The Relational Model and the Structured Query Language

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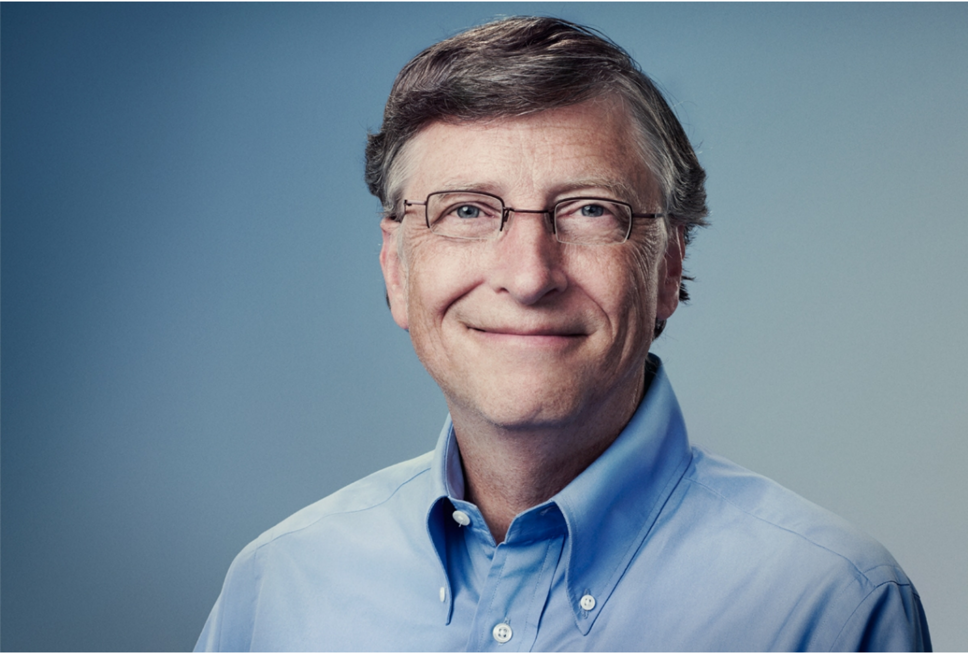
Who are these dudes?

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Databases: Content

- As these are not consumer-facing products, database systems fly under the radar like our energy infrastructure. But they are very, very important.
- They power the deep content of the internet: blogs, consumer applications, health services, etc.
  - Typical web application is server + database + scripting language.
- Huge problems in health services, government, etc. from failure to construct consistent or interoperable models.
  - This is totally solvable, but more political than technical!

Databases

- Databases store data efficiently, and retrieve it quickly.
  - Search efficiently over many GBs, or hundreds of GBs of data...
  - Really huge datasets need different models than discussed today.
- In the 'relational model,' the data are stored in interrelated 'tables.'
- Each record (row) is uniquely identified by a 'primary key' (index).
- Differs from composite objects in object-oriented programming, since many records in one table may link to a single record of another (e.g., people to a city) and several records may link in different ways (grade to teacher, student, and school).

RDB: Time Use Survey, Revisited

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**

The Relational Model: Normal Forms (Good Practice)

Normal forms are defined by E. F. Codd (1971) as:

1. Each record should be 'atomic' that is, non-divisible. A single row/record, should not contain multiple, divisible pieces.
   - The respondent table should not have a cell with the ages of all household members (stored in a 'roster' file).
2. No non-prime attribute of the table may be dependent on a proper subset of <u>any</u> candidate key.
   - In the time use survey, a respondent ID and activity number jointly identify an activity. The table should not, therefore, contain information on the respondent.
3. The values in a row should refer uniquely to the key – not to a non-key attribute.
   - In the time use activity tables, we should not store both the activity code and its interpretation.

To avoid repeating cumbersome calculations, these are sometimes violated.

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...	...	...	...	...

*** Primary Keys**

Good Practice, in Practice

- Each table should contain a single logical element, without repetition.
- One MUST take some care to understand what is unique in your table, and use that property to link tables: the <u>primary key</u>.
- Appropriate primary keys are what make databases actually work efficiently.

Using a Database

Relational Database Management Systems (RDBMSs) and the Structured Query Language (SQL)

- Most of the most-prevalent database systems implement the relational model.* These systems are called RDBMSs.
- Structured Query Language (SQL) (ISO/IEC 9075:2011) is a standardized (ISO/ANSI) language for interacting with RDBMSs.
- Originally intended to be user-facing, so 'fairly intuititive.'
- Despite standardization, the implementations almost all have some (extremely annoying) differences: some tinkering is necessary to migrate between 'dialects.'
  - Nevertheless, the basic functionality – selecting, inserting, deleting, and altering data, is pretty consistent.

