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Relational Algebra: Part III

Complete Course on Database Management System

Vishvadeep Gothi • Lesson 19 • July 12, 2023

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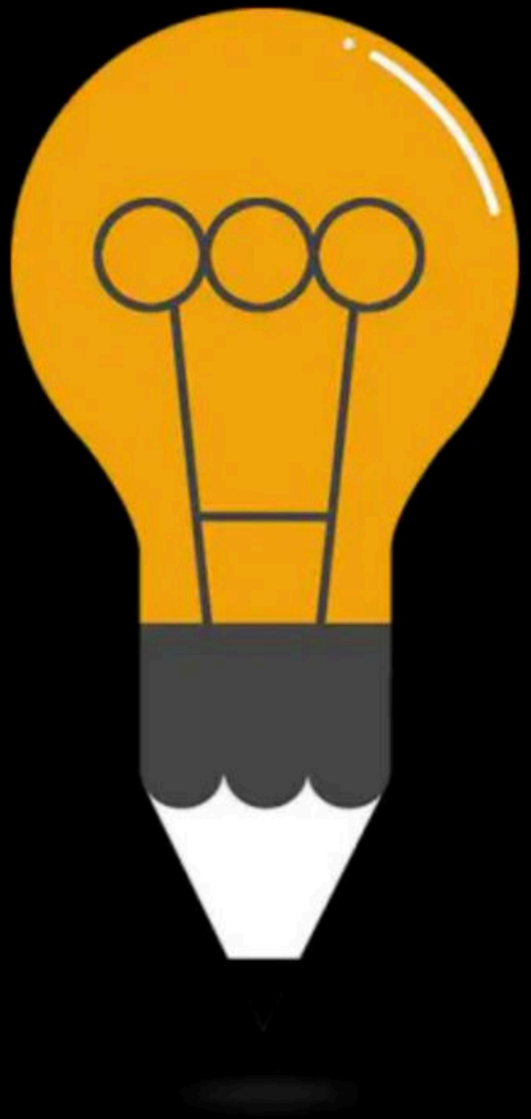

DBMS

Relational Algebra 3

By: Vishvadeep Gothi

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Relational Algebra

Basics Operators:

1. Select (σ)
2. Project (∏)
3. Union (∪)
4. Set Difference (−)
5. Intersection (∩)
6. Cartesian Product (X) 
7. Rename (ρ)
8. Division (÷)

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Joins

1. Condition Join
2. Equi Join
3. Natural Join

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Condition Join

E

Eid	Ename	Rating	Age
20	Ravish	8	24.0
30	Radha	7	25.0
40	Shyam	9	26.0

P

Eid	Pid	Day
20	120	2/8/21
40	115	5/6/21

$$E \bowtie_{E.Eid<P.Eid} P$$

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Equi Join

Employee

Eno	Ename	Sex	Age
101	Ravi	M	24.0
102	Satyam	M	25.0
103	Meera	F	23.0
104	Rohan	M	27.0

Drives

EmpNo	Car
101	Volvo
103	Mercedes
104	Jaguar
104	Toyota

$$Employee \bowtie_{Employee.ENo=Drives.EmpNo} Drives$$

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Natural Join

Student

Rollno	Student_name
1	Amit
2	Priya
3	Rohan
4	Komal

Performance

Rollno	Subject_code	Marks
1	A	84
1	B	90
2	C	92
3	A	85

$$Student \bowtie Performance$$

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Question

Find the name of the customers who have placed atleast one order shipped by shippedID 3?

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Question

Consider following relations:

Drivers (did, dname, rating)

Cars (cid, cmodel, ccolor)

Drives (Did, cid, dateofRace)

Write a query to find all such drivers name who have driven blue color car?

$$\Pi_{dname}\left(\sigma_{drivers.did = drives.did \wedge cars.cid = drives.cid \wedge ccolor = 'blue'}(Drivers \times cars \times Drives)\right)$$

Π_{dname}

$\sigma_{color = 'blue'}$

$(Drivers \bowtie_{Drivers.did = Drives.did} Drives \bowtie_{Drives.cid = cars.cid}$ cars

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Question

Write a query to find all such drivers name who have driven blue color car or Black color car?

$$\pi_{dname}\left(\sigma_{drivers.did = drives.did \wedge cars.cid = drives.cid \wedge (ccolor = 'blue' \vee ccolor = 'black')}\left(drivers \times cars \times drives\right)\right)$$

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Question

Write a query to find all such drivers name who have driven blue color car and Black color car?

