Relational Algebra

S Ranbir Singh

CS344@iitg

Chapter 4: Database Management System, 3rd Ed. Ramakrishnan & Gehrke

Relational Query Languages

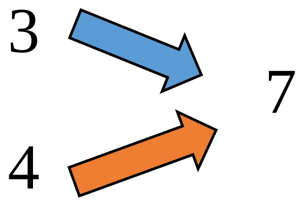
- Languages for describing queries on a relational database
- *Structured Query Language* (SQL)
  - Predominant application-level query language
  - Declarative
- *Relational Algebra*
  - Intermediate language used within DBMS
  - Procedural
- Relational Calculus:
  - Lets users describe what they want, rather than how to compute it.
  - Non-operational, declarative.

What is an Algebra?

- A language based on operators and a domain of values
- Operators map values taken from the domain into other domain values
- Hence, an expression involving operators and arguments produces a value in the domain
- When the domain is a set of all relations (and the operators are as described later), we get the *relational algebra*
- We refer to the expression as a *query* and the value produced as the *query result*

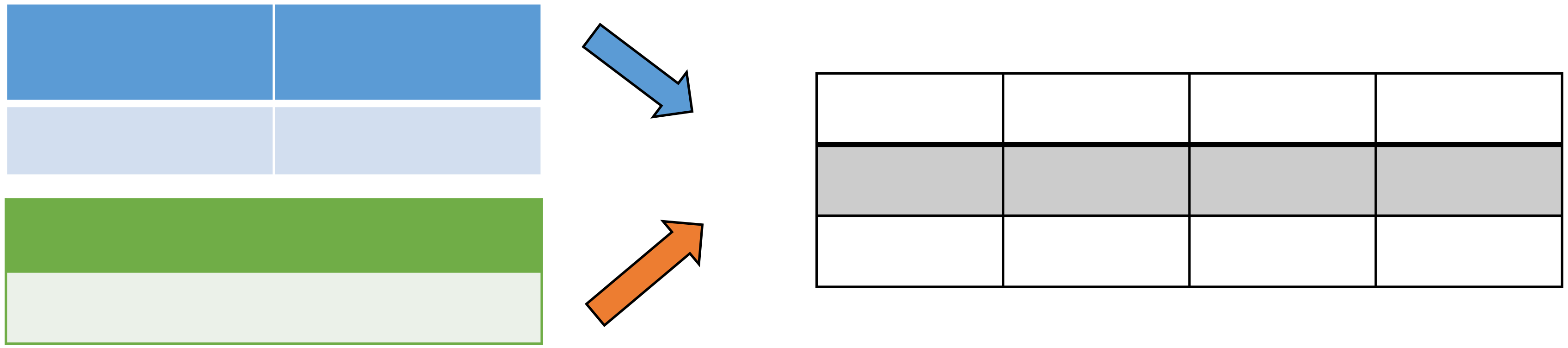
Algebra

- In math, algebraic operations like +, -, x, /.
- Operate on numbers: input are numbers, output are numbers.
- Can also do Boolean algebra on sets, using union, intersect, difference.
- Focus on **algebraic identities**, e.g.
  - x (y+z) = xy + xz.
- (Relational algebra lies between propositional and 1st-order logic.)



Relational Algebra

- Every operator takes <u>one or two</u> relation instances
- A relational algebra expression is recursively defined to be a relation
  - Result is also a relation
  - Can apply operator to
    - Relation from database
    - Relation as a result of another operator

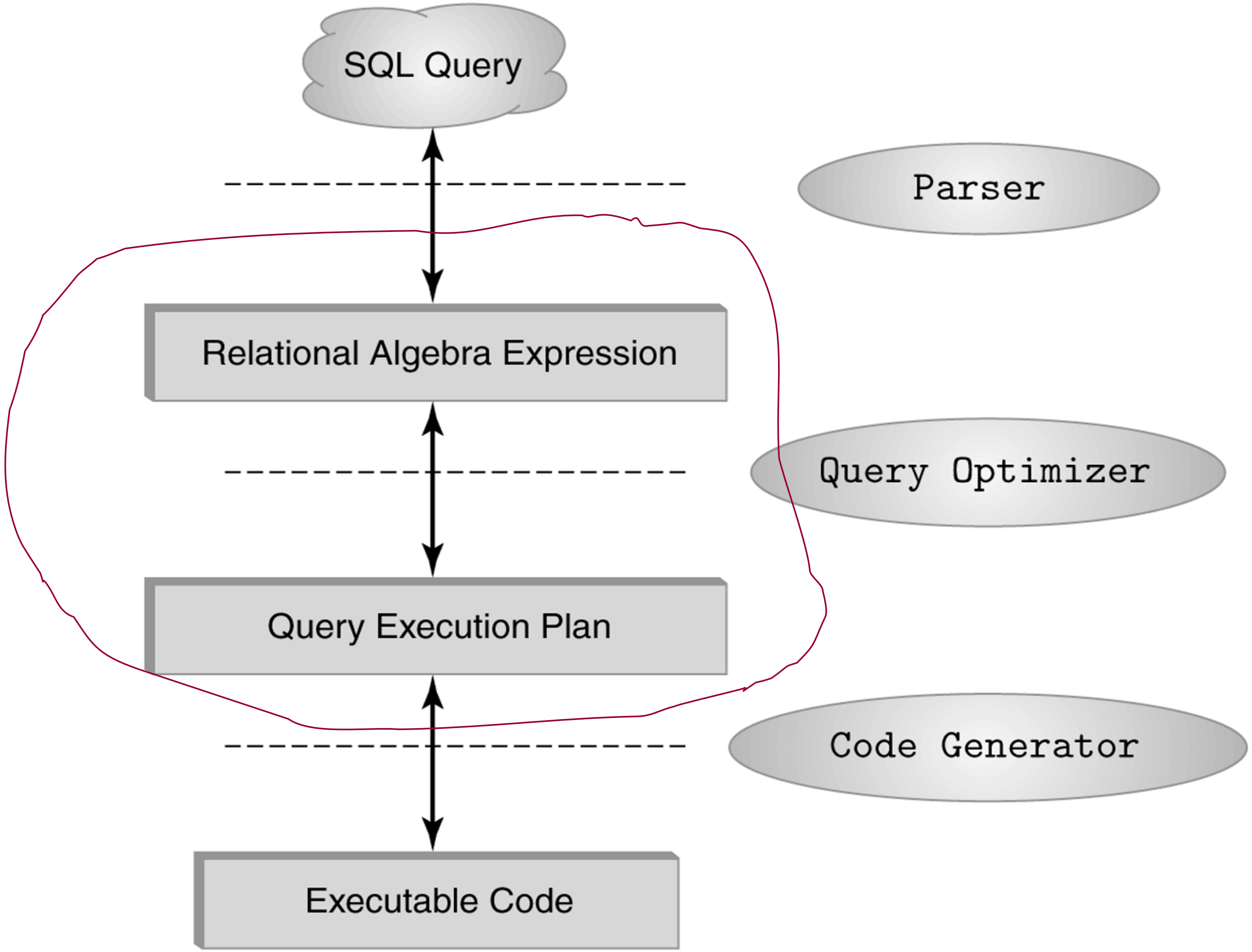


Relational Algebra Operations

- *Domain*: set of relations
- 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 derived operations:
  - Intersection, *join*, division, renaming.

- Since each operation returns a relation, operations can be *composed*!

The Role of Relational Algebra in a DBMS



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*!

Produces table containing subset of columns of argument table

$$\pi_{attribute\ list}(relation)$$

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*!

Produces table containing subset of columns of argument table

$$\pi_{attribute\ list}(relation)$$

Relation: S

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

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

sname	rating
yuppy	9
lubber	8
guppy	5
rusty	10

$\pi_{age}(S)$

age
35.0
55.5

Project Operator

Result is a table (no duplicates); can have fewer tuples than the original

Example:

Person

Id	*Name*	*Address*	*Hobby*
1123	John	123 Main	stamps
1123	John	123 Main	coins
5556	Mary	7 Lake Dr	hiking
9876	Bart	5 Pine St	stamps

$\pi_{Name,Hobby}$(Person)

Name	*Hobby*
John	stamps
John	coins
Mary	hiking
Bart	stamps

Project Operator

- Example:

Person

Id	*Name*	*Address*	*Hobby*
1123	John	123 Main	stamps
1123	John	123 Main	coins
5556	Mary	7 Lake Dr	hiking
9876	Bart	5 Pine St	stamps

$\pi_{Name,Address}$(Person)

Name	*Address*
John	123 Main
Mary	7 Lake Dr
Bart	5 Pine St

Project Operator

- Example:

Person

Id	*Name*	*Address*	*Hobby*
1123	John	123 Main	stamps
1123	John	123 Main	coins
5556	Mary	7 Lake Dr	hiking
9876	Bart	5 Pine St	stamps

$\pi_{Name,Address}$(Person)

Name	*Address*
John	123 Main
Mary	7 Lake Dr
Bart	5 Pine St

SELECT Name, Address FROM Person;

Project Operator

- Example:

Person

Id	*Name*	*Address*	*Hobby*
1123	John	123 Main	stamps
1123	John	123 Main	coins
5556	Mary	7 Lake Dr	hiking
9876	Bart	5 Pine St	stamps

$\pi_{Name,Address}$(Person)

Name	*Address*
John	123 Main
Mary	7 Lake Dr
Bart	5 Pine St

SELECT Name, Address FROM Person;

SELECT * FROM Person; ????

Selection

- Selects rows that satisfy *selection condition*.
- No duplicates in result!
- *Schema* of result identical to schema of (only) input relation.
- Selection conditions:
  - *simple conditions* comparing attribute values (variables) and / or constants or
  - *complex conditions* that combine simple conditions using logical connectives AND and OR.

Produce table containing subset of rows of argument table satisfying condition

$\sigma_{condition}\,(relation)$

Selection

- Selects rows that satisfy *selection condition*.
- No duplicates in result!
- *Schema* of result identical to schema of (only) input relation.
- Selection conditions:
  - *simple conditions* comparing attribute values (variables) and / or constants or
  - *complex conditions* that combine simple conditions using logical connectives AND and OR.

