SQL: Part I

CPS 216

Advanced Database Systems

Announcements (January 20)

- Reading assignment for this week (Ailamaki et al., *VLDB* 2001) has been posted
  - Due Wednesday night
  - Hunt for related/follow-up work too!
- Course project will be assigned this Thursday
- Student presentation sign-up sheet will be circulated this Thursday
  - Allows you to drop your lowest homework grade
- Homework #1 due in two weeks

SQL

- SQL: Structured Query Language
  - Pronounced "S-Q-L" or "sequel"
  - The standard query language support by most commercial DBMS
- A brief history
  - IBM System R
  - ANSI SQL89
  - ANSI SQL92 (SQL2)
  - SQL3 (still under construction after years!)

Creating and dropping tables

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

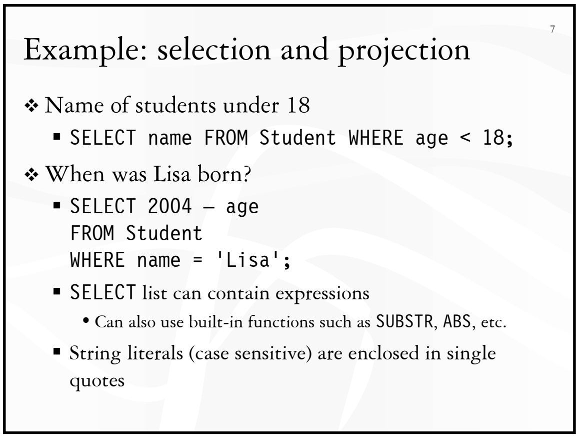
```
create table Student (SID integer,
                      name varchar(30), email varchar(30),
                      age integer, GPA float);
create table Course (CID char(10), title varchar(100));
create table Enroll (SID integer, CID char(10));
drop table Student;
drop table Course;
drop table Enroll;
-- everything from -- to the end of the line is ignored.
-- SQL is insensitive to white space.
-- SQL is case insensitive (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
- Equivalent (not really!) to relational algebra query
  $\pi_{A_1, A_2, \ldots, A_n} (\sigma_{condition} (R_1 \times R_2 \times \ldots \times R_m))$

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"



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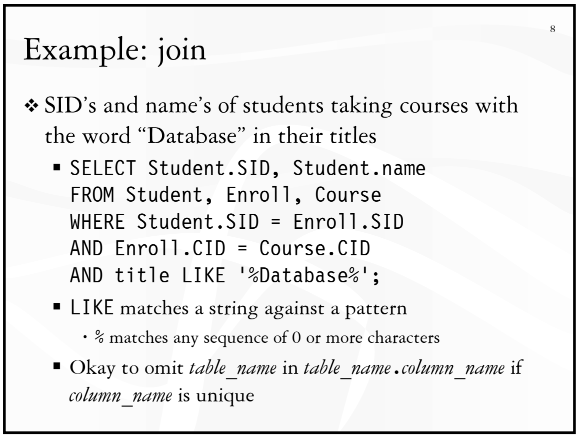
Example: selection and projection

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

  -
    ```
    SELECT 2004 – 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



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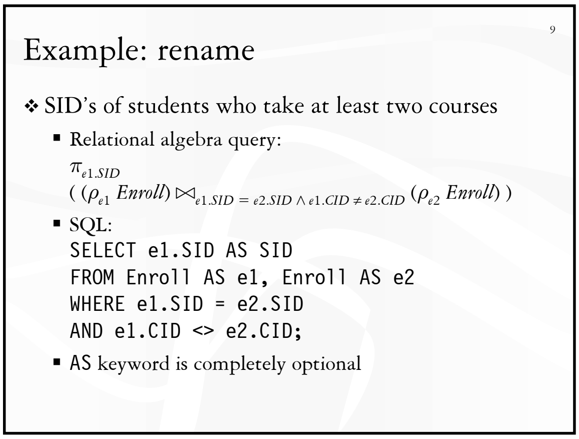
Example: join

- SID's and name's 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



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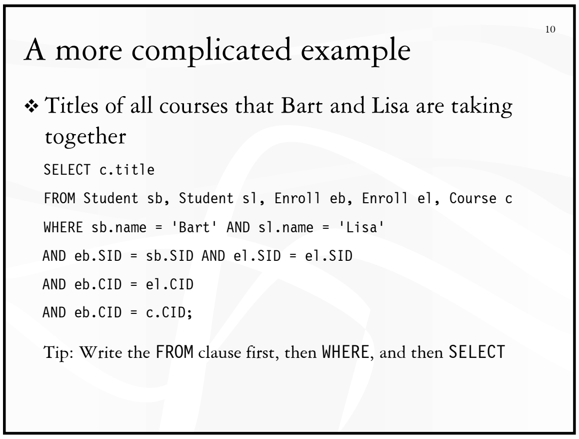
Example: rename

