CompSci 516

Database Systems

Lecture 3

More SQL

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Announcements - 01/13 (Thus)

- HW1-Part 1 posted on sakai: Resources -> Homeworks -> HW1
  - Part 2 will have SQL queries and data analysis, and submission instructions
  - If you have not started working on it yet, start soon!
  - Both parts due on 01/27/2022 (Thursday)

- Threads for project teams posted on Ed
  - If you are looking for teammates or a team, please post

This is an overview and not exhaustive operations allowed in SQL

You will learn more as you run queries

Try on MovieLens data

Users-Ratings-Movies

Sailors-Reserved-Boats

Students-Enrolled-Courses

(entity-relationship-entity)

The SQL Query Language

- To find all 18 year old students, we can write:

all attributes

```
SELECT *
FROM Students S
WHERE S.age=18
```

sid	name	login	age	gpa
53666	Jones	jones@cs	18	3.4
53688	Smith	smith@ee	18	3.2

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

```
SELECT S.name, S.login
```

- To sort results, add at the end ORDER BY: ASC (default) or DESC

```
SELECT *
FROM Students S
WHERE S.age=18
ORDER BY gpa
```

```
ORDER BY gpa DESC, name
```
(first by gpa in descending order, then by name in ascending order)

Querying Multiple Relations

- What does the following query compute?

```
SELECT  S.name, E.cid
FROM  Students S, Enrolled E
WHERE  S.sid=E.sid AND E.grade="A"
```

Given the following instances of Enrolled and Students:

Students

sid	name	login	age	gpa
53666	Jones	jones@cs	18	3.4
53688	Smith	smith@eecs	18	3.2
53650	Smith	smith@math	19	3.8

Enrolled

sid	cid	grade
53831	Carnatic101	C
53831	Reggae203	B
53650	Topology112	A
53666	History105	B

we get: ??

Querying Multiple Relations

- What does the following query compute?

```
SELECT  S.name, E.cid
FROM  Students S, Enrolled E
WHERE  S.sid=E.sid AND E.grade="A"
```

Given the following instances of Enrolled and Students:

Students

sid	name	login	age	gpa
53666	Jones	jones@cs	18	3.4
53688	Smith	smith@eecs	18	3.2
53650	Smith	smith@math	19	3.8

Enrolled

sid	cid	grade
53831	Carnatic101	C
53831	Reggae203	B
53650	Topology112	A
53666	History105	B

we get:

S.name	E.cid
Smith	Topology112

Read yourself, after reading the next few slides first

Basic SQL Query

```
SELECT      [DISTINCT] <target-list>
FROM        <relation-list>
WHERE       <qualification>
```

- relation-list A list of relation names
  - possibly with a "range variable" after each name
- target-list A list of attributes of relations in relation-list
- qualification Comparisons
  - (Attr op const) or (Attr1 op Attr2)
  - where op is one of = , <, >, <=, >= combined using AND, OR and NOT
- DISTINCT is an optional keyword indicating that the answer should not contain duplicates
  - Default is that duplicates are not eliminated!

Read yourself, after reading the next few slides first

Conceptual Evaluation Strategy

```
SELECT      [DISTINCT]  <target-list>
FROM        <relation-list>
WHERE       <qualification>
```

- Semantics of an SQL query defined in terms of the following conceptual evaluation strategy:
  - Compute the cross-product of *<relation-list>*
  - Discard resulting tuples if they fail *<qualifications>*
  - Delete attributes that are not in *<target-list>*
  - If DISTINCT is specified, eliminate duplicate rows

- This strategy is probably the least efficient way to compute a query!
  - An optimizer will find more efficient strategies to compute the same answers

Example of Conceptual Evaluation

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

Sailor

sid	sname	rating	age
22	dustin	7	45
31	lubber	8	55
58	rusty	10	35

Reserves

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

What does this query return?

