# SQL: Part I

CPS 116

Introduction to Database Systems



## Announcements (September 15)

- Homework #1 due tonight
  - Sample solution available next Tuesday
- Homework #2 out next Tuesday
- Project Milestone #1 due in 28 days
  - Come to my office hours if you want to chat about project ideas
- TA out of town until September 26



## 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)
  - ANSI SQL99 (SQL3)
  - ANSI SQL 2003 (+OLAP, XML, etc.)

## Creating and dropping tables

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- 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

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- 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

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- 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

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- Name of students under 18
  - `SELECT name FROM Student WHERE age < 18;`
- When was Lisa born?
  - ```
    SELECT 2005 – 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

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- 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

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- SID's of all pairs of classmates
  - Relational algebra query:

    $\pi_{e1.SID,\ e2.SID}$
    $( \rho_{e1}\ Enroll \bowtie_{e1.CID\ =\ e2.CID \wedge\ e1.SID\ >\ e2.SID}\ \rho_{e2}\ Enroll\ )$
  - 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: $\pi_L (\sigma_p (R_1 \times \ldots \times R_m))$
    - 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

## 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

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*Enroll*

| *SID* | *CID* |
|---|---|
| 142 | CPS196 |
| 142 | CPS114 |
| 123 | CPS196 |
| 857 | CPS196 |
| 857 | CPS130 |
| 456 | CPS114 |
| … | … |

$\pi_{SID}$ *Enroll*

| *SID* |
|---|
| 142 |
| 123 |
| 857 |
| 456 |
| … |

```
SELECT SID
FROM Enroll;
```

| *SID* |
|---|
| 142 |
| 142 |
| 123 |
| 857 |
| 857 |
| 456 |
| … |

## A case for bag semantics

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- Efficiency
- Which one is more useful?
  - $\pi_{GPA}$ *Student*
  - `SELECT GPA FROM Student;`
- Besides, SQL provides the option of set semantics with `DISTINCT` keyword

## Operational semantics of SFW

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- `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

## Example: forcing set semantics

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

## SQL set and bag operations

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- `UNION`, `EXCEPT`, `INTERSECT`
  - Set semantics
    - Duplicates in input tables, if any, are first eliminated
  - 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

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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

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- *Enroll*(*SID*, *CID*), *ClubMember*(*club*, *SID*)
  - ```
    (SELECT SID FROM ClubMember)
    EXCEPT
    (SELECT SID FROM Enroll);
    ```
  - ```
    (SELECT SID FROM ClubMember)
    EXCEPT ALL
    (SELECT SID FROM Enroll);
    ```

## Summary of SQL features covered so far

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

☞ Next: how to nest SQL queries

## Table expression

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- 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?

- What if subquery returns no rows?
  - The value returned is `NULL` and the comparison fails

## `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));
```
```

## Quantified subqueries

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- 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 the result of *subquery* such that *x op t*
  - ☞Beware
    - In common parlance, "any" and "all" seem to be synonyms
    - In SQL, `ANY` really means "some"

## Examples of quantified subqueries

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- 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

## More ways of getting the highest GPA

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- Which students have the highest GPA?

## Summary of SQL features covered so far

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- 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

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- 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

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- 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



- `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` ($\times$)
- 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(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

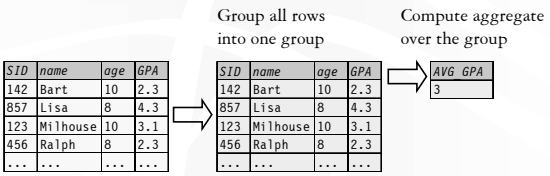
| *age* | *AVG GPA* |
|---|---|
| 10 | 2.7 |
| 8 | 3.3 |
| ... | ... |

## 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;
```




## 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

## 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` ($\times$)
  - Compute `WHERE` ($\sigma$)
  - Compute `GROUP BY`: group rows according to the values of `GROUP BY` columns
  - Compute `HAVING` (another $\sigma$ over the groups)
  - Compute `SELECT` ($\pi$) 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



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

☞ Next: ordering output rows

## ORDER BY

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- 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

## ORDER BY example

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- 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 of output columns instead
    ORDER BY 4 DESC, 2;

## Summary of SQL features covered so far

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

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