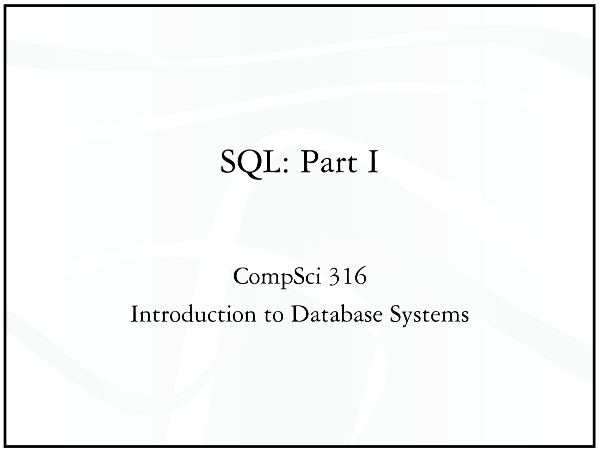
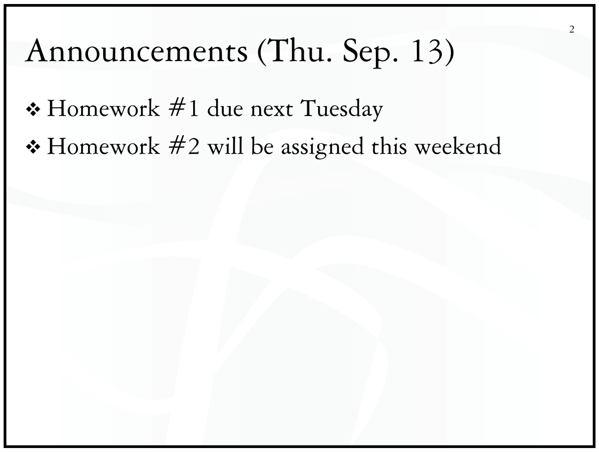


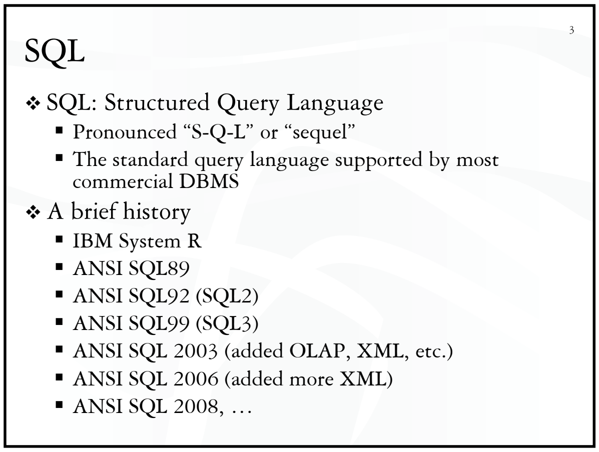
SQL: Part I

CompSci 316
Introduction to Database Systems



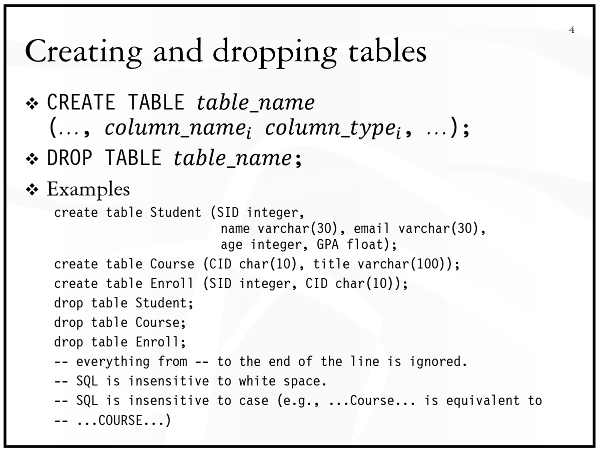
Announcements (Thu. Sep. 13)

- Homework #1 due next Tuesday
- Homework #2 will be assigned this weekend



SQL

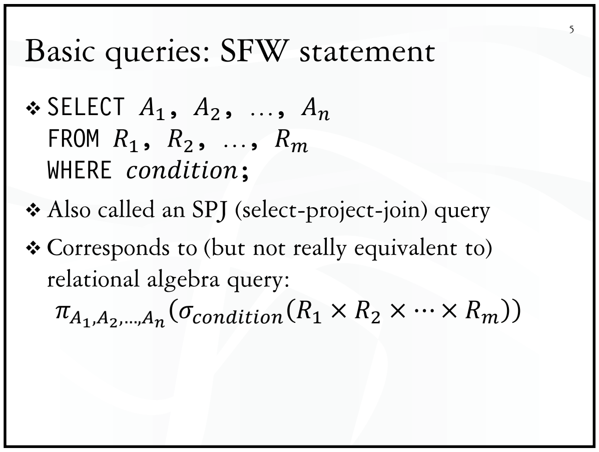
- SQL: Structured Query Language
  - Pronounced “S-Q-L” or “sequel”
  - The standard query language supported by most commercial DBMS
- A brief history
  - IBM System R
  - ANSI SQL89
  - ANSI SQL92 (SQL2)
  - ANSI SQL99 (SQL3)
  - ANSI SQL 2003 (added OLAP, XML, etc.)
  - ANSI SQL 2006 (added more XML)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



