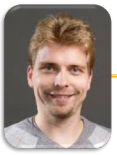


UC Berkeley EECS
Adj. Ass. Prof.
Dr. Gerald Friedland

Computational Structures in Data Science

Lecture #12: SQL

April 22nd, 2019 http://inst.eecs.berkeley.edu/~cs88

Btw. CNN criticizing my work…

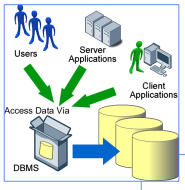
https://www.cnn.com/2019/04/19/tech/ai-facial-recognition/index.html

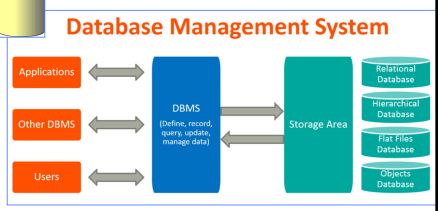
Question

Next lecture…

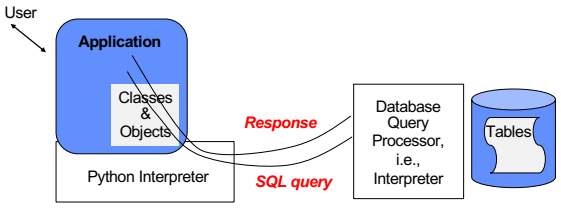
A) Q&A Session
B) Fun Lecture
C) Review Lecture
D) All of the above

Database Management Systems





App in program language issues queries to a database interpreter



- **The SQL language is represented in query strings delivered to a DB backend.**
- **Use the techniques learned here to build clean abstractions.**
- **You have already learned the relational operators!**

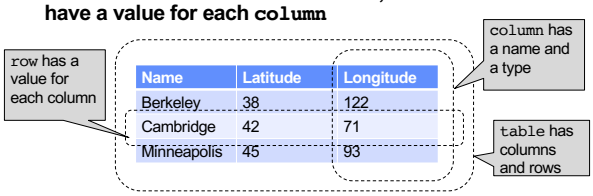
Data 8 Tables

ordered collection of labeled columns of anything

- **A single, simple, powerful data structure for all**
- **Inspired by Excel, SQL, R, Pandas, Numpy, …**

Database Management Systems

- DBMS are persistent tables with powerful relational operators
  - Important, heavily used, interesting!
- A `table` is a collection of `records`, which are `rows` that have a value for each `column`



- Structure Query Language (SQL) is a declarative programming language describing operations on tables

SQL

- A declarative language
  - Described *what* to compute
  - Imperative languages, like python, describe *how* to compute it
  - Query processor (interpreter) chooses which of many equivalent query plans to execute to perform the SQL statements
- ANSI and ISO standard, but many variants
- `select` statement creates a new table, either from scratch or by projecting a table
- `create table` statement gives a global name to a table
- Lots of other statements
  - `analyze, delete, explain, insert, replace, update, …`
- The action is in select

SQL example

- SQL statements create tables
  - Give it a try with sqlite3 or http://kripken.github.io/sql.js/GUI/
  - Each statement ends with ';'

```
culler$ sqlite3
SQLite version 3.9.2 2015-11-02 18:31:45
Enter ".help" for usage hints.
Connected to a transient in-memory database.
Use ".open FILENAME" to reopen on a persistent database.
sqlite> select 38 as latitude, 122 as longitude, "Berkeley" as
name;
38|122|Berkeley
sqlite>
```


A Running example from Data 8 Lec 10

```
# An example of creating a Table from a list of rows.
Table(["Flavor","Color","Price"]).with_rows([
    ('strawberry','pink', 3.55),
    ('chocolate','light brown', 4.75),
    ('chocolate','dark brown', 5.25),
    ('strawberry','pink',5.25),
    ('bubblegum','pink',4.75)])
```

Flavor	Color	Price
strawberry	pink	3.55
chocolate	light brown	4.75
chocolate	dark brown	5.25
strawberry	pink	5.25
bubblegum	pink	4.75


```
culler@CullerMac ~/Classes/CS88-Fa18/ideas/sql> sqlite3 icecream.db
SQLite version 3.13.0 2016-05-18 10:57:30
Enter ".help" for usage hints.
sqlite>
```


select

- Comma-separated list of *column descriptions*
- Column description is an expression, optionally followed by `as` and a column name

```
select [expression] as [name], [expression] as [name]; . . .
```

- Selecting literals creates a one-row table

```
select "strawberry" as Flavor, "pink" as Color, 3.55 as Price;
```

