CSE 305 / CSE532

Lecture 06 (Chapter 5)

Relational Algebra: Under the Hood of SQL

Lecturer: Sael Lee

Slide adapted from the author's and Dr. Ilchul Yoon's slides.

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

What is an Algebra?

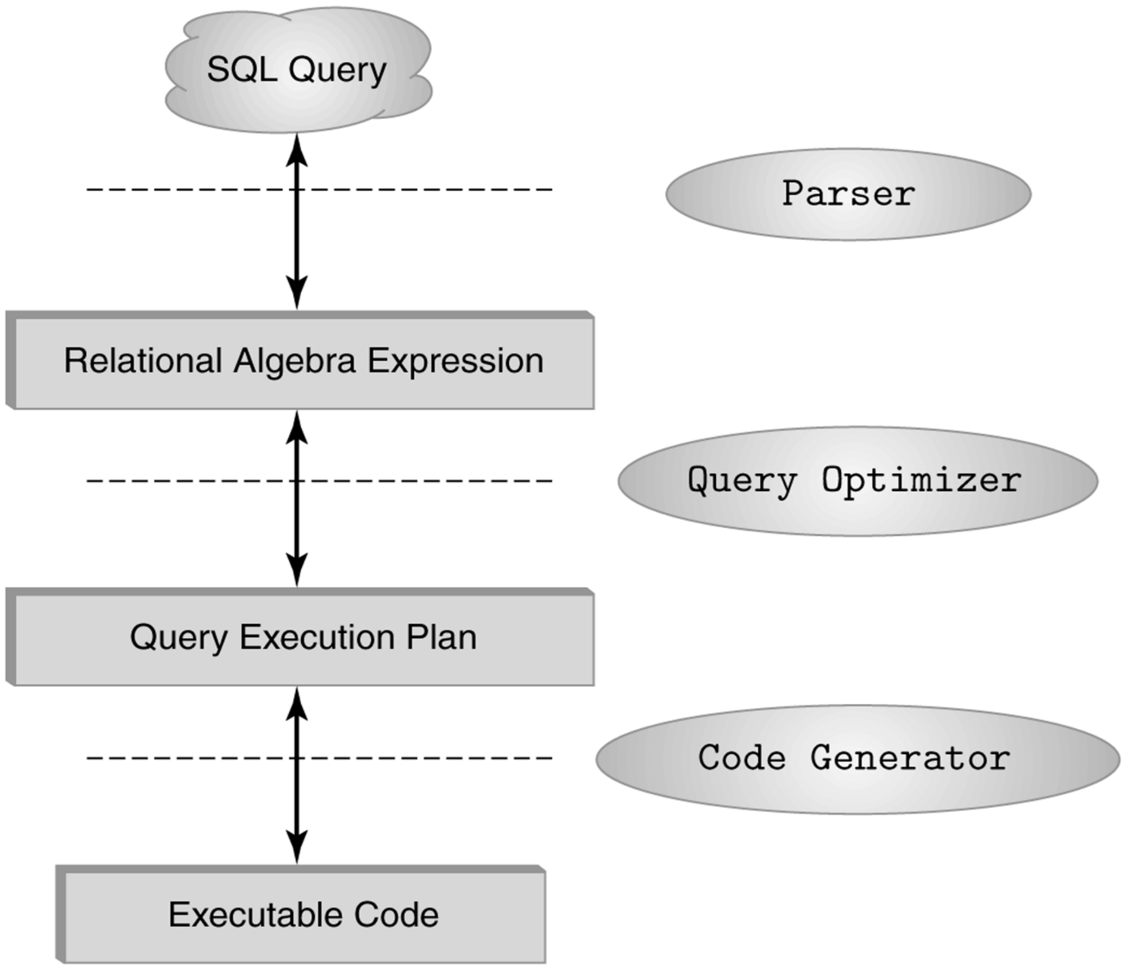
- A language based on operators and a domain of values
- Operators map values taken from the domain into other domain values
- Hence, an expression involving operators and arguments produces a value in the domain
- When the domain is a set of all relations (and the operators are as described later),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

Relational Algebra

- *Domain*: set of relations
- *Basic operators*: **select, project, union, set difference, Cartesian product**
- *Derived operators*: **set intersection, division, join**

- *Procedural*
  - Relational expression specifies query by describing an algorithm (the sequence in which operators are applied) for determining the result of an expression

The Role of Relational Algebra in a DBMS



Select Operator

- Produce table containing subset of rows of argument table satisfying condition

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

- 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

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

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

Selection Condition

- Operators: <, ≤, ≥, >, =, ≠
- Simple selection condition:
  - *<attribute> operator <constant>*
  - *<attribute> operator <attribute>*
- *<condition>* AND *<condition>*
- *<condition>* OR *<condition>*
- NOT *<condition>*

Selection Condition - Examples

- $\sigma_{\text{Id>3000 OR Hobby='hiking'}}$ (Person)
- $\sigma_{\text{Id>3000 AND Id <3999}}$ (Person)
- $\sigma_{\text{NOT(Hobby='hiking')}}$ (Person)
- $\sigma_{\text{Hobby}\neq\text{'hiking'}}$ (Person)

Project Operator

- Produces table containing subset of columns of argument table

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

- 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

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

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

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

Expressions

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

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

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.

Cartesian Product

- If R and S are two relations, R × 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 <u>not</u> be union compatible
- <u>**R × S is expensive to compute**</u>:
  - Factor of two in the size of each row
  - Quadratic in the number of rows

A	B
x1	x2
x3	x4

R

C	D
y1	y2
y3	y4

S

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

R× S

Renaming

- Result of expression evaluation is a relation

- Attributes of relation must have distinct names. This is not guaranteed with Cartesian product
  - e.g., suppose in previous example *a* and *c* have the same name

- Renaming operator tidies this up. To assign the names $A_1, A_2, \ldots A_n$ to the attributes of the *n*-column relation produced by expression *expr* use:

$$expr\ [A_1, A_2, \ldots, A_n]$$

Example

Transcript (*StudId*, *CrsCode*, *Semester*, *Grade*)

Teaching (*ProfId*, *CrsCode*, *Semester*)

$\pi_{\textit{StudId, CrsCode}}$ (Transcript)[*StudId*, *CrsCode1*]

$\times$ $\pi_{\textit{ProfId, CrsCode}}$(Teaching) [*ProfId*, *CrsCode2*]

This is a relation with 4 attributes:

StudId, *CrsCode1*, *ProfId*, *CrsCode2*

Derived Operation: Join (theta-join)

- A (*general* or *theta*) *join* of *R* and *S* is the expression

  $$R \bowtie_{\textit{join-condition}} S$$

  where *join-condition* is a *conjunction* of terms:

  $$A_i \ \textit{oper}\ B_i$$

  in which A_i is an attribute of *R;* B_i is an attribute of *S;* and *oper* is one of =, <, >, ≥ ≠, ≤.

