Database Systems
CSE 414

Lectures 8: Relational Algebra
(Ch. 2.4, & 5.1)

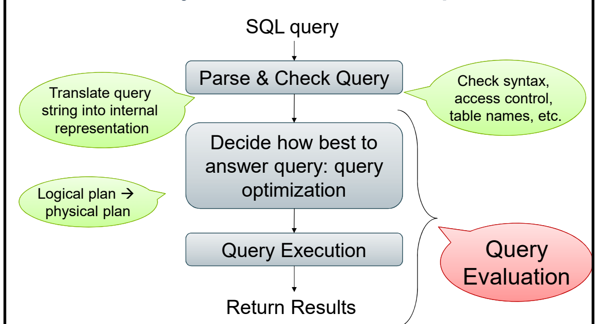
Announcements

- WQ4 is posted and due on Nov. 3, 11pm
- HW2 will be due next Monday 11pm
- Log into Azure web site using your outlook.com email address today if you have not done so already
  - Otherwise the TA cannot give you the Azure access code

Where We Are

- Motivation for using a DBMS for managing data
- SQL:
  - Declaring the schema for our data (CREATE TABLE)
  - Inserting data one row at a time or in bulk (INSERT/.import)
  - Modifying the schema and updating the data (ALTER/UPDATE)
  - Querying the data (SELECT)
- Next step: More knowledge of how DBMSs work
  - Client-server architecture
  - Relational algebra and query execution

Query Evaluation Steps



The WHAT and the HOW

- SQL = WHAT we want to get from the data
- Relational Algebra = HOW to get the data we want
- Move from WHAT to HOW is query optimization
  - SQL ~> Relational Algebra ~> Physical Plan
  - Relational Algebra = Logical Plan

Relational Algebra

Sets vs. Bags

- Sets: {a,b,c}, {a,d,e,f}, { }, . . .
- Bags: {a, a, b, c}, {b, b, b, b, b}, . . .

Relational Algebra has two semantics:

- Set semantics = standard Relational Algebra
- Bag semantics = extended Relational Algebra

DB systems implement bag semantics (Why?)

Relational Algebra Operators

- Union $\cup$, intersection $\cap$, difference -
- Selection σ
- Projection π (Π)
- Cartesian product $\times$, join $\bowtie$
- Rename ρ
- Duplicate elimination δ
- Grouping and aggregation γ
- Sorting τ

RA

Extended RA

Union and Difference

$\boxed{\begin{array}{l} R1 \cup R2 \\ R1 - R2 \end{array}}$

What do they mean over bags ?

What about Intersection ?

- Derived operator using minus

$\boxed{R1 \cap R2 = R1 - (R1 - R2)}$

- Derived using join (will explain later)

$\boxed{R1 \cap R2 = R1 \bowtie R2}$

Selection

- Returns all tuples that satisfy a condition

$\boxed{\sigma_c(R)}$

- Examples
  - $\sigma_{Salary > 40000}$ (Employee)
  - $\sigma_{name = \text{"Smith"}}$ (Employee)
- The condition c can be =, <, $\leq$, >, $\geq$, <> combined with AND, OR, NOT

Employee

SSN	Name	Salary
1234545	John	20000
5423341	Smith	60000
4352342	Fred	50000

$\sigma_{Salary > 40000}$ (Employee)

SSN	Name	Salary
5423341	Smith	60000
4352342	Fred	50000

Projection

- Eliminates columns

$\pi_{A1,\ldots,An}(R)$

- Example: project social-security number and names:
  - $\Pi_{SSN, Name}$ (Employee)
  - Answer(SSN, Name)

Different semantics over sets or bags! Why?

Employee

SSN	Name	Salary
1234545	John	20000
5423341	John	60000
4352342	John	20000

$\pi_{Name, Salary}$ (Employee)

Name	Salary
John	20000
John	60000
John	20000

Bag semantics

Name	Salary
John	20000
John	60000

Set semantics

Which is more efficient?

Composing RA Operators

Patient

no	name	zip	disease
1	p1	98125	flu
2	p2	98125	heart
3	p3	98120	lung
4	p4	98120	heart

$\pi_{zip, disease}$(Patient)

zip	disease
98125	flu
98125	heart
98120	lung
98120	heart

$\sigma_{disease='heart'}$(Patient)

no	name	zip	disease
2	p2	98125	heart
4	p4	98120	heart

$\pi_{zip, disease}(\sigma_{disease='heart'}$(Patient))

zip	disease
98125	heart
98120	heart

Cartesian Product

- Each tuple in R1 with each tuple in R2

$R1 \times R2$

- Rare in practice; mainly used to express joins

Cross-Product Example

Employee

Name	SSN
John	999999999
Tony	777777777

Dependent

EmpSSN	DepName
999999999	Emily
777777777	Joe

Employee × Dependent

Name	SSN	EmpSSN	DepName
John	999999999	999999999	Emily
John	999999999	777777777	Joe
Tony	777777777	999999999	Emily
Tony	777777777	777777777	Joe

