

L4

Relational Algebra

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Supplemental Materials

Helpful References

https://en.wikipedia.org/wiki/Relational_algebra

Overview

Last time, learned about
pre-relational models
an informal introduction to relational model
an introduction to the SQL query language.

Learn about formal relational query languages
Relational Algebra (algebra: perform operations)
Relational Calculus (logic: are statements true?)

Keys to understanding SQL and query processing

Relational algebra is the basis for the most popular **query language** in the universe*

*known universe

What's a Query Language?

Allows manipulation and **retrieval of data** from a database.

Traditionally: QL != programming language

- Doesn't need to be turing complete

- Not* designed for computation

- Supports easy, efficient access to (very) large databases

Recent years

- Scaling to large datasets is a reality

- Powerful way to think about...

 - data algorithms that scale

 - asynchronous/parallel programming

What's a Query Language?

Re-use permitted when acknowledging the original © Daniel Abadi, Shivnath Babu, Fatma Ozcan, and Ippokratis Pandis (2015)

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MapReduce is **not** the answer

- MapReduce is a powerful primitive to do many kinds of parallel data processing
- BUT
 - Little control of data flow
 - Fault tolerance guarantees not always necessary
 - Simplicity leads to inefficiencies
 - Does not interface with existing analysis software
 - Industry has existing training in SQL



SQL interface for Hadoop critical for mass adoption

SQL-on-Hadoop Tutorial

9/30/2015

Tutorial at VLDB 2015 Abadi et al.
<http://www.slideshare.net/abadid/sqlonhadoop-tutorial>

Formal Relational Query Languages

Relational Algebra

Operational, used to represent execution plans

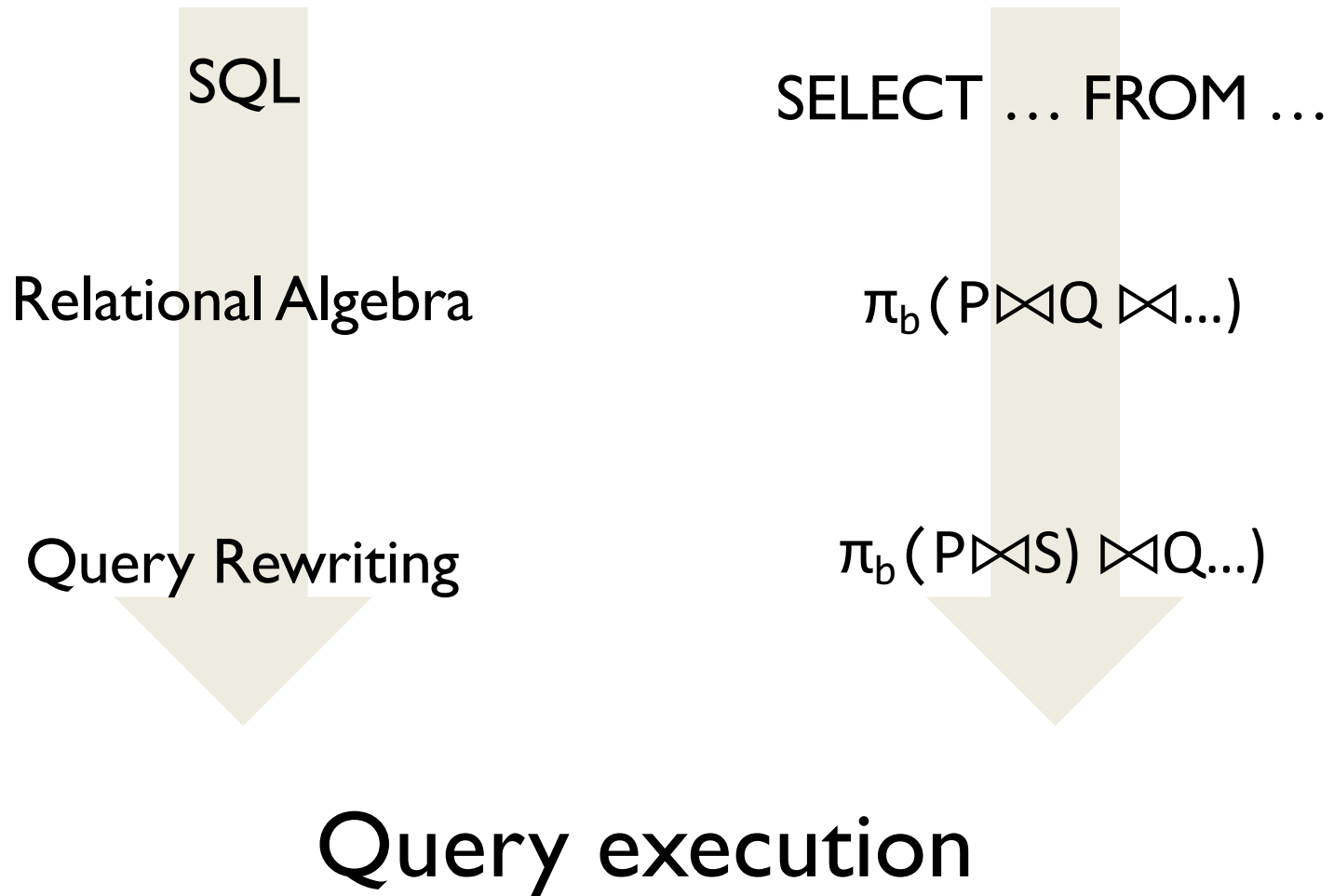
$\pi_{\text{name}}(\sigma_{\text{age} < 30}(\text{Sailors}))$ sailor names younger than 30

Relational Calculus

Logical, describes what data users want (declarative)

$\{ s: \text{name} \mid s \in \text{Sailors} \wedge s.\text{age} < 30 \}$
(this is shorthand)

Journey of a Query



Prelims

Query is a function over **relation instances**

$$Q(R_1, \dots, R_n) = R_{\text{result}}$$

Schemas of input and output relations are *fixed* and well defined by the query Q .

Positional vs Named field notation

- Position easier for formal defs

 - one-indexed (not 0-indexed!!!)

- Named is more readable

- Both used in SQL

Prelims

Relation (for this lecture)

Instance: **set** of tuples (important!)

Schema: list of field names and types (domains)

Students(sid int, name text, major text, gpa int)

How are relations different than generic sets (\mathbb{R})?

