Computational Structures in Data Science

Databases & SQL

Week 7, Summer 2024. 7/29 (Mon)

Lecture 22

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Announcements

- Only two more lectures of (testable) content!
  - Databases & SQL (today), SQL (tomorrow)
- "Official" course evaluation survey released
  - https://course-evaluations.berkeley.edu/Berkeley/
  - Filling this out will be a huge help for the Data/DSUS department with regard to course development, so please fill this out :)
- "Unofficial" Mid-semester survey due tonight (7/29, 11:59 PM PST)
  - Filling this out helps us improve the course, and helps course staff improve. And, +2 pts Extra Credit!

Announcements: AMA Questions Thread

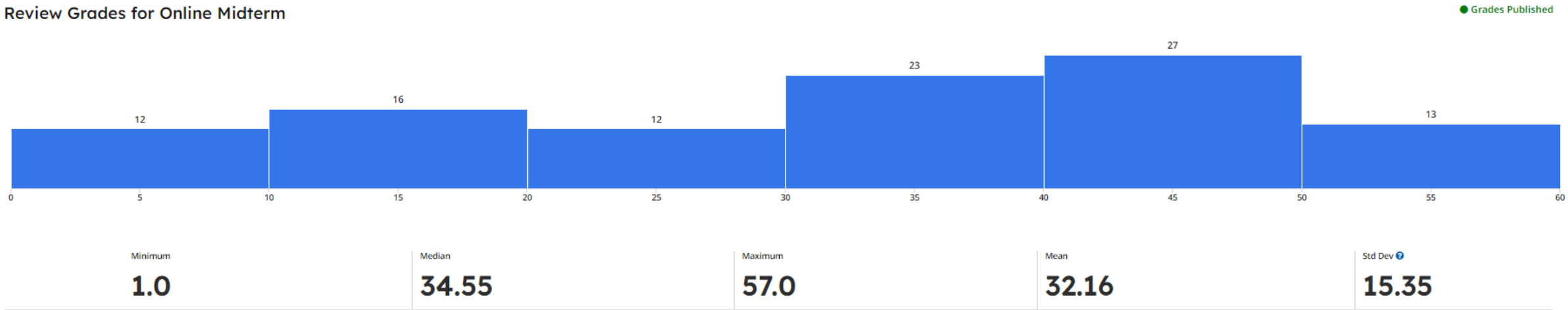
- Wednesday lecture (7/31) will have an **"AMA" (Ask Me Anything) portion**
- **(optional)** Post your questions in the Ed post: "AMA" Lecture Questions Thread

Announcements: Final Exam

- Final exam "primary" time: **Wednesday August 7th, 3PM – 5 PM PST**
- Final exam scheduling form released
  - Gradescope: "(Urgent) Final Exam Scheduling"
  - Due: **Wednesday July 31st 11:59 PM PST**
  - Please fill this out ASAP! For more info, see Ed post.
  - DSP students: you should have received an email for a separate Final exam scheduling form. Please fill this out – if you didn't receive an e-mail, let us know!
- Final exam will have the same style as the Midterm
  - Zoom+Gradescope

Announcements: Midterm

- Midterm grades released on Gradescope
- **Regrade requests** via Gradescope (**Due date: Fri 8/2 11:59 PM PST**)
  - Note: regrade requests must be **specific and well-justified**. Spamming erroneous regrade requests may result in **negative repercussions**. (Gradescope guide: How to submit regrade requests)



