

Chapter 6: Formal Relational Query Languages

Database System Concepts, 6th Ed.

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Chapter 6: Formal Relational Query Languages

Relational Algebra



Relational Algebra

- Procedural language
- Six basic operators
 - □ select: σ
 - □ project: ∏
 - □ union: ∪
 - set difference: -
 - Cartesian product: x
 - \square rename: ρ
- ☐ The operators take one or two relations as inputs and produce a new relation as a result.



Select Operation – Example

Relation r

A	В	C	D
α	α	1	7
α	β	5	7
β	β	12	3
β	β	23	10

$$\bullet$$
 $\sigma_{A=B \land D > 5}(r)$

A	В	C	D
α	α	1	7
β	β	23	10



Select Operation

- □ Notation: $\sigma_p(r)$
- \square p is called the **selection predicate**
- Defined as:

$$\sigma_p(\mathbf{r}) = \{t \mid t \in r \text{ and } p(t)\}$$

Where p is a formula in propositional calculus consisting of **terms** connected by : \land (**and**), \lor (**or**), \neg (**not**) Each **term** is one of:

<attribute> op <attribute> or <constant>

where *op* is one of: =, \neq , >, \geq . <. \leq

Example of selection:



Project Operation – Example

□ Relation *r*.

A	В	C
α	10	1
α	20	1
β	30	1
β	40	2

 \square $\prod_{A,C} (r)$

\boldsymbol{A}	C	A	C
α	1	α	1
α	1	β	1
β	1	β	2
β	2		



Project Operation

Notation:

$$\prod_{A_1,A_2,\ldots,A_k}(r)$$

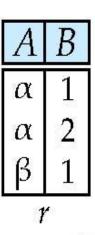
- where A_1 , A_2 are attribute names and r is a relation name.
- The result is defined as the relation of k columns obtained by erasing the columns that are not listed
- Duplicate rows removed from result, since relations are sets
- Example: To eliminate the dept_name attribute of instructor

 $\Pi_{ID, name, salary}$ (instructor)



Union Operation – Example

□ Relations *r*, *s*:



A	В
α	2
β	3

 \square $r \cup s$:



Union Operation

- □ Notation: $r \cup s$
- Defined as:

$$r \cup s = \{t \mid t \in r \text{ or } t \in s\}$$

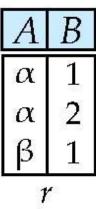
- \square For $r \cup s$ to be valid.
 - 1. *r*, *s* must have the *same* **arity** (same number of attributes)
 - 2. The attribute domains must be **compatible** (example: 2^{nd} column of r deals with the same type of values as does the 2^{nd} column of s)
- Example: to find all courses taught in the Fall 2009 semester, or in the
 Spring 2010 semester, or in both

$$\Pi_{course_id}(\sigma_{semester="Fall"} \land year=2009(section)) \cup \Pi_{course_id}(\sigma_{semester="Spring"} \land year=2010(section))$$



Set difference of two relations

□ Relations *r*, *s*:



A	В
α	2
β	3

 \Box r-s

A	В
α	1
β	1



Set Difference Operation

- □ Notation r s
- Defined as:

$$r-s = \{t \mid t \in r \text{ and } t \notin s\}$$

- Set differences must be taken between compatible relations.
 - r and s must have the same arity
 - attribute domains of *r* and *s* must be compatible
- Example: to find all courses taught in the Fall 2009 semester, but not in the Spring 2010 semester

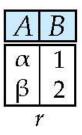
$$\Pi_{course_id}(\sigma_{semester="Fall"} \land year=2009(section))$$
 -

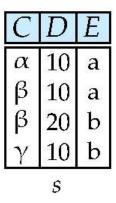
$$\Pi_{course_id}(\sigma_{semester="Spring"} \land year=2010(section))$$



Cartesian-Product Operation – Example

□ Relations *r*, *s*:





 \square $r \times s$:

A	В	C	D	Ε
α	1	α	10	a
α	1	β	10	a
α	1	β	20	b
α	1	γ	10	b
β	2	α	10	a
β	2	β	10	a
β	2	β	20	b
β	2	γ	10	b



Cartesian-Product Operation

- \square Notation $r \times s$
- Defined as:

$$r \times s = \{t \mid q \mid t \in r \text{ and } q \in s\}$$

- Assume that attributes of r(R) and s(S) are disjoint. (That is, $R \cap S = \emptyset$).
- If attributes of r(R) and s(S) are not disjoint, then renaming must be used.