Can assume item structure due to schema

Some algebra operations (x) need to be modified

Will use this later

Relational Algebra Overview

Core 5 operations

PROJECT (π)

SELECT (σ)

UNION (\cup)

SET DIFFERENCE ($-$)

CROSSPRODUCT (\times)

Additional operations

RENAME (ρ)

INTERSECT (\cap)

JOIN (\bowtie)

DIVIDE ($/$)

Instances Used Today: Library

Students, Reservations

Use positional or named field notation

Fields in query results are inherited from input relations (unless specified)

RI

sid	rid	day
1	101	10/10
2	102	11/11

S1

sid	name	gpa	age
1	eugene	4	20
2	barb	3	21
3	tanya	2	88

S2

sid	name	gpa	age
4	aziz	3.2	21
2	barb	3	21
3	tanya	2	88
5	rusty	3.5	21

Project

$$\pi_{\langle \text{attr1}, \dots \rangle}(A) = R_{\text{result}}$$

Pick out desired attributes (subset of columns)

Schema is subset of input schema in the projection list

$\pi_{\langle a, b, c \rangle}(A)$ has output schema (a, b, c) w/ types carried over

Project

S2

sid	name	gpa	age
4	aziz	3.2	21
2	barb	3	21
3	tanya	2	88
5	rusty	3.5	21

$\pi_{\text{name,age}}(S2) =$

name	age
aziz	21
barb	21
tanya	88
rusty	21

Project

S2

sid	name	gpa	age
4	aziz	3.2	21
2	barb	3	21
3	tanya	2	88
5	rusty	3.5	21

$\pi_{\text{name,name,age}}(S2) =$

name	name	age
aziz	aziz	21
barb	barb	21
tanya	tanya	88
rusty	rusty	21

Project

S2

sid	name	gpa	age
4	aziz	3.2	21
2	barb	3	21
3	tanya	2	88
5	rusty	3.5	21

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

age
21
88

Where did all the rows go?

Real systems typically don't remove duplicates. Why?

Select

$$\sigma_{\langle p \rangle}(A) = R_{\text{result}}$$

Select subset of rows that satisfy condition p

Won't have duplicates in result. Why?

Result schema same as input

Select

S1

sid	name	gpa	age
1	eugene	4	20
2	barb	3	21
3	tanya	2	88

$$\sigma_{\text{age} < 30} (S1) =$$

sid	name	gpa	age
1	eugene	4	20
2	barb	3	21

$$\pi_{\text{name}}(\sigma_{\text{age} < 30} (S1)) =$$

name
eugene
barb

Commutative Operations

$$A + B = B + A$$

$$A * B = B * A$$

$$A + (B * C) = (B * C) + A$$

Associative Operations

$$A + (B + C) = (A + B) + C$$

$$A + (B * C) = (A + B) * C$$

Commutative Operations

$$A + B = B + A$$

$$A * B = B * A$$

$$A + (B * C) = (B * C) + A$$

Associative Operations

$$A + (B + C) = (A + B) + C$$

~~$$A + (B * C) = (A + B) * C$$~~

Commutatively

$$\pi_{\text{age}}(\sigma_{\text{age} < 30} (SI))$$

$\sigma_{\text{age} < 30}$

sid	name	gpa	age
1	eugene	4	20
2	barb	3	21
3	tanya	2	88

sid	name	gpa	age
1	eugene	4	20
2	barb	3	21

Commutatively

$$\pi_{\text{age}}(\sigma_{\text{age} < 30}(SI))$$

$\sigma_{\text{age} < 30}$

sid	name	gpa	age
1	eugene	4	20
2	barb	3	21
3	tanya	2	88

π_{age}

sid	name	gpa	age
1	eugene	4	20
2	barb	3	21

=

age
20
21

Commutatively

$$\sigma_{\text{age} < 30}(\pi_{\text{age}}(S))$$

π_{age}

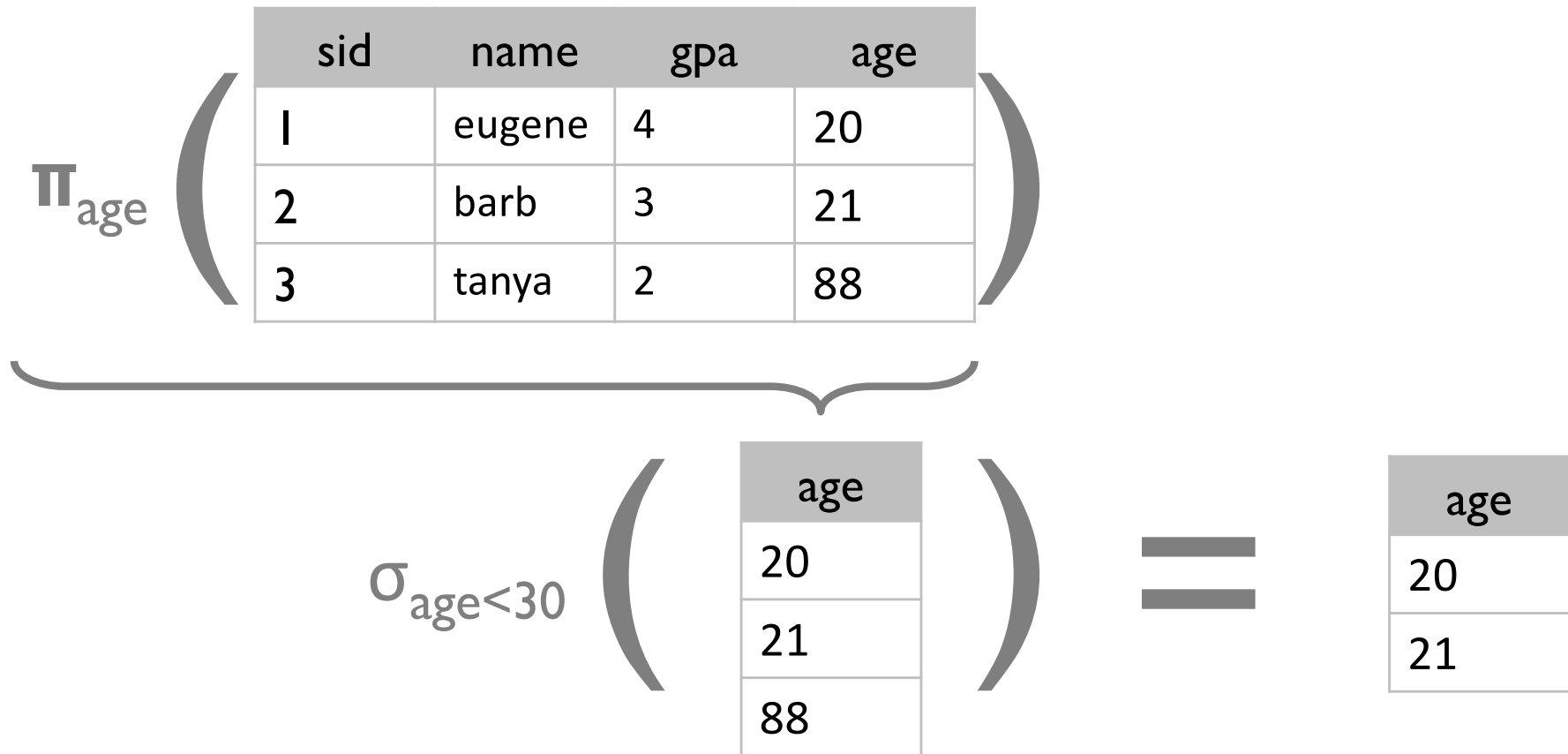
sid	name	gpa	age
1	eugene	4	20
2	barb	3	21
3	tanya	2	88

$\sigma_{\text{age} < 30}$

age
20
21
88

Commutatively

$$\sigma_{\text{age} < 30}(\pi_{\text{age}}(S))$$



Commutatively

Does Project and Select **always** commute?

$$\pi_{\text{age}}(\sigma_{\text{age} < 30}(SI)) = \sigma_{\text{age} < 30}(\pi_{\text{age}}(SI))$$

