Computational Structures in Data Science

Databases & SQL

Berkeley
UNIVERSITY OF CALIFORNIA

Announcements

- Extensions:
  - Final Date for things: End of Dead Week (5/3)
  - Please try not to take that long. ☺
- Ants Checkpoint today!
  - Ants will have a composition/revision workflow
  - Tutors will give you code-level feedback.
    - You'll need to resubmit afterwards with fixes.
    - Typically, re-write a few things which are *already correct* but could be written more clearly. As long as you make a fix, you'll earn the 2 points

Computing In the News

- **Can AI help boost accessibility? These researchers tested it for themselves**
- Generative artificial intelligence tools like ChatGPT, an AI-powered language tool, and Midjourney, an AI-powered image generator, can potentially assist people with various disabilities. These tools could summarize content, compose messages or describe images. Yet the degree of this potential is an open question, since, in addition to regularly spouting inaccuracies and failing at basic reasoning, these tools can perpetuate ableist biases.
- This year, seven researchers at the University of Washington conducted a three-month autoethnographic study — drawing on their own experiences as people with and without disabilities — to test AI tools' utility for accessibility. Though researchers found cases in which the tools were helpful, they also found significant problems with AI tools in most use cases, whether they were generating images, writing Slack messages, summarizing writing or trying to improve the accessibility of documents.

Why SQL? (Review)

- SQL is a ***declarative* programming language** for accessing and modifying data in a relational database.
- It is an entirely new way of thinking ("new" in 1970, and new to you now!) that specifies *what* should happen, but not *how* it should happen.
- One of a few major programming paradigms
  - Imperative/Procedural
  - Object Oriented
  - Functional
  - Declarative

What is SQL?

- A declarative language
  - Described *what* to compute
  - Imperative languages, like python, describe *how* to compute it
  - Query processor (interpreter) chooses which of many equivalent query plans to execute to perform the SQL statements
- ANSI and ISO standard, but many variants
  - We will learn just the basics.
    - CS88's SQL will work on nearly all *relational databases*—databases that use tables.

SQL Statements

- `SELECT` statement creates a new table, either from scratch or by projecting a table
- `CREATE TABLE` statement gives a global name to a table
- Lots of other statements
  - `analyze, delete, explain, insert, replace, update,` …
- SQL queries, aggregates, updates data in a *database.*
- SQL is case-*insensitive*
  - But the *data* can be case-sensitive. (We'll talk about this later…)

What does SQL Look Like?

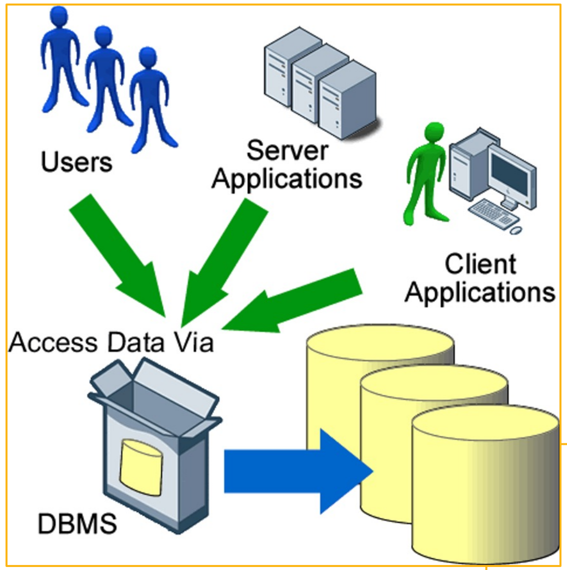
```
SELECT date_trunc('day', created) as date, COUNT(*)
FROM users
WHERE created > current_date - interval '1 year'
GROUP BY date;
```

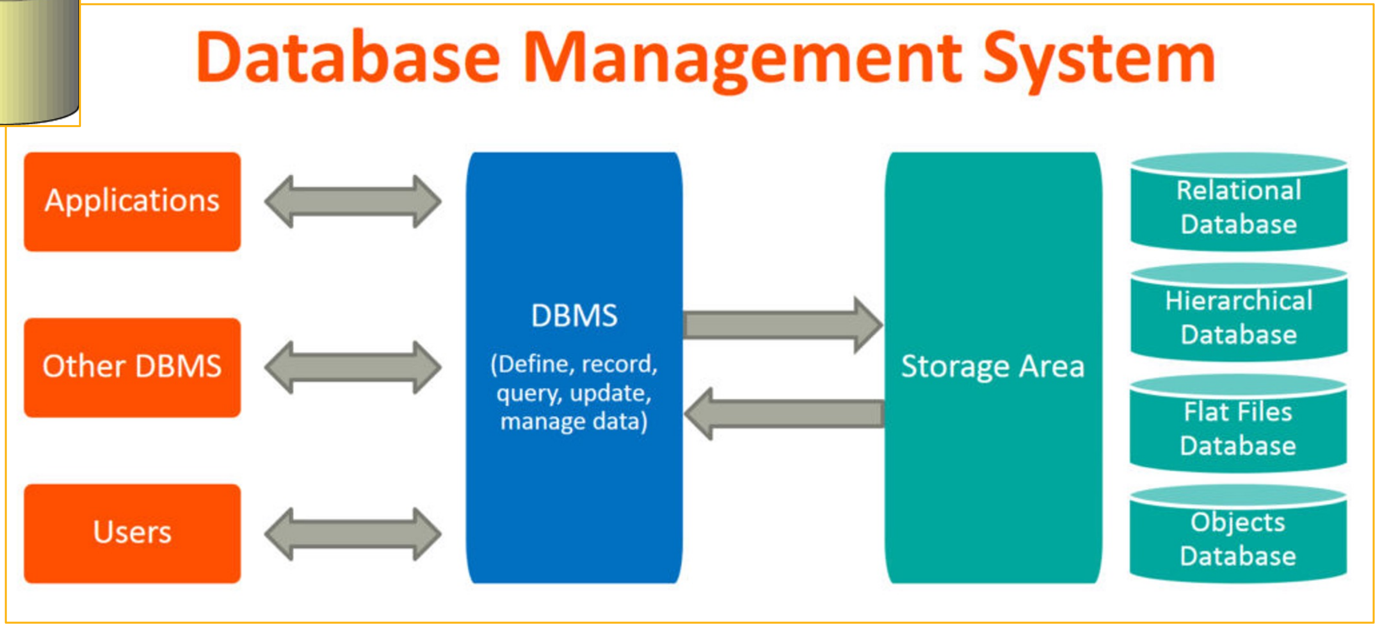
date	count
Apr 17, 2023, 12:00 AM	136
Apr 18, 2023, 12:00 AM	257
Apr 19, 2023, 12:00 AM	326
Apr 20, 2023, 12:00 AM	167
Apr 21, 2023, 12:00 AM	144

Why Databases?

