CS425 – Fall 2016
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Chapter 4: Introduction to SQL

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Chapter 4: Introduction to SQL

- Overview of the SQL Query Language
- Data Definition
- Basic Query Structure
- Additional Basic Operations
- Set Operations
- Null Values
- Aggregate Functions
- Nested Subqueries
- Modification of the Database

Textbook: Chapter 3

History

- IBM Sequel language developed as part of System R project at the IBM San Jose Research Laboratory
- Renamed Structured Query Language (SQL)
- ANSI and ISO standard SQL:
  - SQL-86, SQL-89, SQL-92
  - SQL:1999, SQL:2003, SQL:2008
- Commercial systems offer most, if not all, SQL-92 features, plus varying feature sets from later standards and special proprietary features.
  - Not all examples here may work one-to-one on your particular system.

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Data Definition Language

The SQL **data-definition language (DDL)** allows the specification of information about relations, including:

- The schema for each relation.
- The domain of values associated with each attribute.
- Integrity constraints
- And as we will see later, also other information such as
  - The set of indices to be maintained for each relations.
  - Security and authorization information for each relation.
  - The physical storage structure of each relation on disk.

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Domain Types in SQL

- **char(n).** Fixed length character string, with user-specified length *n.*
- **varchar(n).** Variable length character strings, with user-specified maximum length *n.*
- **int.** Integer (a finite subset of the integers that is machine-dependent).
- **smallint.** Small integer (a machine-dependent subset of the integer domain type).
- **numeric(p,d).** Fixed point number, with user-specified precision of *p* digits, with *n* digits to the right of decimal point.
- **real, double precision.** Floating point and double-precision floating point numbers, with machine-dependent precision.
- **float(n).** Floating point number, with user-specified precision of at least *n* digits.
- More are covered in Chapter 4.

Create Table Construct

- An SQL relation is defined using the **create table** command:

  create table r (A_1 D_1, A_2 D_2, ..., A_n D_n,
  (integrity-constraint$_1$),
  ...,
  (integrity-constraint$_k$))

  - ***r*** is the name of the relation
  - each $\boldsymbol{A_i}$ is an attribute name in the schema of relation ***r***
  - $\boldsymbol{D_i}$ is the data type of values in the domain of attribute $\boldsymbol{A_i}$

- Example:

  create table *instructor* (
  ID **char**(5),
  name **varchar**(20) **not null,**
  dept_name **varchar**(20),
  salary **numeric**(8,2))

- **insert into** *instructor* **values** ('10211', 'Smith', 'Biology', 66000);
- **insert into** *instructor* **values** ('10211', null, 'Biology', 66000);

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Integrity Constraints in Create Table

- **not null**
- **primary key** (A_1, ..., A_n)
- **foreign key** (A_m, ..., A_n) **references** *r*

Example: Declare *ID* as the primary key for *instructor*

.

create table *instructor* (
ID **char**(5),
name **varchar**(20) **not null,**
dept_name **varchar**(20),
salary **numeric**(8,2),
primary key (*ID*),
foreign key *(dept_name*) **references** *department)*

primary key declaration on an attribute automatically ensures **not null**

And a Few More Relation Definitions

- **create table** *student* (
  ID **varchar**(5),
  name **varchar**(20) not null,
  dept_name **varchar**(20),
  tot_cred **numeric**(3,0),
  primary key (*ID*),
  foreign key *(dept_name*) **references** *department)*);
- **create table** *takes* (
  ID **varchar**(5),
  course_id **varchar**(8),
  sec_id **varchar**(8),
  semester **varchar**(6),
  year **numeric**(4,0),
  grade **varchar**(2),
  primary key *(ID, course_id, sec_id, semester, year),*
  foreign key (*ID*) **references** *student,*
  foreign key (*course_id, sec_id, semester, year*) **references** *section*);
  - Note: *sec_id* can be dropped from primary key above, to ensure a student cannot be registered for two sections of the same course in the same semester

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Even more

- **create table** *course* (
  course_id **varchar**(8) **primary key**,
  title **varchar(**50),
  dept_name **varchar**(20),
  credits **numeric**(2,0),
  foreign key *(dept_name*) **references** *department)*);
  - Primary key declaration can be combined with attribute declaration as shown above

Drop and Alter Table Constructs

- **drop table** *student*
  - Deletes the table and its contents
- **alter table**
  - **alter table** *r* **add** *A D*
    - where *A* is the name of the attribute to be added to relation *r* and *D* is the domain of *A.*
    - All tuples in the relation are assigned *null* as the value for the new attribute.
  - **alter table** *r* **drop** *A*
    - where *A* is the name of an attribute of relation *r*
    - Dropping of attributes not supported by many databases
  - And more …

Basic Query Structure

- The SQL **data-manipulation language (DML)** provides the ability to query information, and insert, delete and update tuples
- A typical SQL **query** has the form:

  select $A_1, A_2, ..., A_n$
  from $r_1, r_2, ..., r_m$
  where P

  - $\boldsymbol{A_i}$ represents an attribute
  - $\boldsymbol{R_i}$ represents a relation
  - $\boldsymbol{P}$ is a predicate.
- The result of an SQL query is a **relation**.

The select Clause

- The **select** clause list the attributes desired in the result of a query
  - corresponds to the projection operation of the relational algebra
- Example: find the names of all instructors:

  select *name*
  from *instructor*

- NOTE: SQL keywords are case insensitive (i.e., you may use upper- or lower-case letters.)
  - E.g. *Name* ≡ *NAME* ≡ *name*
  - Some people use upper case wherever we use bold font.

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The select Clause (Cont.)

- SQL allows duplicates in relations as well as in query results.
- To force the elimination of duplicates, insert the keyword **distinct** after select.
- Find the names of all departments with instructor, and remove duplicates

  select distinct *dept_name*
  from *instructor*

- The (redundant) keyword **all** specifies that duplicates not be removed.

  select all *dept_name*
  from *instructor*

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The select Clause (Cont.)

- An asterisk in the select clause denotes "all attributes"

  select *
  from *instructor*

- The **select** clause can contain arithmetic expressions involving the operation, +, –, ∗, and /, and operating on constants or attributes of tuples.
  - Most systems also support additional functions
    - E.g., substring
  - Most systems allow user defined functions (UDFs)
- The query:

  select *ID, name, salary/12*
  from *instructor*

  would return a relation that is the same as the *instructor* relation, except that the value of the attribute *salary* is divided by 12.