Creating and dropping tables

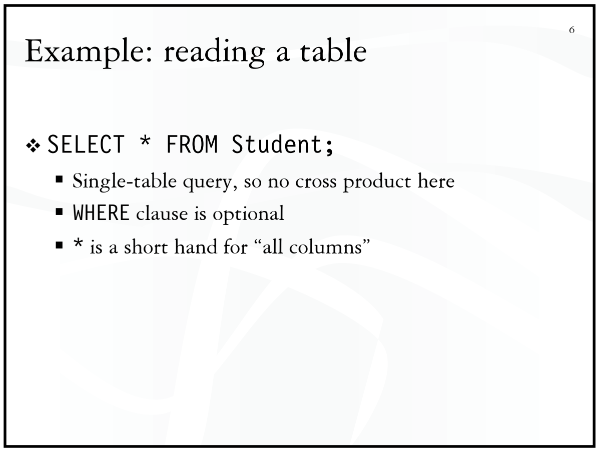
- CREATE TABLE *table_name*
  (…, *column_name$_i$* *column_type$_i$*, …);
- DROP TABLE *table_name*;
- Examples

```
create table Student (SID integer,
                      name varchar(30), email varchar(30),
                      age integer, GPA float);
create table Course (CID char(10), title varchar(100));
create table Enroll (SID integer, CID char(10));
drop table Student;
drop table Course;
drop table Enroll;
-- everything from -- to the end of the line is ignored.
-- SQL is insensitive to white space.
-- SQL is insensitive to case (e.g., ...Course... is equivalent to
-- ...COURSE...)
```



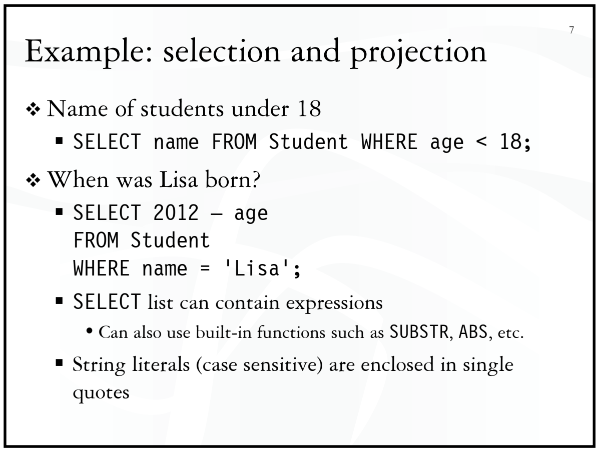
Basic queries: SFW statement

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



Example: reading a table

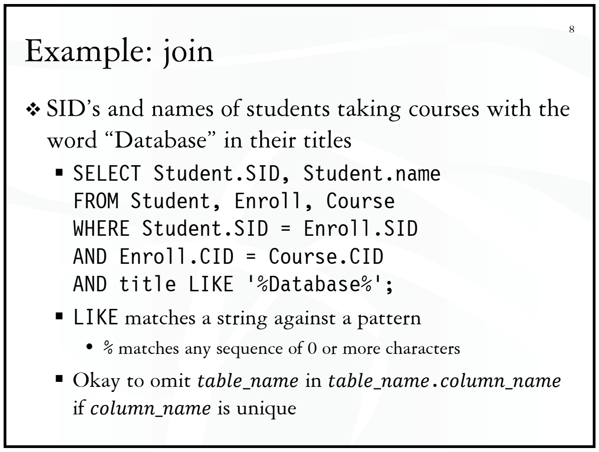
- SELECT * FROM Student;
  - Single-table query, so no cross product here
  - WHERE clause is optional
  - * is a short hand for “all columns”



Example: selection and projection

- Name of students under 18
  - `SELECT name FROM Student WHERE age < 18;`
- When was Lisa born?

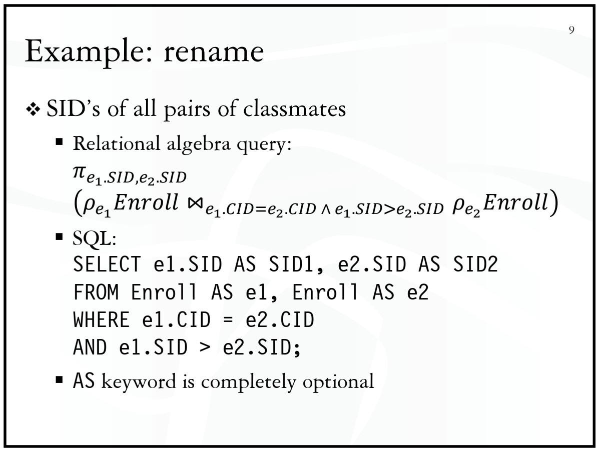
  -
    ```
    SELECT 2012 – age
    FROM Student
    WHERE name = 'Lisa';
    ```
  - `SELECT` list can contain expressions
    - Can also use built-in functions such as `SUBSTR`, `ABS`, etc.
  - String literals (case sensitive) are enclosed in single quotes



Example: join

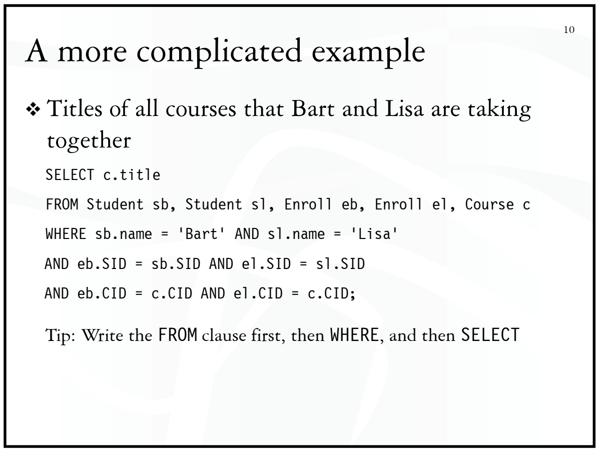
- SID's and names of students taking courses with the word "Database" in their titles