What about

$$\pi_{\text{name}}(\sigma_{\text{age} < 30}(SI))?$$

Commutatively

Does Project and Select commute?

$$\pi_{\text{age}}(\sigma_{\text{age} < 30}(SI)) = \sigma_{\text{age} < 30}(\pi_{\text{age}}(SI))$$

What about

$$\pi_{\text{name}}(\sigma_{\text{age} < 30}(SI)) \neq \sigma_{\text{age} < 30}(\pi_{\text{name}}(SI))$$

Commutatively

Does Project and Select commute?

$$\pi_{\text{age}}(\sigma_{\text{age} < 30}(SI)) = \sigma_{\text{age} < 30}(\pi_{\text{age}}(SI))$$

What about

$$\pi_{\text{name}}(\sigma_{\text{age} < 30}(SI)) \neq \sigma_{\text{age} < 30}(\pi_{\text{name, age}}(SI))$$

Commutatively

Does Project and Select commute?

$$\pi_{\text{age}}(\sigma_{\text{age} < 30}(SI)) = \sigma_{\text{age} < 30}(\pi_{\text{age}}(SI))$$

What about

$$\pi_{\text{name}}(\sigma_{\text{age} < 30}(SI)) = \pi_{\text{name}}(\sigma_{\text{age} < 30}(\pi_{\text{name, age}}(SI)))$$

OK!

Union, Set-Difference

$$A \text{ op } B = R_{\text{result}}$$

A, B must be *union-compatible*

Same number of fields

Field i in each schema have same type

Result Schema borrowed from first arg (A)

A(id int, imgid int) \cup B(blah int, gloop int) = ?

Union, Set-Difference

$$A \text{ op } B = R_{\text{result}}$$

A, B must be *union-compatible*

Same number of fields

Field i in each schema have same type

Result Schema borrowed from first arg (A)

$A(\text{id int, imgid int}) \cup B(\text{blah int, gloop int}) =$

$R_{\text{result}}(\text{id int, imgid int})$

Union, Intersect, Set-Difference

S1

sid	name	gpa	age
1	eugene	4	20
2	barb	3	21
3	tanya	2	88

S2

sid	name	gpa	age
4	aziz	3.2	21
2	barb	3	21
3	tanya	2	88
5	rusty	3.5	21

$S1 \cup S2 =$

sid	name	gpa	age
1	eugene	4	20
4	aziz	3.2	21
5	rusty	3.5	21
3	tanya	2	88
2	barb	3	21

Union, Intersect, Set-Difference

S1

sid	name	gpa	age
1	eugene	4	20
2	barb	3	21
3	tanya	2	88

S2

sid	name	gpa	age
4	aziz	3.2	21
2	barb	3	21
3	tanya	2	88
5	rusty	3.5	21

$S1 - S2 =$

sid	name	gpa	age
1	eugene	4	20

Note on Set Difference & Performance

Notice that most operators are monotonic
increasing size of inputs \rightarrow outputs grow
if $A \supseteq B \rightarrow Q(A, T) \supseteq Q(B, T)$
can compute *incrementally*

Set Difference is *not monotonic*

if $A \supseteq B \rightarrow T - A \subseteq T - B$
e.g., $5 > 1 \rightarrow 9 - 5 < 9 - 1$

Set difference is *blocking*:

For $T - S$, must wait for all S tuples before any results

Cross-Product

$$A(a_1, \dots, a_n) \times B(a_{n+1}, \dots, a_m) = R_{\text{result}}(a_1, \dots, a_m)$$

Each row of A paired with each row of B

Result schema concatenates A and B's fields, inherit if possible

Conflict: students and reservations have *sid* field

Different than mathematical “X” by flattening results:

$$\text{math } A \times B = \{ (a, b) \mid a \in A \wedge b \in B \}$$

$$\text{e.g., } \{1, 2\} \times \{3, 4\} = \{ (1, 3), (1, 4), (2, 3), (2, 4) \}$$

what is $\{1, 2\} \times \{3, 4\} \times \{5, 6\}$?

Cross-Product

SI

sid	name	gpa	age
1	eugene	4	20
2	barb	3	21
3	tanya	2	88

RI

sid	rid	day
1	101	10/10
2	102	11/11

SI x RI =

(sid)	name	gpa	age	(sid)	rid	day
1	eugene	4	20	1	101	10/10
2	barb	3	21	1	101	10/10
3	tanya	2	88	1	101	10/10
1	eugene	4	20	2	102	11/11
2	barb	3	21	2	102	11/11
3	tanya	2	88	2	102	11/11

Rename

$p(<\text{newRelationName}>(<\text{mappings}>), Q)$

Explicitly defines/changes field names of schema

$p(C(I \rightarrow \text{sid1}, 5 \rightarrow \text{sid2}), S1 \times R1)$

$C =$

sid1	name	gpa	age	sid2	rid	day
1	eugene	4	20	1	101	10/10
2	barb	3	21	1	101	10/10
3	tanya	2	88	1	101	10/10
1	eugene	4	20	2	102	11/11
2	barb	3	21	2	102	11/11
3	tanya	2	88	2	102	11/11

Project



Select



Cross product



Difference



Union



Intersect



Compound/Convenience Operators

INTERSECT (\cap)

JOIN (\bowtie)

DIVIDE ($/$)

Intersect

$$A \cap B = R_{\text{result}}$$

A, B must be *union-compatible*

Intersect

S1

sid	name	gpa	age
1	eugene	4	20
2	barb	3	21
3	tanya	2	88

S2

sid	name	gpa	age
4	aziz	3.2	21
2	barb	3	21
3	tanya	2	88
5	rusty	3.5	21

$S1 \cap S2 =$

sid	name	gpa	age
2	barb	3	21
3	tanya	2	88

Intersect

$$A \cap B = R_{\text{result}}$$

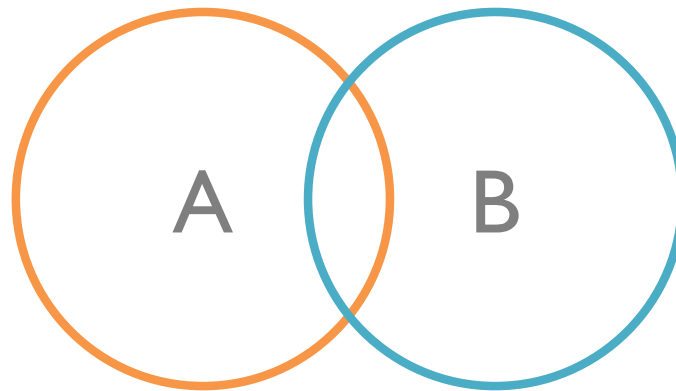
A, B must be *union-compatible*

Can we express using core operators?

$$A \cap B = ?$$

Intersect

$$A \cap B = R_{\text{result}}$$

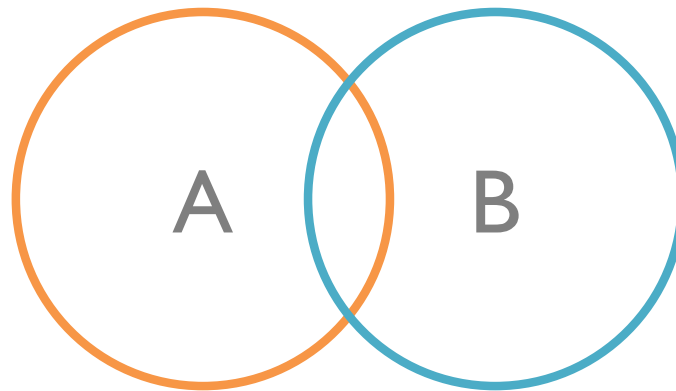


Can we express using core operators?