The from Clause

- The **from** clause lists the relations involved in the query
  - Corresponds to the Cartesian product operation of the relational algebra.
- Find the Cartesian product *instructor X teaches*

  select *
  from *instructor, teaches*

  - generates every possible instructor – teaches pair, with all attributes from both relations
- Cartesian product not very useful directly, but useful combined with where-clause condition (selection operation in relational algebra)

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The where Clause

- The **where** clause specifies conditions that the result must satisfy
  - Corresponds to the selection predicate of the relational algebra.
- To find all instructors in Comp. Sci. dept with salary > 80000

  select *name*
  from *instructor*
  where *dept_name* = 'Comp. Sci.' **and** *salary* > 80000
- Comparison results can be combined using the logical connectives **and, or,** and **not.**
- Comparisons can be applied to results of arithmetic expressions.
- SQL standard: any valid expression that returns a boolean result
  - Vendor specific restrictions may apply!

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Cartesian Product: *instructor X teaches*

instructor

ID	*name*	*dept_name*	*salary*
10101	Srinivasan	Comp. Sci.	65000
12121	Wu	Finance	90000
15151	Mozart	Music	40000
22222	Einstein	Physics	95000
32343	El Said	History	60000

teaches

ID	*course_id*	*sec_id*	*semester*	*year*
10101	CS-101	1	Fall	2009
10101	CS-315	1	Spring	2010
10101	CS-347	1	Fall	2009
12121	FIN-201	1	Spring	2010
15151	MU-199	1	Spring	2010
22222	PHY-101	1	Fall	2009

inst.ID	*name*	*dept_name*	*salary*	*teaches.ID*	*course_id*	*sec_id*	*semester*	*year*
10101	Srinivasan	Comp. Sci.	65000	10101	CS-101	1	Fall	2009
10101	Srinivasan	Comp. Sci.	65000	10101	CS-315	1	Spring	2010
10101	Srinivasan	Comp. Sci.	65000	10101	CS-347	1	Fall	2009
10101	Srinivasan	Comp. Sci.	65000	12121	FIN-201	1	Spring	2010
10101	Srinivasan	Comp. Sci.	65000	15151	MU-199	1	Spring	2010
10101	Srinivasan	Comp. Sci.	65000	22222	PHY-101	1	Fall	2009
...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...
12121	Wu	Finance	90000	10101	CS-101	1	Fall	2009
12121	Wu	Finance	90000	10101	CS-315	1	Spring	2010
12121	Wu	Finance	90000	10101	CS-347	1	Fall	2009
12121	Wu	Finance	90000	12121	FIN-201	1	Spring	2010
12121	Wu	Finance	90000	15151	MU-199	1	Spring	2010
12121	Wu	Finance	90000	22222	PHY-101	1	Fall	2009
...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...

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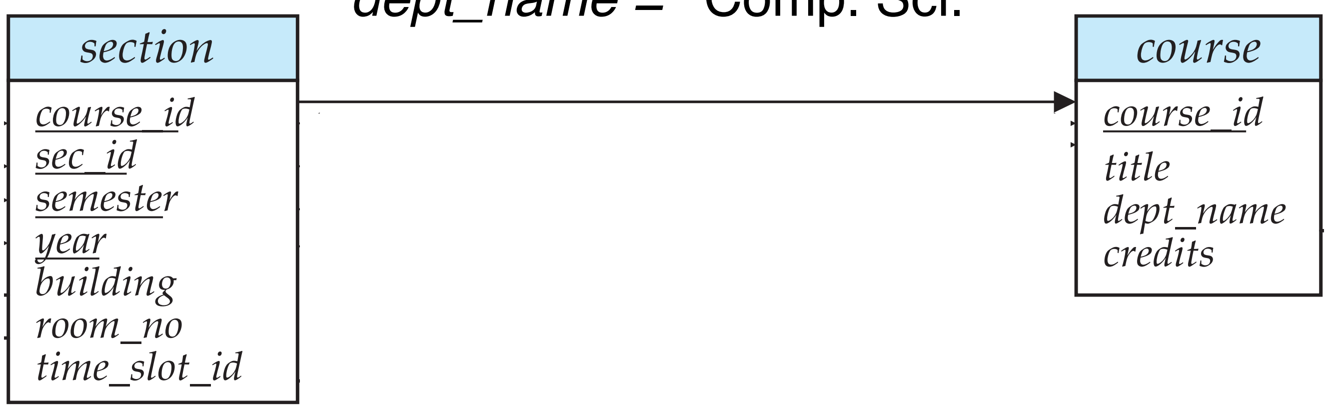
Joins

- For all instructors who have taught some course, find their names and the course ID of the courses they taught.

  select *name, course_id*
  from *instructor, teaches*
  where *instructor.ID = teaches.ID*

- Find the course ID, semester, year and title of each course offered by the Comp. Sci. department

  select *section.course_id, semester, year, title*
  from *section, course*
  where *section.course_id = course.course_id* **and**
  dept_name = 'Comp. Sci.'



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Try Writing Some Queries in SQL

- Suggest queries to be written…..

Joined Relations

- **Join operations** take two relations and return as a result another relation.
- A join operation is a Cartesian product which requires that tuples in the two relations match (under some condition). It also specifies the attributes that are present in the result of the join
- The join operations are typically used as subquery expressions in the **from** clause

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Join operations – Example

- Relation *course*

course_id	*title*	*dept_name*	*credits*
BIO-301	Genetics	Biology	4
CS-190	Game Design	Comp. Sci.	4
CS-315	Robotics	Comp. Sci.	3

- Relation *prereq*

course_id	*prereq_id*
BIO-301	BIO-101
CS-190	CS-101
CS-347	CS-101

- Observe that

  prereq information is missing for CS-315 and

  course information is missing for CS-437

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Natural Join

- Natural join matches tuples with the same values for all common attributes, and retains only one copy of each common column
  - This is the natural join from relational algebra
- **select** *
  from *instructor* **natural join** *teaches*;

ID	*name*	*dept_name*	*salary*	*course_id*	*sec_id*	*semester*	*year*
10101	Srinivasan	Comp. Sci.	65000	CS-101	1	Fall	2009
10101	Srinivasan	Comp. Sci.	65000	CS-315	1	Spring	2010
10101	Srinivasan	Comp. Sci.	65000	CS-347	1	Fall	2009
12121	Wu	Finance	90000	FIN-201	1	Spring	2010
15151	Mozart	Music	40000	MU-199	1	Spring	2010
22222	Einstein	Physics	95000	PHY-101	1	Fall	2009
32343	El Said	History	60000	HIS-351	1	Spring	2010
45565	Katz	Comp. Sci.	75000	CS-101	1	Spring	2010
45565	Katz	Comp. Sci.	75000	CS-319	1	Spring	2010
76766	Crick	Biology	72000	BIO-101	1	Summer	2009
76766	Crick	Biology	72000	BIO-301	1	Summer	2010

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Natural Join Example

- List the names of instructors along with the course ID of the courses that they taught.

