LECTURE 20

SQL I

SQL and databases: alternatives to `pandas` and CSV files.

Goals for Today's Lecture

Lecture 20, Data 100 Summer 2023

Stepping away from Python and `pandas`

- Recognizing situations where we need "bigger" tools for manipulating data
- Writing our first database queries

Agenda

Lecture 20, Data 100 Summer 2023

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

Why Databases?

Lecture 20, Data 100 Summer 2023

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

So Far: CSV Files and pandas

So far in Data 100, we've worked with data stored in CSV files.

`Berkeley_PD_-_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** (see CS (W)186).

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

Lecture 20, Data 100 Summer 2023

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

SQL

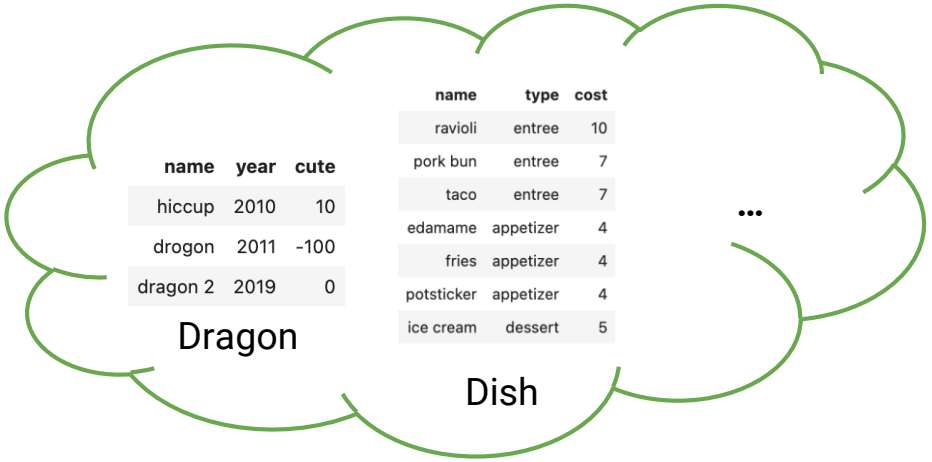
Today we'll be using a programming language called "Structured Query Language" or **SQL**.

- 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



SQL query

```
SELECT *
FROM Dish;
```


results

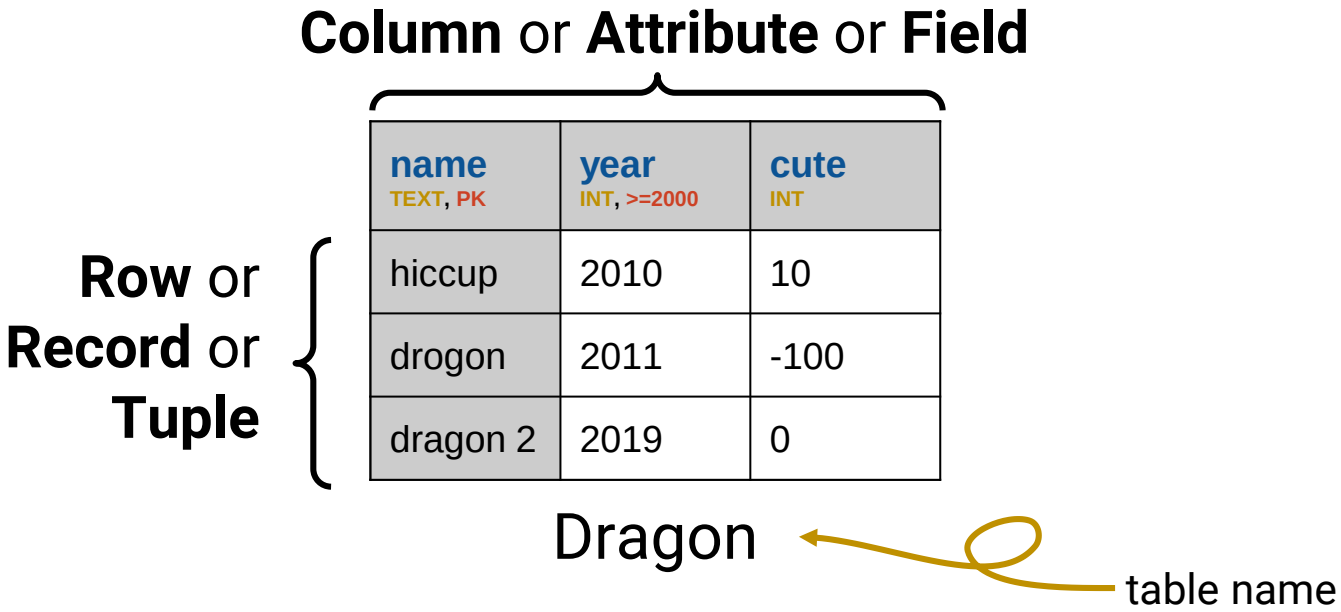
name	type	cost
ravioli	entree	10
pork bun	entree	7
taco	entree	7
edamame	appetizer	4
fries	appetizer	4
potsticker	appetizer	4
ice cream	dessert	5