Produce table containing subset of rows of argument table satisfying condition

$\sigma_{condition}(relation)$

Relation: S

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

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

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

Select Operator

SELECT * FROM Person WHERE Hobby='stamps'

Example:

Person

Id	*Name*	*Address*	*Hobby*
1123	John	123 Main	stamps
1123	John	123 Main	coins
5556	Mary	7 Lake Dr	hiking
9876	Bart	5 Pine St	stamps

$\sigma_{Hobby=\text{'stamps'}}(\text{Person})$

Id	*Name*	*Address*	*Hobby*
1123	John	123 Main	stamps
9876	Bart	5 Pine St	stamps

Selection Condition

- Operators: <, $\leq$, $\geq$, >, =, $\neq$
- Simple selection condition:
  - *<attribute> operator <constant>*
  - *<attribute> operator <attribute>*
- *<condition>* AND *<condition>*
- *<condition>* OR *<condition>*
- NOT *<condition>*

Select Operator

SELECT * FROM Person WHERE Hobby='stamps' AND Name='John';

Example:

Person

Id	*Name*	*Address*	*Hobby*
1123	John	123 Main	stamps
1123	John	123 Main	coins
5556	Mary	7 Lake Dr	hiking
9876	Bart	5 Pine St	stamps

$\sigma_{Hobby=\text{'stamps' AND Name='John'}}$(Person)

Id	*Name*	*Address*	*Hobby*
1123	John	123 Main	stamps

Selection and Projection

$$\pi_{\mathit{Id,\ Name}} (\sigma_{\mathit{Hobby}=\text{'stamps'}\ \text{OR}\ \mathit{Hobby}=\text{'coins'}} (\text{Person}))$$

Id	*Name*	*Address*	*Hobby*
1123	John	123 Main	stamps
1123	John	123 Main	coins
5556	Mary	7 Lake Dr	hiking
9876	Bart	5 Pine St	stamps

Person

Id	*Name*
1123	John
9876	Bart

Result

SELECT Id, Name FROM Person WHERE Hobby=‘stamps’ OR Hobby=‘coin’

Selection and Projection

Relation: S

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

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

sname	rating
yuppy	9
rusty	10

SELECT sname, rating FROM S WHERE rating > 8

Sailors(sid: integer, *sname:* string, *rating:* integer, *age:* real)
Boats(*bid:* integer, *bname:* string, *color:* string)
Reserves(*sid:* integer, *bid:* integer, *day:* date)

bid	*bname*	*color*
101	Interlake	blue
102	Interlake	red
103	Clipper	green
104	Marine	red

An Instance of Boats

sid		*rating*	*age*
22	Dustin	7	45.0
29	Brutus	1	33.0
31	Lubber	8	55.5
32	Andy	8	25.5
58	Rusty	10	35.0
64	Horatio	7	35.0
71	Zorba	10	16.0
74	Horatio	9	35.0
85	Art	3	25.5
95	Bob	3	63.5

An Instance of Sailors

sid	*bid*	*day*
22	101	10/10/98
22	102	10/10/98
22	103	10/8/98
22	104	10/7/98
31	102	11/10/98
31	103	11/6/98
31	104	11/12/98
64	101	9/5/98
64	102	9/8/98
74	103	9/8/98

An Instance of Reserves

Find names of sailors who've reserved boat #103

$$\pi_{sname}(\sigma_{sid=Rsid}(\sigma_{bid=103}\rho(T1(4\rightarrow Rsid), Reserves \times Sailors)))$$

$$\pi_{sname}(\sigma_{sid=Rsid\ AND bid=103}\rho(T1(4\rightarrow Rsid), Reserves \times Sailors))$$

Set Operators

- Relation is a set of tuples, so set operations should apply: $\cap$, $\cup$, $-$ (set difference)
- Result of combining two relations with a set operator is a relation => all its elements must be tuples having same structure
- Hence, scope of set operations limited to *union compatible relations*

Union Compatible Relations

- Two relations are *union compatible* if
  - Both have same number of columns
  - Names of attributes are the same in both
  - Attributes with the same name in both relations have the same domain
- Union compatible relations can be combined using *union*, *intersection*, and *set difference*

Example

Tables:

Person (*SSN, Name, Address, Hobby*)

Professor (*Id, Name, Office, Phone*)

are not union compatible.

But

π_{Name} (Person) and π_{Name} (Professor)

are union compatible so

π_{Name} (Person) - π_{Name} (Professor)

makes sense.

Union, Intersection, Set-Difference

S1

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

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

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

$S1 \cup S2$

sid	sname	rating	age
22	dustin	7	45.0

$S1 - S2$

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

$S1 \cap S2$

UNION, INTERSECT, EXCEPT

$$S1 \cup S2$$

SELECT *column_name(s)* FROM *table1*
UNION
SELECT *column_name(s)* FROM *table2*;

$$S1 \cap S2$$

SELECT *column_name(s)* FROM *table1*
INTERSECT
SELECT *column_name(s)* FROM *table2*;

$$S1 - S2$$

SELECT *column_name(s)* FROM *table1*
MINUS
SELECT *column_name(s)* FROM *table2*;

SELECT *column_name(s)* FROM *table1*
EXCEPT
SELECT *column_name(s)* FROM *table2*;

UNION, INTERSECT, EXCEPT

$$S1 \cup S2$$

SELECT *column_name(s)* FROM *table1*
UNION
SELECT *column_name(s)* FROM *table2*;

$$S1 \cap S2$$

SELECT *column_name(s)* FROM *table1*
INTERSECT
SELECT *column_name(s)* FROM *table2*;

$$S1 - S2$$

SELECT *column_name(s)* FROM *table1*
MINUS
SELECT *column_name(s)* FROM *table2*;

SELECT *column_name(s)* FROM *table1*
EXCEPT
SELECT *column_name(s)* FROM *table2*;

MySQL

```
select a.id from table1 as a where <condition>
        AND a.id NOT IN
                    (select b.id from table2 as b where <condition>);
```

UNION, INTERSECT, EXCEPT

$$S1 \cup S2$$

```
SELECT column_name(s) FROM table1
UNION
SELECT column_name(s) FROM table2;
```

$$S1 \cap S2$$

```
SELECT column_name(s) FROM table1
INTERSECT
SELECT column_name(s) FROM table2;
```

$$S1 - S2$$

```
SELECT column_name(s) FROM table1
MINUS
SELECT column_name(s) FROM table2;
```

```
SELECT column_name(s) FROM table1
EXCEPT
SELECT column_name(s) FROM table2;
```

Renaming

MySQL

```
select a.id from table1 as a where <condition>
        AND a.id NOT IN
                (select b.id from table2 as b where <condition>);
```

EXCEPT/MINUS

$$S1 - S2$$

```
SELECT column_name(s) FROM table1
MINUS
SELECT column_name(s) FROM table2;
```

```
SELECT column_name(s) FROM table1
EXCEPT
SELECT column_name(s) FROM table2;
```

MySQL

```
SELECT * FROM table1 AS a WHERE <condition>
        AND a.id NOT IN
                    (SELECT b.id FROM table2 AS b WHERE <condition>);
```

OR

```
SELECT * FROM table1 a WHERE NOT EXISTS
        ( SELECT * FROM table2 b WHERE a.id = b.id);
```

Cartesian Product

- If *R* and *S* are two relations, $R \times S$ is the set of all concatenated tuples <*x*,*y*>, where *x* is a tuple in *R* and *y* is a tuple in *S*
  - *R* and *S* need not be union compatible.
  - *But R* and *S* must have distinct attribute names.

A	*B*
x1	x2
x3	x4

R

A	*C*
y1	y2
y3	y4

S

A	*B*	*A*	*C*
x1	x2	y1	y2
x1	x2	y3	y4
x3	x4	y1	y2
x3	x4	y3	y4

$R \times S$

Cartesian Product

- If *R* and *S* are two relations, $R \times S$ is the set of all concatenated tuples <*x*,*y*>, where *x* is a tuple in *R* and *y* is a tuple in *S*
  - *R* and *S* need not be union compatible.
  - *But R* and *S* must have distinct attribute names.

A	*B*
x1	x2
x3	x4

R

A	*C*
y1	y2
y3	y4

S

A	*B*	*A*	*C*
x1	x2	y1	y2
x1	x2	y3	y4
x3	x4	y1	y2
x3	x4	y3	y4

$R \times S$

```
SELECT * FROM R, S;
```

Renaming

- *Renaming operator*: $\rho(C(1 \rightarrow X, 3 \rightarrow Y), R \times S)$

$$\rho(\Pi_{A,\rho(A \rightarrow X)}(R) \times \Pi_{A,\rho(A \rightarrow Y)}(S))$$