  - **select** *name*, *course_id*
    from *instructor, teaches*
    where *instructor.ID* = *teaches.ID*;

  - **select** *name*, *course_id*
    from *instructor* **natural join** *teaches*;

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Natural Join (Cont.)

- Danger in natural join: beware of unrelated attributes with same name which get equated incorrectly
- List the names of instructors along with the the titles of courses that they teach
  - Incorrect version (makes course.dept_name = instructor.dept_name)
    - **select** *name*, *title*
      from *instructor* **natural join** *teaches* **natural join** *course*;
  - Correct version
    - **select** *name*, *title*
      from *instructor* **natural join** *teaches*, *course*
      where *teaches*.*course_id* = *course*.*course_id*;
  - Another correct version
    - **select** *name*, *title*
      from (*instructor* **natural join** *teaches*)
      join *course* **using**(*course_id*);

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Outer Join

- An extension of the join operation that avoids loss of information.
- Computes the join and then adds tuples form one relation that does not match tuples in the other relation to the result of the join.
- Uses *null* values.

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Left Outer Join

- *course* **natural left outer join** *prereq*

course_id	*title*	*dept_name*	*credits*	*prereq_id*
BIO-301	Genetics	Biology	4	BIO-101
CS-190	Game Design	Comp. Sci.	4	CS-101
CS-315	Robotics	Comp. Sci.	3	*null*

Right Outer Join

- *course* **natural right outer join** *prereq*

course_id	*title*	*dept_name*	*credits*	*prereq_id*
BIO-301	Genetics	Biology	4	BIO-101
CS-190	Game Design	Comp. Sci.	4	CS-101
CS-347	*null*	*null*	*null*	CS-101

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Joined Relations

- **Join operations** take two relations and return as a result another relation.
- These additional operations are typically used as subquery expressions in the **from** clause
- **Join condition** – defines which tuples in the two relations match, and what attributes are present in the result of the join.
- **Join type** – defines how tuples in each relation that do not match any tuple in the other relation (based on the join condition) are treated.

Join types
inner join
left outer join
right outer join
full outer join

Join Conditions
natural
on <predicate>
using $(A_1, A_1, \ldots, A_n)$

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Full Outer Join

- *course* **natural full outer join** *prereq*

course_id	*title*	*dept_name*	*credits*	*prereq_id*
BIO-301	Genetics	Biology	4	BIO-101
CS-190	Game Design	Comp. Sci.	4	CS-101
CS-315	Robotics	Comp. Sci.	3	*null*
CS-347	*null*	*null*	*null*	CS-101

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Joined Relations – Examples

- *course* **inner join** *prereq* **on** *course.course_id = prereq.course_id*

course_id	*title*	*dept_name*	*credits*	*prereq_id*	*course_id*
BIO-301	Genetics	Biology	4	BIO-101	BIO-301
CS-190	Game Design	Comp. Sci.	4	CS-101	CS-190

- What is the difference between the above, and a natural join?
- *course* **left outer join** *prereq* **on** *course.course_id = prereq.course_id*

course_id	*title*	*dept_name*	*credits*	*prereq_id*	*course_id*
BIO-301	Genetics	Biology	4	BIO-101	BIO-301
CS-190	Game Design	Comp. Sci.	4	CS-101	CS-190
CS-315	Robotics	Comp. Sci.	3	*null*	*null*

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Joined Relations – Examples

- *course* **natural right outer join** *prereq*

course_id	*title*	*dept_name*	*credits*	*prereq_id*
BIO-301	Genetics	Biology	4	BIO-101
CS-190	Game Design	Comp. Sci.	4	CS-101
CS-347	*null*	*null*	*null*	CS-101

- *course* **full outer join** *prereq* **using** (*course_id*)

course_id	*title*	*dept_name*	*credits*	*prereq_id*
BIO-301	Genetics	Biology	4	BIO-101
CS-190	Game Design	Comp. Sci.	4	CS-101
CS-315	Robotics	Comp. Sci.	3	*null*
CS-347	*null*	*null*	*null*	CS-101

The Rename Operation

- The SQL allows renaming relations and attributes using the **as** clause:

  old-name **as** *new-name*

- E.g.
  - **select** *ID, name, salary/12* **as** *monthly_salary*
    from *instructor*

- Find the names of all instructors who have a higher salary than some instructor in 'Comp. Sci'.
  - **select distinct** *T. name*
    from *instructor* **as** *T, instructor* **as** *S*
    where *T.salary > S.salary* **and** *S.dept_name = 'Comp. Sci.'*

- Keyword **as** is optional and may be omitted

  instructor **as** *T ≡ instructor T*

  - Keyword **as** must be omitted in Oracle

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String Operations

- SQL includes a string-matching operator for comparisons on character strings. The operator "like" uses patterns that are described using two special characters:
  - percent (%). The % character matches any substring.
  - underscore (_). The _ character matches any character.
- Find the names of all instructors whose name includes the substring "dar".

  select *name*
  from *instructor*
  where *name* **like** '%dar%'

- Match the string "100 %"

  like '100 \%' **escape** '\'

String Operations (Cont.)

- Patters are case sensitive.
- Pattern matching examples:
  - 'Intro%' matches any string beginning with "Intro".
  - '%Comp%' matches any string containing "Comp" as a substring.
  - '_ _ _' matches any string of exactly three characters.
  - '_ _ _ %' matches any string of at least three characters.

- SQL supports a variety of string operations such as
  - concatenation (using "II")
  - converting from upper to lower case (and vice versa)
  - finding string length, extracting substrings, etc.