  -
    ```
    SELECT Student.SID, Student.name
    FROM Student, Enroll, Course
    WHERE Student.SID = Enroll.SID
    AND Enroll.CID = Course.CID
    AND title LIKE '%Database%';
    ```
  - `LIKE` matches a string against a pattern
    - `%` matches any sequence of 0 or more characters
  - Okay to omit *table_name* in *table_name.column_name* if *column_name* is unique



Example: rename

- SID's of all pairs of classmates
  - Relational algebra query:
    $\pi_{e_1.SID,e_2.SID}$
    $(\rho_{e_1}Enroll \bowtie_{e_1.CID=e_2.CID \wedge e_1.SID>e_2.SID} \rho_{e_2}Enroll)$
  - SQL:
    ```
    SELECT e1.SID AS SID1, e2.SID AS SID2
    FROM Enroll AS e1, Enroll AS e2
    WHERE e1.CID = e2.CID
    AND e1.SID > e2.SID;
    ```
  - `AS` keyword is completely optional

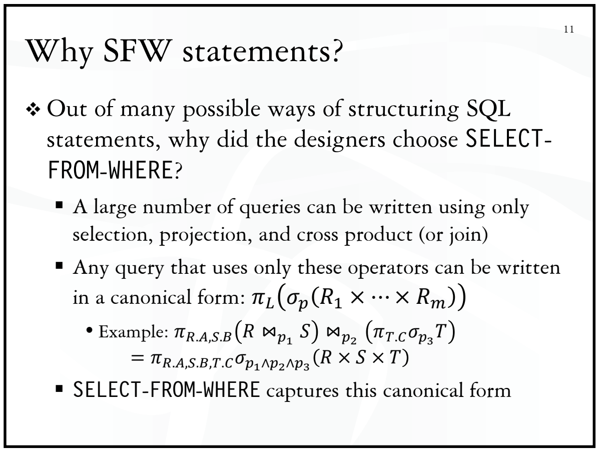


A more complicated example

- Titles of all courses that Bart and Lisa are taking together

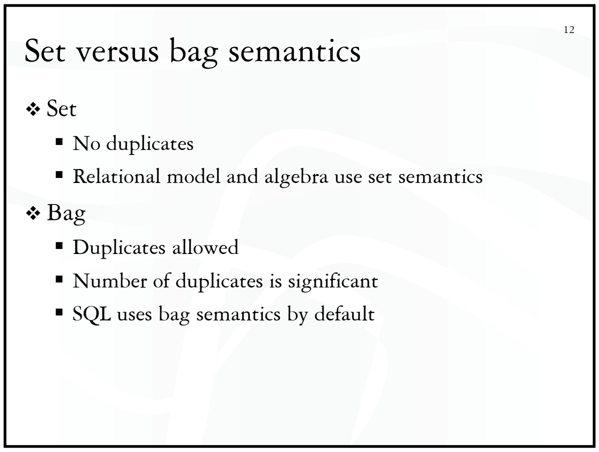
```
SELECT c.title
FROM Student sb, Student sl, Enroll eb, Enroll el, Course c
WHERE sb.name = 'Bart' AND sl.name = 'Lisa'
AND eb.SID = sb.SID AND el.SID = sl.SID
AND eb.CID = c.CID AND el.CID = c.CID;
```

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



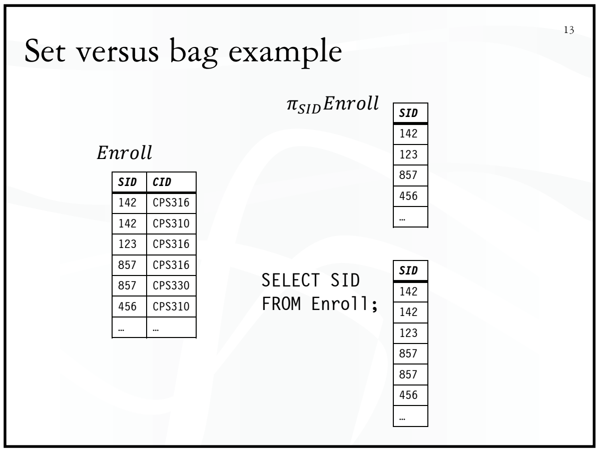
Why SFW statements?

- 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

$Enroll$

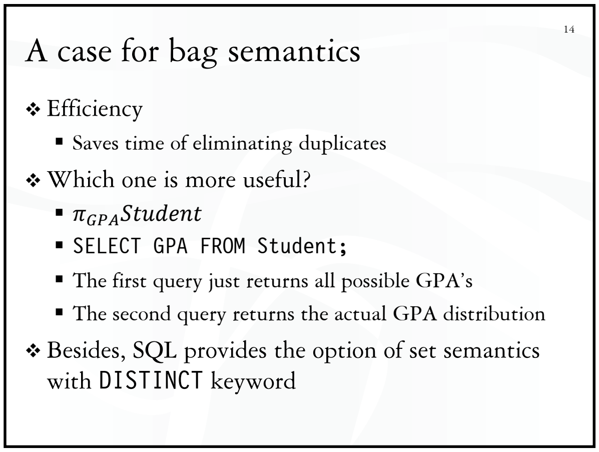
SID	*CID*
142	CPS316
142	CPS310
123	CPS316
857	CPS316
857	CPS330
456	CPS310
…	…