Example of Conceptual Evaluation

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

Sailor

sid	sname	rating	age
22	dustin	7	45
31	lubber	8	55
58	rusty	10	35

Step 1: Form "**cross product**" of Sailor and Reserves

sid	sname	rating	age	sid	bid	day
22	dustin	7	45	22	101	10/10/96
22	dustin	7	45	58	103	11/12/96
31	lubber	8	55	22	101	10/10/96
31	lubber	8	55	58	103	11/12/96
58	rusty	10	35	22	101	10/10/96
58	rusty	10	35	58	103	11/12/96

Reserves

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

Example of Conceptual Evaluation

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

Sailor

sid	sname	rating	age
22	dustin	7	45
31	lubber	8	55
58	rusty	10	35

Step 2: Discard tuples that do not satisfy <qualification>

sid	sname	rating	age	sid	bid	day
~~22~~	~~dustin~~	~~7~~	~~45~~	~~22~~	~~101~~	~~10/10/96~~
~~22~~	~~dustin~~	~~7~~	~~45~~	~~58~~	~~103~~	~~11/12/96~~
~~31~~	~~lubber~~	~~8~~	~~55~~	~~22~~	~~101~~	~~10/10/96~~
~~31~~	~~lubber~~	~~8~~	~~55~~	~~58~~	~~103~~	~~11/12/96~~
~~58~~	~~rusty~~	~~10~~	~~35~~	~~22~~	~~101~~	~~10/10/96~~
58	rusty	10	35	58	103	11/12/96

Reserves

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

Example of Conceptual Evaluation

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

Sailor

sid	sname	rating	age
22	dustin	7	45
31	lubber	8	55
58	rusty	10	35

Reserves

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

Step 3: Select the specified attribute(s)

sid	sname	rating	age	sid	bid	day
~~22~~	~~dustin~~	~~7~~	~~45~~	~~22~~	~~101~~	~~10/10/96~~
~~22~~	~~dustin~~	~~7~~	~~45~~	~~58~~	~~103~~	~~11/12/96~~
~~31~~	~~lubber~~	~~8~~	~~55~~	~~22~~	~~101~~	~~10/10/96~~
~~31~~	~~lubber~~	~~8~~	~~55~~	~~58~~	~~103~~	~~11/12/96~~
~~58~~	~~rusty~~	~~10~~	~~35~~	~~22~~	~~101~~	~~10/10/96~~
58	rusty	10	35	58	103	11/12/96

Recap

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

Always start from “FROM” -- form cross product
Apply “WHERE” -- filter out some tuples (rows)
Apply “SELECT” -- filter out some attributes (columns)

Ques. Does this get evaluated this way in practice in a Database Management System (DBMS)?

No! This is conceptual evaluation for finding what is correct!
We will learn about join and other operator algorithms later

A Note on "Range Variables"

- Sometimes used as a short-name
- 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!

A Note on "Range Variables"

- Really needed only if the same relation appears twice in the FROM clause (called self-joins)

- Find pairs of Sailors of same age

```
SELECT  S1.sname, S2. name
FROM    Sailors S1, Sailors S2
WHERE  S1.age = S2.age AND S1.sid < S2.sid
```

Why do we need the 2nd condition?

Find sailor ids who've reserved at least one boat

```
SELECT  ????
FROM  Sailors S, Reserves R
WHERE  S.sid=R.sid
```

Sailor

sid	sname	rating	age
22	dustin	7	45
31	lubber	8	55
58	rusty	10	35

Reserves

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

Find sailor ids who've reserved at least one boat

```
SELECT S.sid
FROM Sailors S, Reserves R
WHERE S.sid=R.sid
```

Sailor

sid	sname	rating	age
22	dustin	7	45
31	lubber	8	55
58	rusty	10	35

- Would adding DISTINCT to this query make a difference?

Reserves

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

Find sailors who've reserved at least one boat

```
SELECT S.sid
FROM Sailors S, Reserves R
WHERE S.sid=R.sid
```

- Would adding DISTINCT to this query make a difference?
  - Note that if there are multiple bids for the same sid, you get multiple output tuples for the same sid
  - Without distinct, you get them multiple times
- What is the effect of replacing *S.sid* by *S.sname* in the SELECT clause?
  - Would adding DISTINCT to this variant of the query make a difference even if one sid reserves at most one bid?

Sailor

sid	sname	rating	age
22	dustin	7	45
31	lubber	8	55
58	rusty	10	35

Reserves

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

Simple Aggregate Operators

Check yourself:
What do these queries compute?