A	*B*
x1	x2
x3	x4

R

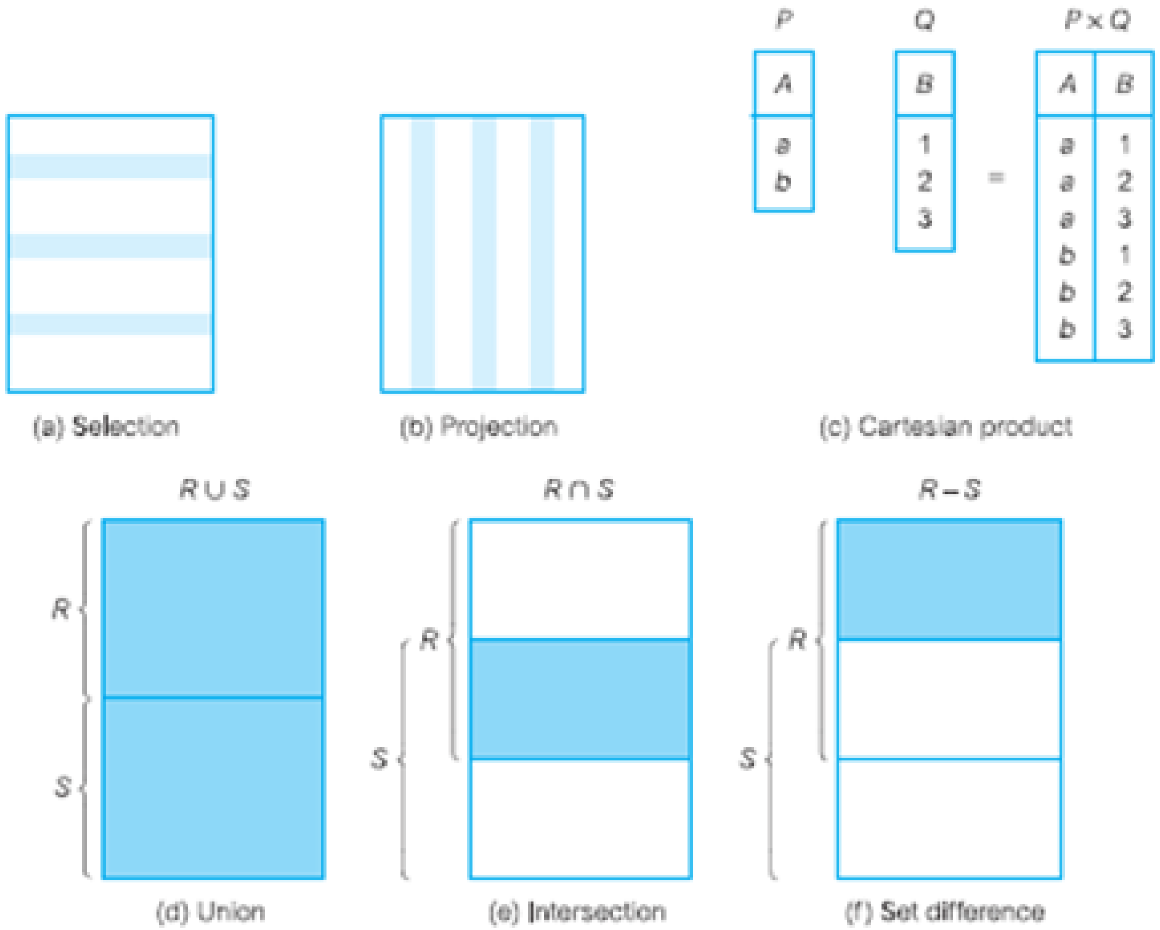
A	*C*
y1	y2
y3	y4

S

X	*B*	*Y*	*C*
x1	x2	y1	y2
x1	x2	y3	y4
x3	x4	y1	y2
x3	x4	y3	y4

$R \times S$

Summary



P
Q
P × Q
A
B
A
B
a
b
1
2
3
=
a
a
a
b
b
b
1
2
3
1
2
3
(a) Selection
(b) Projection
(c) Cartesian product
R ∪ S
R ∩ S
R − S
R
S
R
S
R
S
(d) Union
(e) Intersection
(f) Set difference

Examples

Professor(<u>ssn</u>, profname, status)

Course(<u>crscode</u>, crsname, credits)

Taught(<u>crscode, semester</u>, ssn)

Find those professors who have taught ‘csc6710’ but never ‘csc7710’.

Examples

Professor(<u>ssn</u>, profname, status)

Course(<u>crscode</u>, crsname, credits)

Taught(<u>crscode, semester</u>, ssn)

Find those professors who have taught ‘csc6710’ but never ‘csc7710’.

$$\pi_{ssn}(\sigma_{crscode=\text{‘csc6710’} \wedge crscode!=\text{‘csc7710’}}(Taught))$$

Examples

Professor(<u>ssn</u>, profname, status)

Course(<u>crscode</u>, crsname, credits)

Taught(<u>crscode, semester</u>, ssn)

Find those professors who have taught ‘csc6710’ but never ‘csc7710’.

$$\pi_{ssn}(\sigma_{crscode=\text{‘csc6710’} \cancel{\land} crscode!=\text{‘csc7710’}}(\text{Taught}))$$

Examples

Professor(<u>ssn</u>, profname, status)

Course(<u>crscode</u>, crsname, credits)

Taught(<u>crscode, semester</u>, ssn)

Find those professors who have taught 'csc6710' but never 'csc7710'.

$$\pi_{ssn}(\sigma_{crscode=\text{'csc6710'}}(Taught))-$$
$$\pi_{ssn}(\sigma_{crscode=\text{'csc7710'}}(Taught))$$

Examples

Professor(ssn, profname, status)

Course(crscode, crsname, credits)

Taught(crscode, semester, ssn)

Find those professors who have taught ‘csc6710’ but never ‘csc7710’.

$$\pi_{ssn}(\sigma_{crscode=\text{‘csc6710’}}(\text{Taught}))-$$
$$\pi_{ssn}(\sigma_{crscode=\text{‘csc7710’}}(\text{Taught}))$$

```
SELECT x.ssn FROM Taught AS x WHERE x.crscode=‘csc6710’ AND x.ssn
    NOT IN
        (SELECT ssn FROM Taught WHERE y.crscode=‘csc7710’);
```

```
SELECT x.ssn FROM Taught AS x WHERE x.crscode=‘csc6710’ AND
    NOT EXIST
        (SELECT y.ssn FROM Taught AS y WHERE y.crscode=‘csc7710’ AND x.ssn=y.ssn);
```

Example

Professor(ssn, profname, status)

Course(crscode, crsname, credits)

Taught(crscode, semester, ssn)

Return those professors who have taught both ‘csc6710’ and ‘csc7710’.

Example

Professor(<u>ssn</u>, profname, status)

Course(<u>crscode</u>, crsname, credits)

Taught(<u>crscode, semester</u>, ssn)

Return those professors who have taught both 'csc6710' and 'csc7710'.

$$\pi_{ssn}(\sigma_{crscode='csc6710' \wedge crscode='csc7710'}(Taught))$$

Example

Professor(ssn, profname, status)

Course(crscode, crsname, credits)

Taught(crscode, semester, ssn)

Return those professors who have taught both 'csc6710' and 'csc7710'.

$$\cancel{\pi_{ssn}(\sigma_{crscode=\text{'csc6710'} \wedge crscode=\text{'csc7710'}}(Taught))}$$

$$\pi_{ssn}(\sigma_{crscode=\text{'csc6710'}}(Taught)) \cap$$
$$\pi_{ssn}(\sigma_{crscode=\text{'csc7710'}}(Taught))$$

```
SELECT ssn FROM Taught WHERE crscode='csc6710'
        INTERSECT
                SELECT ssn FROM Taught WHERE crscode='csc7710';
```

Example

Professor(<u>ssn</u>, profname, status)

Course(<u>crscode</u>, crsname, credits)

Taught(<u>crscode, semester</u>, ssn)

Return those professors who have taught both ‘csc6710’ and ‘csc7710’.

$$\cancel{\pi_{ssn}(\sigma_{crscode=\text{‘}csc6710\text{’} \wedge crscode=\text{‘}csc7710\text{’}}(Taught))}$$

$$\pi_{ssn}(\sigma_{crscode=\text{‘}csc6710\text{’}}(Taught)) \cap$$
$$\pi_{ssn}(\sigma_{crscode=\text{‘}csc7710\text{’}}(Taught))$$

```
SELECT x.ssn FROM Taught AS x WHERE x.crscode=‘csc6710’ AND
        x.ssn IN
               (SELECT y.ssn FROM Taught AS y WHERE y. crscode=‘csc7710’);
```

Example

Professor(ssn, profname, status)

Course(crscode, crsname, credits)

Taught(crscode, semester, ssn)

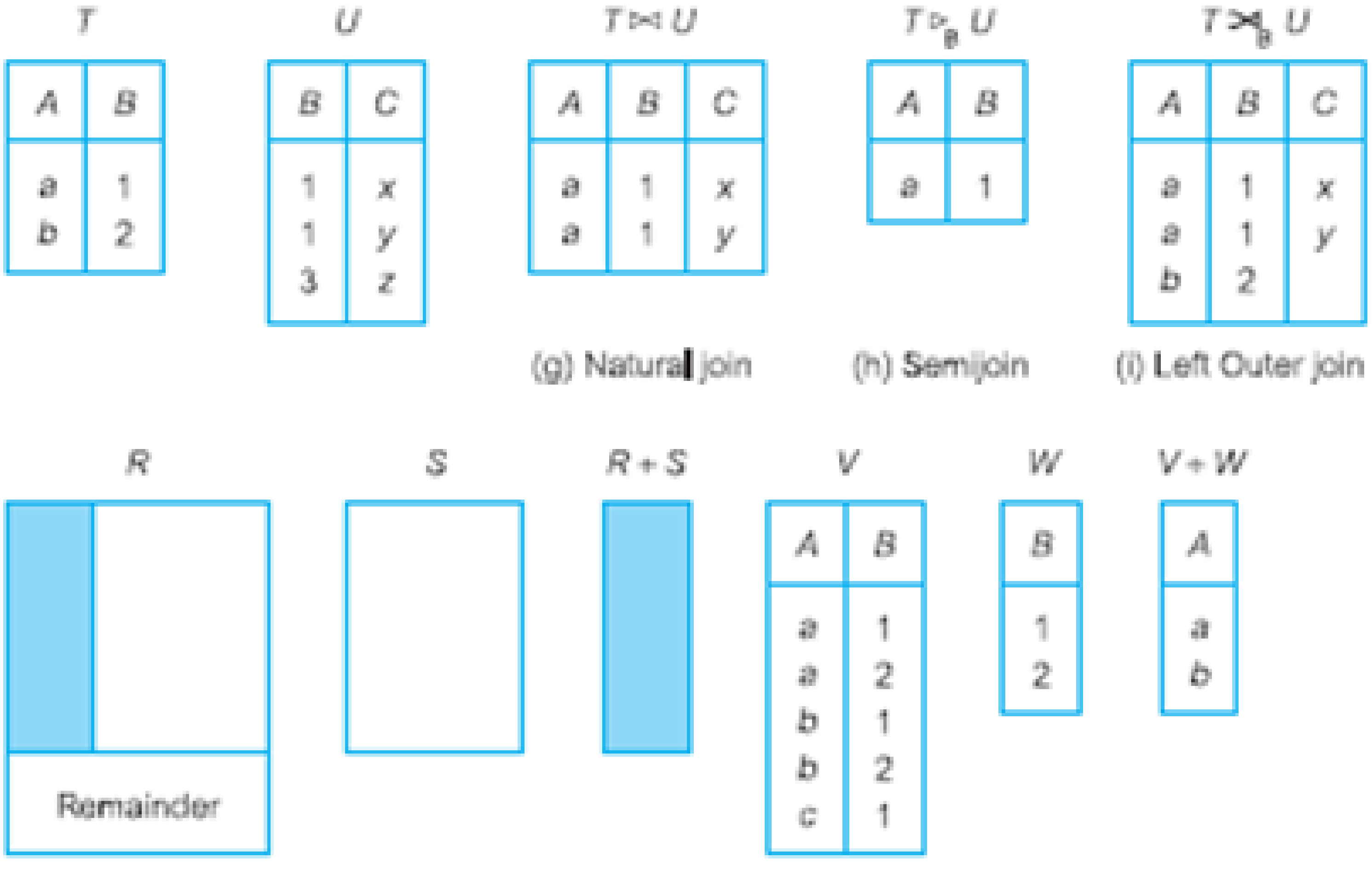
Return those professors who have taught both ‘csc6710’ and ‘csc7710’.

