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Database Technology
SQL Part 1

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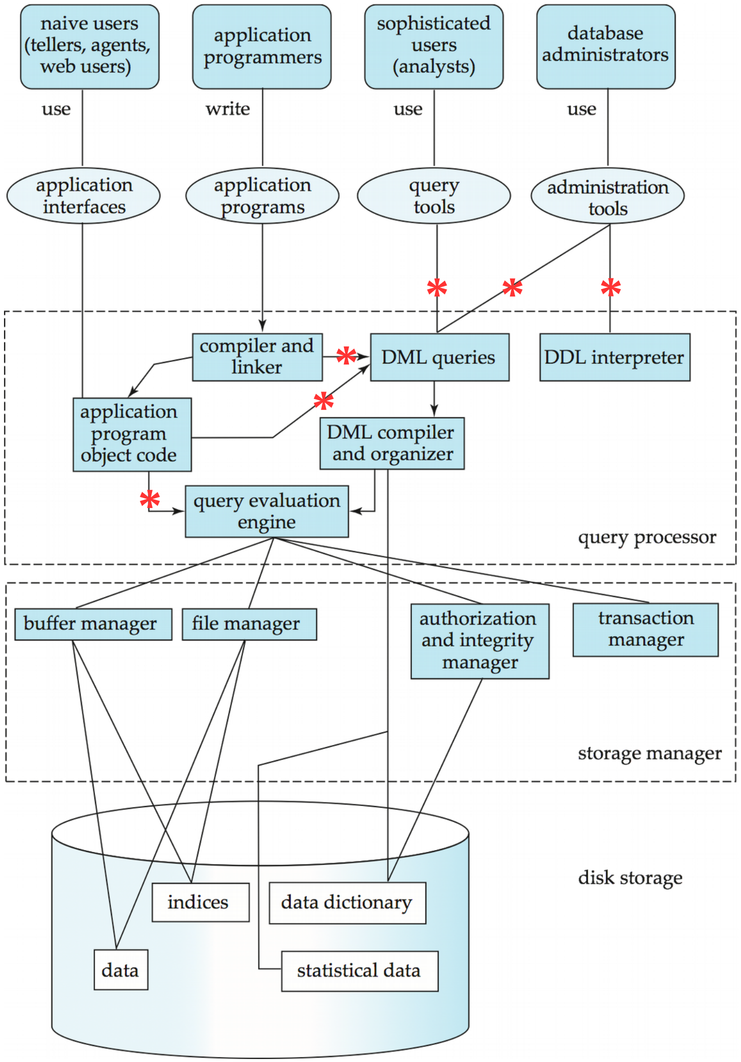
Outline

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

Recap: Database Systems

- Users and applications interact with databases
  - By issuing *queries*
  - Data definition (DDL): defining, altering, deleting tables
  - Data manipulation (DML): reading from & writing to tables
- SQL is both a DDL and a DML
  - The language that most DBMS speak



History

- IBM SEQUEL language developed as part of System R project at the IBM San Jose Research Laboratory
  - *Structured English QUEry Language*
- Renamed Structured Query Language (SQL)
- ANSI and ISO standard SQL:
  - SQL-86
  - SQL-89
  - SQL-92
  - SQL:1999
  - SQL:2003

