LECTURE 16

SQL I

SQL and Databases: An alternative to Pandas and CSV files.

In a scale of 0-10, how would you rate your skills in SQL?

0: No background at all!
10: I am an expert!

Go to www.menti.com and use the code 3066 0696

Why Databases

- **Why Databases**
- Intro to SQL
- Tables and Schema
- Basic Queries
- Grouping

Previously: CSV Files and Pandas

we've usually worked with data stored in CSV files.

`Calls_for_Service.csv` → `pd.read_csv` ↓

	CASENO	OFFENSE	EVENTDT	EVENTTM	CVLEGEND	CVDOW	InDbDate	Block_Location	BLKADDR	City	State
0	21014296	THEFT MISD. (UNDER $950)	04/01/2021 12:00:00 AM	10:58	LARCENY	4	06/15/2021 12:00:00 AM	Berkeley, CA\n(37.869058, -122.270455)	NaN	Berkeley	CA
1	21014391	THEFT MISD. (UNDER $950)	04/01/2021 12:00:00 AM	10:38	LARCENY	4	06/15/2021 12:00:00 AM	Berkeley, CA\n(37.869058, -122.270455)	NaN	Berkeley	CA
2	21090494	THEFT MISD. (UNDER $950)	04/19/2021 12:00:00 AM	12:15	LARCENY	1	06/15/2021 12:00:00 AM	2100 BLOCK HASTE ST\nBerkeley, CA\n(37.864908,...	2100 BLOCK HASTE ST	Berkeley	CA
3	21090204	THEFT FELONY (OVER $950)	02/13/2021 12:00:00 AM	17:00	LARCENY	6	06/15/2021 12:00:00 AM	2600 BLOCK WARRING ST\nBerkeley, CA\n(37.86393...	2600 BLOCK WARRING ST	Berkeley	CA
4	21090179	BURGLARY AUTO	02/08/2021 12:00:00 AM	6:20	BURGLARY - VEHICLE	1	06/15/2021 12:00:00 AM	2700 BLOCK GARBER ST\nBerkeley, CA\n(37.86066,...	2700 BLOCK GARBER ST	Berkeley	CA

Perfectly reasonable workflow for small data that we're not actively sharing with others.

Brief Databases Overview

A **database** is an organized collection of data.

A **Database Management System (DBMS)** is a software system that **stores**, **manages**, and **facilitates access** to one or more databases.

Advantages of DBMS over CSV (or Similar)

Data Storage:

- **Reliable storage** to survive system crashes and disk failures.
- Optimize to **compute on data that does not fit in memory**.
- Special data structures to **improve performance**.

Data Management:

- Configure how data is **logically organized** and **who has access**.
- Can enforce guarantees on the data (e.g. non-negative person weight or age).
    - Can be used to **prevent data anomalies**.
    - Ensures **safe concurrent operations** on data (multiple users reading and writing simultaneously, e.g. ATM transactions).

Intro to SQL

- Why Databases
- **Intro to SQL**
- Tables and Schema
- Basic Queries
- Grouping

SQL

Today we'll be using a programming language called "Structured Query Language" or **SQL**.

- SQL is its own programming language, totally distinct from Python.
- SQL is a special purpose programming language used specifically for communicating with databases.
- We will program in SQL using Jupyter notebooks.

How to pronounce? An ongoing debate.

Let's see a quick demo of how we can use SQL to connect to a database and view a SQL table.

Quick SQL Overview

name	year	cute
hiccup	2010	10
drogon	2011	-100
dragon 2	2019	0

Dragon

name	type	cost
ravioli	entree	10
pork bun	entree	7
taco	entree	7
edamame	appetizer	4
fries	appetizer	4
potsticker	appetizer	4
ice cream	dessert	5

Dish

...

SQLite database

SQL query

```
SELECT *
FROM Dish;
```

results

name	type	cost
ravioli	entree	10
pork bun	entree	7
taco	entree	7
edamame	appetizer	4
fries	appetizer	4
potsticker	appetizer	4
ice cream	dessert	5

jupyter

Demo

Step 1: Load the SQL Module

Our first step is to load the SQL module. We do so using the `ipython` **cell magic** command:

```
%load_ext sql
```

Step 2: Connect to a Database

Our first step is to load the SQL module. We do so using the `ipython` **cell magic** command:

```
%load_ext sql
```

The second step is to connect to a database.