$A \cap B = A - ?$ (think venn diagram)

Intersect

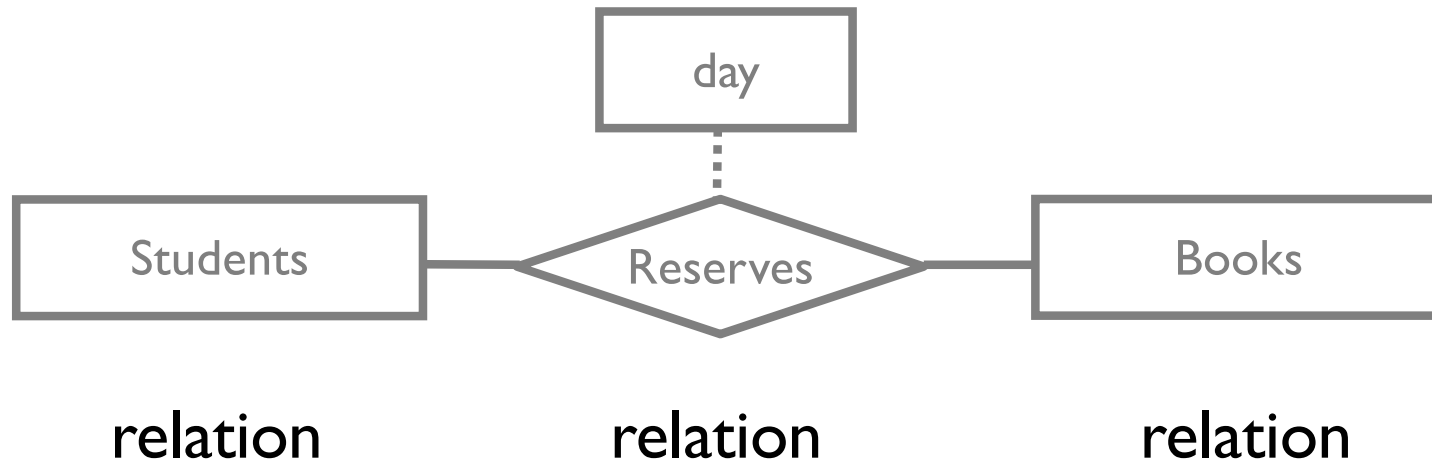
$$A \cap B = R_{\text{result}}$$



Can we express using core operators?

$$A \cap B = A - (A - B)$$

Joins (high level)

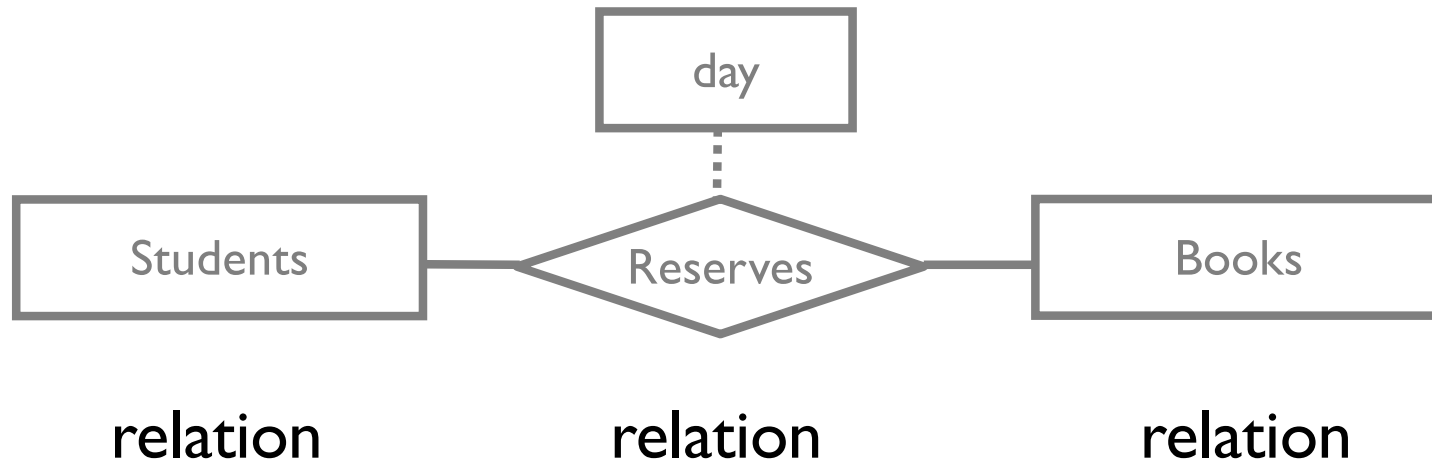


What if you want to query across all three tables?
e.g., all names of students that reserved “The Purple Crayon”

Need to combine these tables

Cross product? But that ignores foreign key references

Joins (high level)



SI

sid	name	gpa	age
1	eugene	4	20
2	barb	3	21
3	tanya	2	88

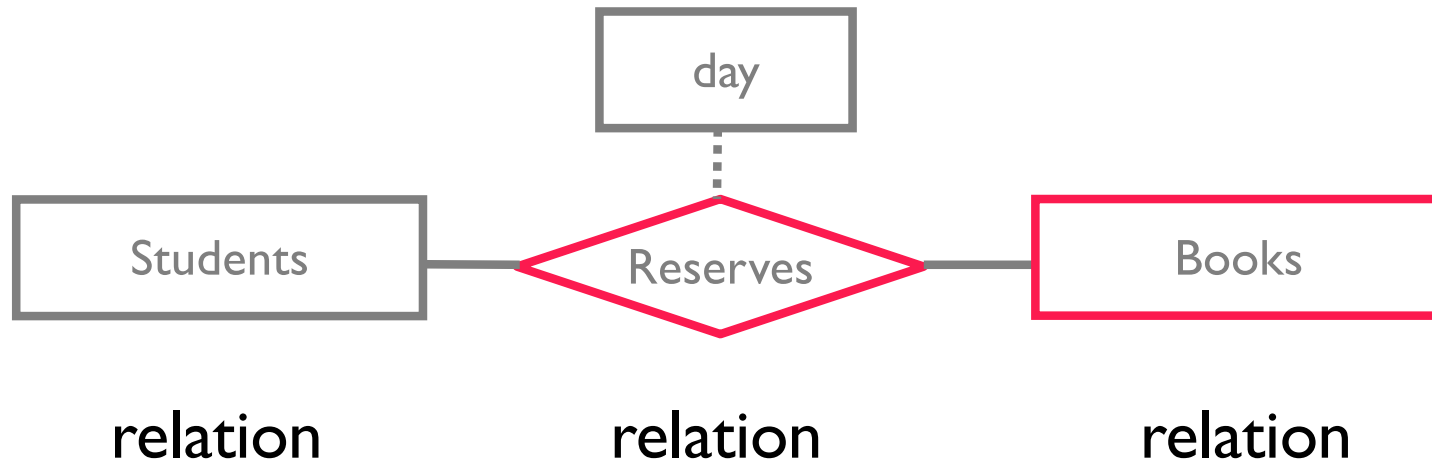
RI

sid	rid	day
1	101	10/10
2	102	11/11

BI

rid	name
101	The Purple Crayon
102	1984

Joins (high level)



