



Advanced Database Systems

Spring 2026

Lecture #03:

Relational Algebra

R&G: Chapters 4.1 & 4.2

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QUERY EXECUTION OVERVIEW

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SQL Query

```
SELECT S.name
FROM Student S, Enrolled E
WHERE S.sid = E.sid
AND E.cid = 'INF-11199'
```

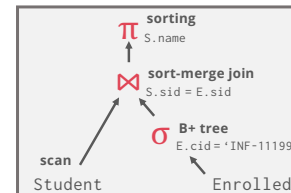


Relational Algebra

```
 $\pi_{S.name}(\sigma_{E.cid = 'INF-11199'}(Student \bowtie_{S.sid = E.sid} Enrolled))$ 
```

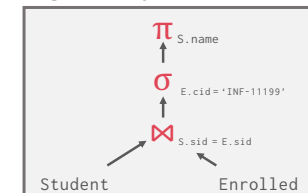
Equivalent to...

Optimised Physical Query Plan



But actually will
produce plan with
operator code

Logical Query Plan



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QUERY EXECUTION OVERVIEW

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SQL Query

```
SELECT S.name
FROM Student S, Enrolled E
WHERE S.sid = E.sid
AND E.cid = 'INF-11199'
```

Declarative description of computation

Say what you want, not how to get it
Enables system to optimize the how

Foundation in formal query languages

Relational Calculus

Relational Algebra

```
 $\pi_{S.name}(\sigma_{E.cid = 'INF-11199'}(Student \bowtie_{S.sid = E.sid} Enrolled))$ 
```

Operational description of computation

Systems execute RA query plans

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RELATIONAL QUERY LANGUAGES

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Relational Calculus (basis for SQL)

Describe the result of computation

Based on first order logic

Tuple Relational Calculus (TRC)

```
{ S | S ∈ Student ∃ E ∈ Enrolled  
( S.sid = E.sid ∧ E.cid = 'INF-11199' ) }
```

Relational Algebra

Algebra on sets

Operational description of transformations



Are these two
equivalent?

Can we go from one
to the other?

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CODD'S THEOREM

Established equivalence in expressivity between:

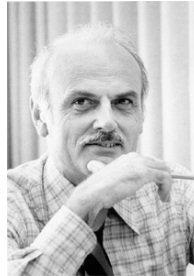
Relational Calculus

Relational Algebra

Why an important result?

Connects declarative representation of queries with operational description

Constructive: we can compile SQL into relational algebra



Edgar F. "Ted" Codd
(1923 - 2003)
Turing Award 1981

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RELATIONAL ALGEBRA

Algebra of operators on relation instances

$\pi_{S.name}(\sigma_{E.cid='INF-11199'}(S \bowtie_{S.sid=E.sid} E))$

Closed: result is also a relation instance

Enables rich composition!

Typed: input schema determines output schema

Can statically check whether queries are legal

σ	Selection
π	Projection
ρ	Renaming
\cup	Union
$-$	Set Difference
\times	Cross Product
\cap	Intersection
\bowtie	Join

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RELATIONAL ALGEBRA AND SETS

Pure relational algebra has set semantics

No duplicate tuples in a relation instance

But can also be defined over bags (multisets)

SQL has multiset (bag) semantics

We will switch to multiset in the system discussion

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SELECTION

Syntax: $\sigma_{\text{predicate}}(R)$

Select a subset of rows (horizontal)
that satisfy a selection predicate

Can combine predicates using conjunctions / disjunctions

Output schema same as input

Duplicate elimination? Not needed

$R(aid, bid)$

aid	bid
a1	101
a2	102
a2	103
a3	104

$\sigma_{aid='a2' \wedge bid > 102}(R)$

aid	bid
a2	103

$\sigma_{aid='a2'}(R)$

aid	bid
a2	102
a2	103

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PROJECTION

Syntax: $\pi_{A1, A2, \dots, An}(R)$

Selects a subset of columns (vertical)

Schema determined by schema of attribute list

Set semantics \rightarrow results in fewer rows

Real systems don't automatically remove duplicates
Why?

- 1) Semantics: keep duplicates for aggregates
- 2) Performance: deduplication not free

$R(aid, bid)$

aid	bid
a1	101
a2	102
a2	103
a3	104

$\pi_{aid}(R)$

aid
a1
a2
a3

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UNION



Syntax: $R \cup S$

Two input relations must be **compatible**

Same number of fields

Fields in corresponding positions have same type

Duplicate elimination in practice (SQL)?