$$\left(\pi_{\text{dname, drivers.did}}\left(\sigma_{\text{drivers.did} = \text{drives.did} \wedge \text{cars.cid} = \text{drives.cid} \wedge \text{color} = \text{'blue'}}(\text{drivers} \times \text{cars} \times \text{drives})\right)\right)$$

$$\cap$$

$$\left(\pi_{\text{dname, drivers.did}}\left(\sigma_{\text{drivers.did} = \text{drives.did} \wedge \text{cars.cid} = \text{drives.cid} \wedge \text{color} = \text{'black'}}(\text{drivers} \times \text{cars} \times \text{drives})\right)\right)$$

Ques) Write a R.A. statements to find name of all such drivers who have driven either green car or red car but not both?

$$(\text{set}(\text{green}) \cup \text{set}(\text{red})) - (\text{green} \cap \text{set})$$

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$$\pi_{drivers.did,\,dname}\left(\sigma_{(color='green'\ \vee\ color='red')}\left(drivers \bowtie drives \bowtie cars\right)\right)$$

$$-\left(\left(\pi_{drivers.did,\,dname}\left(\sigma_{color='green'}\left(drivers \bowtie drives \bowtie cars\right)\right)\right)\right.$$

$$\left.\cap\left(\pi_{drivers.did,\,dnam}\left(\sigma_{color='red'}\left(drivers \bowtie drives \bowtie cars\right)\right)\right)\right)$$

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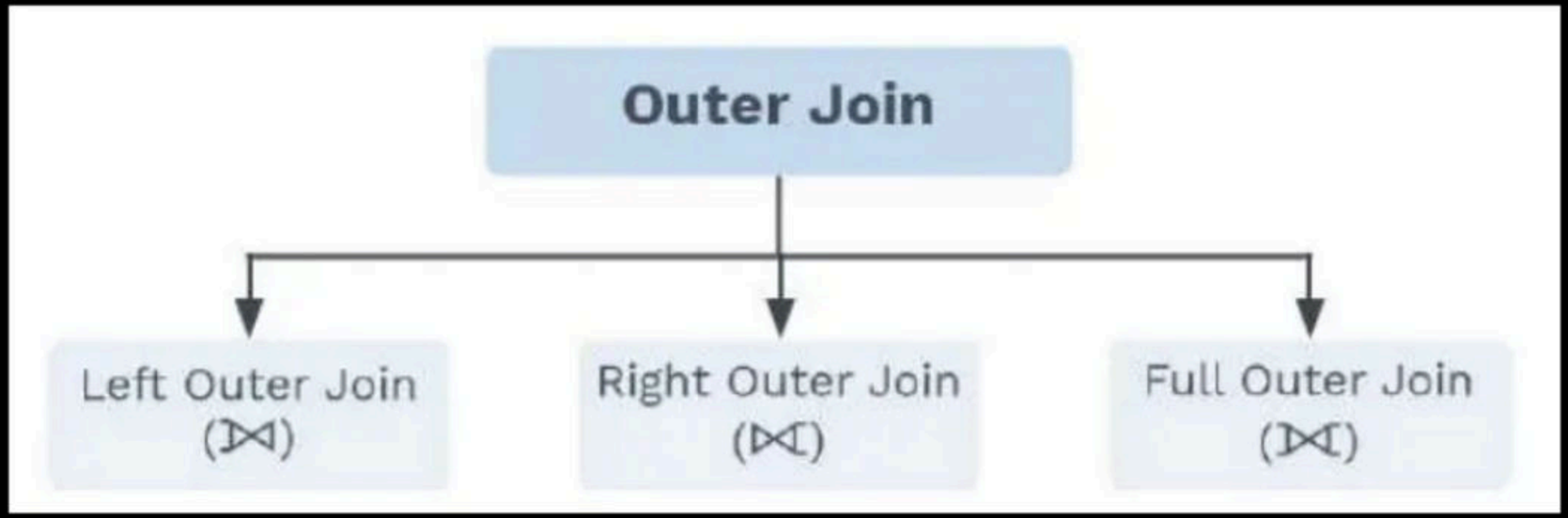
Outer Join



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Rename Operator

Rename (ρ)

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Rename Operator

$\rho_{\text{newname}}(\text{original})$

$\rho_{S}(\text{Student})$

Rename Operator

$\rho_{\text{newname}(c1, c2, \ldots.. cn)}$ (original)

Student

$\rho_{S(R, N, D)}$ (student)

only column names to be renamed :-

$\rho_{r,n,d}$ (student) $\Leftarrow$ new alias of table, with columns r, n, d

$\rho_{rno \rightarrow r}$ (student)

$\rho_{rno \rightarrow r,\ name \rightarrow n}$ (student)

Division Operator

$R1 \div R2$

$R2 \subseteq R1$

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Division Operator

R1

A	B	C
A1	A2	C1
A4	A5	C2
A1	A2	C3
A4	A5	C4

R2

A	B
A1	A2
A4	A5

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Question

Consider following relations:

Cars (cid, cmodel, ccolor)

Drives (Did, cid, dateofRace)

Write a query to find all such drivers id who have driven all cars?

