Introduction to Database Systems

2023-Fall

3. User Interfaces and SQL Language

User interface of DBMS

- A DBMS must offer some interfaces to support user to access database, including:
  - Query Languages
  - Interface and maintaining tools (GUI)
  - APIs
  - Class Library
- Query Languages
  - Formal Query Language
  - Tabular Query Language
  - Graphic Query Language
  - Limited Natural Language Query Language

Example of Tabular Query Language

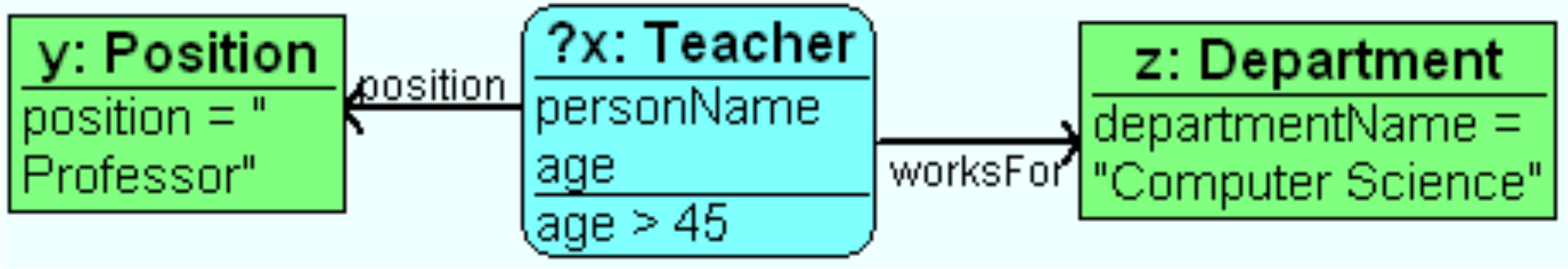
- **Find the names of all students in the department of Info. Science**

Student	Sno	Sname	Ssex	Sage	Sdept
		P.T			IS

PRINT Domain Variables Conditions

Example of Graphic Query Language

Find all Teachers, which have position=”Professor” and which have age>”45” and which work for department=”Computer Science”



User interface of DBMS

- A DBMS must offer some interfaces to support user to access database, including:
  - Query Languages
  - Interface and maintaining tools (GUI)
  - APIs
  - Class Library
- Query Languages
  - Formal Query Language
  - Tabular Query Language
  - Graphic Query Language
  - Limited Natural Language Query Language

Relational Query Languages

- Query languages: Allow manipulation and ***retrieval of data*** from a database.
- Relational model supports simple, powerful QLs:
  - Strong formal foundation based on logic.
  - Allows for much optimization.
- Query Languages **!=** programming languages!
  - QLs not expected to be “Turing complete”.
  - QLs not intended to be used for complex calculations.
  - QLs support easy, efficient access to large data sets.

Formal Relational Query Languages

- Two mathematical Query Languages form the basis for "**real**" languages (e.g. SQL), and for implementation:
  - ***Relational Algebra***: More operational, very useful for representing execution plans.
  - ***Relational Calculus***: Lets users describe what they want, rather than how to compute it. (Non-operational, *declarative*.)
- The most successful relational database language --- SQL (Structured Query Language; Standard Query Language(1986); Now SQL: 2016.)

SQL Language

SQL Roots

- Developed @IBM Research in the 1970s
  - System R project
  - Vs. Berkeley's Quel language (Ingres project)
- Commercialized/Popularized in the 1980s
  - "Intergalactic Dataspeak"
  - IBM beaten to market by a startup called Oracle

SQL's Persistence

- Over 40 years old!
- Questioned repeatedly
  - 90's: Object-Oriented DBMS (OQL, etc.)
  - 2000's: XML (Xquery, Xpath, XSLT)
  - 2010's: NoSQL & MapReduce
- SQL keeps re-emerging as the standard
  - Even Hadoop, Spark etc. mostly used via SQL
  - May not be perfect, but it is useful

SQL Pros and Cons

- Declarative!
  - Say *what* you want, not *how* to get it
- Implemented widely
  - With varying levels of efficiency, completeness
- Constrained
  - Not targeted at Turing-complete tasks
- General-purpose and feature-rich
  - many years of added features
  - extensible: callouts to other languages, data sources

