	Scaling MongoDB
2	978-1-491-93200-1	Graph Databases
3	978-1-449-39041-9	Cassandra: The Definitive Guide
4	007-709500-6	Database Systems

Table 2: Books Table with ID

author_id	Name	Surname
1	Ian	Robinson
2	Kristina	Chodorow
3	Riccardo	Torlone
4	Paolo	Atzeni
5	Stefano	Ceri
6	Stefano	Paraboschi
7	Eben	Hewitt

Table 3: Authors Table with ID

To connect these two tables we use a “relation” or “join” table. In the example the “join” table is the following:

book_id	author_id
2	1
3	7
1	2
4	4
4	5
4	6
4	3

Table 4: BookAuthors Table

In the Table 4 we can see the need of using an ID (named Foreign Key) to identify each row, so it can be referenced uniquely. In some cases we might not need a third table (join table): one of these cases is the “One-to-Many” relationship. The One-to-Many relationship also requires that rows in tables have unique IDs, but unlike the join table used in Many-to-Many relationship, the table with the many side of data has a column reserved for the IDs of the one side of data.

The IDs used to uniquely identify the rows described in the tables are called “Primary Keys”(PK). If this primary key is used in another table it is called “Foreign Key”(FK) and it is usually not unique in the new table. The purpose of the foreign key is to link the two tables in one-to-many relationship.

Usually the primary key generation process is left to the RDBMS (it’s safer this way), which automatically generates the key and usually it is an ordinary integer. For the join tables, the primary key is a combination of the foreign keys. A primary key comprised of more than one attribute is called a “Composite Primary key”(CPK).

1.2 Normal Forms

The First Normal Form (1NF) says that the types must be atomic (the table must be flat) so we cannot have a cell with multiple data(multi-list) in it. This causes some anomalies such as:

- Redundancy: Same data is repeated multiple times. For example, in a university timetable(we will use this example for the whole list), if every course is in only one room we have two attributes: one with the Course and one with the Room, which is redundant.
- Update anomaly: when we update a value of a cell. For example if we update room name in a cell we don’t automatically have an update on all the cell containing that room or the course.
- Delete anomaly: if all the data using a specific information is dropped we lose that specific information too. For example if everyone in drops a class we lose what room the class is in.
- Insert anomaly: we can’t use a specific information without some other data using it. Example is similar to delete anomaly: we cannot reserve a room for a course without having students.

To overcome these anomalies other Normal Forms have been created. To introduce them first we need to introduce a Functional dependency (FD).

Def: Let A, B be sets of attributes, we write $A \rightarrow B$ or say A functionally determines B if, for any tuple t_1 and t_2 :

$$t_1[A] = t_2[A] \Rightarrow t_1[B] = t_2[B]$$

and we call $A \rightarrow B$ a **functional dependency**.

In normal words whenever two tuples agree on A they agree on B. A functional dependency is a form of constraint.

Note: It is easy to disprove a functional dependency, you need only a instance violating it, but to prove it we need to check every valid instance.

We define the **superkey** as a set of attribute A_1, \dots, A_n such as for any other attribute B in the relation R, we have $\{A_1, \dots, A_n\} \rightarrow B$. In other words a super key is a set of one or more attributes (columns), which can uniquely identify a row in a table. A **key** is a minimal superkey (only one attribute) i.e. no subset of a key is a superkey.

The idea to have a normalized database is to search for “bad” FDs: if there are any, then decompose the table into sub-tables (linked usually) until no more bad FDs. When done the database schema is normalized. The normal form are distinct from each other depending on what they define as “bad” FDs.

For the Boyce-Codd Normal Form (BCNF) defines $X \rightarrow A$ as a “good” FD if X is a (super)key and “bad” otherwise. BCNF is a simple condition for removing anomalies from the relations: A relation R is in BCNF if $\{A_1, \dots, A_n\} \rightarrow B$ is a non-trivial FD in R then $\{A_1, \dots, A_n\}$ is a superkey for R.

The problem with BCNF is that to enforce a FD, we must reconstruct original relation on each insert. It’s solution is usually a tradeoff between redundancy/data anomalies and FD preservation.

2 SQL

2.1 Introduction

SQL stands for Structured Query Language and it is a standard language for querying and manipulating data. It is a very high-level programming language and it is very well optimized.

SQL is a:

- Data Definition Language (DDL):
It defines relation *schema* and creates/alters/deletes tables and their attributes.
- Data Manipulation Language (DML):
It Inserts/deletes/modifies tuples in tables and queries one or more tables.