- SID's of students who take at least two courses
  - Relational algebra query:

    $\pi_{e1.SID}$

    $((\rho_{e1}\ Enroll) \bowtie_{e1.SID = e2.SID \wedge e1.CID \neq e2.CID} (\rho_{e2}\ Enroll))$
  - SQL:
    ```
    SELECT e1.SID AS SID
    FROM Enroll AS e1, Enroll AS e2
    WHERE e1.SID = e2.SID
    AND e1.CID <> e2.CID;
    ```
  - `AS` keyword is completely optional



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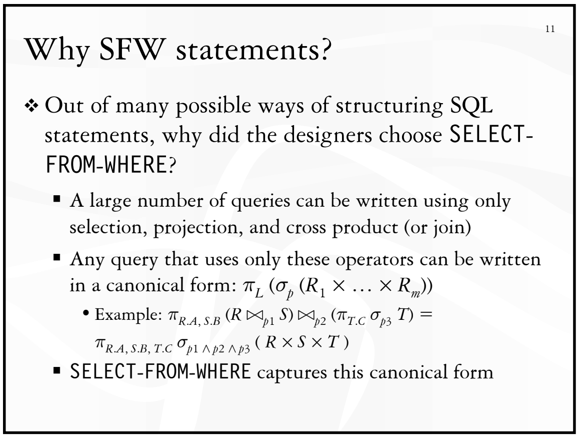
A more complicated example

- 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 = el.SID
AND eb.CID = el.CID
AND eb.CID = c.CID;
```

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



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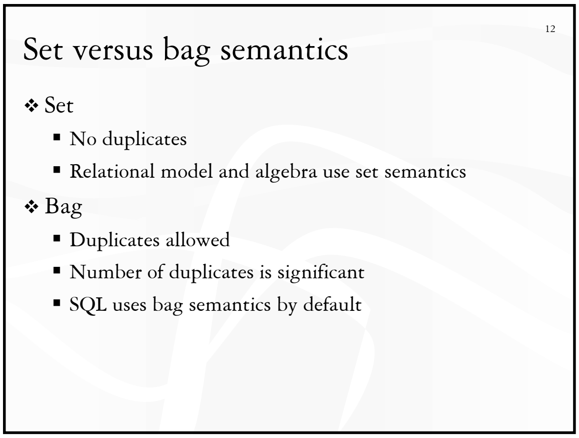
Why SFW statements?

- 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: $\pi_L (\sigma_p (R_1 \times \ldots \times R_m))$
    - Example: $\pi_{R.A, S.B} (R \bowtie_{p1} S) \bowtie_{p2} (\pi_{T.C}\, \sigma_{p3}\, T) = \pi_{R.A, S.B, T.C}\, \sigma_{p1 \wedge p2 \wedge p3} (R \times S \times T)$
  - `SELECT-FROM-WHERE` captures this canonical form



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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	CPS216
142	CPS214
123	CPS216
857	CPS216
857	CPS230
456	CPS214
...	...

π_{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?
  - π_{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

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 $t_1$ 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 $E_1, E_2, …, E_n$
If DISTINCT is present
    Eliminate duplicate rows in output
```

- ❖ t_1, t_2, ..., t_m are often called tuple variables

Example: forcing set semantics

- ❖ SID's of students who take at least two courses

  -
    ```
    SELECT e1.SID AS SID
    FROM Enroll AS e1, Enroll AS e2
    WHERE e1.SID = e2.SID
    AND e1.CID <> e2.CID;
    ```
    - What if Bart takes CPS216 and CPS214?
    - Changing `<>` to `>` may help in this case
    - But what if Bart takes CPS216, CPS214, and CPS230?

  -
    ```
    SELECT DISTINCT e1.SID AS SID
    ...
    ```
    - Duplicate `SID` values are removed from the output

SQL set and bag operations

- ❖ `UNION`, `EXCEPT`, `INTERSECT`
  - Set semantics
  - 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

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

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;
```

Summary of SQL features covered so far

❖ Basic `CREATE/DROP TABLE`

❖ `SELECT-FROM-WHERE` statements (select-project-join queries)

❖ Set and bag operations

❖ Nesting queries using table expressions

☞ So far, not much more than relational algebra

☞ Next: aggregation

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

GROUP BY

❖ `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

`SELECT … FROM … WHERE … GROUP BY …;`

❖ Compute `FROM` (×)

❖ Compute `WHERE` (σ)

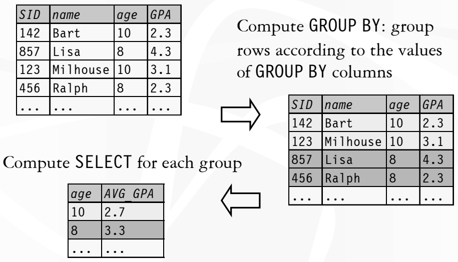
❖ Compute `GROUP BY`: group rows according to the values of `GROUP BY` columns

❖ Compute `SELECT` for each group (π)

☞One output row per group in the final output

Example of computing GROUP BY

