SFU

Database Systems I

CMPT 354 Summer 2024

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31 May 2024

Announcements (Fri. May 31)

- Assignment 2 (Due June 7)
  - Web tool for checking your query result will be available during the weekend
  - Try to run locally first
    - Especially for syntax issues

Outline

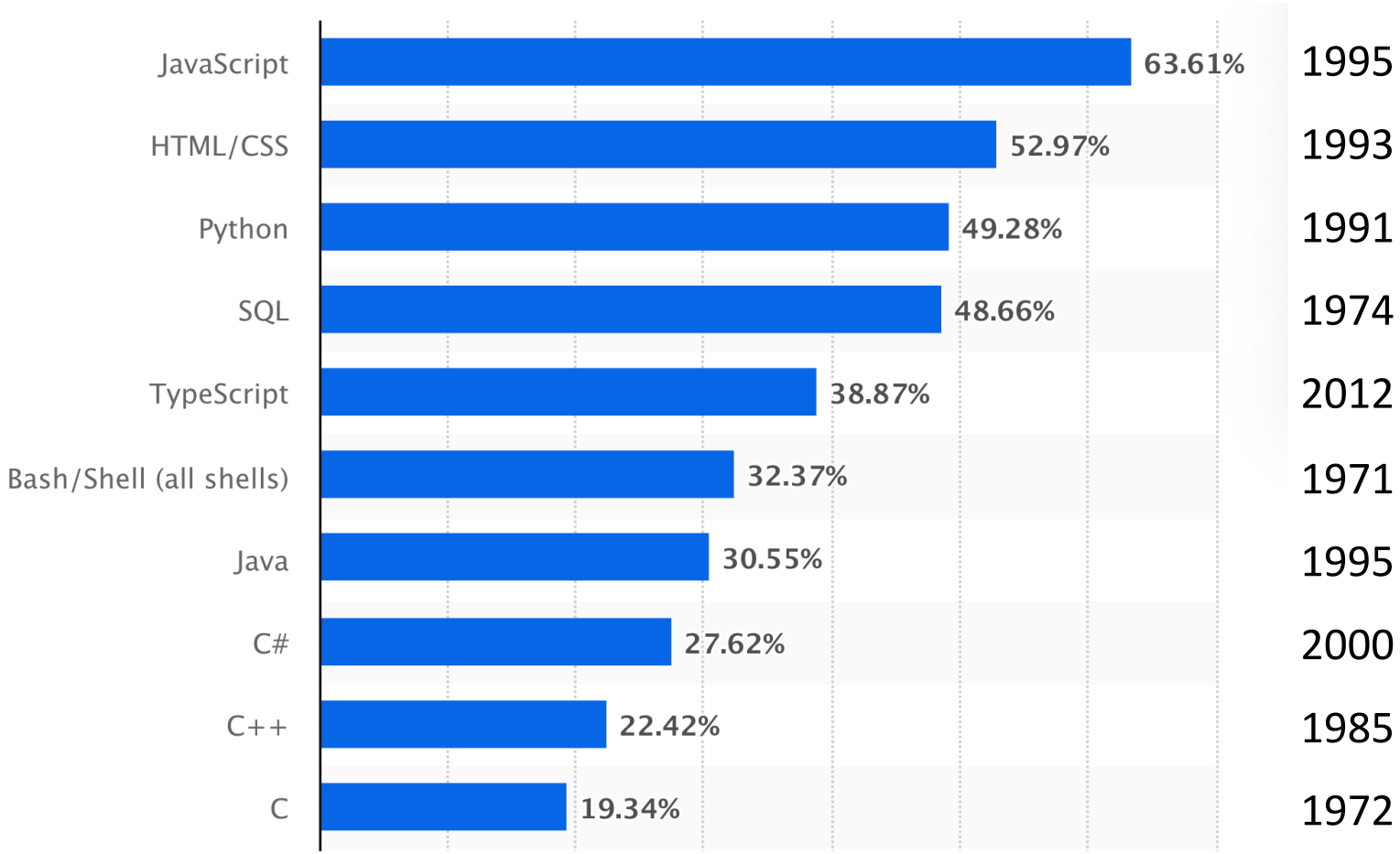
- Intro to SQL & basic examples
- Bag semantics
- Subqueries
- Aggregation
- Ordering

