SD202: Databases

SQL language

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General information

SQL basics

- SQL: Structured Query Language
- Language to manage data in a relational database
- Several sublanguages:
  - Data definition language: create/modify table schema
  - Data manipulation language: create/edit/query data
  - Data control language: users and rights
  - Procedural extensions: PL/SQL, SQL/PSM, PL/pgSQL...
- Implemented by common database engines

The SQL standard

EN ≡ MENU

ICS › 35 › 35.060

ISO/IEC 9075-1:2016

Information technology — Database languages — SQL — Part 1: Framework (SQL/Framework)

ABSTRACT PREVIEW

ISO/IEC 9075-1:2016 describes the conceptual framework used in other parts of ISO/IEC 9075 to specify the grammar of SQL and the result of processing statements in that language by an SQL-implementation.

ISO/IEC 9075-1:2016 also defines terms and notation used in the other parts of ISO/IEC 9075.

GENERAL INFORMATION

Status : Published

Publication date : 2016-12

Edition : 5

Number of pages : 78

SQL is an industry standard:

- First version in 1974
- Latest version in 2016
- 78 pages (not so long!)
- Price: 178 CHF (!)
- Theory: easy migration from a database engine to another
- Practice: many incompatibilities
- Practice: database engines do not usually implement the full standard, and/or add extensions

Declarativity

SQL is a declarative language:

- specify what you want
  - “find all female actors who played in Hollywood movies”
- not how to compute it

Declarativity

SQL is a **declarative** language:

- specify **what** you want
  - "find all female actors who played in Hollywood movies"
- not **how** to compute it
  - this was presented as a "**relational language**" in the previous class (`DROP`, `FILTER`, etc.)
  - "take all films and keep the ones from Hollywood, then take the actors who played there and keep the ones who are female"
  - "take all actors and keep the ones who are female, then take the films where they played and keep the ones from Hollywood"

The database engine will translate SQL to a concrete **execution plan** (more later)

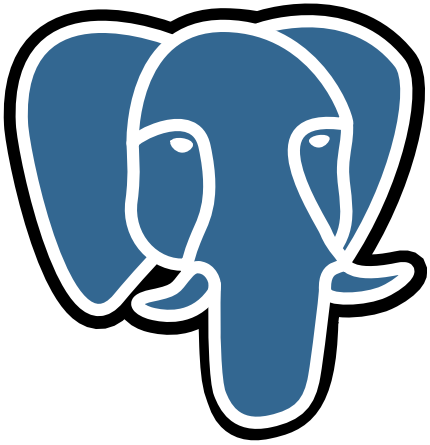
Basic syntax

```
SELECT * FROM Movie WHERE title = 'Avatar';
```

- Keywords are English words and (typically) in uppercase
- Whitespace is ignored (line breaks, etc.)
- Statements are finished by a semicolon
- Comments, with `--` or `/* ... */`

Implementation and setup

Step 1: installing an RDBMS



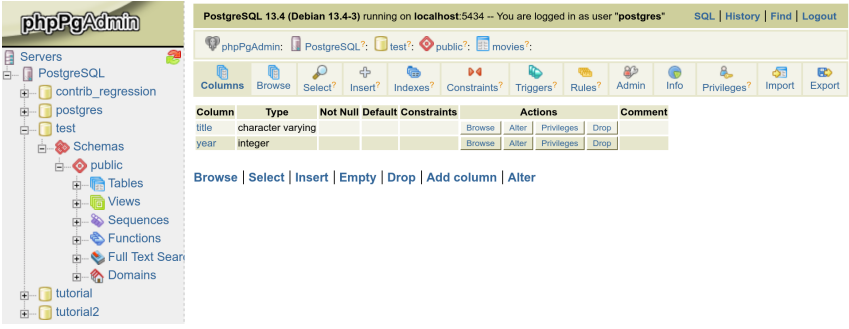
- Install a Relational DataBase Management System
- Let's choose PostgreSQL