$\pi_{SID} Enroll$

SID
142
123
857
456
…

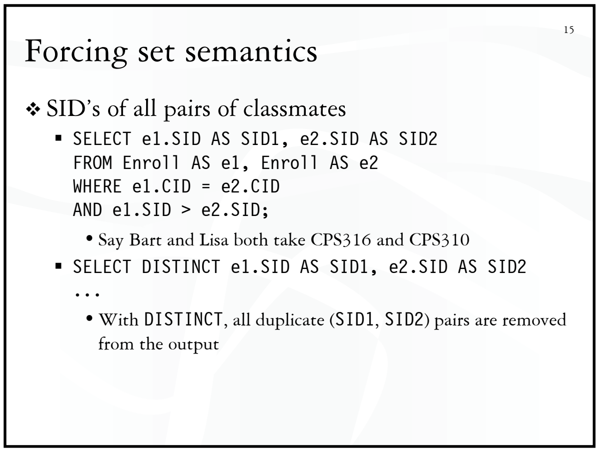
```
SELECT SID
FROM Enroll;
```

SID
142
142
123
857
857
456
…



A case for bag semantics

- ❖ Efficiency
  - Saves time of eliminating duplicates
- ❖ Which one is more useful?
  - $\pi_{GPA} Student$
  - `SELECT GPA FROM Student;`
  - The first query just returns all possible GPA's
  - The second query returns the actual GPA distribution
- ❖ Besides, SQL provides the option of set semantics with `DISTINCT` keyword



Forcing set semantics

- ❖ SID's of all pairs of classmates

  -
    ```
    SELECT e1.SID AS SID1, e2.SID AS SID2
    FROM Enroll AS e1, Enroll AS e2
    WHERE e1.CID = e2.CID
    AND e1.SID > e2.SID;
    ```
    - Say Bart and Lisa both take CPS316 and CPS310

  -
    ```
    SELECT DISTINCT e1.SID AS SID1, e2.SID AS SID2
    ...
    ```
    - With `DISTINCT`, all duplicate (`SID1`, `SID2`) pairs are removed from the output

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Operational 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

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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

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Examples of bag operations

`Bag1`

fruit
apple
apple
orange

`Bag2`

fruit
apple
orange
orange

`Bag1 UNION ALL Bag2`

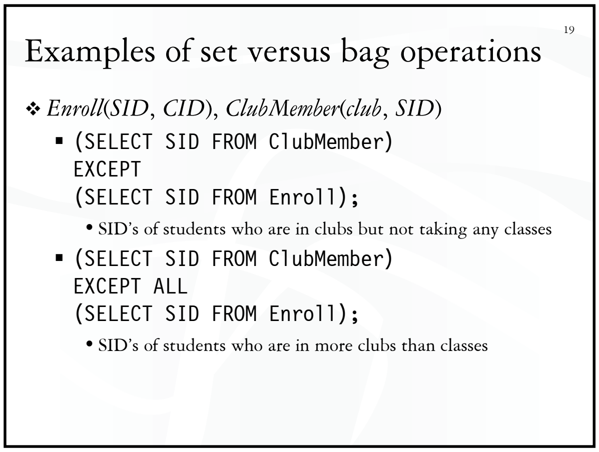
fruit
apple
apple
orange
apple
orange
orange

`Bag1 EXCEPT ALL Bag2`

fruit
apple

`Bag1 INTERSECT ALL Bag2`

fruit
apple
orange

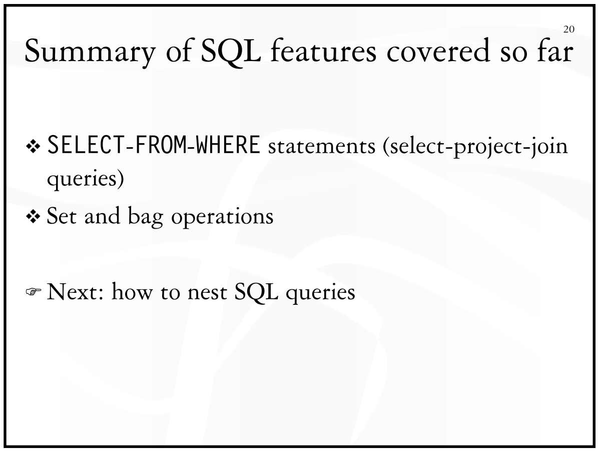


Examples of set versus bag operations

- *Enroll*(*SID*, *CID*), *ClubMember*(*club*, *SID*)

  -
    ```
    (SELECT SID FROM ClubMember)
    EXCEPT
    (SELECT SID FROM Enroll);
    ```
    - SID's of students who are in clubs but not taking any classes

  -
    ```
    (SELECT SID FROM ClubMember)
    EXCEPT ALL
    (SELECT SID FROM Enroll);
    ```
    - SID's of students who are in more clubs than classes



Summary of SQL features covered so far

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

☞ Next: how to nest SQL queries

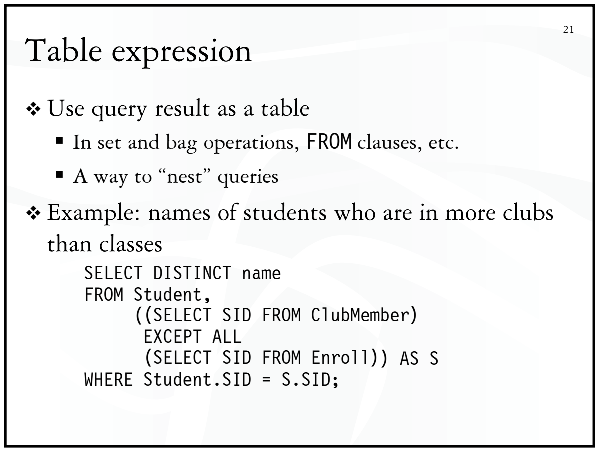
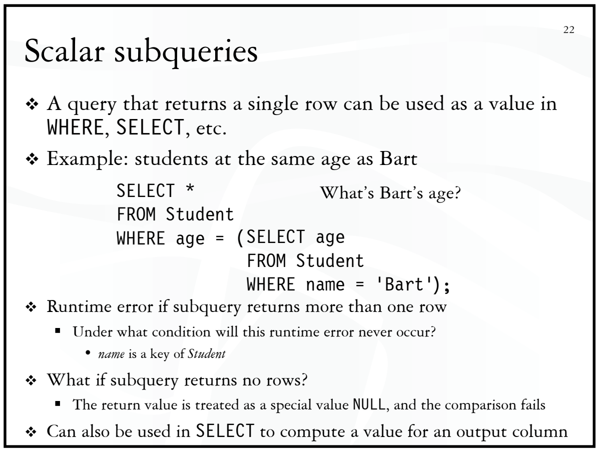


