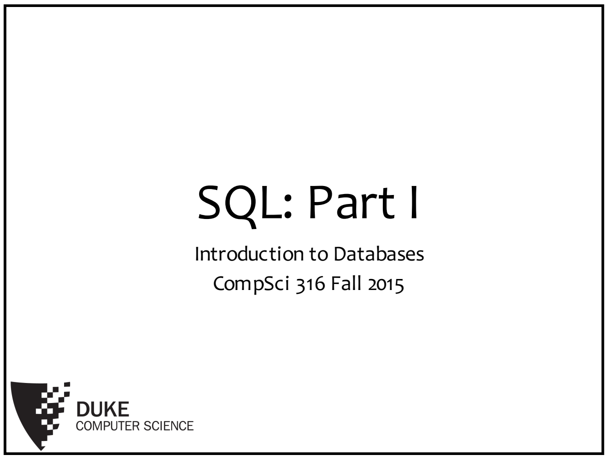
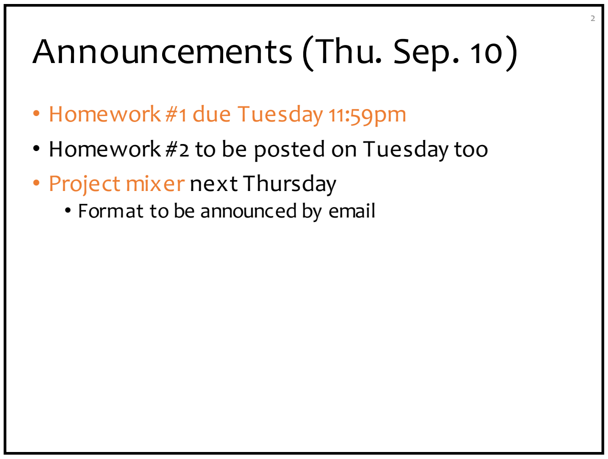


SQL: Part I

Introduction to Databases
CompSci 316 Fall 2015

DUKE
COMPUTER SCIENCE



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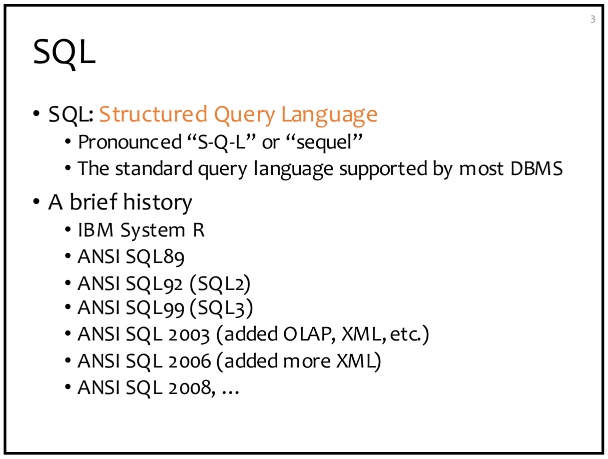
Announcements (Thu. Sep. 10)

- Homework #1 due Tuesday 11:59pm
- Homework #2 to be posted on Tuesday too
- Project mixer next Thursday
  - Format to be announced by email



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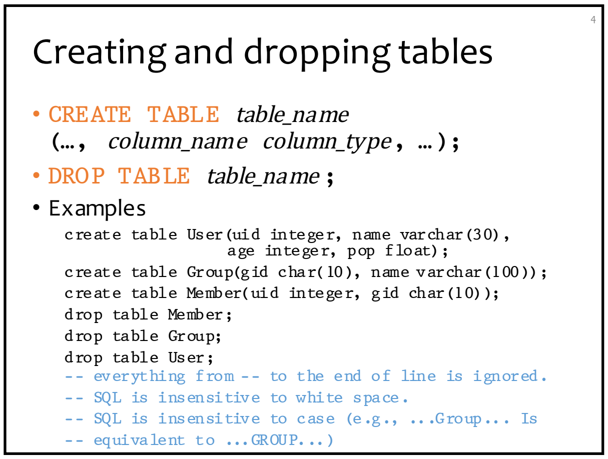
SQL

- 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, …



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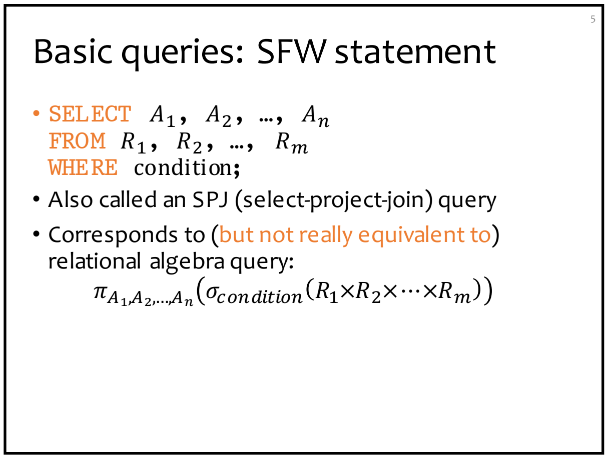
Creating and dropping tables