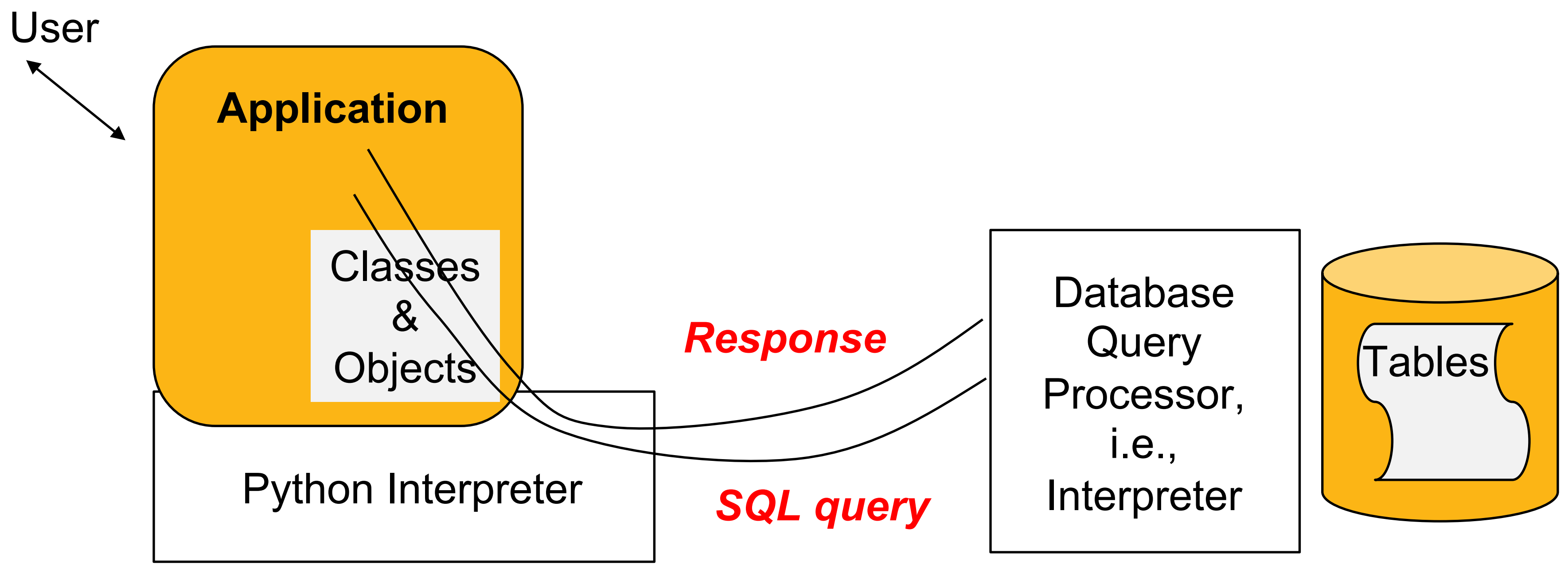
- Data lives in files: website access logs, in images, in CSVs and so on…
    - Useful, but hard to access, aggregate and compute results.
- Databases provide a mechanism to store vast amounts of data in an *organized* manner.
    - The (often) rely on "tables" as an abstraction.
    - There are other kinds of databases, that store "documents" or other forms of data.
- Databases is the topic of CS186
- Elsewhere: Data, it's storage and accessing it are critical to data science.

