SQL: Part I

Introduction to Databases
CompSci 316 Fall 2019
Announcements (Wed. Sep. 11)

• Gradiance ER due today, FD next Monday, and MVD next Wednesday

• Homework 1 due Monday 11:59pm
  • There is a FAQ for Homework 1 on Piazza

• Homework 2 assigned

• Project mixer next Wednesday in class
  • Please send me your slide(s) by next Monday if you want to make a pitch in front of the whole class!
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 \textit{table\_name} \\
  \textit{(..., column\_name column\_type, ...)};

• DROP TABLE \textit{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:

$$\pi_{A_1, A_2, \ldots, A_n}(\sigma_{\text{condition}}(R_1 \times R_2 \times \cdots \times R_m))$$
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:
    \[
    \pi_{m_1.uid,m_2.uid} (\rho_{m_1.Member \bowtie \ m_1.gid=m_2.gid \land m_1.uid>m_2.uid \ \rho_{m_2.Member})
    \]
  • SQL:
    SELECT ml.uid AS uid1, m2.uid AS uid2
    FROM Member AS ml, Member AS m2
    WHERE ml.gid = m2.gid
    AND ml.uid > m2.uid;
  • AS keyword is completely optional
A more complicated example

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

```sql
SELECT g.name
FROM User ul, User u2, Member m1, Member m2, Group g
WHERE ul.name = 'Lisa' AND u2.name = 'Ralph'
AND ul.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: $\pi_{R,A,S,B}(R \bowtie_{p_1} S) \bowtie_{p_2} (\pi_{T,C}\sigma_{p_3} T)$
      $= \pi_{R,A,S,B,T,C}\sigma_{p_1 \land p_2 \land p_3}(R \times S \times T)$
  • `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
Set versus bag example

\[ \pi_{gid} \text{Member} \]

<table>
<thead>
<tr>
<th>gid</th>
<th>Member</th>
</tr>
</thead>
<tbody>
<tr>
<td>dps</td>
<td></td>
</tr>
<tr>
<td>gov</td>
<td></td>
</tr>
<tr>
<td>abc</td>
<td></td>
</tr>
</tbody>
</table>

SELECT gid
FROM Member;

<table>
<thead>
<tr>
<th>gid</th>
<th>Member</th>
</tr>
</thead>
<tbody>
<tr>
<td>dps</td>
<td></td>
</tr>
<tr>
<td>gov</td>
<td></td>
</tr>
<tr>
<td>abc</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>gid</th>
<th>Member</th>
</tr>
</thead>
<tbody>
<tr>
<td>gov</td>
<td></td>
</tr>
<tr>
<td>abc</td>
<td></td>
</tr>
<tr>
<td>...</td>
<td></td>
</tr>
</tbody>
</table>
A case for bag semantics

• 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
Forcing set semantics

• ID’s of all pairs of users that belong to one group
  • \textbf{SELECT} \texttt{ml.uid AS uid1, m2.uid AS uid2}
  \textbf{FROM} Member AS \texttt{ml}, Member AS \texttt{m2}
  \textbf{WHERE} \texttt{ml.gid = m2.gid}
  \texttt{AND} \texttt{ml.uid > m2.uid;}
  • Say Lisa and Ralph are in both the book club and the student government
  • \textbf{SELECT} \textbf{DISTINCT} \texttt{ml.uid AS uid1, m2.uid AS uid2} ...
  • With \textbf{DISTINCT}, all duplicate (\texttt{uid1, uid2}) pairs are removed from the output
Semantics of SFW

• SELECT [DISTINCT] $E_1$, $E_2$, ..., $E_n$
  FROM $R_1$, $R_2$, ..., $R_m$
  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 $t_1$, $t_2$, ..., $t_m$:
        Compute and output $E_1$, $E_2$, ..., $E_n$ as a row
      If DISTINCT is present
        Eliminate duplicate rows in output

• $t_1$, $t_2$, ..., $t_m$ 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 $\cup$, $-$, and $\cap$ 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

<table>
<thead>
<tr>
<th>fruit</th>
</tr>
</thead>
<tbody>
<tr>
<td>apple</td>
</tr>
<tr>
<td>apple</td>
</tr>
<tr>
<td>apple</td>
</tr>
<tr>
<td>orange</td>
</tr>
</tbody>
</table>

Bag2

<table>
<thead>
<tr>
<th>fruit</th>
</tr>
</thead>
<tbody>
<tr>
<td>apple</td>
</tr>
<tr>
<td>orange</td>
</tr>
</tbody>
</table>

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

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

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

• 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

What’s Bart’s age?
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

• 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 \( x \ op \ \textbf{ALL} \ (\text{subquery}) \) ...
  • True iff for all \( t \) in the result of \( \text{subquery} \), \( x \ op \ t \)

• **Existential quantification** (exists):
  ... WHERE \( x \ op \ \textbf{ANY} \ (\text{subquery}) \) ...
  • True iff there exists some \( t \) in \( \text{subquery} \) 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

• 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

• 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 ul.uid
       FROM User AS ul, User AS u2
       WHERE ul.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: \texttt{COUNT, SUM, AVG, MIN, MAX}

• Example: number of users under 18, and their average popularity
  • \texttt{SELECT COUNT(*)}, \texttt{AVG(pop)}
    \texttt{FROM User}
    \texttt{WHERE age < 18;}
  • \texttt{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 (×)
• 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;

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

Compute SELECT for each group

<table>
<thead>
<tr>
<th>uid</th>
<th>name</th>
<th>age</th>
<th>pop</th>
</tr>
</thead>
<tbody>
<tr>
<td>142</td>
<td>Bart</td>
<td>10</td>
<td>0.9</td>
</tr>
<tr>
<td>857</td>
<td>Lisa</td>
<td>8</td>
<td>0.7</td>
</tr>
<tr>
<td>123</td>
<td>Milhouse</td>
<td>10</td>
<td>0.2</td>
</tr>
<tr>
<td>456</td>
<td>Ralph</td>
<td>8</td>
<td>0.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>age</th>
<th>avg_pop</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.55</td>
</tr>
<tr>
<td>8</td>
<td>0.50</td>
</tr>
</tbody>
</table>
Aggregates with no GROUP BY

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

```
SELECT AVG(pop) FROM User;
```

<table>
<thead>
<tr>
<th>uid</th>
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</table>

Group all rows into one group

<table>
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</table>

Aggregate over the whole group

```
avg_pop = \frac{0.9 + 0.7 + 0.2 + 0.3}{4} = 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
  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;
  - 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 (\(\sigma\))
  - Compute GROUP BY: group rows according to the values of GROUP BY columns
  - Compute HAVING (another \(\sigma\) over the groups)
  - Compute SELECT (\(\pi\)) 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, ...