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Question

Consider following relations:

Cars (cid, cmodel, ccolor)

Drives (Did, cid, dateofRace)

Write a query to find all such drivers id who have driven all cars in a day?

Question GATE-2004

Consider the relation Student (name, sex, marks), where the primary key is shown underlined, pertaining to students in a class that has at least one boy and one girl. What does the following relational algebra expression produce? (Note: ρ is the rename operator).

$$\pi_{name}\{\sigma_{sex=female}(\text{Student})\} - \pi_{name}(\text{Student} \bowtie_{(sex=female \wedge x=male \wedge marks \leq m)} \rho_{n,x,m}(\text{Student}))$$

A. names of girl students with the highest marks
B. names of girl students with more marks than some boy student
C. names of girl students with marks not less than some boy student
D. names of girl students with more marks than all the boy students

(name of all female students) — (name of all female students who have scored equal or lesser than any male student)

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student

Name	sex	Marks
	f	50
	F	
	F	
	f	

student

n	x	m
	M	50
	M	60
	M	70
	M	10

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Question GATE-2007

Information about a collection of students is given by the relation studInfo(studId, name, sex). The relation enroll(studId, courseId) gives which student has enrolled for (or taken) what course(s). Assume that every course is taken by at least one male and at least one female student. What does the following relational algebra expression represent?

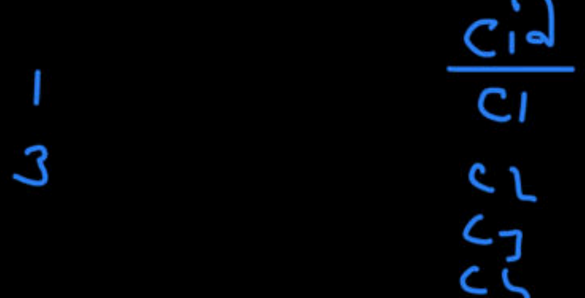
$$\Pi_{\text{courseId}}\left(\left(\Pi_{\text{studId}}\left(\sigma_{\text{sex="female"}}\left(\text{studInfo}\right)\right)\times\Pi_{\text{courseId}}\left(\text{enroll}\right)\right)-\text{enroll}\right)$$

A. Courses in which all the female students are enrolled.

B. Courses in which a proper subset of female students are enrolled.

C. Courses in which only male students are enrolled.

D. None of the above



female sid
1
3
4

X

cid
c1
c2
c3
c4

⇒

1	c1
1	c2
1	c3
1	c4
3	c1
3	c2
3	c3
3	c4
4	c1
4	c2
4	c3
4	c4

—

enroll

1	c1
1	c2
1	c3
1	c4
3	c1
3	c2
2	c1
2	c2
2	c3
2	c4
4	c2

sid	cid
3	c3
3	c4
4	c1
4	c3
4	c4

⇒

cid
c1
c3
c4

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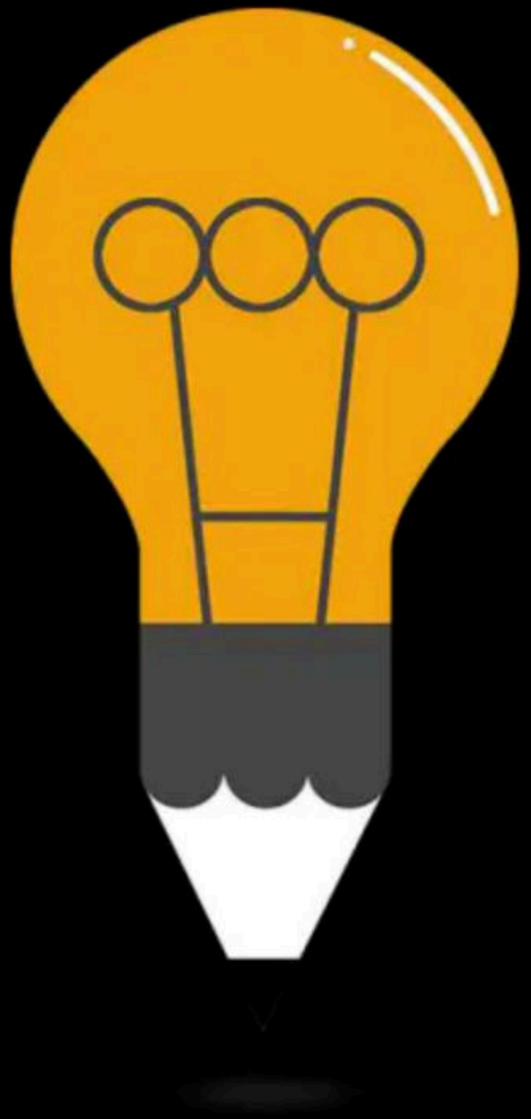

PYQ:

Relational DB Algebra

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Question GATE-1992

Suppose we have a database consisting of the following three relations:

FREQUENTS	(CUSTOMER, HOTEL)
SERVES	(HOTEL, SNACKS)
LIKES	(CUSTOMER, SNACKS)

The first indicates the hotels each customer visits, the second tells which snacks each hotel serves and last indicates which snacks are liked by each customer. Express the following query in relational algebra:

Print the hotels the serve the snack that customer Rama likes.