$$\pi_{ssn}(\sigma_{crscode=\text{‘csc6710’} \wedge crscode=\text{‘csc7710’}}(Taught))$$

$$\pi_{ssn}(\sigma_{crscode=\text{‘csc6710’}}(Taught)) \cap$$
$$\pi_{ssn}(\sigma_{crscode=\text{‘csc7710’}}(Taught))$$

```
SELECT x.ssn FROM Taught AS x WHERE x.crscode='csc6710' AND
        EXIST
              (SELECT y.ssn FROM Taught AS y WHERE y.crscode='csc7710' AND x.ssn=y.ssn);
```

Derived Operators Join and Division



(g) Natural join

(h) Semijoin

(i) Left Outer join

(j) Division (shaded area)

Example of division

Joins

- *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

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

- *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

- *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

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

- *Result schema* similar to cross-product, but only one copy of fields for which equality is specified.
- *Natural Join*: Equijoin on *all* common fields.
  Without specified condition
  means the natural join of A and B. $A \bowtie B$

Natural Join (cont'd)

- More generally:

$$R \bowtie S = \pi_{attr\text{-}list} \left(\sigma_{join\text{-}cond} \left(R \times S \right) \right)$$

where

attr-list = *attributes* (R) $\cup$ *attributes* (S)

(duplicates are eliminated) and *join-cond* has the form:

$R.A_1 = S.A_1$ AND … AND $R.A_n = S.A_n$

where

$\{A_1 \ldots A_n\}$ = *attributes*(R) $\cap$ *attributes*(S)

SQL JOIN

SELECT * FROM table1 join_type table2 [ON (join_condition)]

Types of JOINs

- EQUI JOIN
  - INNER JOIN
  - OUTER JOIN
    - LEFT OUTER JOIN
    - RIGHT OUTER JOIN
    - FULL OUTER JOIN
- NON EQUI JOIN
- NATURAL JOIN
- CROSS JOIN

SQL JOIN

loan-number	branch-name	amount
L-170	Downtown	3000
L-230	Redwood	4000
L-260	Perryridge	1700

loan

customer-name	loan-number
Jones	L-170
Smith	L-230
Hayes	L-155

borrower

SELECT * FROM table1 join_type table2 [ON (join_condition)]

Types of JOINs

- EQUI JOIN
  - INNER JOIN
  - OUTER JOIN
    - LEFT OUTER JOIN
    - RIGHT OUTER JOIN
    - FULL OUTER JOIN
- NON EQUI JOIN
- NATURAL JOIN
- CROSS JOIN

loan-number	branch-name	amount	customer-name	loan-number
L-170	Downtown	3000	Jones	L-170
L-230	Redwood	4000	Smith	L-230

SQL JOIN

loan-number	branch-name	amount
L-170	Downtown	3000
L-230	Redwood	4000
L-260	Perryridge	1700

loan

customer-name	loan-number
Jones	L-170
Smith	L-230
Hayes	L-155

borrower

SELECT * FROM table1 join_type table2 [ON (join_condition)]

Types of JOINs

- EQUI JOIN
  - INNER JOIN
  - OUTER JOIN
    - LEFT OUTER JOIN
    - RIGHT OUTER JOIN
    - FULL OUTER JOIN
- NON EQUI JOIN
- NATURAL JOIN
- CROSS JOIN

loan-number	branch-name	amount	customer-name
L-170	Downtown	3000	Jones
L-230	Redwood	4000	Smith

SQL JOIN

loan-number	branch-name	amount
L-170	Downtown	3000
L-230	Redwood	4000
L-260	Perryridge	1700

loan

customer-name	loan-number
Jones	L-170
Smith	L-230
Hayes	L-155

borrower

SELECT * FROM table1 join_type table2 [ON (join_condition)]

Types of JOINs

- EQUI JOIN
  - INNER JOIN
  - OUTER JOIN
    - LEFT OUTER JOIN
    - RIGHT OUTER JOIN
    - FULL OUTER JOIN
- NON EQUI JOIN
- NATURAL JOIN
- CROSS JOIN

loan-number	branch-name	amount	customer-name	loan-number
L-170	Downtown	3000	Jones	L-170
L-230	Redwood	4000	Smith	L-230

loan-number	branch-name	amount	customer-name
L-170	Downtown	3000	Jones
L-230	Redwood	4000	Smith

SQL JOIN

loan-number	branch-name	amount
L-170	Downtown	3000
L-230	Redwood	4000
L-260	Perryridge	1700

loan

customer-name	loan-number
Jones	L-170
Smith	L-230
Hayes	L-155

borrower

SELECT * FROM table1 join_type table2 [ON (join_condition)]

Types of JOINs

- EQUI JOIN
  - INNER JOIN
  - OUTER JOIN
    - LEFT OUTER JOIN
    - RIGHT OUTER JOIN
    - FULL OUTER JOIN
- NON EQUI JOIN
- NATURAL JOIN
- CROSS JOIN

loan-number	branch-name	amount	customer-name	loan-number
L-170	Downtown	3000	Jones	L-170
L-230	Redwood	4000	Smith	L-230
L-260	Perryridge	1700	null	null

SQL JOIN

loan-number	branch-name	amount
L-170	Downtown	3000
L-230	Redwood	4000
L-260	Perryridge	1700

loan

customer-name	loan-number
Jones	L-170
Smith	L-230
Hayes	L-155

borrower

SELECT * FROM table1 join_type table2 [ON (join_condition)]

Types of JOINs

- EQUI JOIN
  - INNER JOIN
  - OUTER JOIN
    - LEFT OUTER JOIN
    - RIGHT OUTER JOIN
    - FULL OUTER JOIN
- NON EQUI JOIN
- NATURAL JOIN
- CROSS JOIN

loan-number	branch-name	amount	customer-name	loan-number
L-170	Downtown	3000	Jones	L-170
L-230	Redwood	4000	Smith	L-230
null	null	null	Hayes	L-155

SQL JOIN

loan-number	branch-name	amount
L-170	Downtown	3000
L-230	Redwood	4000
L-260	Perryridge	1700

loan

customer-name	loan-number
Jones	L-170
Smith	L-230
Hayes	L-155

borrower

SELECT * FROM table1 join_type table2 [ON (join_condition)]

Types of JOINs

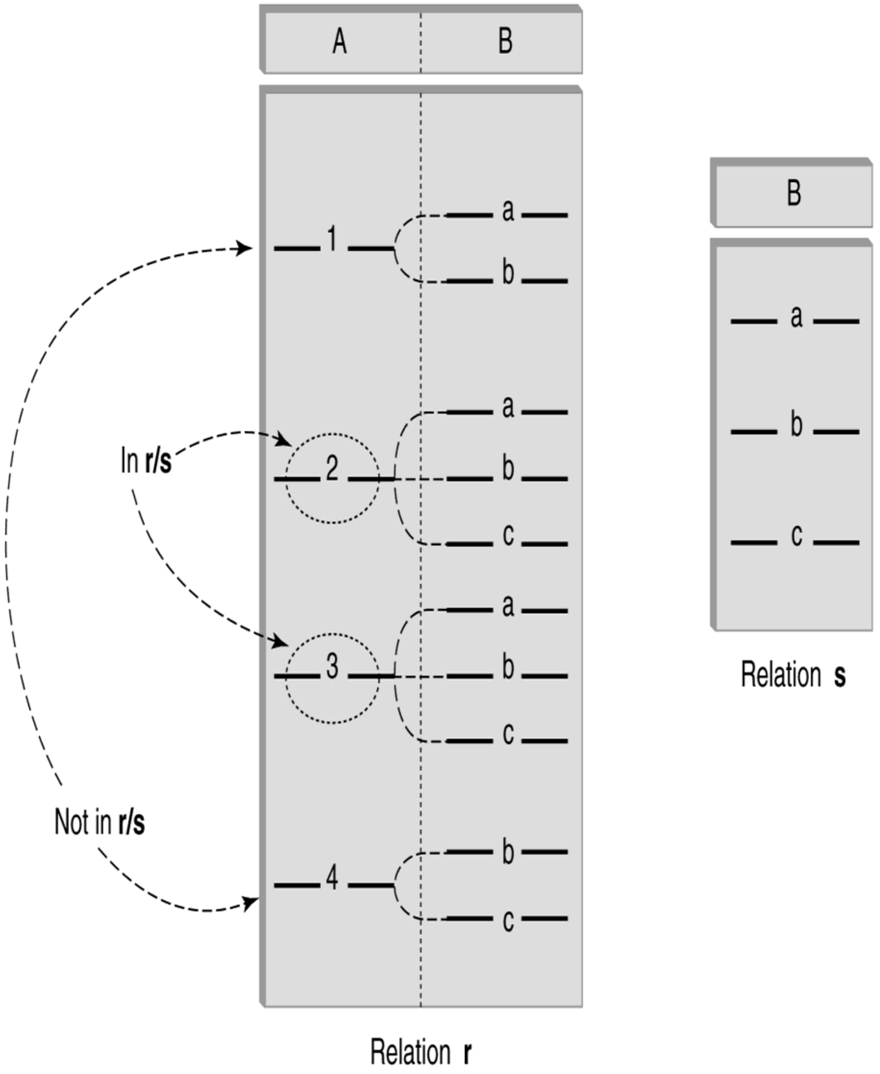
- EQUI JOIN
  - INNER JOIN
  - OUTER JOIN
    - LEFT OUTER JOIN
    - RIGHT OUTER JOIN
    - FULL OUTER JOIN
- NON EQUI JOIN
- NATURAL JOIN
- CROSS JOIN

loan-number	branch-name	amount	customer-name	loan-number
L-170	Downtown	3000	Jones	L-170
L-230	Redwood	4000	Smith	L-230
L-260	Perryridge	1700	null	null
null	null	null	Hayes	L-155

