CSE 562
Database Systems

Relational Algebra/SQL Overview

Some slides are based or modified from originals by
Database Systems: The Complete Book,
Pearson Prentice Hall 2nd Edition
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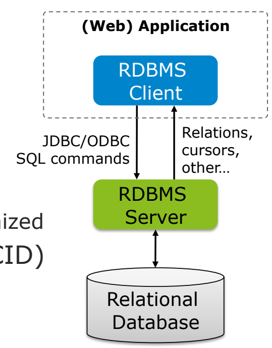
Summary

- **Applications' View of a Relational Database Management System (RDBMS)**
- Relational Algebra Overview
- SQL Overview
- Extended Relational Algebra/Equivalent SQL

Applications' View of an RDBMS System

- Persistent data structure
  - Large volume of data
  - "Independent" from processes using the data
- High-level API for access & modification
  - Declarative, automatically optimized
- Transaction management (ACID)
  - Atomicity: all or none happens, despite failures & errors
  - Concurrency
  - Isolation: appearance of "one at a time"
  - Durability: recovery from failures and other errors



Data Structure: Relational Model

- **Relational Databases:** Schema + Data
- **Schema:**
  - collection of *tables* (also called *relations*)
  - each table has a set of *attributes*
  - no repeating relation names, no repeating attributes in one table
- **Data** (also called *instance*):
  - set of *tuples*
  - tuples have one *value* for each attribute of the table they belong

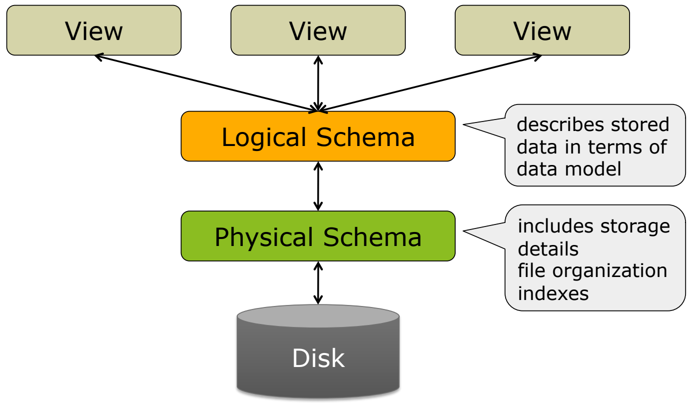
Movie

Title	Director	Actor
Wild	Lynch	Winger
Sky	Berto	Winger
Reds	Beatty	Beatty
Tango	Berto	Brando
Tango	Berto	Winger
Tango	Berto	Snyder

Schedule

Theater	Title
Odeon	Wild
Forum	Reds
Forum	Sky

Levels of Abstraction



Data Independence

- **Physical Data Independence:**
  Applications are insulated from changes in physical storage details
- **Logical Data Independence:**
  Applications are insulated from changes to logical structure of the data
- **Why are these properties important?**
  - Reduce program maintenance
  - Logical database design changes over time
  - Physical database design tuned for performance

Programming Interface: JDBC/ODBC

- How client opens connection with a server
- How access & modification commands are issued

Access (Query) & Modification Language: SQL

- **SQL**
  - used by the database user
  - **declarative**: we only describe **what** we want to retrieve
  - based on tuple relational calculus
- <u>The input to and the output of a query is always a table</u> (regardless of the query language used)
- Internal Equivalent of SQL: **Relational Algebra**
  - used internally by the database system
  - **procedural** (operational): we describe **how** we retrieve

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Basic Relational Algebra Operators

- **Selection** (σ)
  - $\sigma_c R$ selects tuples of the argument relation R that satisfy the condition c
  - The condition c consists of atomic predicates of the form
    - *attr = value* (*attr* is an attribute of *R*)
    - $attr_1 = attr_2$
    - other operators possible (e.g. >, <, !=, LIKE)
  - Bigger conditions constructed by conjunctions (*AND*) and disjunctions (*OR*) of atomic predicates

Find tuples where director="Berto"

$\sigma_{\text{Director}=\text{"Berto"}} Movie$

Title	Director	Actor
Sky	Berto	Winger
Tango	Berto	Brando
Tango	Berto	Winger
Tango	Berto	Snyder