Database Management Systems



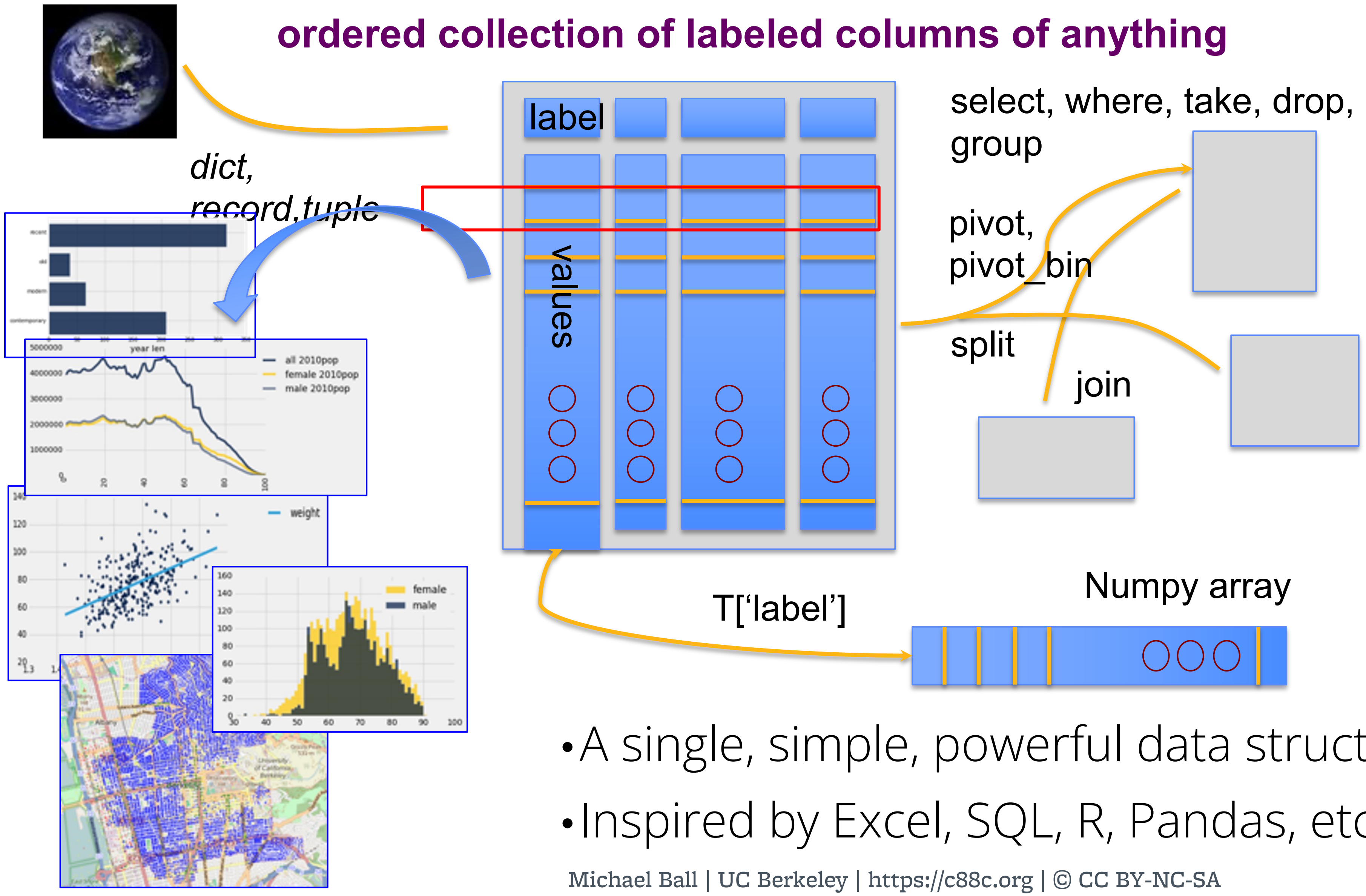


Applications Issue Queries to a Database



- The SQL language is represented in query strings delivered to a DB backend.
- Use the techniques learned here to build clean abstractions.
- You have already learned the relational operators!

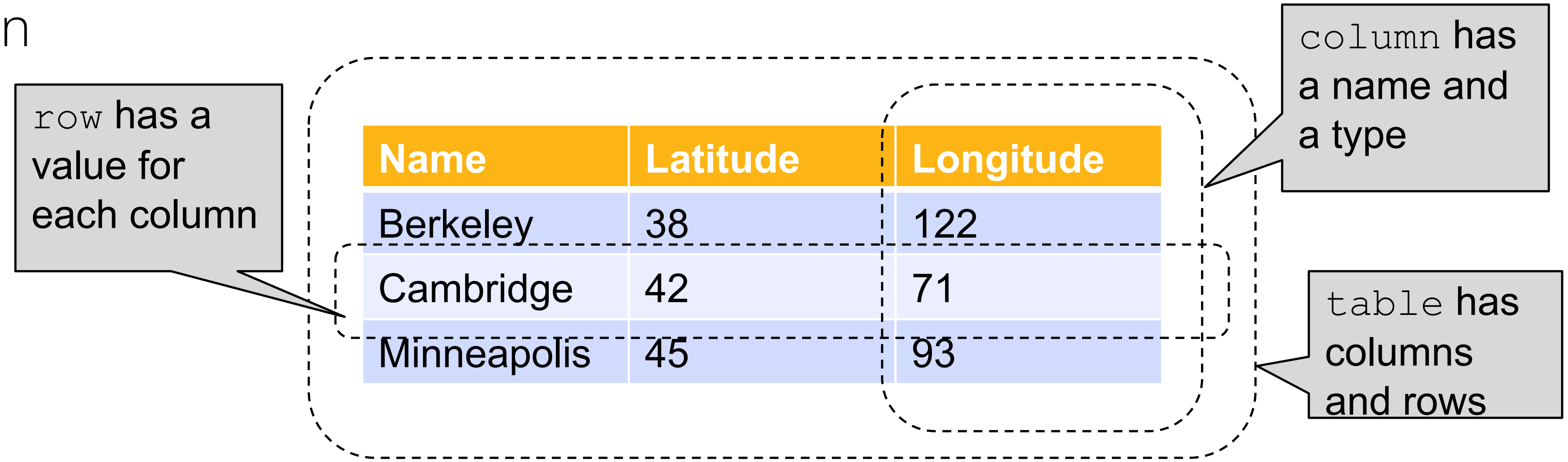
Data 8 Tables, datasicnce



- A single, simple, powerful data structure for all
- Inspired by Excel, SQL, R, Pandas, etc.

Database Management Systems

- DBMS are persistent tables with powerful relational operators
  - Important, heavily used, interesting!
- A table is a collection of records, which are rows that have a value for each column


`row` has a value for each column
`column` has a name and a type
`table` has columns and rows

Name	Latitude	Longitude
Berkeley	38	122
Cambridge	42	71
Minneapolis	45	93

- Structure Query Language (SQL) is a declarative programming language describing operations on tables

You’ve seen (and used) databases

- CSV files: A database with one table
- Excel / Google Sheets:
  - Each "tab" is a table, with rows and columns
- A datascience Table is **not** a database, but is similar
- Websites are backed by databases
  - bCourses, Gradescope, etc have a table of *users, assignments, etc*
  - These tables have standardized rows and columns

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Interacting With A Database

sqlite3 [SQLite Docs]

- Pronounced "sequel lite"
- It's lightweight, fast, and works on most computers natively
  - It's incredibly popular! Used by iOS, Android, Apple apps, and even airplanes!
  - But sqlite is not setup for all applications, like such as websites like Gmail/bCourses, etc.
- A database is a `.db` file, which contains all of your data in an efficient form.
- Many people connect to sqlite through a program like Python OR through the sqlite interpreter.

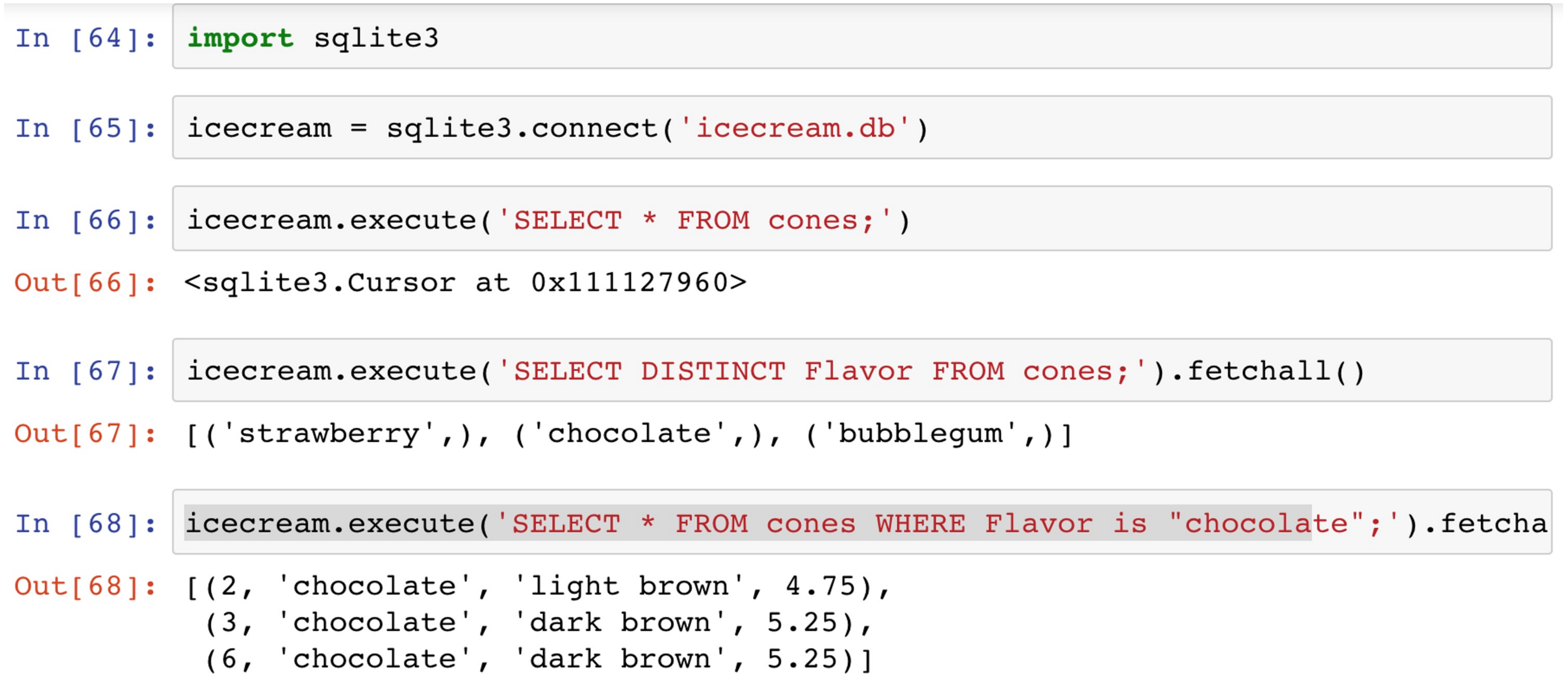
sqlite3 [Python Docs]