COUNT (*)
COUNT ([DISTINCT] A)
SUM ([DISTINCT] A)
AVG ([DISTINCT] A)
MAX (A)
MIN (A)

single column

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

```
SELECT  AVG (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)
```

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

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

CREATING / UPDATING TABLES

Creating Relations in SQL

- Creates the "Students" relation
  - the type (domain) of each field is specified
  - enforced by the DBMS whenever tuples are added or modified

```
CREATE TABLE Students
  (sid CHAR(20),
   name CHAR(20),
   login CHAR(10),
   age INTEGER,
   gpa REAL)
```

- As another example, the "Enrolled" table holds information about courses that students take

```
CREATE TABLE Enrolled
  (sid CHAR(20),
   cid CHAR(20),
   grade CHAR(2))
```

sid	name	login	age	gpa
53666	Jones	jones@cs	18	3.4
53688	Smith	smith@eecs	18	3.2
53650	Smith	smith@math	19	3.8

Students

sid	cid	grade
53831	Carnatic101	C
53831	Reggae203	B
53650	Topology112	A
53666	History105	B

Enrolled

Destroying and Altering Relations

```
DROP TABLE Students
```

- Destroys the relation Students
  - The schema information *and* the tuples are deleted.

```
ALTER TABLE Students
    ADD COLUMN firstYear: integer
```

- The schema of Students is altered by adding a new field; every tuple in the current instance is extended with a NULL value in the new field.

Adding and Deleting Tuples

- Can insert a single tuple using:

```
INSERT INTO  Students (sid, name, login, age, gpa)
VALUES  (53688, 'Smith', 'smith@ee', 18, 3.2)
```

- Can delete all tuples satisfying some condition (e.g., name = Smith):

```
DELETE
FROM Students S
WHERE S.name = 'Smith'
```

Integrity Constraints (ICs)

- IC: condition that must be true for any instance of the database
  - e.g., domain constraints
  - ICs are specified when schema is defined
  - ICs are checked when relations are modified
- A legal instance of a relation is one that satisfies all specified ICs
  - DBMS will not allow illegal instances
- If the DBMS checks ICs, stored data is more faithful to real-world meaning
  - Avoids data entry errors, too!

Keys in a Database

- Key / Candidate Key
- Primary Key
- Super Key
- Foreign Key

- Primary key attributes are underlined in a schema
  - Person(pid, address, name)
  - Person2(address, name, age, job)

Primary Key Constraints

- A set of fields is a key for a relation if :
  1. No two distinct tuples can have same values in all key fields, and
  2. This is not true for any subset of the key

- Only Part 1 holds (Part 2 may be false)? A superkey
  - A key is also a superkey.

- If there are > 1 keys for a relation, one of the keys is chosen (by DBA = DB admin) to be the primary key
  - E.g., sid is a key for Students
  - The set {sid, gpa} is a superkey.

- Any possible benefit to refer to a tuple using primary key (than any key)?

Primary and Candidate Keys in SQL

- Possibly many candidate keys
  - specified using UNIQUE
  - one of which is chosen as the primary key.

- "For a given student and course, there is a single grade."

```
CREATE TABLE Enrolled
  (sid CHAR(20)
   cid  CHAR(20),
   grade CHAR(2),
   PRIMARY KEY  ???)
```

Primary and Candidate Keys in SQL

- Possibly many candidate keys
  - specified using UNIQUE
  - one of which is chosen as the primary key.

- "For a given student and course, there is a single grade."

```
CREATE TABLE Enrolled
  (sid CHAR(20)
   cid  CHAR(20),
   grade CHAR(2),
   PRIMARY KEY  (sid, cid) )
```

Primary and Candidate Keys in SQL

- Possibly many candidate keys
  - specified using UNIQUE
  - one of which is chosen as the primary key.

- "For a given student and course, there is a single grade."

```
CREATE TABLE Enrolled
  (sid CHAR(20)
   cid  CHAR(20),
   grade CHAR(2),
   PRIMARY KEY  (sid, cid) )
```

- vs.

- "Students can take only one course, and receive a single grade for that course; further, no two students in a course receive the same grade."

```
CREATE TABLE Enrolled
  (sid CHAR(20)
   cid  CHAR(20),
   grade CHAR(2),
   PRIMARY KEY ???,
   UNIQUE ??? )
```

Primary and Candidate Keys in SQL

- Possibly many candidate keys
  - specified using UNIQUE
  - one of which is chosen as the primary key.

- "For a given student and course, there is a single grade."

```
CREATE TABLE Enrolled
  (sid CHAR(20)
   cid  CHAR(20),
   grade CHAR(2),
   PRIMARY KEY  (sid,cid) )
```

- vs.

- "Students can take only one course, and receive a single grade for that course; further, no two students in a course receive the same grade."

```
CREATE TABLE Enrolled
  (sid CHAR(20)
   cid  CHAR(20),
   grade CHAR(2),
   PRIMARY KEY sid,
   UNIQUE (cid, grade))
```

Primary and Candidate Keys in SQL

- Possibly many candidate keys
  - specified using UNIQUE
  - one of which is chosen as the primary key.