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Case Construct

- Like case, if, and ? Operators in programming languages

case

  when c_1 **then** e_1

  when c_2 **then** e_2

  …

  [**else** e_n]

end

- Each c_i is a condition
- Each e_1 is an expression
- Returns the first e_i for which c_i evaluates to *true*
  - If none of the c_i is true, then return e_n (**else**)
    - If there is no else return *null*

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Case Construct Example

- Like case, if, and ? Operators in programming languages

```
select
    name,
    case
        when salary > 1000000 then 'premium'
        else 'standard'
    end as customer_group
from customer
```

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Ordering the Display of Tuples

- List in alphabetic order the names of all instructors

  select distinct *name*
  from *instructor*
  order by *name*

- We may specify **desc** for descending order or **asc** for ascending order, for each attribute; ascending order is the default.
  - Example: **order by** *name* **desc**
- Can sort on multiple attributes
  - Example: **order by** *dept_name, name*
- **Order is not expressible in the relational model!**

Where Clause Predicates

- SQL includes a **between** comparison operator
- Example: Find the names of all instructors with salary between \$90,000 and \$100,000 (that is, $\geq$ \$90,000 and $\leq$ \$100,000)
  - **select** *name*
    from *instructor*
    where *salary* **between** 90000 **and** 100000
- Tuple comparison
  - **select** *name*, *course_id*
    from *instructor*, *teaches*
    where (*instructor*.*ID*, *dept_name*) = (*teaches*.*ID*, ' Biology');

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Set Operations

- Find courses that ran in Fall 2009 or in Spring 2010

  (**select** *course_id* **from** *section* **where** *sem* = 'Fall' **and** *year* = 2009)
  union
  (**select** *course_id* **from** *section* **where** *sem* = 'Spring' **and** *year* = 2010)

- Find courses that ran in Fall 2009 and in Spring 2010

  (**select** *course_id* **from** *section* **where** *sem* = 'Fall' **and** *year* = 2009)
  intersect
  (**select** *course_id* **from** *section* **where** *sem* = 'Spring' **and** *year* = 2010)

- Find courses that ran in Fall 2009 but not in Spring 2010

  (**select** *course_id* **from** *section* **where** *sem* = 'Fall' **and** *year* = 2009)
  except
  (**select** *course_id* **from** *section* **where** *sem* = 'Spring' **and** *year* = 2010)

Set Operations

- Set operations **union**, **intersect**, and **except**
  - Each of the above operations automatically eliminates duplicates
- To retain all duplicates use the corresponding multiset versions **union all, intersect all** and **except all.**

  Suppose a tuple occurs *m* times in *r* and *n* times in *s*, then, it occurs:
  - $m + n$ times in *r* **union all** *s*
  - $\min(m,n)$ times in *r* **intersect all** *s*
  - $\max(0, m - n)$ times in *r* **except all** *s*

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Null Values

- It is possible for tuples to have a null value, denoted by *null*, for some of their attributes
- *null* signifies an unknown value or that a value does not exist.
- The result of any arithmetic expression and comparisons involving *null* evaluate to *null*
  - Example: 5 + *null* returns *null*

    null > 5 returns *null*

    null = *null* returns *null*
- The predicate **is null** can be used to check for null values.
  - Example: Find all instructors whose salary is null.

    select *name*
    from *instructor*
    where *salary* **is null**

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Null Values and Three Valued Logic

- Any comparison with *null* returns *null*
  - Example: *5 < null*   *or*   *null <> null*   *or*   *null = null*
- Three-valued logic using the truth value *null*:
  - OR: (*null* **or** *true*) = *true*,
    (*null* **or** *false*) = *null*
    (*null* **or** *null*) = *null*
  - AND: *(true* **and** *null)* = *null,*
    (false **and** *null)* = *false,*
    (null **and** *null)* = *null*
  - NOT*:* (**not** *null)* = *null*
  - "*P* **is null**" evaluates to true if predicate *P* evaluates to *null*
- Result of **where** clause predicate is treated as *false* if it evaluates to *null*

Aggregate Functions

- These functions operate on the multiset of values of a column of a relation, and return a value

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

- Most DBMS support user defined aggregation functions

Aggregate Functions (Cont.)

- Find the average salary of instructors in the Computer Science department
  - **select avg** (*salary*)
    from *instructor*
    where *dept_name*= ' Comp. Sci.' ;
- Find the total number of instructors who teach a course in the Spring 2010 semester
  - **select count** (**distinct** *ID*)
    from *teaches*
    where *semester* = ' Spring' **and** *year* = 2010
- Find the number of tuples in the *course* relation
  - **select count** (*)
    from *course*;

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Aggregate Functions – Group By

- Find the average salary of instructors in each department
  - **select** *dept_name*, **avg** (*salary*)
    from *instructor*
    group by *dept_name*;
  - Note: departments with no instructor will not appear in result

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

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

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Aggregation (Cont.)

- Attributes in **select** clause outside of aggregate functions must appear in **group by** list
  - /* erroneous query */
    select *dept_name*, ***ID***, **avg** (*salary*)
    from *instructor*
    group by *dept_name*;

Aggregate Functions – Having Clause

- Find the names and average salaries of all departments whose average salary is greater than 42000

  select *dept_name*, **avg** (*salary*)
  from *instructor*
  group by *dept_name*
  having avg (*salary*) > 42000;

Note: predicates in the **having** clause are applied after the formation of groups whereas predicates in the **where** clause are applied before forming groups

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Null Values and Aggregates

- Total all salaries

  select sum (*salary*)
  from *instructor*

  - Above statement ignores null amounts
  - Result is *null* if there is no non-null amount
- All aggregate operations except **count(*)** ignore tuples with null values on the aggregated attributes
- What if collection has only null values?
  - count returns 0
  - all other aggregates return null

Empty Relations and Aggregates

- What if the input relation is empty
- Conventions:
  - **sum**: returns *null*
  - **avg**: returns *null*
  - **min**: returns *null*
  - **max**: returns *null*
  - **count**: returns 0

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Duplicates

- In relations with duplicates, SQL can define how many copies of tuples appear in the result.
- **Multiset** **(bag semantics)** versions of some of the relational algebra operators – given multiset relations r_1 and r_2:

1. $\sigma_\theta(r_1)$: If there are c_1 copies of tuple t_1 in r_1, and t_1 satisfies selections σ_θ, then there are c_1 copies of t_1 in $\sigma_\theta(r_1)$.
2. $\Pi_A(r)$: For each copy of tuple t_1 in r_1, there is a copy of tuple $\Pi_A(t_1)$ in $\Pi_A(r_1)$ where $\Pi_A(t_1)$ denotes the projection of the single tuple t_1.
3. $r_1 \times r_2$: If there are c_1 copies of tuple t_1 in r_1 and c_2 copies of tuple t_2 in r_2, there are $c_1 \times c_2$ copies of the tuple $t_1. t_2$ in $r_1 \times r_2$