Table expression

- Use query result as a table
  - In set and bag operations, `FROM` clauses, etc.
  - A way to "nest" queries
- Example: names of students who are in more clubs than classes

```
SELECT DISTINCT name
FROM Student,
     ((SELECT SID FROM ClubMember)
      EXCEPT ALL
      (SELECT SID FROM Enroll)) AS S
WHERE Student.SID = S.SID;
```

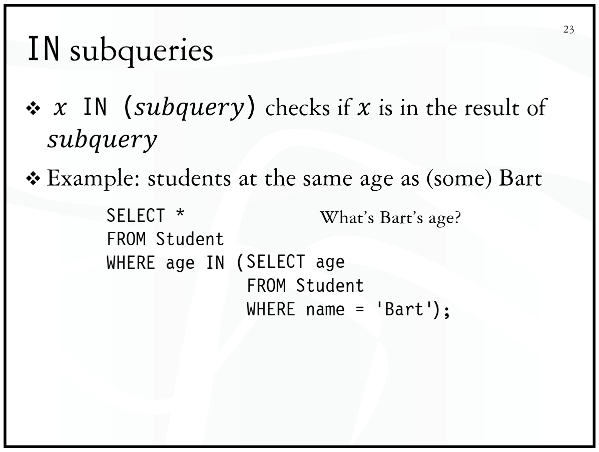


Scalar subqueries

- A query that returns a single row can be used as a value in WHERE, SELECT, etc.
- Example: students at the same age as Bart

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

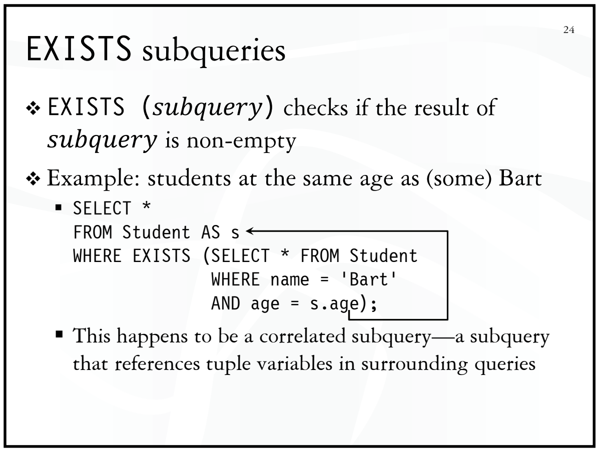
- Runtime error if subquery returns more than one row
  - Under what condition will this runtime error never occur?
    - *name* is a key of *Student*
- What if subquery returns no rows?
  - The return value is treated as a special value NULL, and the comparison fails
- Can also be used in SELECT to compute a value for an output column



IN subqueries

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

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



EXISTS subqueries

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

  -
    ```
    SELECT *
    FROM Student AS s
    WHERE EXISTS (SELECT * FROM Student
                  WHERE name = 'Bart'
                  AND age = s.age);
    ```
  - This happens to be a correlated subquery—a subquery that references tuple variables in surrounding queries

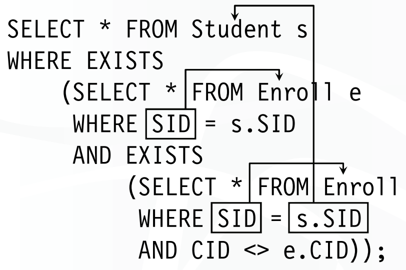
Operational semantics of subqueries

-
  ```
  SELECT *
  FROM Student AS s
  WHERE EXISTS (SELECT * FROM Student
                WHERE name = 'Bart'
                AND age = s.age);
  ```
- For each row `s` in `Student`
  - Evaluate the subquery with the appropriate value of `s.age`
  - If the result of the subquery is not empty, output `s.*`
- The DBMS query optimizer may choose to process the query in an equivalent, but more efficient way (example?)

Scoping rule of subqueries

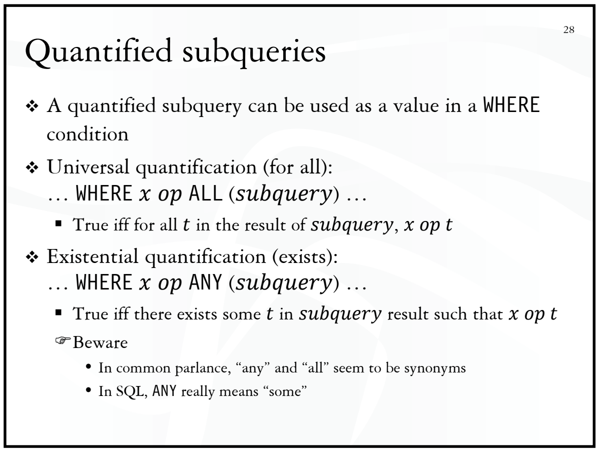
- To find out which table a column belongs to
  - Start with the immediately surrounding query
  - If not found, look in the one surrounding that; repeat if necessary
- Use *table_name*.*column_name* notation and `AS` (renaming) to avoid confusion

Another example