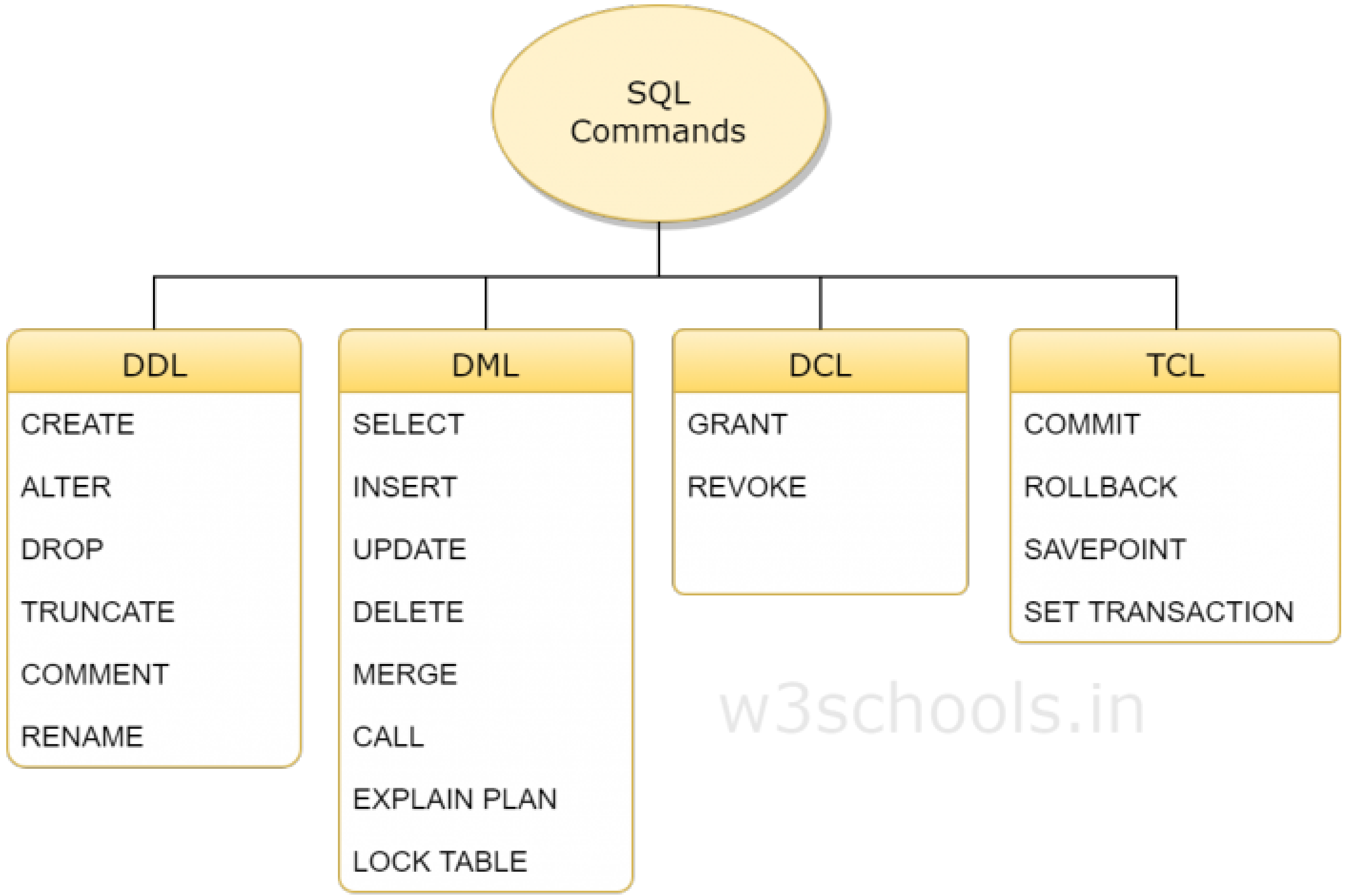
Naming became Y2K compliant! ;-)

ANSI American National Standards Institute

ISO International Organization for Standardization

- Commercial + free 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 on your particular system!

Parts of SQL: The Big Picture



Source: https://www.w3schools.in/mysql/ddl-dml-dcl/

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

Recap: Domain of an Attribute

- The set of allowed values for an attribute
  - Programmers: think *datatype*

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

Simple Domains 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 *d* digits to the right of decimal point. (ex., **numeric**(3,1), allows 44.5 to be stores exactly, but not 444.5 or 0.32)
- **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 (e.g.: date and time) next week

Creating Relations

- 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 A_i is an attribute name in the schema of relation r
- D_i is the datatype/domain of values in the domain of attribute A_i

- Example:

```
create table instructor (
        ID          char(5),
        name        varchar(20),
        dept_name   varchar(20),
        salary      numeric(8,2))
```

A Note on Case Sensitivity

- SQL is completely case insensitive
  - **create table = CREATE TABLE = cReAtE tAbLe**
- Also for names of relations and attributes
  - instructor = Instructor = INSTRUCTOR
  - id = ID = iD
- Each relation / attribute can only exist once
  - Hence, two relations named *instructor* and *Instructor* would not be feasible
- Case sensitivity does *not* apply to values!
  - i.e., “Einstein” and “einstein” are different values!