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Multiset Relational Algebra

- Pure relational algebra operates on **set-semantics** (no duplicates allowed)
  - e.g. after projection
- Multiset (**bag-semantics**) relational algebra retains duplicates, to match SQL semantics
  - SQL duplicate retention was initially for efficiency, but is now a feature
- Multiset relational algebra defined as follows
  - **selection**: has as many duplicates of a tuple as in the input, if the tuple satisfies the selection
  - **projection**: one tuple per input tuple, even if it is a duplicate
  - **cross product**: If there are *m* copies of *t1* in *r*, and *n* copies of *t2* in *s*, there are *m* x *n* copies of *t1.t2* in *r* x *s*
  - Other operators similarly defined
    - E.g. **union**: *m + n copies,* **intersection**: min(*m, n*) copies **difference**: max(0, *m* – *n*) copies

Duplicates (Cont.)

- Example: Suppose multiset relations r_1 (*A, B*) and r_2 (*C*) are as follows:

  $r_1 = \{(1, a)\ (2,a)\}$ $r_2 = \{(2), (3), (3)\}$

- Then $\Pi_B(r_1)$ would be {(a), (a)}, while $\Pi_B(r_1)$ x r_2 would be

  $\{(a,2), (a,2), (a,3), (a,3), (a,3), (a,3)\}$

- SQL duplicate semantics:

  select $A_1, A_2, ..., A_n$

  from $r_1, r_2, ..., r_m$

  where P

  is equivalent to the *multiset* version of the expression:

$$\prod_{A_1, A_2, \ldots, A_n} (\sigma_P (r_1 \times r_2 \times \ldots \times r_m))$$

SQL and Relational Algebra

- **select** $A_1, A_2, .. A_n$
  from $r_1, r_2, \ldots, r_m$
  where P

  is equivalent to the following expression in multiset relational algebra

  $$\Pi_{A1, .., An} (\sigma_P (r_1 \times r_2 \times .. \times r_m))$$

- **select** $A_1, A_2,$ **sum**(A_3)
  from $r_1, r_2, \ldots, r_m$
  where P
  group by A_1, A_2

  is equivalent to the following expression in multiset relational algebra

  $$_{A1, A2}\mathcal{G}_{\textbf{sum}(A3)} (\sigma_P (r_1 \times r_2 \times .. \times r_m)))$$

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SQL and Relational Algebra

- More generally, the non-aggregated attributes in the **select** clause may be a subset of the **group by** attributes, in which case the equivalence is as follows:

  select A_1, **sum**(A_3) *AS sumA3*
  from $r_1, r_2, \ldots, r_m$
  where P
  group by A_1, A_2

  is equivalent to the following expression in multiset relational algebra

$$\Pi_{A1,sumA3}(\,_{A1,A2}\mathcal{G}_{\textbf{sum}(A3)\ \textbf{as}\ sumA3}(\sigma_P(r_1 \times r_2 \times .. \times r_m)))$$

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Subqueries in the From Clause

- SQL allows a subquery expression to be used in the **from** clause
- Find the average instructors' salaries of those departments where the average salary is greater than $42,000.

```
select dept_name, avg_salary
 from (select dept_name, avg (salary) as avg_salary
          from instructor
          group by dept_name)
 where avg_salary > 42000;
```

- Note that we do not need to use the **having** clause
- Another way to write above query

```
select dept_name, avg_salary
 from (select dept_name, avg (salary)
          from instructor
          group by dept_name)
          as dept_avg (dept_name,  avg_salary)
  where avg_salary > 42000;
```


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Nested Subqueries

- SQL provides a mechanism for the nesting of subqueries.
- A **subquery** is a **select-from-where** expression that is nested within another query.
- A common use of subqueries is to perform tests for set membership, set comparisons, and set cardinality.

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Example Query

- Find courses offered in Fall 2009 and in Spring 2010

  select distinct *course_id*
  from *section*
  where *semester* = 'Fall' **and** *year*= 2009 **and**
  course_id **in** (**select** *course_id*
  from *section*
  where *semester* = 'Spring' **and** *year*= 2010);

- Find courses offered in Fall 2009 but not in Spring 2010

  select distinct *course_id*
  from *section*
  where *semester* = 'Fall' **and** *year*= 2009 **and**
  course_id **not in** (**select** *course_id*
  from *section*
  where *semester* = 'Spring' **and** *year*=
  2010);

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Example Query

- Find the total number of (distinct) studentswho have taken course sections taught by the instructor with *ID* 10101

```
select count (distinct ID)
from takes
where (course_id, sec_id, semester, year) in
                    (select course_id, sec_id, semester, year
                 from teaches
                 where teaches.ID= 10101);
```

- Note: Above query can be written in a much simpler manner. The formulation above is simply to illustrate SQL features.

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Quantification

- Find names of instructors with salary greater than that of some (at least one) instructor in the Biology department.

  select distinct *T.name*
  from *instructor* **as** *T*, *instructor* **as** *S*
  where *T.salary* > *S.salary* **and** *S.dept_name* = ' Biology' ;

- Same query using > **some** clause

  select *name*
  from *instructor*
  where *salary* > **some** (**select** *salary*
  from *instructor*
  where *dept_name* = ' Biology');

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Definition of Some Clause

- F <comp> **some** *r* ⇔ ∃ *t* ∈ *r* such that (F <comp> *t*)
  Where <comp> can be: $<, \leq, >, =, \neq$

(5 < **some** $\begin{array}{|c|}\hline 0 \\ \hline 5 \\ \hline 6 \\ \hline \end{array}$) = true (read: 5 < some tuple in the relation)

(5 < **some** $\begin{array}{|c|}\hline 0 \\ \hline 5 \\ \hline \end{array}$) = false

(5 = **some** $\begin{array}{|c|}\hline 0 \\ \hline 5 \\ \hline \end{array}$) = true

(5 ≠ **some** $\begin{array}{|c|}\hline 0 \\ \hline 5 \\ \hline \end{array}$) = true (since 0 ≠ 5)

(= **some**) ≡ **in**

However, (≠ **some**) ≢ **not in**

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Example Query

- Find the names of all instructors whose salary is greater than the salary of all instructors in the Biology department.

```
select name
from instructor
where salary > all (select salary
                    from instructor
                    where dept_name = 'Biology');
```