- `union` of select statements is a table containing the union of the rows

```
select "strawberry" as Flavor, "pink" as Color, 3.55 as Price union
select "chocolate","light brown", 4.75 union
select "chocolate","dark brown", 5.25 union
select "strawberry","pink",5.25 union
select "bubblegum","pink",4.75;
```


create table

- SQL often used interactively
  - Result of select displayed to the user, but not stored
- Create table statement gives the result a name
  - Like a variable, but for a permanent object

```
create table [name] as [select statement];
```

SQL: creating a named table

```
create table cones as
    select 1 as ID, "strawberry" as Flavor, "pink" as Color,
3.55 as Price union
    select 2, "chocolate","light brown", 4.75 union
    select 3, "chocolate","dark brown", 5.25 union
    select 4, "strawberry","pink",5.25 union
    select 5, "bubblegum","pink",4.75 union
    select 6, "chocolate", "dark brown", 5.25;
```

Notice how column names are introduced and implicit later on.

Select …

```
culler@CullerMac ~/Classes/CS88-Fa18/ideas/sql> sqlite3 icecream.db
SQLite version 3.13.0 2016-05-18 10:57:30
Enter ".help" for usage hints.
sqlite> create table cones as
   ...>     select 1 as ID, "strawberry" as Flavor, "pink" as Color, 3.55 as Pri
ce union
   ...>     select 2, "chocolate","light brown", 4.75 union
   ...>     select 3, "chocolate","dark brown", 5.25 union
   ...>     select 4, "strawberry","pink",5.25 union
   ...>     select 5, "bubblegum","pink",4.75 union
   ...>     select 6, "chocolate", "dark brown", 5.25;
sqlite> select * from cones;
1|strawberry|pink|3.55
2|chocolate|light brown|4.75
3|chocolate|dark brown|5.25
4|strawberry|pink|5.25
5|bubblegum|pink|4.75
6|chocolate|dark brown|5.25
sqlite>
```

```
cones = Table(["ID", "Flavor","Color","Price"]).with_rows([
    (1, 'strawberry','pink', 3.55),
    (2, 'chocolate','light brown',4.75),
    (3, 'chocolate','dark brown', 5.25),
    (4, 'strawberry','pink',5.25),
    (5, 'bubblegum','pink',4.75),
    (6, 'chocolate','dark brown', 5.25)
])
cones
```

ID	Flavor	Color	Price
1	strawberry	pink	3.55
2	chocolate	light brown	4.75
3	chocolate	dark brown	5.25
4	strawberry	pink	5.25
5	bubblegum	pink	4.75
6	chocolate	dark brown	5.25

Projecting existing tables

- Input table specified by **from** clause
- Subset of rows selected using a **where** clause
- Ordering of the selected rows declared using an **order by** clause

`select` [columns] `from` [table] `where` [condition] `order by` [order] ;

```
select * from cones order by Price;
```

ID	Flavor	Color	Price
1	strawberry	pink	3.55
2	chocolate	light brown	4.75
5	bubblegum	pink	4.75
3	chocolate	dark brown	5.25
4	strawberry	pink	5.25
6	chocolate	dark brown	5.25

Projection

```
In [5]: cones.select(['Flavor', 'Price'])
Out[5]:
```

Flavor	Price
strawberry	3.55
chocolate	4.75
chocolate	5.25
strawberry	5.25
bubblegum	4.75
chocolate	5.25

```
sqlite> select Flavor, Price from cones;
Flavor|Price
strawberry|3.55
chocolate|4.75
chocolate|5.25
strawberry|5.25
bubblegum|4.75
chocolate|5.25
```

- Select versus indexing a column?

Permanent Data Storage

ID	Flavor	Color	Price
1	strawberry	pink	3.55
2	chocolate	light brown	4.75
5	bubblegum	pink	4.75
3	chocolate	dark brown	5.25
4	strawberry	pink	5.25
6	chocolate	dark brown	5.25

```
sqlite> .quit
culler@CullerMac ~/Classes/CS88-Fa18/ideas/sql> sqlite3 icecream.db
SQLite version 3.13.0 2016-05-18 10:57:30
Enter ".help" for usage hints.
sqlite> .tables
cones
sqlite> select * from cones where Color is "dark brown";
3|chocolate|dark brown|5.25
6|chocolate|dark brown|5.25
sqlite>
```


Filtering rows - where

- Set of Table records (rows) that satisfy a condition

`select` [columns] `from` [table] **`where`** **[condition]** `order by` [order] ;

```
In [5]: cones.select(['Flavor', 'Price'])
Out[5]:
```