- 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...)
```



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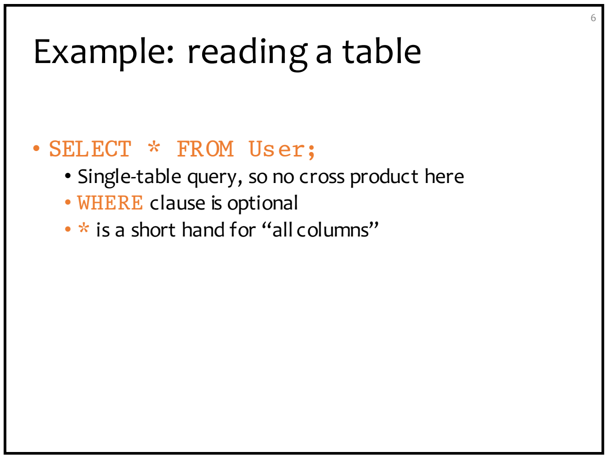
Basic queries: SFW statement

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

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



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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 2015-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

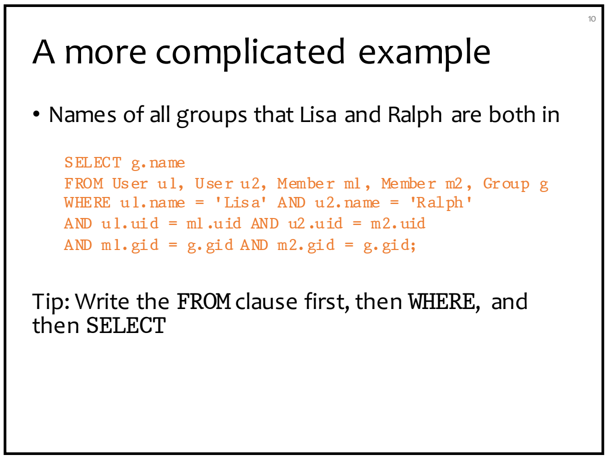
- ID's and names of groups with a user whose name contains "Simpson"

  -
    ```
    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

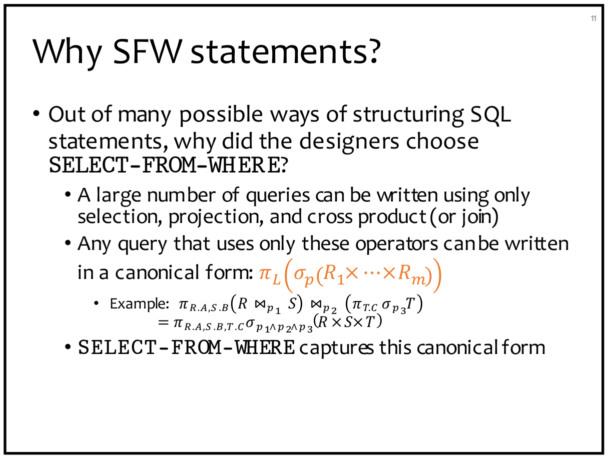


A more complicated example

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

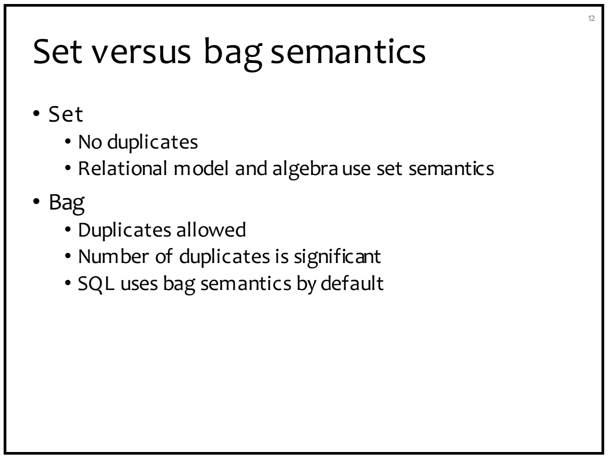
```
SELECT g.name
FROM User u1, User u2, Member m1, Member m2, Group g
WHERE u1.name = 'Lisa' AND u2.name = 'Ralph'
AND u1.uid = m1.uid AND u2.uid = m2.uid
AND m1.gid = g.gid AND m2.gid = g.gid;
```

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



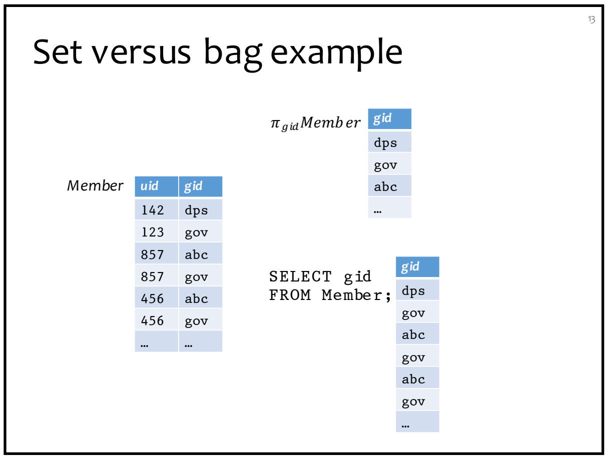
Why SFW statements?