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Question GATE-1994

Consider the following relational schema:

- COURSES (cno, cname)
- STUDENTS (rollno, sname, age, year)
- REGISTERED_FOR (cno, rollno)

The underlined attributes indicate the primary keys for the relations. The 'year' attribute for the STUDENTS relation indicates the year in which the student is currently studying (First year, Second year etc.)

a. Write a relational algebra query to print the roll number of students who have registered for cno 322.

b. Write a SQL query to print the age and year of the youngest student in each year.

Question GATE-1995

Consider the relation scheme.

AUTHOR	(ANAME, INSTITUTION, ACITY, AGE)
PUBLISHER	(PNAME, PCITY)
BOOK	(TITLE, ANAME, PNAME)

Express the following queries using (one or more of) SELECT, PROJECT, JOIN and DIVIDE operations.

Express the following queries using (one or more of) SELECT, PROJECT, JOIN and DIVIDE operations.

a. Get the names of all publishers.

b. Get values of all attributes of all authors who have published a book for the publisher with PNAME='TECHNICAL PUBLISHERS'.

c. Get the names of all authors who have published a book for any publisher located in Madras

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Question GATE-1996

A library relational database system uses the following schema

- USERS (User#, User Name, Home Town)
- BOOKS (Book#, Book Title, Author Name)
- ISSUED (Book#, User#, Date)

Explain in one English sentence, what each of the following relational algebra queries is designed to determine

a. $\sigma_{\text{User\#}=6}\left(\pi_{\text{User\#, Book Title}}\left((\text{USERS} \bowtie \text{ISSUED}) \bowtie \text{BOOKS}\right)\right)$

b. $\pi_{\text{Author Name}}\left(\text{BOOKS} \bowtie \sigma_{\text{Home Town}=\text{Delhi}}\left(\text{USERS} \bowtie \text{ISSUED}\right)\right)$

Question GATE-1997

Consider the following relational database schema:

- EMP (eno name, age)
- PROJ (pno name)
- INVOLVED (eno, pno)

EMP contains information about employees. PROJ about projects and involved about which employees involved in which projects. The underlined attributes are the primary keys for the respective relations.

What is the relational algebra expression containing one or more of $\{\sigma, \pi, \times, \rho, -\}$ which is equivalent to SQL query.

```
select eno  from EMP|INVOLVED where EMP.eno=INVOLVED.eno  and INVOLVED.pno=3
```

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Question GATE-1998

Given two union compatible relations $R_1(A, B)$ and $R_2(C, D)$, what is the result of the operation $R_1 \bowtie_{A=C \wedge B=D} R_2$?

A. $R_1 \cup R_2$

B. $R_1 \times R_2$

C. $R_1 - R_2$

D. $R_1 \cap R_2$

Question GATE-1998

Consider the following relational database schemes:

- COURSES (Cno, Name)
- PRE_REQ(Cno, Pre_Cno)
- COMPLETED (Student_no, Cno)

COURSES gives the number and name of all the available courses.

PRE_REQ gives the information about which courses are pre-requisites for a given course.

COMPLETED indicates what courses have been completed by students

Express the following using relational algebra:

List all the courses for which a student with Student_no 2310 has completed all the pre-requisites.

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Question GATE-1999

Consider the join of a relation R with a relation S. If R has m tuples and S has n tuples then the maximum and minimum sizes of the join respectively are

A. $m+n$ and 0 B. mn and 0 C. $m+n$ and $|m-n|$ D. mn and $m+n$

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Question GATE-2000

Given the relations

- employee (name, salary, dept-no), and
- department (dept-no, dept-name,address),

Which of the following queries cannot be expressed using the basic relational algebra operations $(\sigma, \pi, \times, \bowtie, \cup, \cap, -)$

A. Department address of every employee
B. Employees whose name is the same as their department name
C. The sum of all employees' salaries
D. All employees of a given department

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Question GATE-2001

Suppose the adjacency relation of vertices in a graph is represented in a table Adj (X,Y). Which of the following queries cannot be expressed by a relational algebra expression of constant length?