Recap: Keys

- Primary keys identify a unique tuple of each possible relation *r(R)*
  - Typical examples: IDs, Social Security Number, car license plate
- Primary keys can consist of multiple attributes
  - e.g.: course ID plus semester (CS 460, HWS 2017)
  - Must be minimal – (ID, semester, instructor) would work as well
- Foreign keys refer to other tables
  - i.e., they appear in other tables as primary keys

Defining Keys

- **primary key** (A_1, ..., A_n)
- **foreign key** (A_m, ..., A_n) **references** *r*
- *Example:*

create table *instructor* (
ID **char**(5),
name **varchar**(20),
dept_name **varchar**(20),
salary **numeric**(8,2),
primary key (*ID*),
foreign key *(dept_name*)
references *department(dept_name));*

Removing and Altering Relations

- **Removing relations**
  - **drop table** *r*
- **Altering**
  - **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 existing 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*
    - not supported by many databases

Reading Data

- The **select** clause lists the attributes desired in the result of a query
- Example: find the names of all instructors:

  select *name*
  from *instructor*

- In relational algebra:
  - Π_{name} (*instructor*)

Renaming Columns in a Select

- Columns can be renamed during selection
- **select** *name, salary* **as** *payment* **from** *instructor*

- In relational algebra
  – a composition of projection and renaming:

    $\rho_{\mathit{payment} \leftarrow \mathit{salary}} (\Pi_{\text{name,salary}} (\mathit{instructor}))$

The Select Clause

- An asterisk in the select clause denotes “all attributes”

  select * **from** *instructor*

- An attribute can be a literal with no **from** clause, possibly renamed

  select ‘437’

  select ‘437’ **as** *FOO*

FOO
437

- An attribute can be a literal with **from** clause

  select *name*, ‘Instructor’ **as** *role* **from** *instructor*

  union

  select *name*, ‘Student’ **as** *role* **from** *student*

name	role
Smith	Instructor
Einstein	Instructor
...	...
Johnson	Student
...	...

Duplicates

- Difference to relational algebra
  - Sets do not contain duplicates!
- SQL allows duplicates in relations as well as in query results

unless they have a primary key

- To force the elimination of duplicates, insert the keyword **distinct** after select**.**
- Find the department names of all instructors, and remove duplicates

select distinct *dept_name*
from *instructor*

Arithmetics in the Selection

- The **select** clause can contain arithmetic expressions involving the operation, +, –, ∗, and /, and operating on constants or attributes of tuples
  - Here, we leave relational algebra!

- 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
- Combined with renaming:
  - **select** *ID, name, salary/12* **as** *monthly_salary*

Reading Parts of a Relation

- So far, we have always read an entire relation
- Usually, we are interested only in a small portion
- The **where** clause restricts which parts of the table to read

- To find all instructors in Comp. Sci. dept

  select *name*
  from *instructor*
  where *dept_name* = 'Comp. Sci.'

- In relational algebra: combination of selection and projection

$$\pi_{name}(\sigma_{dept\_name = \text{'Comp. Sci.'}}(r))$$

Reading Parts of a Relation

- Comparison results can be combined using the logical connectives **and, or,** and **not**

  select *name*
  from *instructor*
  where *dept_name* = 'Comp. Sci.' **and** *salary* > 90000

  $\pi_{name}(\sigma_{dept\_name\ =\ \text{'Comp. Sci.'}\ \wedge\ salary>90000}(r))$

- Can be combined with results of arithmetic expressions

  select *name, salary/12* **as** *monthly_salary*
  from *instructor*
  where *dept_name* = 'Comp. Sci.' **and** *monthly_salary* > 7500

Cartesian Product

- Find the Cartesian product, i.e., *instructor x teaches*

  select $*$ **from** *instructor, teaches*

  generates every possible instructor – teaches pair, with all attributes from both relations

- Common attributes (e.g., *ID*), the attributes in the resulting table are renamed using the relation name
  - e.g., *instructor.ID, teaches.ID*

- Relational algebra notation:

  $\rho_{instructor.ID \leftarrow ID}(instructor) \times \rho_{teaches.ID \leftarrow ID}(\text{teaches})$

- not really useful directly, but very useful together with selection...

