SQL: Part I

Introduction to Databases

CompSci 316 Spring 2019

DUKE
COMPUTER SCIENCE

Announcements (Tue. Jan. 29)

- Homework #1 due next week 11:59pm
  - Problem 5 and extra credit problems posted
- Google cloud credit instructions emailed
  - Redeem soon! Use @duke.edu email
- Project mixer next Tuesday in class (first half, 2nd half regular lecture)
  - Presentation by Elliott Bolzan (your UTA) about their project in the last semester – do not miss it!
    - You will get an idea how much work and what output is expected
  - Please let me know by next Monday if you want to make a pitch in front of the class (to recruit teammates)!

SQL

- SQL: Structured Query Language
  - Pronounced “S-Q-L” or “sequel”
  - The standard query language supported by most DBMS
- A brief history
  - IBM System R
  - ANSI SQL89
  - ANSI SQL92 (SQL2)
  - ANSI SQL99 (SQL3)
  - ANSI SQL 2003 (added OLAP, XML, etc.)
  - ANSI SQL 2006 (added more XML)
  - ANSI SQL 2008, …

Creating and dropping tables

- CREATE TABLE *table_name*
  (..., *column_name column_type*, ...);
- DROP TABLE *table_name*;
- Examples

```
create table User(uid integer, name varchar(30),
                  age integer, pop float);
create table Group(gid char(10), name varchar(100));
create table Member(uid integer, gid char(10));
drop table Member;
drop table Group;
drop table User;
-- everything from -- to the end of line is ignored.
-- SQL is insensitive to white space.
-- SQL is insensitive to case (e.g., ...Group... is
-- equivalent to ...GROUP...).
```

Basic queries: SFW statement

- SELECT $A_1, A_2, \ldots, A_n$
  FROM $R_1, R_2, \ldots, R_m$
  WHERE $condition;$
- Also called an SPJ (select-project-join) query
- Corresponds to (but not really equivalent to) relational algebra query:

$$\pi_{A_1,A_2,\ldots,A_n}\left(\sigma_{condition}(R_1 \times R_2 \times \cdots \times R_m)\right)$$

Example: reading a table

- SELECT * FROM User;
  - Single-table query, so no cross product here
  - WHERE clause is optional
  - * is a short hand for “all columns”

Example: selection and projection

- Name of users under 18
  - SELECT name FROM User WHERE age<18;
- When was Lisa born?
  - SELECT 2019-age
    FROM User
    WHERE name = 'Lisa';
  - SELECT list can contain expressions
    - Can also use built-in functions such as SUBSTR, ABS, etc.
  - String literals (case sensitive) are enclosed in single quotes

Example: join

- ID's and names of groups with a user whose name contains "Simpson"
  - SELECT Group.gid, Group.name
    FROM User, Member, Group
    WHERE User.uid = Member.uid
    AND Member.gid = Group.gid
    AND User.name LIKE '%Simpson%';
  - LIKE matches a string against a pattern
    - % matches any sequence of zero or more characters
  - Okay to omit *table_name* in *table_name.column_name* if *column_name* is unique

Example: rename

- ID's of all pairs of users that belong to one group
  - Relational algebra query:

    $\pi_{m_1.uid,m_2.uid}$
    $\left(\rho_{m_1} Member \bowtie_{m_1.gid=m_2.gid \wedge m_1.uid>m_2.uid} \rho_{m_2} Member\right)$
  - SQL:

    SELECT m1.uid AS uid1, m2.uid AS uid2
    FROM Member AS m1, Member AS m2
    WHERE m1.gid = m2.gid
    AND m1.uid > m2.uid;
  - AS keyword is completely optional

A more complicated example

- Names of all groups that Lisa and Ralph are both in

```
SELECT g.name
FROM User u1, User u2, Member m1, Member m2, Group g
WHERE u1.name = 'Lisa' AND u2.name = 'Ralph'
AND u1.uid = m1.uid AND u2.uid = m2.uid
AND m1.gid = g.gid AND m2.gid = g.gid;
```

Tip: Write the FROM clause first, then WHERE, and then SELECT

Why SFW statements?

