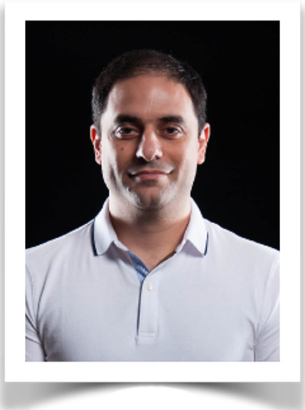
Relational Algebra

Chapter 4

ECS 165A – Winter 2022



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Relational Query Languages

- *Query languages*: Allow manipulation and retrieval of data from a database.
- Relational model supports simple, powerful QLs:
  - Strong formal foundation based on logic.
  - Allows for much optimization.
- Query Languages != programming languages!
  - QLs not expected to be "Turing complete".
  - QLs not intended to be used for complex calculations.
  - QLs support easy, efficient access to large data sets.

Formal Relational Query Languages

- Two mathematical Query Languages form the basis for "real" languages (e.g. SQL), and for implementation:
  - *Relational Algebra*: More operational, very useful for representing execution plans.
  - *Relational Calculus*: Lets users describe what they want, rather than how to compute it. (Non-operational, *declarative*.)

Preliminaries

- A query is applied to *relation instances*, and the result of a query is also a relation instance.
  - *Schemas* of input relations for a query are fixed (but query will run regardless of instance!)
  - The schema for the *result* of a given query is also fixed! Determined by definition of query language constructs.

Example Instances

"Sailors" and "Reserves" relations for our examples.

S1

sid	sname	rating	age
22	dustin	7	45.0
31	lubber	8	55.5
58	rusty	10	35.0

R1

sid	bid	day
22	101	10/10/96
58	103	11/12/96

S2

sid	sname	rating	age
28	yuppy	9	35.0
31	lubber	8	55.5
44	guppy	5	35.0
58	rusty	10	35.0

Relational Algebra

- Basic operations:
  - *Selection* (σ) Selects a subset of rows from relation.
  - *Projection* (Π) Deletes unwanted columns from relation.
  - *Cross-product* ($\times$) Allows us to combine two relations.
  - *Set-difference* ($-$) Tuples in reln. 1, but not in reln. 2.
  - *Union* ($\cup$) Tuples in reln. 1 and in reln. 2.
- Additional operations:
  - Intersection, *join*, division, renaming: Not essential, but (very!) useful.
- Since each operation returns a relation, operations can be *composed*! (Algebra is "closed".)

Projection

- Deletes attributes that are not in *projection list*.
- *Schema* of result contains exactly the fields in the projection list, with the same names that they had in the (only) input relation.
- Projection operator has to eliminate *duplicates*! (Why??)
  - Note: real systems typically don't do duplicate elimination unless the user explicitly asks for it. (Why not?)

sname	rating
yuppy	9
lubber	8
guppy	5
rusty	10

$$\pi_{sname,rating}(S2)$$

age
35.0
55.5

$$\pi_{age}(S2)$$

Selection

S2

sid	sname	rating	age
28	yuppy	9	35.0
31	lubber	8	55.5
44	guppy	5	35.0
58	rusty	10	35.0

- Selects rows that satisfy *selection condition*.
- No duplicates in result! (Why?)
- *Schema* of result identical to schema of (only) input relation.
- *Result* relation can be the *input* for another relational algebra operation! (*Operator composition.*)

sid	sname	rating	age
28	yuppy	9	35.0
58	rusty	10	35.0

$$\sigma_{rating>8}(S2)$$

sname	rating
yuppy	9
rusty	10

$$\pi_{sname,rating}(\sigma_{rating>8}(S2))$$

Union, Intersection, Set-Difference

- All of these operations take two input relations, which must be *union-compatible*:
  - Same number of fields.
  - `Corresponding' fields have the same type.
- What is the *schema* of result?

sid	sname	rating	age
22	dustin	7	45.0
31	lubber	8	55.5
58	rusty	10	35.0

S1

sid	sname	rating	age
28	yuppy	9	35.0
31	lubber	8	55.5
44	guppy	5	35.0
58	rusty	10	35.0

S2

$S1 \cap S2$

sid	sname	rating	age
31	lubber	8	55.5
58	rusty	10	35.0

$S1 - S2$

sid	sname	rating	age
22	dustin	7	45.0

sid	sname	rating	age
22	dustin	7	45.0
31	lubber	8	55.5
58	rusty	10	35.0
44	guppy	5	35.0
28	yuppy	9	35.0

$S1 \cup S2$

Cross-Product

sid	sname	rating	age
22	dustin	7	45.0
31	lubber	8	55.5
58	rusty	10	35.0

S1

sid	bid	day
22	101	10/10/96
58	103	11/12/96

R1

- Each row of S1 is paired with each row of R1.
- *Result schema* has one field per field of S1 and R1, with field names `inherited' if possible.
  - *Conflict*: Both S1 and R1 have a field called *sid*.