A. List all vertices adjacent to a given vertex
B. List all vertices which have self loops
C. List all vertices which belong to cycles of less than three vertices
D. List all vertices reachable from a given vertex

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Question GATE-2001

Let r and s be two relations over the relation schemes R and S respectively, and let A be an attribute in R. The relational algebra expression $\sigma_{A=a}(r \bowtie s)$ is always equal to

A. $\sigma_{A=a}(r)$
B. r
C. $\sigma_{A=a}(r) \bowtie s$
D. None of the above

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Question GATE-2002

A university placement center maintains a relational database of companies that interview students on campus and make job offers to those successful in the interview. The schema of the database is given below:

COMPANY(cname, clocation)	STUDENT(srollno, sname, sdegree)
INTERVIEW(cname, srollno, idate)	OFFER(cname, srollno, osalary)

The COMPANY relation gives the name and location of the company. The STUDENT relation gives the student's roll number, name and the degree program for which the student is registered in the university. The INTERVIEW relation gives the date on which a student is interviewed by a company. The OFFER relation gives the salary offered to a student who is successful in a company's interview. The key for each relation is indicated by the underlined attributes

a. Write a **relational algebra** expressions (using only the operators $\bowtie, \sigma, \pi, \cup, -$) for the following queries.
   i. List the *rollnumbers* and *names* of students who attended at least one interview but did not receive *any* job offer.
   ii. List the *rollnumbers* and *names* of students who went for interviews and received job offers from *every* company with which they interviewed.

b. Write an SQL query to list, for each degree program in which more than *five* students were offered jobs, the name of the degree and the average offered salary of students in this degree program.

Question GATE-2003

Consider the following SQL query

Select distinct $a_1, a_2, \ldots, a_n$

from $r_1, r_2, \ldots, r_m$

where P

For an arbitrary predicate P, this query is equivalent to which of the following relational algebra expressions?

A. $\Pi_{a_1,a_2,\ldots a_n}\sigma_p\left(r_1 \times r_2 \times \cdots \times r_m\right)$

B. $\Pi_{a_1,a_2,\ldots a_n}\sigma_p\left(r_1 \bowtie r_2 \bowtie \cdots \bowtie r_m\right)$

C. $\Pi_{a_1,a_2,\ldots a_n}\sigma_p\left(r_1 \cup r_2 \cup \cdots \cup r_m\right)$

D. $\Pi_{a_1,a_2,\ldots a_n}\sigma_p\left(r_1 \cap r_2 \cap \cdots \cap r_m\right)$

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Question GATE-2004

Consider the relation Student (name, sex, marks), where the primary key is shown underlined, pertaining to students in a class that has at least one boy and one girl. What does the following relational algebra expression produce? (Note: ρ is the rename operator).

$$\pi_{name}\{\sigma_{sex=female}(\text{Student})\} - \pi_{name}(\text{Student} \bowtie_{(sex=female \wedge x=male \wedge marks \leq m)} \rho_{n,x,m}(\text{Student}))$$

A. names of girl students with the highest marks
B. names of girl students with more marks than some boy student
C. names of girl students with marks not less than some boy student
D. names of girl students with more marks than all the boy students

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Question GATE-2005

A table 'student' with schema (roll, name, hostel, marks), and another table 'hobby' with schema (roll, hobbyname) contains records as shown below:

Table: student

Roll	Name	Hostel	Marks
1798	Manoj Rathor	7	95
2154	Soumic Banerjee	5	68
2369	Gumma Reddy	7	86
2581	Pradeep pendse	6	92
2643	Suhas Kulkarni	5	78
2711	Nitin Kadam	8	72
2872	Kiran Vora	5	92
2926	Manoj Kunkalikar	5	94
2959	Hemant Karkhanis	7	88
3125	Rajesh Doshi	5	82

Table: hobby

Roll	Hobby Name
1798	chess
1798	music
2154	music
2369	swimming
2581	cricket
2643	chess
2643	hockey
2711	volleyball
2872	football
2926	cricket
2959	photography
3125	music
3125	chess

The following SQL query is executed on the above tables:

```
select hostel
from student natural join hobby
where marks >= 75 and roll between 2000 and 3000;
```

Relations S and H with the same schema as those of these two tables respectively contain the same information as tuples. A new relation S' is obtained by the following relational algebra operation:

$$S' = \Pi_{\text{hostel}}((\sigma_{s.roll=H.roll}(\sigma_{marks>75 \text{ and } roll>2000 \text{ and } roll<3000}(S)) \times (H))$$

The difference between the number of rows output by the SQL statement and the number of tuples in S' is

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Question GATE-2007

Information about a collection of students is given by the relation $\mathbf{studInfo}(\underline{\mathbf{studId}}, \mathbf{name}, \mathbf{sex})$. The relation $\mathbf{enroll}(\mathbf{studId}, \mathbf{courseId})$ gives which student has enrolled for (or taken) what course(s). Assume that every course is taken by at least one male and at least one female student. What does the following relational algebra expression represent?