- The meaning is:

  $$\sigma_{\textit{join-condition}'}(R \times S)$$

  where *join-condition* and *join-condition*' are the same, except for possible renaming of attributes

Join and Renaming

- **Problem**:
  - R and S might have attributes with the same name – in which case the Cartesian product is not defined
- **Solutions**:
  - Rename attributes prior to forming the product and use new names in join-condition´.
  - Qualify common attribute names with relation names (thereby disambiguating the names).
    - e.g., Transcript.*CrsCode* or Teaching.*CrsCode*
  - This solution is nice, but doesn't always work: consider
    - $R \bowtie_{\text{join\_condition}} R$
    - In R.*A*, how do we know which R is meant?

Theta Join – Example

Employee(*Name, Id, Salary, MngrId*)
Manager(*Name, Id, Salary*)

- Output the names of all employees that earn more than their managers.

$$\pi_{\text{Employee}.Name}(\text{Employee} \bowtie_{E.MngrId = M.Id \text{ AND } E.Salary > M.Salary} \text{Manager})$$

- The join yields a table with attributes:
  - Employee.*Name*, Employee.*Id*, Employee.*Salary*, *MngrId*, Manager.*Name*, Manager.*Id*, Manager.*Salary*

Equijoin Join - Example

- *Equijoin*: Join condition is a conjunction of *equalities*.

$$\pi_{Name,CrsCode}(\text{Student} \bowtie_{Id=StudId} \sigma_{Grade='A'}(\text{Transcript}))$$

Student

Id	*Name*	*Addr*	*Status*
111	John	…..	…..
222	Mary	…..	…..
333	Bill	…..	…..
444	Joe	…..	…..

Transcript

StudId	*CrsCode*	*Sem*	*Grade*
111	CSE305	S00	B
222	CSE306	S99	A
333	CSE304	F99	A

Mary	CSE306
Bill	CSE304

The equijoin is used very frequently since it combines related data in different relations.

Natural Join

- Special case of equijoin:
  - join condition equates *all* and *only* those attributes with the same name (condition doesn't have to be explicitly stated)
  - duplicate columns eliminated from the result

Transcript (*StudId*, *CrsCode*, *Sem*, *Grade*)
Teaching (*ProfId*, *CrsCode*, *Sem*)

$$\text{Transcript} \bowtie \text{Teaching} =$$

$$\pi_{StudId,\ Transcript.CrsCode,\ Transcript.Sem,\ Grade,\ ProfId}\left(\text{Transcript} \bowtie_{CrsCode=CrsCode \text{ AND } Sem=Sem} \text{Teaching}\right)$$

$$[StudId,\ CrsCode,\ Sem,\ Grade,\ ProfId\ ]$$

Natural Join (cont'd)

- More generally:

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

where

(1) attr-list = attributes (*R*) ∪ *attributes* (*S*)

(duplicates are eliminated) and

(2) join-cond has the form:

$A_1 = A_1$ AND … AND $A_n = A_n$

where

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

Natural Join Example

- List all Ids of students who took at least two different courses:

$$\pi_{StudId} (\sigma_{CrsCode \neq CrsCode2} (\text{Transcript} \bowtie \text{Transcript} [StudId, CrsCode2, Sem2, Grade2]))$$

We don’t want to join on *CrsCode*, *Sem*, and *Grade* attributes, hence renaming!

Outer Join

- Three types
  - Left outer join / Right outer join / Full outer join
- Given two relations r and s, the tuples in $r \bowtie^{outer}_{cond} s$ consist of three categories
  1. The tuples that appear in the regular join of r and s, $r \bowtie_{cond} s$
  2. The tuples of r that do not join with any tuple in s
  3. The tuples of s that do not join with any tuple in r

- For left outer join, $1 \cup 2$
- For right outer join, $1 \cup 3$
- For full outer join, $1 \cup 2 \cup 3$

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Lecture 07 (Chapter 5)
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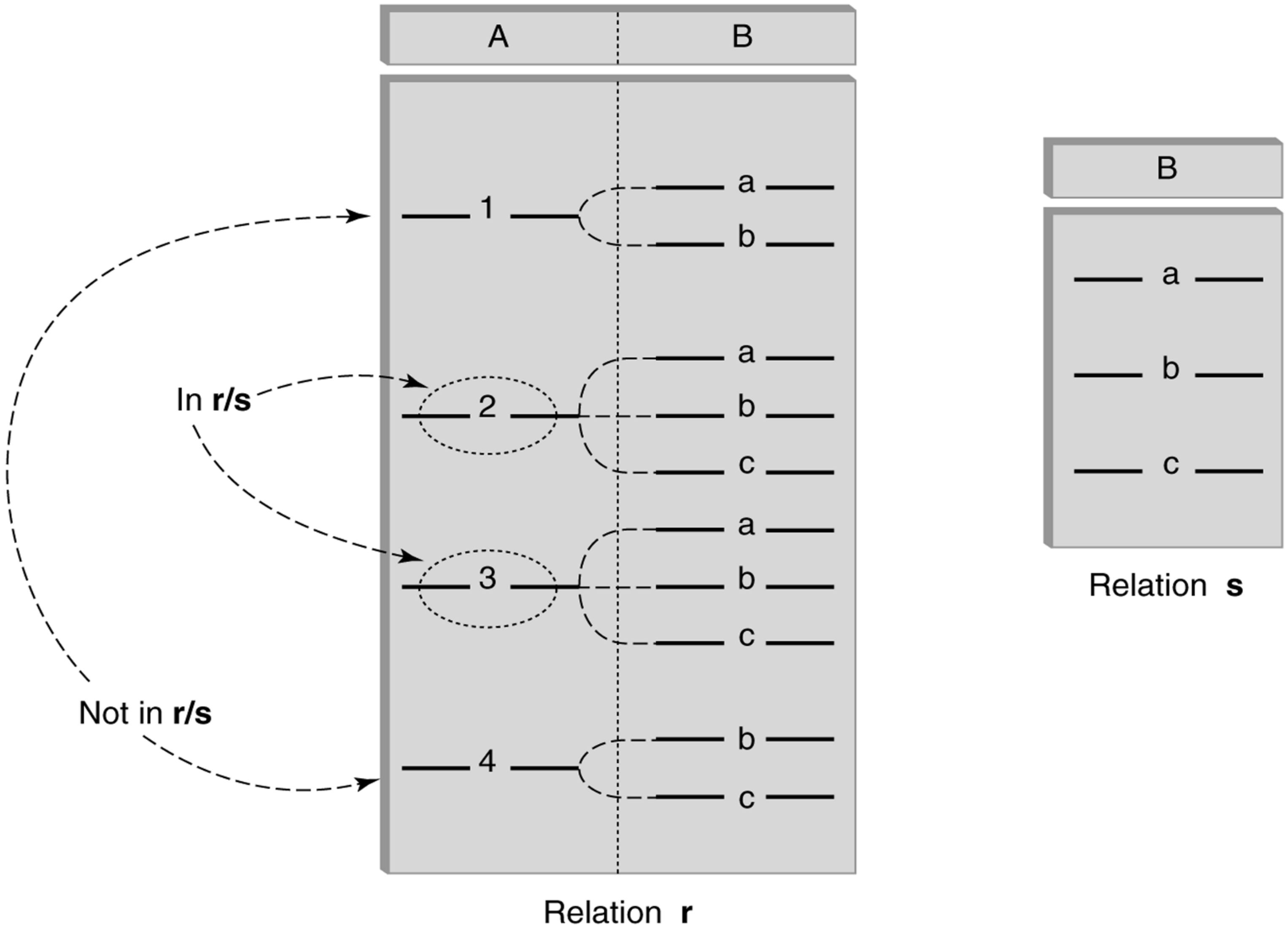
Division

