Intro to Programming for Public Policy Week 8
Relational Databases and SQL

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Databases

Databases as Infrastructure

- Since they are not consumer-facing, the importance of databases as a technological infrastructure is not widely appreciated.
- They are a key component in most applications including websites, health records, supply chains, etc.

Why databases?

- Databases efficiently store and retrieve data.
  - Typical computers have about 8GB memory, a hard limit on what you can simultaneously load.
  - Databases allow efficient row-wise operations
  - Efficiently search hundreds of GB of data
  - Maintain one copy of the data and allow many people to access it (database server)

Example: American Time Use Survey (ATUS)

Activities

Resp.	Activity #	Code	Duration	...
1	1	010101	150	...
1	2	130124	45	...
1	3	010201	30	...
1	4	020201	10	...
1	5	110101	15	...
1	6	180501	20	...
1	...	...	...	...
2	1	010101	240	...
...	...	...	...	...

Respondents

ID	Line	Children	Worked	...
1	1	0	1	...
2	1	1	0	...
3	1	2	1	...
4	1	0	1	...
5	1	3	1	...
6	1	0	0	...
7	1	1	1	...
...	...	...	...	...

CPS

Resp.	Line	Age	Education	...
1	1	38	38	...
1	2	35	0	...
1	3	4	1	...
2	1	53	1	...
2	2	58	0	...
...	...	...	...	...

* Primary Keys

Relational databases

Most databases use a *relational* model:

- Data are stored in *tables*
- Tables are linked using *keys*
- Interact with database using Structured Query Language (SQL)

Why *not* relational databases?

- Extremely large datasets (thousands of gigabytes)
- Not all data is relational (there are databases for that, too!)
- Not all tasks are database tasks (e.g. file manipulation, networking, image processing)

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3. The values in a row should refer uniquely to the key, not to a non-key attribute.
   - e.g. the `activities` table should not include both the activity code and its definition.

Good practice

- Each table should contain a single logical element, without repetition.
- Meaningful and carefully select a *primary key*.
- Appropriate primary keys are what allow databases to work efficiently.

Database concepts

- Tables
- Variables
  - Types
- Constraints
  - Unique
  - Non-null
  - Primary key
  - Foreign key

The collection of tables, variables and constraints together define a database *schema*.

Structured Query Language (SQL)

SQL Overview

- The most popular model among databases is relational. These systems are called *RDBMS*s.
- SQL is the standardized language for working with an RDBMS.
- Originally intended to be user-facing and fairly "intuitive".
- Despite standardization, the implementations (e.g. Oracle, PostgreSQL, SQLite) all have some differences.

Running SQLite

To run SQLite:

```
$ sqlite3 atus.sqlite
SQLite version 3.13.0 2016-05-18 10:57:30
Enter ".help" for usage hints.
sqlite>
```

Navigating SQLite

The biggest differences between RDBMSs are accessing the metadata. To show tables in the database:

```
sqlite> .tables
activities   cps          respondents  roster
```

Table schema

To show the schema of a table (its columns and types):

```
sqlite> .schema --indent cps
CREATE TABLE cps(
  case_id INTEGER,
  line_no INTEGER,
  family_income INTEGER,
  educational_attainment INTEGER,
  duration_of_masters INTEGER,
  years_in_college INTEGER,
  marital_status INTEGER,
  state_code INTEGER,
  age INTEGER,
  years_education INTEGER,
  PRIMARY KEY(case_id, line_no)
);
```

Possible types: integer, real (float), text (string)

Full schema

```
sqlite> .fullschema --indent
CREATE TABLE roster(
  case_id INTEGER,
  line_no INTEGER,
  how_related INTEGER,
  edited_age INTEGER,
  edited_sex INTEGER,
  PRIMARY KEY(case_id, line_no)
);
CREATE TABLE respondents(
  case_id INTEGER,
  line_no INTEGER,
  daily_time_alone INTEGER,
  daily_time_secondary_childcare_hh_or_own_children INTEGE
  worked_last_week INTEGER,
  daily_time_with_family INTEGER,
  daily_time_with_friends INTEGER,
  daily_time_secondary_childcare_hh_children INTEGER,
```

Data dictionaries

- ATUS Data Dictionary:
  - `family_income`: p. 14
  - `educational_attainment`: p. 28
  - `marital_status`: p. 59
- ATUS Lexicon

Selecting columns

To see all of the data in the cps table:

```
SELECT * FROM cps;
```

To see just two of the columns:

```
SELECT marital_status, year_education FROM cps;
```

Notes:

- Queries end with a semi-colon
- Upper case keywords (`SELECT`, `FROM`, etc.) are a convention but not necessary.
- No whitespace requirements.