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, COUNT(*)
FROM users
WHERE date > "2024-06-01"
GROUP BY date;
```

This query means: From the `users` table, fetch all rows whose `date` column is > `current_date`, group them by `date`, and count how large each group is.

Note: query results are also a table!

user_name	date
"bob"	2024-06-01
"alice"	2024-06-01
"louis"	2024-06-02
"alyssa"	2024-06-03
...	...

`users` table

date	count
2024-06-02	136
2024-06-03	257
2024-06-04	326
2024-06-05	167
...	...

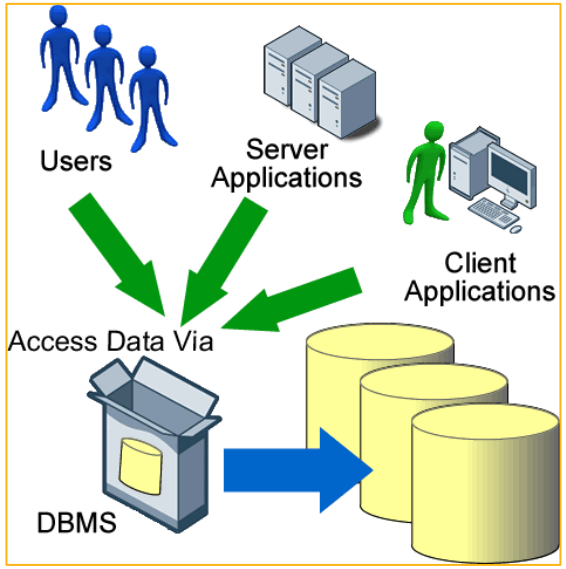
There are 257 rows with date=2024-06-03

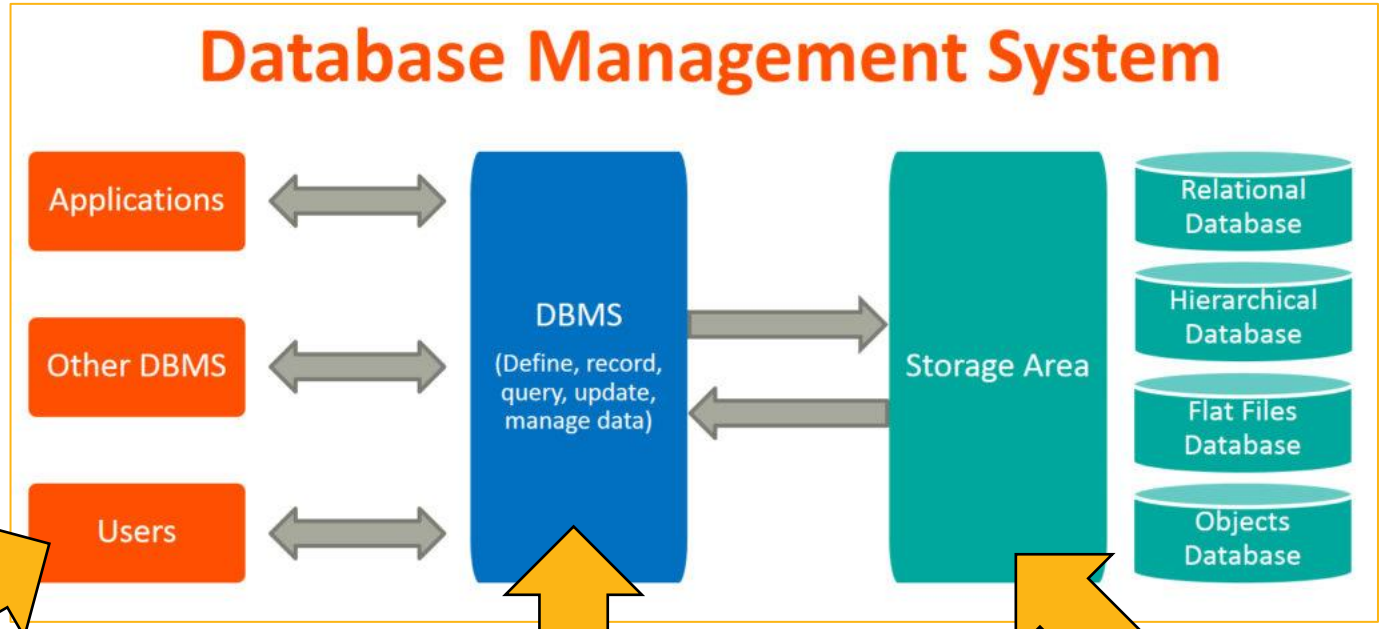
Query results

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.
    - They (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, its storage and accessing it are critical to data science.

Database Management Systems