```
SELECT * FROM Student s
WHERE EXISTS
    (SELECT * FROM Enroll e
     WHERE SID = s.SID
     AND EXISTS
         (SELECT * FROM Enroll
          WHERE SID = s.SID
          AND CID <> e.CID));
```

Students who are taking at least two courses



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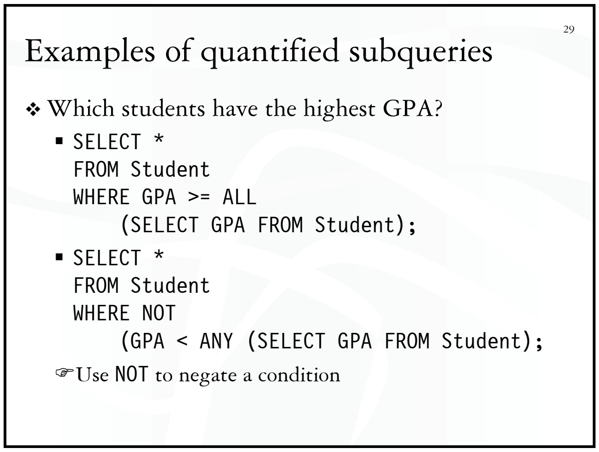
Quantified subqueries

- A quantified subquery can be used 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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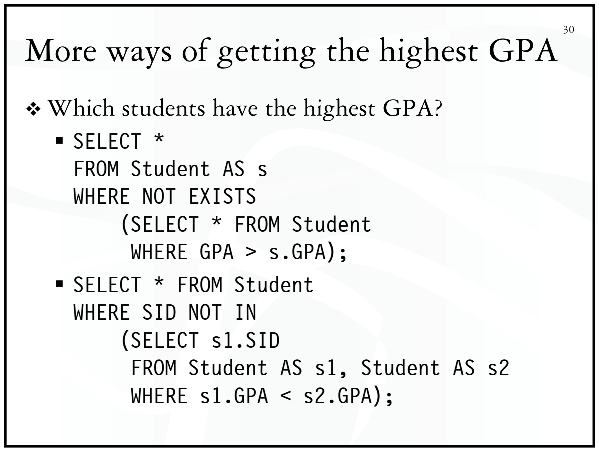
Examples of quantified subqueries

- Which students have the highest GPA?

  -
    ```
    SELECT *
    FROM Student
    WHERE GPA >= ALL
        (SELECT GPA FROM Student);
    ```

  -
    ```
    SELECT *
    FROM Student
    WHERE NOT
        (GPA < ANY (SELECT GPA FROM Student);
    ```
  - ☞Use `NOT` to negate a condition



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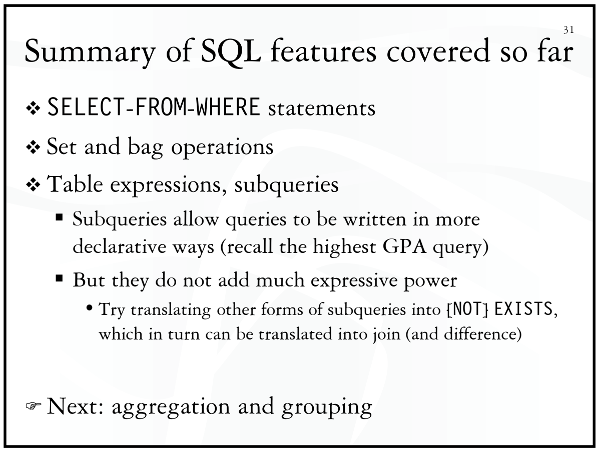
More ways of getting the highest GPA

- Which students have the highest GPA?

  -
    ```
    SELECT *
    FROM Student AS s
    WHERE NOT EXISTS
        (SELECT * FROM Student
         WHERE GPA > s.GPA);
    ```