- `sqlite3` is a Python module which connects to a SQLite database
  - This is the first time you write code that really interacts with data on your computer!
    - **We can modify and delete data!**
  - There's some "boilerplate" setup here, but it's not too bad…

Connecting To a Database (Python 3)

```python
DB_FILENAME = '24-Databases_and_SQL.db'
import sqlite3
# Talking to the database happens through a "connection"
con = sqlite3.connect(DB_FILENAME)
# A cursor is the object we use to execute a query.
cur = con.cursor()
# This returns an iterator!
result = cur.execute("YOUR QUERY")
for row in result:
    print(result) # This is a Tuple!
# Save (commit) the changes
con.commit()
# We can also close the connection if we are done with it.
# Just be sure any changes have been committed or they will be lost.
con.close()
```

SQLite Python API – In a Notebook.



```
In [64]: import sqlite3

In [65]: icecream = sqlite3.connect('icecream.db')

In [66]: icecream.execute('SELECT * FROM cones;')

Out[66]: <sqlite3.Cursor at 0x111127960>

In [67]: icecream.execute('SELECT DISTINCT Flavor FROM cones;').fetchall()

Out[67]: [('strawberry',), ('chocolate',), ('bubblegum',)]

In [68]: icecream.execute('SELECT * FROM cones WHERE Flavor is "chocolate";').fetcha

Out[68]: [(2, 'chocolate', 'light brown', 4.75),
          (3, 'chocolate', 'dark brown', 5.25),
          (6, 'chocolate', 'dark brown', 5.25)]
```

The sqlite console

- Interactive console used *via the Terminal!*
- *Everything is saved automaticaly. BEWARE!*

There are many more commands than the ones shown here!, but these can be neat!

```
👉 sqlite3 24-Databases_and_SQL.db
SQLite version 3.37.0 2021-12-09 01:34:53
Enter ".help" for usage hints.
sqlite> .help
.echo on|off              Turn command echo on or off
.exit ?CODE?              Exit this program with return-code CODE
.headers on|off           Turn display of headers on or off
.help ?-all? ?PATTERN?    Show help text for PATTERN
.quit                     Exit this program
.show                     Show the current values for various settings
.tables ?TABLE?           List names of tables matching LIKE pattern TABLE
.trace ?OPTIONS?          Output each SQL statement as it is run
sqlite> .tables
cones sales
```

Computational Structures in Data Science

Introduction to SQL

SQL Statements

- Statements operate on *tables* inside a *database.*
- **`SELECT`** statement creates a new table, either from scratch or by projecting a table
- **`CREATE TABLE`** statement gives a global name to a table
- Lots of other statements
  - `analyze, delete, explain, insert, replace, update, …`
- SQL queries, aggregates, updates data in a *database.*
- SQL is case-*insensitive*

SQL example

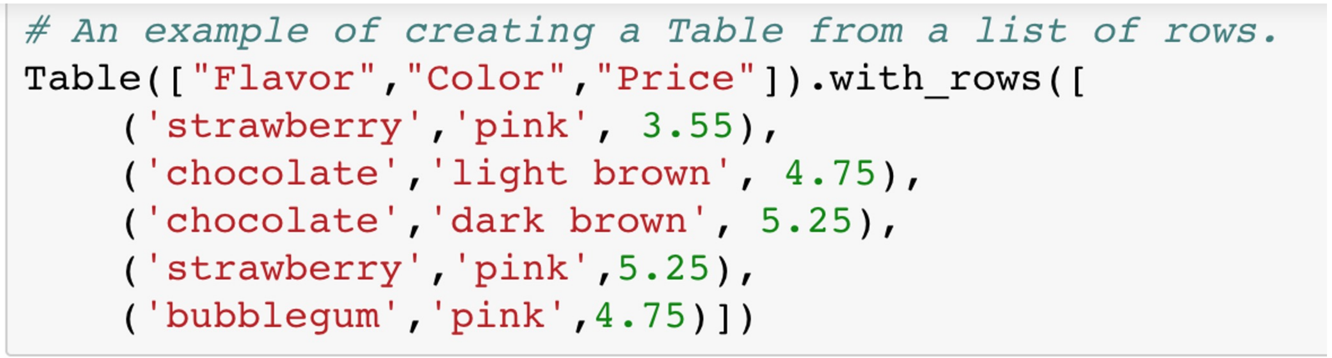
- SQL statements create tables
  - Give it a try with `sqlite3` or code.cs61a.org
  - Each statement ends with ';'

```
cs88 $ sqlite3
SQLite version 3.9.2 2015-11-02 18:31:45
Enter ".help" for usage hints.
Connected to a transient in-memory database.
Use ".open FILENAME" to reopen on a persistent database.
sqlite> select 38 as latitude, 122 as longitude, "Berkeley" as
name;
38|122|Berkeley
sqlite>
```