(sid)	sname	rating	age	(sid)	bid	day
22	dustin	7	45.0	22	101	10/10/96
22	dustin	7	45.0	58	103	11/12/96
31	lubber	8	55.5	22	101	10/10/96
31	lubber	8	55.5	58	103	11/12/96
58	rusty	10	35.0	22	101	10/10/96
58	rusty	10	35.0	58	103	11/12/96

- *Renaming operator*: $\rho\ (C(1 \rightarrow sid1, 5 \rightarrow sid2),\ S1 \times R1)$

Joins

sid	sname	rating	age
22	dustin	7	45.0
31	lubber	8	55.5
58	rusty	10	35.0

S1

sid	bid	day
22	101	10/10/96
58	103	11/12/96

R1

- Condition Join: $R \bowtie_c S = \sigma_c(R \times S)$

(sid)	sname	rating	age	(sid)	bid	day
22	dustin	7	45.0	58	103	11/12/96
31	lubber	8	55.5	58	103	11/12/96

$$R \bowtie_{R1.sid<S1.sid} S$$

- *Result schema* same as that of cross-product.
- Fewer tuples than cross-product, might be able to compute more efficiently
- Sometimes called a *theta-join*.

Joins

sid	sname	rating	age
22	dustin	7	45.0
31	lubber	8	55.5
58	rusty	10	35.0

S1

sid	bid	day
22	101	10/10/96
58	103	11/12/96

R1

- ***Equi-Join***: A special case of condition join where the condition *c* contains only ***equalities***.

sid	sname	rating	age	bid	day
22	dustin	7	45.0	101	10/10/96
58	rusty	10	35.0	103	11/12/96

$$R \bowtie_{sid} S$$

- *Result schema* similar to cross-product, but only one copy of fields for which equality is specified.
- ***Natural Join***: Equijoin on *all* common fields.

Division

- Not supported as a primitive operator, but useful for expressing queries like:

  *Find sailors who have reserved **all** boats.*

- Let *A* have 2 fields, *x* and *y*; *B* have only field *y*:
  - *A/B* = $\left\{ \langle x \rangle \mid \exists \langle x, y \rangle \in A \;\; \forall \langle y \rangle \in B \right\}$
  - i.e., ***A/B* contains all *x* tuples (sailors) such that for *every* *y* tuple (boat) in *B*, there is an *xy* tuple in *A*.**
  - *Or*: If the set of *y* values (boats) associated with an *x* value (sailor) in *A* contains all *y* values in *B*, the *x* value is in *A/B*.
- In general, *x* and *y* can be any lists of fields; *y* is the list of fields in *B*, and $x \cup y$ is the list of fields of *A*.

Examples of Division A/B

sno	pno
s1	p1
s1	p2
s1	p3
s1	p4
s2	p1
s2	p2
s3	p2
s4	p2
s4	p4

A

pno
p2

B1

pno
p2
p4

B2

pno
p1
p2
p4

B3

sno
s1
s2
s3
s4

A/B1

sno
s1
s4

A/B2

sno
s1

A/B3

Find sailors who have reserved all boats? (A/B)

sno	pno
s1	p1
s1	p2
s1	p3
s1	p4
s2	p1
s2	p2
s3	p2
s4	p2
s4	p4

A

pno
p1
p2
p4

B

sno
s1
s2
s3
s4

$\pi_{sno}(A)$

sno	pno
s1	p1
s1	p2
s1	p4
s2	p1
s2	p2
s2	p4
s3	p1
s3	p2
s3	p4
s4	p1
s4	p2
s4	p4

$\pi_{sno}(A) \times B$

sno	pno
s2	p4
s3	p1
s3	p4
s4	p1

$\pi_{sno}(A) \times B - A$

sno
s2
s3
s4

$\pi_{sno}(\pi_{sno}(A) \times B - A)$

disqualified tuples

sno
s1

$$A/B = \pi_{sno}(A) - \pi_{sno}(\pi_{sno}(A) \times B - A)$$

A/B = A − disqualified tuples

Expressing A/B Using Basic Operators

- Division is not essential op; just a useful shorthand.
  - (Also true of joins, but joins are so common that systems implement joins specially.)
- *Idea*: For *A*/*B*, compute all *x* values that are not `disqualified' by some *y* value in *B*.
  - *x* value is *disqualified* if by attaching *y* value from *B*, we obtain an *xy* tuple that is not in *A*.