$$\Pi_{\text{courseId}}\left(\left(\Pi_{\text{studId}}\left(\sigma_{\text{sex="female"}}\left(\text{studInfo}\right)\right)\times\Pi_{\text{courseId}}\left(\text{enroll}\right)\right)-\text{enroll}\right)$$

A. Courses in which all the female students are enrolled.

B. Courses in which a proper subset of female students are enrolled.

C. Courses in which only male students are enrolled.

D. None of the above

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Question GATE-2008

Let R and S be two relations with the following schema

$R(\underline{P, Q}, R1, R2, R3)$

$S(\underline{P, Q}, S1, S2)$

where $\{P, Q\}$ is the key for both schemas. Which of the following queries are equivalent?

I. $\Pi_P (R \bowtie S)$

II. $\Pi_P (R) \bowtie \Pi_P (S)$

III. $\Pi_P (\Pi_{P,Q} (R) \cap \Pi_{P,Q} (S))$

IV. $\Pi_P (\Pi_{P,Q} (R) - (\Pi_{P,Q} (R) - \Pi_{P,Q} (S)))$

A. Only I and II B. Only I and III C. Only I, II and III D. Only I, III and IV

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Question GATE-2012

Suppose $R_1(\underline{A}, B)$ and $R_2(\underline{C}, D)$ are two relation schemas. Let r_1 and r_2 be the corresponding relation instances. B is a foreign key that refers to C in R_2. If data in r_1 and r_2 satisfy referential integrity constraints, which of the following is **ALWAYS TRUE**?

A. $\prod_B(r_1) - \prod_C(r_2) = \varnothing$
B. $\prod_C(r_2) - \prod_B(r_1) = \varnothing$
C. $\prod_B(r_1) = \prod_C(r_2)$
D. $\prod_B(r_1) - \prod_C(r_2) \neq \varnothing$

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Question GATE-2013

In a relational database there are three relations:

- Customers = C(CName),
- Shops = S(SName),
- Buys = B(CName, SName).

Which of the following relational algebra expressions returns the names of shops that have no customers at all? projection operator.]

A. $\Pi_{SName} B$
B. $S - B$
C. $S - \Pi_{SName} B$
D. $S - \Pi_{SName}((C \times S) - B)$

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Question GATE-2014

What is the optimized version of the relation algebra expression $\pi_{A1}(\pi_{A2}(\sigma_{F1}(\sigma_{F2}(r))))$, where $A1, A2$ are sets of attributes in r with $A1 \subset A2$ and $F1, F2$ are Boolean expressions based on the attributes in r?

A. $\pi_{A1}(\sigma_{(F1 \wedge F2)}(r))$

B. $\pi_{A1}(\sigma_{(F1 \vee F2)}(r))$

C. $\pi_{A2}(\sigma_{(F1 \wedge F2)}(r))$

D. $\pi_{A2}(\sigma_{(F1 \vee F2)}(r))$

Question GATE-2014

Consider the relational schema given below, where **eId** of the relation **dependent** is a foreign key referring to **empId** of the relation **employee**. Assume that every employee has at least one associated dependent in the **dependent** relation.

employee (empId, empName, empAge)

dependent (depId, eId, depName, depAge)

Consider the following relational algebra query:

$$\Pi_{empId}\,(employee) - \Pi_{empId}\,(employee \bowtie_{(empId=eID)\wedge(empAge\leq depAge)} dependent)$$

The above query evaluates to the set of **empId**s of employees whose age is greater than that of

A. some dependent.
B. all dependents.
C. some of his/her dependents.
D. all of his/her dependents.

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Question GATE-2015

SELECT operation in SQL is equivalent to

A. The selection operation in relational algebra
B. The selection operation in relational algebra, except that SELECT in SQL retains duplicates
C. The projection operation in relational algebra
D. The projection operation in relational algebra, except that SELECT in SQL retains duplicates

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Question GATE-2017

Consider a database that has the relation schema CR(StudentName, CourseName). An instance of the schema CR is as given below.

StudentName	CourseName
SA	CA
SA	CB
SA	CC
SB	CB
SB	CC
SC	CA
SC	CB
SC	CC
SD	CA
SD	CB
SD	CC
SD	CD
SE	CD
SE	CA
SE	CB
SF	CA
SF	CB
SF	CC

The following query is made on the database.

- $T1 \leftarrow \pi_{CourseName}\left(\sigma_{StudentName=SA}\left(CR\right)\right)$
- $T2 \leftarrow CR \div T1$

The number of rows in $T2$ is _____ .