Division

- Goal: Produce the tuples in one relation r, that match *all* tuples in another relation s
  - $r\ (A_1, \ldots A_n, B_1, \ldots B_m)$
  - $s\ (B_1 \ldots B_m)$
  - r/s, with attributes $A_1, \ldots A_n$, is the set of all tuples <*a*> such that for every tuple <*b*> in *s*, <*a,b*> is in *r*

Example: List of sailors who've reserved all boats



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

Division

Given two relations(tables): R(x,y) , S(y).

R(x,y) div S(y) means gives all distinct values of x from R that are associated with all values of y in S.

Computation of Division : R(x,y) div S(y)
Steps:

- Find out all possible combinations of S(y) with R(x) by computing R(x) x(cross join) S(y)
  - r1 = R(x) X S(y)

- Subtract actual R(x,y) from r1, say r2
  - r2 = r1 –R(x,y)

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

- x in r2 are those that are not associated with every value in S(y); therefore R(x)-r2(x) gives us x that are associated with all values in S

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

Find the names of sailors who've reserved all boats

$$\rho\ (Tempsids, (\pi_{sid,bid} \mathrm{Re}serves) \,/\, (\pi_{bid}\ Boats))$$

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

Find the names of sailors who've reserved all boats

$$\rho\ (Tempsids, (\pi_{sid,bid} \mathrm{Re}serves) \ / \ (\pi_{bid}\ Boats))$$

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

To find sailors who've reserved all 'red boats:

$$\ldots.. \qquad / \, p_{bid}(s_{color='red'}\ Boats)$$

Find the names of sailors who've reserved all boats

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

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

```
SELECT sid FROM Reserves WHERE bid NOT IN
   ( SELECT sid FROM (
                        (SELECT sid , bid FROM
                             (  SELECT bid FROM Boats                    //S(y) x R(x)
                              CROSS JOIN
                              SELECT DISTINCT sid FROM Reserves
                            ) AS r1                                      // r1(x,y) = S(y) x R(x)
                       )
                       EXCEPT
                       (SELECT sid , bid FROM Reserves)
                     ) AS r2                                             // r2=r1 – R
  );                                                                     //  R / S
```

Find the names of sailors who've reserved all boats

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

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

```
SELECT * FROM Reserves AS r WHERE
    NOT EXISTS
    ( (SELECT b.bid FROM Boats AS b )
          EXCEPT
      (SELECT t.bid FROM Reserves AS t WHERE t.bid = r.bid )
    );
```

Aggregate Functions and Operations

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

  avg: average value
  min: minimum value
  max: maximum value
  sum: sum of values
  count: number of values

- **Aggregate operation** in relational algebra

$$_{G1,\ G2,\ \ldots,\ Gn}\ \mathcal{G}_{\ F1(A1),\ F2(A2),\ldots,\ Fn(An)}\ (E)$$

  - *E* is any relational-algebra expression
  - $G_1, G_2 \ldots, G_n$ is a list of attributes on which to group (can be empty)
  - Each F_i is an aggregate function
  - Each A_i is an attribute name

Aggregate Operation – Example

Relation *r*:

A	*B*	*C*
α	α	7
α	β	7
β	β	3
β	β	10

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

sum-C
27

SELECT COUNT(*)
FROM r

SELECT SUM(c)
FROM r

SELECT MAX (*c*)
FROM r

Aggregates (cont'd)

Professor(<u>ssn</u>, profname, status)

Course(<u>crscode</u>, crsname, credits)

Taught(<u>crscode, semester</u>, ssn)

Count the number of courses taught in semester S2000

```
SELECT COUNT (T.CrsCode)
FROM Teaching T
WHERE  T.Semester = 'S2000'
```

But if multiple sections of same course are taught, use:

```
SELECT COUNT (DISTINCT T.CrsCode)
FROM Teaching T
WHERE  T.Semester = 'S2000'
```

Aggregate Operation – Example

Relation *account* grouped by *branch-name*:

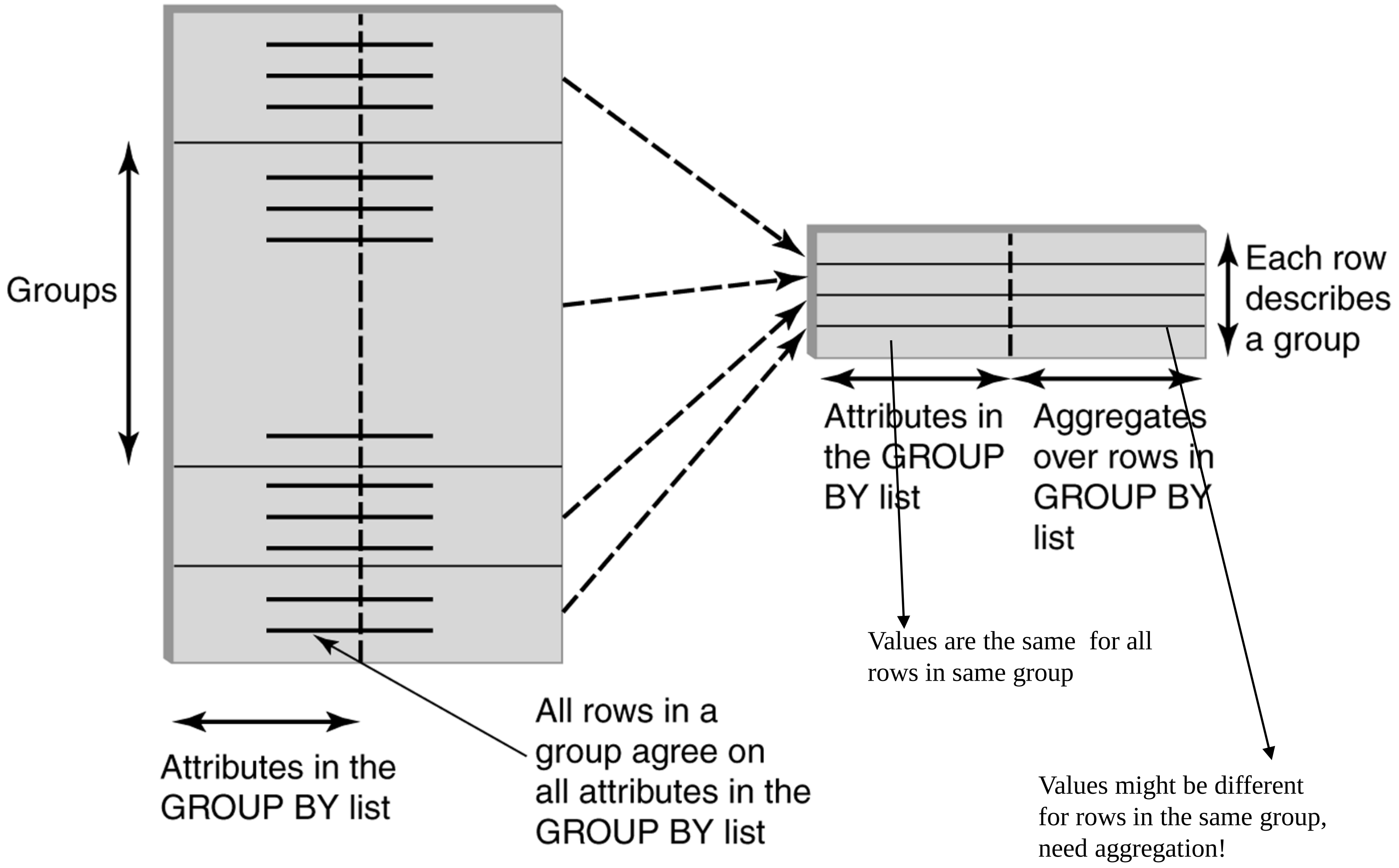
branch-name	*account-number*	*balance*
Perryridge	A-102	400
Perryridge	A-201	900
Brighton	A-217	750
Brighton	A-215	750
Redwood	A-222	700

$$_{branch\text{-}name}\,\mathcal{G}_{\,sum(balance)}\,(account)$$

branch-name	*balance*
Perryridge	1300
Brighton	1500
Redwood	700

```
SELECT    branch-name, SUM(balance)
  FROM      account
  GROUP BY  branch-name
```

GROUP BY



Groups
Each row describes a group
Attributes in the GROUP BY list
Aggregates over rows in GROUP BY list
Values are the same for all rows in same group
Attributes in the GROUP BY list
All rows in a group agree on all attributes in the GROUP BY list
Values might be different for rows in the same group, need aggregation!

Grouping

Professor(<u>ssn</u>, profname, status)

Course(<u>crscode</u>, crsname, credits)

Taught(<u>crscode, semester, ssn</u>)

But how do we compute the number of courses taught in semester S2000 *per professor*?