UNION – eliminates duplicates

UNION ALL – keeps duplicates

$R(aid, bid)$

aid	bid
a1	101
a2	102
a3	103

$S(aid, bid)$

aid	bid
a3	103
a4	104
a5	105

$R \cup S$

aid	bid
a1	101
a2	102
a3	103
a4	104
a5	105

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SET DIFFERENCE



Syntax: $R - S$

Same as with union, both input relations must be **compatible**

Duplicate elimination? Not needed

SQL expression: EXCEPT

EXCEPT vs EXCEPT ALL

$R(aid, bid)$

aid	bid
a1	101
a2	102
a3	103

$S(aid, bid)$

aid	bid
a3	103
a4	104
a5	105

$R - S$

aid	bid
a1	101
a2	102

$S - R$

aid	bid
a4	103
a5	105

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CROSS PRODUCT

Syntax: $R \times S$

Each row of R paired with each row of S

How many rows in result? $|R| * |S|$

Schema compatibility? Not needed

Duplicates? None generated

$R \times S$ has two bid attributes

Not allowed, leave them unnamed

Identify attributes by position

$R(aid, bid)$

aid	bid
a1	101
a2	102
a3	103

$S(bid, cid)$

bid	cid
b3	23
b4	24

$R \times S$

aid	(bid)	(bid)	cid
a1	101	b3	23
a1	101	b4	24
a2	102	b3	23
a2	102	b4	24
a3	103	b3	23
a3	103	b4	24

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RENAMING (ρ = "rho")

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Renames relations and their attributes

Note that relational algebra doesn't require names

We could just use positional arguments

$\rho(\text{Temp}(2 \rightarrow \text{bid1}, 3 \rightarrow \text{bid2}), R \times S)$

Output Relation
Name

Renaming List
position \rightarrow new name

Input
Expression

$R \times S$

aid	(bid)	(bid)	cid
a1	101	b3	23
a1	101	b4	24
a2	102	b3	23
a2	102	b4	24

Temp

aid	bid1	bid2	cid
a1	101	b3	23
a1	101	b4	24
a2	102	b3	23
a2	102	b4	24

COMPOUND OPERATOR: INTERSECTION

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Syntax: $R \cap S$



Same as with union, both input relations must be **compatible**

SQL expression: INTERSECT

Equivalent to: $R - (R - S)$

$R(\text{aid}, \text{bid})$

aid	bid
a1	101
a2	102
a3	103

$S(\text{aid}, \text{bid})$

aid	bid
a3	103
a4	104
a5	105

$R \cap S$

aid	bid
a3	103

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COMPOUND OPERATOR: JOIN

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Joins are compound operators (like intersection):

Generally, $\sigma_{\theta}(R \times S)$

Hierarchy of common kinds:

Theta Join (\bowtie_{θ}): join on logical expression θ

Equi-Join: theta join with theta being a conjunction of equalities

Natural Join (\bowtie): equi-join on all matching column names

Note: we will need to learn a good join algorithm

Avoid cross-product if we can!

THETA JOIN EXAMPLE

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Student

sid	name	age
12344	Jones	18
12355	Smith	23
12366	Gold	21

Student $\bowtie_{\text{sid}=\text{sid}}$ Enrolled

(sid)	name	age	(sid)	cid	grade
12344	Jones	18	12344	INF-10080	65
12355	Smith	23	12355	INF-11199	72

Enrolled

sid	cid	grade
12344	INF-10080	65
12355	INF-11199	72

Note that output needs a rename operator!

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THETA JOIN EXAMPLE 2

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Example: Get senior students for each student

Student ⋈_{field3 < field6} **Student** (i.e., age < age2)

$$R \bowtie_{\theta} S = \sigma_{\theta}(R \times S)$$

Student ⋈_{field3 < field6} **Student**

(sid)	(name)	(age)	(sid)	(name)	(age)
12344	Jones	18	12355	Smith	23
12344	Jones	18	12366	Gold	21
12366	Gold	21	12355	Smith	23

Output schema same as that of cross product

Student

sid	name	age
12344	Jones	18
12355	Smith	23
12366	Gold	21

NATURAL JOIN

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Syntax: **R** ⋈ **S**

Special case of equi-join in which equalities are specified for all matching fields and duplicate fields are projected away

$$R \bowtie S = \pi_{\text{unique fld.}} \sigma_{\text{eq.matching fld.}} (R \times S)$$

Compute $R \times S$

Select rows where fields appearing in both relations have equal values

Project onto the set of all unique fields

R(aid, bid)

aid	bid
a1	101
a2	102
a3	103

S(bid, cid)

bid	cid
101	c3
101	c4
105	c5

R ⋈ S

aid	bid	cid
a1	101	c3
a1	101	c4

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EXTRA OPERATORS

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Group By / Aggregation (**γ**)

$\gamma_{\text{dept, AVG(age)}}(\text{Student})$

$\gamma_{\text{dept, AVG(age), COUNT(*) > 2}}(\text{Student})$

with selection (HAVING clause)

Duplicate Elimination (**δ**)

only under multiset (bag) interpretation of relational algebra

Assignment (**R ← S**)

Sorting (**τ**)

Division (**R ÷ S**)

SUMMARY

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Relational Algebra

A small set of operators mapping relations to relations

Operational, in the sense that you specify the explicit order of operations

A closed set of operators! Mix and match

Basic operators: **σ**, **π**, **ρ**, **U**, **-**, **×**

Important compound operators: **⋈**, **⋈_⊆**

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