This is CS50x

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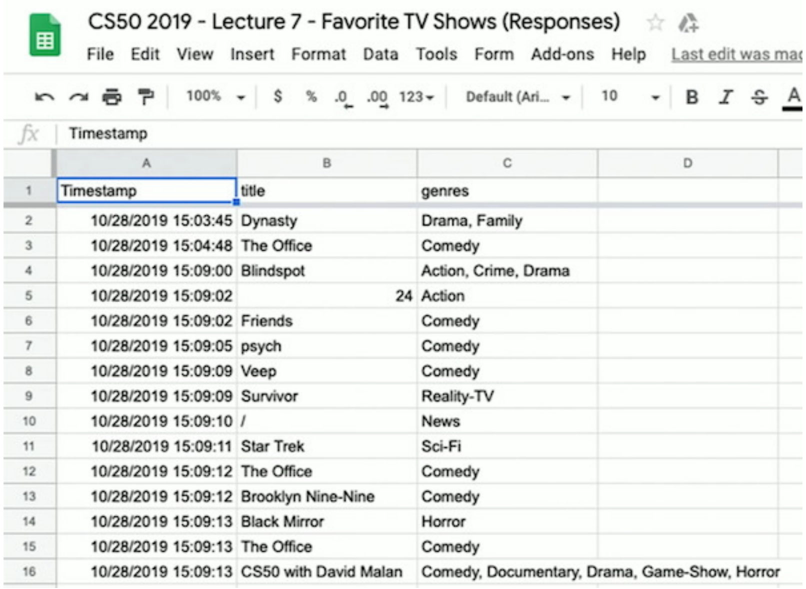
Lecture 7

Spreadsheets

- Most of us are familiar with spreadsheets, rows of data, with each column in a row having a different piece of data that relate to each other somehow.
- A database is an application that can store data, and we can think of Google Sheets as one such application.
- For example, we created a Google Form to ask students their favorite TV show and genre of it. We look thorugh the responses, and see that the spreadsheet has three columns: "Timestamp", "title", and "genres":


CS50 2019 - Lecture 7 - Favorite TV Shows (Responses)
File Edit View Insert Format Data Tools Form Add-ons Help Last edit was mad
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fx Timestamp

	A	B	C	D
1	Timestamp	title	genres	
2	10/28/2019 15:03:45	Dynasty	Drama, Family	
3	10/28/2019 15:04:48	The Office	Comedy	
4	10/28/2019 15:09:00	Blindspot	Action, Crime, Drama	
5	10/28/2019 15:09:02	24	Action	
6	10/28/2019 15:09:02	Friends	Comedy	
7	10/28/2019 15:09:05	psych	Comedy	
8	10/28/2019 15:09:09	Veep	Comedy	
9	10/28/2019 15:09:09	Survivor	Reality-TV	
10	10/28/2019 15:09:10	/	News	
11	10/28/2019 15:09:11	Star Trek	Sci-Fi	
12	10/28/2019 15:09:12	The Office	Comedy	
13	10/28/2019 15:09:12	Brooklyn Nine-Nine	Comedy	
14	10/28/2019 15:09:13	Black Mirror	Horror	
15	10/28/2019 15:09:13	The Office	Comedy	
16	10/28/2019 15:09:13	CS50 with David Malan	Comedy, Documentary, Drama, Game-Show, Horror	

- We can download a CSV file from the spreadsheet with "File > Download", upload it to our IDE, and see that it's a text file with comma-separated values matching the spreadsheet's data.
- We'll write `favorites.py` :

```
import csv

with open("CS50 2019 - Lecture 7 - Favorite TV Shows (Responses) - Form Responses 1.csv", "r") as file:
    reader = csv.DictReader(file)

    for row in reader:
        print(row["title"])
```

  - We're just going to open the file and make sure we can get the title of each row.