- Strategy 1: Fire off a separate query for <u>each</u> professor:

```
SELECT   COUNT(T.CrsCode)
FROM     Teaching T
WHERE    T.Semester = 'S2000' AND T.ProfId = 123456789
```

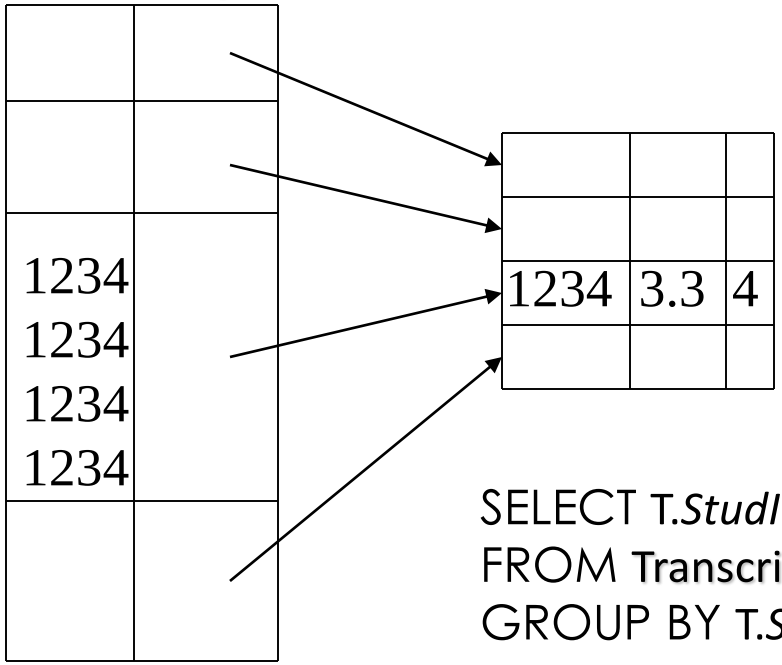
  - Cumbersome
  - What if the number of professors changes? Add another query?

- Strategy 2: define a special *grouping operator*:

```
SELECT     T.ProfId,  COUNT(T.CrsCode)
FROM       Teaching  T
WHERE      T.Semester = 'S2000'
GROUP BY  T.ProfId
```

GROUP BY - Example

Transcript



Attributes:
- –student's *Id*
- –avg grade
- –number of courses

SELECT T.*StudId*, AVG(T.*Grade*), COUNT (*)
FROM Transcript T
GROUP BY T.*StudId*

-Finally, each group of rows is aggregated into one row

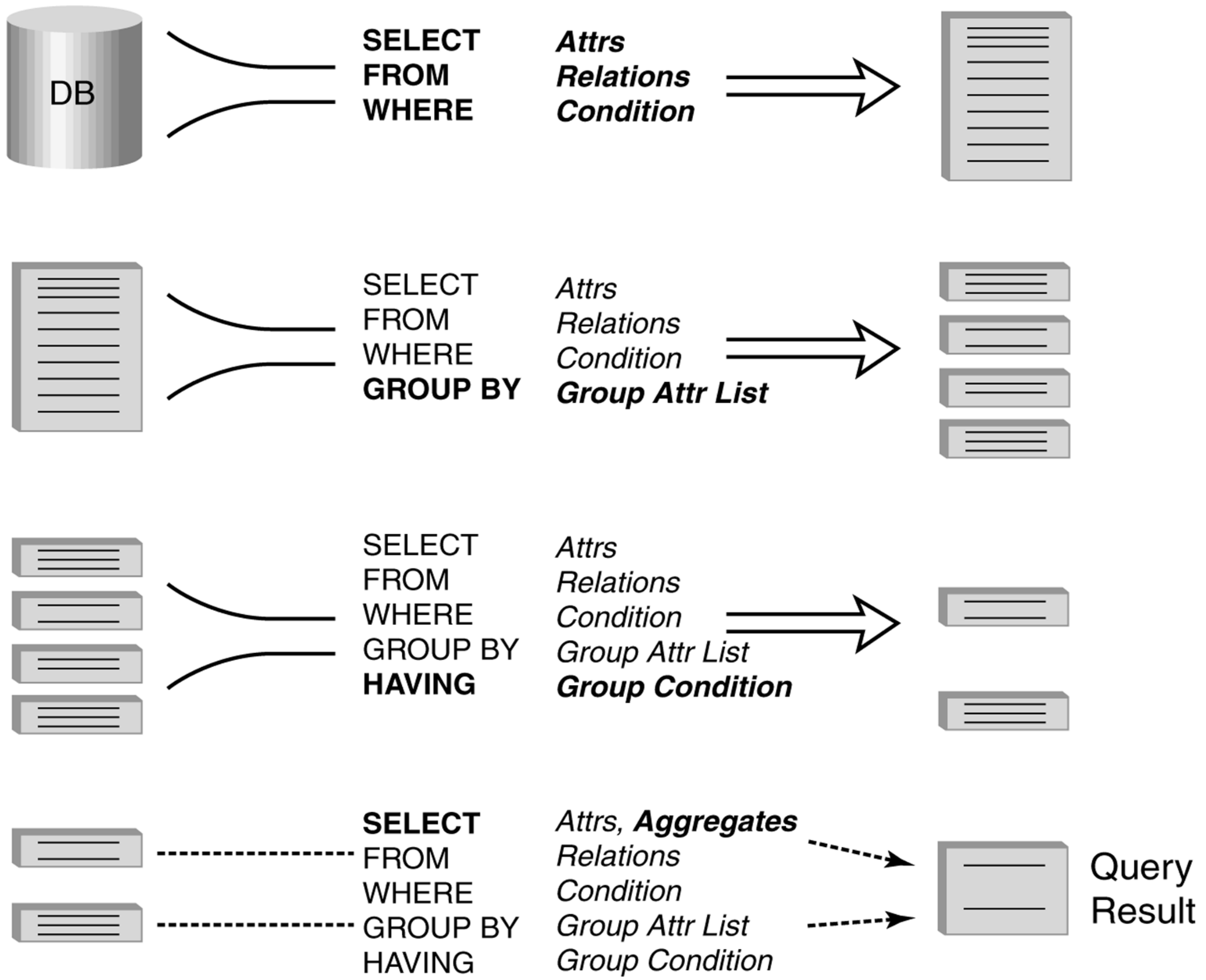
HAVING Clause

- Eliminates unwanted groups (analogous to WHERE clause, but works on groups instead of individual tuples)
- HAVING condition is constructed from attributes of GROUP BY list and aggregates on attributes not in that list

```
SELECT  T.StudId,
        AVG(T.Grade)  AS  CumGpa,
        COUNT (*)  AS  NumCrs
FROM    Transcript  T
WHERE   T.CrsCode  LIKE  'CS%'
GROUP BY  T.StudId
HAVING  AVG (T.Grade) > 3.5
```

Apply to each group not to the whole table

Evaluation of GroupBy with Having



Example

Student (*Id, Name, Addr, Status*)
Professor (*Id, Name, DeptId*)
Course (*DeptId, CrsCode, CrsName, Descr*)
Transcript (*StudId, CrsCode, Semester, Grade* , *Credit*)
Teaching (*ProfId, CrsCode, Semester*)
Department (*DeptId, Name*)

Output the name and address of all seniors whose average Grade > 3.5 and total credit >90

SELECT S.*Id*, S.*Name*
FROM Student S, Transcript T
WHERE S.*Id* = T.*StudId* AND S.*Status* = 'senior'

GROUP BY
- S.Id -- *wrong*
- S.Id, S.Name -- *right*

Every attribute that occurs in SELECT *clause must also occur in* GROUP BY *or it must be an aggregate. S.Name does not.*

HAVING AVG (T.*Grade*) > 3.5 AND SUM (T.*Credit*) > 90

Aggregates: Proper and Improper Usage

SELECT COUNT (T.*CrsCode*), T. *ProfId*

– *makes no sense (in the absence of* GROUP BY *clause)*

SELECT COUNT (*), AVG (T.*Grade*)

– *but this is OK*

WHERE T.*Grade* > COUNT (SELECT ….)

– *aggregate cannot be applied to result of* SELECT *statement*

ORDER BY Clause

Causes rows to be output in a specified order

SELECT T.*StudId*, COUNT (*) AS *NumCrs*,
AVG(T.*Grade*) AS *CumGpa*
FROM Transcript T
WHERE T.*CrsCode* LIKE 'CS%'
GROUP BY T.*StudId*
HAVING AVG (T.*Grade*) > 3.5
ORDER BY DESC *CumGpa*, ASC *StudId*

Descending

Ascending

Query Evaluation with GROUP BY, HAVING, ORDER BY

As before

1 Evaluate FROM: produces Cartesian product, A, of tables in FROM list

2 Evaluate WHERE: produces table, B, consisting of rows of A that satisfy WHERE condition

3 Evaluate GROUP BY: partitions B into groups that agree on attribute values in GROUP BY list

4 Evaluate HAVING: eliminates groups in B that do not satisfy HAVING condition

5 Evaluate SELECT: produces table C containing a row for each group. Attributes in SELECT list limited to those in GROUP BY list and aggregates over group

6 Evaluate ORDER BY: orders rows of C

Nulls

- *Conditions*: *x op y* (where *op* is <, >, <>, =, etc.) has value *unknown* (*U*) when either x or y is null
  - WHERE T.*cost* > T.*price*
- *Arithmetic expression*: x *op y* (where *op* is +, –, *, etc.) has value NULL if x or y is NULL
  - WHERE (T. *price*/T.*cost*) > 2
- *Aggregates*: COUNT counts NULLs like any other value; other aggregates ignore NULLs

```
SELECT  COUNT (T.CrsCode), AVG (T.Grade)
FROM    Transcript T
WHERE   T.StudId = '1234'
```

Nulls (cont'd)

- WHERE clause uses a ***three-valued logic – T, F, U(ndefined)*** – to filter rows. Portion of truth table:

C1	*C2*	*C1* AND *C2*	*C1* OR *C2*
T	U	U	T
F	U	F	U
U	U	U	U

- Rows are discarded if WHERE condition is *F(alse)* or U(*nknown)*
- Ex: WHERE T.*CrsCode* = 'CS305' AND T.*Grade* > 2.5

Exercise

Query 3

Professor(<u>ssn</u>, profname, status)

Course(<u>crscode</u>, crsname, credits)

Taught(<u>crscode, semester</u>, ssn)

Return those professors who have never taught ‘csc7710’.