Find tuples where director=actor

$\sigma_{\text{Director}=\text{Actor}} Movie$

Title	Director	Actor
Reds	Beatty	Beatty

$\sigma_{\text{Director}=\text{"Berto" OR Director}=\text{Actor}} Movie$

Title	Director	Actor
Sky	Berto	Winger
Reds	Beatty	Beatty
Tango	Berto	Brando
Tango	Berto	Winger
Tango	Berto	Snyder

Basic Relational Algebra Operators

- **Projection** (π)
  - $\pi_{attr_1,\ldots,attr_N} R$ returns a table that has only the attributes $attr_1$, …, $attr_N$ of *R*
  - ***no*** duplicate tuples in the result (the example has only one <Tango,Berto> tuple
- **Cartesian Product** (x)
  - the schema of the result has all attributes of both *R* and *S*
  - for every tuple $r \in R$ and $s \in S$, there is a result tuple that consists of *r* and *s*
  - if both *R* and *S* have an attribute *A,* then rename to *R.A* and *S.A*

Project title & director of Movie

$\pi_{\text{Title,Director}} Movie$

Title	Director
Sky	Berto
Tango	Berto

R

A	B
0	1
2	4

S

A	C
a	b
c	d

R X S

R.A	B	S.A	C
0	1	a	b
0	1	c	d
2	4	a	b
2	4	c	d

Basic Relational Algebra Operations

- **Rename** (ρ)
  - $\rho_{A \to B} R$ renames attribute *A* of relation *R* into *B*
  - $\rho_S R$ renames relation *R* into *S*
- **Union** ($\cup$)
  - applies to two tables *R* and *S* with same schema
  - $R \cup S$ is the set of tuples that are in *R* or *S* or both
- **Difference** (−)
  - applies to two tables *R* and *S* with same schema
  - $R - S$ is the set of tuples in *R* but not in *S*

Find all people, i.e., actors and directors, of the table Movie

$$\pi_{\text{People}} \rho_{\text{Actor} \to \text{People}} Movie$$
$$\cup\, \pi_{\text{People}} \rho_{\text{Director} \to \text{People}} Movie$$

Find all directors who are not actors

$$\pi_{\text{Director}} Movie$$
$$-\, \rho_{\text{Actor} \to \text{Director}} \pi_{\text{Actor}} Movie$$

Other Relational Algebra Operations

- **Extended Projection**: Using the same $\pi_L R$ operator, we allow the list L to contain arbitrary expressions involving attributes:
  1. Arithmetic on attributes, e.g., *A+B→C*
  2. Duplicate occurrences of the same attribute
- Example

$R =$

A	B
1	2
3	4

$\pi_{A+B \rightarrow C,A,A}(R) =$

C	A1	A2
3	1	1
7	3	3

Other Relational Algebra Operations

- **Theta-Join**: R1 $\bowtie_C$ R2
  - Take the product R1 X R2
  - Then apply σ_c to the result
- As for σ, c can be any boolean-valued condition
  - Historic versions of this operator allowed only A θ B, where θ is =, <, etc.; hence the name "theta-join"
- Example: *Movie* $\bowtie_{Movie.Title=Schedule.Title}$ *Schedule*

Movie.Title	Director	Actor	Schedule.Title	Theater
Wild	Lynch	Winger	Wild	Odeon
Sky	Berto	Winger	Sky	Forum
Reds	Beatty	Beatty	Reds	Forum

Other Relational Algebra Operations

- **Natural Join**: R1 $\bowtie$ R2
  A useful join variant connects two relations by:
  - Equating attributes of the same name, and
  - Projecting out one copy of each pair of equated attributes
- Example: *Movie* $\bowtie$ *Schedule*

Title	Director	Actor	Theater
Wild	Lynch	Winger	Odeon
Sky	Berto	Winger	Forum
Reds	Beatty	Beatty	Forum

Building Complex Expressions

- Algebras allow us to express sequences of operations in a natural way
  - Example: in arithmetic – $(x + 4)*(y - 3)$
- Relational algebra allows the same
- Three notations, just as in arithmetic:
  1. Sequences of assignment statements
  2. Expressions with several operators
  3. Expression trees

Sequences of Assignments

- Create temporary relation names
- Renaming can be implied by giving relations a list of attributes
- Example: **R3 := R1** $\bowtie_C$ **R2** can be written:
  - **R4 := R1 X R2**
  - **R3 :=** σ_c **(R4)**