- 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*

- Can be expressed in terms of projection, set difference, and cross-product

Division (cont'd)



Division

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  - $r\ (A_1, \ldots A_n, B_1, \ldots B_m)$
  - $s\ (B_1 \ldots B_m)$
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- Can be expressed in terms of projection, set difference, and cross-product

$$T_1 = \pi_A (R) \times S$$
$$T_2 = \pi_A (T_1 - R)$$
$$T_3 = \pi_A (R) - T_2$$

Division - Example

- List the Ids of students who have passed *all* courses that were taught in spring 2006

- *Numerator*:
  - *StudId* and *CrsCode* for every course passed by every student:

$$\pi_{StudId,\ CrsCode}(\sigma_{Grade \neq 'F'}(\text{Transcript}))$$

- *Denominator*:
  - *CrsCode* of all courses taught in spring 2006

$$\pi_{CrsCode}(\sigma_{Semester='S2006'}(\text{Teaching}))$$

- Result is *numerator/denominator*

Example

- Suppose we want to know, from the *Movies* relation, "What are the titles and years of movies made by Fox that are at least 100 minutes long?"

Movies(<u>title</u>, year, length, genre, studioName, producerC#)

MoviewStar(<u>name</u>, address gender, DOB)

StarIn(<u>movieTitle, movieYear, starName</u>)

MovieExec(name, address, <u>cert#</u>, netWorth)

Studio(name, address, <u>PresC#</u>)

Administrivia

- No class on 3/31 (Tuesday) and 4/2 (Thursday)
  - **Makeup class: TBA**
- Term Project requirements
  - General requirements and Journal/conference attributes are posted in Bb.

Schema for Student Registration System

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

Query Sublanguage of SQL

```
SELECT  C.CrsName
FROM  Course C
WHERE  C.DeptId = ‘CS’
```

- *Tuple variable* C ranges over rows of Course.
- An evaluation strategy:
  - FROM clause produces Cartesian product of listed tables
  - WHERE clause assigns rows to C in sequence and produces table containing only rows satisfying condition
  - SELECT clause retains listed columns
- Equivalent to: $\pi_{CrsName}\sigma_{DeptId=\text{‘CS’}}(\text{Course})$

Join Queries

```
SELECT  C.CrsName
FROM  Course C, Teaching T
WHERE  C.CrsCode=T.CrsCode AND T.Semester='S2000'
```

- List courses taught in S2000
- Tuple variables clarify meaning.
- Join condition "C.*CrsCode*=T.*CrsCode*"
  - relates facts to each other
- Selection condition " T.*Semester*='S2000' "
  - eliminates irrelevant rows
- Equivalent (using natural join) to:

$$\pi_{CrsName}(\text{Course} \bowtie \sigma_{Semester=\text{'S2000'}}(\text{Teaching}))$$

$$\pi_{CrsName}(\sigma_{Sem=\text{'S2000'}}(\text{Course} \bowtie \text{Teaching}))$$

Correspondence Between SQL and Relational Algebra

```
SELECT   C.CrsName
FROM   Course C, Teaching T
WHERE   C.CrsCode = T.CrsCode  AND  T.Semester = 'S2000'
```

- Also equivalent to:

$$\pi_{CrsName}\, \sigma_{C\_CrsCode=T\_CrsCode\ AND\ Semester='S2000'}$$
$$(\text{Course}\ [C\_CrsCode, DeptId, CrsName, Desc] \times \text{Teaching}\ [ProfId, T\_CrsCode, Semester])$$

- This is the simplest evaluation algorithm for SELECT.
- Relational algebra expressions are procedural.
  - Which of the two equivalent expressions is more easily evaluated?

Self-join Queries

- Find Ids of all professors who taught at least two courses in the same semester:

```
SELECT  T1.ProfId
FROM  Teaching T1, Teaching T2
WHERE  T1.ProfId = T2.ProfId
    AND  T1.Semester = T2.Semester
    AND  T1.CrsCode <> T2.CrsCode
```

- *Tuple variables are essential in this query!*
- Equivalent to:

$$\pi_{ProfId}(\sigma_{T1.CrsCode \neq T2.CrsCode}(\text{Teaching}[ProfId,\ T1.CrsCode,\ Semester] \bowtie \text{Teaching}[ProfId,\ T2.CrsCode,\ Semester]))$$

Duplicates

- Duplicate rows are not allowed in a relation
- However, duplicate elimination from query result is costly and not done by default; must be explicitly requested:

```
SELECT DISTINCT .....
FROM .....
```

Use of Expressions

- Equality and comparison operators apply to strings (based on lexical ordering)

  WHERE S.*Name* < 'P'

- Concatenate operator applies to strings

  WHERE S.*Name* || '--' || S.*Address* = ….

