Introduction to Data Management CSE 344

Lectures 8: Relational Algebra

Announcements

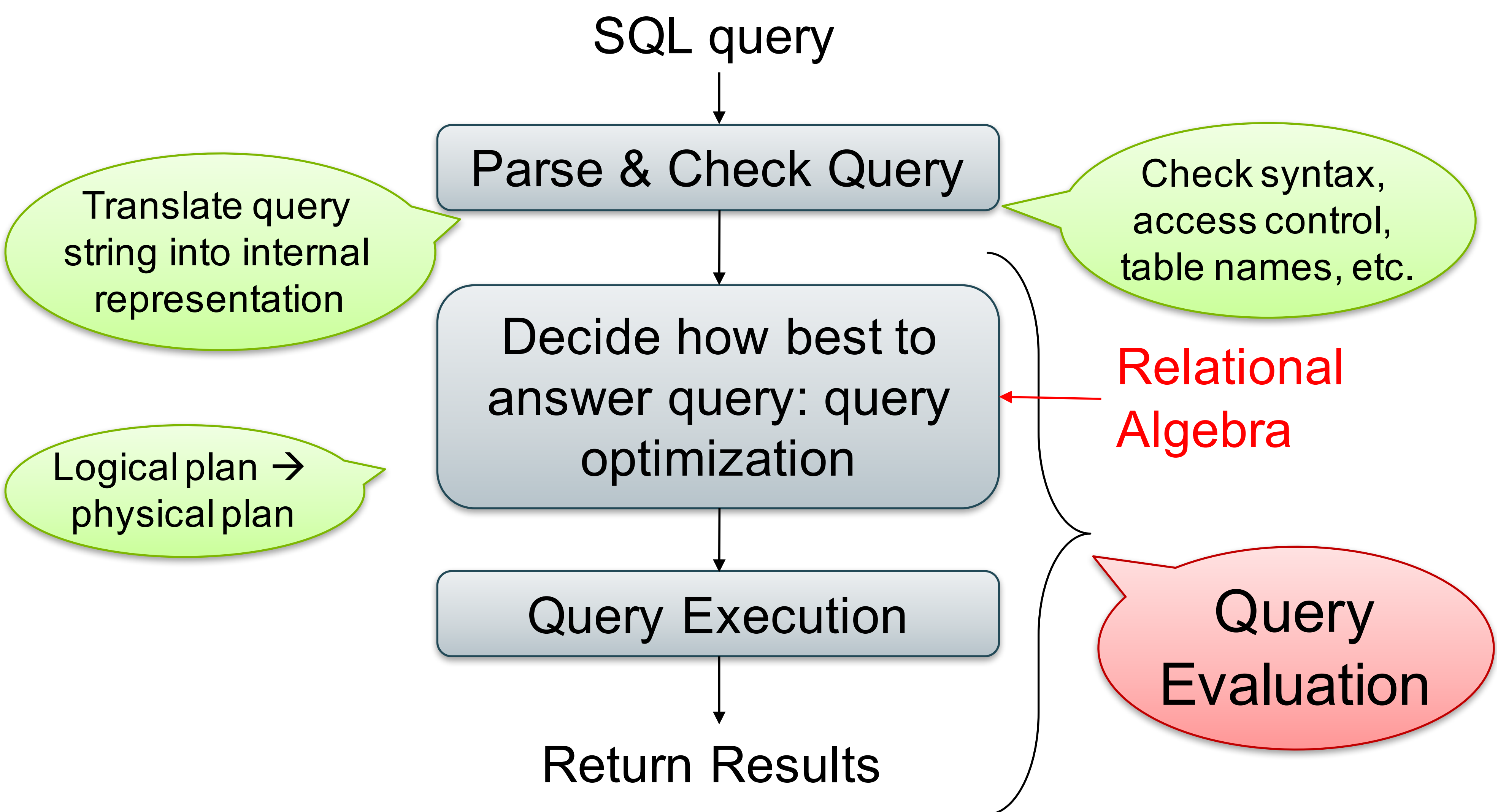
- Homework 3 is posted
  - Microsoft Azure Cloud services!
  - Use the promotion code you received
  - Due on 2/1
- Make sure you read the textbook!
  - Very good coverage of RA