Step 2: interacting with the RDBMS

- Simplest way: use the command line
- Special commands (for PostgreSQL):
  - `\l` to list databases
  - `\c database` to change database
  - `\dt` to list tables
  - `\d table` to show details about a table
- You can issue commands (do not forget the semicolon)
- You can retrieve query results on standard output
- You can pipe a command from standard input

Step 2a: using a graphical interface

You can install phppgadmin:



Step 2b: using an API

First create a user to connect to the database:

```
CREATE USER testuser WITH ENCRYPTED PASSWORD 'PASS'
GRANT ALL PRIVILEGES ON DATABASE test TO testuser;
\c test
GRANT ALL PRIVILEGES ON ALL TABLES IN SCHEMA public TO testuser;
```

Then write code (here, psycopg2 with Python):

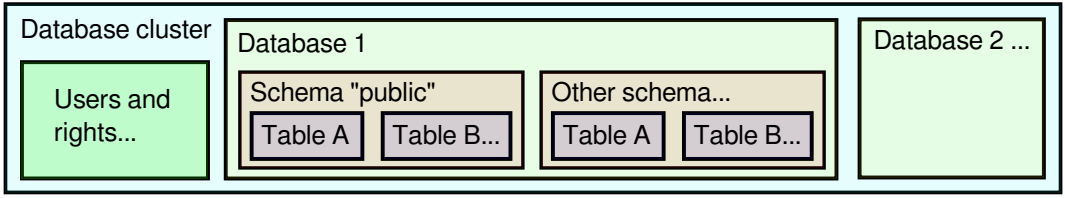
```
import psycopg2
conn = psycopg2.connect(
    "host=localhost dbname=test port=5434 user=testuser password=PASS")
cur = conn.cursor()
cur.execute("SELECT * FROM Movies")
print (cur.fetchone())
conn.close()
```

Other approach: SQLite

- Install `sqlite`
- Run `sqlite3 file.sqlite`
- That's it!
- Graphical interface: `sqlitebrowser`

Schema creation

Overall structure



- A database cluster contains users/groups and databases
- A database contains several schemas (the default one is public)
- A schema contains tables
  - The same table name can occur in multiple schemas
  - Can be qualified with the schema name
  - Notion of search path to disambiguate unqualified names
- A table has a structure (also called its schema) and data (rows)

Basics

Recall that the relational model is composed of several tables:

Movie

id	name	year
1	Avatar	2009
2	Avengers: Endgame	2019

Basic instruction to create a table:

```
CREATE TABLE Movie(id SERIAL, title VARCHAR, year INT);
```

Naming tables and attributes

- Table names should be singular
- No accents, no special characters, underscores rather than spaces
  - You can use double quotes for this, but discouraged
- Table and attribute names are not case-sensitive
  - Except if using double quotes – still discouraged
- Probably have a column named id for the primary key (later)
- Several tables can have the same attribute name, but they will need to be disambiguated (e.g., `R.id` vs `S.id`)
- Avoid any reserved names (e.g., `end`)
- Most important: consistency!

Basic PostgreSQL types

- `BOOLEAN` for Boolean values
- `INT` for integers (4-byte)
  - `SERIAL` for an auto-incrementing identifier (4-byte), or `AUTO_INCREMENT` with MySQL
- `REAL` for floating-point numbers (4-byte)
- `NUMERIC` for high-precision numbers (1000 digits)
- `TEXT` or `VARCHAR`: text
  - `VARCHAR(42)`: text of length at most 42
- `BYTEA` or `BLOB` for binary strings
- `TIMESTAMP` for date and time (can be `WITH TIME ZONE`), `DATE`, etc.
- Other: money, enumerated types (enums), geometric types, JSON and XML, network addresses, UUIDs, arrays…