- Expressions can also be used in SELECT clause:

```
SELECT  S.Name || '--' || S.Address AS NmAdd
FROM  Student S
```

Set Operators

- SQL provides UNION, EXCEPT (set difference), and INTERSECT for union compatible tables
- Example
  - Find all professors in the CS Department and all professors that have taught CS courses

```
(SELECT   P.Name
 FROM   Professor P, Teaching T
 WHERE  P.Id=T.ProfId AND T.CrsCode LIKE ‘CS%’)
UNION
(SELECT  P.Name
 FROM  Professor P
 WHERE  P.DeptId = ‘CS’)
```

Nested Queries

- List all courses that were not taught in S2000

```
SELECT C.CrsName
FROM Course C
WHERE C.CrsCode  NOT  IN
     (SELECT T.CrsCode       -- subquery
       FROM Teaching T
       WHERE T.Sem = 'S2000')
```

- Evaluation strategy
  - *Subquery evaluated once* to produces set of courses taught in S2000. Each row (as C) tested against this set.

Correlated Nested Queries

- Output a row <*prof, dept*> if *prof* has taught a course in *dept*.

```
SELECT  P.Name, D.Name                     --outer query
FROM Professor P, Department D
WHERE  P.Id  IN
          -- set of  all ProfId's who have taught a course in D.DeptId
          (SELECT T.ProfId                          --subquery
           FROM Teaching T, Course C
           WHERE T.CrsCode = C.CrsCode  AND
                 C.DeptId = D.DeptId               --correlation
          )
```

Correlated Nested Queries (con't)

- Tuple variables T and C are *local* to subquery
- Tuple variables P and D are *global* to subquery

- *Correlation*: subquery uses a global variable, D
  - The value of D.*DeptId* parameterizes an evaluation of the subquery
  - *Subquery must (at least) be re-evaluated for each distinct value of D.DeptId*

- *Correlated queries can be expensive to evaluate*

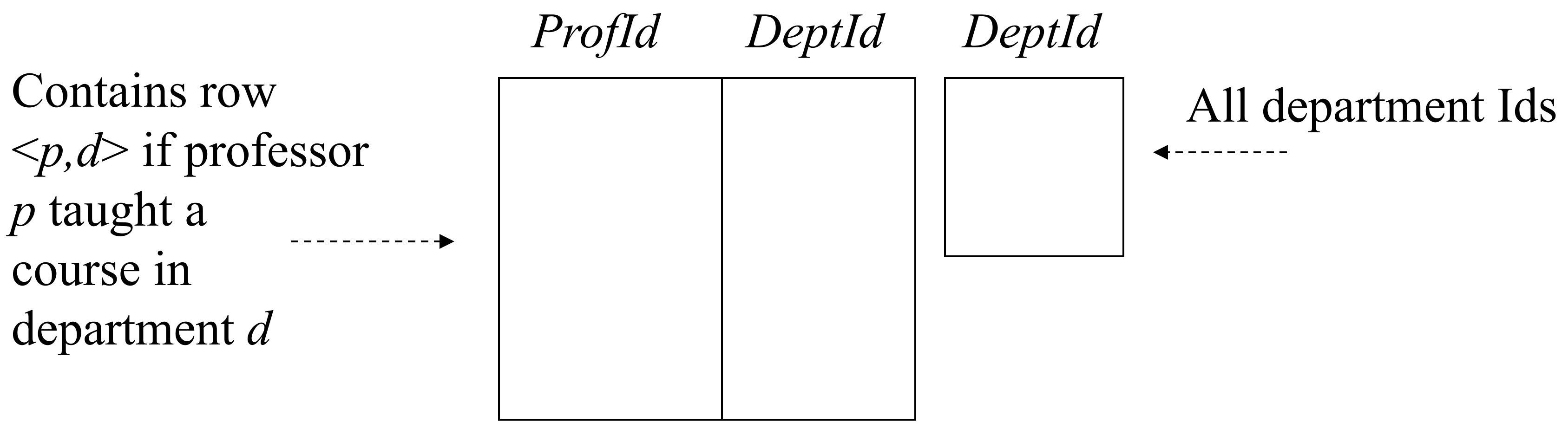
EXISTS Operator

- Simply, used to check if a nested subquery returns no answers
- Example
  - Find all students who never took a computer science course

```
SELECT S.Id
FROM Student S
WHERE NOT EXISTS (
        -- All CS courses taken by S.Id
         SELECT T.CrsCode
         FROM Transcript T
         WHERE T.CrsCode LIKE ‘CS%’ AND
                    T.StudID = S.Id )
```

Division in SQL

- *Query type*: Find the subset of items in one set that are related to *all* items in another set
- *Example*
  - Find professor Ids who taught courses in all departments
  - Why does this involve division?


ProfId
DeptId
DeptId
Contains row *<p,d>* if professor *p* taught a course in department *d*
All department Ids

$$\pi_{ProfId,DeptId}(\text{Teaching} \bowtie \text{Course}) \;/\; \pi_{DeptId}(\text{Department})$$

Division in SQL

- *Strategy for implementing division in SQL:*
  - Find a set, A, of all departments in which a particular professor, *p*, has taught a course
  - Find set, B, of all departments
  - Output *p* if A $\subseteq$ B, or, equivalently, if B – A is empty

Division – SQL Solution

```
SELECT  P.Id
FROM  Professor P
WHERE NOT EXISTS
    (SELECT  D.DeptId              -- set B of all dept Ids
      FROM  Department D

     EXCEPT

      SELECT  C.DeptId               -- set A of dept Ids of depts in
                                      -- which P taught a course
      FROM  Teaching T, Course C
      WHERE  T.ProfId = P.Id        -- global variable
           AND  T.CrsCode = C.CrsCode)
```

Set Comparison Operator

- *Is there a student in the university whose GPA is higher than that of all junior students?*

```
SELECT S.Id
FROM Student S
WHERE S.GPA > ALL (
        SELECT S.GPA
        FROM Student S
        WHERE S.Status = ‘junior’ )
```

- What happens if we replace > ALL with >= ANY ?