Demo

Tables and Schema

Lecture 20, Data 100 Summer 2023

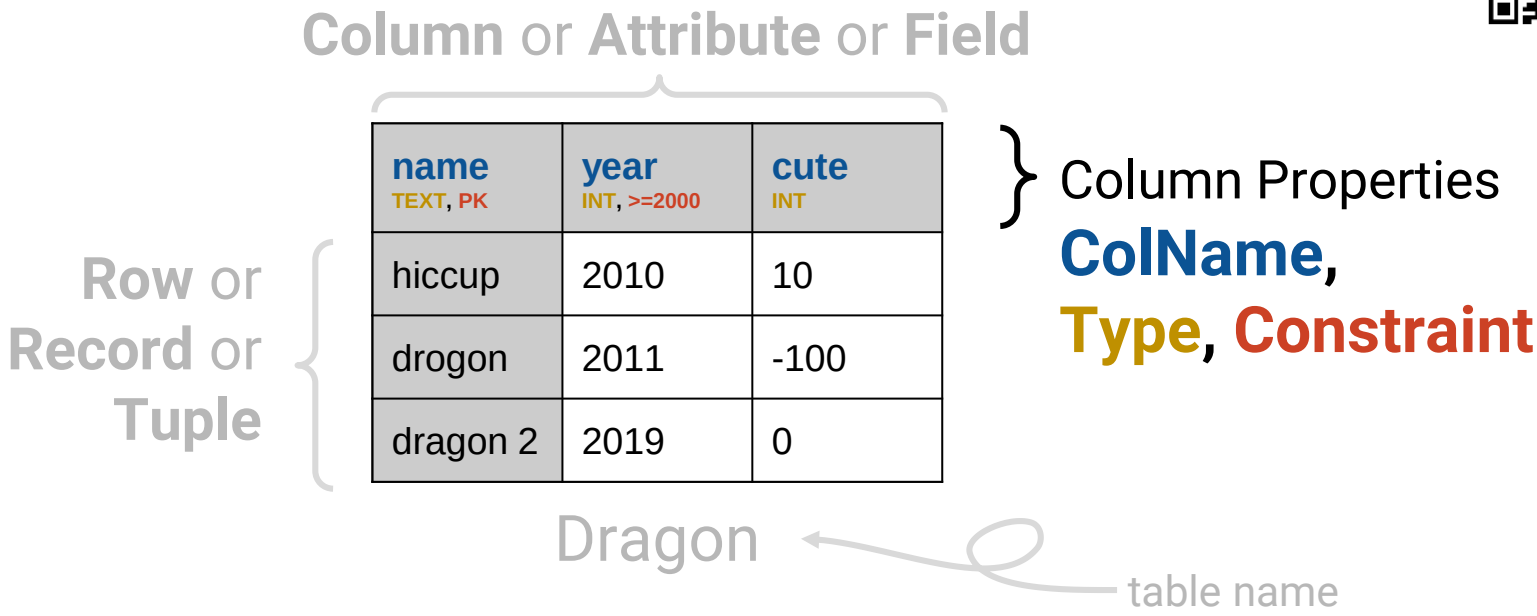
- Why Databases?
- Intro to SQL
- **Tables and Schema**
- Basic queries
- Grouping



SQL tables are also called relations.

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

SQL Terminology



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:

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

In Data 100, we will use SQLite.

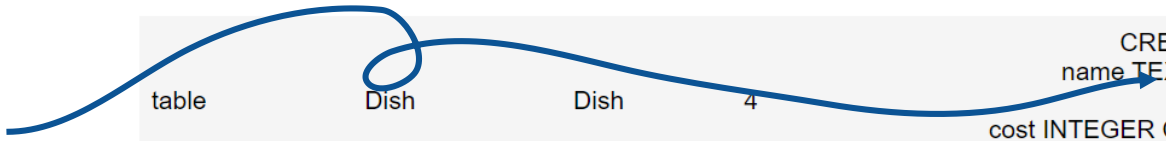
Example Constraints

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.

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')))

What is this primary key constraint?



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

Lecture 20, Data 100 Summer 2023

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

Summary So Far

Query Syntax So Far

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

;

Marks the end of a SQL statement.

Goal of this section

New keywords

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

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”.