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 (1970s)
  - ANSI SQL89
  - ANSI SQL92 (SQL2)
  - ANSI SQL99 (SQL3)
  - ANSI SQL 2003 (added OLAP, XML, etc.)
  - ANSI SQL 2006 (added more XML)
  - ANSI SQL 2008, …

The curious staying power of SQL

- The most popular programming languages according to *statista*, 2023



SQL

- Data-definition language (DDL): define/modify schemas, delete relations
- Data-manipulation language (DML): query information, and insert/delete/modify tuples
- Integrity constraints: specify constraints that the data stored in the database must satisfy
- Intermediate/Advanced topics (next weeks):
  - E.g., triggers, views, indexes, programming, recursive queries

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 (selection-projection-join) query
- Corresponds to (but not really equivalent to) relational algebra query:

Why is it not equivalent to relational algebra query?

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

SQL and relational algebra has semantic differences
SQL has multi-sets, and relational algebra only has sets

Example: reading a table

- List all rows in the User 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 2023-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

- List 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 …;
    ```
    ```

Example: join

- List 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: $\pi_{R.A,S.B}(R \bowtie_{p_1} S) \bowtie_{p_2} (\pi_{T.C}\sigma_{p_3}T)$
      $= \pi_{R.A,S.B,T.C}\sigma_{p_1\wedge p_2\wedge p_3}(R\times S\times T)$
  - `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

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

- 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
  - ```
    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, …, 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 $t_1, t_2, \ldots, t_m$:
  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

If a row appears more often in the second table, then the difference will return you zero

Obtaining does not tell you much, except that the row occurs in neither table or that the row occurs more often in the second table

Examples of set operations

Bag1

fruit
apple
apple
orange
apple

Bag2

fruit
apple
orange
orange

Text

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

fruit
apple
orange

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

fruit
apple

Ask professor about this

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

fruit
apple
orange

Examples of bag operations

Bag1

fruit
apple
apple
orange
apple

Bag2

fruit
apple
orange
orange

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

fruit
apple
apple
orange
apple
apple
orange
orange

Ask professor about this result

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

fruit
apple
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 (selection-projection-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

What's Bart's age?

This error will never occur if the name 'Bart' is unique
    ```

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');
    ```

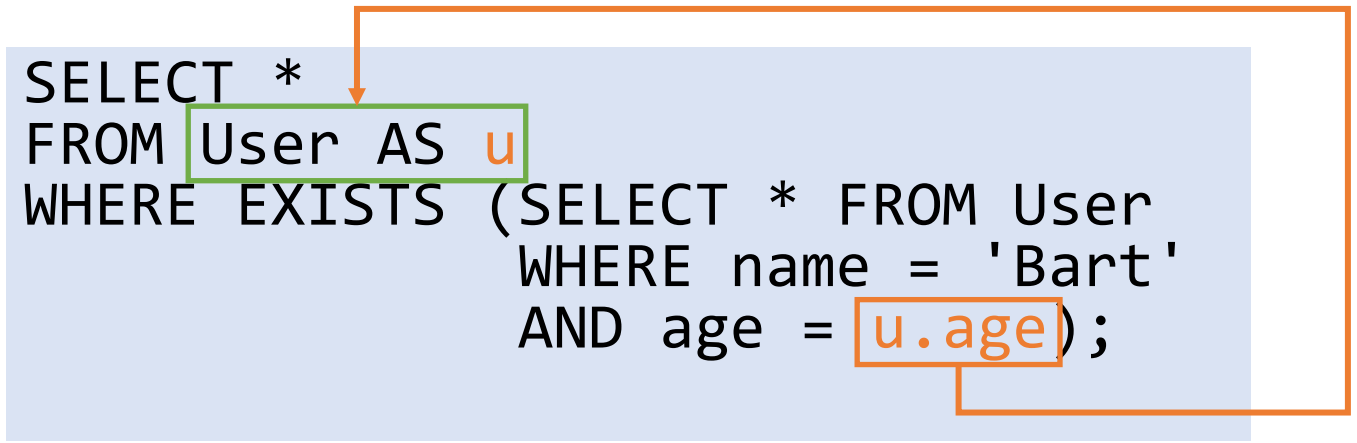
What's Bart's age?
    ```

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);
    ```

    Checks if there is a bart
  - 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);
```