Flavor	Price
strawberry	3.55
chocolate	4.75
chocolate	5.25
strawberry	5.25
bubblegum	4.75
chocolate	5.25

```
sqlite> select * from cones where Flavor = "chocolate";
ID|Flavor|Color|Price
2|chocolate|light brown|4.75
3|chocolate|dark brown|5.25
6|chocolate|dark brown|5.25
```

```
cones.where(cones["Price"] > 5)
```

ID	Flavor	Color	Price
3	chocolate	dark brown	5.25
4	strawberry	pink	5.25
6	chocolate	dark brown	5.25

SQL:

```
sqlite> select * from cones where Price > 5;
ID|Flavor|Color|Price
3|chocolate|dark brown|5.25
4|strawberry|pink|5.25
6|chocolate|dark brown|5.25
```

SQL Operators for predicate

- use the **WHERE** clause in the SQL statements such as SELECT, UPDATE and DELETE to filter rows that do not meet a specified condition

SQLite understands the following binary operators, in order from highest to lowest precedence:

```
||
*    /    %
+    -
<<   >>   &    |
<    <=   >    >=
=    ==   !=   <>   IS   IS NOT   IN   LIKE   GLOB   MATCH   REGEXP
AND
OR
```

Supported unary prefix operators are these:

```
~    +    -    NOT
```


Approximate Matching …

Regular expression matches are so common that they are built in in SQL.

```
sqlite> select * from cones where Flavor like "%berry%";
Flavor|Color|Price
strawberry|pink|3.55
strawberry|pink|5.25
sqlite>
```

On the other hand, you have the full power of Python to express what you mean.

```
cones.where(cones.apply(lambda x:'berry' in x, 'Flavor'))
```

ID	Flavor	Color	Price
1	strawberry	pink	3.55
4	strawberry	pink	5.25

Group and Aggregate

- The **GROUP BY** clause is used to group rows returned by SELECT statement into a set of summary rows or groups based on values of columns or expressions.
- Apply an aggregate function, such as SUM, AVG, MIN, MAX or COUNT, to each group to output the summary information.

```
cones.group('Flavor')
```

Flavor	count
bubblegum	1
chocolate	3
strawberry	2

```
sqlite> select count(Price), Flavor from cones group by Flavor;
count(Price)|Flavor
1|bubblegum
2|chocolate
2|strawberry
```

```
cones.select(['Flavor', 'Price']).group('Flavor', np.mean)
```

Flavor	Price mean
bubblegum	4.75
chocolate	5.08333
strawberry	4.4

```
sqlite> select avg(Price), Flavor from cones group by Flavor;
avg(Price)|Flavor
4.75|bubblegum
5.0|chocolate
4.4|strawberry
```


Unique / Distinct values

```
select DISTINCT [columns] from [table] where [condition] order by [order];
```

```
sqlite> select distinct Flavor, Color from cones;
strawberry|pink
chocolate|light brown
chocolate|dark brown
bubblegum|pink
sqlite>
```

```
In [8]: cones.groups(['Flavor', 'Color']).drop('count')
Out[8]:
```

Flavor	Color
bubblegum	pink
chocolate	dark brown
chocolate	light brown
strawberry	pink

```
In [7]: np.unique(cones['Flavor'])
Out[7]: array(['bubblegum', 'chocolate', 'strawberry'], dtype='<U10')
```

- **Built in to the language or a composable tool?**

Joining tables

- **Two tables are joined by a comma to yield all combinations of a row from each**
  - **`select * from sales, cones;`**

```
create table sales as
    select "Baskin" as Cashier, 1 as TID union
    select "Baskin", 3 union
    select "Baskin", 4 union
    select "Robin", 2 union
    select "Robin", 5 union
    select "Robin", 6;
```

Cashier	TID
Baskin	1
Robin	2
Baskin	3
Baskin	4
Robin	5
Robin	6

```
sales.join('TID', cones, 'ID')
```