- Now we can use a dictionary to count the number of times we've seen each title, with the keys being the titles and the values for each key an integer, tracking how many times we've seen that title:

```
import csv

counts = {}

with open("CS50 2019 - Lecture 7 - Favorite TV Shows (Responses) - Form Responses 1.csv", "r") as file:
    reader = csv.DictReader(file)

    for row in reader:
        title = row["title"]
        if title in counts:
            counts[title] += 1
        else:
            counts[title] = 1

for title, count in counts.items():
    print(title, count, sep=" | ")
```

  - In each row, we can get the `title` with `row["title"]` .
  - Here, if we've seen the title before (it's in `counts`), we can just add 1 to the value. Otherwise, we need to set the initial value to 1.
  - Finally, we can print out our dictionary's keys and values with a separator so it's a bit easier to read.
- We can change the way we iterate to `for title, count in sorted(counts.items()):` , and we'll see our dictionary sorted by the keys, alphabetically.
- But we can sort by the key-value pairs in the dictionary with:

```
def f(item):
  return item[1]

for title, count in sorted(counts.items(), key=f, reverse=True):
```

  - We define a function, `f` , which just returns the value from the `item` in the dictionary with `item[1]` . The `sorted` function, in turn, can use that as the key to sort the dictionary's items. And we'll also pass in `reverse=True` to sort from largest to smallest, instead of smallest to largest.
- We can actually define our function in the same line, with this syntax:

```
for title, count in sorted(counts.items(), key=lambda item: item[1], reverse=True):
```

  - We pass in a lambda, or anonymous function, as the key, which takes in the `item` and returns `item[1]` .
- Finally, we can make all the titles lowercase with `title = row["title"].lower()` , so our counts can be a little more accurate even if the names weren't typed in the exact same way.

SQL

- We'll look at a new program in our terminal window, `sqlite3` , a command-line program that lets us use another language, SQL (pronounced like "sequel").
- We'll run some commands to create a new database called `favorites.db` and import our CSV file into a table called "favorites":

```
~/ $ sqlite3 favorites.db
SQLite version 3.22.0 2018-01-22 18:45:57
Enter ".help" for usage hints.
sqlite> .mode csv
sqlite> .import "CS50 2019 - Lecture 7 - Favorite TV Shows (Responses) - Form Responses 1.csv" favorites
```

- We see a `favorites.db` in our IDE after we run this, and now we can use SQL to interact with our data:

```
sqlite> SELECT title FROM favorites;
title
Dynasty
The Office
Blindspot
24
Friends
psych
Veep
Survivor
...
```

- We can even sort our results:

```
sqlite> SELECT title FROM favorites ORDER BY title;
title
/
24
9009
Adventure Time
Airplane Repo
Always Sunny
Ancient Aliens
...
```

- And get a count of the number of times each title appears:

```
sqlite> SELECT title, COUNT(title) FROM favorites GROUP BY title;
title | COUNT(title)
/ | 1
24 | 1
9009 | 1
Adventure Time | 1
Airplane Repo | 1
Always Sunny | 1
Ancient Aliens | 1
...
```

- We can even set the count of each title to a new variable, `n`, and order our results by that, in descending order. Then we can see the top 10 results with `LIMIT 10`:

```
sqlite> SELECT title, COUNT(title) AS n FROM favorites GROUP BY title ORDER BY n DESC LIMIT 10;
title | n
The Office | 30
Friends | 20
Game of Thrones | 20
Breaking Bad | 14
Black Mirror | 9
Rick and Morty | 9
Brooklyn Nine-Nine | 5
Game of thrones | 5
No | 5
Prison Break | 5
```

- SQL is a language that lets us work with a relational database, an application lets us store data and work with them more quickly than with a CSV.
- With `.schema`, we can see how the format for the table for our data is created:

```
sqlite> .schema
CREATE TABLE favorites(
  "Timestamp" TEXT,
  "title" TEXT,
  "genres" TEXT
);
```

- It turns out that, when working with data, we only need four operations:
  - `CREATE`
  - `READ`
  - `UPDATE`
  - `DELETE`
- In SQL, the commands to perform each of these operations are:
  - `INSERT`
  - `SELECT`
  - `UPDATE`
  - `DELETE`
- First, we'll need to insert a table with the `CREATE TABLE table (column type, ...);` command.
- SQL, too, has its own data types to optimize the amount of space used for storing data:
  - `BLOB`, for "binary large object", raw binary data that might represent files
  - `INTEGER`
    - `smallint`
    - `integer`
    - `bigint`