- 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



Set versus bag example

$\pi_{gid} Member$

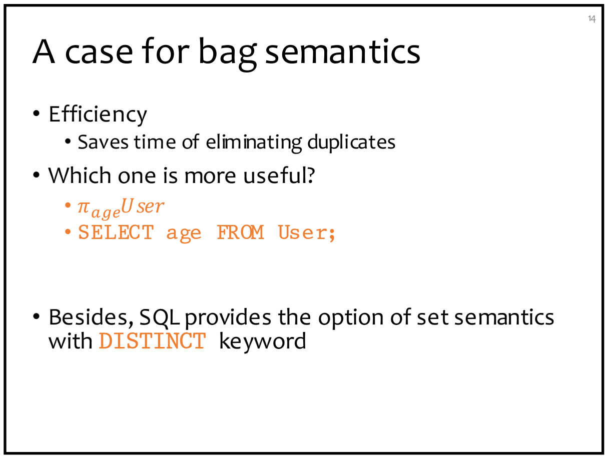
gid
dps
gov
abc
…

Member

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

```
SELECT gid
FROM Member;
```

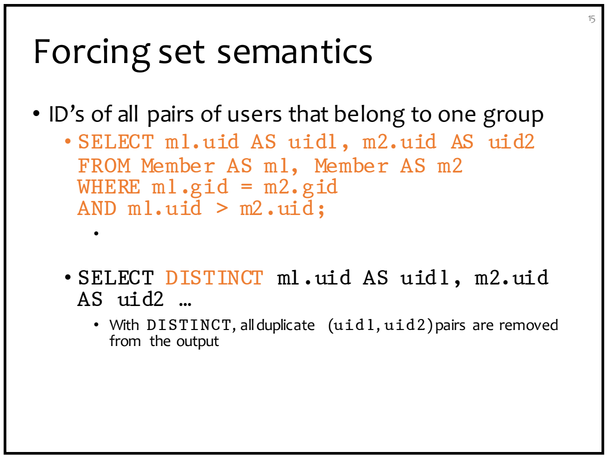
gid
dps
gov
abc
gov
abc
gov
…



A case for bag semantics

- Efficiency
  - Saves time of eliminating duplicates
- Which one is more useful?
  - $\pi_{age} User$
  - `SELECT age FROM User;`

- 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;
    ```
    -

  - `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 $t_1$ 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);
```

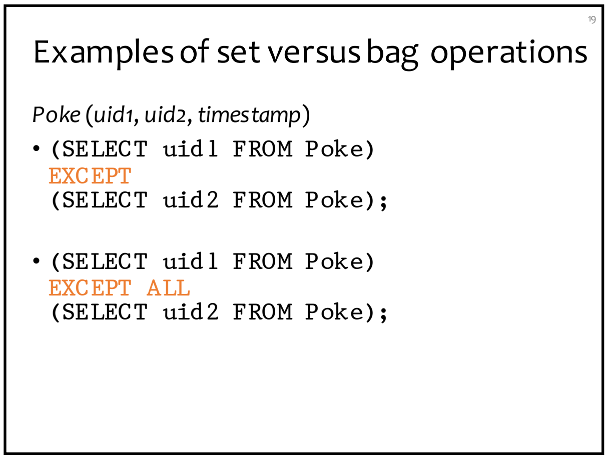
fruit
apple
apple
orange
apple
orange
orange

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

fruit
apple

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

fruit
apple
orange

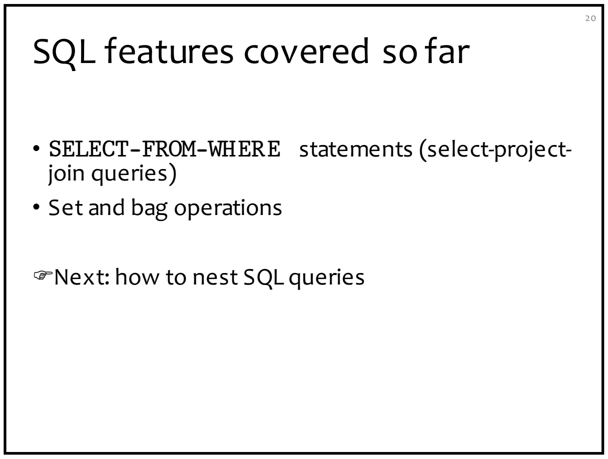


Examples of set versus bag operations

Poke (uid1, uid2, timestamp)

