# This is CS50x

CS50's Introduction to Computer Science

OpenCourseWare

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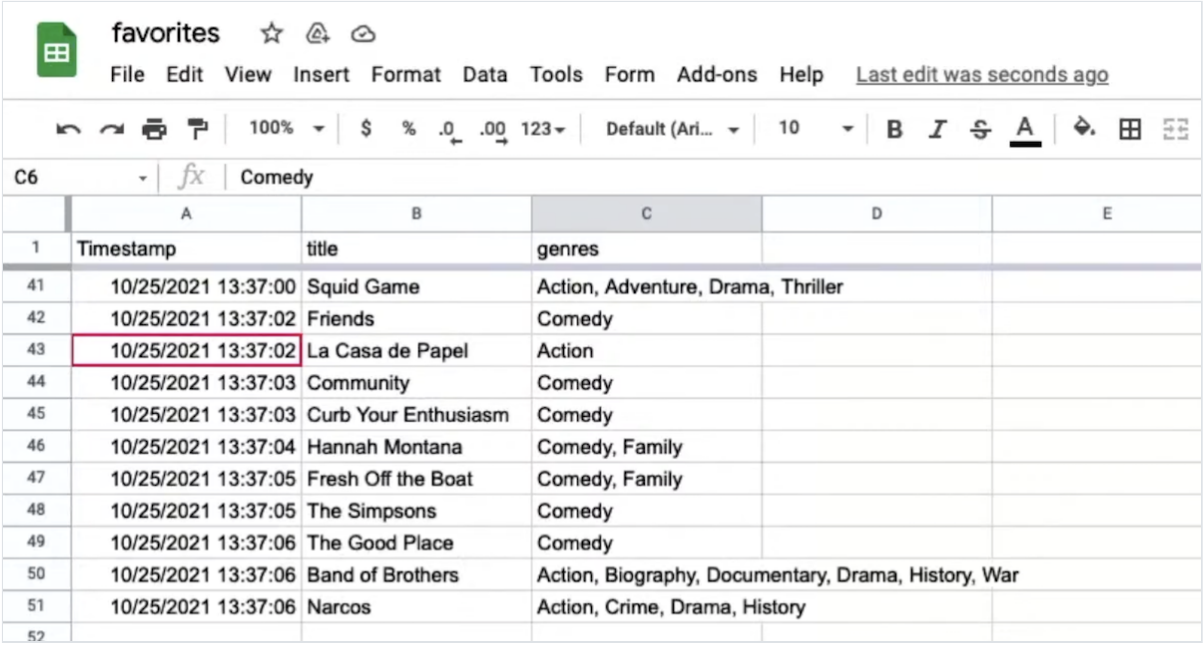
## Lecture 7



### Data processing

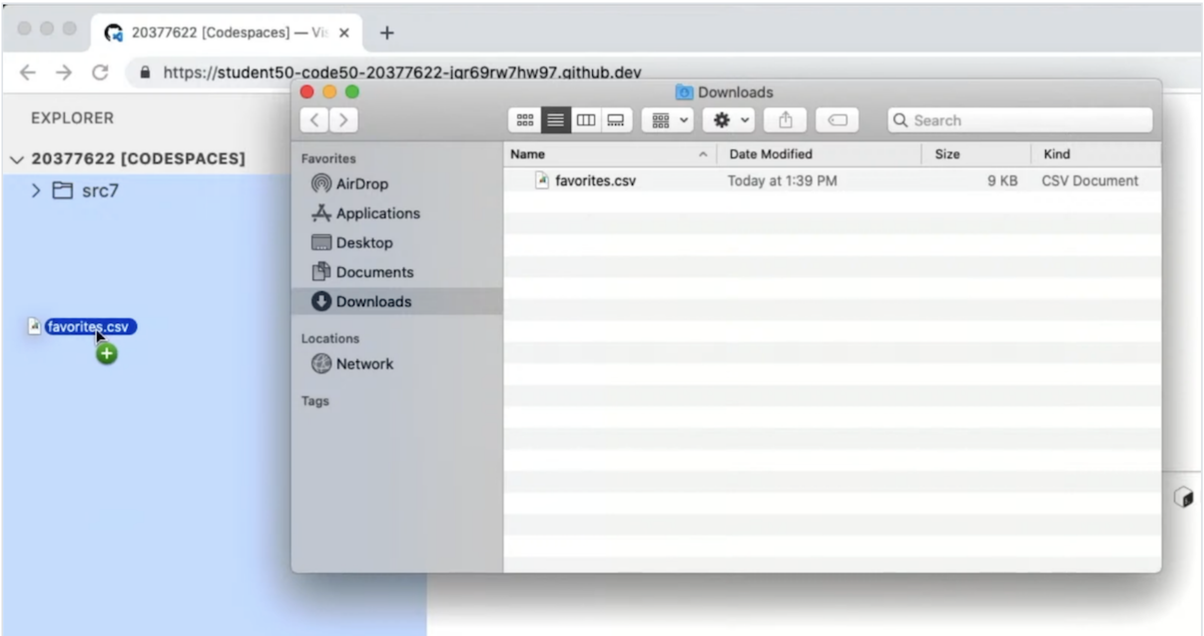
- Last week, we collected a survey of Hogwarts house (https://harrypotter.fandom.com/wiki/Hogwarts_Houses) preferences, and tallied the data from a CSV file with Python.
- This week, we'll collect some more data about your favorite TV shows and their genres.