Modifying and deleting a table

```
ALTER TABLE Movie ADD COLUMN test BOOLEAN;
ALTER TABLE Movie ALTER COLUMN test TYPE int USING test::integer;
ALTER TABLE Movie RENAME COLUMN test TO test2;
ALTER TABLE Movie DROP COLUMN test;
ALTER TABLE Movie RENAME TO Movie2;
DROP TABLE Movie2;
```

Constraints

We can enforce some constraints on the tuples that we create:

- Check constraints
- Keys and uniqueness constraints (related to schema design)
- Foreign key constraints

Check constraints

```
CREATE TABLE Filming(id SERIAL PRIMARY KEY, title VARCHAR,
  tstart DATE CHECK (tstart > '1895-01-01'),
  tend DATE,
  CHECK (tstart < tend));
```

- Constraints can check values in the current tuple
- You can give names to constraints to refer to them
- Special case: `NOT NULL` to disallow the default value (`NULL`)

Primary keys and uniqueness constraints

- `PRIMARY KEY`: value is unique, non-`NULL`, and is the “main way” to refer to a tuple of the table
  - In practice, you often use a column `id` just for that purpose
  - Can be an existing identifier (e.g., ISBN) if you trust it
  - Can be multiple columns for an n:n-relation (more later)
- `UNIQUE`: value (or tuple of values) is unique

These constraints automatically create an index (see later)

Foreign keys

```
ALTER TABLE Movie ADD COLUMN filming INT REFERENCES Filming(id)
```

The value of the `filming` attribute must be the `id` of a tuple in `Filming` relation

- You can have a foreign key on a tuple of columns, e.g., `FOREIGN KEY (a, b) REFERENCES Table(c, d)`)
- The target attribute(s) must have a uniqueness constraint
  - Usually, it is the primary key, and you can omit the attribute name
- `NULL` is allowed (unless you imposed `NOT NULL`)
- This constraint can be broken when changing the referenced table!

Repairing foreign key violations

- Default: prohibit deletion (except in a transaction, see later)
- `ON DELETE RESTRICT`: completely prohibit deletion
- `ON DELETE CASCADE`: also delete referencing tuples (dangerous)
- `ON DELETE SET NULL`: replace the reference by a `NULL`
- `ON DELETE SET DEFAULT`: replace the reference by the default value (which must also obey the foreign key constraint)
- Same questions when updating tuples

Creating data

INSERT query

```
INSERT INTO Movie (title, year) VALUES ('Titanic', '1997');
```

- Can specify multiple tuples to insert
- Can omit the field names, they are then filled in order
- Instead of specifying `VALUES`, we can put a `SELECT` query to execute on existing data (see later)

Default values for an insert

For fields that are not specified:

- For a `SERIAL`, automatically use a "next" value
- If a `DEFAULT` value was supplied, use it
- Otherwise, use `NULL`
- (Failure if `NOT NULL` was specified)

Performance of bulk `INSERT`s

Doing multiple `INSERT`s can be slow... to improve performance:

- Do the `INSERT`s within a single transaction rather than committing after each `INSERT`
- Run a single `INSERT` command with multiple values
- Temporarily remove keys and indexes (and rebuild them at the end)
- Use the `COPY` command to load a file directly

Reading data

Most basic `SELECT` query

```
SELECT * FROM Movie;
```

```
 id |            title              | year
----+-------------------------------+------
  1 | Frozen II                     | 2019
  2 | Titanic                       | 1997
  3 | Avengers: Endgame             | 2019
  4 | Avengers: Infinity War        | 2018
  5 | Star Wars: The Force Awakens | 2015
  6 | Avatar                        | 2009
```

Projection: removing some attributes

```
SELECT year FROM Movie;
SELECT DISTINCT year FROM Movie;
SELECT DISTINCT ON (year) * FROM movie;
```

The `DISTINCT` keyword is not enabled by default (performance)

Renaming output attributes

```
SELECT title AS t, year AS y FROM Movie;
```

```
 id |            t                  | y
----+-------------------------------+------
  1 | Frozen II                     | 2019
  2 | Titanic                       | 1997
  3 | Avengers: Endgame             | 2019
  4 | Avengers: Infinity War        | 2018
  5 | Star Wars: The Force Awakens  | 2015
  6 | Avatar                        | 2009
```