SQL Language

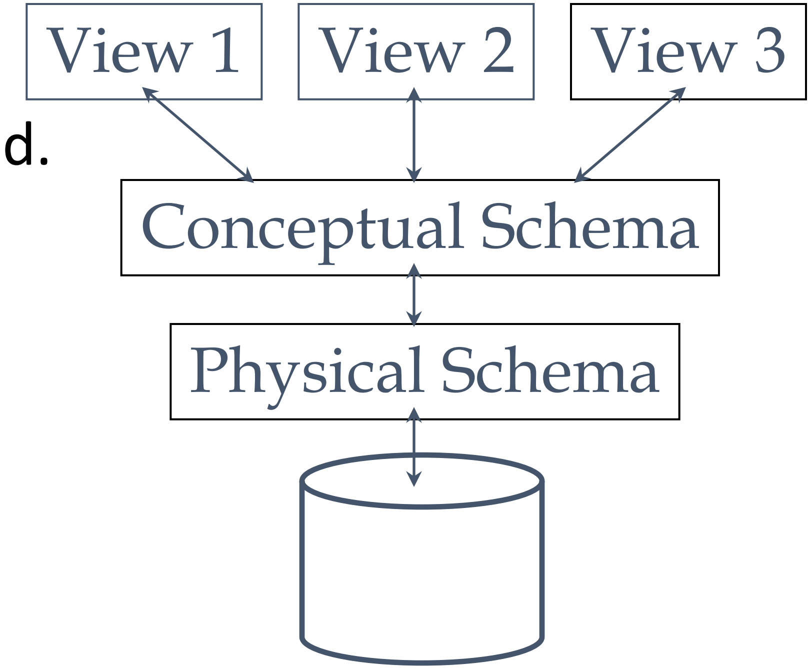
- It can be divided into four parts according to functions.
  - ***Data Definition Language (DDL),*** used to define, delete, or alter data schema.
  - Query Language (QL), used to retrieve data
  - ***Data Manipulation Language (DML),*** used to insert, delete, or update data.
  - Data Control Language (DCL), used to control user's access authority to data.
- RDBMS responsible for efficient evaluation.
  - Choose and run algorithms for declarative queries
    - Choice of algorithm must not affect query answer.

Important terms and concepts

- Base table
- View
- Data type supported
- NULL
- UNIQUE
- DEFAULT
- PRIMARY KEY
- FOREIGN KEY
- CHECK (Integration Constraint)

Levels of Abstraction: ANSI-SPARC Architecture

- Many *views*, single *conceptual (logical) schema* and *physical schema*.
  - Views describe how users see the data.
  - Conceptual schema defines logical structure
  - Physical schema describes the files and indexes used.



☛ *Schemas are defined using DDL; data is modified/queried using DML.*

Example Instances

- We will use these instances of the Sailors, Reserves and Boats relations in our examples.

R1

sid	bid	day
22	101	10/10/96
58	103	11/12/96

B1

bid	bname	color
101	tiger	red
103	lion	green
105	hero	blue

S1

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

S2

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

The SQL DDL: Sailors

```
CREATE TABLE Sailors (
        sid INTEGER,
        sname CHAR(20),
        rating INTEGER,
        age FLOAT

        PRIMARY KEY (sid));
```

sid	sname	rating	age
1	Fred	7	22
2	Jim	2	39
3	Nancy	8	27

The SQL DDL: Boats

```
CREATE TABLE Boats (
  bid INTEGER,
  bname CHAR (20),
  color CHAR(10),
  PRIMARY KEY (bid));
```

<u>bid</u>	bname	color
101	Nina	red
102	Pinta	blue
103	Santa Maria	red

The SQL DDL: Reserves

```
CREATE TABLE Reserves (
   sid INTEGER,
   bid INTEGER,
   day DATE,
   PRIMARY KEY (sid, bid, day)
   FOREIGN KEY (sid) REFERENCES Sailors,
   FOREIGN KEY (bid) REFERENCES Boats);
```

sid	bid	day
1	102	9/12
2	102	9/13

Updates to tables

- **Insert**
  - **insert into** *instructor* **values** ('10211', 'Smith', 'Biology', 66000);
- **Delete**
  - Remove all tuples from the *student* relation
    - **delete from** *student*
- **Drop Table**
  - **drop table** *r*
- **Alter**
  - **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 exiting 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.

DML 1

The SQL DML

Sailors

<u>sid</u>	sname	rating	age
1	Fred	7	22
2	Jim	2	39
3	Nancy	8	27

- Find all 27-year-old sailors:

```
SELECT *
FROM  Sailors AS S
WHERE S.age=27;
```

- To find just names and rating, replace the first line to:

```
SELECT S.sname, S.rating
```

Basic Single-Table Queries

SELECT [*DISTINCT*] <*column expression list*>
FROM <*single table*>
[**WHERE** <*predicate*>]

- Simplest version is straightforward
  - Produce all tuples in the table that satisfy the predicate
  - Output the expressions in the SELECT list
  - Expression can be a column reference, or an arithmetic expression over column refs

SELECT

- 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 department names of all instructors, and remove duplicates

select distinct *dept_name*
from *instructor*

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

- The keyword **all** specifies that duplicates should not be removed.