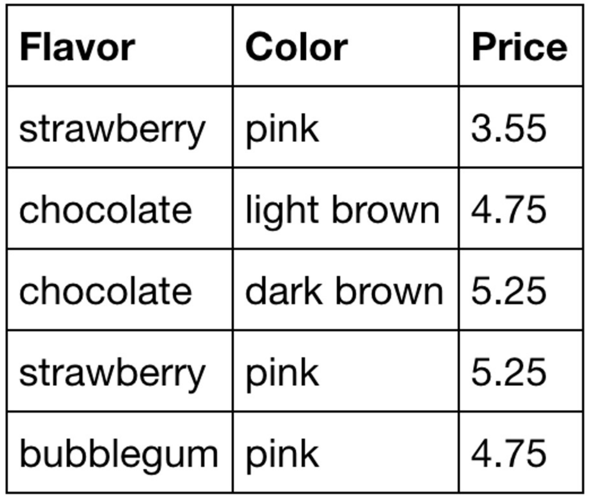
SQL Basics

- SQL Keywords are case-*insensitive*
  - e.g. `SELECT` and `select` do the same thing
  - I *try* to capitalize them to make it clear what's-what.
- The order of SQL keywords matters
  - e.g. `SELECT ... FROM … WHERE …`
- Every statement ends in a `;`
- Whitespace doesn't matter
  - But indentations and newlines help make queries readable!
- Despite being a standard, differences do exist between databases. We use `sqlite3`.

A Running example from Data 8

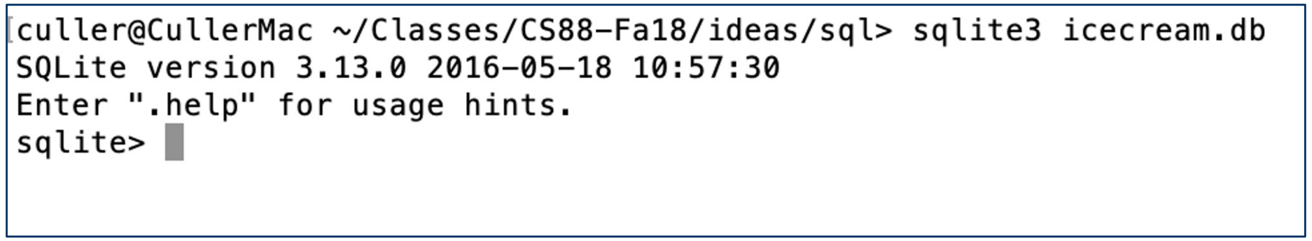


```python
# An example of creating a Table from a list of rows.
Table(["Flavor","Color","Price"]).with_rows([
    ('strawberry','pink', 3.55),
    ('chocolate','light brown', 4.75),
    ('chocolate','dark brown', 5.25),
    ('strawberry','pink',5.25),
    ('bubblegum','pink',4.75)])
```



Flavor	Color	Price
strawberry	pink	3.55
chocolate	light brown	4.75
chocolate	dark brown	5.25
strawberry	pink	5.25
bubblegum	pink	4.75

SQLite



```
culler@CullerMac ~/Classes/CS88-Fa18/ideas/sql> sqlite3 icecream.db
SQLite version 3.13.0 2016-05-18 10:57:30
Enter ".help" for usage hints.
sqlite> 
```

SELECT

- Comma-separated list of column descriptions
- Column description is an expression, optionally followed by as and a column name

```
SELECT [expression] AS [name], [expression] AS [name]; . . .
```

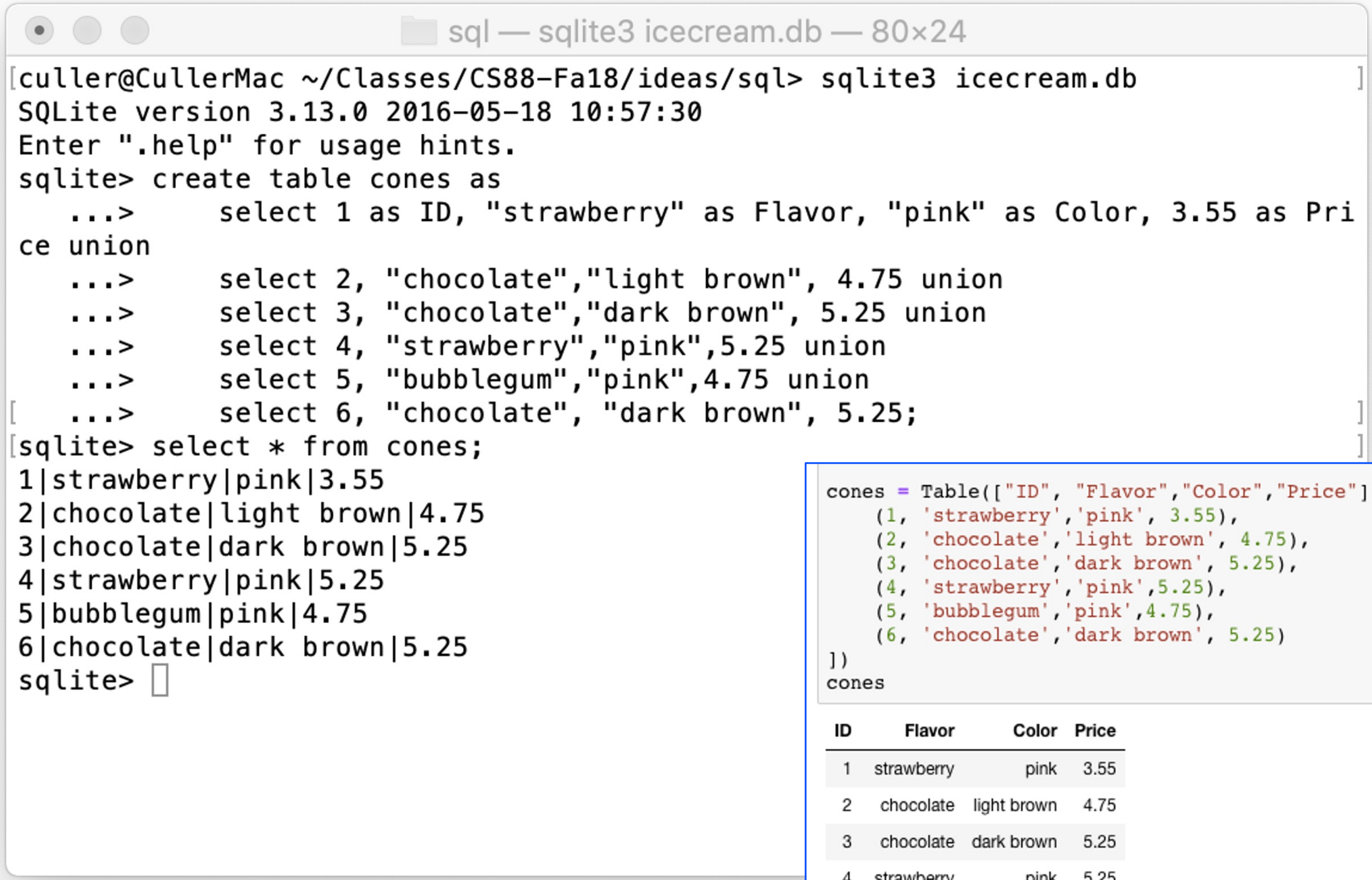
- Selecting literals creates a one-row table

```
select "strawberry" as Flavor, "pink" as Color, 3.55 as Price;
```

