

MAD76 Academy: E. SQL Databases

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1 Agenda

- What is SQL? (see Section 2)
- Database for MAD76 race management (see Section 3)
- SQL in Python (see Section 4)

Teaching Objectives

- Understand relational databases
- Understand relations (tables) and relationships
- Learn how to organize data in tables
- Learn how to query and manage data in SQL
- Learn how to use SQLite3
- Learn how to call SQLite from Python

2 What is SQL

- SQL (Structured Query Language) is a programming language for relational databases [1]
- SQL is an ANSI standard
- SQL is supported by many database systems
- SQL was invented by IBM in the 1970s
- SQL is used for querying, updating, and managing data in a database
- SQL can be used from command line, programming languages, and GUIs

2.1 Relational Database Systems

- A relational database is a collection of data organized in tables (relations)

SimpleCountryTable		
Name	Capital	Continent
Germany	Berlin	Europe
USA	Washington, D.C.	North America
Japan	Tokyo	Asia
France	Paris	Europe

- Each table consists of rows and columns
- Mathematical concept: Relational Algebra
- Design concept: Entity-Relationship Model (E-R Model)
 - entities (e.g, country)
 - attributes (e.g., name, capital)
 - relationships (e.g., belongs to continent)

- Tables can be related to each other through *primary* and *foreign keys*

CountryTable			
ID	Name	Capital	ContinentTable.ID
1	Germany	Berlin	1
2	USA	Washington, D.C.	2
3	Japan	Tokyo	4
4	France	Paris	1
5	Kenya	Nairobi	3
primary key			foreign key

ContinentTable	
ID	Name
1	Europe
2	North America
3	Africa
4	Asia
5	Australia
primary key	

- Relational databases use SQL for querying and managing data
- Commercial database systems: IBM DB2, Oracle Database, Microsoft SQL Server
- Open-source database systems:
 - MySQL (from Oracle)
 - MariaDB (open-source fork of MySQL)
 - PostgreSQL (advanced)
 - SQLite (serverless, alternative to file storage, only for single user, for embedded systems)

- *ACID* properties for reliable *transactions*
 - *Atomicity*: transactions are all-or-nothing
 - *Consistency*: transactions bring the database from valid states to another
 - *Isolation*: transactions do not interfere with each other
 - *Durability*: transactions are permanent, once committed (even in system crashes)
- SQLite has poor performance for multi-user web / cloud applications, since writing operations lock the entire database
 ~> extremely slow

2.2 Other Database Systems

- NoSQL databases
 - Non-relational
 - No fixed schema
 - Designed for scalability and flexibility
 - Not-only SQL: can support SQL-like queries
 - Use by large-scale web applications
 - Examples:
 - * Document stores (e.g., MongoDB, CouchDB)
 - * Key-value stores (e.g., Redis, DynamoDB)
 - * Column-family stores (e.g., Apache Cassandra, HBase)
 - * Graph databases (e.g., Neo4j, Amazon Neptune)
- Object-oriented databases: not so popular as in the 1990s

3 MAD76 Database

- MAD76 database is for race management
- and stores
 - race events
 - drivers
 - cars
 - race results: lap times
- MAD76 database is implemented in SQLite
- and stored in a single file `~labor/src/mad76/mad_ws/install/mbmadmgmt/share/mbmadmgmt/data/mad.db`

- SQLite has

- the command line interface (CLI) `sqlite3` for SQL commands

```
sqlite3 ~labor/src/mad76/mad_ws/install/mbmadmgmt/share/mbmadmgmt/data/mad.db
```

- * `sqlite3` further has special commands, e.g., `.help` or `.tables`

```
.help  
.tables
```

- * `sqlite3` can be exited by hitting Ctrl-D or typing `.exit`

- the GUI `sqlitebrowser` for browsing and editing the database

```
sqlitebrowser ~labor/src/mad76/mad_ws/install/mbmadmgmt/share/mbmadmgmt/data/mad.db
```

- application-programming interfaces (APIs) for many programming languages. We use

- * Python package `sqlite3` (see Section 4)

- * Python package `peewee`: an object-relational mapper (ORM), which maps tables to Python classes (not covered here)

3.1 MAD76 Tables (Relations)

- List the tables in mad.db with command `.tables`

```
sqlite3 ~labor/src/mad76/mad_ws/install/mbmadmgmt/share/mbmadmgmt/data/mad.db  
.tables
```