select all *dept_name*
from *instructor*

SELECT

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

  select *
  from *instructor*

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

  select '437'

  - Results is a table with one column and a single row with value "437"
  - Can give the column a name using:

    select '437' **as** *FOO*

SELECT

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

  select 'A'
  from *instructor*

  - Result is a table with one column and *N* rows (number of tuples in the *instructors* table), each row with value “A”

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

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

- SQL allows the use of the logical connectives **and, or,** and **not**
- Comparisons can be applied to results of arithmetic expressions
- To find all instructors in Comp. Sci. dept with salary > 70000

```
select name
from instructor
where dept_name = 'Comp. Sci.'  and salary > 70000
```

name
Katz
Brandt

SELECT DISTINCT

```
SELECT [DISTINCT] <column expression list>
FROM <single table>
[WHERE <predicate>]
```

SELECT DISTINCT S.name, S.gpa
FROM students S
WHERE S.dept = 'CS'

- DISTINCT specifies removal of duplicate rows before output
- Can refer to the students table as “S”, this is called an ***alias***

The Rename Operation

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

  old-name **AS** *new-name*

- 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*

A Note on Range Variables

- Really needed only if the same relation appears twice in the FROM clause. The previous query can also be written as:

```
SELECT  S.sname
FROM    Sailors S, Reserves R
WHERE   S.sid=R.sid AND bid=103
```

OR

```
SELECT  sname
FROM    Sailors, Reserves
WHERE   Sailors.sid=Reserves.sid
        AND bid=103
```

It is good style, however, to use range variables always!

Expressions and Strings

```
SELECT  S.age, age1=S.age-5, 2*S.age AS age2
FROM  Sailors S
WHERE  S.sname LIKE 'B_%B'
```

- Illustrates use of arithmetic expressions and string pattern matching: *Find triples (of ages of sailors and two fields defined by expressions) for sailors whose names begin and end with B and contain at least three characters.*
- AS and = are two ways to name fields in result.
- LIKE is used for string matching. '_' stands for any one character and '%' stands for 0 or more arbitrary characters.

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');

Tuple Relational Calculus

- *Query* has the form:

  { t[<*attribute list*>] | P(t)}

- t is called *tuple variable*.

✓ *Answer* includes all tuples t<*attribute list*> that make the *formula* P(t) be *true*.

✓ Example query: Find all sailors' name whose rating above 7 and younger than 50;

  $\{\ t[\ N\ ]\ |\ t \in \mathit{Sailors} \wedge t.T>7 \wedge t.A<50\ \}$

ORDER BY

```
SELECT S.name, S.gpa, S.age*2 AS a2
FROM Students S
WHERE S.dept = 'CS'
ORDER BY S.gpa, S.name, a2;
```

- ORDER BY clause specifies output to be sorted
  - ***Lexicographic*** ordering
- Obviously must refer to columns in the output
  - Note the AS clause for naming output columns!

ORDER BY, Pt. 2

```
SELECT  S.name, S.gpa, S.age*2 AS a2
FROM Students S
WHERE S.dept = 'CS'
ORDER BY S.gpa DESC, S.name ASC, a2;
```

- Ascending order by default, but can be overridden
  - DESC flag for descending, ASC for ascending
  - Can mix and match, lexicographically

LIMIT

```
SELECT  S.name, S.gpa, S.age*2 AS a2
FROM Students S
WHERE S.dept = 'CS'
ORDER BY S.gpa DESC, S.name ASC, a2;
LIMIT 3 ;
```

- Only produces the first <integer> output rows
- Typically used with ORDER BY
  - Otherwise the output is ***non-deterministic***
  - Not a "pure" declarative construct in that case – output set depends on algorithm for query processing

Aggregate Operators

- Significant extension of relational algebra.
  - COUNT (*)
  - COUNT ([DISTINCT] A)
  - SUM ([DISTINCT] A)
  - AVG ([DISTINCT] A)
  - MAX (A)
  - MIN (A)
- *A* is single column

Aggregates

```
SELECT [DISTINCT] AVG(S.gpa)
FROM Students S
WHERE S.dept = 'CS'
```

- Before producing output, compute a summary (a.k.a. an *aggregate*) of some arithmetic expression
- Produces **1 row** of output
  - with one column in this case
- Other aggregates: SUM, COUNT, MAX, MIN

Examples of Aggregate Operators

```
SELECT  COUNT (*)
FROM  Sailors S
```

```
SELECT  COUNT (DISTINCT S.rating)
FROM  Sailors S
WHERE S.sname='Bob'
```

```
SELECT  AVG (S.age)
FROM  Sailors S
WHERE  S.rating=10
```

```
SELECT  AVG (DISTINCT S.age)
FROM  Sailors S
WHERE  S.rating=10
```

```
SELECT  S.sname
FROM  Sailors S
WHERE  S.rating= (SELECT  MAX(S2.rating)
                  FROM  Sailors S2)
```