A **relation** (or **table**) in SQL is a multiset of tuples having the attributes specified by the schema. As **multiset** we mean that is an unordered list (so multiple duplicates instances are allowed) and an **attribute** is a typed data entry present in each tuples in the relation. An attribute must have an atomic type in standard SQL. The atomic types are:

- Characters: CHAR(20), VARCHAR(50)
- Numbers: INT, BIGINT, SMALLINT, FLOAT
- Others: MONEY, DATETIME, etc.

A **tuple** (**row**) is a single entry in the table having the attributes specified by the schema.

The **schema** of a table is the table name, it’s attributes and they types, a key is an attribute whose values are unique. A **key** is a minimal subset of attributes that acts as a unique identifier for tuples in a relation.

A key is an implicit constraint on which tuples can be in the relation: so if two tuples agree on the same value of the key, then they must be the same tuples.

If some information is missing or is not known SQL uses the NULL value. To check if a value is NULL we cannot say value=NULL since it’s unknown. We need to use “IS NULL” command of SQL. SQL offers the possibility to constrain a column to be NOT NULL or supports other constraints such as maximum number of values per attributes. It’s thanks to the schema and constraints that the databases understand the semantics of the data.

2.2 Constraints in SQL

A constraint is a relationship among data elements that the DBMS is required to enforce. The triggers are executed when a specified condition occurs, it’s usually easier to implement than a constraint. Kinds of constraints are:

- (Foreign) Keys
- Value-Based constraint (constrain a certain value)
- Tuple-Based constraint (relationship among components)
- Assertion (any SQL boolean expression)

When creating a table we create a key using a constraint of UNIQUE or PRIMARY KEY. While expressing a Foreign Key we need to use the keyword REFERENCES after an attribute or as an element of the schema and the referenced attribute must be declared either as a PRIMARY KEY or UNIQUE. Here is an example:

```
--For the single attribute key
CREATE TABLE table_1(
    attribute_1 CHAR(20) UNIQUE,
    attribute_2 VARCHAR(20)
);

--For the multi-attribute key
CREATE TABLE table_2(
    attribute_1 CHAR(20),
    attribute_2 VARCHAR(20),
    attribute_3 REAL,
    PRIMARY KEY (attribute_1,attribute_2)
);

--Foreign key reference example
CREATE TABLE table_1(
    attribute_1 CHAR(20) UNIQUE,
    attribute_2 VARCHAR(20)
);
CREATE TABLE table_2(
    attribute_3 CHAR(20),
    attribute_4 VARCHAR(20) REFERENCES table_1(attribute_1),
    attribute_5 REAL,
);

--Foreign key as schema element
CREATE TABLE table_1(
    attribute_1 CHAR(20) UNIQUE,
    attribute_2 VARCHAR(20)
);
CREATE TABLE table_2(
    attribute_3 CHAR(20),
    attribute_4 VARCHAR(20),
    attribute_5 REAL,
    FOREIGN KEY(attribute_4) REFERENCES table_1(attribute_1)
);
```

Once we have a foreign key constraint there are two possible violations:

1. Insert or update to table_2, that introduces values not found in table_1.
2. Delete or update to table_1, causing some tuples of table_2 to be disrupted.

In case of 1. we reject such operation. In case 2. in case of deletion or update we can proceed in three different ways:

1. Default: Reject the modification like in case of 1.
2. Cascade: Make the same changes in table_2, in case of deletion (update) of a row of table_1, delete (update) all the related tuples of table_2.
3. Set NULL: Change the element to NULL.

One of these policies need to be chosen. We choose them while declaring the Foreign key and are of form (after foreign key declaration): ON [UPDATE,DELETE] [SET NULL CASCADE], if not declared the default(reject) is used. Here is an example:

```

CREATE TABLE table_1(
attr_1 CHAR(20) UNIQUE,
attr_2 VARCHAR(20)
);
CREATE TABLE table_2(
attr_3 CHAR(20),
attr_4 VARCHAR(20),
attr_5 REAL,
FOREIGN KEY(attr_4)
REFERENCES table_1(attr_1)
ON DELETE SET NULL
ON UPDATE CASCADE
);

```

Some other constraint are Attribute-Based checks to constraint on the value of a particular attribute. In this case add CHECK(<condition>) to the declaration for the attribute. We might use the name of the attribute in the condition but any other relation or attribute name must be in a subquery. The checks are performed only when a value for that attribute is inserted or updated. It can be added as a relation-schema element(like for the foreign key).