Expressions in a Single Assignment

- Example: the theta-join **R3 := R1** $\bowtie_C$ **R2** can be written: **R3 :=** σ_c**(R1 X R2)**
- Precedence of relational operators:
  1. Unary operators – select, project, rename – have highest precedence, bind first
  2. Then come products and joins
  3. Then intersection
  4. Finally, union and set difference bind last
- But you can always insert parentheses to force the order you desire

Expression Trees

- Leaves are operands – either variables standing for relations or particular, constant relations
- Interior nodes are operators, applied to their child or children

$\pi_{S.Theater}$
|
$\sigma_{M.Title = S.Title \text{ AND } M.Actor = 'Winger'}$
|
X
Movie M   Schedule S

Schemas for Interior Nodes

- An expression tree defines a schema for the relation associated with each interior node
- Similarly, a sequence of assignments defines a schema for each relation on the left of the := sign

Schema-Defining Rules 1

- For **union**, **intersection**, and **difference**, the schemas of the two operands must be the same, so use that schema for the result
- **Selection**: schema of the result is the same as the schema of the operand
- **Projection**: list of attributes tells us the schema

Schema-Defining Rules 2

- **Product**: the schema is the attributes of both relations
  - Use R.*A*, etc., to distinguish two attributes named *A*
- **Theta-join**: same as product
- **Natural join**: use attributes of both relations
  - Shared attribute names are merged
- **Renaming**: the operator tells the schema

Relational Algebra on Bags

- A *bag* is like a set, but an element may appear more than once
  - *Multiset* is another name for "bag"
- Example:
  - {1,2,1,3} is a bag
  - {1,2,3} is also a bag that happens to be a set
- Bags also resemble lists, but order in a bag is unimportant
- Example: {1,2,1} = {1,1,2} as bags, but [1,2,1] != [1,1,2] as lists

Why Bags?

- SQL, the most important query language for relational databases is actually a bag language
  - SQL will eliminate duplicates, but usually only if you ask it to do so explicitly
- Some operations, like projection, are much more efficient on bags than sets

Operations on Bags

- **Selection** applies to each tuple, so its effect on bags is like its effect on sets
- **Projection** also applies to each tuple, but as a bag operator, we do not eliminate duplicates
- **Products and joins** are done on each pair of tuples, so duplicates in bags have no effect on how we operate

Examples

- Bag Selection

$\sigma_{A+B<5}(R) =$

A	B
1	2
1	2

$R =$

A	B
1	2
5	6
1	2

- Bag Projection

$\pi_{A}(R) =$

A
1
5
1

Examples

- Bag Product

$R \times S =$

A	R.B	S.B	C
1	2	3	4
1	2	7	8
5	6	3	4
5	6	7	8
1	2	3	4
1	2	7	8

$R =$

A	B
1	2
5	6
1	2

$S =$

B	C
3	4
7	8

- Bag Theta-Join

$R \bowtie_{R.B<S.B} S =$

A	R.B	S.B	C
1	2	3	4
1	2	7	8
5	6	7	8
1	2	3	4
1	2	7	8

Bag Union

- Union, intersection, and difference need new definitions for bags
- An element appears in the **union** of two bags the sum of the number of times it appears in each bag
- Example:

  {1,2,1} ∪ {1,1,2,3,1} = {1,1,1,1,1,2,2,3}

Bag Intersection

- An element appears in the **intersection** of two bags the minimum of the number of times it appears in either
- Example: {1,2,1} ∩ {1,2,3} = {1,2}

Bag Difference

- An element appears in the **difference** $A - B$ of bags as many times as it appears in A, minus the number of times it appears in B
  - But never less than 0 times
- Example: {1,2,1} − {1,2,3} = {1}
  {1,2,1} − {1,1,1} = {2}

Beware: Bag Laws != Set Laws

- Not all algebraic laws that hold for sets also hold for bags
- Example: the commutative law for union *does* hold for bags ($R \cup S = S \cup R$)
  - Since addition is commutative, adding the number of times x appears in R and S doesn't depend on the order of R and S

An Example of Inequivalence

- Set union is *idempotent*, meaning that $S \cup S = S$
- However, for bags, if x appears n times in S, then it appears $2n$ times in $S \cup S$
- Thus $S \cup S$!= S in general