- We get hundreds of responses from the audience, and start looking at them on Google Sheets, a web-based spreadsheet application, showing our data in rows and columns:




| | A | B | C | D | E |
|---|---|---|---|---|---|
| 1 | Timestamp | title | genres | | |
| 41 | 10/25/2021 13:37:00 | Squid Game | Action, Adventure, Drama, Thriller | | |
| 42 | 10/25/2021 13:37:02 | Friends | Comedy | | |
| 43 | 10/25/2021 13:37:02 | La Casa de Papel | Action | | |
| 44 | 10/25/2021 13:37:03 | Community | Comedy | | |
| 45 | 10/25/2021 13:37:03 | Curb Your Enthusiasm | Comedy | | |
| 46 | 10/25/2021 13:37:04 | Hannah Montana | Comedy, Family | | |
| 47 | 10/25/2021 13:37:05 | Fresh Off the Boat | Comedy, Family | | |
| 48 | 10/25/2021 13:37:05 | The Simpsons | Comedy | | |
| 49 | 10/25/2021 13:37:06 | The Good Place | Comedy | | |
| 50 | 10/25/2021 13:37:06 | Band of Brothers | Action, Biography, Documentary, Drama, History, War | | |
| 51 | 10/25/2021 13:37:06 | Narcos | Action, Crime, Drama, History | | |
| 52 | | | | | |

- Like we did last week, we can download our data as a CSV file, which is an example of a **flat-file database**, where the data for each column is separated by commas, and each row is on a new line, saved simply as a text file in ASCII or Unicode.
  - A flat-file database is completely portable, which means that we can open it on nearly any operating system without special software like Microsoft Excel or Apple Numbers.
- We'll upload the CSV file to our instance of VS Code by dragging and dropping it:



- Then, we'll see the file opened in an editor:

  favorites.csv

  ```
  Timestamp,title,genres
  10/25/2021 11:21:46,How i met your mother,Comedy
  10/25/2021 12:19:26,The Sopranos,"Comedy, Crime, Drama, Horror, Sci-Fi, Talk-Show, Thriller"
  10/25/2021 13:34:34,Friday Night Lights,"Drama, Family, Sport"
  10/25/2021 13:36:10,Family Guy,"Animation, Comedy"
  10/25/2021 13:36:18,New Girl,Comedy
  10/25/2021 13:36:22,Friends,Comedy
  10/25/2021 13:36:23,The Office,Comedy
  10/25/2021 13:36:25,Breaking Bad,"Crime, Drama"
  10/25/2021 13:36:28,Modern Family,Comedy
  10/25/2021 13:36:34,The Office,Comedy
  10/25/2021 13:36:35,White Collar,"Action, Crime, Drama"
  10/25/2021 13:36:36,Modern Family,"Comedy, Family"
  10/25/2021 13:36:36,Game of Thrones,"Action, Adventure, Drama, Fantasy, Thriller, War"
  10/25/2021 13:36:36,the Untamed,"Action, Drama, Fantasy, History, Romance"
  10/25/2021 13:36:36,The 100,"Action, Sci-Fi"
  10/25/2021 13:36:37,Modern Family,"Comedy, Family"
  10/25/2021 13:36:38,The Office,Comedy
  10/25/2021 13:36:38,New Girl,Comedy
  10/25/2021 13:36:39,The Office,Comedy
  10/25/2021 13:36:40,Avatar: The Last Airbender,"Adventure, Animation"
  10/25/2021 13:36:40,Cobra Kai,"Action, Sport"
  ```

  - Notice that some rows have multiple genres, and those are surrounded by quotes, like `"Crime, Drama"`, so that the commas *within* our data aren't misinterpreted.
- Let's write a new program, `favorites.py`, to read our CSV file:

  ```
  import csv

  with open("favorites.csv", "r") as file:
      reader = csv.reader(file)
      next(reader)
      for row in reader:
          print(row[1])
  ```

  - We'll open the file with a reference called `file`, using the `with` keyword in Python that will close our file for us.
  - The `csv` library has a `reader` function that will create a `reader` variable we can use to read in the file as a CSV.
  - We'll call `next` to skip the first row, since that's the header row.
  - Then, we'll use a loop to print the second column in each row, which is the title.
- Now, if we run our program, we'll see a list of show titles:

  ```
  $ python favorites.py
  ...
  Friends
  ...
  friends
  ...
  Friends
  ...
  ```

  - But for the show titled "Friends", some entries are capitalized and some are lowercased.

## Cleaning

- To improve our program, we'll first use a `DictReader`, dictionary reader, which creates a dictionary from each row, allowing us to access each column by its name. We also don't need to skip the header row in this case, since the `DictReader` will use it automatically.

```
import csv

with open("favorites.csv", "r") as file:
    reader = csv.DictReader(file)

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

  - Since the first row in our CSV has the names of the columns, it can be used to label each column in our data as well. Now our program will still work, even if the order of the columns are changed.
- Now let's try to filter out duplicates in our responses:

```
import csv

titles = []

with open("favorites.csv", "r") as file:
    reader = csv.DictReader(file)

    for row in reader:
        if not row["title"] in titles:
            titles.append(row["title"])

for title in titles:
    print(title)
```

  - We'll make a new list called `titles`, and only add each row's title if it's not already in the list. Then, we can print all the titles:

    ```
    $ python favorites.py
    ...
    Friends
    ...
    friends
    ...
    ```

    - We see that there are still near-duplicates, since `Friends` and `friends` are indeed different strings still.
- We'll want to change the current title to all uppercase, and remove whitespace around it, before we add it to our list:

```
import csv

```

```
titles = []

with open("favorites.csv", "r") as file:
    reader = csv.DictReader(file)

    for row in reader:
        title = row["title"].strip().upper()
        if not title in titles:
            titles.append(title)

for title in titles:
    print(title)
```

- Now, we've **canonicalized**, or standardized, our data, and our list of titles are much cleaner:

```
$ python favorites.py
...
NEW GIRL
FRIENDS
THE OFFICE
BREAKING BAD
...
```

- It turns out that Python has another data structure built-in, `set`, which ensures that all the values are unique:

```
import csv

titles = set()

with open("favorites.csv", "r") as file:
    reader = csv.DictReader(file)

    for row in reader:
        title = row["title"].strip().upper()
        titles.add(title)

for title in titles:
    print(title)
```

  - Now, we can call `add` on the set, and not have to check ourselves if it's already in the set.
- To sort the titles, we can just change our loop to `for title in sorted(titles)`, which will sort our set before we iterate over it:

```
import csv

titles = set()
```

```
with open("favorites.csv", "r") as file:
    reader = csv.DictReader(file)

    for row in reader:
        title = row["title"].strip().upper()
        titles.add(title)

for title in sorted(titles):
    print(title)
```

```
$ python favorites.py
ADVENTURE TIME
ANNE WITH AN E
...
AVATAR
AVATAR THE LAST AIRBENDER
AVATAR: THE LAST AIRBENDER
...
BROOKLYN 99
BROOKLYN-99
...
```

- Now, we see our titles alphabetized, but there were still a few different ways that a show's title could be entered. We'll leave these differences there for now, since it will likely take a bit more effort to fully standardize our data.

## Counting

- We can use a dictionary, instead of a set, to count the number of times we've seen each title, with the keys being the titles and the values being an integer counting the number of times we see each of them:

```
import csv

titles = {}

with open("favorites.csv", "r") as file:
    reader = csv.DictReader(file)

    for row in reader:
        title = row["title"].strip().upper()
        titles[title] += 1

for title in sorted(titles):
    print(title)
```

    - As we read each row, we increase the value stored for that title in the dictionary by 1.
- We'll run this program, and see:

```
$ python favorites.py
Traceback (most recent call last):
  File "/workspaces/20377622/favorites.py", line 9, in <module>
    titles[title] += 1
KeyError: 'HOW I MET YOUR MOTHER'
```

    - We have a `KeyError`, since the title `HOW I MET YOUR MOTHER` isn't in the dictionary yet.
- We'll have to add each title to our dictionary first, and set the initial value to 1:

```
import csv

titles = {}

with open("favorites.csv", "r") as file:
    reader = csv.DictReader(file)

    for row in reader:
        title = row["title"].strip().upper()
        if title in titles:
            titles[title] += 1
        else:
            titles[title] = 1

for title in sorted(titles):
    print(title, titles[title])
```

    - We'll add the values, or counts, to our loop that prints every show name.
- We can also set the initial value to 0, and then increment it by 1 no matter what:

```
import csv

titles = {}

with open("favorites.csv", "r") as file:
    reader = csv.DictReader(file)

    for row in reader:
        title = row["title"].strip().upper()
        if not title in titles:
            titles[title] = 0
        titles[title] += 1
```

```
for title in sorted(titles):
    print(title, titles[title])
```

```
$ python favorites.py
ADVENTURE TIME 1
ANNE WITH AN E 1
ARCHER 1
...
AVATAR THE LAST AIRBENDER 5
...
COMMUNITY 8
...
```

- Now, the key will exist in the dictionary, and we can safely refer to its value in the dictionary.

- We can sort by the values in the dictionary by changing our loop to:

```
...
def get_value(title):
    return titles[title]

for title in sorted(titles, key=get_value, reverse=True):
    print(title, titles[title])
```

  - We define a function, `f`, which just returns the value of a title in the dictionary with `titles[title]`. The `sorted` function, in turn, will take in that function as the key to sort the dictionary. And we'll also pass in `reverse=True` to sort from largest to smallest, instead of smallest to largest.
  - So now we'll see the most popular shows printed:

```
$ python favorites.py
THE OFFICE 15
FRIENDS 9
COMMUNITY 8
GAME OF THRONES 6
...
```

- We can actually define our function in the same line, with this syntax:

```
for title in sorted(titles, key=lambda title: titles[title], reverse=Tru
    print(title, titles[title])
```

  - We can write and pass in a **lambda**, or anonymous function, which has no name but takes in some argument or arguments, and returns a value immediately.
  - Notice that there are no parentheses or `return` keyword, but concisely has the same effect as our `get_value` function earlier.

- We can also try to count all the occurrences of a specific title:

```
import csv

counter = 0

with open("favorites.csv", "r") as file:
    reader = csv.DictReader(file)

    for row in reader:
        title = row["title"].strip().upper()
        if title == "THE OFFICE":
            counter += 1

print(f"Number of people who like The Office: {counter}")
```

```
$ python favorites.py
Number of people who like The Office: 15
```

- We'll have a simple `counter` variable, and add one to it.

- Now, if our data referred to the same show in different ways, we can try to check if the word "OFFICE" was in the title at all:

```
import csv

counter = 0

with open("favorites.csv", "r") as file:
    reader = csv.DictReader(file)

    for row in reader:
        title = row["title"].strip().upper()
        if "OFFICE" in title:
            counter += 1

print(f"Number of people who like The Office: {counter}")
```

```
$ python favorites.py
Number of people who like The Office: 16
```

- It turns out that a row has a typo, "Thevoffice", so now our count is correct.

- We can also use **regular expressions**, a standardized way to represent a pattern that a string must match.
- For example, we can write a regular expression that matches email addresses:

```
.*@.*\..*
```

- The first period, `.`, indicates any character. The following asterisk, `*`, indicates 0 or more times. Then, we want an at sign, `@`. Then we want 0 or more characters again,

`.*`, and then a literal period in our string, escaped with `\.`. Finally, we want 0 or more characters again with `.*`.

- Since we probably want at least 1 character in each segment of an email address, we should change our regular expression to:

```
.+@.+\..+
```

  - The plus sign, `+`, means we are matching for the previous character 1 or more times.
  - We can restrict the domain of the email to `.edu` by changing our regular expression to `.+@.+\.edu`.

- Languages like Python and JavaScript support regular expressions, which are like a mini-language in themselves, with syntax like:
  - `.` for any character
  - `.*` for 0 or more characters
  - `.+` for 1 or more characters
  - `?` for an optional character
  - `^` for start of input
  - `$` for end of input
  - ...
- We can change our program earlier to use `re`, a Python library for regular expressions:

```
import csv
import re

counter = 0

with open("favorites.csv", "r") as file:
    reader = csv.DictReader(file)

    for row in reader:
        title = row["title"].strip().upper()
        if re.search("OFFICE", title):
            counter += 1

print(f"Number of people who like The Office: {counter}")
```

```
$ python favorites.py
Number of people who like The Office: 16
```

  - The `re` library has a function, `search`, to which we can pass a pattern and string to see if there is a match.
  - We can change our expression to `"^(OFFICE|THE OFFICE)$"`, which will match either `OFFICE` or `THE OFFICE`, but only if they start at the beginning of the string,

and stop at the end of the string (i.e., there are no other words before or after).
    - We can even change `THE OFFICE` to `THE.OFFICE`, allowing any character (like a typo) to be in between those words.
- We can also write a program to ask the user for a particular title and report its popularity:

```
import csv

title = input("Title: ").strip().upper()

counter = 0

with open("favorites.csv", "r") as file:
    reader = csv.DictReader(file)
    for row in reader:
        if row["title"].strip().upper() == title:
            counter += 1

print(counter)
```

```
$ python favorites.py
Title: the office
13
```

    - We ask the user for input, and then open our CSV file. Since we're looking for just one title, we can have one `counter` variable that we increment.
    - We check for a match after standardizing both the user's input and each row's title.

## Relational databases

- **Relational databases** are programs that store data, ultimately in files, but with additional data structures and interfaces that allow us to search and store data more efficiently.
- When working with data, we generally need four types of basic operations with the acronym `CRUD`:
    - `CREATE`
    - `READ`
    - `UPDATE`
    - `DELETE`

## SQL

- With another programming language, **SQL** (pronounced like "sequel"), we can interact with databases with verbs like:
    - `CREATE`, `INSERT`

    - `SELECT`
    - `UPDATE`
    - `DELETE`, `DROP`
- Syntax in SQL might look like:

```
CREATE TABLE table (column type, ...);
```

    - With this statement, we can create a **table**, which is like a spreadsheet with rows and columns.
    - In SQL, we choose the types of data that each column will store.
- We'll use a common database program called **SQLite**, one of many available programs that support SQL. Other database programs include Oracle Database, MySQL, PostgreSQL, and Microsoft Access.
- SQLite stores our data in a binary file, with 0s and 1s that represent data efficiently. We'll interact with our tables of data through a command-line program, `sqlite3`.
- We'll run some commands in VS Code to import our CSV file into a database:

```
$ sqlite3 favorites.db
SQLite version 3.36.0 2021-06-18 18:36:39
Enter ".help" for usage hints.
sqlite> .mode csv
sqlite> .import favorites.csv favorites
```

    - First, we'll run the `sqlite3` program with `favorites.db` as the name of the file for our database.
    - With `.import`, SQLite creates a table in our database with the data from our CSV file.
- Now, we'll see three files, including `favorites.db`:

```
$ ls
favorites.csv  favorites.db  favorites.py
```

- We can open our database file again, and check the schema, or design, of our new table with `.schema`:

```
$ sqlite3 favorites.db
SQLite version 3.36.0 2021-06-18 18:36:39
Enter ".help" for usage hints.
sqlite> .schema
CREATE TABLE IF NOT EXISTS "favorites"(
  "Timestamp" TEXT,
  "title" TEXT,
  "genres" TEXT
);
```

    - We see that `.import` used the `CREATE TABLE ...` command to create a table called `favorites`, with column names automatically copied from the CSV's header row, and types for each of them assumed to be text.
- We can select, or read data, with:

```
sqlite> SELECT title FROM favorites;
+------------------------------------+
|                title               |
+------------------------------------+
| How i met your mother              |
| The Sopranos                       |
| Friday Night Lights                |
...
```

    - With a command in the format `SELECT columns FROM table;`, we can read data from one or more columns. For example, we can write `SELECT title, genre FROM favorites;` to select both the title and genre.
- SQL supports many functions that we can use to count and summarize data:
    - `AVG`
    - `COUNT`
    - `DISTINCT`
    - `LOWER`
    - `MAX`
    - `MIN`
    - `UPPER`
    - ...
- We can clean up our titles as before, converting them to uppercase and printing only the unique values:

```
sqlite> SELECT DISTINCT(UPPER(title)) FROM shows;
...
| LAW AND ORDER                      |
| B99                                |
| GOT                                |
...
```

- We can also get a count of how many responses there are:

```
sqlite> SELECT COUNT(title) FROM favorites;
+--------------+
| COUNT(title) |
+--------------+
| 158          |
+--------------+
```

- We can also add more phrases to our command:
  - `WHERE`, adding a Boolean expression to filter our data
  - `LIKE`, filtering responses more loosely
  - `ORDER BY`
  - `LIMIT`
  - `GROUP BY`
  - ...
- We can limit the number of results:

```
sqlite> SELECT title FROM favorites LIMIT 10;
+------------------------+
|         title          |
+------------------------+
| How i met your mother |
| The Sopranos           |
| Friday Night Lights    |
| Family Guy             |
| New Girl               |
| Friends                |
| Office                 |
| Breaking Bad           |
| Modern Family          |
| Office                 |
+------------------------+
```

- We can also look for titles matching a string:

```
sqlite> SELECT title FROM favorites WHERE title LIKE "%office%";
+-------------+
|    title    |
+-------------+
| Office      |
| Office      |
| The Office  |
| The Office  |
| The Office  |
| The Office  |
| The Office  |
| The Office  |
| The Office  |
| The Office  |
| The Office  |
| the office  |
| The Office  |
| ThE OffiCE  |
| The Office  |
```

```
| Thevoffice   |
+--------------+
```

- The `%` character is a placeholder for zero or more other characters, so SQL supports some pattern matching, though not it's not as powerful as regular expressions are.

- We can select just the count in our command:

```
sqlite> SELECT COUNT(title) FROM favorites WHERE title LIKE "%office%";
+--------------+
| COUNT(title) |
+--------------+
| 16           |
+--------------+
```

- If we don't like a show, we can even delete it:

```
sqlite> SELECT COUNT(title) FROM favorites WHERE title LIKE "%friends%"
+--------------+
| COUNT(title) |
+--------------+
| 9            |
+--------------+
sqlite> DELETE FROM favorites WHERE title LIKE "%friends%";
sqlite> SELECT COUNT(title) FROM favorites WHERE title LIKE "%friends%"
+--------------+
| COUNT(title) |
+--------------+
| 0            |
+--------------+
```

  - With SQL, we can change our data more easily and quickly than with Python.

- We can update a specific row of data:

```
sqlite> SELECT title FROM favorites WHERE title = "Thevoffice";
+------------+
|   title    |
+------------+
| Thevoffice |
+------------+
sqlite> UPDATE favorites SET title = "The Office" WHERE title = "Thevof
sqlite> SELECT title FROM favorites WHERE title = "Thevoffice";
sqlite>
```

  - Now, we've changed that row's value.

- We can change the values in multiple rows, too:

```
sqlite> SELECT genres FROM favorites WHERE title = "Game of Thrones";
+----------------------------------------------------------------------
|                                                      genres
+----------------------------------------------------------------------
| Action, Adventure, Drama, Fantasy, Thriller, War
| Action, Adventure, Drama
| Action, Adventure, Comedy, Drama, Family, Fantasy, History, Horror, Mu
| Action, Drama, Family, Fantasy, War
| Fantasy, Thriller, War
+----------------------------------------------------------------------
sqlite> UPDATE favorites SET genres = "Action, Adventure, Drama, Fantasy
sqlite> SELECT genres FROM favorites WHERE title = "Game of Thrones";
+---------------------------------------------------+
|                     genres                        |
+---------------------------------------------------+
| Action, Adventure, Drama, Fantasy, Thriller, War |
| Action, Adventure, Drama, Fantasy, Thriller, War |
| Action, Adventure, Drama, Fantasy, Thriller, War |
| Action, Adventure, Drama, Fantasy, Thriller, War |
| Action, Adventure, Drama, Fantasy, Thriller, War |
+---------------------------------------------------+
```

- With `DELETE` and `DROP`, we can remove rows and even entire tables as well.
- And notice that in our commands, we've written SQL keywords in all caps, so they stand out more.
- There also isn't a built-in way to undo commands, so if we make a mistake we might have to build our database again!

## Tables

- We'll take a look at our schema again:

```
sqlite> .schema
CREATE TABLE IF NOT EXISTS "favorites"(
  "Timestamp" TEXT,
  "title" TEXT,
  "genres" TEXT
);
```

- If we look at our values of genres, we see some redundancy:

```
sqlite> SELECT genres FROM favorites;
+------------------------------------------------------------+
|                          genres                            |
+------------------------------------------------------------+
| Comedy                                                     |
| Comedy, Crime, Drama, Horror, Sci-Fi, Talk-Show, Thriller |
```

```
| Drama, Family, Sport                                              |
| Animation, Comedy                                                 |
| Comedy, Drama                                                     |
...
```

- And if we want to search for shows that are comedies, we have to search with not just `SELECT title FROM favorites WHERE genre = "Comedy";`, but also `... WHERE genre = "Comedy, Drama";`, `... WHERE genre = "Comedy, News";`, and so on.
- We can use the `LIKE` keyword again, but two genres, "Music" and "Musical", are similar enough for that to be problematic.
- We can actually write our own Python program that will use SQL to import our CSV data into *two* tables:

```
# Imports titles and genres from CSV into a SQLite database

import cs50
import csv

# Create database
open("favorites8.db", "w").close()
db = cs50.SQL("sqlite:///favorites8.db")

# Create tables
db.execute("CREATE TABLE shows (id INTEGER, title TEXT NOT NULL, PRIMARY
db.execute("CREATE TABLE genres (show_id INTEGER, genre TEXT NOT NULL, F

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

    # Create DictReader
    reader = csv.DictReader(file)

    # Iterate over CSV file
    for row in reader:

        # Canoncalize title
        title = row["title"].strip().upper()

        # Insert title
        show_id = db.execute("INSERT INTO shows (title) VALUES(?)", titl

        # Insert genres
        for genre in row["genres"].split(", "):

            db.execute("INSERT INTO genres (show_id, genre) VALUES(?, ?
```

  - First, we import the Python `cs50` library so we can run SQL commands more easily.

- Then, the rest of this code will import each row of `favorites.csv`.
- Now, our database will have this design:

```
$ sqlite3 favorites8.db
SQLite version 3.36.0 2021-06-18 18:36:39
Enter ".help" for usage hints.
sqlite> .schema
CREATE TABLE shows (id INTEGER, title TEXT NOT NULL, PRIMARY KEY(id));
CREATE TABLE genres (show_id INTEGER, genre TEXT NOT NULL, FOREIGN KEY(s
```

  - We have one table, `shows`, with an `id` column and a `title` column. We can specify that a `title` isn't null, and that `id` is the column we want to use as a primary key.
  - Then, we'll have a table called `genres`, where we have a `show_id` column that references our `shows` table, along with a `genre` column.
  - This is an example of a **relation**, like a link, between rows in different tables in our database.
- In our `shows` table, we'll see each show with an `id` number:

```
sqlite> SELECT * FROM shows;
+-----+------------------------------------+
| id  |               title                |
+-----+------------------------------------+
| 1   | HOW I MET YOUR MOTHER              |
| 2   | THE SOPRANOS                       |
| 3   | FRIDAY NIGHT LIGHTS                |
| 4   | FAMILY GUY                         |
| 5   | NEW GIRL                           |
| 6   | FRIENDS                            |
| 7   | OFFICE                             |
...
```

- And we can see that the `genres` table has one or more rows for each `show_id`:

```
sqlite> SELECT * FROM genres;
+---------+-------------+
| show_id |    genre    |
+---------+-------------+
| 1       | Comedy      |
| 2       | Comedy      |
| 2       | Crime       |
| 2       | Drama       |
| 2       | Horror      |
| 2       | Sci-Fi      |
| 2       | Talk-Show   |
| 2       | Thriller    |
| 3       | Drama       |
```

```
| 3         | Family       |
| 3         | Sport        |
| 4         | Animation    |
| 4         | Comedy       |
| 5         | Comedy       |
| 6         | Comedy       |
| 7         | Comedy       |
...
```

- Since each show may have more than one genre, we can have more than one row per show in our `genres` table, known as a **one-to-many** relationship.
- Furthermore, the data is now cleaner, since each genre name is in its own row.

- We can select all the shows are that comedies by selecting from the `genres` table first, and then looking for those `id` s in the `shows` table:

```
sqlite> SELECT title FROM shows WHERE id IN (SELECT show_id FROM genres
+------------------------------------+
|               title                |
+------------------------------------+
| HOW I MET YOUR MOTHER              |
| THE SOPRANOS                       |
| FAMILY GUY                         |
| NEW GIRL                           |
| FRIENDS                            |
| OFFICE                             |
| MODERN FAMILY                      |
...
```

- Notice that we've nested two queries, where the inner one returns a list of show `id` s, and the outer one uses those to select the titles of shows that match.

- Now we can sort and show just the unique titles by adding to our command:

```
sqlite> SELECT DISTINCT(title) FROM shows WHERE id IN (SELECT show_id FI
+------------------------------------+
|               title                |
+------------------------------------+
| ARCHER                             |
| ARRESTED DEVELOPMENT               |
| AVATAR THE LAST AIRBENDER          |
| B99                                |
| BILLIONS                           |
| BLACK MIRROR                       |
...
```

- And we can add new data to each table, in order to add another show. First, we'll add a new row to the `shows` table for Seinfeld:

```
sqlite> INSERT INTO shows (title) VALUES("Seinfeld");
```

- Then, we can get our row's `id` by looking for it in the table:

```
sqlite> SELECT * FROM shows WHERE title = "Seinfeld";
+-----+----------+
| id  |  title   |
+-----+----------+
| 159 | Seinfeld |
+-----+----------+
```

- We'll use that as the `show_id` to add a new row in the `genres` table:

```
sqlite> INSERT INTO genres (show_id, genre) VALUES(159, "Comedy");
```

- Then, we'll use `UPDATE` to set the title to uppercase:

```
sqlite> UPDATE shows SET title = "SEINFELD" WHERE title = "Seinfeld";
```

- Finally, we'll run the same command as before, and see our new show is indeed in the list of comedies:

```
sqlite> SELECT DISTINCT(title) FROM shows WHERE id IN (SELECT show_id FI
...
| SEINFELD                        |
...
```

## SQL with Python

- It turns out that we'll be able to write Python code that automates this, so we can imagine building web applications that can programmatically store and look up user data, online shopping orders, and more.
- We can write a program that asks the user for a show title and then prints its popularity:

```
import csv

from cs50 import SQL

db = SQL("sqlite:///favorites.db")

title = input("Title: ").strip()

rows = db.execute("SELECT COUNT(*) AS counter FROM favorites WHERE title

row = rows[0]

```

```
print(row["counter"])
```

- We'll use the `cs50` library to run SQL commands more easily, and open the `favorites.db` database we created earlier.
- We'll prompt the user for a title, and then execute a command. A `?` in the command will allow us to safely substitute variables in our command.
- The results are returned in a list of rows, and `COUNT(*)` returns just one row. In our command, we'll add `AS counter`, so the count is returned in the row (which is a dictionary) with the column name `counter`.

- We can run our program and search for "The Office":

```
$ python favorites.py
Title: The Office
12
```

- And we can tweak our program to print all the rows that match:

```
import csv

from cs50 import SQL

db = SQL("sqlite:///favorites.db")

title = input("Title: ").strip()

rows = db.execute("SELECT title FROM favorites WHERE title LIKE ?", tit

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

```
$ python favorites.py
Title: The Office
The Office
The Office
The Office
The Office
The Office
The Office
The Office
The Office
the office
The Office
ThE OffiCE
The Office
The Office
```

- Since `LIKE` is case-insensitive, we see all the various ways the titles were capitalized.