- "For a given student and course, there is a single grade."

```
CREATE TABLE Enrolled
  (sid CHAR(20)
   cid  CHAR(20),
   grade CHAR(2),
   PRIMARY KEY  (sid,cid) )
```

- vs.

- "Students can take only one course, and receive a single grade for that course; further, no two students in a course receive the same grade."

```
CREATE TABLE Enrolled
  (sid CHAR(20)
   cid  CHAR(20),
   grade CHAR(2),
   PRIMARY KEY sid,
   UNIQUE (cid, grade))
```

- Used carelessly, an IC can prevent the storage of database instances that arise in practice!

Foreign Keys, Referential Integrity

- Foreign key : Set of fields in one relation that is used to `refer' to a tuple in another relation
  - Must correspond to primary key of the second relation
  - Like a `logical pointer'

- E.g. sid is a foreign key referring to Students:
  - Enrolled(sid: string, cid: string, grade: string)
  - If all foreign key constraints are enforced, referential integrity is achieved
  - i.e., no dangling references

Foreign Keys in SQL

- Only students listed in the Students relation should be allowed to enroll for courses

```
CREATE TABLE Enrolled
  (sid CHAR(20),  cid CHAR(20),  grade CHAR(2),
   PRIMARY KEY  (sid,cid),
   FOREIGN KEY (sid) REFERENCES Students )
```

Enrolled

sid	cid	grade
53666	Carnatic101	C
53666	Reggae203	B
53650	Topology112	A
53666	History105	B

Students

sid	name	login	age	gpa
53666	Jones	jones@cs	18	3.4
53688	Smith	smith@eecs	18	3.2
53650	Smith	smith@math	19	3.8

Enforcing Referential Integrity

- Consider Students and Enrolled
  - sid in Enrolled is a foreign key that references Students.
- What should be done if an Enrolled tuple with a non-existent student id is inserted?
  - Reject it!
- What should be done if a Students tuple is deleted?
  - Three semantics allowed by SQL
  1. Also delete all Enrolled tuples that refer to it (cascade delete)
  2. Disallow deletion of a Students tuple that is referred to
  3. Set sid in Enrolled tuples that refer to it to a default sid
  4. (in addition in SQL): Set sid in Enrolled tuples that refer to it to a special value null, denoting `unknown' or `inapplicable'
- Similar if primary key of Students tuple is updated

Referential Integrity in SQL

- SQL/92 and SQL:1999 support all 4 options on deletes and updates.
  - Default is NO ACTION (delete/update is rejected)
  - CASCADE (also delete all tuples that refer to deleted tuple)
  - SET NULL / SET DEFAULT (sets foreign key value of referencing tuple)

```
CREATE TABLE Enrolled
  (sid CHAR(20) DEFAULT '000',
   cid CHAR(20),
   grade CHAR(2),
   PRIMARY KEY  (sid,cid),
   FOREIGN KEY (sid)
    REFERENCES Students
     ON DELETE CASCADE
     ON UPDATE SET DEFAULT )
```

Where do ICs Come From?

- ICs are based upon the semantics of the real-world enterprise that is being described in the database relations

- Can we infer ICs from an instance?
  - We can check a database instance to see if an IC is violated, but we can NEVER infer that an IC is true by looking at an instance.
  - An IC is a statement about all possible instances!
  - From example, we know name is not a key, but the assertion that sid is a key is given to us.

- Key and foreign key ICs are the most common; more general ICs supported too

Example Instances

- What does the key (sid, bid, day) in Reserves mean?
- If the key for the Reserves relation contained only the attributes *(sid, bid)*, how would the semantics differ?

Sailor

sid	sname	rating	age
22	dustin	7	45
31	lubber	8	55
58	rusty	10	35

Reserves

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

End of Lecture-3 (01/13)

- TODOs:
  1. Start working on HW1-Part I:
     - Sakai -> Resources -> Homeworks -> HW1
  2. Read course policy (link) carefully before you start
  3. Go to office hours if you have questions
     - Links on Ed
  4. Check out the Project thread on Ed and keep looking for teams / teammates
  5. Practice SQL on MovieLens, create / update new tables in a new database

Optional reading for SQL programming

Prepared statements: motivation

```
while True:
    # Input bar, beer, price...
    cur.execute('''
UPDATE Serves
SET price = %s
WHERE bar = %s AND beer = %s''', (price, bar, beer))
    # Check result...
```