Query output

```
sqlite> SELECT * from cps;
...
20151212152498|1|11|43|-1|-1|1|39|37|17
20151212152498|2|11|43|-1|-1|1|39|34|17
20151212152498|3|11|-1|-1|-1|-1|39|8|-1
20151212152498|4|11|-1|-1|-1|-1|39|5|-1
```

You may prefer the output after changing these settings:

```
sqlite> .mode columns
sqlite> .headers on
```

LIMIT

Akin to `head` in the command line and pandas, use the SQL keyword `LIMIT` to restrict output:

```
SELECT * FROM cps LIMIT 10;
```

WHERE

To restrict to rows satisfying a certain condition use a `WHERE` clause.

- when `years_education = -1` the education variable is missing:

```
SELECT years_education
FROM cps
WHERE years_education > -1;
```

- Use `AND`, `OR`, `NOT` to perform boolean logic, as in python:

```
SELECT years_education, state_code
FROM cps
WHERE years_education > -1 AND
      state_code = 17;          -- 17 is Illinois
```

- Comment to end of line using `--` (akin to # in python)

ORDER BY

- Can sort results by a column (defaults to ascending):

```
SELECT * FROM cps
ORDER BY family_income;
```

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- To make it descending:

```
SELECT * FROM cps
ORDER BY family_income DESC;
```

ORDER BY

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```
SELECT * FROM cps
ORDER BY family_income;
```

- To make it descending:

```
SELECT * FROM cps
ORDER BY family_income DESC;
```

- Combine with `LIMIT` as to find top or bottom:

```
SELECT * FROM cps
ORDER BY family_income DESC
LIMIT 10;
```

COUNT

Very useful *aggregate* function is COUNT:

```
SELECT count(*) FROM cps
WHERE educational_attainment > -1;
```

An aggregate function is one that returns a single row for the table.

`COUNT` details

- Could do `COUNT(family_income)` or `COUNT(age)` to count the number of non-null values in the given column.
- In this data nothing is null, missingness is represented by -1.
- `COUNT(*)` counts all rows.

More aggregates

- To calculate the average value of a column:

```sql
SELECT AVG(age) FROM cps;
```

- To get the maximum:

```sql
SELECT MAX(age) FROM cps;
```

- And minimum:

```sql
SELECT MIN(age) FROM cps;
```

- Combine them:

```sql
SELECT MIN(age), AVG(age), MAX(age)
FROM cps;
```

Booleans and aggregation

To find the proportion of respondents whose educational attainment is available that have a bachelors degree:

```
SELECT AVG(educational_attainment > 42)
FROM cps
WHERE educational_attainment > 0;
```

GROUP BY

```sql
SELECT number_of_hh_children,
       count(*),
       AVG(daily_time_alone/60)
FROM respondents
GROUP BY number_of_hh_children;
```

```
number_of_hh_children  count(*)  AVG(daily_time_alone/60)
---------------------  --------  ------------------------
0                      6360      7.10943396226415
1                      1944      3.92181069958848
2                      1734      3.42214532871972
3                      599       2.779632721202
4                      190       3.07368421052632
5                      49        3.26530612244898
6                      23        3.30434782608696
7                      3         2.33333333333333
8                      2         0.5
9                      1         0.0
```

GROUP BY with ORDER BY

```
SELECT state_code,
       COUNT(*) as Count,
       AVG(educational_attainment > 42) AS Bachelors
FROM cps
WHERE educational_attainment > 0 -- i.e. defined
GROUP BY state_code
ORDER BY Bachelors DESC
LIMIT 10;
```

Notes:

- In a `GROUP BY`, the `WHERE` clause filters the rows going in to the aggregation
- `ORDER BY` orders the resulting groups, not the rows in the source table (cps).
- `AS` gives the column an alias

HAVING

- In a `GROUP BY`, the `WHERE` clause filters the rows going in to the aggregation.
- To filter the resulting groups use `HAVING`:

```
SELECT state_code,
       COUNT(*) as Count,
       AVG(educational_attainment > 42) AS Bachelors
FROM cps
WHERE educational_attainment > 0 -- i.e. defined
GROUP BY state_code
HAVING Count > 100
ORDER BY Bachelors DESC
LIMIT 10;
```

JOIN

Relational databases are all about relationships! We can harness the relationships in the data with a JOIN query:

```
SELECT cps.case_id,
       educational_attainment,
       spouse_or_partner_present
FROM respondents
JOIN cps
ON respondents.case_id = cps.case_id AND
   cps.line_no = 1;
```

The result of this query has a row for each respondent (all respondents are in the CPS table).

JOIN with GROUP BY

The combination of JOIN and GROUP BY is very powerful:

```
SELECT
  educational_attainment,
  AVG(spouse_or_partner_present = 1) Married
FROM cps JOIN respondents
ON cps.case_id = respondents .case_id AND
   cps.line_no = 1
WHERE number_of_hh_children > 0
GROUP BY educational_attainment;
```