Relational Languages:

Recap of ICS 324

Lecture objectives

- Briefly mention relational languages covered in ICS 334
  - Relational Algebra
  - SQL

- Relational Languages

- Relational Algebra
  - Relational Operators
  - Selection
  - Projection
  - Cross product
  - Join
  - Natural Join
  - Union
  - Difference
  - Intersection
  - Renaming
  - Summary
- SQL

-- Input relations

Student

SID	name	Age	GPA
111	Mustafa	17	3.2
222	Ali	17	2.8
333	Ahmed	22	2.5
444	Lutfi	20	3.5
….	….	….	….
….	….	….	….

Enroll

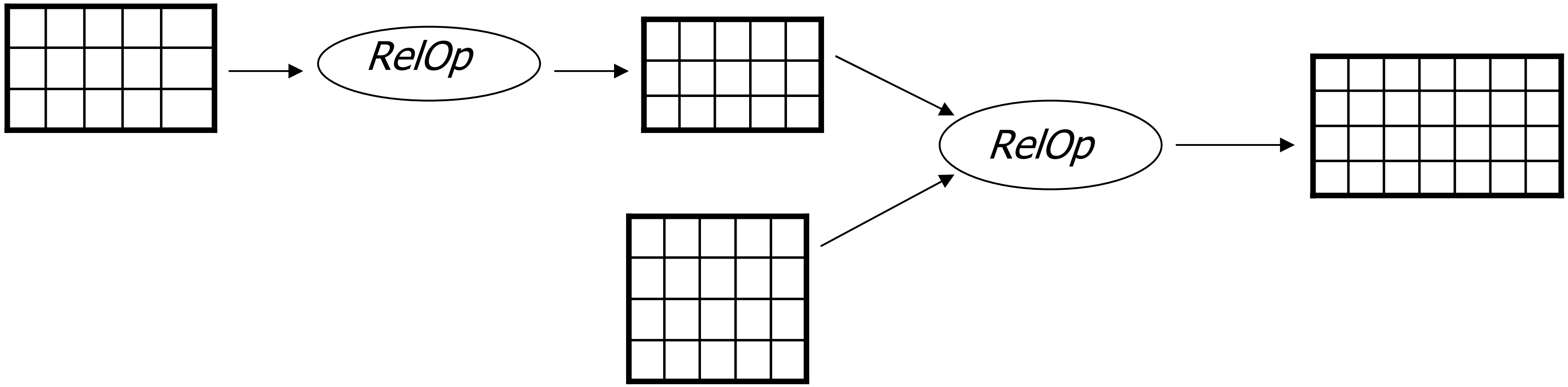
SID	CID
111	ICS 102
222	ICS 434
222	ICS 431
333	ICS 334
333	ICS 431
444	ICS 102
…..	……
…..	….

Course

CID	Title
ICS 102	Java
ICS 202	Data structures
ICS 434	Advanced Databases
ICS 334	Databases
ICS 431	Operating Systems
…..	……
……	……

-- Relational algebra operators

- Relational algebra is notation for operations on relations, like constructing new relations and defining queries on relations.
- Very important for query optimization.
- Core set of operators:
  - Selection, projection, cross product, union, difference, and, renaming
- Additional, derived operators:
  - Join, natural join, intersection, etc.



--- Selection …

- Input: a table *R*
- Notation: $\sigma_p(R)$
  - *p* is called a selection condition/predicate
- Purpose: filter rows according to some criteria
- Output: same columns as *R*, but only rows of *R* that satisfy *p*

… --- Selection …

- Example
  - Students with GPA higher than 3.0

$$\sigma_{GPA > 3.0}\,(\mathit{Student})$$

SID	name	Age	GPA
111	Mustafa	17	3.2
222	Ali	17	2.8
333	Ahmed	22	2.5
444	Lutfi	20	3.5
….	….	….	….

$$\longrightarrow \sigma_{GPA > 3.0} \longrightarrow$$

SID	name	YOB	GPA
111	Mustafa	1985	3.2
444	Lutfi	1984	3.5
….	….	….	….

… --- Selection

- Selection predicate in general can include any column of *R*, constants, comparisons such as =, ≤, etc., and Boolean connectives V, Λ, and ¬
- Example: List all A students under 18 or over 20

$$\sigma_{GPA \geq 4.0 \wedge (age < 18 \vee age > 20)} (Student)$$

- But you must be able to evaluate the predicate over a single row
- Example: student with the highest GPA

$$\cancel{\sigma_{GPA \geq \text{all } GPA} (Student)}$$

--- Projection …

- Input: a table R
- Notation: $\Pi_L (R)$
  - L is a list of columns in R
- Purpose: select columns to output
- Output: same rows, but only the columns in L. Duplicate output rows are removed.

… --- Projection

- Example:
  - ID's and names of all students

$$\Pi_{SID,\ name}\ (\ Student\ )$$

SID	name	Age	GPA
111	Mustafa	17	3.2
222	Ali	17	2.8
333	Ahmed	22	2.5
444	Lutfi	20	3.5
….	….	….	….