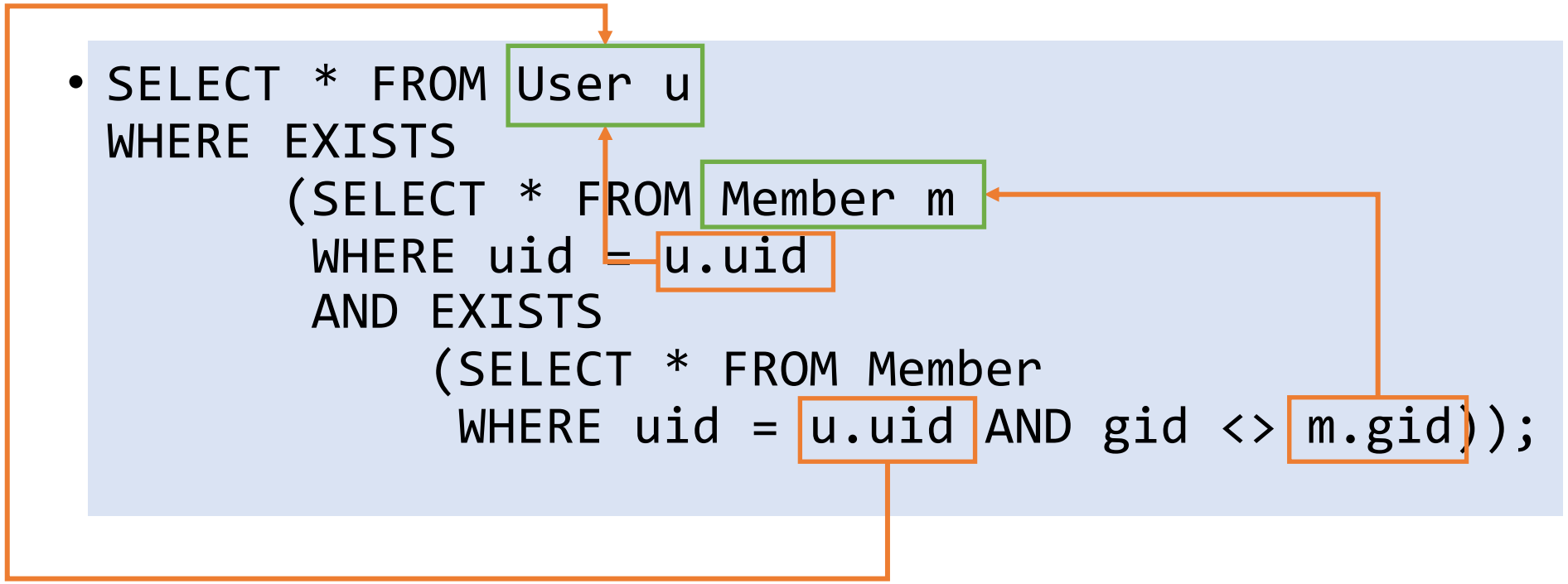
- For each row u in User
  - Evaluate the subquery with the value of u.age
  - If the result of the subquery is not empty, output u.*
- The DBMS query optimizer may choose to process the query in an equivalent, but more efficient way (example?)

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

Is this right?
Will this not
exclude the most unpopular user?

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 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) 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 (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

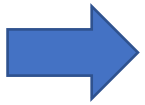
☞ Number of groups =
number of rows in the final output

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

Since each group can have multiple values in the column, you can not know which value will be returned if you only select one of the values

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;` WRONG!
  - 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, …