- union of select statements is a table containing the union of the rows

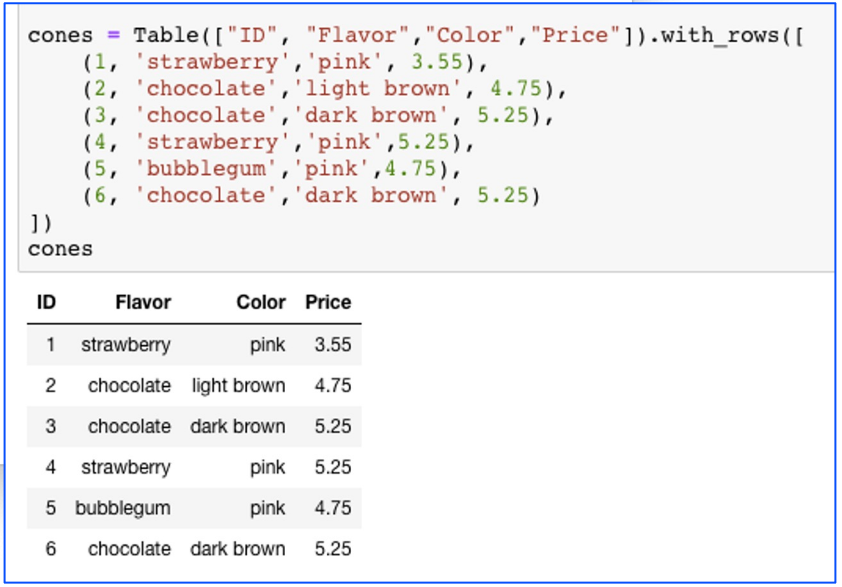
```
select "strawberry" as Flavor, "pink" as Color, 3.55 as Price union
select "chocolate","light brown", 4.75 union
select "chocolate","dark brown", 5.25 union
select "strawberry","pink",5.25 union
select "bubblegum","pink",4.75;
```

Select ...



sql — sqlite3 icecream.db — 80×24

```
culler@CullerMac ~/Classes/CS88-Fa18/ideas/sql> sqlite3 icecream.db
SQLite version 3.13.0 2016-05-18 10:57:30
Enter ".help" for usage hints.
sqlite> create table cones as
   ...>     select 1 as ID, "strawberry" as Flavor, "pink" as Color, 3.55 as Pri
ce union
   ...>     select 2, "chocolate","light brown", 4.75 union
   ...>     select 3, "chocolate","dark brown", 5.25 union
   ...>     select 4, "strawberry","pink",5.25 union
   ...>     select 5, "bubblegum","pink",4.75 union
   ...>     select 6, "chocolate", "dark brown", 5.25;
sqlite> select * from cones;
1|strawberry|pink|3.55
2|chocolate|light brown|4.75
3|chocolate|dark brown|5.25
4|strawberry|pink|5.25
5|bubblegum|pink|4.75
6|chocolate|dark brown|5.25
sqlite> 
```



```
cones = Table(["ID", "Flavor","Color","Price"]).with_rows([
    (1, 'strawberry','pink', 3.55),
    (2, 'chocolate','light brown', 4.75),
    (3, 'chocolate','dark brown', 5.25),
    (4, 'strawberry','pink',5.25),
    (5, 'bubblegum','pink',4.75),
    (6, 'chocolate','dark brown', 5.25)
])
cones
```

ID	Flavor	Color	Price
1	strawberry	pink	3.55
2	chocolate	light brown	4.75
3	chocolate	dark brown	5.25
4	strawberry	pink	5.25
5	bubblegum	pink	4.75
6	chocolate	dark brown	5.25

Projecting existing tables

- Input table specified by from clause
- Subset of rows selected using a where clause
- Ordering of the selected rows declared using an order by clause

```
select [columns] from [table] where [condition] order by [order] ;
```

```
SELECT * FROM cones ORDER BY Price;
```

ID	Flavor	Color	Price
1	strawberry	pink	3.55
2	chocolate	light brown	4.75
5	bubblegum	pink	4.75
3	chocolate	dark brown	5.25
4	strawberry	pink	5.25
6	chocolate	dark brown	5.25

Wildcards

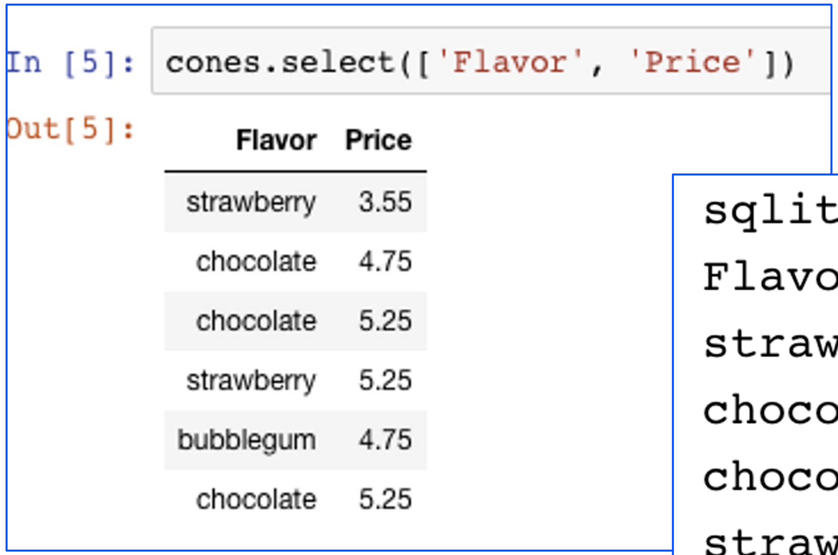
- What if we want to SELECT all columns and all rows in a table?
- What does ***** do?
- The *asterisk* (or star) is a stand-in to mean "any value"
- SELECT * ... means "Select all columns"
- Outside of SQL, * is a very common operator:
  - Regular Expressions (in DATA 100 / CS 61B) * means match "any character"
  - In Unix/Linux (macOS) * is a wildcard in the command line.