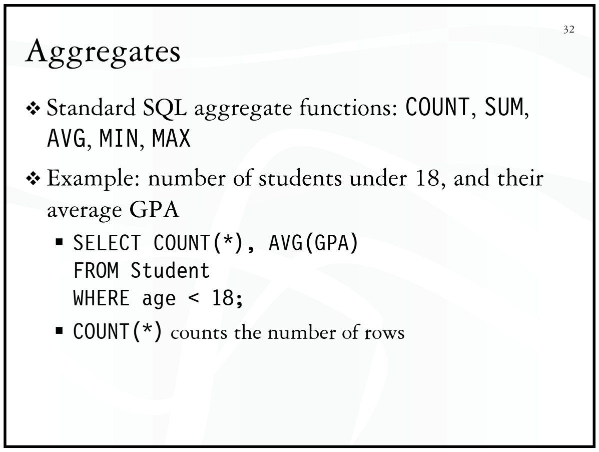
  -
    ```
    SELECT * FROM Student
    WHERE SID NOT IN
        (SELECT s1.SID
         FROM Student AS s1, Student AS s2
         WHERE s1.GPA < s2.GPA);
    ```



Summary of SQL features covered so far

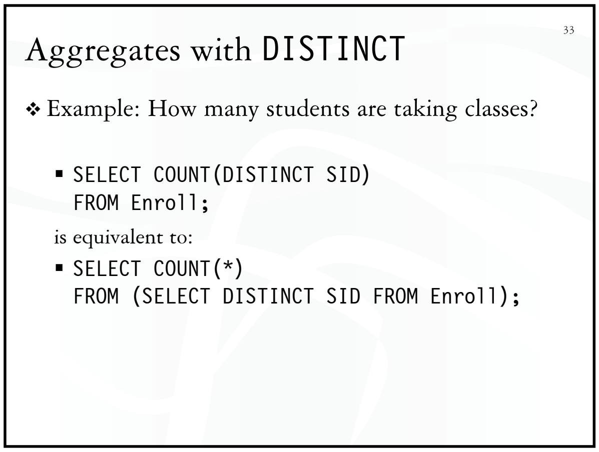
- ❖ `SELECT-FROM-WHERE` statements
- ❖ Set and bag operations
- ❖ Table expressions, subqueries
  - ▪ Subqueries allow queries to be written in more declarative ways (recall the highest GPA query)
  - ▪ But they do not add much expressive power
    - • Try translating other forms of subqueries into [NOT] EXISTS, which in turn can be translated into join (and difference)

☞ Next: aggregation and grouping



Aggregates

- ❖ Standard SQL aggregate functions: `COUNT`, `SUM`, `AVG`, `MIN`, `MAX`
- ❖ Example: number of students under 18, and their average GPA
  - ▪
    ```
    SELECT COUNT(*), AVG(GPA)
    FROM Student
    WHERE age < 18;
    ```
  - ▪ `COUNT(*)` counts the number of rows



Aggregates with DISTINCT

- ❖ Example: How many students are taking classes?
  - ▪
    ```
    SELECT COUNT(DISTINCT SID)
    FROM Enroll;
    ```

  is equivalent to:

  - ▪
    ```
    SELECT COUNT(*)
    FROM (SELECT DISTINCT SID FROM Enroll);
    ```

GROUP BY

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- SELECT … FROM … WHERE …
  GROUP BY *list_of_columns*;
- Example: find the average GPA for each age group

  -
    ```
    SELECT age, AVG(GPA)
    FROM Student
    GROUP BY age;
    ```

Operational semantics of GROUP BY

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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

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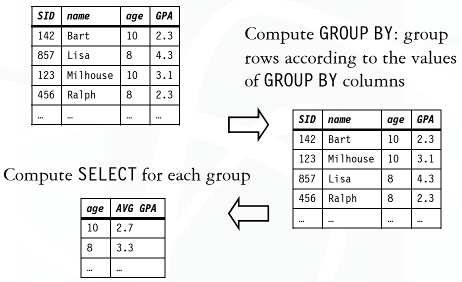
```
SELECT age, AVG(GPA) FROM Student GROUP BY age;
```



SID	name	age	GPA
142	Bart	10	2.3
857	Lisa	8	4.3
123	Milhouse	10	3.1
456	Ralph	8	2.3
…	…	…	…

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

SID	name	age	GPA
142	Bart	10	2.3
123	Milhouse	10	3.1
857	Lisa	8	4.3
456	Ralph	8	2.3
…	…	…	…

Compute SELECT for each group

age	AVG GPA
10	2.7
8	3.3
…	…

Aggregates with no GROUP BY

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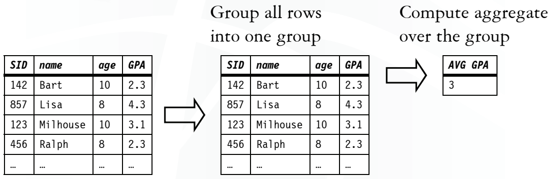
- An aggregate query with no GROUP BY clause represent a special case where all rows go into one group

```
SELECT AVG(GPA) FROM Student;
```



Group all rows into one group

Compute aggregate over the group

SID	name	age	GPA
142	Bart	10	2.3
857	Lisa	8	4.3
123	Milhouse	10	3.1
456	Ralph	8	2.3
…	…	…	…

SID	name	age	GPA
142	Bart	10	2.3
857	Lisa	8	4.3
123	Milhouse	10	3.1
456	Ralph	8	2.3
…	…	…	…

AVG GPA
3

Restriction on SELECT

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- 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 any SELECT expression produces only one value for each group

Examples of invalid queries

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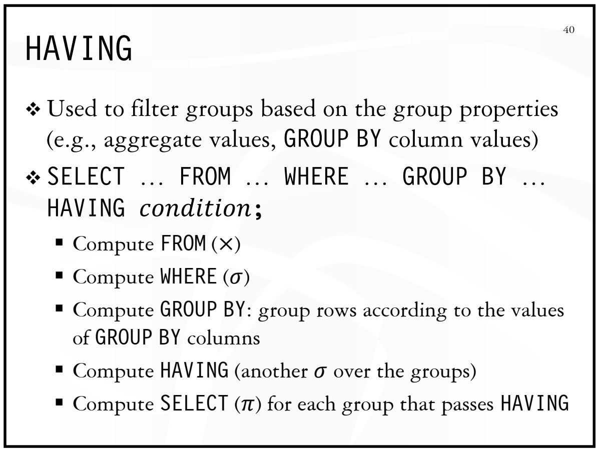
- SELECT ~~SID,~~ age FROM Student GROUP BY age;
  - Recall there is one output row per group
  - There can be multiple SID values per group
- SELECT ~~SID,~~ MAX(GPA) FROM Student;
  - Recall there is only one group for an aggregate query with no GROUP BY clause
  - There can be multiple SID values
  - Wishful thinking (that the output SID value is the one associated with the highest GPA) does NOT work

  ☞Another way of writing the max GPA query?