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Question GATE-2018

Consider the relations $r(A, B)$ and $s(B, C)$, where $s.B$ is a primary key and $r.B$ is a foreign key referencing $s.B$. Consider the query

$Q : r \bowtie (\sigma_{B<5}(s))$

Let LOJ denote the natural left outer-join operation. Assume that r and s contain no null values.

Which of the following is NOT equivalent to Q?

A. $\sigma_{B<5}(r \bowtie s)$
B. $\sigma_{B<5}(r \; LOJ \; s)$
C. $r \; LOJ \; (\sigma_{B<5}(s))$
D. $\sigma_{B<5}(r) \; LOJ \; s$

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Question GATE-2019

Consider the following relations $P(X, Y, Z), Q(X, Y, T)$ and $R(Y, V)$.

Table: P

X	Y	Z
X1	Y1	Z1
X1	Y1	Z2
X2	Y2	Z2
X2	Y4	Z4

Table: Q

X	Y	T
X2	Y1	2
X1	Y2	5
X1	Y1	6
X3	Y3	1

Table: R

Y	V
Y1	V1
Y3	V2
Y2	V3
Y2	V2

How many tuples will be returned by the following relational algebra query?

$$\Pi_x(\sigma_{(P.Y=R.Y \wedge R.V=V2))}(P \times R)) - \Pi_x(\sigma_{(Q.Y=R.Y \wedge Q.T>2))}(Q \times R))$$

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Question GATE-2021

A relation $r(A, B)$ in a relational database has 1200 tuples. The attribute A has integer values ranging from 6 to 20, and the attribute B has integer values ranging from 1 to 20. Assume that the attributes A and B are independently distributed.

The estimated number of tuples in the output of $\sigma_{(A>10)\vee(B=18)}(r)$ is _____.

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Question GATE-2021

The following relation records the age of 500 employees of a company, where $empNo$ (indicating the employee number) is the key:

$$empAge(\underline{empNo}, age)$$

Consider the following relational algebra expression:

$$\Pi_{empNo}(empAge \bowtie_{(age>age1)} \rho_{empNo1,age1}(empAge))$$

What does the above expression generate?

A. Employee numbers of only those employees whose age is the maximum
B. Employee numbers of only those employees whose age is more than the age of exactly one other employee
C. Employee numbers of all employees whose age is not the minimum
D. Employee numbers of all employees whose age is the minimum

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Question GATE-2022

Q.25	Consider the following three relations in a relational database. $Employee(\underline{eId}, Name)$, $Brand(\underline{bId}, bName)$, $Own(\underline{eId}, \underline{bId})$ Which of the following relational algebra expressions return the set of *eIds* who own all the brands?
(A)	$\Pi_{eId}(\Pi_{eId,bId}(Own) / \Pi_{bId}(Brand))$
(B)	$\Pi_{eId}(Own) - \Pi_{eId}\left((\Pi_{eId}(Own) \times \Pi_{bId}(Brand)) - \Pi_{eId,bId}(Own)\right)$
(C)	$\Pi_{eId}(\Pi_{eId,bId}(Own) / \Pi_{bId}(Own))$
(D)	$\Pi_{eId}\left((\Pi_{eId}(Own) \times \Pi_{bId}(Own)) / \Pi_{bId}(Brand)\right)$