Disqualified *x* values: $\pi_x((\pi_x(A) \times B) - A)$

A/B: $\pi_x(A)$ − all disqualified tuples

sid	sname	rating	age
22	dustin	7	45.0
31	lubber	8	55.5
58	rusty	10	35.0

S1

sid	bid	day
22	101	10/10/96
58	103	11/12/96

R1

Find names of sailors who've reserved boat #103

- Solution 1: $\pi_{sname}((\sigma_{bid=103} Reserves) \bowtie Sailors)$

- Solution 2: $\rho(Temp1, \sigma_{bid=103} Reserves)$

  $\rho(Temp2, Temp1 \bowtie Sailors)$

  $\pi_{sname}(Temp2)$

- Solution 3: $\pi_{sname}(\sigma_{bid=103}(Reserves \bowtie Sailors))$

sid	sname	rating	age
22	dustin	7	45.0
31	lubber	8	55.5
58	rusty	10	35.0

S1

sid	bid	day
22	101	10/10/96
58	103	11/12/96

R1

Find names of sailors who've reserved a red boat

- Information about boat color only available in Boats; so need an extra join:

$$\pi_{sname}((\sigma_{color='red'}Boats) \bowtie Reserves \bowtie Sailors)$$

- A more efficient solution:

$$\pi_{sname}(\pi_{sid}(\pi_{bid}(\sigma_{color='red'}Boats) \bowtie Reserves) \bowtie Sailors))$$

A query optimizer can find this, given the first solution!

sid	sname	rating	age
22	dustin	7	45.0
31	lubber	8	55.5
58	rusty	10	35.0

S1

sid	bid	day
22	101	10/10/96
58	103	11/12/96

R1

Find sailors who've reserved a red or a green boat

- Can identify all red or green boats, then find sailors who've reserved one of these boats:

$$\rho(Tempboats, (\sigma_{color='red' \vee color='green'} Boats))$$

$$\pi_{sname}(Tempboats \bowtie Reserves \bowtie Sailors)$$

- Can also define Tempboats using union! (How?)
- What happens if $\vee$ is replaced by $\wedge$ in this query?

sid	sname	rating	age
22	dustin	7	45.0
31	lubber	8	55.5
58	rusty	10	35.0

S1

sid	bid	day
22	101	10/10/96
58	103	11/12/96

R1

Find sailors who've reserved a red and a green boat

- Previous approach won't work! Must identify sailors who've reserved red boats, sailors who've reserved green boats, then find the intersection (note that *sid* is a key for Sailors):

$$\rho(Tempred, \pi_{sid}((\sigma_{color='red'} Boats) \bowtie Reserves))$$

$$\rho(Tempgreen, \pi_{sid}((\sigma_{color='green'} Boats) \bowtie Reserves))$$

$$\pi_{sname}((Tempred \cap Tempgreen) \bowtie Sailors)$$

sid	sname	rating	age
22	dustin	7	45.0
31	lubber	8	55.5
58	rusty	10	35.0

S1

sid	bid	day
22	101	10/10/96
58	103	11/12/96

R1

Find the names of sailors who've reserved all boats

- Uses division; schemas of the input relations to / must be carefully chosen:

$$\rho(Tempsids, (\pi_{sid,bid}Reserves)/(\pi_{bid}Boats))$$

$$\pi_{sname}(Tempsids \bowtie Sailors)$$

- To find sailors who've reserved all 'Interlake' boats:

$$\ldots\ldots \quad / \pi_{bid}(\sigma_{bname='Interlake'} Boats)$$

Summary

- The relational model has rigorously defined query languages that are simple and powerful.
- Relational algebra is more operational; useful as internal representation for query evaluation plans.
- Several ways of expressing a given query; a query optimizer should choose the most efficient version.