We use the `%%sql` header to tell Jupyter that this cell represents SQL code rather than Python code.

```
%%sql
sqlite:///data/basic_examples.db
```

(A note about SQLite)

Our first step is to load the SQL module. We do so using the `ipython` **cell magic** command:

```
%load_ext sql
```

The second step is to connect to a database.

We use the `%%sql` header to tell Jupyter that this cell represents SQL code rather than Python code.

```
%%sql
sqlite:///data/basic_examples.db
```

```
Connected: @data/18_basic_examples.db
```

In real world practice, you'd probably connect to a remote server.

There are various extensions to SQL.

We are learning the SQL commands and syntax supported by the SQLite library.

If you're curious: `SQLite` is a library that provides a relational DBMS (RDBMS). It is lightweight and offers file-based databases.

Tables and Schema

SQL Terminology

Column or **Attribute** or **Field**

Row or **Record** or **Tuple**

name TEXT, PK	**year** INT, >=2000	**cute** INT
hiccup	2010	10
drogon	2011	-100
dragon 2	2019	0

Dragon

table name

SQL tables are also called relations.

SQL Style: Use *singular, CamelCase* names for SQL tables! For more, see this post.

SQL Terminology

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Dragon

table name

Column Properties

ColName, Type, Constraint

SQL **tables** are also called **relations**.

SQL Style: Use *singular, CamelCase* names for SQL tables! For more, see this post.

Every column in a SQL table has three properties: **ColName, Type**, and zero or more **Constraints**. (Contrast with `pandas`: `Series` have names and types, but no constraints.)

Table Schema

A **schema** describes the logical structure of a table. Whenever a new table is created, the creator must declare its schema.

For each column, specify the:

- **Column name**
- **Data type**
- **Constraint(s) on values**

```
CREATE TABLE Dragon (
name TEXT PRIMARY KEY,
year INTEGER CHECK (year >= 2000),
cute INTEGER
)
```

Repeat for all tables in the database (see demo nb):

type	name	tbl_name	rootpage	sql
table	sqlite_sequence	sqlite_sequence	7	CREATE TABLE sqlite_sequence(name,seq)
table	Dragon	Dragon	2	CREATE TABLE Dragon (name TEXT PRIMARY KEY, year INTEGER CHECK (year >= 2000), cute INTEGER)
table	Dish	Dish	4	CREATE TABLE Dish (name TEXT PRIMARY KEY, type TEXT, cost INTEGER CHECK (cost >= 0))

Example Types

Some examples of SQL **types**:

- `INT`: Integers.
- `FLOAT`: Floating point numbers.
- `TEXT`: Strings of text.
- `BLOB`: Arbitrary data, e.g. songs, video files, etc.
- `DATETIME`: A date and time.

Note: Different implementations of SQL support different types.

- SQLite: https://www.sqlite.org/datatype3.html
- MySQL: https://dev.mysql.com/doc/refman/8.0/en/data-types.html

we will use SQLite!

Example Constraints

Some examples of **constraints**:

- `CHECK`: data must obey the given check constraint.
- `PRIMARY KEY`: specifies that this key is used to uniquely identify rows in the table.
- `NOT NULL`: null data cannot be inserted for this column.
- `DEFAULT`: provides a default value to use if user does not specify on insertion.

What is this primary key constraint?

type	name	tbl_name	rootpage	sql
table	sqlite_sequence	sqlite_sequence	7	CREATE TABLE sqlite_sequence(name,seq)
table	Dragon	Dragon	2	CREATE TABLE Dragon (name TEXT PRIMARY KEY, year INTEGER CHECK (year >= 2000), cute INTEGER)
table	Dish	Dish	4	CREATE TABLE Dish (name TEXT PRIMARY KEY, type TEXT, cost INTEGER CHECK (cost >= 0))
table	Scene	Scene	6	CREATE TABLE Scene (id INTEGER PRIMARY KEY AUTOINCREMENT, biome TEXT NOT NULL, city TEXT NOT NULL, visitors INTEGER CHECK (visitors >= 0), created_at DATETIME DEFAULT (DATETIME('now')))

Primary Keys

A **primary key** is the set of column(s) used to uniquely identify each record in the table.