Composition of Operations

- Can build expressions using multiple operations
- □ Example: $\sigma_{A=C}(r \times s)$
- \square rxs

A	В	C	D	Ε
α	1	α	10	a
α	1	β	10	a
α	1	β	20	b
α	1	γ	10	b
β	2	α	10	a
β	2	β	10	a
β	2	β	20	b
β	2	γ	10	b

 \Box $\sigma_{A=C}(r \times s)$

A	В	C	D	E
α	1	α	10	a
β	2	β	10	a
β	2	β	20	b



Rename Operation

- Allows us to name, and therefore to refer to, the results of relationalalgebra expressions.
- Allows us to refer to a relation by more than one name.
- Example:

$$\rho_X(E)$$

returns the expression *E* under the name *X*

□ If a relational-algebra expression E has arity n, then

$$\rho_{x(A_1,A_2,...,A_n)}(E)$$

returns the result of expression E under the name X, and with the attributes renamed to A_1 , A_2 ,, A_n .



Example Query

- Find the largest salary in the university
 - Step 1: find instructor salaries that are less than some other instructor salary (i.e. not maximum)
 - using a copy of instructor under a new name d
 - $\Pi_{instructor.salary}$ ($\sigma_{instructor.salary} < d_{instructor}$)) (instructor $\times \rho_{d}$ (instructor)))
 - Step 2: Find the largest salary

```
 \begin{array}{c} \Pi_{salary} \ (\textit{instructor}) - \\ \Pi_{\textit{instructor.salary}} \ (\sigma_{\textit{instructor.salary}} < \textit{d,salary} \\ (\textit{instructor} \ \textit{x} \ \rho_{\textit{d}} \ (\textit{instructor}))) \end{array}
```



Example Queries

- Find the names of all instructors in the Physics department, along with the course_id of all courses they have taught
 - Query 1

```
\prod_{instructor.ID,course\_id} (\sigma_{dept\_name="Physics"} (\sigma_{instructor.ID=teaches.ID} (instructor x teaches)))
```

Query 2

```
\prod_{instructor.ID,course\_id} (\sigma_{instructor.ID=teaches.ID} (\sigma_{dept\_name="Physics"} (instructor) x teaches))
```



Formal Definition

- A basic expression in the relational algebra consists of either one of the following:
 - A relation in the database
 - A constant relation
- Let E_1 and E_2 be relational-algebra expressions; the following are all relational-algebra expressions:
 - \Box $E_1 \cup E_2$
 - $E_1 E_2$
 - \Box $E_1 \times E_2$
 - $\sigma_p(E_1)$, P is a predicate on attributes in E_1
 - \square $\prod_{S}(E_1)$, S is a list consisting of some of the attributes in E_1
 - $\rho_{X}(E_{1})$, x is the new name for the result of E_{1}



Additional Operations

We define additional operations that do not add any power to the relational algebra, but that simplify common queries.

- Set intersection
- Natural join
- Assignment
- Outer join



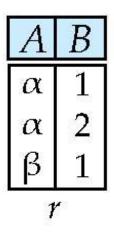
Set-Intersection Operation

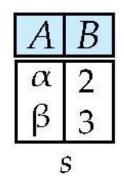
- \square Notation: $r \cap s$
- Defined as:
- Assume:
 - □ *r*, *s* have the *same arity*
 - attributes of r and s are compatible



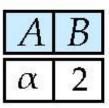
Set-Intersection Operation – Example

□ Relation *r*, *s*:





 \square $r \cap s$





Natural-Join Operation

- Notation: r ⋈s
- Let r and s be relations on schemas R and S respectively. Then, $r \bowtie s$ is a relation on schema $R \cup S$ obtained as follows:
 - Consider each pair of tuples t_r from r and t_s from s.
 - If t_r and t_s have the same value on each of the attributes in $R \cap S$, add a tuple t to the result, where
 - t has the same value as t_r on r
 - t has the same value as t_S on s
- Example:

$$R = (A, B, C, D)$$

$$S = (E, B, D)$$

- □ Result schema = (A, B, C, D, E)
- $r\bowtie s$ is defined as:

$$\prod_{r.A, r.B, r.C, r.D, s.E} (\sigma_{r.B = s.B \land r.D = s.D} (r \times s))$$



Natural Join Example

□ Relations r, s:

A	В	C	D
α	1	α	a
β	2	γ	a
γ	4	β	b
α	1	γ	a
δ	2	β	b

В	D	Ε
1	a	α
3	a	β
1	a	γ
2	b	δ
3	b	3
	S	

□ r⋈s

A	В	C	D	E
α	1	α	a	α
α	1	α	a	γ
α	1	γ	a	α
α	1	γ	a	γ
δ	2	β	b	δ



Natural Join

- ☐ Find the names of all instructors in the Comp. Sci. department together with the course titles of all the courses that the instructors teach
 - $\ \ \square \ \ \ \prod_{name, \ title} (\sigma_{dept_name="Comp. \ Sci."} \ (instructor \bowtie teaches \bowtie course))$
- Natural join is associative
 - □ (instructor \bowtie teaches) \bowtie course is equivalent to instructor \bowtie (teaches \bowtie course)
- Natural join is commutative
 - instruct ⋈ teaches is equivalent to teaches ⋈ instructor



Assignment Operation

- □ The assignment operation (\leftarrow) provides a convenient way to express complex queries.
 - Write query as a sequential program consisting of
 - a series of assignments
 - followed by an expression whose value is displayed as a result of the query.
 - Assignment must always be made to a temporary relation variable.



Outer Join

- An extension of the join operation that avoids loss of information.
- Computes the join and then adds tuples form one relation that does not match tuples in the other relation to the result of the join.
- □ Uses *null* values:
 - null signifies that the value is unknown or does not exist
 - All comparisons involving *null* are (roughly speaking) **false** by definition.
 - We shall study precise meaning of comparisons with nulls later



Outer Join – Example

□ Relation *instructor*

ID	name	dept_name
10101	Srinivasan	Comp. Sci.
12121	Wu	Finance
15151	Mozart	Music

□ Relation *teaches*

ID	course_id
10101	CS-101
12121	FIN-201
76766	BIO-101



Outer Join – Example

Join

instructor ⋈ *teaches*

ID	name	dept_name	course_id
10101	Srinivasan	Comp. Sci.	CS-101
12121	Wu	Finance	FIN-201

■ Left Outer Join

instructor \(\sqrt{teaches} \)

ID	name	dept_name	course_id
10101	Srinivasan	Comp. Sci.	CS-101
12121	Wu	Finance	FIN-201
15151	Mozart	Music	null



Outer Join – Example

□ Right Outer Join

instructor ⋈ *teaches*

ID	name	dept_name	course_id
10101	Srinivasan	Comp. Sci.	CS-101
12121	Wu	Finance	FIN-201
76766	null	null	BIO-101

□ Full Outer Join

instructor \(\subseteq \) teaches

ID	name	dept_name	course_id
10101	Srinivasan	Comp. Sci.	CS-101
12121	Wu	Finance	FIN-201
15151	Mozart	Music	null
76766	null	null	BIO-101



Null Values

- It is possible for tuples to have a null value, denoted by *null*, for some of their attributes
- null signifies an unknown value or that a value does not exist.
- ☐ The result of any arithmetic expression involving *null* is *null*.
- Aggregate functions simply ignore null values (as in SQL)
- ☐ For duplicate elimination and grouping, null is treated like any other value, and two nulls are assumed to be the same (as in SQL)



Null Values

- Comparisons with null values return the special truth value: unknown
- ☐ Three-valued logic using the truth value *unknown*:

```
OR: (unknown or true) = true,(unknown or false) = unknown(unknown or unknown) = unknown
```