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SQL Queries: The Basic From

- Basic form
  SELECT $a_1,\ldots,a_N$
  FROM $R_1,\ldots,R_M$
  [WHERE *condition*]
- Equivalent relational algebra expression

$$\pi_{a_1,\ldots,a_N}\sigma_{\text{condition}}(R_1 \times \ldots \times R_M)$$

- WHERE clause is optional
- When more than one relations in the FROM clause have an attribute named *A,* we refer to a specific *A* attribute as *<RelationName>.A*

Find titles of currently playing movies

```
SELECT Title
FROM Schedule
```

Find the titles of all movies by "Berto"

```
SELECT Title
FROM Schedule
WHERE Director="Berto"
```

Find the titles and the directors of all currently playing movies

```
SELECT Movie.Title, Director
FROM Movie, Schedule
WHERE Movie.Title=Schedule.Title
```


SQL Queries: Aliases

- Use the same relation more than once in the FROM clause
- Tuple variables
- Example: Find actors who are also directors

```
SELECT t.Actor
FROM Movie t, Movie s
WHERE t.Actor=s.Director
```


SQL Queries: Nesting

- The WHERE clause can contain predicates of the form
  - *attr/value* IN *<query>*
  - *attr/value* NOT IN *<query>*
- The predicate is satisfied if the *attr* or *value* appears in the result of the nested *<query>*
- Queries involving nesting but no negation can always be un-nested, unlike queries with nesting and negation

Typical use: "Find objects that always satisfy property X", e.g., find actors playing in every movie by "Berto":

```
SELECT Actor
FROM Movie
WHERE Actor NOT IN (
    SELECT t.Actor
    FROM Movie t, Movie s
    WHERE s.Director="Berto"
    AND t.Actor NOT IN (
        SELECT Actor
        FROM Movie
        WHERE Title=s.Title
        )
    )
```

The shaded query finds actors NOT playing in some movie by "Berto". The top lines complement the shaded part.

Homework Problem

- Compare with shaded sub-query of previous slide. The sample data may help you.

```
SELECT Actor
FROM Movie
WHERE Actor NOT IN (
    SELECT Actor
    FROM Movie
    WHERE Director="Berto"
    )
```

Actor	Director	Movie
a	B	1
a	B	2
b	B	1
c	X	3
d	B	1
d	B	2
d	X	3

Nested Queries: Existential Quantification

- *A op* **ANY** *<nested query>* is satisfied if ***there is*** a value *X* in the result of the *<nested query>* and the condition *A op X* is satisfied
  - (= **ANY**) ≡ **IN**
  - But, (≠ **ANY**) ≢ **NOT IN**

Find directors of currently playing movies

```
SELECT Director
FROM Movie
WHERE Title = ANY
    SELECT Title
    FROM Schedule
```


Nested Queries: Universal Quantification

- *A op* **ALL** *<nested query>* is satisfied if ***for every*** value *X* in the result of the *<nested query>* the condition *A op X* is satisfied
  - (≠ **ALL**) ≡ **NOT IN**
  - But, (= **ALL**) ≢ **IN**

Find the employees with the highest salary

```
SELECT Name
FROM Employee
WHERE Salary >= ALL
    SELECT Salary
    FROM Employee
```


Nested Queries: Set Comparison

<nested query 1>
CONTAINS
<nested query 2>

Find actors playing in every movie by "Berto"

```
SELECT s.Actor
FROM Movie s
WHERE
    (SELECT Title
     FROM Movie t
     WHERE t.Actor = s.Actor)
    CONTAINS
    (SELECT Title
     FROM Movie
     WHERE Director = "Berto")
```

SQL: Union, Intersection, Difference

- **Union**
  <SQL query 1>
  UNION
  <SQL query 2>
- **Intersection**
  <SQL query 1>
  INTERSECT
  <SQL query 2>
- **Difference**
  <SQL query 1>
  MINUS
  <SQL query 2>

Find all actors or directors

```
(SELECT Actor
 FROM Movie)
UNION
(SELECT Director
 FROM Movie)
```

Find all actors who are not directors

```
(SELECT Actor
 FROM Movie)
MINUS
(SELECT Director
 FROM Movie)
```


NULL Values

- Tuples in SQL relations can have NULL as a value for one or more components
- Meaning depends on context. Two common cases:
  - **Missing value**: e.g., we know movie Tango has a third actor, but we don't know who she/he is

Title	Director	Actor
Tango	Berto	Brando
Tango	Berto	Winger
Tango	Berto	NULL

  - **Inapplicable**: e.g., the value of attribute **spouse** for an unmarried person