What’s different about this table? IDs!

- *In practice,* every row or *record* in a table should have a **unique unambiguous ID**
- **Why?**
  - How do we know if a record is the same as some other value?
- A properly setup table will handle this for you. ☺
- We'll see it's use in next lecture.

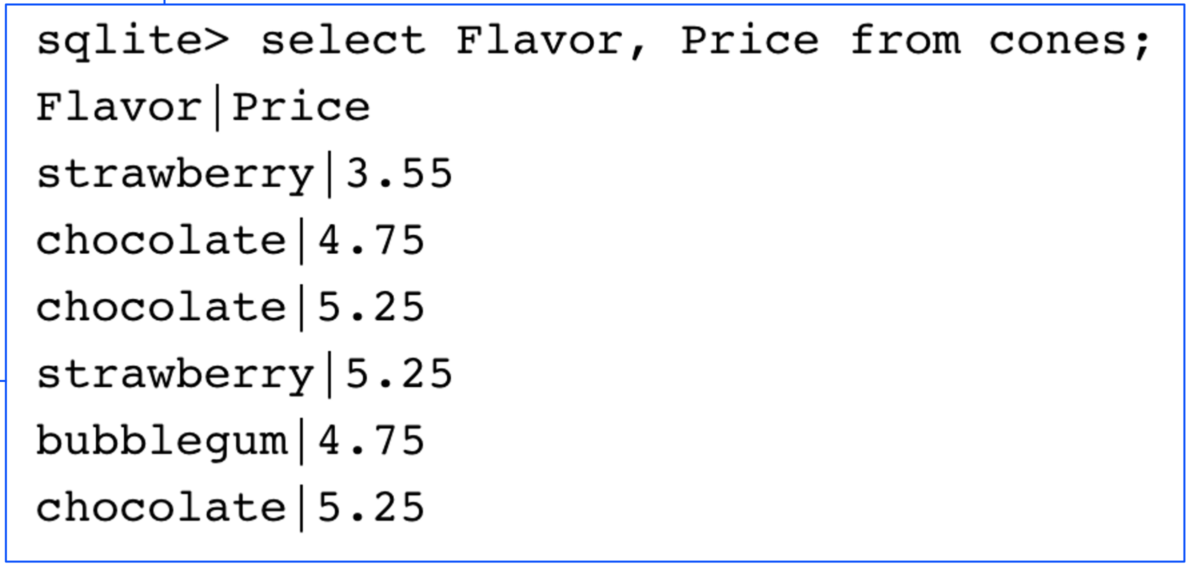
Projection

- A "projection" is a view of a table, it doesn't alter the state of the table.



```
In [5]: cones.select(['Flavor', 'Price'])
Out[5]:
```

Flavor	Price
strawberry	3.55
chocolate	4.75
chocolate	5.25
strawberry	5.25
bubblegum	4.75
chocolate	5.25



```
sqlite> select Flavor, Price from cones;
Flavor|Price
strawberry|3.55
chocolate|4.75
chocolate|5.25
strawberry|5.25
bubblegum|4.75
chocolate|5.25
```

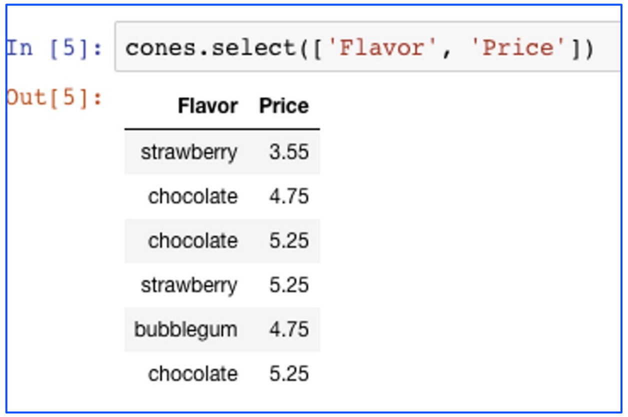
Computational Structures in Data Science

Filtering in SQL

Filtering rows - where

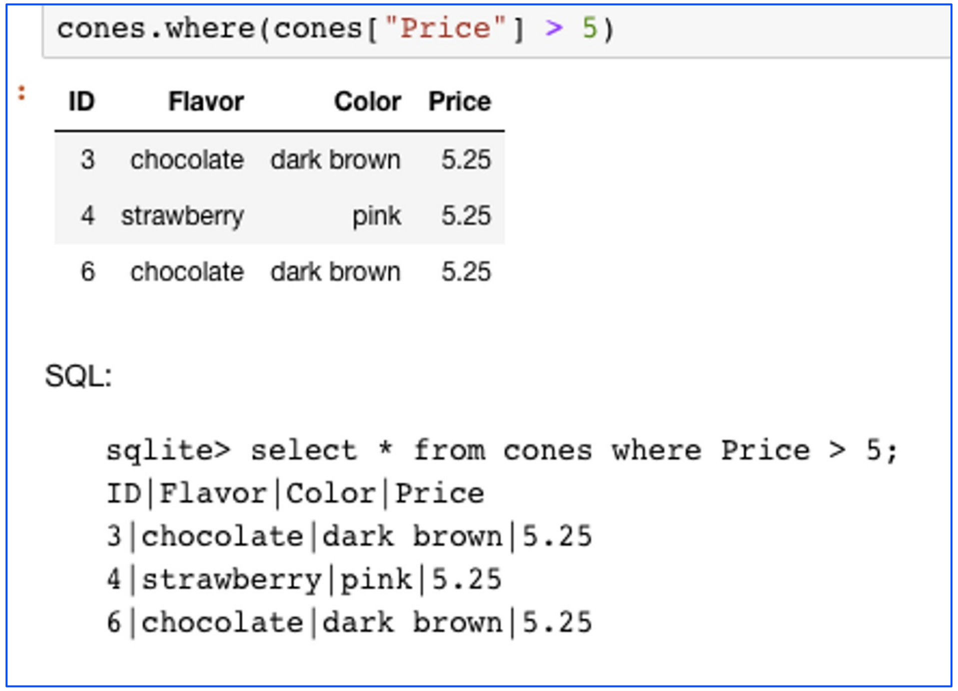
- Set of Table records (rows) that satisfy a condition

```
select [columns] from [table] where [condition] order by [order] ;
```



```
In [5]: cones.select(['Flavor', 'Price'])
Out[5]:
```