Nested Query in the FROM clause

- Use nested query in the FROM clause and rename it
- For example
  - *Find the students who took a course from every professor in the CS department*

```
SELECT S.Id
FROM Student S
EXCEPT
SELECT S.Id
FROM Student S,
          ( SELECT P.Id
             FROM Professor P
             WHERE P.Dept = 'CS') AS C
WHERE C.ProfId NOT IN
           ( SELECT T.ProfId
             FROM Teaching T, Transcript R
             WHERE T.CrsCode = R.CrsCode AND
                        T.Semester = R.Semester AND
                        S.Id = R.StudId )
```

Aggregates

- Functions that operate on sets:
  - COUNT, SUM, AVG, MAX, MIN
- Produce numbers (not tables)
- Not part of relational algebra (but not hard to add)

```
SELECT COUNT(*)          SELECT MAX (Salary)
FROM  Professor P        FROM  Employee E
```

- Do not mix aggregate and an attribute in the SELECT

```
SELECT COUNT(*), S.Id
FROM  Student S
WHERE S.Name = 'JohnDoe'
```

- Aggregate functions can't be used in the WHERE clause

Aggregates (cont'd)

- Count the number of courses taught in 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'
```

Grouping

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

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

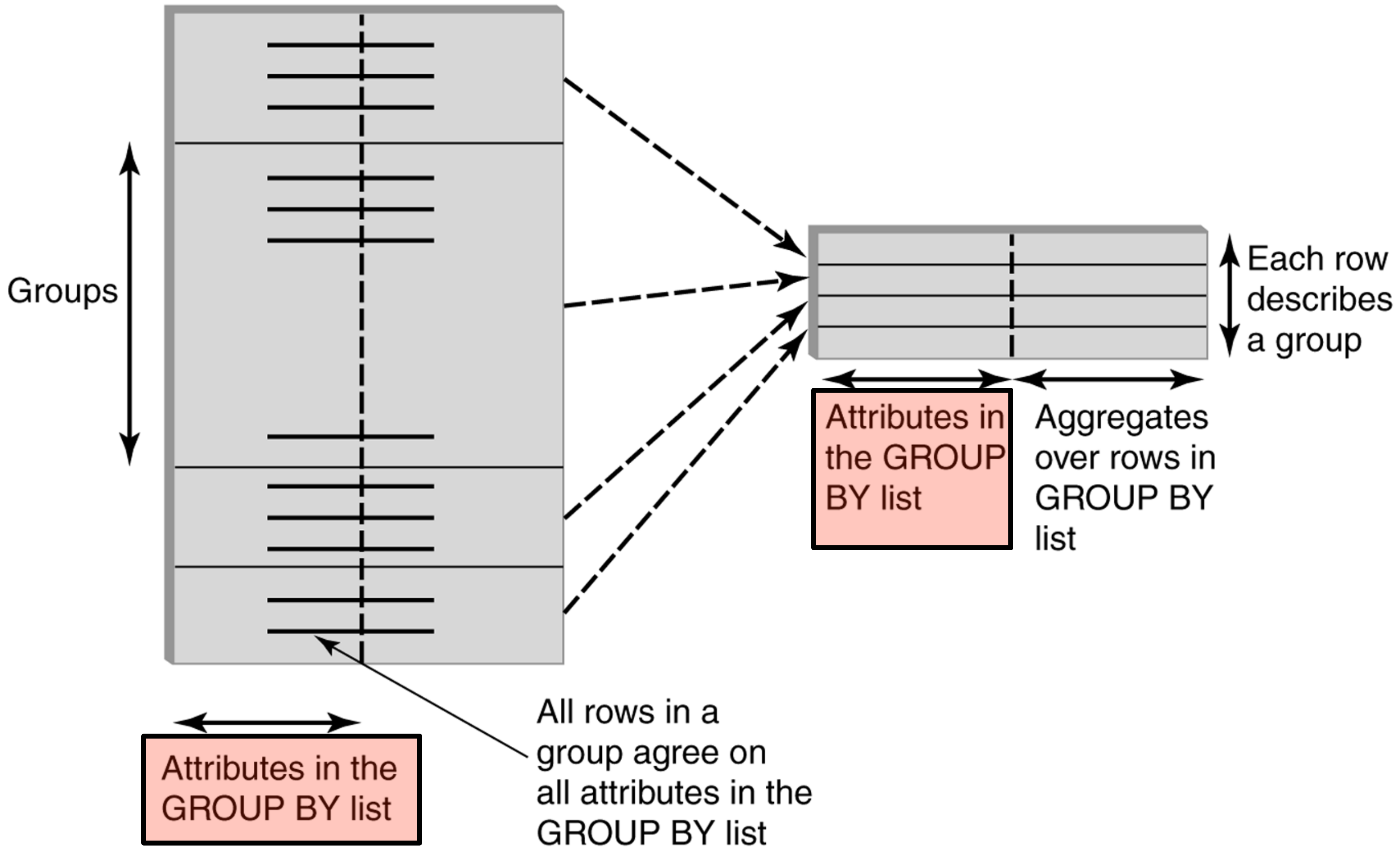
```
SELECT   COUNT(T.CrsCode)
FROM     Teaching T
WHERE  T.Semester = 'S2000' AND T.ProfId = 123456789
```

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

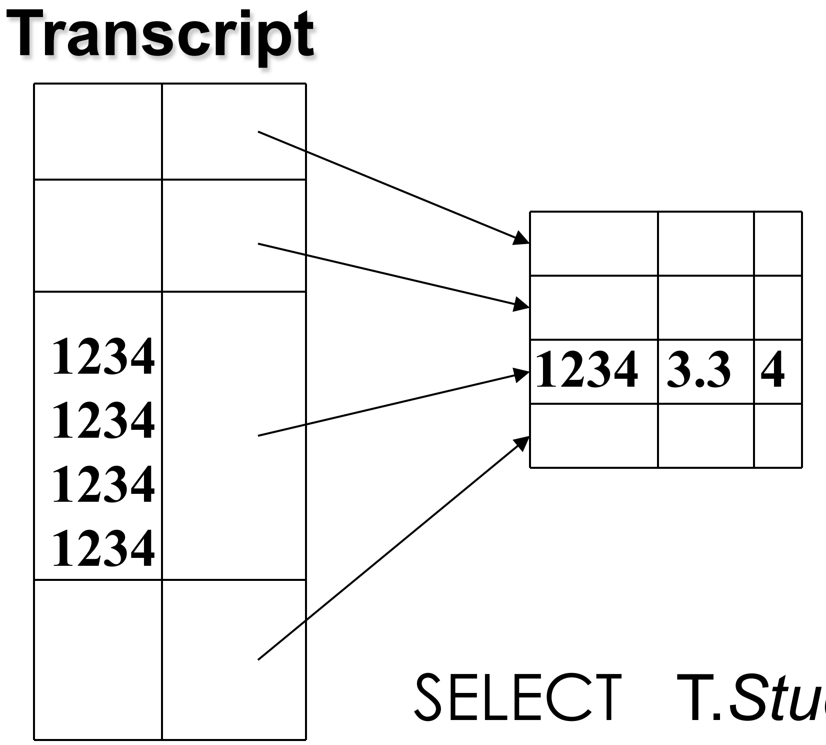
- Strategy 2: define a special ***grouping operator***:

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

GROUP BY


Groups
Each row describes a group
Attributes in the GROUP BY list
Aggregates over rows in GROUP BY list
Attributes in the GROUP BY list
All rows in a group agree on all attributes in the GROUP BY list

GROUP BY - Example



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

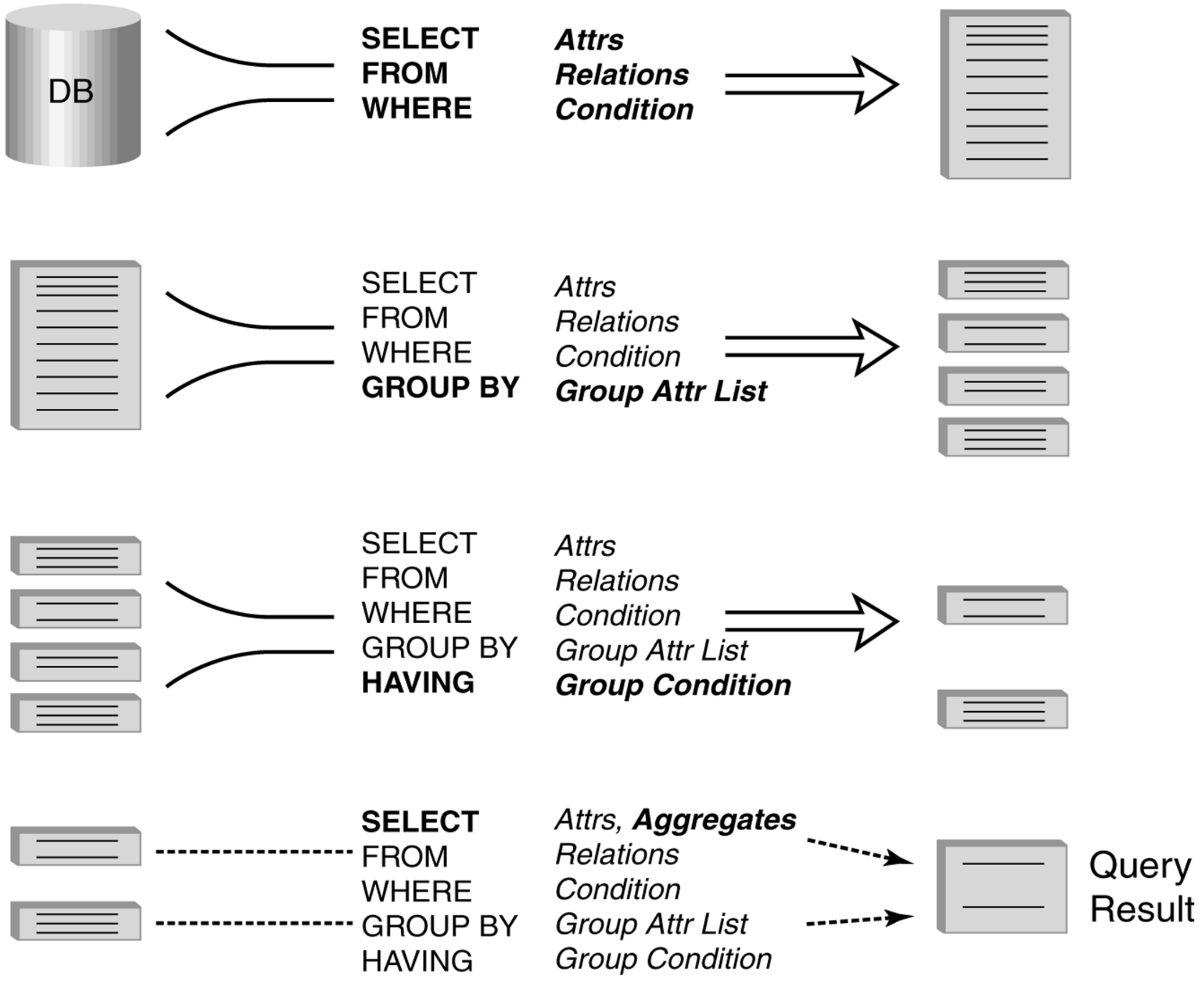
```
SELECT   T.StudId, AVG(T.Grade), COUNT (*)
FROM   Transcript T
GROUP BY   T.StudId
```

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
```