-
  ```
  (SELECT uid1 FROM Poke)
  EXCEPT
  (SELECT uid2 FROM Poke);
  ```

-
  ```
  (SELECT uid1 FROM Poke)
  EXCEPT ALL
  (SELECT uid2 FROM Poke);
  ```



SQL features covered so far

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

☞Next: how to nest SQL queries

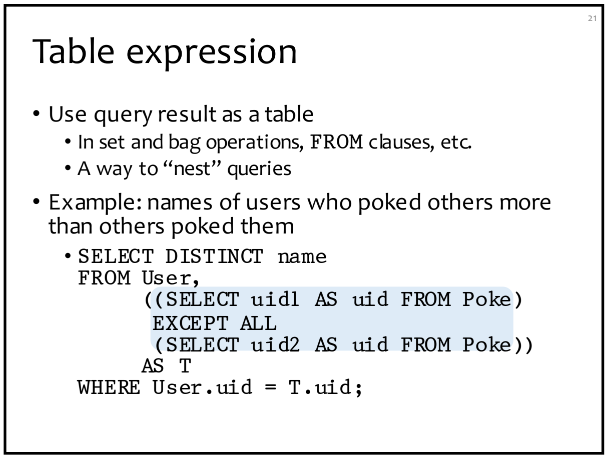
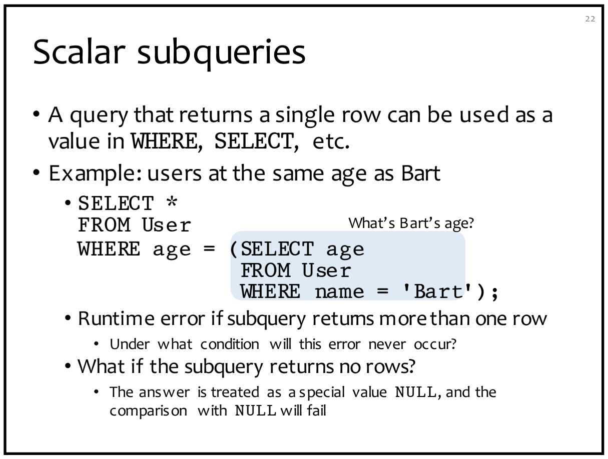


Table expression

- 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;
    ```



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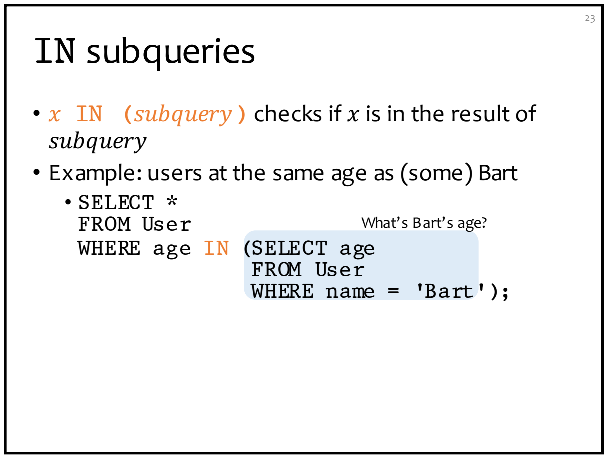
Scalar subqueries

- 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                    What's Bart's age?
    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



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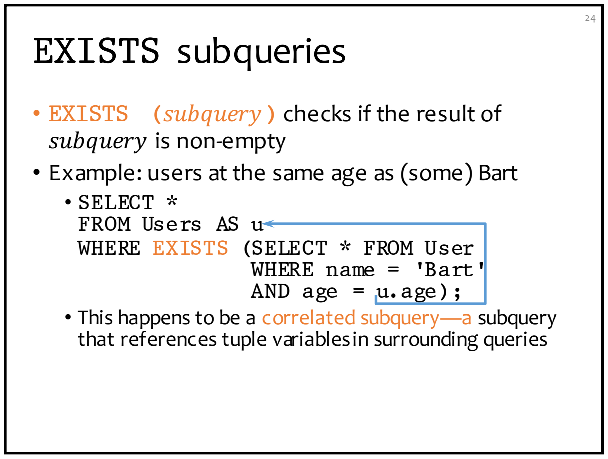
IN subqueries

- *x* IN (*subquery*) checks if *x* is in the result of *subquery*
- Example: users at the same age as (some) Bart

  -
    ```
    SELECT *
    FROM User                     What's Bart's age?
    WHERE age IN (SELECT age
                  FROM User
                  WHERE name = 'Bart');
    ```