Definition of all Clause

- F <comp> **all** *r* ⇔ ∀ *t* ∈ *r* (F <comp> *t*)

$$(5 < \textbf{all} \begin{array}{|c|}\hline 0 \\ \hline 5 \\ \hline 6 \\ \hline \end{array}) = \text{false}$$

$$(5 < \textbf{all} \begin{array}{|c|}\hline 6 \\ \hline 10 \\ \hline \end{array}) = \text{true}$$

$$(5 = \textbf{all} \begin{array}{|c|}\hline 4 \\ \hline 5 \\ \hline \end{array}) = \text{false}$$

$$(5 \neq \textbf{all} \begin{array}{|c|}\hline 4 \\ \hline 6 \\ \hline \end{array}) = \text{true (since } 5 \neq 4 \text{ and } 5 \neq 6)$$

($\neq$ **all**) ≡ **not in**

However, (= **all**) $\not\equiv$ **in**

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Test for Empty Relations

- The **exists** construct returns the value **true** if the argument subquery returns a nonempty result.
- **exists** $r \Leftrightarrow r \neq \emptyset$
- **not exists** $r \Leftrightarrow r = \emptyset$

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Correlation Variables

- Yet another way of specifying the query "Find all courses taught in both the Fall 2009 semester and in the Spring 2010 semester"

```
select course_id
from section as S
where semester = 'Fall' and year= 2009 and
        exists (select *
                from section as T
                where semester = 'Spring' and year= 2010
                      and S.course_id= T.course_id);
```

- **Correlated subquery**
- **Correlation name** or **correlation variable**

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Not Exists

- Find all students who have taken all courses offered in the Biology department.

```
select distinct S.ID, S.name
from student as S
where not exists ( (select course_id
                    from course
                    where dept_name = ' Biology' )
                   except
                    (select T.course_id
                     from takes as T
                     where S.ID = T.ID));
```

- Note that $X - Y = \emptyset \iff X \subseteq Y$
- *Note:* Cannot write this query using = **all** and its variants

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Test for Absence of Duplicate Tuples

- The **unique** construct tests whether a subquery has any duplicate tuples in its result.
  - (Evaluates to "true" on an empty set)
- Find all courses that were offered at most once in 2009

```
select T.course_id
from course as T
where unique (select R.course_id
              from section as R
              where T.course_id= R.course_id
                    and R.year = 2009);
```

Correlated Subqueries in the From Clause

- And yet another way to write it: **lateral** clause

  select *name*, *salary*, *avg_salary*
  from *instructor I1*,
  lateral (**select avg**(*salary*) as *avg_salary*
  from *instructor I2*
  where *I2*.*dept_name*= *I1*.*dept_name*);

- Lateral clause permits later part of the **from** clause (after the lateral keyword) to access correlation variables from the earlier part.
- Note: lateral is part of the SQL standard, but is not supported on many database systems; some databases such as SQL Server offer alternative syntax

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With Clause

- The **with** clause provides a way of defining a temporary view whose definition is available only to the query in which the **with** clause occurs.
- Find all departments with the maximum budget

> **with** *max_budget* (*value*) **as**
>   (**select max**(*budget*)
>   **from** *department*)
> **select** *budget*
> **from** *department*, *max_budget*
> **where** *department.budget* = *max_budget.value*;

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Complex Queries using With Clause

- With clause is very useful for writing complex queries
- Supported by most database systems, with minor syntax variations
- Find all departments where the total salary is greater than the average of the total salary at all departments

```
with dept _total (dept_name, value) as
        (select dept_name, sum(salary)
         from instructor
         group by dept_name),
dept_total_avg(value) as
       (select avg(value)
       from dept_total)
select dept_name
from dept_total, dept_total_avg
where dept_total.value >= dept_total_avg.value;
```

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Scalar Subquery

- Scalar subquery is one which is used where a single value is expected
- E.g.

```
select dept_name,
    (select count(*)
      from instructor
     where department.dept_name = instructor.dept_name)
    as num_instructors
from department;
```

- E.g.

```
select name
from instructor
where salary * 10 >
    (select budget from department
     where department.dept_name = instructor.dept_name)
```

- Runtime error if subquery returns more than one result tuple

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Query Features Recap - Syntax

- An SQL query is either a Select-from-where block or a set operation
- An SQL query block is structured like this:

SELECT [**DISTINCT**] select_list

[**FROM** from_list]

[**WHERE** where_condition]

[**GROUP BY** group_by_list]

[**HAVING** having_condition]

[**ORDER BY** order_by_list]

- Set operations

  [Query Block] set_op [Query Block]

  set_op: [**ALL**] **UNION** | **INTERSECT** | **EXCEPT**

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Query Features Recap - Syntax

- Almost all clauses are optional
- Examples:
  - **SELECT** * **FROM** r;
  - **SELECT** 1;
    - Convention: returns single tuple
  - **SELECT** ‘ok’ **FROM** accounts **HAVING** sum(balance) = 0;
  - **SELECT** 1 **GROUP BY** 1;
  - **SELECT** 1 **HAVING** true;
  - Let r be a relation with two attributes a and b
    - **SELECT** a,b **FROM** r
      WHERE a **IN** (**SELECT** a **FROM** r) **AND** b **IN** (**SELECT** b **FROM** r)
      GROUP BY a,b **HAVING** count(*) > 0;
- Note:
  - Not all systems support all of this “non-sense”

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Syntax - SELECT

- **SELECT** [**DISTINCT [ON (distinct_list)]**] select_list
- select_list
  - List of projection expressions
    - [expr] [**AS** name]
  - expr
    - Expression over attributes, constants, arithmetic operators, functions, **CASE**-construct, aggregation functions
- distinct_list
  - List of expressions
- Examples:
  - **SELECT DISTINCT ON** (a % 2) a **FROM** r;
  - **SELECT** substring(a, 1,2) **AS** x **FROM** r;
  - **SELECT CASE WHEN** a = 2 **THEN** a **ELSE** null **END AS** b **FROM** r;
  - **SELECT** a = b **AS** is_a_equal_to_b **FROM** r;

Syntax - FROM

- **FROM** from_list
- from_list
  - List of from clause expressions
    - subquery | relation | constant_relation | join_expr [alias]
  - subquery
    - Any valid SQL query – alias is not optional
  - relation
    - A relation in the database
  - constant_relation
    - (**VALUES** tuples) – alias is not optional
  - join_expr
    - joins between from_clause entries
  - alias
    - [AS] b [(attribute_name_list)]

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Syntax – FROM (cont.)