Query Evaluation with Aggregate Functions



Example

- Output the id and name of all seniors on the Dean's List (average grade over 3.5, and more than 90 credits.)

```
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

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

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

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 StudIdc
```

Descending

Ascending

Query Evaluation with GROUP BY, HAVING, ORDER BY

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

JOIN Expressions in the FROM Clause

- Called ‘table expressions’
- Format
  - Table1 [NATURAL] [INNER|FULL|LEFT|OUTER] JOIN table 2 [ON condition]
- List average grade for every student in the database

```
SELECT  S.Name, AVG(S.Grade)
FROM   Student  LEFT JOIN Transcript
ON Student.Id = Transcript.StudId  AS S
GROUP BY  S.Id
```

vs.

```
SELECT  S.Name, AVG(T.Grade)
FROM   Student S, Transcript T
WHERE S.Id = T.StudId
GROUP BY  S.Id
```

Views

- Used as a relation, but rows are not physically stored.
  - The contents of a view is computed when it is used within an SQL statement
- View is the result of a SELECT statement over other views and base relations
- When used in an SQL statement, the view definition is substituted for the view name in the statement
  - As SELECT statement nested in FROM clause

View – Usage Example

```
CREATE VIEW  CumGpa (StudId, Cum) AS
    SELECT  T.StudId,  AVG (T.Grade)
    FROM Transcript T
    GROUP BY T.StudId
```

```
SELECT  S.Name, C.Cum
FROM  CumGpa C,  Student S
WHERE  C.StudId = S.StudId AND C.Cum > 3.5
```

View Benefits

- *Access Control*: Users are not granted access to base tables. Instead they are granted access to the view of the database appropriate to their needs.
  - *External schema* is composed of views.
  - View allows owner to provide SELECT access to a subset of columns (analogous to providing UPDATE and INSERT access to a subset of columns)

