

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)

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	...
...

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	...
...

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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 - ▶ e.g. `respondents` table should not have a cell with the ages of all household members (instead there is a `roster` table)
2. No non-prime attribute of the table may be dependent on a proper subset of any candidate key.
 - ▶ e.g. the `activity` table, identified by the respondent and activity number, should not contain general information on the respondent.
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 *RDBMSs*.
- ▶ 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)

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

- ▶ To make it descending:

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

ORDER BY

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

```
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:

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

- ▶ To get the maximum:

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

- ▶ And minimum:

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

- ▶ Combine them:

```
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

```
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 ;
```