SI

sid	name	gpa	age
1	eugene	4	20
2	barb	3	21
3	tanya	2	88

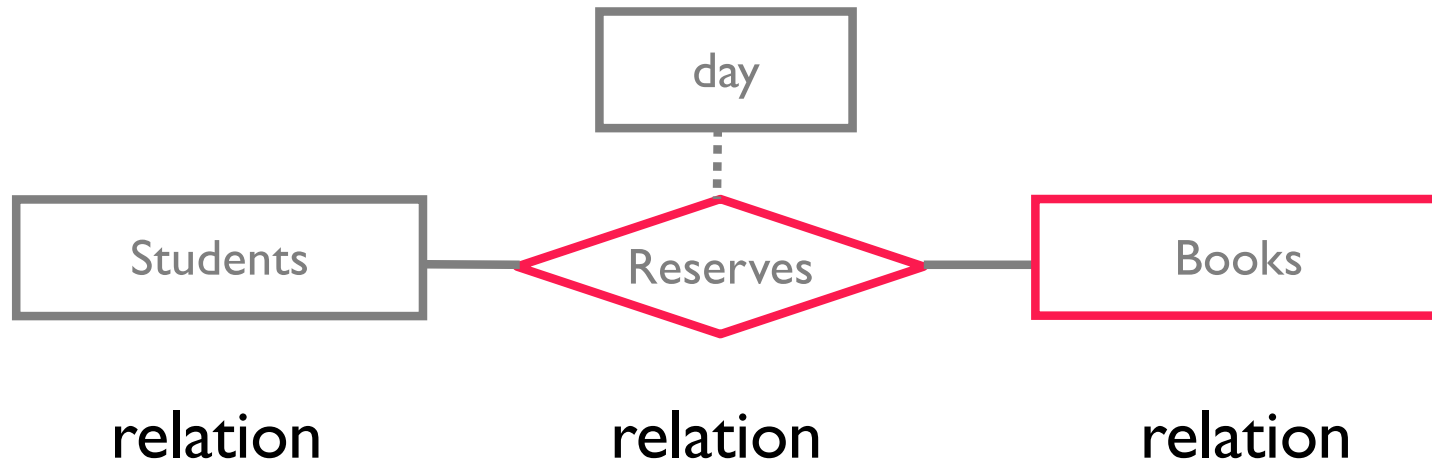
RI

sid	rid	day
1	101	10/10
2	102	11/11

BI

rid	name
101	The Purple Crayon
102	1984

Joins (high level)



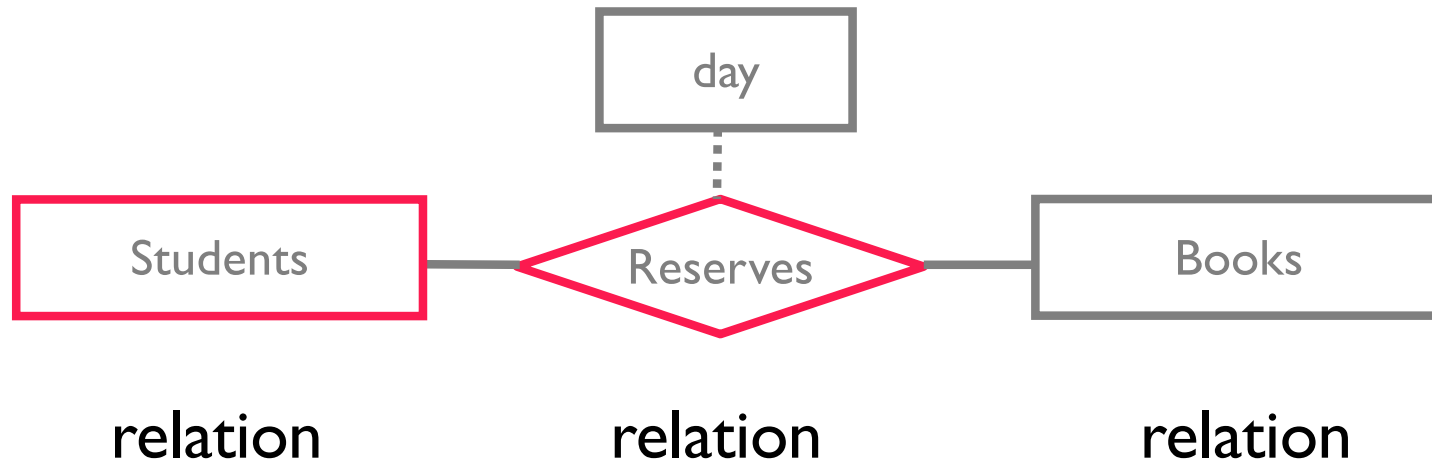
SI

sid	name	gpa	age
1	eugene	4	20
2	barb	3	21
3	tanya	2	88

RBI

sid	(rid)	day	(rid)	name
1	101	10/10	101	The Purple Crayon
2	102	11/11	102	1984

Joins (high level)



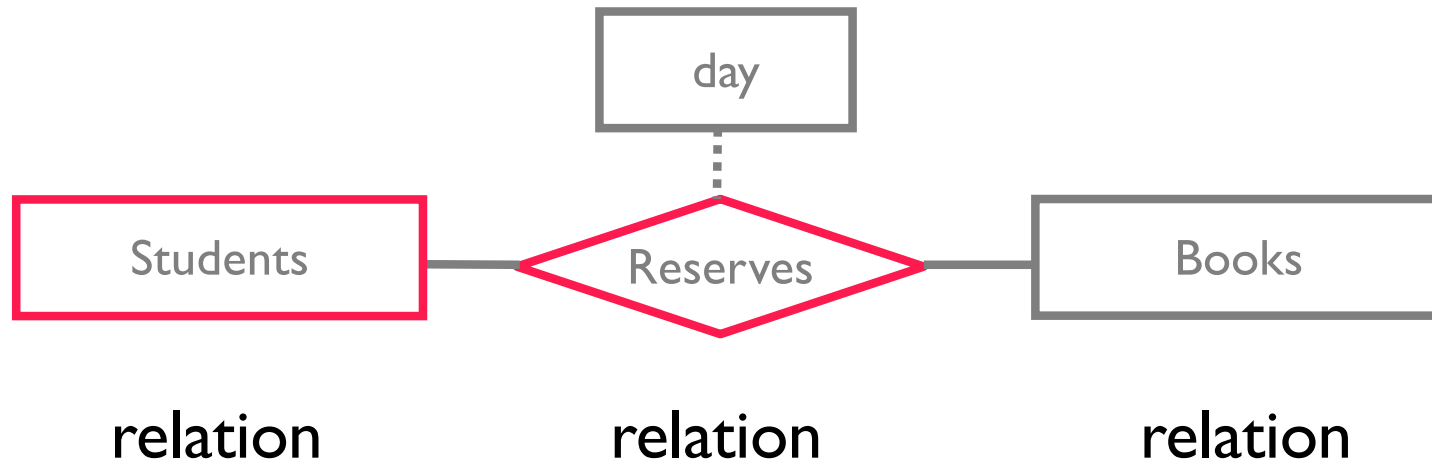
SI

sid	name	gpa	age
1	eugene	4	20
2	barb	3	21
3	tanya	2	88

RBI

sid	(rid)	day	(rid)	name
1	101	10/10	101	The Purple Crayon
2	102	11/11	102	1984

Joins (high level)