Renaming

- Changes the schema, not the instance

$\rho_{B1,\ldots,Bn}(R)$

- Example:
  - $\rho_{N, S}$(Employee) → Answer(N, S)

Not really used by systems, but needed on paper

Natural Join

$R1 \bowtie R2$

- Meaning: $R1 \bowtie R2 = \pi_A(\sigma_\theta(R1 \times R2))$
- Where:
  - Selection σ checks equality of all common attributes (attributes with same names)
  - Projection π eliminates duplicate common attributes

Natural Join Example

R

A	B
X	Y
X	Z
Y	Z
Z	V

S

B	C
Z	U
V	W
Z	V

$R \bowtie S$ = $\pi_{A,B,C}(\sigma_{R.B=S.B}(R \times S))$

A	B	C
X	Z	U
X	Z	V
Y	Z	U
Y	Z	V
Z	V	W

Natural Join Example 2

AnonPatient P

age	zip	disease
54	98125	heart
20	98120	flu

Voters V

name	age	zip
p1	54	98125
p2	20	98120

$P \bowtie V$

age	zip	disease	name
54	98125	heart	p1
20	98120	flu	p2

Natural Join

- Given schemas R(A, B, C, D), S(A, C, E), what is the schema of $R \bowtie S$?
  - (A, B, C, D, E) through join on (A, C)
- Given R(A, B, C), S(D, E), what is $R \bowtie S$?
  - (A, B, C, D, E) through cross product
- Given R(A, B), S(A, B), what is $R \bowtie S$?
  - (A, B) through intersection

AnonPatient (age, zip, disease)
Voters (name, age, zip)

Theta Join

- A join that involves a predicate

$$R1 \bowtie_\theta R2 \;=\; \sigma_\theta(R1 \times R2)$$

- Here θ can be any condition
- For our voters/patients example:

$P \bowtie_{\text{P.zip = V.zip and P.age >= V.age -1 and P.age <= V.age +1}} V$

Equijoin

- A theta join where θ is an equality predicate
- By far the most used variant of join in practice

Equijoin Example

AnonPatient P

age	zip	disease
54	98125	heart
20	98120	flu

Voters V

name	age	zip
p1	54	98125
p2	20	98120

$P \bowtie_{P.age=V.age} V$

P.age	P.zip	P.disease	P.name	V.zip	V.age
54	98125	heart	p1	98125	54
20	98120	flu	p2	98120	20

Join Summary

- **Theta-join**: $R \bowtie_\theta S = \sigma_\theta(R \times S)$
  - Join of R and S with a join condition θ
  - Cross-product followed by selection θ
- **Equijoin**: $R \bowtie_\theta S = \sigma_\theta(R \times S)$
  - Join condition θ consists only of equalities
- **Natural join**: $R \bowtie S = \pi_A (\sigma_\theta(R \times S))$
  - Equijoin
  - Equality on **all** fields with same name in R and in S
  - Projection π_A drops all redundant attributes

So Which Join Is It ?

When we write $R \bowtie S$, we usually mean an equijoin, but we often omit the equality predicate when it is clear from the context

More Joins

- **Outer join**
  - Include tuples with no matches in the output
  - Use NULL values for missing attributes
  - Does not eliminate duplicate columns
- Variants
  - Left outer join
  - Right outer join
  - Full outer join

Outer Join Example

AnonPatient P

age	zip	disease
54	98125	heart
20	98120	flu
33	98120	lung

AnnonJob J

job	age	zip
lawyer	54	98125
cashier	20	98120

$P ⟕ J$

P.age	P.zip	disease	job	J.age	J.zip
54	98125	heart	lawyer	54	98125
20	98120	flu	cashier	20	98120
33	98120	lung	null	null	null

More Examples

```
Supplier(sno, sname, scity, sstate)
Part(pno, pname, psize, pcolor)
Supply(sno, pno, qty, price)
```

Name of supplier of parts with size greater than 10
$\pi_{sname}(\text{Supplier} \bowtie \text{Supply} \bowtie (\sigma_{psize>10}\ (\text{Part}))$

Name of supplier of red parts or parts with size greater than 10
$\pi_{sname}(\text{Supplier} \bowtie \text{Supply} \bowtie (\sigma_{psize>10}\ (\text{Part}) \cup \sigma_{pcolor='red'}\ (\text{Part})\ )\ )$