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 SELECTed 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

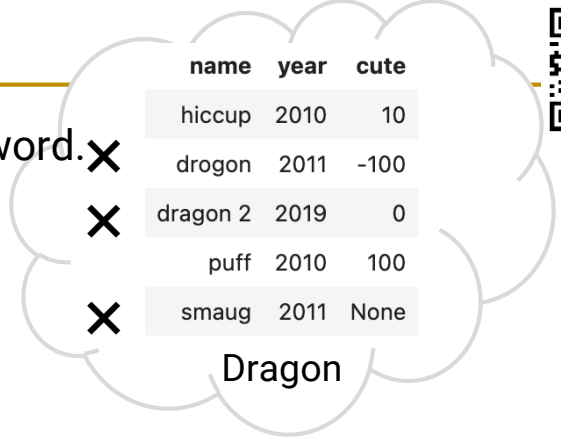
WHERE: Select a rows based on conditions

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



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;
```

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;
```

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

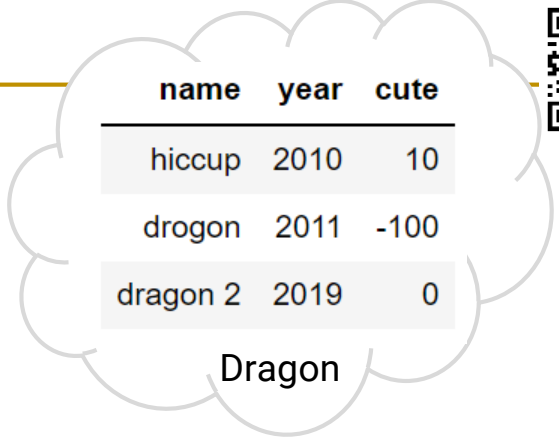
Specify which column(s) we should order the data by

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

Can also order by multiple columns (for tiebreaks)

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.

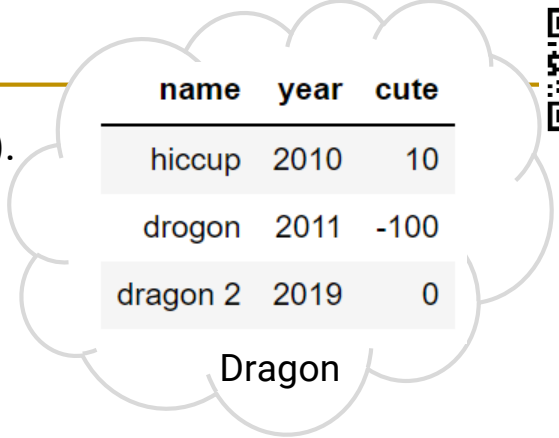
name	year	cute
drogon	2011	-100
dragon 2	2019	0

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



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!

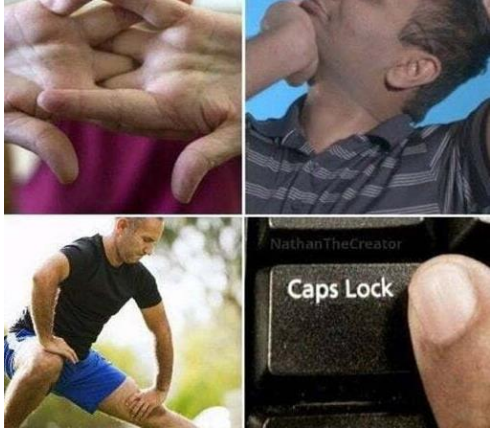
Summary So Far

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.

Interlude



I'm planning to make a film series on databases.
I've got the first part ready.
Now I can't think of a SQL.

Grouping

Lecture 20, Data 100 Summer 2023

- Why Databases?
- Intro to SQL
- Tables and Schema
- Basic Queries
- **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;
```

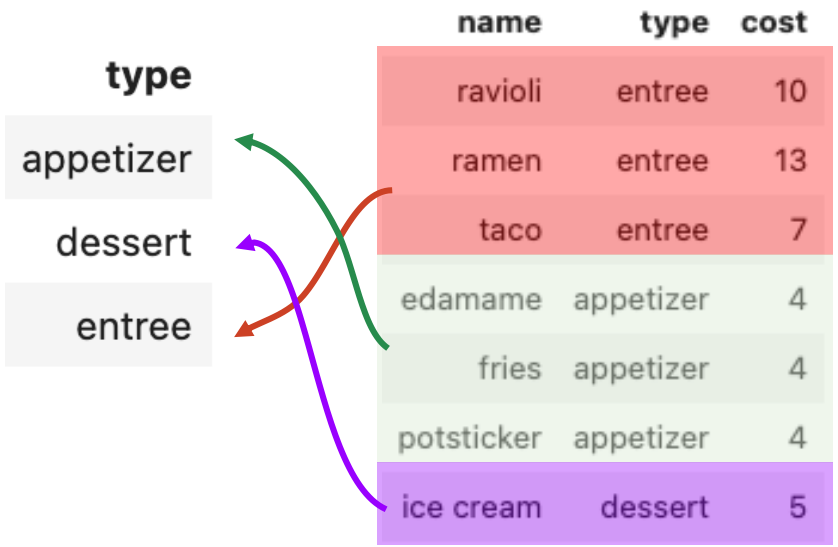
Incorrect ×

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;
```



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…

Wait, something's weird…

```
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

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>
> 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.

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;
```

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

year	COUNT(cute)
2010	2
2011	1
2019	1

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

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

year	COUNT(*)
2010	2
2011	2
2019	1

`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.)**