```
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

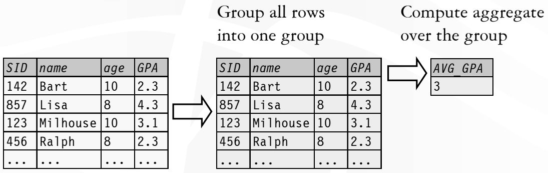
SID	name	age	GPA
142	Bart	10	2.3
123	Milhouse	10	3.1
857	Lisa	8	4.3
456	Ralph	8	2.3
...	...	...	...

Compute SELECT for each group

age	AVG_GPA
10	2.7
8	3.3
...	...

Aggregates with no GROUP BY

- ❖ An aggregate query with no GROUP BY clause represent a special case where all rows go into one group
  `SELECT AVG(GPA) FROM Student;`



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

Group all rows into one 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
...	...	...	...

Compute aggregate over the group

AVG_GPA
3

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 any SELECT expression produces only one value for each group

Examples of invalid queries

- ❖ `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

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

- ❖ 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

Summary of SQL features covered so far

- Basic `CREATE`/`DROP TABLE`
- `SELECT-FROM-WHERE` statements
- Set and bag operations
- Table expressions
- Aggregation and grouping
  - More expressive power than relational algebra

☞ Next: `NULL`'s

Incomplete information

- Example: *Student* (*SID*, *name*, *age*, *GPA*)
- Value unknown
  - We do not know Nelson's age
- Value not applicable
  - Nelson has not taken any classes yet; what is his GPA?

Solution 1

- A dedicated special value for each domain (type)
  - GPA cannot be –1, so use –1 as a special value to indicate a missing or invalid GPA
  - Leads to incorrect answers if not careful
    - `SELECT AVG(GPA) FROM Student;`
  - Complicates applications

    -
      ```
      SELECT AVG(GPA) FROM Student
      WHERE GPA <> -1;
      ```
  - Remember the pre-Y2K bug?
    - 09/09/99 was used as a missing or invalid date value

Solution 2

- A valid-bit for every column
  - *Student* (*SID*, *name*, *name_is_valid*,
age, *age_is_valid*,
GPA, *GPA_is_valid*)
  - Still complicates applications

    -
      ```
      SELECT AVG(GPA) FROM Student
      WHERE GPA_is_valid;
      ```

SQL's solution

- A special value `NULL`
  - Same for every domain
  - Special rules for dealing with `NULL`'s
- Example: *Student* (*SID*, *name*, *age*, *GPA*)
  - ⟨ 789, "Nelson", `NULL`, `NULL` ⟩

Rules for `NULL`'s

- When we operate on a `NULL` and another value (including another `NULL`) using +, –, etc., the result is `NULL`
- Aggregate functions ignore `NULL`, except `COUNT(*)` (since it counts rows)

Three-valued logic

- When we compare a NULL with another value (including another NULL) using =, >, etc., the result is UNKNOWN
- TRUE = 1, FALSE = 0, UNKNOWN = 0.5
- x AND y = min(x, y)
- x OR y = max(x, y)
- NOT x = 1 – x
- WHERE and HAVING clauses only select rows for output if the condition evaluates to TRUE
  - UNKNOWN is insufficient

Unfortunate consequences

- SELECT AVG(GPA) FROM Student;
  SELECT SUM(GPA)/COUNT(*) FROM Student;
  - Not equivalent
  - Although AVG(GPA) = SUM(GPA)/COUNT(GPA) still
- SELECT * FROM Student;
  SELECT * FROM Student WHERE GPA = GPA;
  - Not equivalent

☞ Be careful: NULL breaks many equivalences

Another problem

- Example: Who has NULL GPA values?
  - SELECT * FROM Student WHERE GPA = NULL;
    - Does not work; never returns anything
  - (SELECT * FROM Student)
    EXCEPT ALL
    (SELECT * FROM Student WHERE GPA = GPA)
    - Works, but ugly
  - Introduced built-in predicates IS NULL and IS NOT NULL
    - SELECT * FROM Student WHERE GPA IS NULL;

Summary of SQL features covered so far

- Basic CREATE/DROP TABLE
- SELECT-FROM-WHERE statements
- Set and bag operations
- Table expressions
- Aggregation and grouping
- NULL's

☞ Next: subqueries, modifications, constraints, and views