- AND: (true and unknown) = unknown,(false and unknown) = false,(unknown and unknown) = unknown
- □ NOT: (**not** *unknown*) = *unknown*
- In SQL "P is unknown" evaluates to true if predicate P evaluates to unknown
- Result of select predicate is treated as false if it evaluates to unknown



Division Operator

Given relations r(R) and s(S), such that $S \subset R$, $r \div s$ is the largest relation t(R-S) such that

$$t \times s \subset r$$

- E.g. let $r(ID, course_id) = \prod_{ID, course_id} (takes)$ and $s(course_id) = \prod_{course_id} (\sigma_{dept_name="Biology"}(course)$ then $r \div s$ gives us students who have taken all courses in the Biology department
- □ Can write r ÷ s as

$$temp1 \leftarrow \prod_{R-S} (r)$$

 $temp2 \leftarrow \prod_{R-S} ((temp1 \times s) - \prod_{R-S,S} (r))$
 $result = temp1 - temp2$

- □ The result to the right of the ← is assigned to the relation variable on the left of the ←.
- May use variable in subsequent expressions.



relations *r, s*:

Α	В
$\begin{bmatrix} \alpha \\ \alpha \\ \alpha \\ \beta \\ \gamma \\ \delta \\ \delta \\ \epsilon \end{bmatrix}$	1 2 3 1 1 1 3 4 6
β	1 2

В S

 \square $r \div s$:

 $\begin{bmatrix} A \\ \alpha \\ B \end{bmatrix}$



Extended Relational-Algebra-Operations

- Generalized Projection
- Aggregate Functions



Generalized Projection

Extends the projection operation by allowing arithmetic functions to be used in the projection list.

$$\prod_{F_1, F_2}, ..., F_n(E)$$

- ☐ *E* is any relational-algebra expression
- Each of F_1 , F_2 , ..., F_n are are arithmetic expressions involving constants and attributes in the schema of E.
- Given relation instructor(ID, name, dept_name, salary) where salary is annual salary, get the same information but with monthly salary

 $\Pi_{ID, name, dept name, salary/12}$ (instructor)



Aggregate Functions and Operations

Aggregation function takes a collection of values and returns a single value as a result.

avg: average valuemin: minimum valuemax: maximum valuesum: sum of values

count: number of values

Aggregate operation in relational algebra

$$G_1, G_2, ..., G_n \in F_1(A_1), F_2(A_2, ..., F_n(A_n))$$

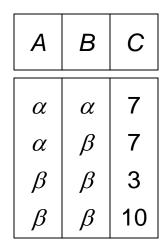
E is any relational-algebra expression

- G_1, G_2, \dots, G_n is a list of attributes on which to group (can be empty)
- \square Each F_i is an aggregate function
- \Box Each A_i is an attribute name
- lacktriangledown Note: Some books/articles use γ instead of $\mathcal G$ (Calligraphic G)



Aggregate Operation – Example

□ Relation *r*.



 $\ \ \ \ \mathcal{G}_{\mathbf{sum(c)}}(\mathbf{r})$

sum(c) 27



Aggregate Operation – Example

Find the average salary in each department $dept_name \ Gavg(salary)$ (instructor)

ID	name	dept_name	salary
76766	Crick	Biology	72000
45565	Katz	Comp. Sci.	75000
10101	Srinivasan	Comp. Sci.	65000
83821	Brandt	Comp. Sci.	92000
98345	Kim	Elec. Eng.	80000
12121	Wu	Finance	90000
76543	Singh	Finance	80000
32343	El Said	History	60000
58583	Califieri	History	62000
15151	Mozart	Music	40000
33456	Gold	Physics	87000
22222	Einstein	Physics	95000

dept_name	avg_salary
Biology	72000
Comp. Sci.	77333
Elec. Eng.	80000
Finance	85000
History	61000
Music	40000
Physics	91000



Aggregate Functions (Cont.)

- Result of aggregation does not have a name
 - Can use rename operation to give it a name
 - For convenience, we permit renaming as part of aggregate operation

dept_name Gavg(salary) as avg_{sal} (instructor)