The last one is the Assertion, these are database-scheme elements and defined by:
 CREATE ASSERTION <name> CHECK (<condition>); the condition may refer to any relation or attribute in the database schema. For example, if there are two tables, Bars and Drinkers and we want to assert that there cannot be more bars than drinkers, the code is:

```

CREATE ASSERTION FewBar CHECK (
(SELECT COUNT(*) FROM Bars) <=
(SELECT COUNT(*) FROM DRINKERS)
);

```

In principle, we must check the assertion after every modification to any relation of the database but a clever system can observe that only certain changes could cause a given assertion to be violated. Problem is the DBMS often can't tell when they need to be checked. The Triggers let the user decide when to check for any condition. An example is when using a foreign key constraint, instead of rejecting insertions with unknown elements, a trigger can add that new element to the original table with other attributes set as NULL.

2.3 SQL Data Manipulation Operations

2.3.1 Basic Commands for a single table

To project a table we use SELECT FROM:

```

SELECT <attributes>
FROM <one or more relations>
WHERE [optional]<conditions>

```

If after SELECT in the attributes we use * we select all of the attributes. Note that the commands are case insensitive but the values are case sensitive and when using condition on strings we have to use single quotes 'value' and not the double ones.

Assume having a table of authors named Authors with the following schema:

id	last_name	first_name	DoB	income	genre
INT	CHAR	CHAR	DATETIME	REAL	CHAR

For the duplicated values we can use DISTINCT after SELECT and in there WHERE we can have more than one conditions using AND or OR.

For conditions on strings we have the following syntax: % means “any string”, _(underscore) means “any character” and when using them we need to use LIKE in WHERE clause. To order them we have to use ORDER BY (DESC) <attribute>, DESC for descending order by default is ascending, here is an example using all the points:

```
--Distinct Genres of Authors whose name start with S and the third letter is a
SELECT DISTINCT genre
FROM Authors
WHERE first_name LIKE 'S_a%'
ORDER BY DESC genre;
```

To count the number of rows use count(*) in the SELECT clause. To count the number of values not null in a specific column use count(column1,column2) in the SELECT clause. Some of the other operations that can be done in the SELECT clause are AVG, SUM, MIN, MAX.

This operations are heavily used together with GROUP BY. GROUP BY is useful to aggregate the data, if we want to calculate the average income for each genre we do it as follows:

```
SELECT genre, AVG(income)
FROM Authors
GROUP BY genre;
```

Attention: we can have in SELECT only the attributes present in GROUP BY or other attributes with some aggregate operation only, never by themselves. All the operation mentioned were considered in the case of one table.

2.3.2 Basic Commands on two (or more) tables [JOIN/WHERE]

Now let’s focus our attention to the case of two tables. Assume having the Authors table, Books table, a BooksAuthors join table and an Editions table with the following schema:

id	last_name	first_name	DoB	income	genre
INT	CHAR	CHAR	DATETIME	REAL	CHAR

Authors Table

id	title	ISBN
INT	CHAR	BIGINT

Books Table

book_id	author_id
INT	INT

BooksAuthors Table

edition_id	book_id	date_of_publication	edition_number
INT	INT	INT	INT

Editions Table

We can use the foreign key to connect two tables either in FROM using a JOIN or in WHERE. Here are these two methods:

```
--WHERE version to find author of book_id = 1
SELECT first_name, last_name
FROM Authors, BooksAuthors
```

```

WHERE BooksAuthors.author_id = Authors.id
    AND book_id = 1;
-- JOIN version to find author of book_id = 1
SELECT first_name, last_name
FROM Authors JOIN BookAuthors
    ON BooksAuthors.author_id = Authors.id
WHERE book_id = 1;
--JOIN version is preferred when only 2 tables are involved

```

Some result of the JOIN might be duplicated if the foreign key is present in the table more than 1 times, it might be useful to use DISTINCT in this case. Here is an example to find who has written a book whose ISBN ends with 5 and has last name with exactly 5 characters, here we need to use 3 table so we will use the WHERE version of linking tables:

```

SELECT Books.id, ISBN, Authors.id, last_name, first_name
FROM Books, Authors, BooksAuthors
WHERE Books.id = BooksAuthors.book_id AND
    BooksAuthors.author_id = Authors.id AND
    last_name LIKE '_____' AND
    isbn LIKE "%5"

```

Sometimes it become more complex to write down the table name every time so we can give the aliases. For example we call Books - b, Authors - a and BooksAuthors - ba and use the same query as before but easier to write down:

```

SELECT b.id, ISBN, a.id, last_name, first_name
FROM Books b, Authors a, BooksAuthors ba
WHERE b.id = ba.book_id AND
    ba.author_id = a.id AND
    last_name LIKE '_____' AND
    isbn LIKE '%5'

```

The Join semantics between two Tables T1 and T2 is a cross product between T1 and T2, then it selects the rows satisfying the WHERE clause and then it projects on the columns in the SELECT clause.