Cartesian Product

instructor

ID	*name*	*dept_name*	*salary*
10101	Srinivasan	Comp. Sci.	65000
12121	Wu	Finance	90000
15151			
22222			
32343			

teaches

ID	*course_id*	*sec_id*	*semester*	*year*
10101	CS-101	1	Fall	2009
10101	CS-315	1	Spring	2010
				2009
				2010
				2010
				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	Pinance	90000	10101	CS-347	1	Fall	2009
12121	Wu	Pinance	90000	12121	FIN-201	1	Spring	2010
12121	Wu	Finance	90000	15151	MU-199	1	Spring	2010
12121	Wu	Pinance	90000	22222	PHY-101	1	Fall	2009
...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...

Cartesian Products with Selection

- Find the names of all instructors who have taught some course and the course_id

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

- Relational algebra:

  $\pi_{name,course\_id}(\sigma_{instructor.ID=teaches.ID}(\rho_{instructor.ID \leftarrow ID}((instructor) \text{ x } \rho_{teaches.ID \leftarrow ID}(\text{teaches}))))$

- Find the names of all instructors in the Art department who have taught some course and the course_id

  select *name, course_id*
  from *instructor , teaches*
  where *instructor.ID = teaches.ID* ***and*** *instructor. dept_name* = ‘Art’

  $\pi_{name,course\_id}(\sigma_{instructor.ID=teaches.ID \wedge dept\_name='Art'}(\rho_{instructor.ID \leftarrow ID}($
  $(instructor) \text{ x } \rho_{teaches.ID \leftarrow ID}(\text{teaches}))))$

Cartesian Product of a Table with Itself

- Find the names of all instructors who have a higher salary than some instructor in 'Comp. Sci'.
  - We need the same table twice
  - So, we have to use it under different names

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

    $\pi_{T,name}(\sigma_{T.salary>S.salary \wedge S.dept\_name='Comp.\ Sci.'}(\rho_T(\text{instructor}) \times \rho_S(\text{instructor})))$

- What happens if we omit the **distinct** here?

Searching in Texts

- So far, we have handled exact equality in selections
- Sometimes, we want to search differently
  - All books that contain “database”
  - All authors starting with “S”
  - …

- In SQL: comparing with **like** and two special characters:
  - _ = any arbitrary character
  - % = any number of arbitrary characters
  - masking with backslash

    select … where *title* **like** ‘%database%’

    select … **where** *author* **like** ‘S%’

    select … **where** *amount* **like** *‘100\%’*

Ordering Results

- Recap: Relational Algebra works on sets
  - i.e., it does not have orderings

- For database applications, ordering is often useful, e.g.,
  - list students ordered by names

    select *id,name*
    from *student*
    order by *name*

  - list instructors ordered by department first, then by name

    select *id,name,dept_name*
    from *instructor*
    order by *dept_name, name*

Limiting Results

- Find the three lecturers with the highest salaries

  select *id,name,salary*
  from *instructor*
  order by *salary* **desc**
  limit 3;

- *Note:* the **desc** keyword creates a descending ordering
- **asc** also exists and creates an ascending ordering
  - also the default when not specifiying the direction

Paging with LIMIT and OFFSET

- Applications, e.g., Web applications, often offer a *paged* view
- Example:
  - Display student list on pages of 100 students
  - with navigation (next page, previous page)

select *id,name*
from *student*
order by *name*
limit 100
offset 100;

- **offset** 100 means: skip the first 100 entries
  - i.e., this query would create the second page
- *Note:* offset should only be used with **order by**
  - otherwise, the results are not deterministic

Set Operations

- All courses that are offered in HWS 2017 *and* FSS 2018

  (**select** *course_id* **from** *section* **where** *sem* = 'HWS' **and** *year* = 2017)
  intersect
  (**select** *course_id* **from** *section* **where** *sem* = 'FSS' **and** *year* = 2018)

  $\pi_{course\_id}(\sigma_{sem='HWS' \land year=2017}(\text{section})) \cap \pi_{course\_id}(\sigma_{sem='FSS' \land year=2018}(\text{section}))$