Find the name and age of the oldest sailor(s)

- The first query is ***illegal***! (We'll look into the reason a bit later, when we discuss **GROUP BY**.)
- The third query is equivalent to the second query, and is allowed in the SQL/92 standard, but is not supported in some systems.

```
SELECT  S.sname, MAX (S.age)
FROM  Sailors S
```

```
SELECT  S.sname, S.age
FROM  Sailors S
WHERE  S.age =
          (SELECT  MAX (S2.age)
           FROM  Sailors S2)
```

```
SELECT  S.sname, S.age
FROM  Sailors S
WHERE  (SELECT  MAX (S2.age)
        FROM  Sailors S2)
        = S.age
```

Motivation for Grouping

- So far, we've applied aggregate operators to all (qualifying) tuples. Sometimes, we want to apply them to each of several *groups* of tuples.
- Consider: *Find the age of the youngest sailor for each rating level.*
  - In general, we don't know how many rating levels exist, and what the rating values for these levels are!
  - Suppose we know that rating values go from 1 to 10; we can write 10 queries that look like this (!):

For i = 1, 2, … , 10:

```
SELECT  MIN (S.age)
FROM  Sailors S
WHERE  S.rating = i
```

GROUP BY

SELECT [DISTINCT] **AVG**(S.gpa), S.dept
FROM Students S
GROUP BY S.dept

- Partition table into groups with same GROUP BY column values
  - Can group by ***a list of columns***
- Produce an aggregate result per group
  - Cardinality of output = # of distinct group values
- Note: can put grouping columns in SELECT list

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

HAVING

```
SELECT [DISTINCT] AVG(S.gpa), S.dept
FROM Students S
GROUP BY S.dept
HAVING COUNT(*) > 2
```

- The HAVING predicate ***filters*** groups
- HAVING is applied ***after*** grouping and aggregation
  - Hence can contain anything that could go in the SELECT list
  - I.e. aggs or **GROUP BY** columns
- **HAVING can only be used in aggregate queries**
- It's an optional clause

Putting it all together

```
SELECT S.dept, AVG(S.gpa), COUNT(*)
FROM Students S
WHERE S.gender = 'F'
GROUP BY S.dept
HAVING COUNT(*) >= 2
ORDER BY S.dept;
```

Find age of the youngest sailor with age ≥ 18, for each rating with at least 2 <u>such</u> sailors

```
SELECT  S.rating,  MIN (S.age) AS minage
FROM  Sailors S
WHERE  S.age >= 18
GROUP BY  S.rating
HAVING  COUNT (*) > 1
```

Sailors instance:

sid	sname	rating	age
22	dustin	7	45.0
29	brutus	1	33.0
31	lubber	8	55.5
32	andy	8	25.5
58	rusty	10	35.0
64	horatio	7	35.0
71	zorba	10	16.0
74	horatio	9	35.0
85	art	3	25.5
95	bob	3	63.5
96	frodo	3	25.5

Answer relation:

rating	minage
3	25.5
7	35.0
8	25.5

Find age of the youngest sailor with age ≥ 18, for each rating with at least 2 <u>such</u> sailors.

rating	age
7	45.0
1	33.0
8	55.5
8	25.5
10	35.0
7	35.0
10	16.0
9	35.0
3	25.5
3	63.5
3	25.5

rating	age
1	33.0
3	25.5
3	63.5
3	25.5
7	45.0
7	35.0
8	55.5
8	25.5
9	35.0
10	35.0

rating	minage
3	25.5
7	35.0
8	25.5

DISTINCT Aggregates

Are these the same or different?

```
SELECT COUNT(DISTINCT S.name)
FROM Students S
WHERE S.dept = 'CS';
```

```
SELECT DISTINCT COUNT(S.name)
FROM Students S
WHERE S.dept = 'CS';
```

What Is This Asking For?

SELECT S.name, **AVG**(S.gpa)
FROM Students S
GROUP BY S.dept;

SQL DML:
General Single-Table Queries

SELECT [DISTINCT] <*column expression list*>
FROM <*single table*>
[**WHERE** <*predicate*>]
[**GROUP BY** <*column list*>
[**HAVING** <*predicate*>]]
[**ORDER BY** <*column list*>]
[**LIMIT** <integer>];

Summary

- Relational model has **well-defined query semantics**
- Modern SQL extends “pure” relational model

  (some extra goodies for duplicate row, non-atomic types… more in next lecture)
- Typically, many ways to write a query
  - DBMS figures out a fast way to execute a query, regardless of how it is written.