- Out of many possible ways of structuring SQL statements, why did the designers choose SELECT-FROM-WHERE?
  - A large number of queries can be written using only selection, projection, and cross product (or join)
  - Any query that uses only these operators can be written in a canonical form: $\pi_L\left(\sigma_p(R_1 \times \cdots \times R_m)\right)$
    - Example: $\pi_{R.A,S.B}\left(R \bowtie_{p_1} S\right) \bowtie_{p_2} \left(\pi_{T.C}\sigma_{p_3}T\right)$
      $= \pi_{R.A,S.B,T.C}\sigma_{p_1 \wedge p_2 \wedge p_3}(R \times S \times T)$
  - SELECT-FROM-WHERE captures this canonical form

Set versus bag semantics

- Set
  - No duplicates
  - Relational model and algebra use set semantics
- Bag
  - Duplicates allowed
  - Number of duplicates is significant
  - SQL uses bag semantics by default

User(uid, name, pop)
Member(uid, gid)
Group(gid, name)

Set versus bag example

Member

uid	*gid*
142	dps
123	gov
857	abc
857	gov
456	abc
456	gov
…	…

$\pi_{gid} Member$

gid
dps
gov
abc
…

SELECT gid
FROM Member;

gid
dps
gov
abc
gov
abc
gov
…

A case for bag semantics

User(uid, name, pop)
Member(uid, gid)
Group(gid, name)

- Efficiency
  - Saves time of eliminating duplicates
- Which one is more useful?
  - $\pi_{age} User$
  - SELECT age FROM User;
  - The first query just returns all possible user ages
  - The second query returns the user age distribution
- Besides, SQL provides the option of set semantics with DISTINCT keyword

User(uid, name, pop)
Member(uid, gid)
Group(gid, name)

Forcing set semantics

- ID's of all pairs of users that belong to one group
  - SELECT m1.uid AS uid1, m2.uid AS uid2
    FROM Member AS m1, Member AS m2
    WHERE m1.gid = m2.gid
    AND m1.uid > m2.uid;
    - Say Lisa and Ralph are in both the book club and the student government
  - SELECT DISTINCT m1.uid AS uid1, m2.uid AS uid2 …
    - With DISTINCT, all duplicate (uid1, uid2) pairs are removed from the output

Semantics of SFW

- SELECT [DISTINCT] $E_1, E_2, \ldots, E_n$
  FROM $R_1, R_2, \ldots, R_m$
  WHERE $condition$;
- For each t_1 in R_1:
  For each t_2 in R_2: … …
  For each t_m in R_m:
  If $condition$ is true over $t_1, t_2, \ldots, t_m$:
  Compute and output $E_1, E_2, \ldots, E_n$ as a row
  If DISTINCT is present
  Eliminate duplicate rows in output
- $t_1, t_2, \ldots, t_m$ are often called tuple variables

SQL set and bag operations

- UNION, EXCEPT, INTERSECT
  - Set semantics
    - Duplicates in input tables, if any, are first eliminated
    - Duplicates in result are also eliminated (for UNION)
  - Exactly like set ∪, −, and ∩ in relational algebra
- UNION ALL, EXCEPT ALL, INTERSECT ALL
  - Bag semantics
  - Think of each row as having an implicit count (the number of times it appears in the table)
  - Bag union: sum up the counts from two tables
  - Bag difference: proper-subtract the two counts
  - Bag intersection: take the minimum of the two counts

Examples of bag operations

Bag1

fruit
apple
apple
orange

Bag2

fruit
apple
orange
orange

```
(SELECT * FROM Bag1)
UNION ALL
(SELECT * FROM Bag2);
```

fruit
apple
apple
orange
apple
orange
orange

```
(SELECT * FROM Bag1)
EXCEPT ALL
(SELECT * FROM Bag2);
```

fruit
apple

```
(SELECT * FROM Bag1)
INTERSECT ALL
(SELECT * FROM Bag2);
```

fruit
apple
orange

Examples of set versus bag operations

Poke (*uid1*, *uid2*, *timestamp*)