- Examples (relation r with attributes a and b):
  - **SELECT** * **FROM** r;
  - **SELECT** * **FROM** r **AS** g(v,w);
  - **SELECT** * **FROM** r x;
  - **SELECT** * **FROM** (**VALUES** (1,2), (3,1)) **AS** s(u,v);
  - **SELECT** * **FROM** r **NATURAL JOIN** s, t;
  - **SELECT** * **FROM** ((r **JOIN** s **ON** (r.a = s.c)) **NATURAL JOIN** (**SELECT** * **FROM** t) **AS** new);
  - **SELECT** * **FROM** (**SELECT** * **FROM** r) **AS** r;
  - **SELECT** * **FROM** (**SELECT** * **FROM** (**SELECT** * **FROM** r) **AS** r) **AS** r;

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Syntax - WHERE

- **WHERE** where_condition
- where_condition: A boolean expression over
  - Attributes
  - Constants: e.g., true, 1, 0.5, ‘hello’
  - Comparison operators: =, <, >, **IS DISTINCT FROM, IS NULL**, …
  - Arithmetic operators: +,-,/,%
  - Function calls
  - Nested subquery expressions
- Examples
  - **SELECT** * **FROM** r **WHERE** a = 2;
  - **SELECT** * **FROM** r **WHERE** true **OR** false**;**
  - **SELECT** * **FROM** r **WHERE NOT**(a = 2 **OR** a = 3)**;**
  - **SELECT** * **FROM** r **WHERE** a **IS DISTINCT FROM** b**;**
  - **SELECT** * **FROM** r **WHERE** a < **ANY** (**SELECT** c **FROM** s)**;**
  - **SELECT** * **FROM** r **WHERE** a = (**SELECT** count(*) **FROM** s);

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Syntax – GROUP BY

- **GROUP BY** group_by_list
- group_by_list
  - List of expressions
    - Expression over attributes, constants, arithmetic operators, functions, **CASE**-construct, aggregation functions
- Examples:
  - **SELECT** sum(a), b **FROM** r **GROUP BY** b;
  - **SELECT** sum(a), b, c **FROM** r **GROUP BY** b, c;
  - **SELECT** sum(a), b/2 **FROM** r **GROUP BY** b/2;
  - **SELECT** sum(a), b **FROM** r **GROUP BY** b > 5;
    - Incorrect, cannot select b, because it is not an expression in the group by clause
  - **SELECT** sum(a), b **FROM** r **GROUP BY** b **IN** (**SELECT** c **FROM** s);

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Syntax – HAVING

- **HAVING** having_condition
- having_condition
  - Like where_condition except that expressions over attributes have either to be in the **GROUP BY** clause or are aggregated
- Examples:
  - **SELECT** sum(a), b **FROM** r **GROUP BY** b **HAVING** sum(a) > 10;
  - **SELECT** sum(a), b **FROM** r **GROUP BY** b **HAVING** sum(a) + 5 > 10;
  - **SELECT** sum(a), b **FROM** r **GROUP BY** b **HAVING** true;
  - **SELECT** sum(a), b **FROM** r **GROUP BY** b **HAVING** count(*) = 50;
  - **SELECT** b **FROM** r **GROUP BY** b **HAVING** sum(a) > 10;

Syntax – ORDER BY

- **ORDER BY** order_by_list
- order_by_list
  - Like select_list minus renaming
  - Optional [**ASC** | **DESC**] for each item
- Examples:
  - **SELECT** * **FROM** r **ORDER BY** a;
  - **SELECT** * **FROM** r **ORDER BY** b, a;
  - **SELECT** * **FROM** r **ORDER BY** a * 2;
  - **SELECT** * **FROM** r **ORDER BY** a * 2, a;
  - **SELECT** * **FROM** r **ORDER BY** a + (SELECT count(*) FROM s);

Query Semantics

- Evaluation Algorithm (you can do it manually – sort of)

1. Compute **FROM** clause
   1. Compute cross product of all items in the **FROM** clause
      - Relations: nothing to do
      - Subqueries: use this algorithm to recursively compute the result of subqueries first
      - Join expressions: compute the join
2. Compute **WHERE** clause
   1. For each tuple in the result of 1. evaluate the **WHERE** clause condition
3. Compute **GROUP BY** clause
   1. Group the results of step 2. on the **GROUP BY** expressions
4. Compute **HAVING** clause
   1. For each group (if any) evaluate the **HAVING** condition

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Query Semantics (Cont.)

5. Compute **ORDER BY** clause
   5. Order the result of step 4 on the **ORDER BY** expressions
6. Compute **SELECT** clause
   5. Project each result tuple from step 5 on the **SELECT** expressions

- If the **WHERE**, **SELECT**, **GROUP BY**, **HAVING**, **ORDER BY** clauses have any nested subqueries
  - For each tuple t in the result of the **FROM** clause
    - Substitute the correlated attributes with values from t
    - Evaluate the resulting query
    - Use the result to evaluate the expression in the clause the subquery occurs in

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Query Semantics (Cont.)

- Equivalent relational algebra expression
  - **ORDER BY** has no equivalent, because relations are unordered
  - Nested subqueries: need to extend algebra (not covered here)
- Each query block is equivalent to

$$\pi(\sigma(\mathcal{G}(\pi(\sigma(F_1 \times \ldots F_n)))))$$

- Where F_i is the translation of the i^{th} **FROM** clause item
- Note: we leave out the arguments

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Modification of the Database

- Deletion of tuples from a given relation
- Insertion of new tuples into a given relation
- Updating values in some tuples in a given relation

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Modification of the Database – Deletion

- Delete all instructors

  delete from *instructor*

- Delete all instructors from the Finance department

  delete from *instructor*
  where *dept_name*= ' Finance' ;

- Delete all tuples in the *instructor* relation for those instructors associated with a department located in the Watson building.

  delete from *instructor*
  where *dept_name* **in** (**select** *dept_name*
  from *department*
  where *building* = ' Watson');

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Deletion (Cont.)