- All courses that are offered in HWS 2017 *but not in* FSS 2018

  (**select** *course_id* **from** *section* **where** *sem* = 'HWS' **and** *year* = 2017)
  except
  (**select** *course_id* **from** *section* **where** *sem* = 'FSS' **and** *year* = 2018)

  $\pi_{course\_id}(\sigma_{sem='HWS' \land year=2017}(\text{section})) - \pi_{course\_id}(\sigma_{sem='FSS' \land year=2018}(\text{section}))$

Set Operations

- All courses that are offered in HWS 2017 *or* FSS 2018

  (**select** *course_id* **from** *section* **where** *sem* = 'HWS' **and** *year* = 2017)
  union
  (**select** *course_id* **from** *section* **where** *sem* = 'FSS' **and** *year* = 2018)

  $\pi_{course\_id}(\sigma_{sem='HWS' \wedge year=2017}(\text{section})) \cup \pi_{course\_id}(\sigma_{sem='FSS' \wedge year=2018}(\text{section}))$

- Alternative solution

  (**select** course_id **from** section **where**
  ((*sem* = 'HWS' **and** *year* = 2017) **or** (*sem* = 'FSS' **and** *year* = 2018))

  $\pi_{course\_id}(\sigma_{(sem='HWS' \wedge year=2017) \vee (sem='FSSS' \wedge year=2018))}(\text{section}))$

Aggregate Functions – Examples

- Find the average salary of instructors in the Computer Science department
  - **select avg** (*salary*)
    from *instructor*
    where *dept_name*= ’Comp. Sci.’;
- Find the number of tuples in the *course* relation
  - **select count** (*)
    from *course*;
- 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;

Why do we need **distinct** here?

Aggregate Functions with Group By

- Find the average salary of instructors in each department
  - **select** *dept_name*, **avg** (*salary*) **as** *avg_salary*
    from *instructor*
    group by *dept_name*;

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

Aggregate Functions with Group By

- 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*;

why?

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

Conditions on Aggregate Values

- Find the names and average salaries of all departments whose average salary is greater than 42000
  - **select** *dept_name*, **avg** (*salary*) **as** *avg_salary*
from *instructor*
group by *dept_name*
where *avg_salary* > 42000;

- Problem:
  - Aggregation is performed *after* selection and projection
  - Hence, the variable *avg_salary* is not available when the **where** clause is evaluated

→ The above query will not work

Conditions on Aggregate Values

- Find the names and average salaries of all departments whose average salary is greater than 42000
  - **select** *dept_name*, **avg** (*salary*) **as** *avg_salary*
    from *instructor*
    group by *dept_name*
    having *avg_salary* > 42000;

- The **having** clause is evaluated *after* the aggregation
- Hence, it is different from the **where** clause

- Rule of thumb
  - Conditions on aggregate values can only be defined using **having**

NULL Values

- *null* signifies an unknown value or that a value does not exist
- It is possible for tuples to have a null value, denoted by *null*, for some of their attributes
  - can be forbidden by a **not null** constraint
  - keys can never be null!
- The result of any arithmetic expression involving *null* is *null*
- Example: 5 + *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**

NULL Values and Three Valued Logic

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

Aggregates and NULL Values

- Total all salaries

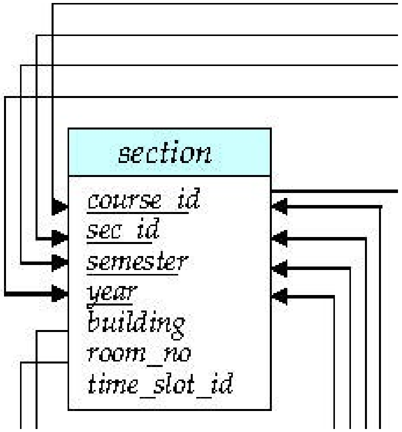
  select sum (*salary*)
  from *instructor*

  – 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

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

Caveats with NOT NULL Constraints

- Rationale:
  - Each course takes place at a specific room and time slot
  - We'll create a **not null** constraint on those fields
  - *Note:* no online courses here