SRBI

(sid)	(name)	gpa	age	(sid)	(rid)	day	(rid)	(name)
1	eugene	4	20	1	101	10/10	101	The Purple Crayon
2	barb	3	21	2	102	11/11	102	1984

theta (θ) Join

$$A \bowtie_c B = \sigma_c(A \times B)$$

Most general form

Result schema same as cross product

Often *far* more efficient to compute than cross product

Commutative

$$(A \bowtie_c B) \bowtie_c C = A \bowtie_c (B \bowtie_c C)$$

theta (θ) Join

SI

sid	name	gpa	age
1	eugene	4	20
2	barb	3	21
3	tanya	2	88

RI

sid	rid	day
1	101	10/10
2	102	11/11

$SI \bowtie_{SI.sid \leq RI.sid} RI =$

$\sigma_{SI.sid \leq RI.sid}(SI \times RI)$

(sid)	name	gpa	age	(sid)	rid	day
1	eugene	4	20	1	101	10/10
2	barb	3	21	1	101	10/10
3	tanya	2	88	1	101	10/10
1	eugene	4	20	2	102	11/11
2	barb	3	21	2	102	11/11
3	tanya	2	88	2	102	11/11

theta (θ) Join

SI

sid	name	gpa	age
1	eugene	4	20
2	barb	3	21
3	tanya	2	88

RI

sid	rid	day
1	101	10/10
2	102	11/11

$SI \bowtie_{SI.sid \leq RI.sid} RI =$

$\sigma_{SI.sid \leq RI.sid}(SI \times RI)$

(sid)	name	gpa	age	(sid)	rid	day
1	eugene	4	20	1	101	10/10
2	barb	3	21	1	101	10/10
3	tanya	2	88	1	101	10/10
1	eugene	4	20	2	102	11/11
2	barb	3	21	2	102	11/11
3	tanya	2	88	2	102	11/11

theta (θ) Join

SI

sid	name	gpa	age
1	eugene	4	20
2	barb	3	21
3	tanya	2	88

RI

sid	rid	day
1	101	10/10
2	102	11/11

$$SI \bowtie_{SI.sid \leq RI.sid} RI =$$

$$\sigma_{SI.sid \leq RI.sid}(SI \times RI) =$$

(sid)	name	gpa	age	(sid)	rid	day
1	eugene	4	20	1	101	10/10
1	eugene	4	20	2	102	11/11
2	barb	3	21	2	102	11/11

Equi-Join

$$A \bowtie_{\text{attr}} B = \pi_{\text{all attrs except B.attr}}(A \bowtie_{A.\text{attr} = B.\text{attr}} B)$$

Special case where the condition is attribute equality

Result schema only keeps *one copy* of equality fields

Natural Join ($A \bowtie B$):

Equijoin on *all* shared fields (fields w/ same name)

Equi-Join

SI

sid	name	gpa	age
1	eugene	4	20
2	barb	3	21
3	tanya	2	88

RI

sid	rid	day
1	101	10/10
2	102	11/11

$SI \bowtie_{sid} RI$

sid	name	gpa	age	rid	day
1	eugene	4	20	101	10/10
2	barb	3	21	102	11/11

Equi-Join

SI

sid	name	day	gpa	age
1	eugene	10/10	4	20
2	barb	12/12	3	21
3	tanya	3/3	2	88

RI

sid	rid	day
1	101	10/10
2	102	11/11

$SI \bowtie_{\text{sid,name}} RI = \text{INVALID!}$ name not in RI

$SI \bowtie_{\text{sid,day}} RI = SI \bowtie_{SI.sid=RI.sid \wedge SI.day=RI.day} RI$

sid	name	day	gpa	age	rid
1	eugene	10/10	4	20	101

$SI \bowtie RI = SI \bowtie_{\text{sid,day}} RI$

(Not covered in class)

Division

Let us have relations $A(x, y)$, $B(y)$

$$A/B = \{ \langle x \rangle \mid \forall y \in B \langle x, y \rangle \in A \}$$

Find all students that have reserved all books

$A/B =$ all x (students) s.t. for every y (reservation), $\langle x, y \rangle \in A$

Good to ponder, not supported in most systems (why?)

Generalization

y can be a list of fields in B

$x \cup y$ is fields in A

(Not covered in class)

Examples

A

sid	rid
1	1
1	2
1	3
1	4
2	1
2	2
3	2
4	2
4	4

R1

rid
2

A/R1

R2

rid
2
4

A/R2

R3

rid
1
2
4

A/R3

Which sid values have relationship with all vals in Rx?

(Not covered in class)

Examples

A

sid	rid
1	1
1	2
1	3
1	4
2	1
2	2
3	2
4	2
4	4

R1

rid
2

sid
1
2
3
4

A/R1

R2

rid
2
4

A/R2

R3

rid
1
2
4

A/R3

Which sid values have relationship with all vals in Rx?

(Not covered in class)

Examples

A

sid	rid
1	1
1	2
1	3
1	4
2	1
2	2
3	2
4	2
4	4

R1

rid
2

sid
1
2
3
4

A/R1

R2

rid
2
4

sid
1
4

A/R2

R3

rid
1
2
4

A/R3

Which sid values have relationship with all vals in Rx?

(Not covered in class)

Examples

A

sid	rid
1	1
1	2
1	3
1	4
2	1
2	2
3	2
4	2
4	4

R1

rid
2

sid
1
2
3
4

A/R1

R2

rid
2
4

sid
1
4

A/R2

R3

rid
1
2
4

sid
1

A/R3

Which sid values have relationship with all vals in Rx?

(Not covered in class)

Is A/B a Fundamental Operation?

No. Shorthand like Joins

joins natively supported: ubiquitous, can be optimized

Hint: Find all x s not 'disqualified' by some y in B .

$A(x, y), B(y)$

x value is *disqualified* if

1. by attaching y value from B (e.g., create $\langle x, y \rangle$)
2. we obtain an $\langle x, y \rangle$ that is not in A .