    - `NUMERIC`
        - `boolean`
        - `date`
        - `datetime`
        - `numeric(scale,precision)` , which solves floating-point imprecision by using as many bits as needed, for each digit before and after the decimal point
        - `time`
        - `timestamp`
    - `REAL`
        - `real` , for floating-point values
        - `double precision` , with more bits
    - `TEXT`
        - `char(n)` , for an exact number of characters
        - `varchar(n)` , for a variable number of characters, up to a certain limit
        - `text`
- SQLite is one database application that supports SQL, and there are many companies with server applications that support SQL, includes Oracle Database, MySQL, PostgreSQL, MariaDB, and Microsoft Access.
- After inserting values, we can use functions to perform calculations, too:
    - `AVG`
    - `COUNT`
    - `DISTINCT` , for getting distinct values without duplicates
    - `MAX`
    - `MIN`
    - …
- There are also other operations we can combine as needed:
    - `WHERE` , matching on some strict condition
    - `LIKE` , matching on substrings for text
    - `LIMIT`
    - `GROUP BY`
    - `ORDER BY`
    - `JOIN` , combining data from multiple tables
- We can update data with `UPDATE table SET column=value WHERE condition;` , which could include 0, 1, or more rows depending on our condition. For example, we might say `UPDATE favorites SET title = "The Office" WHERE title LIKE "%office"` , and that will set all the rows with the title containing "office" to be "The Office" so we can make them consistent.
- And we can remove matching rows with `DELETE FROM table WHERE condition;` , as in `DELETE FROM favorites WHERE title = "Friends";` .
- We can even delete an entire table altogether with another command, `DROP` .

IMDb

- IMDb, or "Internet Movie Database", has datasets [available to download (https://www.imdb.com/interfaces/)](https://www.imdb.com/interfaces/) as TSV, or tab-separate values, files.
- For example, we can download `title.basics.tsv.gz` , which will contain basic data about titles:
    - `tconst` , a unique identifier for each title, like `tt4786824`
    - `titleType` , the type of the title, like `tvSeries`
    - `primaryTitle` , the main title used, like `The Crown`
    - `startYear` , the year a title was released, like `2016`
    - `genres` , a comma-separated list of genres, like `Drama,History`
- We take a look at `title.basics.tsv` after we've unzipped it, and we see that the first rows are indeed the headers we expected and each row has values separated by tabs. But the file has more than 6 million rows, so even searching for one value takes a moment.
- We'll download the file into our IDE with `wget` , and then `gunzip` to unzip it. But our IDE doesn't have enough space, so we'll use our Mac's terminal instead.
- We'll write `import.py` to read the file in:

```
import csv

# Open TSV file for reading
with open("title.basics.tsv", "r") as titles:

    # Since the file is a TSV file, we can use the CSV reader and change
    # the separator to a tab.
    reader = csv.DictReader(titles, delimiter="\t")

    # Open new CSV file for writing
    with open("shows0.csv", "w") as shows:

        # Create writer
        writer = csv.writer(shows)

        # Write header of the columns we want
        writer.writerow(["tconst", "primaryTitle", "startYear", "genres"])

        # Iterate over TSV file
        for row in reader:

            # If non-adult TV show
            if row["titleType"] == "tvSeries" and row["isAdult"] == "0":

                # Write row
                writer.writerow([row["tconst"], row["primaryTitle"], row["startYear"], row["genres"]])
```

- Now, we can open `shows0.csv` and see a smaller set of data. But it turns out, for some of the rows, `startYear` has a value of `\N`, and that's a special value from IMDb when they want to represent values that are missing. So we can filter out those values and convert the `startYear` to an integer to filter for shows after 1970:

```
...
# If year not missing (We need to escape the backslash too)
if row["startYear"] != "\\N":

    # If since 1970
    if int(row["startYear"]) >= 1970:

        # Write row
        writer.writerow([row["tconst"], row["primaryTitle"], row["startYear"], row["genres"]])
```

- We can write a program to search for a particular title:

```
import csv

# Prompt user for title
title = input("Title: ")

# Open CSV file
with open("shows2.csv", "r") as input:

    # Create DictReader
    reader = csv.DictReader(input)

    # Iterate over CSV file
    for row in reader:

        # Search for title
        if title.lower() == row["primaryTitle"].lower():
            print(row["primaryTitle"], row["startYear"], row["genres"], sep=" | ")
```