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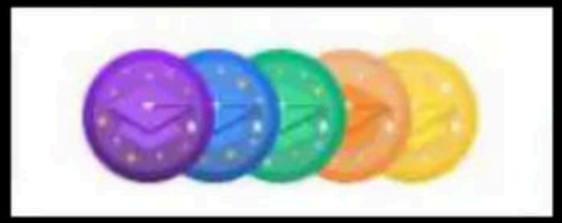
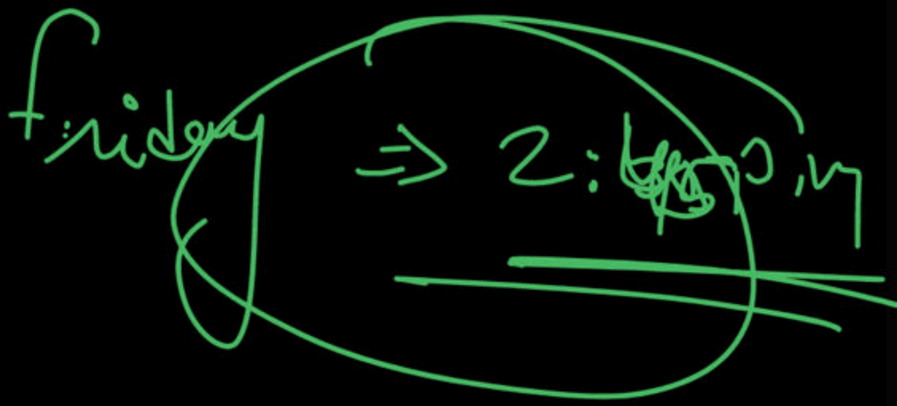
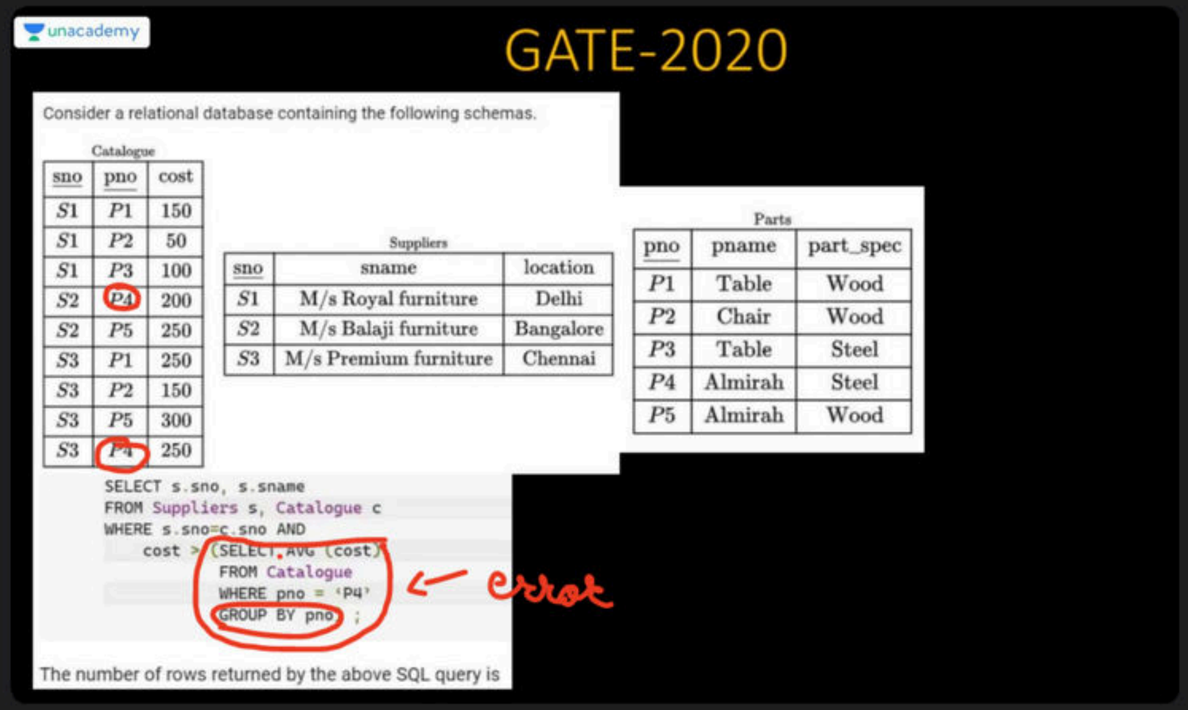
Happy Learning.!





▲ 1 • Asked by Saishubham

Please help me with this doubt



▲ 1 • Asked by Srishti

sir, In first sigma condition -> not able to understand why union is working but not intersection?

$$\Pi_{divers.did,\,dname}\left(\sigma_{ccolor='green'\ \vee\ ccolor='red'}\left(divers \bowtie divers \bowtie cars\right)\right)$$

$$-\left(\left(\Pi_{divers.did,\,dname}\left(\sigma_{ccolor='green'}\left(divers \bowtie divers \bowtie cars\right)\right)\right)\right.$$

$$\left.\cap\left(\Pi_{divers.did,\,dnam}\left(\sigma_{ccolor='red'}\left(divers \bowtie divers \bowtie cars\right)\right)\right)\right)$$

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▲ 1 • Asked by Vaishnavij...

Please help me with this doubt

Consider a machine with a 2-way set associative data cache of size 64 *Kbytes* and block size 16 *bytes*. The cache is managed using 32 *bit* virtual addresses and the page size is 4 *Kbytes*. A program to be run on this machine begins as follows:

```
double ARR[1024][1024];
int i, j;
/*Initialize array ARR to 0.0 */
for(i = 0; i < 1024; i++)
    for(j = 0; j < 1024; j++)
        ARR[i][j] = 0.0;
```

The size of double is 8 bytes. Array *ARR* is located in memory starting at the beginning of virtual page $0xFF000$ and stored in row major order. The cache is initially empty and no pre-fetching is done. The only data memory references made by the program are those to array *ARR*.

The total size of the tags in the cache directory is:

A. 32 *Kbits*
B. 34 *Kbits*
C. 64 *Kbits*
D. 68 *Kbits*

$2^{12} * 16$ bits

2^{16} bits

64k bits