## IMDb

- IMDb, or the Internet Movie Database, has datasets available for download as TSV (tab-separated values) files.
- We'll open a database that the staff has created beforehand:

```
$ sqlite3 shows.db
SQLite version 3.36.0 2021-06-18 18:36:39
Enter ".help" for usage hints.
sqlite> .schema
CREATE TABLE shows (
                    id INTEGER,
                    title TEXT NOT NULL,
                    year NUMERIC,
                    episodes INTEGER,
                    PRIMARY KEY(id)
                );
CREATE TABLE genres (
                    show_id INTEGER NOT NULL,
                    genre TEXT NOT NULL,
                    FOREIGN KEY(show_id) REFERENCES shows(id)
                );
CREATE TABLE stars (
                show_id INTEGER NOT NULL,
                person_id INTEGER NOT NULL,
                FOREIGN KEY(show_id) REFERENCES shows(id),
                FOREIGN KEY(person_id) REFERENCES people(id)
            );
CREATE TABLE writers (
                show_id INTEGER NOT NULL,
                person_id INTEGER NOT NULL,
                FOREIGN KEY(show_id) REFERENCES shows(id),
                FOREIGN KEY(person_id) REFERENCES people(id)
            );
CREATE TABLE ratings (
                show_id INTEGER NOT NULL,
                rating REAL NOT NULL,
                votes INTEGER NOT NULL,
                FOREIGN KEY(show_id) REFERENCES shows(id)
            );
CREATE TABLE people (
                id INTEGER,
                name TEXT NOT NULL,
                birth NUMERIC,
```

```
            PRIMARY KEY(id)
        );
```

- Notice that we have multiple tables, each of which has columns of various data types.
- In both the `stars` and `writers` table, for example, we have a `show_id` column that references the `id` of some row in the `shows` table, and a `person_id` column that references the `id` of some row in the `people` table. Effectively, they link shows and people by their `id`s.

- It turns out that SQL, too, has its own data types:
  - **`BLOB`**, for "binary large object", raw binary data that might represent files
  - **`INTEGER`**
  - **`NUMERIC`**, number-like but not quite a number, like a date or time
  - **`REAL`**, for floating-point values
  - **`TEXT`**, like strings
- Columns can also have additional attributes:
  - **`PRIMARY KEY`**, like the `id` columns above that will be used to uniquely identify each row
  - **`FOREIGN KEY`**, like the `show_id` column above that refers to a column in some other table
- We can see that there are millions of rows in the `people` table:

```
sqlite> SELECT * FROM people;
...
| 13058200 | Emilio Mancuso                                     |
| 13058201 | Pietro Furnis                                      |
| 13058202 | Ida Lonati Frati                                   |
+----------+----------------------------------------------------+-----
```

- But like before, we can search for just one row:

```
sqlite> SELECT * FROM people WHERE name = "Steve Carell";
+--------+--------------+-------+
|   id   |     name     | birth |
+--------+--------------+-------+
| 136797 | Steve Carell | 1962  |
+--------+--------------+-------+
```

- It turns out that there are a few shows titled "The Office":

```
sqlite> SELECT * FROM shows WHERE title = "The Office";
+---------+------------+------+----------+
|   id    |   title    | year | episodes |
+---------+------------+------+----------+
```

```
| 112108  | The Office | 1995 | 6        |
| 290978  | The Office | 2001 | 14       |
| 386676  | The Office | 2005 | 188      |
| 1791001 | The Office | 2010 | 30       |
| 2186395 | The Office | 2012 | 8        |
| 8305218 | The Office | 2019 | 28       |
+---------+------------+------+----------+
```

- The most popular one, with 188 episodes, is the one we want, so we can get just that one:

```
sqlite> SELECT * FROM shows WHERE title = "The Office" and year = "2005"
+--------+------------+------+----------+
|   id   |   title    | year | episodes |
+--------+------------+------+----------+
| 386676 | The Office | 2005 | 188      |
+--------+------------+------+----------+
```

- We can turn on a timer and see that our original command took about 0.02 seconds to run:

```
sqlite> .timer on
sqlite> SELECT * FROM shows WHERE title = "The Office";
+---------+------------+------+----------+
|   id    |   title    | year | episodes |
+---------+------------+------+----------+
| 112108  | The Office | 1995 | 6        |
| 290978  | The Office | 2001 | 14       |
| 386676  | The Office | 2005 | 188      |
| 1791001 | The Office | 2010 | 30       |
| 2186395 | The Office | 2012 | 8        |
| 8305218 | The Office | 2019 | 28       |
+---------+------------+------+----------+
Run Time: real 0.021 user 0.016419 sys 0.004117
```

- We can create an **index**, or additional data structures that our database program will use for future searches:

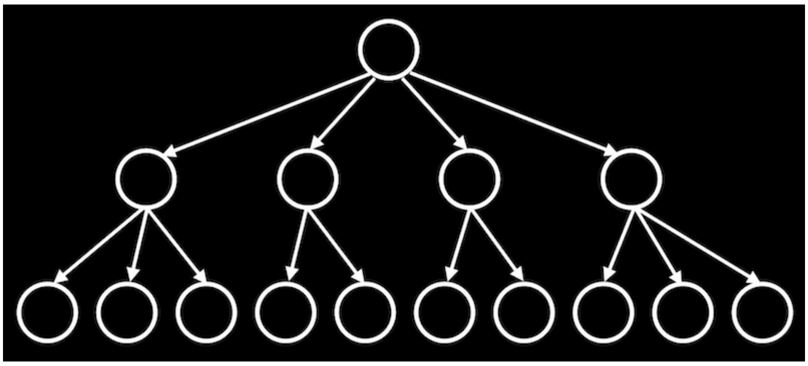
```
sqlite> CREATE INDEX "title_index" ON "shows" ("title");
Run Time: real 0.349 user 0.195206 sys 0.051217
```