(Not covered in class)

A

sid	rid
1	1
1	2
1	3
1	4
2	1
2	2
3	2
4	2
4	4

B

rid
2
4

Disqualified =

A/B =

(Not covered in class)

A

sid	rid
1	1
1	2
1	3
1	4
2	1
2	2
3	2
4	2
4	4

B

rid
2
4

$\pi_{\text{sid}}(A)$

sid
1
2
3
4

Disqualified =

A/B =

(Not covered in class)

A

sid	rid
1	1
1	2
1	3
1	4
2	1
2	2
3	2
4	2
4	4

B

rid
2
4

$\pi_{\text{sid}}(A)$

sid
1
2
3
4

$\pi_{\text{sid}}(A) \times B$

sid	rid
1	2
1	4
2	2
2	4
3	2
3	4
4	2
4	4

Disqualified =
A/B =

$(\pi_{\text{sid}}(A) \times B)$

(Not covered in class)

A

sid	rid
1	1
1	2
1	3
1	4
2	1
2	2
3	2
4	2
4	4

B

rid
2
4

$\pi_{\text{sid}}(A)$

sid
1
2
3
4

$\pi_{\text{sid}}(A) \times B$

sid	rid
1	2
1	4
2	2
2	4
3	2
3	4
4	2
4	4

$(\pi_{\text{sid}}(A) \times B) - A$

sid	rid
2	4
3	4

Disqualified =
A/B =

$((\pi_{\text{sid}}(A) \times B) - A)$

(Not covered in class)

A

sid	rid
1	1
1	2
1	3
1	4
2	1
2	2
3	2
4	2
4	4

B

rid
2
4

$\pi_{\text{sid}}(A)$

sid
1
2
3
4

$\pi_{\text{sid}}(A) \times B$

sid	rid
1	2
1	4
2	2
2	4
3	2
3	4
4	2
4	4

$(\pi_{\text{sid}}(A) \times B) - A$

sid	rid
2	4
3	4

sid

1
4

A/B

Disqualified = $\pi_{\text{sid}}((\pi_{\text{sid}}(A) \times B) - A)$

A/B = $\pi_{\text{sid}}(A) - \text{Disqualified}$

Different Plans, Same Results

Semantic equivalence:
results are *always* the same

Note that it is independent
of the database instance!

Names of students that reserved book 2

$$\pi_{\text{name}}(\sigma_{\text{rid}=2} (R1) \bowtie SI)$$

Equivalent Queries

$$\begin{aligned} & p(\text{tmp1}, \sigma_{\text{rid}=2} (R1)) \\ & p(\text{tmp2}, \text{tmp1} \bowtie SI) \\ & \pi_{\text{name}}(\text{tmp2}) \end{aligned}$$
$$\pi_{\text{name}}(\sigma_{\text{rid}=2}(R1 \bowtie SI))$$

Names of students that reserved db books

Book(rid, type) Reserve(sid, rid) Student(sid, name)

Need to join DB books with reserve and students

$\sigma_{\text{type}='db'}$ (Book)

Names of students that reserved db books

Book(rid, type) Reserve(sid, rid) Student(sid, name)

Need to join DB books with reserve and students

$\sigma_{\text{type}='db'}(\text{Book}) \bowtie \text{Reserve}$

Names of students that reserved db books

Book(rid, type) Reserve(sid, rid) Student(sid, name)

Need to join DB books with reserve and students

$\sigma_{\text{type}='db'} (\text{Book}) \bowtie \text{Reserve} \bowtie \text{Student}$

Names of students that reserved db books

Book(rid, type) Reserve(sid, rid) Student(sid, name)

Need to join DB books with reserve and students

$\pi_{\text{name}}(\sigma_{\text{type}='db'}(\text{Book}) \bowtie \text{Reserve} \bowtie \text{Student})$

Names of students that reserved db books

Book(rid, type) Reserve(sid, rid) Student(sid, name)

Need to join DB books with reserve and students

$\pi_{\text{name}}(\sigma_{\text{type}='db'}(\text{Book}) \bowtie \text{Reserve} \bowtie \text{Student})$

More efficient query

$\pi_{\text{name}}(\pi_{\text{sid}}((\pi_{\text{rid}} \sigma_{\text{type}='db'}(\text{Book})) \bowtie \text{Reserve}) \bowtie \text{Student})$

Query optimizer can find the more efficient query!

Names of students that reserved db books

Book(rid, type) Reserve(sid, rid) Student(sid, name)

Need to join DB books with reserve and students

$\pi_{\text{name}}(\sigma_{\text{type}='db'}(\text{Book}) \bowtie \text{Reserve} \bowtie \text{Student})$

More efficient query

$\pi_{\text{name}}(\pi_{\text{sid}}((\pi_{\text{rid}} \sigma_{\text{type}='db'}(\text{Book})) \bowtie \text{Reserve}) \bowtie \text{Student})$

Query optimizer can find the more efficient query!

Names of students that reserved db books

Book(rid, type) Reserve(sid, rid) Student(sid, name)

Need to join DB books with reserve and students

$\pi_{\text{name}}(\sigma_{\text{type}='db'}(\text{Book}) \bowtie \text{Reserve} \bowtie \text{Student})$

More efficient query

$\pi_{\text{name}}(\pi_{\text{sid}}((\pi_{\text{rid}} \sigma_{\text{type}='db'}(\text{Book})) \bowtie \text{Reserve}) \bowtie \text{Student})$

Query optimizer can find the more efficient query!

Names of students that reserved db books

Book(rid, type) Reserve(sid, rid) Student(sid, name)

Need to join DB books with reserve and students

$\pi_{\text{name}}(\sigma_{\text{type}='db'}(\text{Book}) \bowtie \text{Reserve} \bowtie \text{Student})$

More efficient query

$\pi_{\text{name}}(\pi_{\text{sid}}((\pi_{\text{rid}} \sigma_{\text{type}='db'}(\text{Book})) \bowtie \text{Reserve}) \bowtie \text{Student})$

Query optimizer can find the more efficient query!

Logistics

Due:

HWI Part 2

Project I Part I

Midterm in 2 weeks

- Virtual on gradescope, during class time, open book
- First Q related to CS academic honesty policy
- Practice exams on course webpage

Students that reserved DB or HCI book

1. Find all DB or HCI books
2. Find students that reserved one of those books

$\rho(\text{tmp}, (\sigma_{\text{type}='DB' \vee \text{type}='HCI'} (\text{Book})))$
 $\pi_{\text{name}}(\text{tmp} \bowtie \text{Reserve} \bowtie \text{Student})$

” \vee ” means logical OR

Alternatives

define tmp using UNION (how?)

Using UNION

$p(tmp1, (\sigma_{type='DB'} (Book)))$

$p(dbnames, \pi_{name}(tmp1 \bowtie Reserve \bowtie Student))$

$p(tmp2, (\sigma_{type='HCI'} (Book)))$

$p(hcinames, \pi_{name}(tmp2 \bowtie Reserve \bowtie Student))$

$dbnames \cup hcinames$

Natural Joins

$$R(a,b,c) \bowtie S(d) =$$

$$R(a,b,c) \bowtie S(d) =$$

$$\sigma_{\text{TRUE}}(R \times \bar{S}) =$$

$$R \times S$$

$$R(a,b,c) \bowtie S(a) =$$

$$\pi_{R.a, R.b, R.c} \sigma_{R.a = S.a}(R \times S)$$

$$R(a,b,c) \bowtie S(a,b,d) = R \bowtie_{a,b} S =$$

$$\pi_{R.a, R.b, R.c, S.d} \sigma_{R.a = S.a \wedge R.b = S.b}(R \times S)$$

Students that reserved a DB and HCI book

Can we change \vee into \wedge (AND)?