- In the Dragon table, the "**name**" of each Dragon is the primary key.
- In other words, no two dragons can have the same name!
- Primary key is used **under the hood** for all sorts of optimizations.

name TEXT, PK	**year** INT, >=2000	**cute** INT
hiccup	2010	10
drogon	2011	-100
dragon 2	2019	0

Why specify primary keys? More next time when we discuss JOINs…

Basic Queries

- Why Databases
- Intro to SQL
- Tables and Schema
- **Basic Queries**
- Grouping

Query Syntax So Far

```
SELECT <column list>
FROM <table>
```

;

Marks the end of a SQL statement.

Summary so far

New keywords

```
SELECT <column list>
FROM <table>
[WHERE <predicate>]
[ORDER BY <column list>]
[LIMIT <number of rows>]
[OFFSET <number of rows>];
```

Goal of this section

By the end of this section, you will learn these new keywords!

But first, more SELECT

Recall our simplest query, which returns the full relation:

```
SELECT *
FROM Dragon;
```

table name

name	year	cute
hiccup	2010	10
drogon	2011	-100
dragon 2	2019	0
puff	2010	100
smaug	2011	None

`SELECT` specifies the column(s) that we wish to appear in the output. `FROM` specifies the database table from which to select data.

Every query must include a `SELECT` clause (how else would we know what to return?) and a `FROM` clause (how else would we know where to get the data?)

An asterisk (*) is shorthand for “all columns”. *Let’s see a bit more in our demo.*

But first, more `SELECT`

Recall our simplest query, which returns the full relation:

```
SELECT *
FROM Dragon;
```

table name

name	year	cute
hiccup	2010	10
drogon	2011	-100
dragon 2	2019	0
puff	2010	100
smaug	2011	None

We can also `SELECT` only a **subset of the columns**:

column expression list

```
SELECT cute, year
FROM Dragon;
```

cute	year
10	2010
-100	2011
0	2019
100	2010
None	2011

Columns selected in specified order

Aliasing with AS

To rename a `SELECT`ed column, use the `AS` keyword

```
SELECT cute AS cuteness,
       year AS birth
FROM Dragon;
```

cuteness	birth
10	2010
-100	2011
0	2019
100	2010
None	2011

An **alias** is a name given to a column or table by a programmer. Here, “cuteness” is an alias of the original “cute” column (and “birth” is an alias of “year”)

SQL Style: Newline Separators

The following two queries both retrieve the same relation:

```
SELECT cute AS cuteness,
       year AS birth
FROM Dragon;
```

(more readable)

```
SELECT cute AS
cuteness, year AS
birth FROM Dragon;
```

cuteness	birth
10	2010
-100	2011
0	2019
100	2010
None	2011

Use newlines and whitespace wisely in your SQL queries.
It will simplify your debugging process!

Uniqueness with `DISTINCT`

To return only unique values, combine **`SELECT`** with the **`DISTINCT`** keyword

```
SELECT DISTINCT year
FROM Dragon;
```

Notice that 2010 and 2011 only appear once each in the output.

name	year	cute
hiccup	2010	10
drogon	2011	-100
dragon 2	2019	0
puff	2010	100
smaug	2011	None

→

year
2010
2011
2019

`WHERE`: Select a rows based on conditions

To select only some rows of a table, we can use the `WHERE` keyword.

```
SELECT name, year
FROM Dragon
WHERE cute > 0;
```

condition

name	year
hiccup	2010
puff	2010

name	year	cute
hiccup	2010	10
drogon	2011	-100
dragon 2	2019	0
puff	2010	100
smaug	2011	None

Dragon

WHERE: Select a rows based on conditions

Comparators **OR**, **AND**, and **NOT** let us form more complex conditions.

```
SELECT name, year
FROM Dragon
WHERE cute > 0 OR year > 2013;
```

$\underbrace{\texttt{cute > 0 OR year > 2013;}}_{\textbf{condition}}$

name	cute	year
hiccup	10	2010
dragon 2	0	2019
puff	100	2010

Check if values are contained IN a specified list

```
SELECT name, year
FROM Dragon
WHERE name IN ('puff', 'hiccup');
```

name	year
hiccup	2010
puff	2010

`WHERE` with NULL Values

NULL (the SQL equivalent of NaN) is stored in a special format – we can't use the "standard" operators =, >, and <.