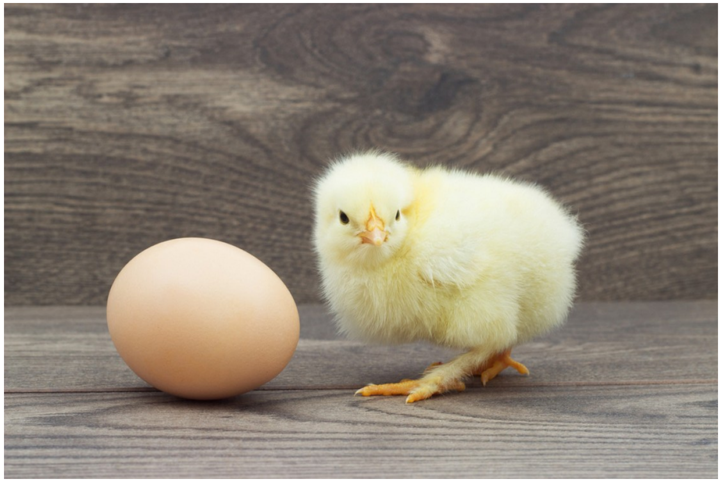


- Use case:
  - First: enter all courses in the system
  - Second: run clever time and room allocation algorithm
    - Which will then fill all the buildings and time slots

Caveats with NOT NULL Constraints (ctd.)

- Example: every employee needs a substitute
  - **create table** *employee* (
    ID **varchar**(5),
    name **varchar**(20) not null,
    substitute **varchar**(5) not null,
    primary key *(ID),*
    foreign key (*substitute*) **references** *employee(ID)*);

- What do you think?



Subqueries

- SQL provides a mechanism for the nesting of subqueries. A **subquery** is a **select-from-where** expression that is nested within another query.
- The nesting can be done in the following SQL query

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

  as follows:
- A_i can be replaced be a subquery that generates a single value
- r_i can be replaced by any valid subquery
- P can be replaced with an expression of the form:

  B <operation> (subquery)

  Where *B* is an attribute and <operation> to be defined later

Subqueries in the WHERE Clause

- A common use of subqueries is to perform tests:
  - for set membership
  - for set comparisons
  - for set cardinality

Test for Set Membership

- 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);

Test for Set Membership

- Find the total number of (distinct) students who 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: in all of those cases,
  other (sometimes much simpler) solutions are possible
  - In SQL, there are often different ways to solve a problem
  - A question of personal taste
  - But also: a question of performance...

Test for Set Membership

- Find the total number of (distinct) students who 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);

creates a temporary table

- vs.

select count (**distinct** *takes.ID*)
from *takes, teaches*
where *takes.course_id* = *teaches.course_id* **and** *teaches.ID* = 10101;

computes Cartesian product

Set Comparison with SOME

- 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’);

Set Comparison with ALL

- Find names of instructors with salary greater than that of all instructors in the Biology department

  select *name*
  from *instructor*
  where *salary* > **all** (**select** *salary*
  from *instructor*
  where *dept name* = 'Biology');

- Note: we could also achieve this with MIN and MAX aggregates in the subqueries

Definition: Comparisons with SOME

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

(5 < **some**

0
5
6

) = true (read: 5 < some tuple in the relation)

(5 < **some**

0
5

) = false

(5 = **some**

0
5

) = true

(5 ≠ **some**

0
5

) = true (since 0 ≠ 5)

(= **some**) ≡ **in**
However, (≠ **some**) ≢ **not in**

Definition: Comparisons with ALL

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

(5 < **all**

0
5
6

) = false

(5 < **all**

6
10

) = true

(5 = **all**

4
5

) = false

(5 ≠ **all**

4
6

) = true (since 5 ≠ 4 and 5 ≠ 6)

(≠ **all**) ≡ **not in**

However, (= **all**) ≢ **in**

Existential Quantification in Subqueries

- 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*);

- The **exists** construct returns the value **true** if the result of the subquery is not empty
  - **exists** $r \Leftrightarrow r \neq \emptyset$
  - **not exists** $r \Leftrightarrow r = \emptyset$

Subqueries with 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));
```

  - First nested query lists all courses offered in Biology
  - Second nested query lists all courses a particular student took

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

Test for Duplicate Tuples

- 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);
```

- The **unique** construct evaluates to “true” if a given subquery contains no duplicates
- With **not unique**, we could query for courses that were offered more than once

Subqueries in the FROM Clause

- So far, we have considered subqueries in the **where** 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
  - why?