- Table race stores a list of race events
- Table driver stores a list of drivers
- Table car stores a list of cars

- Switch on headers to see the tables' column names in next commands

```
.headers on
```

Table race

race		
id	name	timestamp
1	MAD76	2025-09-28 09:11:55.926030
...
INTEGER primary key	VARCHAR(64)	DATETIME

- Display all rows (race events) of table race

```
select * from race;
```

- Display table information including column names and datatypes

```
PRAGMA table_info(race);
```

- INTEGER: integer number
- VARCHAR(n): string of maximum length n
- DATETIME: date and time

- The *primary key* is column *id* which must be unique for each row
- *Primary keys* are used as *foreign keys* in other tables for relationships

- You may create a new race event by SQL command insert

```
insert into race (name, timestamp) values ('school visit', '2025-09-29 04:00:00');
```

- Attribute id is automatically generated as the next integer number 2, because it is defined as INTEGER PRIMARY KEY

- Re-display all rows

```
select * from race;
```

Table driver

driver		
id	name	robot
1	Zeus	0
2	Apollo	0
3	Athena	0
4	Hera	0
...
INTEGER primary key	VARCHAR(64)	INTEGER 0 for human drivers, 1 for robot drivers

- Display all rows of table driver

```
select * from driver;
```

Table car

car					
id	minlaptime	maxavgspeed	carid	race_id	driver_id
1	3.99969887733459	0.391122311353683	0	1	1
2	3.7996678352356	0.411522477865219	0	1	2
3	3.3248438835144	0.470151901245117	0	1	3
4	3.57491326332092	0.437629461288452	0	1	4
...
INTEGER primary key	REAL minimum lap time of individual car in race	REAL maximum speed of individual car in race	INTEGER real car id 0 = orange/red car	INTEGER foreign key to table race	INTEGER foreign key to table driver

- Display all columns and rows of table car

```
select * from car;
```

- Display columns id and minlaptime, only

```
select id, minlaptime from car;
```

- Compute all-time best lap time of all cars in all races

```
select min(minlaptime) from car;
```

- Compute average lap speed of all cars in all races

```
select avg(maxavgspeed) from car;
```


3.2 Joining Tables

- Tables can be joined by *inner join*, *left join*, *right join*, and *full outer join*
- Joins are based on relationships through primary and foreign keys
- Here: *inner join* of tables *car* and *driver* by matching `car.driver_id = driver.id`

```
select car.id, car.minlaptime, driver.name from car inner join driver on car.driver_id = driver.id;
```

- Sort by minimum lap time

```
select car.id, car.minlaptime, driver.name from car inner join driver on car.driver_id = driver.id order by car.minlaptime;
```

- Alternative short form

```
select car.id, car.minlaptime, driver.name from car, driver where car.driver_id = driver.id order by car.minlaptime;
```

- This is how the ranking table is computed on MAD76 webpage <http://localhost:8082>

3.3 So why do we split data into multiple tables?

- To reduce data redundancy and improve data integrity
- To organize data in a logical way
- To make it easier to manage and query data
- To allow for more flexible and efficient data access (less memory and CPU usage)
- Bad design would be to store all data in a single table

race_driver_car					
id	race	driver	carid	minlaptime	maxavgspeed
1	Sunday	Athena	0	0.3	0.5
2	Sunday	Zeus	0	0.35	0.4
3	Sunday	Apollo	0	0.4	0.45
4	Monday	Athena	0	0.5	0.6
5	Monday	Zeus	0	0.55	0.65

- Redundant (duplicate) data: Driver and race names are repeated
- No data integrity: If a driver's name or race name changes, it must be updated in multiple rows
- Avoid redundancy by *normalization* (*normal forms 1 to 5*) [1]

4 SQL in Python

- Package sqlite3 allows calling SQL commands from Python

```
import sqlite3 as sql

# Connect to the database
db = sql.connect('~labor/src/mad76/mad_ws/install/mbmadmgmt/share/mbmadmgmt/data/mad.db')

# Execute SQL commands
rows = db.execute("select car.id, car.minlaptime, driver.name from car inner join driver on car.driver_id = driver.id order by car.minlaptime").fetchall()
for row in rows:
    print(row)

# Close the connection
db.close()
```

- `fetchall()` returns a list of tuples containing the query result
- Each tuple contains one row of the result
- Each element of the tuple contains one column of the result

References

- [1] Edwin Schicker. *Datenbanken und SQL*. 6th. Springer, 2025.