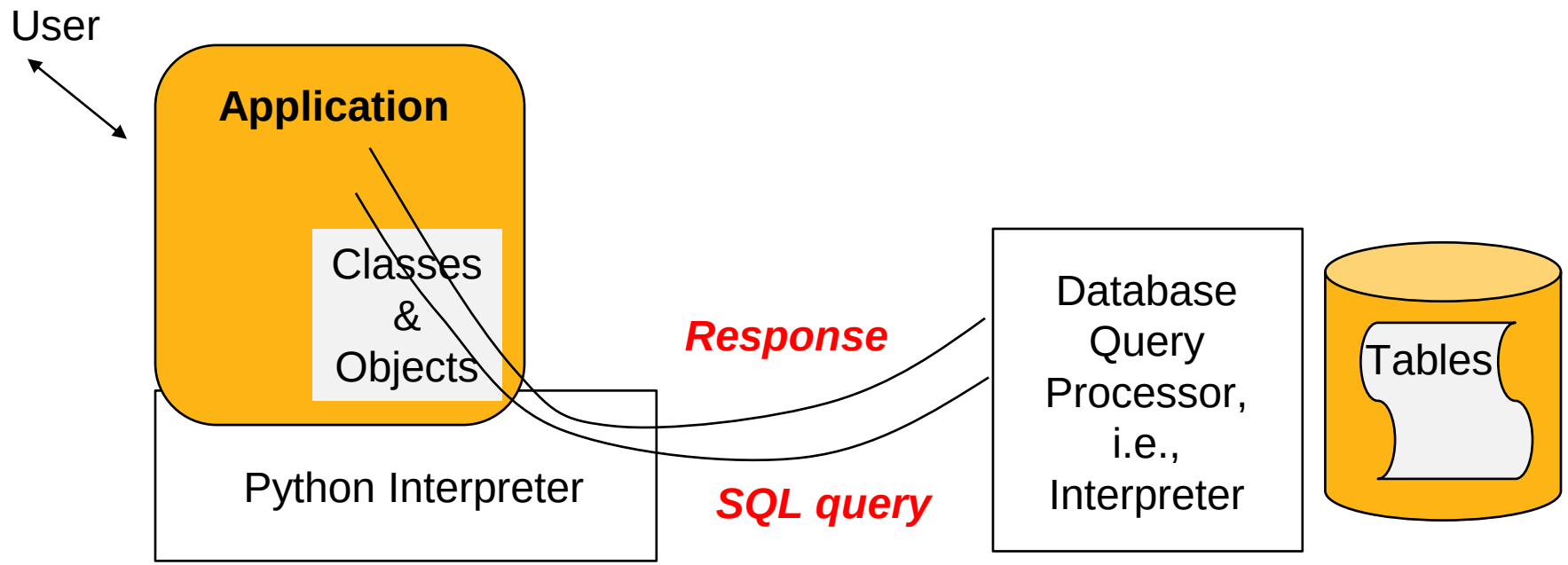


Applications.
Ex: a data scientist wants to perform **exploratory data analysis** on a health dataset.
Ex: a DS wants to see if a website change improved user engagement metrics.

Interface between Users and underlying data. Provides an **abstraction layer** so that Users can focus on **solving problems** (eg data science) instead of **data details** (eg how the underlying data is stored, etc)
Ex: MySQL, sqlite3

Data implementation details. **Data file format** (binary, text, CSV, parquet). **Data location** (cloud vs on-site). Techniques to arrange data to **optimize for access**.

Applications Issue Queries to a Database

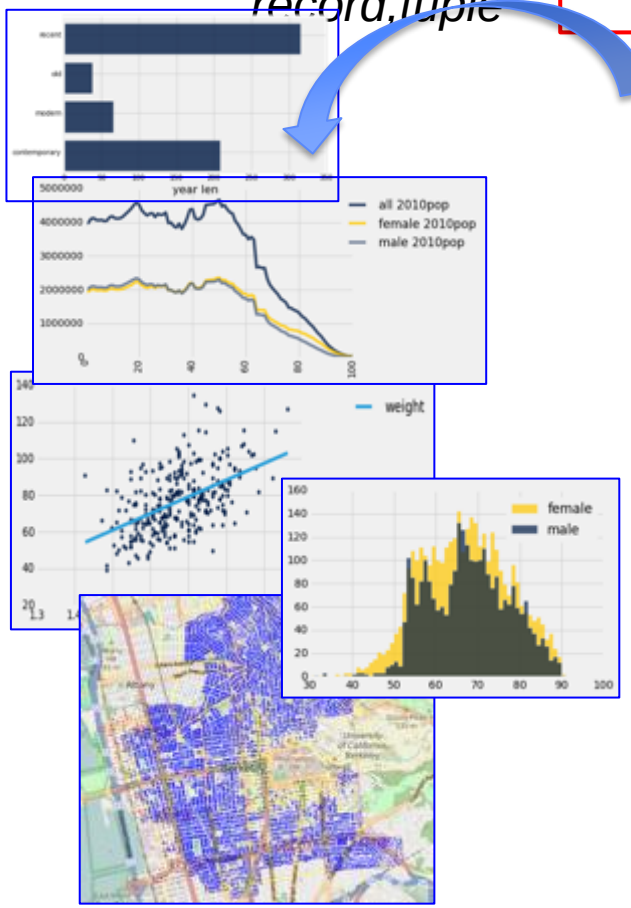


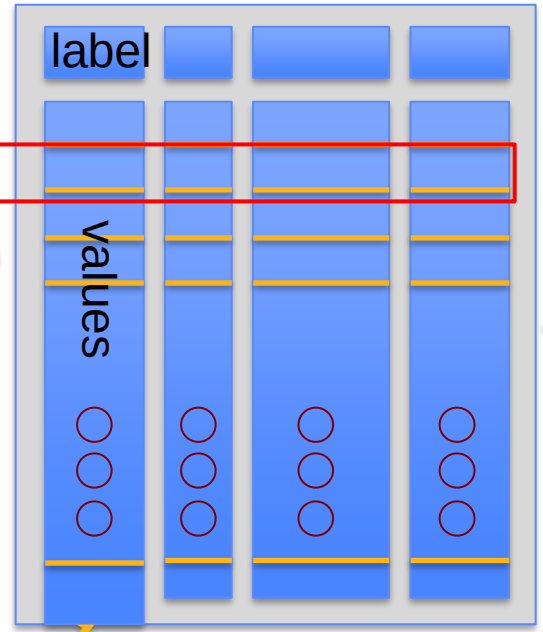
- The SQL language is represented in query strings delivered to a DB backend.