Relational Algebra Solution

Professor(<u>ssn</u>, profname, status)

Course(<u>crscode</u>, crsname, credits)

Taught(<u>crscode, semester</u>, <u>ssn)</u>

$$\pi_{ssn}(\sigma_{crscode <> \text{'csc7710'}}(Taught))$$

Relational Algebra Solution

Professor(ssn, profname, status)

Course(crscode, crsname, credits)

Taught(crscode, semester, ssn)

$\pi_{ssn}(\sigma_{crscode <> 'csc7710'}(Taught))$, wrong answer!

$\pi_{ssn}(Professor) - \pi_{ssn}(\sigma_{crscode = 'csc7710'}(Taught))$, correct answer!

Relational Algebra Solution

Professor(ssn, profname, status)

Course(crscode, crsname, credits)

Taught(crscode, semester, ssn)

$\pi_{ssn}(\sigma_{crscode<>\text{‘csc7710’}}(Taught))$, wrong answer!

$\pi_{ssn}(Professor)-\pi_{ssn}(\sigma_{crscode=\text{‘csc7710’}}(Taught))$, correct answer!

```
(SELECT ssn
From Professor)
EXCEPT
(SELECT ssn
From Taught T
Where T.crscode = 'CSC7710')
```

Professor(ssn, profname, status)
Course(crscode, crsname, credits)
Taught(crscode, semester, ssn)

Query 4

Return those professors who taught ‘CSC6710’ and ‘CSC7710” in the same semester

Professor(ssn, profname, status)
Course(crscode, crsname, credits)
Taught(crscode, semester, ssn)

Query 4

Return those professors who taught ‘CSC6710’ and ‘CSC7710” in the same semester

$\pi_{ssn}(\sigma_{crscode1=\text{'csc6710'}}(Taught[crscode1, ssn, semester]) \bowtie \sigma_{crscode2=\text{'csc7710'}}(Taught[crscode2, ssn, semester]))$

Professor(ssn, profname, status)

Course(crscode, crsname, credits)

Taught(crscode, semester, ssn)

Query 4

Return those professors who taught ‘CSC6710’ and ‘CSC7710” in the same semester

$\pi_{ssn}(\sigma_{crscode1=\text{‘csc6710’}}(\text{Taught}[crscode1, ssn, semester])$

$\sigma_{crscode2=\text{‘csc7710’}}(\text{Taught}[crscode2, ssn, semester]))$

SELECT T1.ssn
From Taught T1, Taught T2,
Where T1.crscode = ‘CSC6710’ AND T2.crscode=‘CSC7710’ AND T1.ssn=T2.ssn AND T1.semester=T2.semester

Professor(ssn, profname, status)

Course(crscode, crsname, credits)

Taught(crscode, semester, ssn)

Query 5

Return those professors who taught ‘CSC6710’ or ‘CSC7710”
but not both.

Professor(ssn, profname, status)

Course(crscode, crsname, credits)

Taught(crscode, semester, ssn)

Query 5

Return those professors who taught 'CSC6710' or 'CSC7710" but not both.

$$\pi_{ssn}(\sigma_{crscode='csc6710' \vee crscode='csc7710'}(Taught)) - (\pi_{ssn}(\sigma_{crscode='csc6710'}(Taught)) \cap \pi_{ssn}(\sigma_{crscode='csc7710'}(Taught)))$$

Query 5

Professor(ssn, profname, status)

Course(crscode, crsname, credits)

Taught(crscode, semester, ssn)

Return those professors who taught ‘CSC6710’ or ‘CSC7710”
but not both.

$$\pi_{ssn}(\sigma_{crscode=\text{'csc6710'} \vee crscode=\text{'csc7710'}}(Taught)) - (\pi_{ssn}(\sigma_{crscode=\text{'csc6710'}}(Taught)) \cap \pi_{ssn}(\sigma_{crscode=\text{'csc7710'}}(Taught)))$$

```
(SELECT ssn
FROM Taught T
WHERE T.crscode=‘CSC6710’ OR T.crscode=‘CSC7710’)
Except
(SELECT T1.ssn
From Taught T1, Taught T2,
Where T1.crscode = ‘CSC6710’) AND
T2.crscode=‘CSC7710’ AND T1.ssn=T2.ssn)
```

Professor(ssn, profname, status)

Course(crscode, crsname, credits)

Taught(crscode, semester, ssn)

Query 6

Return those courses that have never been taught.

Professor(ssn, profname, status)

Course(crscode, crsname, credits)

Taught(crscode, semester, ssn)

Query 6

Return those courses that have never been taught.

$\pi_{crscode}(\text{Course})-\pi_{crscode}(\text{Taught})$

Query 6

Professor(<u>ssn</u>, profname, status)

Course(<u>crscode</u>, crsname, credits)

Taught(<u>crscode, semester, ssn</u>)

Return those courses that have never been taught.

$$\pi_{crscode}(Course) - \pi_{crscode}(Taught)$$

```
(SELECT crscode FROM Course)
EXCEPT
(SELECT crscode FROM TAUGHT )
```

Query 7

Professor(<u>ssn</u>, profname, status)

Course(<u>crscode</u>, crsname, credits)

Taught(<u>crscode, semester, ssn</u>)

Return those courses that have been taught at least in two semesters.

Query 7

Professor(ssn, profname, status)

Course(crscode, crsname, credits)

Taught(crscode, semester, ssn)

Return those courses that have been taught at least in two semesters.

$\pi_{crscode}(\sigma_{semester1 <> semester2}($

$Taught[crscode, ssn1, semester1] \bowtie$
$Taught[crscode, ssn2, semester2]))$

Query 7

Professor(ssn, profname, status)

Course(crscode, crsname, credits)

Taught(crscode, semester, ssn)

Return those courses that have been taught at least in two semesters.

$$\pi_{crscode}(\sigma_{semester1 <> semester2}(\text{Taught}[crscode, semester1] \bowtie \text{Taught}[crscode, semester2]))$$

```
SELECT T1.crscode
FROM Taught T1, Taught T2
WHERE T1.crscode=T2.crscode AND T1.semester <> T2.semester
```

Query 8

Professor(<u>ssn</u>, profname, status)

Course(<u>crscode</u>, crsname, credits)

Taught(<u>crscode, semester</u>, ssn)

Return those courses that have been taught at least in 10 semesters.

SQL Solution

Professor(ssn, profname, status)

Course(crscode, crsname, credits)

Taught(crscode, semester, ssn)

```
SELECT crscode
FROM Taught
GROUP BY crscode
HAVING COUNT(*) >= 10
```

Query 9

Professor(ssn, profname, status)

Course(crscode, crsname, credits)

Taught(crscode, semester, ssn)

Return those courses that have been taught by at least 5 different professors.

SQL Solution

Professor(ssn, profname, status)

Course(crscode, crsname, credits)

Taught(crscode, semester, ssn)

```
SELECT crscode
FROM (SELECT DISTINCT crscode, ssn FROM TAUGHT)
GROUP BY crscode
HAVING COUNT(*) >= 5
```

Query 10

Professor(ssn, profname, status)

Course(crscode, crsname, credits)

Taught(crscode, semester, ssn)

Return the names of professors who ever taught ‘CSC6710’.

Relational Algebra Solution

Professor(ssn, profname, status)

Course(crscode, crsname, credits)

Taught(crscode, semester, ssn)

$$\pi_{profname}(\sigma_{crscode=\text{'csc6710'}}(Taught) \bowtie Professor)$$

SQL Solution

Professor(<u>ssn</u>, profname, status)

Course(<u>crscode</u>, crsname, credits)

Taught(<u>crscode, semester, ssn</u>)

```
SELECT P.profname
FROM Professor P, Taught  T
WHERE P.ssn = T.ssn AND T.crscode = 'CSC6710'
```

Query 11

Professor(ssn, profname, status)

Course(crscode, crsname, credits)

Taught(crscode, semester, ssn)

Return the names of full professors who ever taught ‘CSC6710’.

Relational Algebra Solution

Professor(<u>ssn</u>, profname, status)

Course(<u>crscode</u>, crsname, credits)

Taught(<u>crscode, semester, ssn</u>)

$$\pi_{profname}(\sigma_{crscode=\text{'csc6710'}}(Taught) \bowtie \sigma_{status=\text{'full'}}(Professor))$$

SQL Solution

Professor(<u>ssn</u>, profname, status)

Course(<u>crscode</u>, crsname, credits)

Taught(<u>crscode, semester</u>, ssn)

```
SELECT P.profname
FROM Professor P, Taught  T
WHERE P.status = 'full' AND P.ssn = T.ssn AND T.crscode =
'CSC6710'
```

Query 12

Professor(ssn, profname, status)

Course(crscode, crsname, credits)

Taught(crscode, semester, ssn)

Return the names of full professors who ever taught more than two courses in one semester.

SQL Solution

Professor(<u>ssn</u>, profname, status)

Course(<u>crscode</u>, crsname, credits)

Taught(<u>crscode, semester</u>, ssn)

```
SELECT P.profname
FROM Professor P
WHERE ssn IN(
SELECT ssn
FROM Taught
GROUP BY ssn, semester
HAVING COUNT(*) > 2
)
```

Query 13

Professor(ssn, profname, status)

Course(crscode, crsname, credits)

Taught(crscode, semester, ssn)

Delete those professors who never taught a course.