* There are always exceptions...

(Some of) The Most Prevalent Databases

ORACLE®

MariaDB

MySQL®

SQLite

Microsoft® SQL Server™®

PostgreSQL

mongoDB®

(Some of) The Most Prevalent Databases

ORACLE®

MariaDB

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SQLite

Microsoft® SQL Server®

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NoSQL

(Some of) The Most Prevalent Databases

ORACLE®

MariaDB

MySQL®

SQLite

This class.

Microsoft® SQL Server®

PostgreSQL

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Opening SQLite

- To just open a file, do:

```
sqlite3 atus.sqlite
```

- This should give you a new prompt.
- To make the output clearer, you can do:

```
.mode columns
.headers on
```

- You can also run a file, like so:

```
sqlite3 atus.sqlite < ex/limit_cps.sql
```

- We'll talk about interfacing to pandas, on Wednesday

Navigating SQLite: Time Use Survey

The biggest difference between RDBMS implementations is in access to the metadata: a list of tables and their schema (format).

- To show the tables in the database:

```
sqlite> .tables
sqlite> .fullschema --indent
```

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

```
sqlite> .schema cps
```

- Types in SQLite: integer, real (float), text (string), or null.
  - Other RDBMSs have more types – e.g., datetime, or even geographies.
  - SQLite just has date functions.

SELECTing Columns: Vertical Slicing

This is THE basic SQL syntax that you will use.

- Selecting all (*) columns from the cps table:

```
SELECT * FROM cps;
```

- You can also name specific columns:

```
SELECT marital_status, years_education FROM cps;
```

- Each query ends by a semi-colon.
- Upper case keywords an old convention: SQL strings are often used in other languages, and therefore aren't color-highlighted. Not necessary.
- There is absolutely no requirement about the formatting of the query.

LIMIT (i.e., .head())

- Normally, this would come a bit later... but the last output was pretty excessive. For exploration, use 'LIMIT':

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

WHERE Requirements: Horizontal Slicing

- Make requirements with 'WHERE':

```
SELECT years_education
FROM cps
WHERE years_education > 0; /* i.e., exists */
```

- Can make multiple requirements with AND or OR:

```
SELECT years_education, state_code
FROM cps
WHERE years_education > 0 AND
      state_code = 17;
```

- Note the single '=' sign.

GROUP BY (i.e., .groupby())

- This functions exactly as groupby() in pandas.
- 'Group' by one or more variables, to aggregate over others.
  - Unlike most RDBMSs, SQLite won't complain if you mix and match aggregating functions and non-aggregated fields – so be careful.
- Many functions: `AVG`, `SUM`, `MAX`, `MIN`, `COUNT`, etc.

```sql
SELECT
  number_of_hh_children,
  AVG(daily_time_alone)
FROM
  respondents
GROUP BY
  number_of_hh_children
;
```

ORDER BY (i.e., .sort_values(by = "..."))

- Sort by one or more fields, ascending or descending (ASC or DESC).

```
SELECT
  state_code,
  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;
```

- Note also the use of AS (like in python!), to alias a long column name.

JOIN (i.e., .join())

- In households with children, what is the likelihood that a spouse or partner is present, by levels of education. Must JOIN tables.
- Alternatively, this can be done with multiple tables in 'FROM' and join conditions under 'WHERE.'

```sql
SELECT
  educational_attainment,
  AVG(spouse_or_partner_present == 1) Married,
  COUNT(spouse_or_partner_present == 1) "(N)"
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;
```

JOIN (i.e., .join())

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

HAVING (Requirements on Groups)

- HAVING is like WHERE for grouped values.
- For instance, you could present averages only for groups with COUNT() larger than 30, or averages or sums above a threshold.

```
SELECT
  number_of_hh_children Children,
  AVG(daily_time_secondary_childcare_hh_children/60)
    AS "Secondary Childcare",
  COUNT(number_of_hh_children) N
FROM respondents
GROUP BY number_of_hh_children
HAVING N > 30;
```

Subqueries

- You can use subqueries as tables, for multiple levels of grouping.
- How much time does each sex claim to spend in 'Personal/Private activities' such as 'necking' and 'private activity, unspecified'?

```
SELECT sex, COUNT(sex), AVG(time) FROM (
  SELECT
    roster.case_id, AVG(edited_sex) sex,
    SUM((activity_code = 10401) * (duration))
      AS time
  FROM roster
  INNER JOIN activities ON
    roster.case_id = activities.case_id
  WHERE roster.line_no = 1 AND
        18 < edited_age AND edited_age < 45
  GROUP BY roster.case_id
) GROUP BY sex;
```

On The Structure

- Good news is: SQL queries basically always follow the same structure.
- You may or may not need all the pieces, but there's no question about the order– there's only one way.
- There are a few more keywords, but the format of the query on the last page is as complicated as `SELECT` statements get.