- (SELECT uid1 FROM Poke)
  EXCEPT
  (SELECT uid2 FROM Poke);
  - Users who poked others but never got poked by others
- (SELECT uid1 FROM Poke)
  EXCEPT ALL
  (SELECT uid2 FROM Poke);
  - Users who poked others more than others poke them

SQL features covered so far

- SELECT-FROM-WHERE statements (select-project-join queries)
- Set and bag operations

☞Next: how to nest SQL queries

Table subqueries

- Use query result as a table
  - In set and bag operations, FROM clauses, etc.
  - A way to "nest" queries
- Example: names of users who poked others more than others poked them
  - SELECT DISTINCT name
    FROM User,
    ((SELECT uid1 AS uid FROM Poke)
    EXCEPT ALL
    (SELECT uid2 AS uid FROM Poke))
    AS T
    WHERE User.uid = T.uid;

Scalar subqueries

- A query that returns a single row can be used as a value in WHERE, SELECT, etc.
- Example: users at the same age as Bart
  - SELECT *
    FROM User
    WHERE age = (SELECT age
      FROM User
      WHERE name = 'Bart');

    What's Bart's age?
  - Runtime error if subquery returns more than one row
    - Under what condition will this error never occur?
  - What if the subquery returns no rows?
    - The answer is treated as a special value NULL, and the comparison with NULL will fail

IN subqueries

- x IN $(subquery)$ checks if x is in the result of $subquery$
- Example: users at the same age as (some) Bart
  - SELECT *
    FROM User
    WHERE age IN (SELECT age
      FROM User
      WHERE name = 'Bart');

What's Bart's age?

EXISTS subqueries

- EXISTS ($subquery$) checks if the result of $subquery$ is non-empty
- Example: users at the same age as (some) Bart
  - SELECT *
    FROM User AS u
    WHERE EXISTS (SELECT * FROM User
                  WHERE name = 'Bart'
                  AND age = u.age);
  - This happens to be a correlated subquery—a subquery that references tuple variables in surrounding queries

Semantics of subqueries

- SELECT *
  FROM User AS u
  WHERE EXISTS (SELECT * FROM User
  WHERE name = 'Bart'
  AND age = u.age);

- For each row u in User
  - Evaluate the subquery with the value of u.age
  - If the result of the subquery is not empty, output u.*
- The DBMS query optimizer may choose to process the query in an equivalent, but more efficient way (example?)

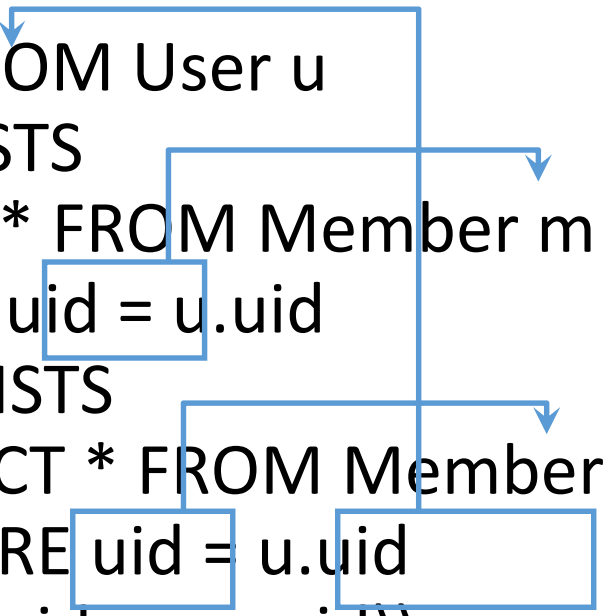
Scoping rule of subqueries

- To find out which table a column belongs to
  - Start with the immediately surrounding query
  - If not found, look in the one surrounding that; repeat if necessary
- Use *table_name.column_name* notation and AS (renaming) to avoid confusion

Another example

User(uid, name, pop)
Member(uid, gid)
Group(gid, name)

- SELECT * FROM User u
  WHERE EXISTS
  (SELECT * FROM Member m
  WHERE uid = u.uid
  AND EXISTS
  (SELECT * FROM Member
  WHERE uid = u.uid
  AND gid <> m.gid));