  - We can run this program and see our results, but we can see how SQL can do a better job.
- In Python, we can connect to a SQL database and read our file into it once, so we can make lots of queries without writing new programs and without having to read the entire file each time.
- Let's do this more easily with the CS50 library:

```
import cs50
import csv

# Create database by opening and closing an empty file first
open(f"shows3.db", "w").close()
db = cs50.SQL("sqlite:///shows3.db")

# Create table called `shows`, and specify the columns we want,
# all of which will be text except `startYear`
db.execute("CREATE TABLE shows (tconst TEXT, primaryTitle TEXT, startYear NUMERIC, genres TEXT)")

# Open TSV file
# https://datasets.imdbws.com/title.basics.tsv.gz
with open("title.basics.tsv", "r") as titles:

    # Create DictReader
    reader = csv.DictReader(titles, delimiter="\t")

    # Iterate over TSV file
    for row in reader:

        # If non-adult TV show
        if row["titleType"] == "tvSeries" and row["isAdult"] == "0":

            # If year not missing
            if row["startYear"] != "\\N":

                # If since 1970
                startYear = int(row["startYear"])
                if startYear >= 1970:

                    # Insert show by substituting values into each ? placeholder
                    db.execute("INSERT INTO shows (tconst, primaryTitle, startYear, genres) VALUES(?, ?, ?, ?)",
                               row["tconst"], row["primaryTitle"], startYear, genres)
```

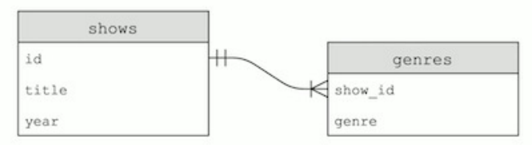
- Now we can run `sqlite3 shows3.db` and run commands like before, such as `SELECT * FROM shows LIMIT 10;` .
- With `SELECT COUNT(*) FROM shows;` we can see that there are more than 150,000 shows in our table, and with `SELECT COUNT(*) FROM shows WHERE startYear = 2019;` , we see that there were more than 6000 this year.

Multiple tables

- But each of the rows will only have one column for genres, and the values are multiple genres put together. So we can go back to our import program, and add another table:

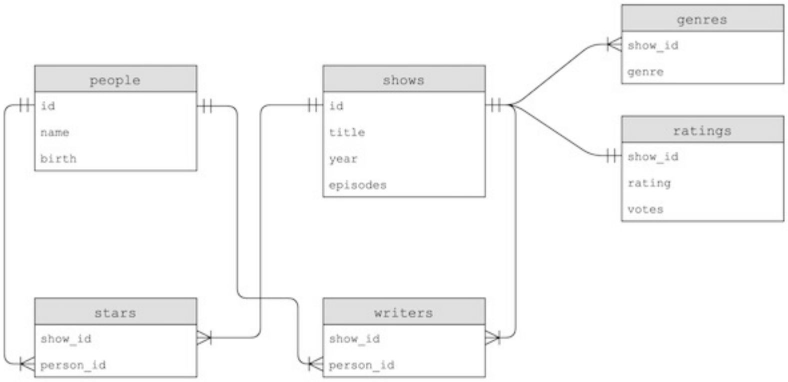
```
import cs50
import csv

# Create database
open(f"shows4.db", "w").close()
db = cs50.SQL("sqlite:///shows4.db")

# Create tables
db.execute("CREATE TABLE shows (id INT, title TEXT, year NUMERIC, PRIMARY KEY(id))")

# The `genres` table will have a column called `show_id` that references
# the `shows` table above
db.execute("CREATE TABLE genres (show_id INT, genre TEXT, FOREIGN KEY(show_id) REFERENCES shows(id))")

# Open TSV file
# https://datasets.imdbws.com/title.basics.tsv.gz
with open("title.basics.tsv", "r") as titles:

    # Create DictReader
    reader = csv.DictReader(titles, delimiter="\t")

    # Iterate over TSV file
    for row in reader:

        # If non-adult TV show
        if row["titleType"] == "tvSeries" and row["isAdult"] == "0":

            # If year not missing
            if row["startYear"] != "\\N":

                # If since 1970
                startYear = int(row["startYear"])
                if startYear >= 1970:

                    # Trim prefix from tconst
                    id = int(row["tconst"][2:])

                    # Insert show
                    db.execute("INSERT INTO shows (id, title, year) VALUES(?, ?, ?)", id, row["primaryTitle"], startYear)

                    # Insert genres
                    if row["genres"] != "\\N":
                        for genre in row["genres"].split(","):
                            db.execute("INSERT INTO genres (show_id, genre) VALUES(?, ?)", id, genre)
```

  - So now our `shows` table no longer has a `genres` column, but instead we have a `genres` table with each row representing a show and an associated genre. Now, a particular show can have multiple genres we can search for, and we can get other data about the show from the `shows` table given its ID.
- In fact, we can combine both tables with `SELECT * FROM shows WHERE id IN (SELECT show_id FROM genres WHERE genre = "Comedy") AND year = 2019;` . We're filtering our `shows` table by IDs where the ID in the `genres` table has a value of "Comedy" for the `genre` column, and has the value of 2019 for the `year` column.
- Our tables look like this:



  - Since the ID in the `genre` table come from the `shows` table, we call it `show_id` . And the arrow indicates that a single show ID might have many matching rows in the `genres` table.
- We see that some datasets from IMDb, like `title.principals.tsv` , have only IDs for certain columns that we'll have to look up in other tables.