Flavor	Price
strawberry	3.55
chocolate	4.75
chocolate	5.25
strawberry	5.25
bubblegum	4.75
chocolate	5.25

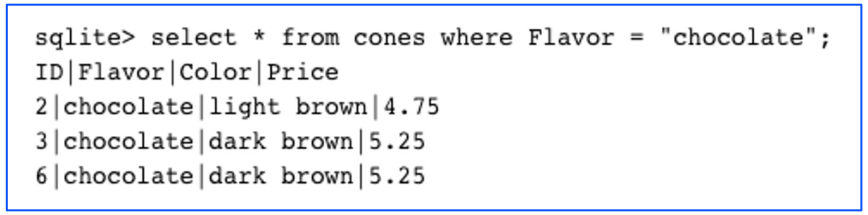


```
cones.where(cones["Price"] > 5)
```

ID	Flavor	Color	Price
3	chocolate	dark brown	5.25
4	strawberry	pink	5.25
6	chocolate	dark brown	5.25

SQL:

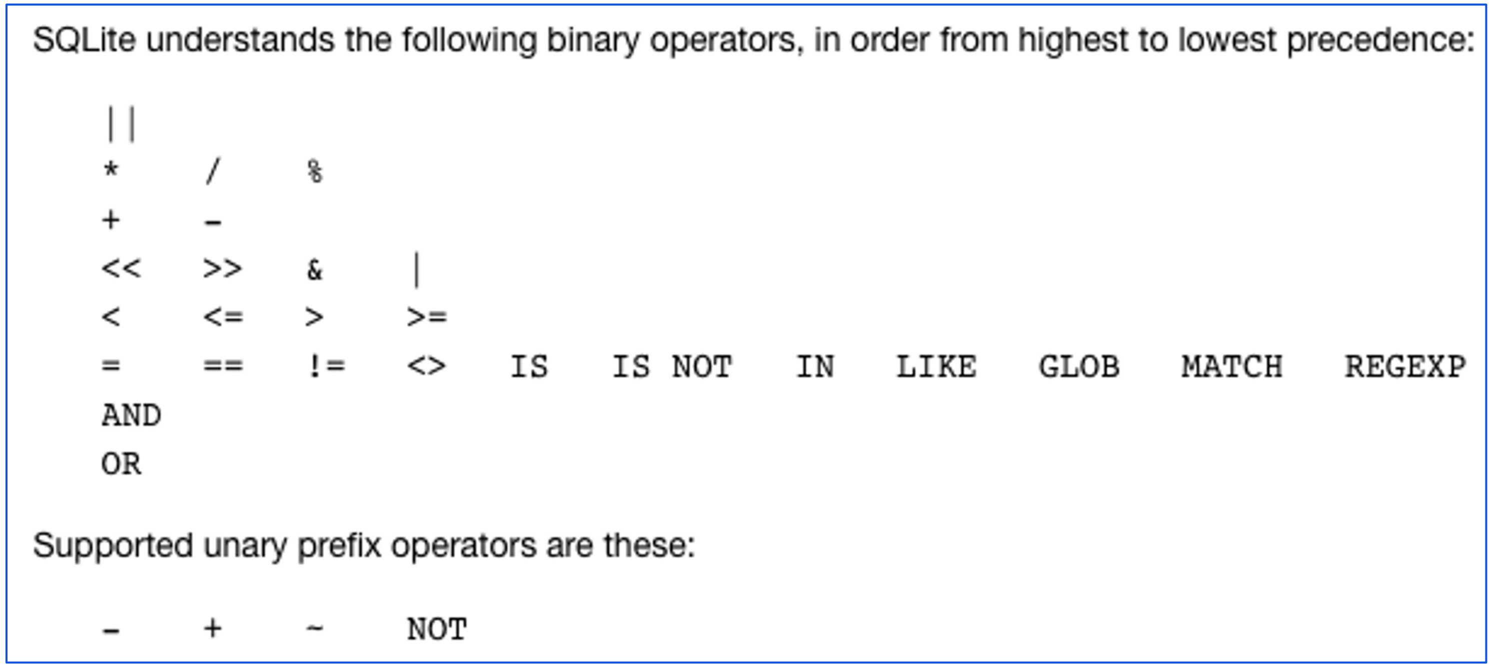
```
sqlite> select * from cones where Price > 5;
ID|Flavor|Color|Price
3|chocolate|dark brown|5.25
4|strawberry|pink|5.25
6|chocolate|dark brown|5.25
```



```
sqlite> select * from cones where Flavor = "chocolate";
ID|Flavor|Color|Price
2|chocolate|light brown|4.75
3|chocolate|dark brown|5.25
6|chocolate|dark brown|5.25
```

SQL Operators for predicate

- use the WHERE clause in the SQL statements such as SELECT, UPDATE and DELETE to filter rows that do not meet a specified condition



SQLite understands the following binary operators, in order from highest to lowest precedence:

```
||
*    /    %
+    -
<<   >>   &    |
<    <=   >    >=
=    ==   !=   <>   IS   IS NOT   IN   LIKE   GLOB   MATCH   REGEXP
AND
OR
```

Supported unary prefix operators are these:

```
-    +    ~    NOT
```

Summary

- SQL a declarative programming language on relational tables
  - largely familiar to you from data8
  - create, select, where, order, group by, join
- Databases are accessed through Applications
  - e.g., all modern web apps have Database backend
  - Queries are issued through API
    - Be careful about app corrupting the database
- Data analytics tend to draw database into memory and operate on it as a data structure
  - e.g., Tables

CREATE TABLE

- SQL often used interactively
  - Result of select displayed to the user, but not stored
- Create table statement gives the result a name
  - Like a variable, but for a permanent object

```
create table [name] as [select statement];
```

SQL: creating a named table

```sql
create table cones as
    select 1 as ID, "strawberry" as Flavor, "pink" as Color,
3.55 as Price union
    select 2, "chocolate","light brown", 4.75 union
    select 3, "chocolate","dark brown", 5.25 union
    select 4, "strawberry","pink",5.25 union
    select 5, "bubblegum","pink",4.75 union
    select 6, "chocolate", "dark brown", 5.25;
```

Notice how column names are introduced and implicit later on.

Summary – Part 1

```
SELECT  <col spec> FROM <table spec> WHERE <cond spec>
    GROUP BY <group spec> ORDER BY <order spec> ;
```

```
INSERT INTO table(column1, column2,...)
      VALUES (value1, value2,...);
```

```
CREATE TABLE name ( <columns> ) ;
```

```
CREATE TABLE name AS  <select statement> ;
```

```
DROP TABLE name ;
```