Where We Are

- Data models
- SQL, SQL, SQL
  - Declaring the schema for our data (CREATE TABLE)
  - Inserting data one row at a time or in bulk (INSERT/.import)
  - Querying the data (SELECT)
  - Modifying the schema and updating the data (ALTER/UPDATE)

- Next step: More knowledge of how DBMSs work
  - Relational algebra, query execution, and physical tuning
  - Client-server architecture

Query Evaluation Steps



The WHAT and the HOW

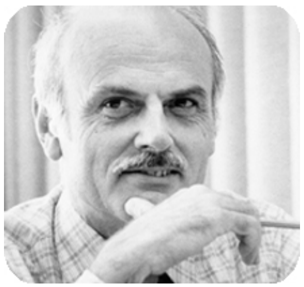
- SQL = WHAT we want to get from the data
- Relational Algebra = HOW to get the data we want
- The passage from WHAT to HOW is called query optimization
  - SQL → Logical Plan → Physical Plan
  - Logical plan expressed using relational algebra

Relational Algebra

Turing Awards in Data Management

Charles Bachman, 1973

IDS and CODASYL



Ted Codd, 1981

Relational model

Jim Gray, 1998

Transaction processing

Michael Stonebraker, 2014

INGRES and Postgres

Sets v.s. 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
- Cartesian product X, join $\bowtie$
- Rename ρ
- Duplicate elimination δ
- Grouping and aggregation γ
- Sorting τ

RA

Extended RA

All operators take in 1 or more relations as inputs and return another relation

Union and Difference

$R1 \cup R2$

$R1 - R2$

What do they mean over bags ?

What about Intersection ?

- Derived operator using minus

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

  - Only makes sense if result is ≥ 0

- Derived using join

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

  - Only makes sense if R1 and R2 have the same schema

Selection

- Returns all tuples which satisfy a condition

$$\boxed{\sigma_c(R)}$$

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

Employee

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

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

SSN	Name	Salary
5423341	Smith	60000
4352342	Fred	50000

Projection

- Eliminates columns

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

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

Different semantics over sets or bags! Why?

Employee

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

$\pi_{\text{Name,Salary}}$ (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

$$\boxed{R1 \times R2}$$

- 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 X 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

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

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

Not really used by systems, but needed on paper

Natural Join

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

- Meaning: $R1 \bowtie R2 = \Pi_A(\sigma_\theta (R1 \times R2))$
- Where:
  - Selection σ_θ checks equality of all common attributes (i.e., attributes with same names)
  - Projection Π_A 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 ⋈ S =

$\Pi_{ABC}(\sigma_{R.B=S.B}(R \times S))$

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

join predicate :

P.age = V.age

AND

P.zip = V.zip

Natural Join

- Given schemas R(A, B, C, D), S(A, C, E), what is the schema of R $\bowtie$ S ?

- Given R(A, B, C), S(D, E), what is R $\bowtie$ S?

- Given R(A, B), S(A, B), what is R $\bowtie$ S?

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

Theta Join

- A join that involves a predicate

$$\boxed{R1 \bowtie_{\theta} R2 \;=\; \sigma_{\theta}\,(R1 \times R2)}$$

- Here θ can be any condition
- No projection in this case!
- For our voters/patients example:

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

Equijoin

- A theta join where θ is an equality predicate
- Projection drops all redundant attributes

$$\boxed{R1 \bowtie_{\theta} R2 \quad = \pi_{A}(\sigma_{\theta} (R1 \text{ X } R2))}$$

- By far the most used variant of join in practice
- What is the relationship with natural join?

Equijoin Example

AnonPatient P

age	zip	disease
54	98125	heart
20	98120	flu

Voters V

name	age	zip
p1	54	98125
p2	20	98120

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

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

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**: $R \bowtie_{\theta} S = \pi_A(\sigma_{\theta}(R \times S))$
  - Join condition θ consists only of equalities
  - Projection π_A drops all redundant attributes
- **Natural join**: $R \bowtie S = \pi_A(\sigma_{\theta}(R \times S))$
  - 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	33	98120

⟕ LOJ

⟖ ROJ

⟗ FOJ

Some 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

$\pi_{sname}(\text{Supplier} \bowtie \text{Supply} \bowtie (\sigma_{psize>10} (\text{Part}) \cup \sigma_{pcolor='red'} (\text{Part})))$

Can be represented as trees as well (as seen from last class)