SQL: Part I

Introduction to Databases
CompSci 316 Fall 2021
Announcements (Thu. Sep. 9)

• Gradiance ER due today, FD next Tue., and MVD next Thu.
• Homework 1 due Tuesday 11:59pm
  • Check Ed for Yihao’s post about Help Session notes & recording
• Homework 2 to be assigned later tonight
• Please start reading the project description!
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**

```sql
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** \( \text{condition} \);

- 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 shorthand for “all columns”
Example: selection and projection

• Name of users under 18
  • SELECT name FROM User WHERE age<18;

• When was Lisa born?
  • SELECT 2021-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:
    \[ \pi_{m_1.uid, m_2.uid} \left( \rho_{m_1} Member \bowtie_{m_1.gid=m_2.gid \land m_1.uid>m_2.uid} \rho_{m_2} Member \right) \]
  • 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 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: \( \pi_L \left( \sigma_p \left( R_1 \times \cdots \times R_m \right) \right) \)
    • Example: \( \pi_{R.A,S,B} \left( R \bowtie_{p_1} S \right) \bowtie_{p_2} \left( \pi_{T.C} \sigma_{p_3} T \right) \)
      \[ = \pi_{R.A,S,B,T.C} \sigma_{p_1 \land p_2 \land p_3} \left( R \times S \times T \right) \]
  • 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

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

**Member**

<table>
<thead>
<tr>
<th>uid</th>
<th>gid</th>
</tr>
</thead>
<tbody>
<tr>
<td>142</td>
<td>dps</td>
</tr>
<tr>
<td>123</td>
<td>gov</td>
</tr>
<tr>
<td>857</td>
<td>abc</td>
</tr>
<tr>
<td>857</td>
<td>gov</td>
</tr>
<tr>
<td>456</td>
<td>abc</td>
</tr>
<tr>
<td>456</td>
<td>gov</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

**SELECT gid FROM Member;**

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

• Efficiency
  • Saves time of eliminating duplicates

• Which one is more useful?
  • $\pi_{age \text{User}}$
  • `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
  • 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 \textit{condition};

- For each \( t_1 \) in \( R_1 \):
  For each \( t_2 \) in \( R_2 \): \ldots \ldots
    For each \( t_m \) in \( R_m \):
      If \textit{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 \textit{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 | Bag2
---|---
fruit | fruit
apple | apple
apple | orange
orange | orange

(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 (besides set/bag operations)
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
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');
**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 \( x \ op \ ALL(subquery) \) ...
  • True iff for all \( t \) in the result of \( subquery \), \( x \ op \ t \)

• Existential quantification (exists):
  ... WHERE \( x \ op \ ANY|SOME(subquery) \) ...
  • 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
  • But 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

今の次: 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)
  AS T;
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 ($\sigma$)
• Compute GROUP BY: group rows according to the values of GROUP BY columns
• Compute SELECT for each group ($\pi$)
  • 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;
```

<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>

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

Compute SELECT for each group

<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>
<tr>
<td>142</td>
<td>Bart</td>
</tr>
<tr>
<td>123</td>
<td>Milhouse</td>
</tr>
<tr>
<td>857</td>
<td>Lisa</td>
</tr>
<tr>
<td>456</td>
<td>Ralph</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>
<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>
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<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>

Group all rows into one 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>
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<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>

Aggregate over the whole group

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?

 Opr 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 (×)
  • 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, ...