Views – Limiting Visibility

Grade **projected out**

- CREATE VIEW PartOfTranscript (*StudId, CrsCode, Semester*) AS

  SELECT T. *StudId*, T.*CrsCode*, T.*Semester* -- *limit columns*

  FROM Transcript T

  WHERE T.*Semester* = 'S2000' -- *limit rows*

- Give permissions to access data through view:

  GRANT SELECT ON PartOfTranscript TO joe

- This would have been analogous to:

  GRANT SELECT (*StudId,CrsCode,Semester*) ON Transcript TO joe

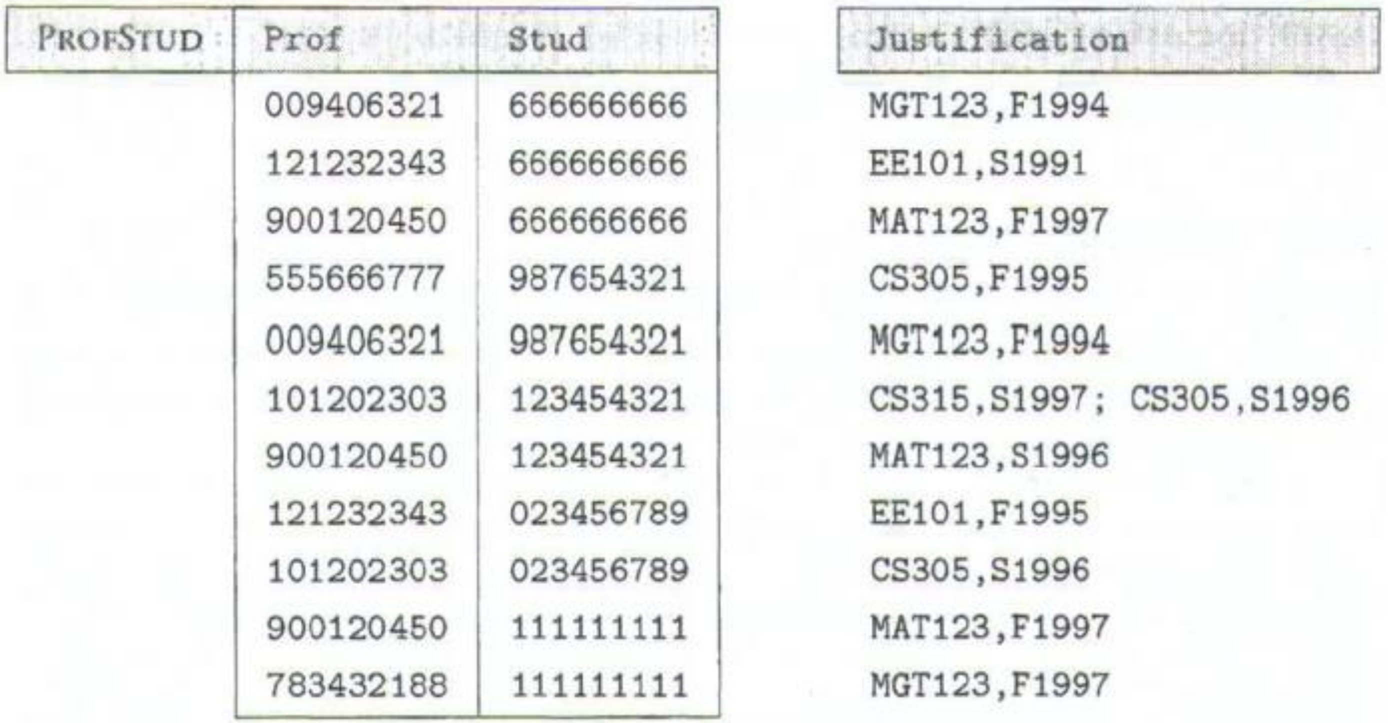
on regular tables, ***if*** SQL allowed attribute lists in GRANT SELECT

View Benefits (cont'd)

- *Customization*: Users need not see full complexity of database. View creates the illusion of a simpler database customized to the needs of a particular category of users
  - Ease of use and learning
  - Security
  - Logical data independence
- A view is *similar in many ways to a subroutine* in standard programming
  - Can be reused in multiple queries

Materialized Views

- Cached view – caching if popular with many queries
  - Dramatic reduction of query response time
  - Expensive update operation
  - Adding/removing tuples in base relations may (or may not) affect view



PROFSTUD	Prof	Stud	Justification
	009406321	666666666	MGT123,F1994
	121232343	666666666	EE101,S1991
	900120450	666666666	MAT123,F1997
	555666777	987654321	CS305,F1995
	009406321	987654321	MGT123,F1994
	101202303	123454321	CS315,S1997; CS305,S1996
	900120450	123454321	MAT123,S1996
	121232343	023456789	EE101,F1995
	101202303	023456789	CS305,S1996
	900120450	111111111	MAT123,F1997
	783432188	111111111	MGT123,F1997

FIGURE 3.9 Contents of the view defined by SQL statement (3.5).

Materialized Views (Con'd)

- View cache maintenance are expensive.
  - Incremental re-compute considering changes

- View cache is very important in data warehousing
  - *Data warehouse is an (infrequently updated) database that typically consist of complex materialized views of the data stored in a separate production database.*
  - Optimized for querying, not transaction processing

```
CREATE MATERIALIZED VIEW PROFSTUD(Prof, Stud)
            BUILD IMMEDIATE
            REFRESH FAST ON COMMIT
            ENABLE QUERY REWRITE
AS
    SELECT  T.ProfId, R.StudId)
    FROM Transcript R, Teaching T
    WHERE .....
```

Oracle Example

CSE 305 / CSE532

Lecture 08 (Chapter 5)

Relational Algebra: Under the Hood of SQL

Lecturer: Sael Lee

Slide adapted from the author's and Dr. Ilchul Yoon's slides.

Nulls and 3-valued logic

- *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)*
  - e.g., WHERE T.*CrsCode* = 'CS305' AND T.*Grade* > 2.5
- If a CHECK clause evaluates to unknown, the integrity constraints are considered to be observed.