- Delete all instructors whose salary is less than the average salary of instructors

  delete from *instructor*
  where *salary* < (**select avg** (*salary*) **from** *instructor*);

  - Problem: as we delete tuples from instructor, the average salary changes
  - Solution used in SQL:
    1. First, compute **avg** salary and find all tuples to delete
    2. Next, delete all tuples found above (without recomputing **avg** or retesting the tuples)

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Modification of the Database – Insertion

- Add a new tuple to *course*

  insert into *course*
  values (' CS-437' , ' Database Systems' , ' Comp. Sci.' , 4);

- or equivalently

  insert into *course* (*course_id*, *title*, *dept_name*, *credits*)
  values (' CS-437' , ' Database Systems' , ' Comp. Sci.' , 4);

- Add a new tuple to *student* with *tot_creds* set to null

  insert into *student*
  values (' 3003' , ' Green' , ' Finance' , *null*);

Insertion (Cont.)

- Add all instructors to the *student* relation with tot_creds set to 0

  insert into *student*
  select *ID, name, dept_name, 0*
  from *instructor*

- The **select from where** statement is evaluated fully before any of its results are inserted into the relation (otherwise queries like

  insert into *table*1 **select** * **from** *table*1

  would cause problems, if *table1* did not have any primary key defined.

Modification of the Database – Updates

- Increase salaries of instructors whose salary is over $100,000 by 3%, and all others receive a 5% raise
  - Write two **update** statements:

    update *instructor*
        set *salary* = *salary* * 1.03
        where *salary* > 100000;
    update *instructor*
        set *salary* = *salary* * 1.05
        where *salary* <= 100000;

  - The order is important
  - Can be done better using the **case** statement (next slide)

Case Statement for Conditional Updates

- Same query as before but with case statement

update *instructor*
set *salary* = **case**
when *salary* <= 100000 **then** *salary* * 1.05
else *salary* * 1.03
end

Updates with Scalar Subqueries

- Recompute and update tot_creds value for all students

```
update student S
   set tot_cred = ( select sum(credits)
                    from takes natural join course
                    where S.ID= takes.ID and
                          takes.grade <> 'F' and
                          takes.grade is not null);
```

- Sets *tot_creds* to null for students who have not taken any course
- Instead of **sum**(*credits*), use:

```
case
    when sum(credits) is not null then sum(credits)
    else 0
end
```

- Or **COALESCE**(sum(credits),0)
  - **COALESCE** returns first non-null arguments

Recap

- SQL queries
  - Clauses: **SELECT**, **FROM** , **WHERE**, **GROUP BY**, **HAVING**, **ORDER BY**
  - Nested subqueries
  - Equivalence with relational algebra
- SQL update, inserts, deletes
  - Semantics of referencing updated relation in **WHERE**
- SQL DDL
  - Table definition: **CREATE TABLE**

End of Chapter 4

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Outline

- Introduction
- Relational Data Model
- Formal Relational Languages (relational algebra)
- **SQL - Intermediate**
- Database Design
- Transaction Processing, Recovery, and Concurrency Control
- Storage and File Structures
- Indexing and Hashing
- Query Processing and Optimization

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Advanced SQL Features**

- Create a table with the same schema as an existing table:
  create table *temp_account* **like** *account*

Figure 3.02

name
Srinivasan
Wu
Mozart
Einstein
El Said
Gold
Katz
Califieri
Singh
Crick
Brandt
Kim

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Figure 3.03

dept_name
Comp. Sci.
Finance
Music
Physics
History
Physics
Comp. Sci.
History
Finance
Biology
Comp. Sci.
Elec. Eng.

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Figure 3.04

name
Katz
Brandt

Figure 3.05

name	*dept_name*	*building*
Srinivasan	Comp. Sci.	Taylor
Wu	Finance	Painter
Mozart	Music	Packard
Einstein	Physics	Watson
El Said	History	Painter
Gold	Physics	Watson
Katz	Comp. Sci.	Taylor
Califieri	History	Painter
Singh	Finance	Painter
Crick	Biology	Watson
Brandt	Comp. Sci.	Taylor
Kim	Elec. Eng.	Taylor

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Figure 3.07

name	*Course_id*
Srinivasan	CS-101
Srinivasan	CS-315
Srinivasan	CS-347
Wu	FIN-201
Mozart	MU-199
Einstein	PHY-101
El Said	HIS-351
Katz	CS-101
Katz	CS-319
Crick	BIO-101
Crick	BIO-301
Brandt	CS-190
Brandt	CS-190
Brandt	CS-319
Kim	EE-181

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Figure 3.08

ID	*name*	*dept_name*	*salary*	*course_id*	*sec_id*	*semester*	*year*
10101	Srinivasan	Comp. Sci.	65000	CS-101	1	Fall	2009
10101	Srinivasan	Comp. Sci.	65000	CS-315	1	Spring	2010
10101	Srinivasan	Comp. Sci.	65000	CS-347	1	Fall	2009
12121	Wu	Finance	90000	FIN-201	1	Spring	2010
15151	Mozart	Music	40000	MU-199	1	Spring	2010
22222	Einstein	Physics	95000	PHY-101	1	Fall	2009
32343	El Said	History	60000	HIS-351	1	Spring	2010
45565	Katz	Comp. Sci.	75000	CS-101	1	Spring	2010
45565	Katz	Comp. Sci.	75000	CS-319	1	Spring	2010
76766	Crick	Biology	72000	BIO-101	1	Summer	2009
76766	Crick	Biology	72000	BIO-301	1	Summer	2010
83821	Brandt	Comp. Sci.	92000	CS-190	1	Spring	2009
83821	Brandt	Comp. Sci.	92000	CS-190	2	Spring	2009
83821	Brandt	Comp. Sci.	92000	CS-319	2	Spring	2010
98345	Kim	Elec. Eng.	80000	EE-181	1	Spring	2009

Figure 3.09

course_id
CS-101
CS-347
PHY-101

Figure 3.10

course_id
CS-101
CS-315
CS-319
CS-319
FIN-201
HIS-351
MU-199

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Figure 3.11

course_id
CS-101
CS-315
CS-319
CS-347
FIN-201
HIS-351
MU-199
PHY-101

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Figure 3.12

course_id
CS-101

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Figure 3.13

course_id
CS-347
PHY-101

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Figure 3.16

dept_name	*count*
Comp. Sci.	3
Finance	1
History	1
Music	1

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Figure 3.17

dept_name	*avg(salary)*
Physics	91000
Elec. Eng.	80000
Finance	85000
Comp. Sci.	77333
Biology	72000
History	61000

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