Comparing NULL's to Values

- The logic of conditions in SQL is really 3-valued logic: TRUE, FALSE, UNKNOWN
- Comparing any value (including NULL itself) with NULL yields UNKNOWN
- A tuple is in a query answer iff the WHERE clause is TRUE (not FALSE or UNKNOWN)

Three-Valued Logic

- To understand how AND, OR, and NOT work in 3-valued logic, think of TRUE = 1, FALSE = 0, and UNKNOWN = ½
- AND = MIN; OR = MAX, NOT(x) = 1-x
- **Example**:
  TRUE AND (FALSE OR NOT(UNKNOWN)) =
  MIN(1, MAX(0, (1 - ½))) =
  MIN(1, MAX(0, ½)) = MIN(1, ½) = ½

Surprising Example

- From the following Sells relation:

book	store	price
Harry Potter	Amazon	NULL

SELECT book
FROM Sells
WHERE price < 20.00 OR price >= 20.00;

$$\underbrace{\underbrace{\text{price} < 20.00}_{\text{UNKNOWN}} \text{ OR } \underbrace{\text{price} >= 20.00}_{\text{UNKNOWN}}}_{\text{UNKNOWN}}$$

Reason: 2-Valued Laws != 3-Valued Laws

- Some common laws, like commutativity of AND, hold in 3-valued logic
- But not others, e.g., the **law of the excluded middle**: *p* OR NOT *p* = TRUE
  - When *p* = UNKNOWN, the left side is
    MAX(½, (1 – ½)) = ½ != 1

Bag Semantics

- Although the SELECT-FROM-WHERE statement uses bag semantics, the default for union, intersection, and difference is set semantics
  - That is, duplicates are eliminated as the operation is applied

Motivation: Efficiency

- When doing projection, it is easier to avoid eliminating duplicates
  - Just work tuple-at-a-time
- For intersection or difference, it is most efficient to sort the relations first
  - At that point you may as well eliminate the duplicates anyway

Controlling Duplicate Elimination

- Force the result to be a set by
  SELECT DISTINCT …
- Force the result to be a bag (i.e., don't eliminate duplicates) by ALL, as in
  … UNION **ALL** …

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The Extended Algebra

δ = eliminate duplicates from bags

τ = sort tuples

γ = grouping and aggregation

Duplicate Elimination

- R1 := δ(R2)
- R1 consists of one copy of each tuple that appears in R2 one or more times
- Example: R =

A	B
1	2
3	4
1	2

δ(R)=

A	B
1	2
3	4

Sorting

- R1 := τ_L (R2)
  - L is a list of some of the attributes of R2
- R1 is the list of tuples of R2 sorted first on the value of the first attribute on L, then on the second attribute of L, and so on
  - Break ties arbitrarily
- τ is the only operator whose result is neither a set nor a bag

Aggregation Operators

- Aggregation operators are not operators of relational algebra
- Rather, they apply to entire columns of a table and produce a single result
- The most important examples: SUM, AVG, COUNT, MIN, and MAX
- Example: R =

A	B
1	3
3	4
3	2

SUM(A) = 7
COUNT(A) = 3
MAX(B) = 4
AVG(B) = 3

Grouping Operator

- R1 := γ_L (R2)
  L is a list of elements that are either:
  1. Individual (**grouping**) attributes
  2. AGG(A), where AGG is one of the aggregation operators and A is an attribute
     - An arrow and a new attribute name renames the component

Applying γ_L(R)

- Group R according to all the grouping attributes on list L
  - That is: form one group for each distinct list of values for those attributes in R
- Within each group, compute AGG(A) for each aggregation on list L
- Result has one tuple for each group:
  1. The grouping attributes and
  2. Their group's aggregations

Example: Grouping/Aggregation

R =

A	B	C
1	2	3
4	5	6
1	2	5

$\gamma_{A,B,\mathrm{AVG(C)}\to X}$ (R) = ??