- Users who join at least two groups

Quantified subqueries

- A quantified subquery can be used syntactically as a value in a WHERE condition
- Universal quantification (for all):
  ... WHERE $x\ op$ ALL$(subquery)$ ...
  - True iff for all t in the result of $subquery$, $x\ op\ t$
- Existential quantification (exists):
  ... WHERE $x\ op$ ANY$(subquery)$ ...
  - True iff there exists some t in $subquery$ result such that $x\ op\ t$

  ☞ Beware
  - In common parlance, "any" and "all" seem to be synonyms
  - In SQL, ANY really means "some"

Examples of quantified subqueries

User(uid, name, pop)
Member(uid, gid)
Group(gid, name)

- Which users are the most popular?
  - SELECT *
    FROM User
    WHERE pop >= ALL(SELECT pop FROM User);
  - SELECT *
    FROM User
    WHERE NOT
      (pop < ANY(SELECT pop FROM User);

☞Use NOT to negate a condition

More ways to get the most popular

User(uid, name, pop)
Member(uid, gid)
Group(gid, name)

- Which users are the most popular?

  - SELECT *
    FROM User AS u
    WHERE NOT EXISTS
      (SELECT * FROM User
       WHERE pop > u.pop);

  - SELECT * FROM User
    WHERE uid NOT IN
      (SELECT u1.uid
       FROM User AS u1, User AS u2
       WHERE u1.pop < u2.pop);

SQL features covered so far

- SELECT-FROM-WHERE statements
- Set and bag operations
- Subqueries
  - Subqueries allow queries to be written in more declarative ways (recall the "most popular" query)
  - But in many cases they don't add expressive power
    - Try translating other forms of subqueries into [NOT] EXISTS, which in turn can be translated into join (and difference)
      - Watch out for number of duplicates though

☞Next: aggregation and grouping

Aggregates

- Standard SQL aggregate functions: COUNT, SUM, AVG, MIN, MAX
- Example: number of users under 18, and their average popularity
  - SELECT COUNT(*), AVG(pop)
    FROM User
    WHERE age < 18;
  - COUNT(*) counts the number of rows

Aggregates with DISTINCT

- Example: How many users are in some group?

  - SELECT COUNT(DISTINCT uid)
    FROM Member;

  is equivalent to:

  - SELECT COUNT(*)
    FROM (SELECT DISTINCT uid FROM Member);

Grouping

- SELECT … FROM … WHERE …
  GROUP BY *list_of_columns*;

- Example: compute average popularity for each age group
  - SELECT age, AVG(pop)
    FROM User
    GROUP BY age;

Semantics of GROUP BY

SELECT … FROM … WHERE … GROUP BY …;

- Compute FROM ($\times$)
- Compute WHERE (σ)
- Compute GROUP BY: group rows according to the values of GROUP BY columns
- Compute SELECT for each group (π)
  - For aggregation functions with DISTINCT inputs, first eliminate duplicates within the group

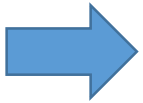
☞Number of groups =
number of rows in the final output

Example of computing GROUP BY

SELECT age, AVG(pop) FROM User GROUP BY age;

uid	*name*	*age*	*pop*
142	Bart	10	0.9
857	Lisa	8	0.7
123	Milhouse	10	0.2
456	Ralph	8	0.3

Compute GROUP BY: group rows according to the values of GROUP BY columns



uid	*name*	*age*	*pop*
142	Bart	10	0.9
123	Milhouse	10	0.2
857	Lisa	8	0.7
456	Ralph	8	0.3

Compute SELECT for each group

age	*avg_pop*
10	0.55
8	0.50

Aggregates with no GROUP BY

- An aggregate query with no GROUP BY clause = all rows go into one group

  SELECT AVG(pop) FROM User;

Group all rows into one group

Aggregate over the whole group

uid	*name*	*age*	*pop*
142	Bart	10	0.9
857	Lisa	8	0.7
123	Milhouse	10	0.2
456	Ralph	8	0.3

uid	*name*	*age*	*pop*
142	Bart	10	0.9
857	Lisa	8	0.7
123	Milhouse	10	0.2
456	Ralph	8	0.3

avg_pop
0.525

Restriction on SELECT

- If a query uses aggregation/group by, then every column referenced in SELECT must be either
  - Aggregated, or
  - A GROUP BY column

Why?