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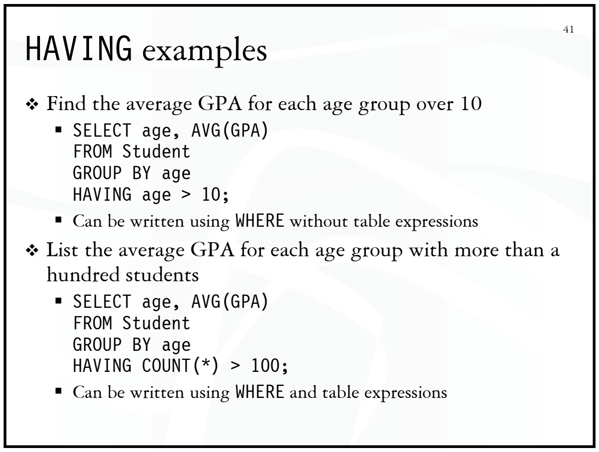
HAVING

- ❖ 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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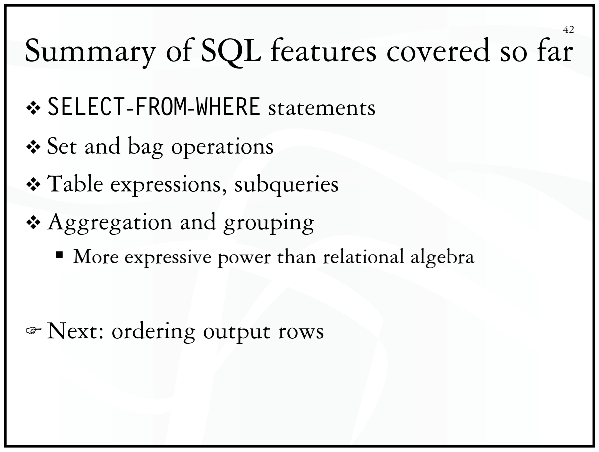
HAVING examples

- ❖ Find the average GPA for each age group over 10

  -
    ```
    SELECT age, AVG(GPA)
    FROM Student
    GROUP BY age
    HAVING age > 10;
    ```
  - Can be written using WHERE without table expressions
- ❖ List the average GPA for each age group with more than a hundred students

  -
    ```
    SELECT age, AVG(GPA)
    FROM Student
    GROUP BY age
    HAVING COUNT(*) > 100;
    ```
  - Can be written using WHERE and table expressions



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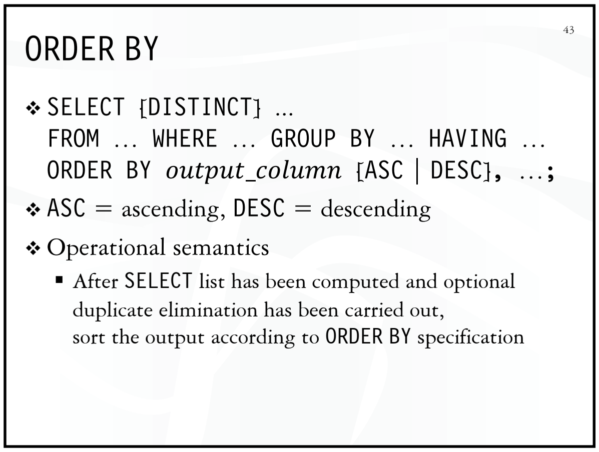
Summary of SQL features covered so far

- ❖ 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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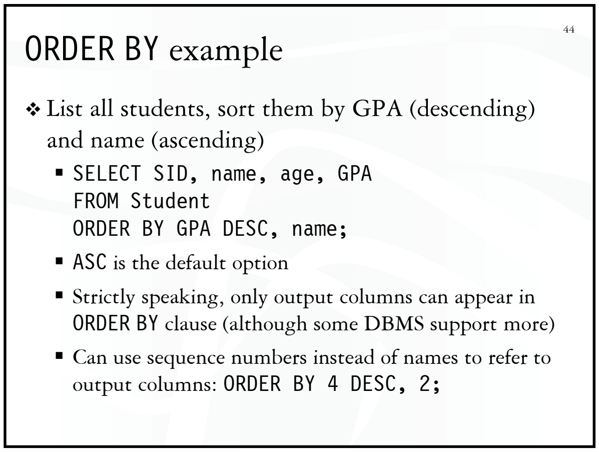
ORDER BY

- ❖ SELECT [DISTINCT] …
  FROM … WHERE … GROUP BY … HAVING …
  ORDER BY *output_column* [ASC | DESC], …;
- ❖ ASC = ascending, DESC = descending
- ❖ Operational 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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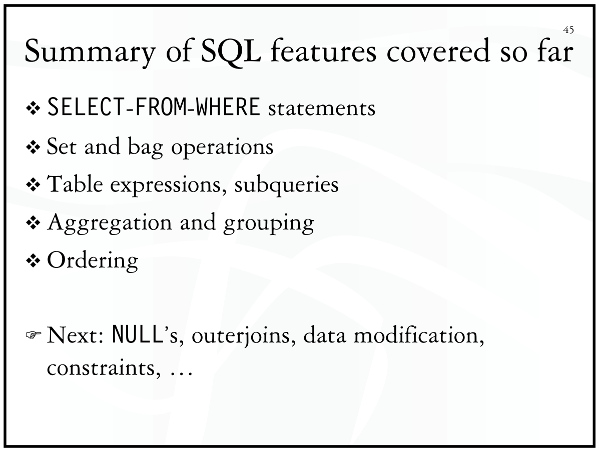
ORDER BY example

- ❖ List all students, sort them by GPA (descending) and name (ascending)

  -
    ```
    SELECT SID, name, age, GPA
    FROM Student
    ORDER BY GPA 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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Summary of 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, …