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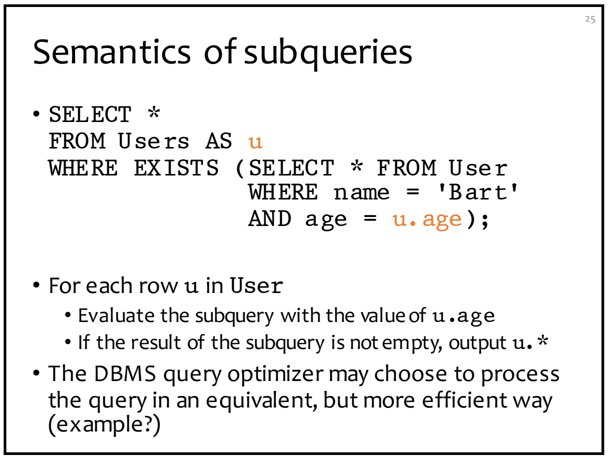
EXISTS subqueries

- EXISTS (*subquery*) checks if the result of *subquery* is non-empty
- Example: users at the same age as (some) Bart

  -
    ```
    SELECT *
    FROM Users 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



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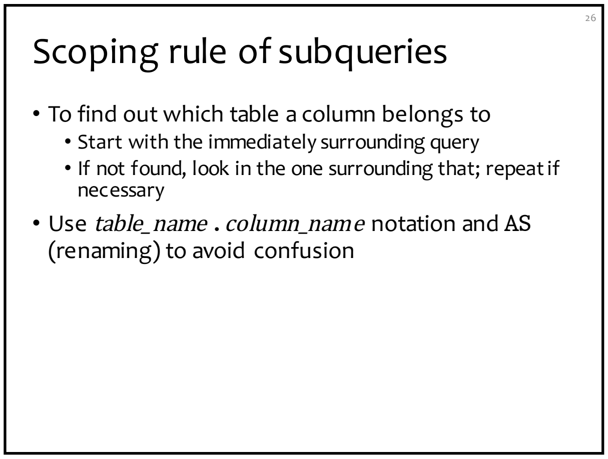
Semantics of subqueries

-
  ```
  SELECT *
  FROM Users 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?)



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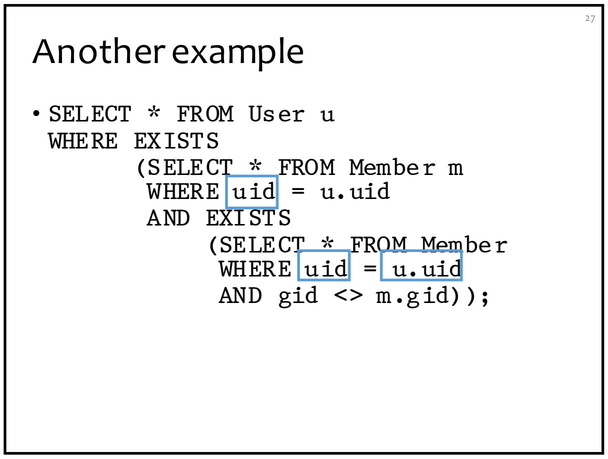
Scoping rule of subqueries

- 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



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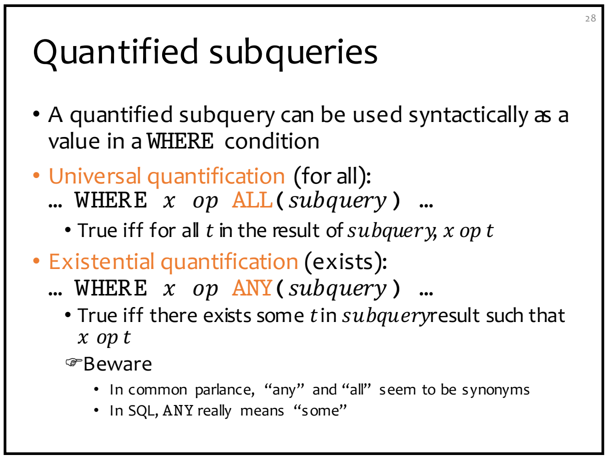
Another example

-
  ```
  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));
  ```



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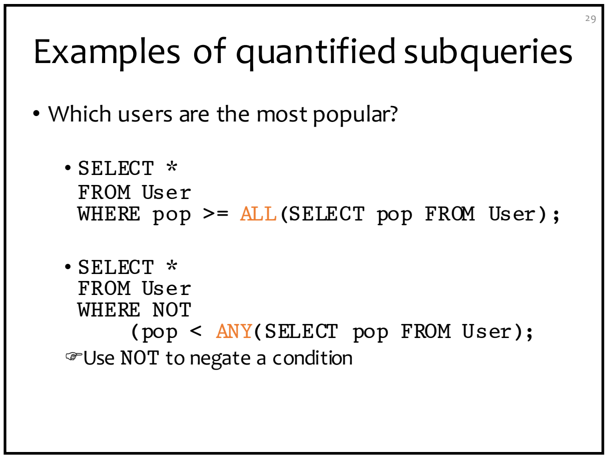
Quantified subqueries