Creating Tables

CREATE TABLE

- Most likely, you will be a database rather than developer.
- But it's useful to understand how to create a simple database.

```
■ sqlite3 my_new_db.sqlite
```

```sql
CREATE TABLE test (id INTEGER PRIMARY KEY NOT NULL,
                   Name TEXT, Birthday TEXT, Fruit TEXT);
```

- This defines the schema of a table.
  - SQLite recognizes: `INTEGER`, `REAL`, `TEXT`, `BLOB`, and `NULL`.
- The `id` column will auto-increment, to provide a unique primary key.
- `NOT NULL` and `PRIMARY KEY` are constraints, that help the RDBMS optimally parse a statement.

INSERT Rows

- Insert values like so:

```
INSERT INTO test (Name, Birthday, Fruit)
          VALUES ("Annie Oakley", "1860-08-13", "Peaches");
INSERT INTO test (Name, Birthday, Fruit)
          VALUES ("Freddie Mercury", "1946-09-05", "Plums");

INSERT INTO test (Name, Birthday, Fruit)
          VALUES ("Lyndon Johnson", "1908-08-27", "Pears"),
                 ("Jason Bourne", "1970-09-13", "Strawberries"),
                 ("Jesus of Nazareth", "0000-12-25", "Cumquat");
```

- Multiple values are both convenient and efficient.
- Trying to insert multiplepeople with

When the RDBMS evaluates a statement, it begins by 'parsing' and compiling it: reading it and turning it into a computer-ready, optimized plan. Most RDBMSs treat this as separate from the execution step, so you can 'recycle' the execution plan. (To my knowledge, `sqlite3` does not provide this access.)

Creating a Table From the Command Line

- There's a shortcut in `sqlite3` for loading data from a csv file:

```
■ CREATE TABLE chicago (Last TEXT, First TEXT,
Position TEXT, Department TEXT, Salary REAL);
■ .mode csv
■ .import salaries.csv chicago
```

- You'll try this, for homework.

Access from Python

Using the sqlite3 Library

- Straightforward python interface: `sqlite3` (**docs**).
- And pandas totally builds in support, like read_csv/read_json.

```
import sqlite3

con = sqlite3.connect("atus.sqlite")
result = con.execute("SELECT case_id, line_no, family_income "
                     "FROM cps WHERE line_no = 1 "
                     "LIMIT 10")

for row in result: print(row)
```

- Other library, `sqlalchemy`, extends this interface, makes access feel more object-oriented.

Using the sqlite3 Library

- Straightforward python interface: `sqlite3` (**docs**).
- And pandas totally builds in support, like read_csv/read_json.

```
import sqlite3, pandas as pd

con = sqlite3.connect("atus.sqlite")
cps = pd.read_sql_query("SELECT case_id, line_no, family_income "
                        "FROM cps WHERE line_no = 1 "
                        "LIMIT 10", con,
                        index_col = "case_id")
print(cps)
```

- Other library, `sqlalchemy`, extends this interface, makes access feel more object-oriented.

Broader Example: Goal

- Want direct child engagement by parent education.
  - Will sum over activities, per person.
- Use `years_education`, `activity_code`, and `duration`; join on `case_id` and `line_no`.
  - Codes are codes 301XX, 302XX, 303XX.
- Require children in household and respondent to work (edited_labor_force_status < 3).

1. Write a SQL query to give us the formatted data.
2. Use this query load the data in pandas, and plot it.

A Larger Example: SQL

```sql
SELECT
  respondents.case_id,
  cps.years_education AS 'Parental Education',
  SUM((activity_code/100 IN (301, 302, 303)) * duration/60.)
    AS 'Direct Engagement'
FROM respondents
INNER JOIN cps ON
  respondents.case_id = cps.case_id AND
  respondents.line_no = cps.line_no
INNER JOIN activities ON
  respondents.case_id = activities.case_id
WHERE
  number_of_hh_children > 0 AND
  edited_labor_force_status < 3
GROUP BY respondents.case_id;
```

A Larger Example: Python

```python
import sqlite3, pandas as pd
from matplotlib import pyplot as plt

con = sqlite3.connect("atus.sqlite")

query = ""
for l in open("ex/direct_engagement.sql"): query += l

df = pd.read_sql_query(query, con)
ax = df.boxplot("Direct Engagement", "Parental Education")

plt.suptitle("")
ax.set(title = "", ylim = (0, 7),
       xlabel = "Parental Education [Years]",
       ylabel = "Direct Engagement [Hours]")
ax.get_figure().savefig("engagement.pdf", bbox_inches='tight')
```

Result (Lower Stats than Before)