Filtering: the `WHERE` clause

```sql
SELECT * FROM Movie WHERE year = '2019';
SELECT title FROM Movie WHERE year = '2019';
SELECT title FROM Movie WHERE year = '2019' AND title LIKE '%Frozen%';
```

Possible conditions

- Compare attribute values to constants, or among themselves
- Test equality, inequality, order
- Boolean conditions : `AND`, `OR`, `NOT`
- Value lists: `year IN ('2019', '43')`
- `LIKE` operator: tests string equality to a pattern with '`%`' and '`_`'
  - `ILIKE`: case-insensitive
- More complex expressions, e.g., `WHERE LENGTH(title) > 10`
- For performance, distinguish between:
  - Conditions that require a full scan of the table
  - Conditions implementable using indexes

Selecting multiple tables: PRODUCT

```
SELECT * FROM Movie, Actor;
SELECT * FROM Movie, Actor, Actor_in_movie;
```

Exercise: how to select the titles of movies and the names of actors who played in that movie?

Selecting multiple tables: PRODUCT

```
SELECT * FROM Movie, Actor;
SELECT * FROM Movie, Actor, Actor_in_movie;
```

Exercise: how to select the titles of movies and the names of actors who played in that movie?

We want to do a join:

```
SELECT title, year, name FROM Movie, Actor, Actor_in_movie
    WHERE Actor.id = Actor_in_movie.actor
    AND Movie.id = Actor_in_movie.movie;
```

Note the disambiguation of ambiguous attribute names

Other kinds of join

```
SELECT title, actor FROM Movie, Actor_in_movie
      WHERE Movie.id = Actor_in_movie.movie;
SELECT title, actor FROM Movie INNER JOIN Actor_in_movie
      ON Movie.id = Actor_in_movie.movie;
SELECT title, actor FROM Movie LEFT OUTER JOIN Actor_in_movie
      ON Movie.id = Actor_in_movie.movie;
SELECT title, actor FROM Movie RIGHT OUTER JOIN Actor_in_movie
      ON Movie.id = Actor_in_movie.movie;
SELECT title, actor FROM Movie FULL OUTER JOIN Actor_in_movie
      ON Movie.id = Actor_in_movie.movie;
```

Can you guess the difference?

Difference between joins

These two are equivalent: they drop any rows that do not match:

```
SELECT title, actor FROM Movie, Actor_in_movie WHERE Movie.id = Actor_in_movie.movie;
SELECT title, actor FROM Movie INNER JOIN Actor_in_movie ON Movie.id = Actor_in_movie.movie;
```

This one adds one copy of the left table rows that do not match (with `NULL`s):

```
SELECT title, actor FROM Movie LEFT OUTER JOIN Actor_in_movie ON Movie.id = Actor_in_movie.movie;
```

Likewise for the right table rows:

```
SELECT title, actor FROM Movie RIGHT OUTER JOIN Actor_in_movie ON Movie.id = Actor_in_movie.movie;
```

Likewise for both tables:

```
SELECT title, actor FROM Movie FULL OUTER JOIN Actor_in_movie ON Movie.id = Actor_in_movie.movie;
```

Exercise: In this example, some of these are equivalent. Why?

Unioning: `UNION`

```
SELECT * FROM Teacher UNION SELECT * FROM Actor;
```

- The number of columns and types must be the same (but the names do not have to be)
- Removes duplicates unless you use `UNION ALL`

Difference: EXCEPT

```
SELECT id FROM Teacher EXCEPT SELECT id FROM Actor;
```

- Same condition on columns; also `EXCEPT ALL`
- Also `INSERSECT` and `INTERSECT ALL` for intersection

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- Same condition on columns; also `EXCEPT ALL`
- Also `INSERSECT` and `INTERSECT ALL` for intersection

Exercise: how to express `INTERSECT` using a `WHERE` clause?