SQL Solution

Professor(<u>ssn</u>, profname, status)

Course(<u>crscode</u>, crsname, credits)

Taught(<u>crscode, semester</u>, ssn)

```
DELETE FROM Professor
WHERE ssn NOT IN
(SELECT ssn
FROM Taught
)
```

Query 14

Professor(<u>ssn</u>, profname, status)

Course(<u>crscode</u>, crsname, credits)

Taught(<u>crscode, semester</u>, ssn)

Change all the credits to 4 for those courses that are taught in f2006 semester.

SQL Solution

Professor(<u>ssn</u>, profname, status)

Course(<u>crscode</u>, crsname, credits)

Taught(<u>crscode, semester</u>, <u>ssn</u>)

```
UPDATE Course
SET credits = 4
WHERE crscode IN
(
   SELECT crscode
   FROM Taught
   WHERE semester = 'f2006'
)
```

Query 15

Professor(ssn, profname, status)
Course(crscode, crsname, credits)
Taught(crscode, semester, ssn)

Return the names of the professors who have taught more than 30 credits of courses.

SQL Solution

Professor(ssn, profname, status)

Course(crscode, crsname, credits)

Taught(crscode, semester, ssn)

```
SELECT profname
FROM Professor
WHERE ssn IN
(
    SELECT T.ssn
    FROM Taught  T, Course C
    WHERE T.crscode = C.crscode
    GROUP BY T.ssn
    HAVING SUM(C.credits) > 30
)
```

Query 16

Professor(ssn, profname, status)

Course(crscode, crsname, credits)

Taught(crscode, semester, ssn)

Return the name(s) of the professor(s) who taught the most number of courses in S2006.

SQL Solution

Professor(<u>ssn</u>, profname, status)

Course(<u>crscode</u>, crsname, credits)

Taught(<u>crscode, semester</u>, ssn)

```
SELECT profname
FROM Professor
WHERE ssn IN(
    SELECT ssn FROM Taught
    WHERE semester = ‘S2006’
    GROUP BY ssn
     HAVING COUNT(*) =
          (SELECT MAX(Num)
           FROM
               (SELECT ssn, COUNT(*) as Num
               FROM Taught
               WHERE semester = ‘S2006’
               GROUP BY ssn)
          )
)
```

Query 17

Professor(<u>ssn</u>, profname, status)

Course(<u>crscode</u>, crsname, credits)

Taught(<u>crscode, semester</u>, ssn)

List all the course names that professor ‘Smith” taught in Fall of 2007.

Relational Algebra Solution

Professor(ssn, profname, status)

Course(crscode, crsname, credits)

Taught(crscode, semester, ssn)

$$\pi_{crsname}(\sigma_{profname=\text{'Smith'}}(Professor) \bowtie \sigma_{semester=\text{'f2007'}}(Taught) \bowtie Course)$$

SQL Solution

Professor(<u>ssn</u>, profname, status)

Course(<u>crscode</u>, crsname, credits)

Taught(<u>crscode, semester</u>, ssn)

```
SELECT crsname
FROM Professor P, Taught T, Course C
WHERE P.profname = 'Smith' AND P.ssn = T.ssn AND
T.semester = 'F2007' AND T.crscode = C.crscode
```

Query 18

Professor(<u>ssn</u>, profname, status)

Course(<u>crscode</u>, crsname, credits)

Taught(<u>crscode, semester</u>, ssn)

In chronological order, list the number of courses that the professor with ssn ssn = 123456789 taught in each semester.

SQL Solution

Professor(<u>ssn</u>, profname, status)

Course(<u>crscode</u>, crsname, credits)

Taught(<u>crscode, semester, ssn</u>)

```
SELECT semester, COUNT(*)
FROM Taught
WHERE ssn = ‘123456789’
GROUP BY semester
ORDER BY semester ASC
```

Query 19

Professor(ssn, profname, status)

Course(crscode, crsname, credits)

Taught(crscode, semester, ssn)

In alphabetical order of the names of professors, list the name of each professor and the total number of courses she/he has taught.

SQL Solution

Professor(ssn, profname, status)

Course(crscode, crsname, credits)

Taught(crscode, semester, ssn)

```
SELECT P.profname, COUNT(*)
FROM Professor P, Taught T
WHERE P.ssn = T.ssn
GROUP BY P.ssn, P.profname
ORDER BY P.profname ASC
```

Query 20

Professor(<u>ssn</u>, profname, status)

Course(<u>crscode</u>, crsname, credits)

Taught(<u>crscode, semester</u>, ssn)

Delete those professors who taught less than 10 courses.

SQL Solution

Professor(ssn, profname, status)

Course(crscode, crsname, credits)

Taught(crscode, semester, ssn)

```
DELETE FROM Professor
WHERE ssn IN(
    SELECT ssn
    FROM Taught
    GROUP BY ssn
    HAVING COUNT(*) < 10
)
```

Query 21

Professor(<u>ssn</u>, profname, status)

Course(<u>crscode</u>, crsname, credits)

Taught(<u>crscode, semester, ssn</u>)

Delete those professors who taught less than 40 credits.

SQL Solution

Professor(<u>ssn</u>, profname, status)

Course(<u>crscode</u>, crsname, credits)

Taught(<u>crscode, semester, ssn</u>)

```
DELETE FROM Professor
WHERE ssn IN(
    SELECT T.ssn
    FROM Taught T, Course C
    WHERE T.crscode = C.crscode
    GROUP BY ssn
    HAVING SUM(C.credits) < 40
)
```

Query 22

Professor(<u>ssn</u>, profname, status)

Course(<u>crscode</u>, crsname, credits)

Taught(<u>crscode, semester</u>, ssn)

List those professors who have not taught any course in the past three semesters (F2006, W2007, F2007).

SQL Solution

Professor(<u>ssn</u>, profname, status)

Course(<u>crscode</u>, crsname, credits)

Taught(<u>crscode, semester</u>, ssn)

```
SELECT *
FROM Professor P
WHERE NOT EXISTS(
      SELECT *
      FROM Taught
      WHERE P.ssn = T.ssn AND (T.semester = ‘F2006’ OR
      T.semester = ‘W2007’ OR T.semester=‘F2007’))
)
```

Query 23

Professor(<u>ssn</u>, profname, status)

Course(<u>crscode</u>, crsname, credits)

Taught(<u>crscode, semester</u>, ssn)

List the names of those courses that professor Smith have never taught.

Relational Algebra Solution

Professor(<u>ssn</u>, profname, status)

Course(<u>crscode</u>, crsname, credits)

Taught(<u>crscode, semester</u>, ssn)

$\pi_{crsname}(\text{Course})-$
$\pi_{crsname}(\sigma_{profname=\text{'Smith'}}(\text{Professor}) \bowtie$
$(\text{Taught}) \bowtie$

$\text{Course})$

SQL Solution

Professor(<u>ssn</u>, profname, status)

Course(<u>crscode</u>, crsname, credits)

Taught(<u>crscode, semester</u>, ssn<u>)</u>

```
SELECT crsname
FROM Course C
WHERE NOT EXISTS
      SELECT *
      FROM Professor P, Taught T
      WHERE P.profname='Smith' AND P.ssn = T.ssn AND
T.crscode = C.crscode
)
```

Query 24

Professor(ssn, profname, status)

Course(crscode, crsname, credits)

Taught(crscode, semester, ssn)

Return those courses that have been taught by all professors.

Relational Algebra Solution

Professor(ssn, profname, status)

Course(crscode, crsname, credits)

Taught(crscode, semester, ssn)

$$\pi_{crscode,\ ssn}(Taught) / \pi_{ssn}(Professor)$$

SQL Solution

Professor(<u>ssn</u>, profname, status)

Course(<u>crscode</u>, crsname, credits)

Taught(<u>crscode, semester</u>, ssn)

```
SELECT crscode
FROM Taught T1
WHERE NOT EXISTS(
       (SELECT ssn
       FROM Professor)
       EXCEPT
       (SELECT ssn
        FROM Taught T2
        WHERE T2.crscode = T1.crscode)
)
```

Query 25

Professor(<u>ssn</u>, profname, status)

Course(<u>crscode</u>, crsname, credits)

Taught(<u>crscode, semester</u>, ssn)

Return those courses that have been taught in all semesters.

Relational Algebra Solution

Professor(<u>ssn</u>, profname, status)

Course(<u>crscode</u>, crsname, credits)

Taught(<u>crscode, semester</u>, ssn)

$$\pi_{crscode,\ semester}(Taught) / \pi_{semester}(Taught)$$

SQL Solution

Professor(<u>ssn</u>, profname, status)

Course(<u>crscode</u>, crsname, credits)

Taught(<u>crscode, semester</u>, ssn)

```
SELECT crscode
FROM Taught T1
WHERE NOT EXISTS(
        (SELECT semester
        FROM Taught)
        EXCEPT
        (SELECT semester
         FROM Taught T2
         WHERE T2.crscode = T1.crscode)
)
```

Query 25

Professor(<u>ssn</u>, profname, status)

Course(<u>crscode</u>, crsname, credits)

Taught(<u>crscode, semester</u>, ssn)

Return those courses that have been taught ONLY by junior professors.

Relational Algebra Solution

Professor(ssn, profname, status)

Course(crscode, crsname, credits)

Taught(crscode, semester, ssn)

$$\pi_{crscode}(\text{Course}) - \pi_{crscode}(\sigma_{status \neq \text{'Junior'}}(\text{Professor}) \bowtie \text{Taught})$$

SQL Solution

Professor(<u>ssn</u>, profname, status)

Course(<u>crscode</u>, crsname, credits)

Taught(<u>crscode, semester</u>, ssn)

```
SELECT crscode
FROM  Course C
WHERE c.crscode NOT IN(
       (SELECT crscode
        FROM Taught T, Professor P
        WHERE T.ssn = P.ssn AND P.status='Junior'
)
```

Find names of sailors who've reserved boat #103

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

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

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

$\pi_{sname}\,(Temp2)$

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

Exercise: Find names of sailors who've reserved a red boat

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

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

❖ A more efficient solution:

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

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

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

- Can identify all red or green boats, then find sailors who have 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?

Exercise: Find sailors who've reserved a red <u>and</u> 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):

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

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

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