- Use the techniques learned here to build clean abstractions.
- You have already learned the relational operators!

Data 8 Tables, `datascience`

ordered collection of labeled columns of anything

dict, record, tuple





select, where, take, drop, group

pivot, pivot_bin

split

join

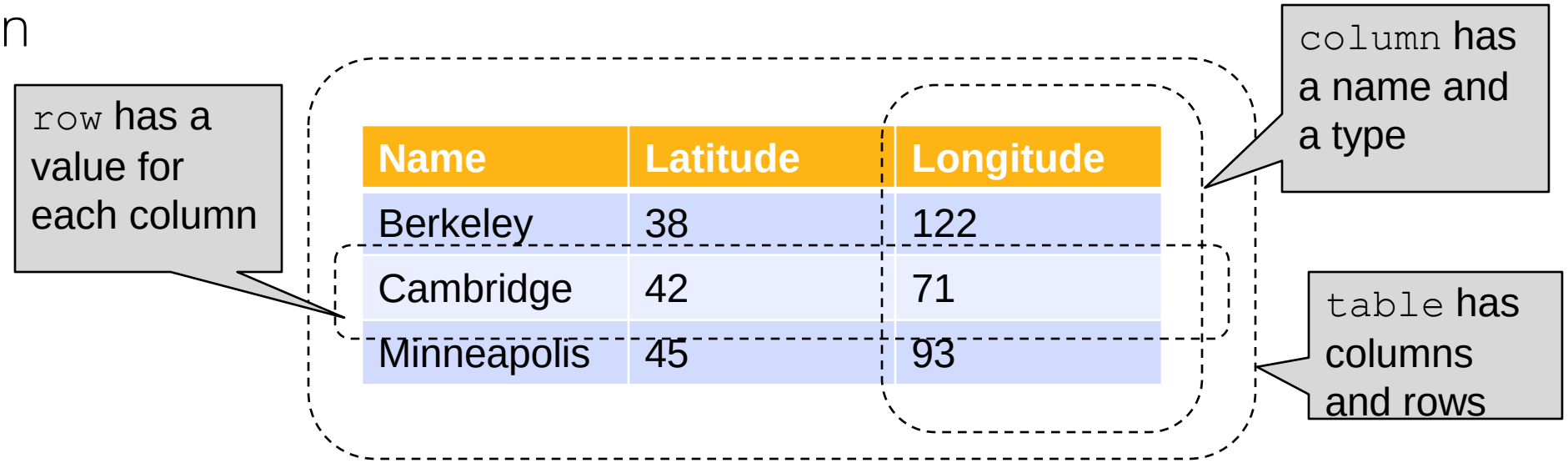
T['label']

Numpy array

- 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



- 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

Data: structured vs unstructured

- **Structured data**: in practice, means "tabular" data
  - Ex: tables, spreadsheets. Each row follows a set **schema**
- **Unstructured data**: everything else
  - raw text logs
  - images/videos
- In practice: people will ingest unstructured data (eg User engagement logs) and process them into a structured format

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