☞This restriction ensures that any SELECT expression produces only one value for each group

Examples of invalid queries

- SELECT uid, age WRONG!
  FROM User GROUP BY age;
  - Recall there is one output row per group
  - There can be multiple *uid* values per group
- SELECT uid, MAX(pop) FROM User; WRONG!
  - Recall there is only one group for an aggregate query with no GROUP BY clause
  - There can be multiple *uid* values
  - Wishful thinking (that the output *uid* value is the one associated with the highest popularity) does NOT work

☞Another way of writing the "most popular" query?

HAVING

- Used to filter groups based on the group properties (e.g., aggregate values, GROUP BY column values)
- SELECT … FROM … WHERE … GROUP BY … HAVING $condition$;
  - Compute FROM ($\times$)
  - Compute WHERE (σ)
  - Compute GROUP BY: group rows according to the values of GROUP BY columns
  - Compute HAVING (another σ over the groups)
  - Compute SELECT (π) for each group that passes HAVING

HAVING examples

- List the average popularity for each age group with more than a hundred users
  - SELECT age, AVG(pop)
    FROM User
    GROUP BY age
    HAVING COUNT(*) > 100;
  - Can be written using WHERE and table subqueries
- Find average popularity for each age group over 10
  - SELECT age, AVG(pop)
    FROM User
    GROUP BY age
    HAVING age > 10;
  - Can be written using WHERE without table subqueries

SQL features covered so far

- SELECT-FROM-WHERE statements
- Set and bag operations
- Subqueries
- Aggregation and grouping
  - More expressive power than relational algebra

☞Next: ordering output rows

ORDER BY

- SELECT [DISTINCT] …
  FROM … WHERE … GROUP BY … HAVING …
  ORDER BY *output_column* [ASC|DESC], …;
- ASC = ascending, DESC = descending
- Semantics: After SELECT list has been computed and optional duplicate elimination has been carried out, sort the output according to ORDER BY specification

ORDER BY example

- List all users, sort them by popularity (descending) and name (ascending)
  - SELECT uid, name, age, pop
    FROM User
    ORDER BY pop DESC, name;
  - ASC is the default option
  - Strictly speaking, only output columns can appear in ORDER BY clause (although some DBMS support more)
  - Can use sequence numbers instead of names to refer to output columns: ORDER BY 4 DESC, 2;

SQL features covered so far

- SELECT-FROM-WHERE statements
- Set and bag operations
- Subqueries
- Aggregation and grouping
- Ordering

☞Next: NULL's, outerjoins, data modification, constraints, …

Additional Example on SQL evaluation

Find age of the youngest sailor with age >= 18, for each rating with at least 2 such sailors.

```
SELECT  S.rating,  MIN (S.age) AS minage
FROM  Sailors S
WHERE  S.age >= 18
GROUP BY  S.rating
HAVING  COUNT (*) > 1
```

Answer relation:

rating	minage
3	25.5
7	35.0
8	25.5

Sailors instance:

sid	sname	rating	age
22	dustin	7	45.0
29	brutus	1	33.0
31	lubber	8	55.5
32	andy	8	25.5
58	rusty	10	35.0
64	horatio	7	35.0
71	zorba	10	16.0
74	horatio	9	35.0
85	art	3	25.5
95	bob	3	63.5
96	frodo	3	25.5

Find age of the youngest sailor with age >= 18, for each rating with at least 2 such sailors.

```
SELECT  S.rating,  MIN
(S.age) AS minage
FROM  Sailors S
WHERE  S.age >= 18
GROUP BY  S.rating
HAVING  COUNT (*) > 1
```

Step 1: Form the cross product: FROM clause
(some attributes are omitted for simplicity)