Creating Temporary Relations Using WITH

- Find all departments with the maximum budget

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

> this defines the structure of the temporary relation (datatypes are implicit)

- The **with** clause provides a way of defining a temporary relation whose definition is available only to the query in which the **with** clause occurs

Creating Temporary Relations Using WITH

- A more complex example involving two temporary relations:
  - 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;
```

Scalar Subqueries in the SELECT Part

- List all departments along with the number of instructors in each department

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

- Scalar subqueries return a single result
  - More specifically: a single *tuple*
- Runtime error if subquery returns more than one result tuple

Summary of Subqueries

- SELECT queries are the most often used part of SQL
- Their basic structure is simple, but subqueries are a powerful means to make them quite expressive

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

- Subqueries in **select** part (A_1, A_2, ..., A_n)
  - Scalar subqueries (single values, like aggregates)
- Subqueries in **from** part (r_1, r_2, ..., r_m)
  - Temporary relations (can also be defined using **with**)
- Subqueries in **where** part (P)
  - Set comparisons, empty sets, test for duplicates
  - Universal and existential quantification

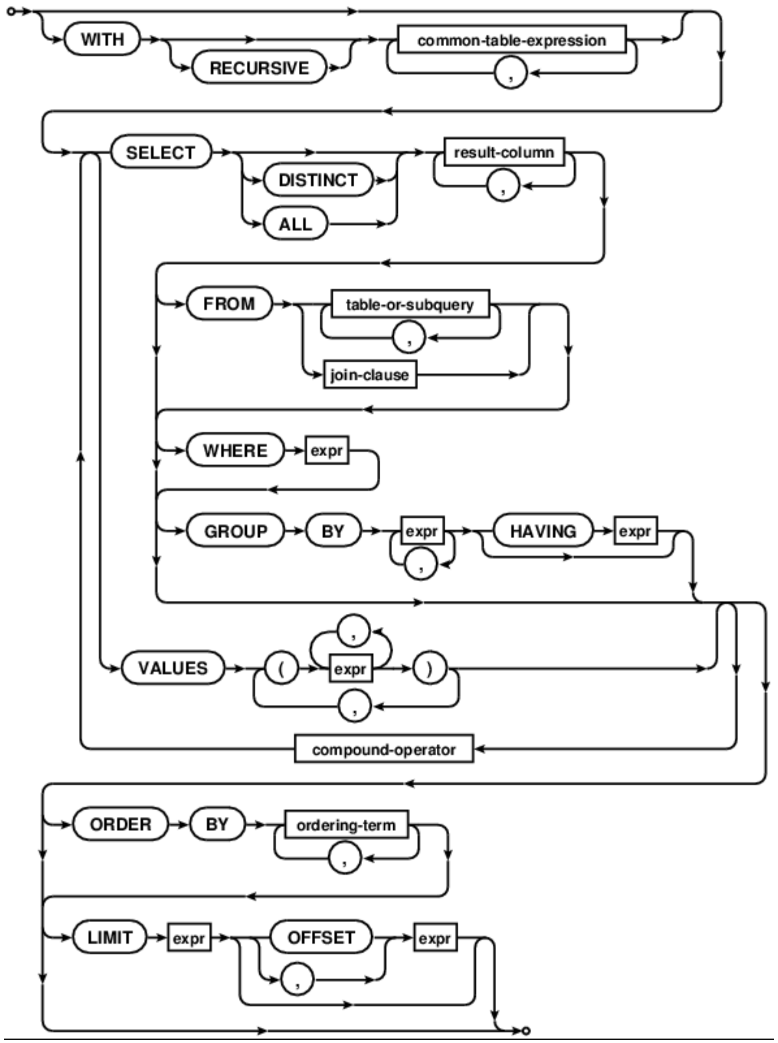
Summary and Take Aways

- SQL is a standarized language for relational databases
  - DDL: Data Definition Language
  - DML: Data Manipulation Language

- DDL
  - Create and remove tables
  - Define table structure
- DML
  - Read data from tables using SELECT
  - Write data to tables (coming up)

SQL SELECT at a Glance

- The tool support of SQL varies
- what we have covered here is standard SQL
  - Supported by *most* tools



Questions?