TID	Cashier	Flavor	Color	Price
1	Baskin	strawberry	pink	3.55
2	Robin	chocolate	light brown	4.75
3	Baskin	chocolate	dark brown	5.25
4	Baskin	strawberry	pink	5.25
5	Robin	bubblegum	pink	4.75
6	Robin	chocolate	dark brown	5.25

```
sqlite> select * from sales, cones;
Baskin|1|1|strawberry|pink|3.55
Baskin|1|2|chocolate|light brown|4.75
Baskin|1|3|chocolate|dark brown|5.25
Baskin|1|4|strawberry|pink|5.25
Baskin|1|5|bubblegum|pink|4.75
Baskin|1|6|chocolate|dark brown|5.25
Baskin|3|1|strawberry|pink|3.55
Baskin|3|2|chocolate|light brown|4.75
Baskin|3|3|chocolate|dark brown|5.25
Baskin|3|4|strawberry|pink|5.25
Baskin|3|5|bubblegum|pink|4.75
Baskin|3|6|chocolate|dark brown|5.25
Baskin|4|1|strawberry|pink|3.55
Baskin|4|2|chocolate|light brown|4.75
Baskin|4|3|chocolate|dark brown|5.25
Baskin|4|4|strawberry|pink|5.25
Baskin|4|5|bubblegum|pink|4.75
Baskin|4|6|chocolate|dark brown|5.25
Robin|2|1|strawberry|pink|3.55
Robin|2|2|chocolate|light brown|4.75
Robin|2|3|chocolate|dark brown|5.25
Robin|2|4|strawberry|pink|5.25
Robin|2|5|bubblegum|pink|4.75
Robin|2|6|chocolate|dark brown|5.25
Robin|5|1|strawberry|pink|3.55
Robin|5|2|chocolate|light brown|4.75
Robin|5|3|chocolate|dark brown|5.25
Robin|5|4|strawberry|pink|5.25
Robin|5|5|bubblegum|pink|4.75
Robin|5|6|chocolate|dark brown|5.25
Robin|6|1|strawberry|pink|3.55
Robin|6|2|chocolate|light brown|4.75
Robin|6|3|chocolate|dark brown|5.25
Robin|6|4|strawberry|pink|5.25
Robin|6|5|bubblegum|pink|4.75
Robin|6|6|chocolate|dark brown|5.25
```


Inner Join

```
select * from sales, cones where TID=ID;
```

```
sales.join('TID', cones, 'ID')
```

TID	Cashier	Flavor	Color	Price
1	Baskin	strawberry	pink	3.55
2	Robin	chocolate	light brown	4.75
3	Baskin	chocolate	dark brown	5.25
4	Baskin	strawberry	pink	5.25
5	Robin	bubblegum	pink	4.75
6	Robin	chocolate	dark brown	5.25

```
sqlite> select * from sales, cones where TID=ID;
Baskin|1|1|strawberry|pink|3.55
Baskin|3|3|chocolate|dark brown|5.25
Baskin|4|4|strawberry|pink|5.25
Robin|2|2|chocolate|light brown|4.75
Robin|5|5|bubblegum|pink|4.75
Robin|6|6|chocolate|dark brown|5.25
sqlite>
```

SQL: using named tables - `from`

```
select "delicious" as Taste, Flavor, Color from cones
       where Flavor is "chocolate" union
select "other", Flavor, Color from cones
       where Flavor is not "chocolate";
```

```
sqlite> select "delicious" as Taste, Flavor, Color from cones where Flavor is "chocolate" union
   ...> select "other", Flavor, Color from cones where Flavor is not "chocolate";
Taste|Flavor|Color
delicious|chocolate|dark brown
delicious|chocolate|light brown
other|bubblegum|pink
other|strawberry|pink
sqlite>
```


Queries within queries

- **Any place that a table is named within a select statement, a table could be computed**
  - **As a sub-query**

```
select TID from sales where Cashier is "Baskin";

select * from cones
    where ID in (select TID from sales where Cashier is "Baskin");
```

```
sqlite> select * from cones
   ...>     where ID in (select TID from sales where Cashier is "Baskin");
ID|Flavor|Color|Price
1|strawberry|pink|3.55
3|chocolate|dark brown|5.25
4|strawberry|pink|5.25
```


Inserting new records (rows)

```
INSERT INTO table(column1, column2,...)
       VALUES (value1, value2,...);
```

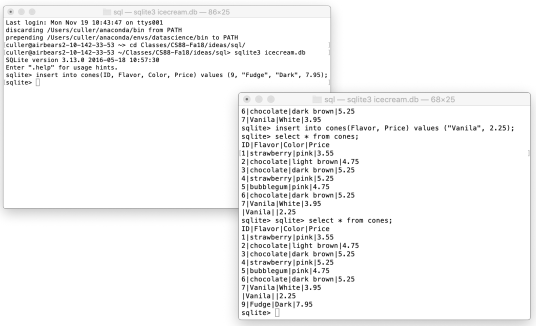
```
sqlite> insert into cones(ID, Flavor, Color, Price) values (7, "Vanila", "White", 3.95);
sqlite> select * from cones;
ID|Flavor|Color|Price
1|strawberry|pink|3.55
2|chocolate|light brown|4.75
3|chocolate|dark brown|5.25
4|strawberry|pink|5.25
5|bubblegum|pink|4.75
6|chocolate|dark brown|5.25
7|Vanila|White|3.95
sqlite>
```

```
cones.append((7, "Vanila", "White", 3.95))
cones
```