Instead, check if something `IS` or `IS NOT NULL`

```
SELECT name, year
FROM Dragon
WHERE year IS NOT NULL;
```

name	cute
hiccup	10
drogon	-100
dragon 2	0
puff	100

Always work with NULLs using the `IS` operator. NULL cannot work with standard comparisons: in fact, NULL = NULL actually returns False!

`ORDER BY`: Sort rows

Specify which column(s) we should order the data by

```
SELECT *
FROM Dragon
ORDER BY cute DESC;
```

$\underbrace{\texttt{cute}}_{\text{column}}$

(by default, SQL orders by ascending order: **ASC**)

name	year	cute
puff	2010	100
hiccup	2010	10
dragon 2	2019	0
drogon	2011	-100
smaug	2011	None

ORDER BY: Sort rows

Specify which column(s) we should order the data by

```
SELECT *
FROM Dragon
ORDER BY year, cute DESC;
```

Can also order by multiple columns (for tiebreaks)

Sorts `year` in ascending order and `cute` in descending order. If you want `year` to be ordered in descending order as well, you need to specify `year DESC, cute DESC;`

name	year	cute
puff	2010	100
hiccup	2010	10
drogon	2011	-100
smaug	2011	None
dragon 2	2019	0

OFFSET and LIMIT?

1.
```
SELECT *
FROM Dragon
LIMIT 2;
```

A.

name	year	cute
hiccup	2010	10
drogon	2011	-100

2.
```
SELECT *
FROM Dragon
LIMIT 2
OFFSET 1;
```

B.

name	year	cute
drogon	2011	-100
dragon 2	2019	0

name	year	cute
hiccup	2010	10
drogon	2011	-100
dragon 2	2019	0

Dragon

Matching: Which query matches each relation?

(no Slido) What do you think the **`LIMIT`** and **`OFFSET`** keywords do?

OFFSET and LIMIT

The LIMIT keyword lets you retrieve N rows (like **pandas head**).

```
SELECT *
FROM Dragon
LIMIT 2;
```

name	year	cute
hiccup	2010	10
drogon	2011	-100

name	year	cute
hiccup	2010	10
drogon	2011	-100
dragon 2	2019	0

Dragon

The OFFSET keyword tells SQL to skip the first N rows of the output, then apply LIMIT.

```
SELECT *
FROM Dragon
LIMIT 2
OFFSET 1;
```

name	year	cute
drogon	2011	-100
dragon 2	2019	0

⚠️ Unless you use ORDER BY, there is **no guaranteed order** of rows in the relation!

Summary so far

New keywords

```
SELECT <column list>
FROM <table>
[WHERE <predicate>]
[ORDER BY <column list>]
[LIMIT <number of rows>]
[OFFSET <number of rows>];
```

- *All* queries must include `SELECT` and `FROM`. The remaining keywords are optional.
- By convention, use **all caps** for keywords in SQL statements.
- Use **newlines** to make code more readable.

Grouping

The Dish Table

We're ready for a more complicated table.

```
SELECT *
FROM Dish;
```

name	type	cost
ravioli	entree	10
ramen	entree	13
taco	entree	7
edamame	appetizer	4
fries	appetizer	4
potsticker	appetizer	4
ice cream	dessert	5

The Dish Table

We're ready for a more complicated table.

```
SELECT *
FROM Dish;
```

name	type	cost
ravioli	entree	10
ramen	entree	13
taco	entree	7
edamame	appetizer	4
fries	appetizer	4
potsticker	appetizer	4
ice cream	dessert	5

Notice the repeated dish types. What if we wanted to investigate trends across each group?