First, group R by A and B:

A	B	C
1	2	3
1	2	5
4	5	6

Then, average C within groups:

A	B	X
1	2	4
4	5	6

Outerjoin

- Suppose we join $R \bowtie_C S$
- A tuple of *R* that has no tuple of *S* with which it joins is said to be **dangling**
  - Similarly for a tuple of *S*
- Outerjoin preserves dangling tuples by padding them with NULLs

Example: Outerjoin

R =

A	B
1	2
4	5

S =

B	C
2	3
6	7

(1,2) joins with (2,3), but the other two tuples are dangling

R OUTERJOIN S =

A	B	C
1	2	3
4	5	NULL
NULL	6	7

SQL Outerjoins

- R OUTER JOIN S is the core of an outerjoin expression
- It is modified by:
  1. Optional NATURAL in front of OUTER
  2. Optional ON <condition> after JOIN

     Only one of these
  3. Optional LEFT, RIGHT, or FULL before OUTER
     - LEFT = pad dangling tuples of R only
     - RIGHT = pad dangling tuples of S only
     - FULL = pad both; this choice is the default

SQL Aggregations

- SUM, AVG, COUNT, MIN, and MAX can be applied to a column in a SELECT clause to produce that aggregation on the column
- Also, COUNT(*) counts the number of tuples
- **Example**: Find the average salary of all employees

Employee

Name	Dept	Salary
Joe	Toys	45
Nick	PCs	50
Jim	Toys	35
Jack	PCs	40

```
SELECT AvgSal = AVG(Salary)
FROM Employee
```

AvgSal
42.5

Eliminating Duplicates in a SQL Aggregation

- Use DISTINCT inside an aggregation
- **Example**: Find the number of *different* departments:

```
SELECT COUNT(DISTINCT Dept)
FROM Employee
```

Employee

Name	Dept	Salary
Joe	Toys	45
Nick	PCs	50
Jim	Toys	35
Jack	PCs	40

NULL's Ignored in SQL Aggregation

- NULL never contributes to a sum, average, or count, and can never be the minimum or maximum of a column
- But if there are no non-NULL values in a column, then the result of the aggregation is NULL
  - **Exception**: COUNT of an empty set is 0

Example: Effect of NULL's

```
SELECT COUNT(*)
FROM Employee
WHERE Dept="Toys";
```

The number of employees in the Toys department

```
SELECT COUNT(Salary)
FROM Employee
WHERE Dept="Toys";
```

The number of employees in the Toys department with a known salary

Employee

Name	Dept	Salary
Joe	Toys	45
Jim	Toys	NULL
Jack	PCs	40

SQL Grouping

- We may follow a SELECT-FROM-WHERE expression by GROUP BY and a list of attributes
- The relation that results from the SELECT-FROM-WHERE is grouped according to the values of all those attributes, and any aggregation is applied only within each group

Example: SQL Grouping

Find the average salary for each department:

SELECT Dept, AvgSal = **AVG**(Salary)
FROM Employee
GROUP BY Dept

Dept	AvgSal
Toys	40
PCs	45

Employee

Name	Dept	Salary
Joe	Toys	45
Nick	PCs	50
Jim	Toys	35
Jack	PCs	40

Example: Null Values and Aggregates

- Example: **R**

a	b
x	1
x	2
x	null
null	null
null	null

- **select count**(a), **count**(b), **avg**(b), **count**(*)
from R
group by a

count(a)	count(b)	avg(b)	count(*)
3	2	1.5	3
0	0	null	2

Restriction on SELECT Lists With Aggregation

- If any aggregation is used, then each element of the SELECT list must be either:
  1. Aggregated, or
  2. An attribute on the GROUP BY list
- **Example**: You might think you could find the department with the highest salary by:

  SELECT Dept, MaxSal = **MAX**(Salary)
  FROM Employee

  But this query is illegal in SQL

SQL HAVING Clauses

- HAVING <condition> may follow a GROUP BY clause
- If so, the condition applies to each group, and groups not satisfying the condition are eliminated

Example: SQL HAVING

- **Example**: Find the average salary of for each department that has either more than 1 employee or starts with a "To":

```
SELECT Dept, AvgSal=(AVG(Salary))
FROM Employee
GROUP BY Dept
HAVING COUNT(Name) > 1 OR Dept LIKE "To"
```


Requirements on HAVING Conditions

- Conditions may refer to attributes only if they are either:
  1. A grouping attribute, or
  2. Aggregated

  (same condition as for SELECT clauses with aggregation)

Summary of SQL Queries

- A query in SQL can consist of up to six clauses, but only the first two, SELECT and FROM, are mandatory.
- The clauses are specified in the following order:

```
SELECT      <attribute list>
FROM        <table list>
[WHERE      <condition>]
[GROUP BY   <grouping attribute(s)>]
[HAVING     <group condition>]
[ORDER BY   <attribute list>]
```