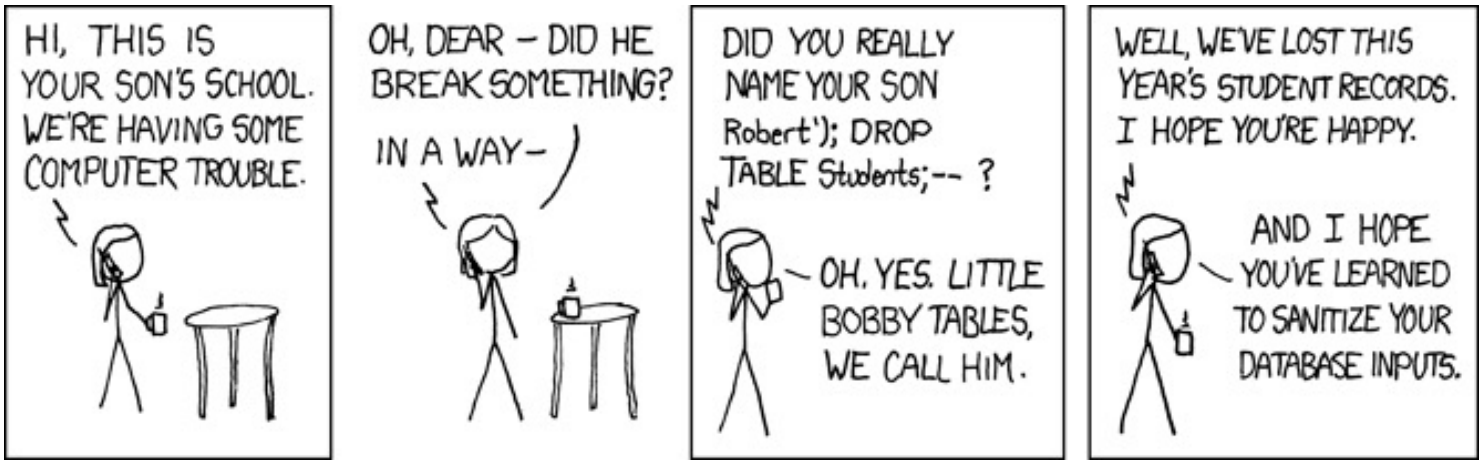
- Every time we send an SQL string to the DBMS, it must perform parsing, semantic analysis, optimization, compilation, and finally execution
- A typical application issues many queries with a small number of patterns (with different parameter values)
- Can we reduce this overhead?

Prepared statements: example

```
cur.execute('''                         # Prepare once (in SQL).
PREPARE update_price AS                 # Name the prepared plan,
UPDATE Serves
SET price = $1                          # and note the $1, $2, ... notation for
WHERE bar = $2 AND beer = $3''') # parameter placeholders.
while True:
    # Input bar, beer, price...
    cur.execute('EXECUTE update_price(%s, %s, %s)',\      # Execute many times.
            (price, bar, beer))
                        # Note the switch back to %s for parameter placeholders.
    # Check result...
```

- The DBMS performs parsing, semantic analysis, optimization, and compilation only once, when it "prepares" the statement
- At execution time, the DBMS only needs to check parameter types and validate the compiled plan
- Most other API's have better support for prepared statements than psycopg2
  - E.g., they would provide a cur.prepare() method

SQL Injection Attack



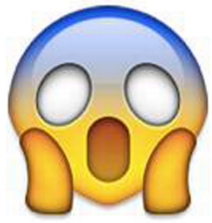
http://xkcd.com/327/

- The school probably had something like:

```
cur.execute("SELECT * FROM Students " + \
        "WHERE (name = '" + name + "')")
```

  where name is a string input by user

- Suppose name = Robert'; DROP TABLE Students



  - Drop deletes a table
  - -- starts a comment
  - Becomes SELECT * FROM Students WHERE (name = 'Robert'; DROP TABLE Students; -- ')

Guarding against SQL injection

- Escape certain characters in a user input string, to ensure that it remains a single string
  - E.g., ', which would terminate a string in SQL, must be replaced by '' (two single quotes in a row) within the input string
- Luckily, most API's provide ways to "sanitize" input automatically (if you use them properly)
  - E.g., pass parameter values in psycopg2 through %s's
- Check out Ashley Madison data breach story or https://medium.com/five-guys-facts/sql-injection-98199af86c9