ID	Flavor	Color	Price
1	strawberry	pink	3.55
2	chocolate	light brown	4.75
3	chocolate	dark brown	5.25
4	strawberry	pink	5.25
5	bubblegum	pink	4.75
6	chocolate	dark brown	5.25
7	Vanila	White	3.95

- **A database table is typically a shared, durable repository shared by multiple applications**

Multiple clients of the database



- **All of the inserts update the common repository**

SQLite python API

```
In [64]: import sqlite3

In [65]: icecream = sqlite3.connect('icecream.db')

In [66]: icecream.execute('SELECT * FROM cones;')
Out[66]: <sqlite3.Cursor at 0x111127960>

In [67]: icecream.execute('SELECT DISTINCT Flavor FROM cones;').fetchall()
Out[67]: [('strawberry',), ('chocolate',), ('bubblegum',)]

In [68]: icecream.execute('SELECT * FROM cones WHERE Flavor is "chocolate";').fetcha
Out[68]: [(2, 'chocolate', 'light brown', 4.75),
          (3, 'chocolate', 'dark brown', 5.25),
          (6, 'chocolate', 'dark brown', 5.25)]
```


Creating DB Abstractions

```
class SQL_Table(Table):
    """ Extend Table class with methods to read/write a Table
    from/to a table in a SQLite3 database.
    """
    @classmethod
    def read(cls, filepath, table, verbose=False):
        """Create a SQL_Table by reading a table from a SQL database."""

        dbconn = sqlite3.connect(filepath,
                                 detect_types=sqlite3.PARSE_COLNAMES)

        col_names = sqlcol_names(dbconn, table)
        rows = sqlexec(dbconn,'SELECT * from %s;' % table, verbose).fetchal
        dbconn.close()
        return cls(col_names).with_rows(rows)
```

DB Abstraction (cont)

```
class SQL_Table(Table):
    ...
    def write(self, filepath, table, verbose=False, overwrite=True):
        """Write a Table into a SQL database as a SQL table."""

        dbconn = sqlite3.connect(filepath)
        # Create table and insert each row
        cols = build_list(self.labels)
        sqlexec(dbconn, "CREATE TABLE %s %s;" % (table, cols), verbose)
        for row in self.rows:
            sqlexec(dbconn, 'INSERT INTO %s VALUES %s;' % (table, tuple(row
        dbconn.commit()
        dbconn.close()

    @classmethod
    def cast(cls, table):
        """Return a SQL_Table version of a Table."""
        return cls().with_columns(zip(table.labels, table.columns))
```


Summary – Part 1

```
SELECT <col spec> FROM <table spec> WHERE <cond spec>
    GROUP BY <group spec> ORDER BY <order spec> ;
```

```
INSERT INTO table(column1, column2,...)
      VALUES (value1, value2,...);
```

```
CREATE TABLE name ( <columns> ) ;
```

```
CREATE TABLE name AS <select statement> ;
```

```
DROP TABLE name ;
```


Summary

- **SQL a declarative programming language on relational tables**
  - **largely familiar to you from data8**
  - **create, select, where, order, group by, join**
- **Databases are accessed through Applications**
  - **e.g., all modern web apps have Database backend**
  - **Queries are issued through API**
    - » **Be careful about app corrupting the database**
- **Data analytics tend to draw database into memory and operate on it as a data structure**
  - **e.g., Tables**
- **More in lab**

Solutions for the Wandering Mind

1) Adding two n-bit integers, how many bits can the result have?
Maximally n+1 bits (1 overflow bit).
2) Multiplying two n bit integers, how many bits can the result have?
log a*b=log a+log b=>log n*n=2*log n. 2*n bits.
Assume:

a) Exceptions don't exist
b) We only reserve 8bit for an integer variable (0-255)

Questions:
1) What would be the result of an addition 255+255?
(255+255) modulo 255=0. One entire summand is lost!
2) What would be the result of a multiplication 255*255?
(255*255) modulo 255=0. The error is: 64770!

Solutions for the Wandering Mind

3) Assume I additions of 8bit integers into the same 8bit variable. Can you formulate the maximum error that can occur as a function of I?

Each addition can maximally lose the entire 8bits. The error accumulates. This is, each addition loses maximally 8bits. So it's I*8bits of loss. So the maximum error 255*I.

For multiplication it's 255^I. This is, exponential error!
(Also compare Lyapunov Exponent in physics)

This is taught in CS61C