- 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”



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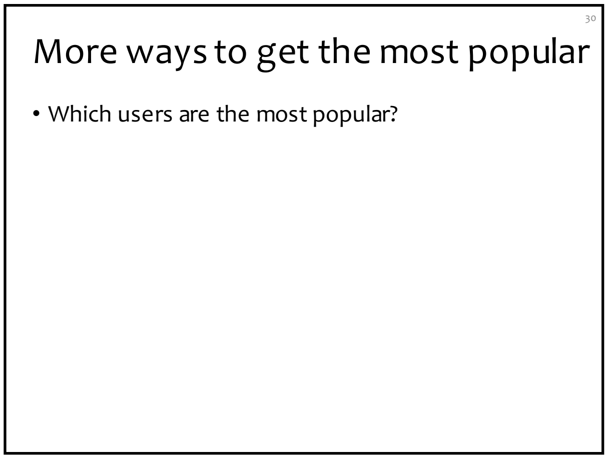
Examples of quantified subqueries

- 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



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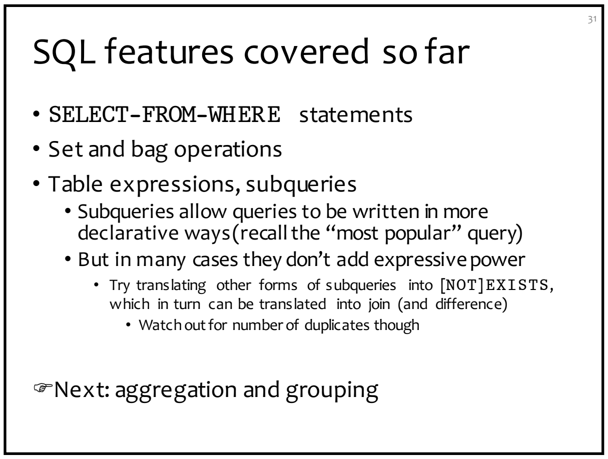
More ways to get the most popular

- Which users are the most popular?



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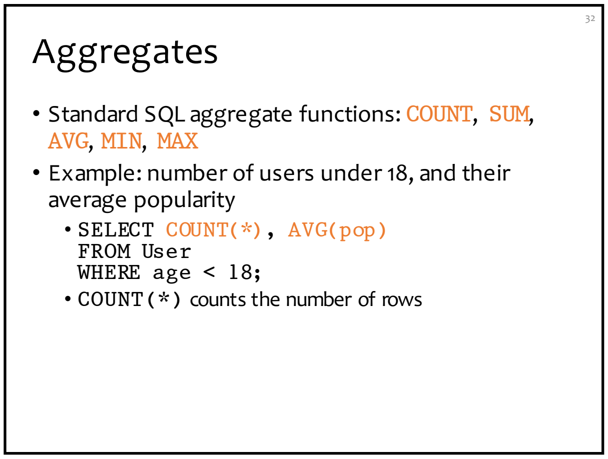
SQL features covered so far

- `SELECT-FROM-WHERE` statements
- Set and bag operations
- Table expressions, 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



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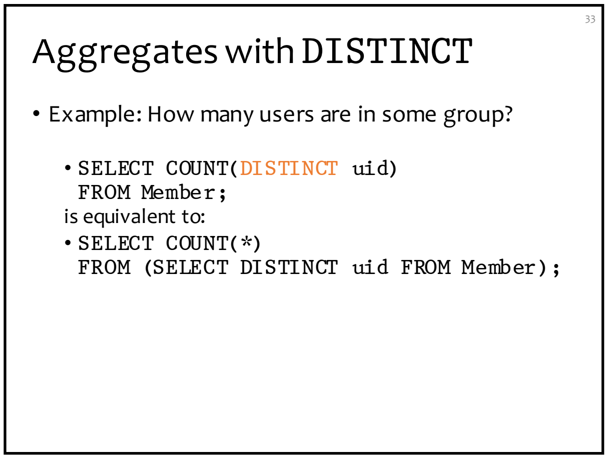
Aggregates

- 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



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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);
    ```

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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;
    ```

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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

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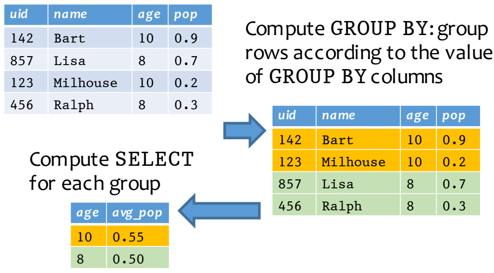
Example of computing GROUP BY