Summary of SQL Queries (cont'd)

- The SELECT-clause lists the attributes or functions to be retrieved
- The FROM-clause specifies all relations (or aliases) needed in the query but not those needed in nested queries
- The WHERE-clause specifies the conditions for selection and join of tuples from the relations specified in the FROM-clause
- GROUP BY specifies grouping attributes
- HAVING specifies a condition for selection of groups
- ORDER BY specifies an order for displaying the result of a query
- A query is evaluated by first applying the WHERE-clause, then GROUP BY and HAVING, and finally the SELECT-clause

Recursion in SQL

- SQL:1999 permits recursive queries
- Example: find all employee-manager pairs, where the employee reports to the manager directly or indirectly (that is manager's manager, manager's manager's manager, etc.)

```
WITH RECURSIVE empl(employee_name, manager_name) AS (
      SELECT employee_name, manager_name
      FROM manager
   UNION
      SELECT manager.employee_name, empl.manager_name
      FROM manager, empl
      WHERE manager.manager_name = empl.employe_name)
SELECT *
FROM empl
```

- This example query computes the *transitive closure* of the manager relation

The Power of Recursion

- Recursive queries make it possible to write queries, such as transitive closure queries, that cannot be written without recursion or iteration
  - Intuition: Without recursion, a non-recursive non-iterative program can perform only a fixed number of joins of manager with itself
    - This can give only a fixed number of levels of managers
    - Given a program we can construct a database with a greater number of levels of managers on which the program will not work

The Power of Recursion (cont'd)

- Computing transitive closure
  - The next slide shows a manager relation and finds all employees managed by "Jones"
  - Each step of the iterative process constructs an extended version of *empl* from its recursive definition
  - The final result is called the *fixed point* of the recursive definition

Example of Fixed-Point Computation

employee_name	*manager_name*
Alon	Barinsky
Barinsky	Estovar
Corbin	Duarte
Duarte	Jones
Estovar	Jones
Jones	Klinger
Rensal	Klinger

Iteration number	*Tuples in empl*
0	
1	(Duarte), (Estovar)
2	(Duarte), (Estovar), (Barinsky), (Corbin)
3	(Duarte), (Estovar), (Barinsky), (Corbin), (Alon)
4	(Duarte), (Estovar), (Barinsky), (Corbin), (Alon)

The Power of Recursion (cont'd)

- Recursive queries are required to be **monotonic**, that is, if we add tuples to manager the query result contains all of the tuples it contained before, plus possibly more
- Example:

```
SELECT AvgSal = AVG(Salary)
FROM Employee
```

is not monotone in Employee

- – Inserting a tuple into Employee usually changes the average salary and thus deletes the old average salary

SQL as a Data Manipulation Language: Insertions

Inserting tuples

```
INSERT INTO R
    VALUES (v1,…,vk);
```

- some values may be left NULL
- use results of queries for insertion

```
INSERT INTO R
    SELECT …
    FROM …
    WHERE …
```

```
INSERT INTO Movie
VALUES ("Brave", "Gibson", "Gibson");

INSERT INTO Movie(Title,Director)
VALUES ("Brave", "Gibson");

INSERT INTO EuroMovie
  SELECT *
  FROM Movie
  WHERE Director = "Berto"
```


SQL as a Data Manipulation Language: Deletions

- Deletion basic form: delete every tuple that satisfies *<cond>*

```
DELETE FROM R
WHERE <cond>
```

- Delete the movies that are not currently playing

```
DELETE FROM Movie
WHERE Title NOT IN
    SELECT Title
    FROM Schedule
```

SQL as a Data Manipulation Language: Updates

- Update basic form: update every tuple that satisfies <*cond*> in the way specified by the SET clause

  UPDATE *R*

  SET A_1=<exp_1>,…,A_k=<exp_k>

  WHERE <*cond*>

- Change all "Berto" entries to "Bertoluci"

  UPDATE Movie
  SET Director="Bertoluci"
  WHERE Director="Berto"

- Increase all salaries in the Toys dept by 10%

  UPDATE Employee
  SET Salary = 1.1 * Salary
  WHERE Dept = "Toys"

- The "rich get richer" exercise: Increase by 10% the salary of the employee with the highest salary

This Time

- Relational Algebra
  - Chapter 2: 2.4
  - Chapter 5: 5.1, 5.2
- SQL
  - Chapter 6
  - Chapter 10: 10.2