Order of operations: SELECT → FROM → WHERE → GROUP BY

```
SELECT type, SUM(cost)
FROM Dish
GROUP BY type;
```

Correct! ✅

```
GROUP BY type
SELECT type, SUM(cost)
FROM Dish;
```

Incorrect ❌

Always follow the SQL order of operations. Let SQL take care of the rest.

GROUP BY

`GROUP BY` is similar to pandas `groupby()`.

```
SELECT type
FROM Dragon
GROUP BY type;
```

type
appetizer
dessert
entree

name	type	cost
ravioli	entree	10
ramen	entree	13
taco	entree	7
edamame	appetizer	4
fries	appetizer	4
potsticker	appetizer	4
ice cream	dessert	5

Aggregating Across Groups

Like `pandas`, SQL has **aggregate functions**: `MAX, SUM, AVG, FIRST,` etc.

For more aggregations, see: https://www.sqlite.org/lang_aggfunc.html

```
SELECT type, SUM(cost)
FROM Dish
GROUP BY type;
```

type	SUM(cost)
appetizer	12
dessert	5
entree	30

Wait, something's weird…

Declarative Programming

Wait, something's weird…

```sql
SELECT type, SUM(cost)
FROM Dish
GROUP BY type;
```

We told SQL to SUM in our SELECT statement…

…but didn't specify the groups until GROUP BY

This is okay!

Unlike Python, SQL is a **declarative programming language**.

> *Declarative programming is a non-imperative style of programming in which programs describe their desired results without explicitly listing commands or steps that must be performed.*
>
> [Wikipedia]

Declarative Programming

> *Declarative programming is a non-imperative style of programming in which programs describe their desired results without explicitly listing commands or steps that must be performed.*
>
> Wikipedia

What this means to us:

- We "declare" our desired end result
- SQL handles the rest! We do *not* need to specify any logical steps for how this result should be created

We just need to follow the **SQL order of operations** with our clauses to allow SQL to parse our request. Everything else will be handled behind the scenes.

High-level cheat sheet on order of **execution** by the SQL engine (more info):

1. FROM
2. JOIN
3. WHERE
4. GROUP BY
5. SELECT
6. ORDER BY

Using Multiple Aggregation Functions

```
SELECT type,
       SUM(cost),
       MIN(cost),
       MAX(name)
FROM Dish
GROUP BY type;
```

What do you think will happen?

name	type	cost
ravioli	entree	10
ramen	entree	13
taco	entree	7
edamame	appetizer	4
fries	appetizer	4
potsticker	appetizer	4
ice cream	dessert	5

Dish

Using Multiple Aggregation Functions

```
SELECT type,
       SUM(cost),
       MIN(cost),
       MAX(name)
FROM Dish
GROUP BY type;
```

type	SUM(cost)	MIN(cost)	MAX(name)
appetizer	12	4	potsticker
dessert	5	5	ice cream
entree	30	7	taco

name	type	cost
ravioli	entree	10
ramen	entree	13
taco	entree	7
edamame	appetizer	4
fries	appetizer	4
potsticker	appetizer	4
ice cream	dessert	5

Dish

This was much more difficult in **pandas**!

The COUNT Aggregation

COUNT is used to count the number of rows belonging to a group.

```
SELECT year, COUNT(cute)
FROM Dragon
GROUP BY year;
```

year	COUNT(cute)
2010	2
2011	1
2019	1

Similar to pandas `groupby().count()`

```
SELECT year, COUNT(*)
FROM Dragon
GROUP BY year;
```

year	COUNT(*)
2010	2
2011	2
2019	1

Similar to pandas `groupby().size()`

`COUNT(*)` returns the number of rows in each group, including rows with **NULLs**.

Summary so far

New keywords

```
SELECT <column expression list>
FROM <table>
[WHERE <predicate>]
[GROUP BY <column list>]
[ORDER BY <column list>]
[LIMIT <number of rows>]
[OFFSET <number of rows>];
```

- By convention, use **all caps** for keywords in SQL statements.
- Use **newlines** to make SQL code more readable.
- **AS** keyword: rename columns during selection process.
- **Column Expressions may include aggregation functions (`MAX`, `MIN`, etc.)**