Assume that a author has written no books, when we do join between Authors and BooksAuthors that author will not appear. If we want him to appear we need to use LEFT JOIN with Authors on the LEFT, here is an example of the outer join(which is a union and the inner join is a intersection):

```

SELECT Authors.id, last_name, first_name, Books.id, ISBN
FROM Books, Authors LEFT JOIN BooksAuthors
    ON Authors.id = BooksAuthors.author_id
WHERE Books.id = BooksAuthors.book_id
--Now in the result we will se also the authors with Books.id and ISBN value as NULL (no books
    were written)

```

We can give also the projected columns an alias, here is an example where we count the number of books written by an author, using an outer join to have also the authors with 0 books:

```

SELECT Authors.id, last_name, first_name ,
    count(Books.id) as number --Here is how to rename a column
FROM Books, Authors LEFT JOIN BooksAuthors
    On Authors.id = BooksAuthors.author_id
WHERE Books.id = BooksAuthors.author_id
GROUP BY Author.id, last_name, first_name; --Here we need all the columns written in the SELECT

```

2.4 SET Operations

We can intersect two or more tables using the INTERSECT clause, it acts as the normal intersection between two sets where sets are the rows. It is rarely used because can be replaced with a more complex WHERE condition (for example using AND). Here is an example to find Authors with Income>90000 and with the last name containing an o:

```
SELECT last_name, first_name
FROM Authors
WHERE Income > 90000
INTERSECT
SELECT last_name, first_name
FROM Authors
WHERE last_name LIKE '%o%'

--Equivalent "complex" WHERE AND condition
SELECT last_name, first_name
FROM Authors
WHERE Income > 90000 AND last_name LIKE '%o%'
```

We can also do the UNION between two sets, also this one is rarely used because it can be replaced by a more complex WHERE condition if no duplicates are there. To do union with duplicates UNION ALL can be used. Here is an example to find authors with income>90000 or name containing an o:

```
SELECT last_name, first_name
FROM Authors
WHERE Income > 90000
UNION
SELECT last_name, first_name
FROM Authors
WHERE last_name LIKE '%o%'

--If no duplicates equivalent is the WHERE - OR
SELECT last_name, first_name
FROM Authors
WHERE Income > 90000 OR last_name LIKE '%o%'

--Union with duplicates
SELECT last_name, first_name
FROM Authors
WHERE Income > 90000
UNION ALL --Here is the difference
SELECT last_name, first_name
FROM Authors
WHERE last_name LIKE '%o%'
```

One command of the set operation that is used in practice is the EXCEPT which is a difference between two sets, it can be replaced with a much more complex nested query.

```
SELECT last_name, first_name
FROM Authors
WHERE Income > 90000
EXCEPT
SELECT last_name, first_name
FROM Authors
WHERE last_name LIKE '%o%'
```

The code above will return us all the author with income>90000 and the last name not containing an o.

2.5 Nested Queries

We can replace some of the SET operations with nested queries:

To remove the intersect we can proceed as follows:

```
SELECT last_name, first_name
FROM Authors
WHERE Income > 90000 AND last_name IN
  (SELECT last_name, first_name
   FROM Authors
   WHERE last_name LIKE '%o%')
```

To remove the Except:

```
SELECT last_name, first_name
FROM Authors
WHERE Income > 90000 AND last_name NOT IN
  (SELECT last_name, first_name
   FROM Authors
   WHERE last_name LIKE '%o%')
```

There are also other uses of the nested queries for example finding the author with maximum income:

```
SELECT last_name, first_name
FROM Authors A1
WHERE A1.income >= ALL (SELECT A2.income
                       FROM Authors)
```

Another command that can be used after WHERE is the ANY instead of ALL. In this case the result will be every row that satisfies the condition for at least one other row of the nested query, in case of all the result is the set of rows that satisfies the condition for all of the rows in the nested query. In SQLite the command ALL is replaced by MAX.