$\rho(\text{tmp}, (\sigma_{\text{type}='DB' \wedge \text{type}='HCI'}(\text{Book})))$
 $\pi_{\text{name}}(\text{tmp} \bowtie \text{Reserve} \bowtie \text{Student})$

NO

Why?

$\rho(\text{tmp}, (\sigma_{\text{type}='DB' \wedge \text{type}='HCI'} (\text{Book})))$
 $\pi_{\text{name}}(\text{tmp} \bowtie \text{Reserve} \bowtie \text{Student})$

for b in Book:

if b.type = 'DB' and b.type = 'HCI': // resolves to FALSE

for r in Reserve:

for s in Student:

if r.sid = s.sid and r.bid = b.bid:

yield b.name

Students that reserved a DB and HCl book

Does previous approach work?

1. Find students that reserved DB books
2. Find students that reserved HCl books
3. Intersection

$$\begin{aligned} & \rho(\text{tmpDB}, \pi_{\text{sid}}(\sigma_{\text{type}=\text{'DB'}} \text{Book}) \bowtie \text{Reserve}) \\ & \rho(\text{tmpHCl}, \pi_{\text{sid}}(\sigma_{\text{type}=\text{'HCl'}} \text{Book}) \bowtie \text{Reserve}) \\ & \pi_{\text{name}}((\text{tmpDB} \cap \text{tmpHCl}) \bowtie \text{Student}) \end{aligned}$$

Students that reserved all books

Students where, **for all books**, the student reserved the book
no concept of “for all” in relational algebra...

Students – Students that didn't reserve all books

Students that reserved all books

Students where, **for all books**, the student reserved the book
no concept of “for all” in relational algebra...

Students – Students where there is a book that they did not reserve

Students that reserved all books

Students where, **for all books**, the student reserved the book
no concept of “for all” in relational algebra...

Students – (Students s where (Books – Books s reserved))
$$p(s_reserved, \pi_{bid} \sigma_{sid=bob}(Reserve))$$

Students – (Students s where (Books – Books s reserved))
$$p(s_not_reserved, \pi_{bid}(Books) - s_res)$$

Students – (Students s where (Books – Books s reserved))
$$\pi_{sid,bid}(Students \times Books)$$

Students that reserved all books

Students where, **for all books**, the student reserved the book
no concept of “for all” in relational algebra...

Students – (Students s where (Books – Books s reserved))
$$p(s_reserved, \pi_{bid} \sigma_{sid=bob}(Reserve))$$

Students – (Students s where (Books – Books s reserved))
$$p(s_not_reserved, \pi_{bid}(Books) - s_res)$$

Students – (Students s where (Books – Books s reserved))
$$\pi_{sid,bid}(Students \times Books) - \pi_{sid,bid}(Reserve)$$

Students that reserved all books

Students where, **for all books**, the student reserved the book
no concept of “for all” in relational algebra...

Students – (Students s where (Books – Books s reserved))
$$p(s_reserved, \pi_{bid} \sigma_{sid=bob}(Reserve))$$

Students – (Students s where (Books – Books s reserved))
$$p(s_not_reserved, \pi_{bid}(Books) - s_res)$$

Students – (Students s where (Books – Books s reserved))
$$p(del_sids, \pi_{sid}(\pi_{sid,bid}(Students \times Books) - \pi_{sid,bid}(Reserve)))$$

Students that reserved all books

Students where, **for all books**, the student reserved the book
no concept of “for all” in relational algebra...

Students – (Students s where (Books – Books s reserved))
 $\rho(s_reserved, \pi_{bid} \sigma_{sid=bob}(Reserve))$

Students – (Students s where (Books – Books s reserved))
 $\rho(s_not_reserved, \pi_{bid}(Books) - s_res)$

Students – (Students s where (Books – Books s reserved))
 $\rho(del_sids, \pi_{sid}(\pi_{sid,bid}(Students \times Books) - \pi_{sid,bid}(Reserve)))$

$\pi_{sid}(Students) - del_sids$

Students that reserved all books

(Not covered in class)

Use division

Be careful with schemas of inputs to / !

Books(rid, type) Reserves(sid, rid, date) Students(sid,)

p(tmp, (Reserves / Books))

tmp ⋈ Students

Type error

Students that reserved all books

(Not covered in class)

Use division

Be careful with schemas of inputs to / !

Books(rid, type) Reserves(sid, rid, date) Students(sid,)

$p(tmp, (Reserves / \pi_{rid}(Books)))$

$tmp \bowtie Students$

Each student must have reserved all books on the same date!

Students that reserved all books

(Not covered in class)

Use division

Be careful with schemas of inputs to / !

Books(rid, type) Reserves(sid, rid, date) Students(sid)

$\rho(\text{tmp}, (\pi_{\text{sid,rid}} (\text{Reserves})) / (\pi_{\text{rid}} (\text{Books})))$

$\text{tmp} \bowtie \text{Student}$

What if want students that reserved all horror books?

$\rho(\text{tmp}, (\pi_{\text{sid,rid}} \text{Reserves}) / (\pi_{\text{rid}} (\sigma_{\text{type}='horror'} \text{Book})))$

Let's step back

Relational algebra is expressiveness benchmark

A language that can express relational algebra is
“relationally complete”

Limitations

nulls

aggregation

recursion

duplicates

can't really type on keyboard...

Equi-Joins are everywhere

Matching of two sets based on shared attributes

Yelp: Join between your location and restaurants

Market: Join between consumers and suppliers

High five: Join between two hands on time and space

Comm.: Join between minds on ideas/concepts

PLANES



ARE JOINS BETWEEN CITIES

imgflip.com

Who Cares about Relational Alg?

Clean query semantics & rich program analysis

Helps/enables optimization

Opens up rich set of topics

- Materialized views

- Data lineage/provenance

- Query by example

- Distributed query execution

- ...

You see its fingerprints **EVERYWHERE!**

What can we do with RA?

Query(DB instance) \rightarrow Relation instance

What can we do with RA?

Query(**DB instance**) = **Relation instance**

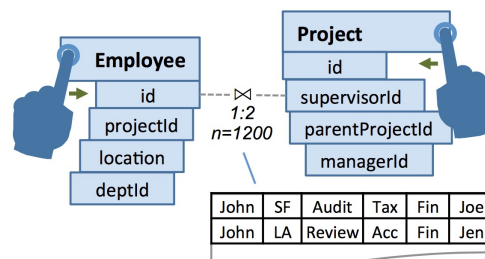
Query by example

Here's **DB instance** and **result**, generate the **query**

Data Generation:

Here's **query** and **result**, generate a **DB instance**

Novel relationally
complete interfaces



GestureDB. Nandi et al.

Summary

Relational Algebra (RA) operators

Operators are closed

inputs & outputs are relations

Multiple Relational Algebra queries can be equivalent

It is operational

Same semantics but different performance

Forms basis for optimizations

Next Time

~~Relational Calculus~~

SQL