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



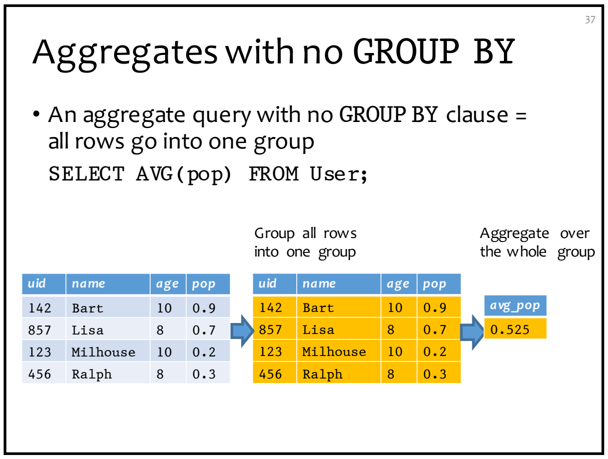
uid	name	age	pop
142	Bart	10	0.9
857	Lisa	8	0.7
123	Milhouse	10	0.2
456	Ralph	8	0.3

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;

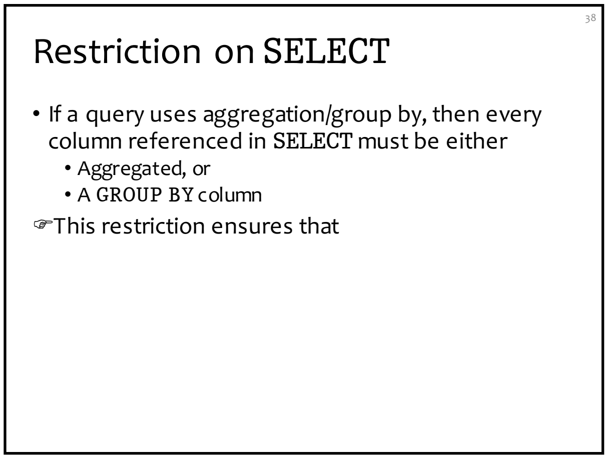
uid	name	age	pop
142	Bart	10	0.9
857	Lisa	8	0.7
123	Milhouse	10	0.2
456	Ralph	8	0.3

Group all rows into one 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

Aggregate over the whole group

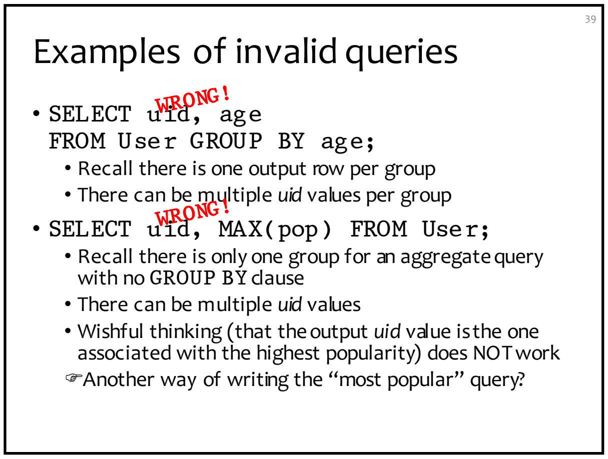
avg_pop
0.525



Restriction on SELECT

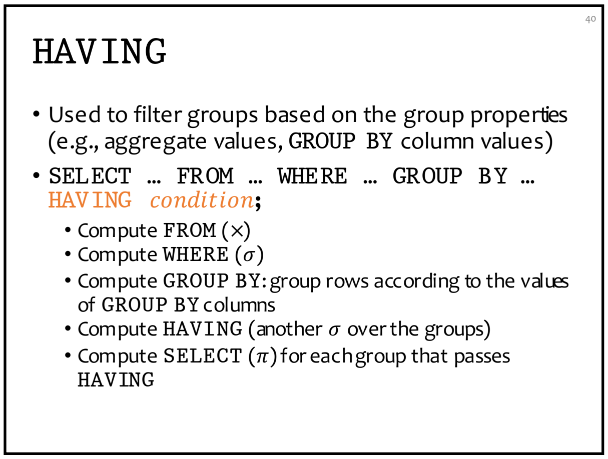
- If a query uses aggregation/group by, then every column referenced in SELECT must be either
  - Aggregated, or
  - A GROUP BY column

☞This restriction ensures that



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?