$\longrightarrow \Pi_{SID,\ name} \longrightarrow$

SID	name
111	Mustafa
222	Ali
333	Ahmed
444	Lutfi
….	….

--- Cross product …

- Input: two tables R and S
- Notation: $R \times S$
- Purpose: pairs rows from two tables
- Output: for each row r in R and each row s in S, output a row rs (concatenation of r and s)
  - The ordering of columns in a table is considered unimportant (as is the ordering of rows)
  - That means cross product is commutative, i.e., $R \times S = S \times R$ for any R and S

… --- Cross product

- Example: *Student* × *Enroll*

Enroll

SID	CID
111	ICS 102
222	ICS 434
222	ICS 431
333	ICS 334
333	ICS 431
444	ICS 102
…..	….

Student

SID	name	Age	GPA
111	Mustafa	17	3.2
222	Ali	17	2.8
333	Ahmed	22	2.5
444	Lutfi	20	3.5
….	….	….	….

X

SID	Name	Age	GPA	SID	CID
111	Mustafa	17	3.2	111	ICS 102
111	Mustafa	17	3.2	222	ICS 434
111	Mustafa	17	3.2	222	ICS 431
111	Mustafa	17	3.2	333	ICS 334
….	….	….			….

--- Join

- Input: two tables R and S
- Notation: $R \bowtie_p S$
  - p is called a join condition/predicate
- Purpose: relate rows from two tables according to some criteria
- Output: for each row r in R and each row s in S, output a row rs if r and s satisfy
- Shorthand for $\sigma_p (R \times S)$

… --- Join

- Example: Info about students, plus CID's of their courses

$$Student \bowtie_{Student.SID = Enroll.SID} Enroll$$

Student

SID	name	Age	GPA
111	Mustafa	17	3.2
222	Ali	17	2.8
333	Ahmed	22	2.5
444	Lutfi	20	3.5
….	….	….	….

Enroll

SID	CID
111	ICS 102
222	ICS 434
222	ICS 431
333	ICS 334
333	ICS 431
444	ICS 102
…..	….

$\bowtie_{Student.SID = Enroll.SID}$

SID	Name	Age	GPA	SID	CID
111	Mustafa	17	3.2	111	ICS 102
222	Ali	17	2.8	222	ICS 434
222	Ali	17	2.8	222	ICS 431
333	Ahmed	22	2.5	333	ICS 334
….	….	….			….

--- Natural Join

- Input: two tables *R* and *S*
- Notation: $R \bowtie S$
- Purpose: relate rows from two tables, and
  - Enforce equality on all common attributes
  - Eliminate one copy of common attributes
- Shorthand for $\Pi_L (R \bowtie_p S)$
  - *L* is the union of all attributes from *R* and *S*, with duplicates removed
  - *p* equates all attributes common to *R* and *S*

… --- Natural Join

- Example: Info about students, plus CID's of their courses

  Student $\bowtie$ *Enroll*

Student

SID	name	Age	GPA
111	Mustafa	17	3.2
222	Ali	17	2.8
333	Ahmed	22	2.5
444	Lutfi	20	3.5
….	….	….	….

Enroll

SID	CID
111	ICS 102
222	ICS 434
222	ICS 431
333	ICS 334
333	ICS 431
444	ICS 102
…..	….

$\bowtie$

SID	Name	Age	GPA	CID
111	Mustafa	17	3.2	ICS 102
222	Ali	17	2.8	ICS 434
222	Ali	17	2.8	ICS 431
333	Ahmed	22	2.5	ICS 334
….	….	….		….

--- Union

- Input: two tables R and S
- Notation: $R \cup S$
  - R and S must have identical schema
- Output:
  - Has the same schema as R and S
  - Contains all rows in R and all rows in S, with duplicates eliminated

--- Difference

- Input: two tables R and S
- Notation: $R - S$
  - R and S must have identical schema
- Output:
  - Has the same schema as R and S
  - Contains all rows in R that are not found in S

--- Intersection

- Input: two tables R and S
- Notation: $R \cap S$
  - R and S must have identical schema
- Output:
  - Has the same schema as R and S
  - Contains all rows that are in both R and S
- Shorthand for $R - (R - S)$
- Also equivalent to $S - (S - R)$
- And to $R \bowtie S$

--- Renaming

- Input: a table R
- Notation: $\rho_S(R)$, or $\rho_{S(A1, A2, \ldots)}(R)$
- Purpose: rename a table and/or its columns
- Output: a renamed table with the same rows as R
- Used to
  - Avoid confusion caused by identical column names
  - Create identical columns names for natural joins

--- Summary of Relational Algebra Operators

- Core
  - Selection: $\sigma_{p}(R)$
  - Projection: $\Pi_{L}(R)$
  - Cross product: $R \times S$
  - Union: $R \cup S$
  - Difference: $R - S$
  - Renaming: $\rho_{S(A1, A2, \ldots)}(R)$
- Derived
  - Join: $R \bowtie_{p} S$
  - Natural join: $R \bowtie S$
  - Intersection: $R \cap S$
  - Many more: Semijoin, anti-semijoin, quotient, aggregation, …

-- SQL

- Definition
- Basic CREATE/DROP TABLE
- INSERT
- DELETE
- UPDATE
- SELECT
- Set and bag operations
- Aggregation and grouping
- NULL’s
- SQL Constraints
- Others

--- Definition

- SQL: Structured Query Language
- Pronounced “S-Q-L” or “sequel”
- The standard query language support by most commercial DBMS

--- Creating and dropping tables

- CREATE TABLE *table_name* (…, *column_namei column_typei*, …);
- 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...)