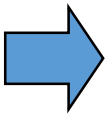
rating	age
7	45.0
1	33.0
8	55.5
8	25.5
10	35.0
7	35.0
10	16.0
9	35.0
3	25.5
3	63.5
3	25.5

Find age of the youngest sailor with age >= 18, for each rating with at least 2 such sailors.

```
SELECT  S.rating,  MIN
(S.age) AS minage
FROM  Sailors S
WHERE  S.age >= 18
GROUP BY  S.rating
HAVING  COUNT (*) > 1
```

Step 2: Apply WHERE clause

rating	age
7	45.0
1	33.0
8	55.5
8	25.5
10	35.0
7	35.0
10	16.0
9	35.0
3	25.5
3	63.5
3	25.5



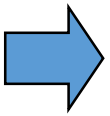
rating	age
7	45.0
1	33.0
8	55.5
8	25.5
10	35.0
7	35.0
~~10~~	~~16.0~~
9	35.0
3	25.5
3	63.5
3	25.5

Find age of the youngest sailor with age >= 18, for each rating with at least 2 such sailors.

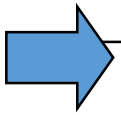
```
SELECT  S.rating,  MIN
(S.age) AS minage
FROM  Sailors S
WHERE  S.age >= 18
GROUP BY  S.rating
HAVING  COUNT (*) > 1
```

Step 3: Apply GROUP BY according to the listed attributes

rating	age
7	45.0
1	33.0
8	55.5
8	25.5
10	35.0
7	35.0
10	16.0
9	35.0
3	25.5
3	63.5
3	25.5



rating	age
7	45.0
1	33.0
8	55.5
8	25.5
10	35.0
7	35.0
10	16.0
9	35.0
3	25.5
3	63.5
3	25.5



rating	age
1	33.0
3	25.5
3	63.5
3	25.5
7	45.0
7	35.0
8	55.5
8	25.5
9	35.0
10	35.0

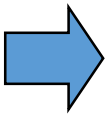
Find age of the youngest sailor with age >= 18, for each rating with at least 2 such sailors.

Step 4: Apply HAVING clause

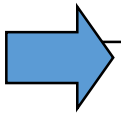
The *group-qualification* is applied to eliminate some groups

```
SELECT  S.rating,  MIN (S.age) AS minage
FROM  Sailors S
WHERE  S.age >= 18
GROUP BY  S.rating
HAVING  COUNT (*) > 1
```

rating	age
7	45.0
1	33.0
8	55.5
8	25.5
10	35.0
7	35.0
10	16.0
9	35.0
3	25.5
3	63.5
3	25.5



rating	age
7	45.0
1	33.0
8	55.5
8	25.5
10	35.0
7	35.0
10	16.0
9	35.0
3	25.5
3	63.5
3	25.5



rating	age
1	33.0
3	25.5
3	63.5
3	25.5
7	45.0
7	35.0
8	55.5
8	25.5
9	35.0
10	35.0

Find age of the youngest sailor with age >= 18, for each rating with at least 2 such sailors.

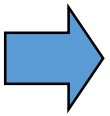
SELECT S.rating, MIN (S.age) AS minage
FROM Sailors S
WHERE S.age >= 18
GROUP BY S.rating
HAVING COUNT (*) > 1

Step 5: Apply SELECT clause

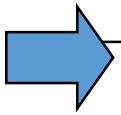
Apply the aggregate operator

At the end, one tuple per group

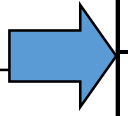
rating	age
7	45.0
1	33.0
8	55.5
8	25.5
10	35.0
7	35.0
10	16.0
9	35.0
3	25.5
3	63.5
3	25.5



rating	age
7	45.0
1	33.0
8	55.5
8	25.5
10	35.0
7	35.0
10	16.0
9	35.0
3	25.5
3	63.5
3	25.5



rating	age
1	33.0
3	25.5
3	63.5
3	25.5
7	45.0
7	35.0
8	55.5
8	25.5
9	35.0
10	35.0



rating	minage
3	25.5
7	35.0
8	25.5