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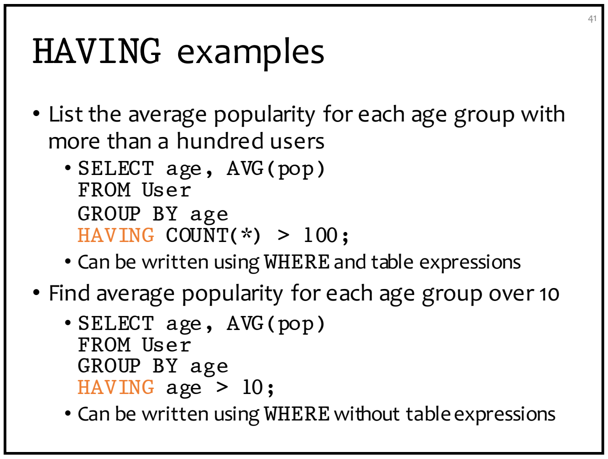
HAVING

- 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



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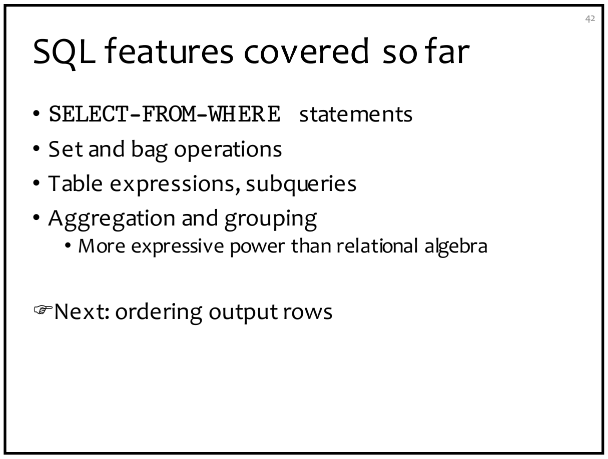
HAVING examples

- 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 expressions
- 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 expressions



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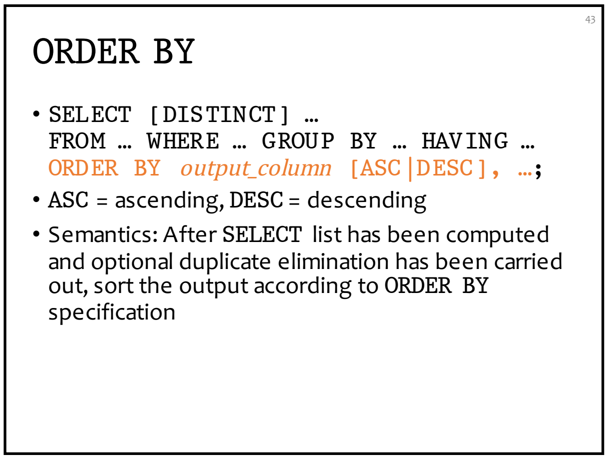
SQL features covered so far

- SELECT-FROM-WHERE statements
- Set and bag operations
- Table expressions, subqueries
- Aggregation and grouping
  - More expressive power than relational algebra

☞Next: ordering output rows



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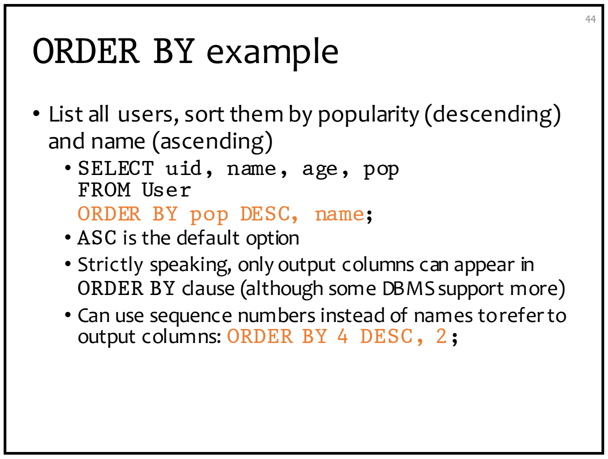
ORDER BY

- 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



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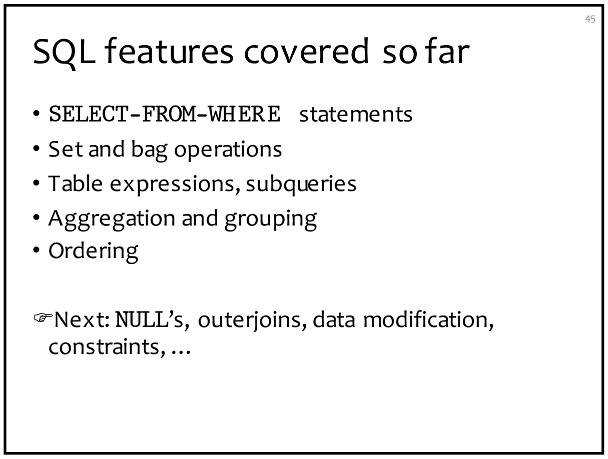
ORDER BY example

- 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;



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SQL features covered so far

- SELECT-FROM-WHERE statements
- Set and bag operations
- Table expressions, subqueries
- Aggregation and grouping
- Ordering

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