--- INSERT

- Insert one row
- INSERT INTO Enroll VALUES (111, 'ICS334');
  - Student 111 takes ICS 334

- Insert the result of a query
- INSERT INTO Enroll
  (SELECT SID, 'ICS334' FROM Student
  WHERE SID NOT IN (SELECT SID FROM Enroll
  WHERE CID = 'ICS334'));
  - Force everybody to take ICS 334

--- DELETE

- Delete everything
- `DELETE FROM Enroll;`
- Delete according to a WHERE condition
- Example: Student 111 drops ICS 334
- ```
  DELETE FROM Enroll
  WHERE SID = 111 AND CID = 'ICS334';
  ```
- Example: Drop students with GPA lower than 1.0 from all ICS classes
- ```
  DELETE FROM Enroll
  WHERE SID IN (SELECT SID FROM Student
  WHERE GPA < 1.0)
  AND CID LIKE 'ICS%';
  ```

--- Update

- Example: Student 111 changes name to “Hazem” and GPA to 3.0
- ```
  UPDATE Student
  SET name = 'Hazem', GPA = 3.0
  WHERE SID = 111;
  ```
- Example: Assign every student average GPA
- ```
  UPDATE Student
  SET GPA = (SELECT AVG(GPA) FROM Student);
  ```
  - But update of every row causes average GPA to change!
  - Average GPA is computed over the old Student table

--- Select

- SELECT * FROM Student;
- Single-table query
- WHERE clause is optional
- * is a short hand for “all columns”
- Equivalent to: $\sigma_{SID, name, age, GPA}$ (Student)

--- Selection and Projection

- Name of students under 18

```
SELECT name
FROM Student
WHERE age < 18;
```

- When was Mustafa born?

```
SELECT 2006 – age
FROM Student
WHERE name = 'Mustafa';
```

- 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

--- 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

--- rename

- 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;
```

- AS keyword is completely optional

--- A more complicated example

- Titles of all courses that Ali and Mustafa are taking together

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

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

--- Set versus bag semantics

- 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 verses bag example

Enroll

SID	CID
111	ICS 102
222	ICS 434
222	ICS 431
333	ICS 334
333	ICS 431
444	ICS 102
.....	....

Π_{SID} *(Enroll)*

SID
111
222
333
444
.....

Set

Select SID
From Enroll

SID
111
222
222
333
333
444
.....

Bag

--- 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 SELECT

- SELECT [DISTINCT] *E*1, *E*2, …, *En*
  FROM *R*1, *R*2, …, *Rm*
  WHERE *condition*;

- For each *t*1 in *R*1:
  - For each *t*2 in *R*2: … …
    - For each *tm* in *Rm*:
      - If *condition* is true over *t*1, *t*2, …, *tm*:
        - Compute and output *E*1, *E*2, …, *En*

- If DISTINCT is present eliminate duplicate rows in output

- *t*1, *t*2, …, *tm* are often called tuple variables

--- SQL set and bag operations

- UNION, EXCEPT, INTERSECT
  - Set semantics
  - Exactly like set $\cup$, $-$, and $\cap$ 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 INTERSECT ALL Bag2

Fruit
Apple
Orange

Bag1 UNION ALL Bag2

Fruit
Apple
Apple
Orange
Apple
Orange
Orange

Bag1 EXCEPT ALL Bag2

Fruit
Apple

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

--- 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 example

- 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

--- 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)
- When we compare a NULL with another value (including another NULL) using =, >, etc., the result is UNKNOWN.
- 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;`
  ```

--- SQL constraints

- NOT NULL
- Key
- Referential integrity (foreign key)
- CHECK

--- Example

- ```
  CREATE TABLE Student
  (SID INTEGER PRIMARY KEY,
  name VARCHAR(30) NOT NULL,
  email VARCHAR(30) UNIQUE,
  age INTEGER,
  GPA FLOAT);
  ```

- ```
  CREATE TABLE Course
  (CID CHAR(10) PRIMARY KEY,
  title VARCHAR(100) NOT NULL);
  ```

- ```
  CREATE TABLE Enroll
  (SID INTEGER NOT NULL,
  CID CHAR(10) NOT NULL,
  PRIMARY KEY(SID, CID));
  ```
  ```

--- Others

- Subqueries
  - Simple:
    - IN
  - Quantified
    - ALL
    - ANY
  - Coorelated
    - EXISTS
- Views
- Triggers
- Indexes

END of ICS 334