Modifying Tables – Insert

- Inserting a single row into a table
  - Attribute list can be omitted if it is the same as in CREATE TABLE (but do not omit it)
  - NULL and DEFAULT values can be specified

```
INSERT INTO  Transcript(StudId, CrsCode, Semester, Grade)
VALUES (12345, ‘CSE305’, ‘S2000’,  NULL)
```

Bulk Insertion

- Insert the rows output by a SELECT

```
CREATE TABLE DeansList (
        StudId         INTEGER,
        Credits        INTEGER,
        CumGpa         FLOAT,
        PRIMARY KEY  StudId )


INSERT INTO  DeansList (StudId, Credits, CumGpa)
        SELECT         T.StudId, 3 * COUNT (*),  AVG(T.Grade)
        FROM           Transcript T
        GROUP BY       T.StudId
        HAVING  AVG (T.Grade) > 3.5  AND  COUNT(*) > 30
```

Modifying Tables – Delete and Update

- DELETE is similar to SELECT except:
  - No project list in DELETE clause
  - No Cartesian product in FROM clause (only 1 table name)
  - Rows satisfying WHERE clause (general form, including subqueries, allowed) are deleted instead of output

```
DELETE FROM Transcript T
WHERE  T.Grade IS NULL  AND  T.Semester <> ‘S2000’
```

- Updates rows in a single table
  - All rows satisfying WHERE clause (general form, including subqueries, allowed) are updated

```
UPDATE  Employee E
SET        E.Salary = E.Salary * 1.05
WHERE   E.Department = ‘R&D’
```

Updating Views

- Question: Since views look like tables to users, can they be updated?
- Answer: Yes – a view update changes the underlying base table to produce the requested change to the view

```
CREATE VIEW   CsReg (StudId, CrsCode, Semester) AS
SELECT         T.StudId, T. CrsCode, T.Semester
FROM           Transcript T
WHERE      T.CrsCode LIKE ‘CS%’  AND  T.Semester=‘S2000’
```

Updating Views - Problem 1

```
INSERT INTO CsReg (StudId, CrsCode, Semester)
VALUES (1111, ‘CSE305’, ‘S2000’)
```

- **Question**: What value should be placed in attributes of underlying table that have been projected out (e.g., *Grade*)?
- **Answer**: Simple. NULL (assuming null allowed in the missing attribute) or DEFAULT

Updating Views - Problem 2

```
INSERT INTO CsReg (StudId, CrsCode, Semester)
VALUES (1111, 'ECO105', 'S2000')
```

This is not CS course!!!

- **Problem**: New tuple not in view
- **Solution**: Allow insertion (assuming the WITH CHECK OPTION clause has not been appended to the CREATE VIEW statement)

Updating Views - Problem 3

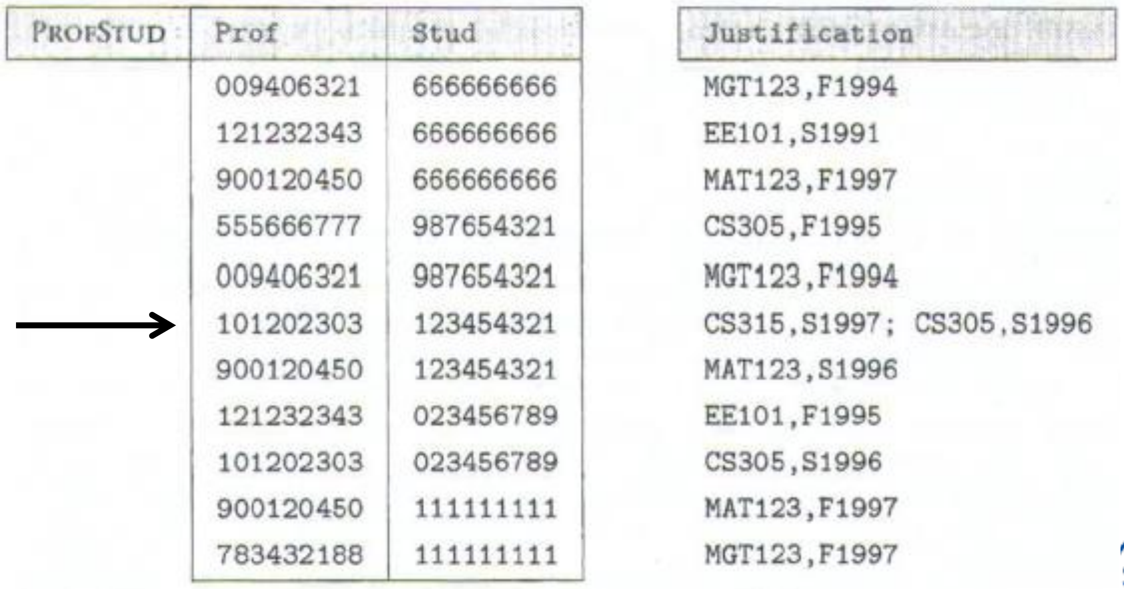
- Update to a view might *not uniquely* specify the change to the base table(s) that results in the desired modification of the view (ambiguity)

```
CREATE VIEW   ProfDept (PrName, DeName)  AS
SELECT    P.Name, D.Name
FROM      Professor P, Department D
WHERE     P.DeptId = D.DeptId
```

- Tuple <Smith, CS> can be deleted from ProfDept by:
  - Deleting row for Smith from Professor (but this is inappropriate if he is still at the University)
  - Deleting row for CS from Department (not what is intended)
  - Updating row for Smith in Professor by setting *DeptId* to null (seems like a good idea, but how would the computer know?)

Updating Views - Problem 3 (Cont’d)

- What to do at deleting <101202303, 123454321>>
  - Delete two rows from **Teaching**?
  - Delete two rows from **Transcript**?
  - Delete one with CS315 from Teaching and one with CS305 Transcript from Transcript? Or, CS305 from Teaching and CS315 from Transcript?



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	900120450	123454321	MAT123,S1996
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	101202303	023456789	CS305,S1996
	900120450	111111111	MAT123,F1997
	783432188	111111111	MGT123,F1997

FIGURE 3.9 Contents of the view defined by SQL statement (3.5).

Updatable Views - Restrictions

- Updatable views are restricted to those in which
  - No Cartesian product in FROM clause
  - No aggregates, GROUP BY, HAVING, set operation
  - No expressions, DISTINCT keyword in the SELECT clause
  - …

For example, if we allowed:

```
CREATE VIEW AvgSalary (DeptId, Avg_Sal ) AS
   SELECT  E.DeptId, AVG(E.Salary)
    FROM   Employee E
    GROUP BY E.DeptId
```

then how do we handle:

```
UPDATE AvgSalary
  SET Avg_Sal = 1.1 * Avg_Sal
```