Ordering data

By default, the data is not sorted and the order is not consistent:

- `ORDER BY date`
- `ORDER BY date DESC`
- `ORDER BY a + b`

`LIMIT` and `OFFSET`

Sometimes, we do not want the full result (e.g., pagination)

- `LIMIT 1`
- `LIMIT 2`
- `OFFSET 1 LIMIT 1`
- `OFFSET 1 LIMIT 2`

Do not forget to use `ORDER BY`!

Advanced SELECT clauses

Groups and aggregation

```
SELECT genre, MAX(year) FROM Movie GROUP BY genre;
```

- Create one group per value of `genre` (could be multiple attributes)
- Attributes not in `GROUP BY` can only be aggregated
- Common aggregate functions: min, max, count, average, sum

Advanced aggregation

- You can filter out groups with a `HAVING` clause (like `WHERE`, but evaluated after the aggregation)
- You can also use window functions to compute aggregates in a rolling fashion following some partitioning of the data

```
SELECT *, RANK() OVER (PARTITION BY genre ORDER BY id) AS rank
    FROM Movie;
SELECT *, MIN(year) OVER (PARTITION BY genre ORDER BY year) AS minyear
    FROM Movie;
```

Subqueries in FROM

The FROM clause of a SELECT query can refer to a table evaluated with another SELECT query:

```
SELECT * FROM
    (SELECT * FROM Movie WHERE title LIKE 'Avengers%') AS M1
    WHERE year = '2019';
```

The subquery must have an alias (here, M1), even if it is not used

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Exercise: Can you simplify this query?

Subqueries in `WHERE` (with `EXISTS`, etc.)

The `WHERE` clause of a `SELECT` query can check existence of a query result

```
SELECT id, title FROM Movie WHERE EXISTS
    (SELECT 1 FROM Actor_in_movie WHERE movie = Movie.id);
```

Other possibility:

```
SELECT id, title FROM Movie WHERE id IN
    (SELECT movie FROM Actor_in_movie);
```

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Other operators : `= ANY`, `= SOME`, etc.

Exercise

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```
-- first select the greatest year
SELECT max(year) AS maxyear FROM Movie;
-- now select where the year is greatest
SELECT title, year
    FROM Movie, (SELECT max(year) AS maxyear FROM MOVIE) AS T
    WHERE Movie.year = T.maxyear;
```

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```

How can you find the latest films for each genre?

```
SELECT title, year, Movie.genre FROM Movie,
    (SELECT genre, max(year) AS maxyear FROM MOVIE GROUP BY genre) AS T
    WHERE Movie.year = T.maxyear AND Movie.genre = T.genre;
```

Recap: full SELECT syntax

```
SELECT [DISTINCT] [attrs]
FROM [tables, possibly with subexpressions]
WHERE [condition]
GROUP BY [grouping element]
HAVING [filter on groups]
UNION/INTERSECT/EXCEPT [ALL] [other queries...]
ORDER BY [criterion]
LIMIT [limit]
OFFSET [offset]
```

Modifying and deleting data

`DELETE` and `TRUNCATE` commands

To remove tuples:

```
DELETE FROM Table WHERE [condition]
```

Warning:

- This can remove more data than expected if the condition is wrong
- There is no confirmation

To remove all rows (faster):

```
TRUNCATE TABLE Table
```

Warning: this will remove all data (without confirming)

`UPDATE` command

```sql
UPDATE Actor SET name = 'Eliott Page' WHERE id = 42;
UPDATE Movie SET year = year+1 WHERE title LIKE 'Avengers%';
```

Warning:

- This can mess up more data than expected if the condition is wrong
- There is no confirmation!

Avoiding data disasters

- Use a transaction and only `COMMIT` when you are sure of the result
- Have backups, e.g., use `pg_dump`
- Run a `SELECT` before `UPDATE` or `DELETE`, with the same `WHERE` clause