- Now, our search command takes nearly no time:

```
sqlite> SELECT * FROM shows WHERE title = "The Office";
+---------+------------+------+----------+
|   id    |   title    | year | episodes |
+---------+------------+------+----------+
| 112108  | The Office | 1995 | 6        |
| 290978  | The Office | 2001 | 14       |
| 386676  | The Office | 2005 | 188      |
```

```
| 1791001 | The Office | 2010 | 30        |
| 2186395 | The Office | 2012 | 8         |
| 8305218 | The Office | 2019 | 28        |
+---------+------------+------+----------+
Run Time: real 0.000 user 0.000104 sys 0.000124
```

- It turns out that these data structures are generally **B-trees**, like binary trees we've seen in C but with more children, with nodes organized such that we can search faster than linearly:



  - Creating an index takes some time up front, perhaps by sorting the data, but afterwards we can search much more quickly.
- With our data spread among different tables, we can nest our queries to get useful data. For example, we can get all the titles of shows starring a particular person:

```
sqlite3> SELECT title FROM shows WHERE id IN (SELECT show_id FROM stars
+------------------------------------+
|               title                |
+------------------------------------+
| The Dana Carvey Show               |
| Over the Top                       |
| Watching Ellie                     |
| Come to Papa                       |
| The Office                         |
...
```

  - We'll `SELECT` the `title` from the `shows` table for shows with an `id` that matches a list of `show_id`s from the `stars` table. Those `show_id`s, in turn, must have a `person_id` that matches the `id` of Steve Carell in the `people` table.
- Our query runs pretty quickly, but we can create a few more indexes:

```
sqlite> CREATE INDEX person_index ON stars (person_id);
Run Time: real 0.890 user 0.662294 sys 0.097505
sqlite> CREATE INDEX show_index ON stars (show_id);
Run Time: real 0.644 user 0.469162 sys 0.058866
sqlite> CREATE INDEX name_index ON people (name);
Run Time: real 0.840 user 0.609600 sys 0.088177
```

  - Each index takes almost a second to build, but afterwards, our same query takes very little time to run.

- It turns out that we can use `JOIN` commands to combine tables in our queries:

```
sqlite> SELECT title FROM people
   ...> JOIN stars ON people.id = stars.person_id
   ...> JOIN shows ON stars.show_id = shows.id
   ...> WHERE name = "Steve Carell";
```

  - With the `JOIN` syntax, we can virtually combine tables based on their foreign keys, and use their columns as though they were one table. Here, we're matching the `people` table with the `stars` table, and then with the `shows` table.
- We can format the same query a little better by listing the tables we want to use all at once:

```
sqlite> SELECT title FROM people, stars, shows
   ...> WHERE people.id = stars.person_id
   ...> AND stars.show_id = shows.id
   ...> AND name = "Steve Carell";
+-------------------------------------+
|                title                |
+-------------------------------------+
| The Dana Carvey Show                |
| Over the Top                        |
| Watching Ellie                      |
| Come to Papa                        |
| The Office                          |
```

- The downside to having lots of indexes is that each of them take up some amount of space, which might become significant with lots of data and lots of indexes.

## Problems

- One problem in SQL is called a **SQL injection attack**, where an someone can inject, or place, their own commands into inputs that we then run on our database.
- We might encounter a login page for a website that asks for a username and password, and checks for those in a SQL database.
- Our query for searching for a user might be:

```
rows = db.execute("SELECT * FROM users WHERE username = ? AND password =

if len(rows) == 1:
    # Log user in
```

  - By using the `?` symbols as placeholders, our SQL library will escape the input, or prevent dangerous characters from being interpreted as part of the command.
- In contrast, we might have a SQL query that's a formatted string, such as:

```
rows = db.execute(f"SELECT * FROM users WHERE username = '{username}' AI

if len(rows) == 1:
    # Log user in
```

- If a user types in `malan@harvard.edu'--` as their input, then the query will end up being:

  ```
  rows = db.execute(f"SELECT * FROM users WHERE username = 'malan@harvard
  ```

  - This query will actually select the row where `username = 'malan@harvard.edu'`, without checking the password, since the single quotes end the input, and `--` turns the rest of the line into a comment in SQL.
- The user could even add a semicolon, `;`, and write a new command of their own, that our database will execute.
- Another set of problems with databases are **race conditions**, where shared data is unintentionally changed by code running on different devices or servers at the same time.
- One example is a popular post getting lots of likes. A server might try to increment the number of likes, asking the database for the current number of likes, adding one, and updating the value in the database:

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

  - Two different servers, responding to two different users, might get the same starting number of likes since the first line of code runs at the same time on each server.
  - Then, both will use `UPDATE` to set the *same* new number of likes, even though there should have been two separate increments.
- Another example might be of 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. 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 as well. Later, there will be two jugs of milk in the fridge.
- We can solve this problem by locking the fridge so that our roommate can't check whether there is milk until we've gotten back.
- To solve this problem, SQL supports **transactions**, where we can lock rows in a database, such that a particular set of actions are **atomic**, or guaranteed to happen together.
- For example, we can fix our problem above with:

  ```
  db.execute("BEGIN TRANSACTION")
  rows = db.execute("SELECT likes FROM posts WHERE id = ?", id);
  ```

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

    - The database will ensure that all the queries in between are executed together.
- But the more transactions we have, the slower our applications might be, since each server has to wait for other servers' transactions to finish.