```
[2024-06-01 00:23:01] User 'louis' logged in
[2024-06-01 00:23:02] User 'alice' logged in
[2024-06-01 00:23:32] User 'alice' defeated 'louis'
[2024-06-01 00:23:32] User 'alice' leveled up!
[2024-06-01 00:23:38] User 'louis' messaged 'lol'
[2024-06-01 00:23:40] User 'louis' logged out
...
```

NETFLIX

In this class (C88C) we'll focus on **structured (tabular) data**, which **SQL** excels at

Computational Structures in Data Science

Interacting With A Database

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Eric Kim | UC Berkeley | https://c88c.org

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 (eg compressed, postprocessed, etc).
- 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...
  - **Note**: in this class (C88C) we will NOT be using Python+sqlite3 for SQL, instead we'll primarily be using the SQL interactive console. So, the next few slides are for "fun"
    - More of a glimpse into how language wrappers on top of SQL exists

Connecting To a Database (Python 3)

```
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 automatically. BEWARE!*

```
👉 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
```

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

(Not required for this class) To install sqlite3, visit https://www.sqlite.org/download.html

C88C sqlite_shell.py interactive console

- C88C has a special sqlite_shell.py script just for the class! Similar in spirit to the `sqlite3` executable. This is what we'll use for labs/homeworks!
- *Everything is saved automatically. BEWARE!*

👉 `python3 sqlite_shell.py 24-Databases_and_SQL.db`

```
SQLite version 3.40.1 (adapter version 2.6.0)
Enter ".help" for usage hints.
sqlite> .help
.cd DIRECTORY          Change the working directory to DIRECTORY
.dump                  Dump the database in an SQL text format
.exit                  Exit this program
.help                  Show this message
.open FILE             Close existing database and reopen FILE
.print STRING...       Print literal STRING
.quit                  Exit this program
.read FILENAME         Execute SQL in FILENAME
.schema ?PATTERN?      Show the CREATE statements matching PATTERN
.show                  Show the current values for various settings
.tables ?TABLE?        List names of tables
sqlite> .tables
sales
cones
```

This .db file is a **persistent file** that lives on your computer that contains your tables/data in a special format that sqlite_shell.py knows how to work with.

Notably: making changes to tables within your sqlite_shell.py session will **modify your .db file**, meaning changes persist between sqlite_shell.py sessions! Neat!

Aka "mutation" on a file-system level.

Computational Structures in Data Science

Introduction to SQL

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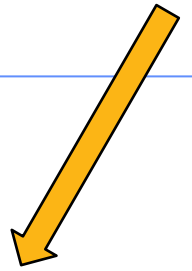
SQL Statements

- 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 ";"

Tip: "transient in-memory database" means "we're not using a persistent db file", aka "data changes will NOT persist after exiting this sqlite3 session



```
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

```
# 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


```
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

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Eric Kim | UC Berkeley | https://c88c.org |

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

```
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
```

```
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
```


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

```
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 (and SQL demo)

```
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 ;
```