- By reading the descriptions for each table, we can see that all of the data can be used to construct these tables:



  - Notice that, for example, a person's name could also be copied to the `stars` or `writers` tables, but instead only the `person_id` is used to link to the data in the `people` table. This way, we only need to update the name in one place if we need to make a change.
- We'll open a database, `shows.db` , with these tables to look at some more examples.
- We'll download a program called DB Browser for SQLite (https://sqlitebrowser.org/dl/), which will have a graphical user interface to browse our tables and data. We can use the "Execute SQL" tab to run SQL directly in the program, too.
- We can run `SELECT * FROM shows JOIN genres ON show.id = genres.show_id;` to join two tables by matching IDs in columns we specify. Then we'll get back a wider table, with columns from each of those two tables.
- We can take a person's ID and find them in shows with `SELECT * FROM stars WHERE person_id = 1122;` , but we can do a query inside our query with `SELECT show_id FROM stars WHERE person_id = (SELECT id FROM people WHERE name = "Ellen DeGeneres");` .
- This gives us back the `show_id` , so to get the show data we can run: `SELECT * FROM shows WHERE id IN (...);` with `...` being the query above.
- We can get the same results with:

```
SELECT title FROM
people JOIN stars ON people.id = stars.person_id JOIN
shows ON stars.show_id = shows.id
WHERE name = "Ellen DeGeneres"
```

  - We join the `people` table with the `stars` table, and then with the `shows` table by specifying columns that should match between the tables, and then selecting just the `title` with a filter on the name.
  - But now we can select other fields from our combined tables, too.
- It turns out that we can specify columns of our tables to be special types, such as:
  - `PRIMARY KEY` , used as the primary identifier for a row
  - `FOREIGN KEY` , which points to a row in another table
  - `UNIQUE` , which means it has to be unique in this table
  - `INDEX` , which asks our database to create a index to more quickly query based on this column. An index is a data structure like a tree, which helps us search for values.
- We can create an index with `CREATE INDEX person_index ON stars (person_id);` . Then the `person_id` column will have an index called `person_index` . With the right indexes, our join query is several hundred times faster.

Problems

- One problem with databases is **race conditions**, where the timing of two actions or events cause unexpected behavior.
- For example, consider two roommates and a shared fridge in their dorm. The first roommate comes home, and sees that there is no milk in the fridge. So the first roommate leaves to the store to buy milk, and while they are at the store, the second roommate comes home, sees that there is no milk, and leaves for another store to get milk. Later, there will be two jugs of milk in the fridge. By leaving a note, we can solve this problem. We can even lock the fridge so that our roommate can't check whether there is milk, until we've gotten back.
- This can happen in our database if we have something like this:

```
rows = db.execute("SELECT likes FROM posts WHERE id=?", id);
likes = rows[0]["likes"]
db.execute("UPDATE posts SET likes = ?", likes + 1);
```

  - First, we're getting the number of likes on a post with a given ID. Then, we set the number of likes to that number plus one.
  - But now if we have two different web servers both trying to add a like, they might both set it to the same value instead of actually adding one each time. For example, if there are 2 likes, both servers will check the number of likes, see that there are 2, and set the value to 3. One of the likes will then be lost.

- To solve this, we can use transactions, where a set of actions is guaranteed to happen together.
- Another problem in SQL is called a **SQL injection attack**, where an adversary can execute their own commands on our database.
- For example, someone might try type in `malan@harvard.edu'--` as their email. If we have a SQL query that's a formatted string (without escaping, or substituting dangerous characters from, the input), such as `f"SELECT * FROM users WHERE username = '{username}' AND password = '{password}'"` , then the query will end up being `f"SELECT * FROM users WHERE username = 'malan@harvard.edu'--' AND password = '{password}'"` , which will actually select the row where `username = 'malan@harvard.edu'` and turn the rest of the line into a comment. To prevent this, we should use `?` placeholders for our SQL library to automatically escape inputs from the user.