CompSci 516

Database Systems

Lecture 2

SQL

Instructor: Sudeepa Roy

Announcements

- If you are enrolled to the class, but have not received the email from Piazza, please send me an email
- If you are on the waitlist and want to enroll, please send me an email
- HW1 will be released soon (~tomorrow)
- TA office hours:
  - Yuchao: LSRC D309, Mondays 1:30-2:30 pm
  - Tianpeng: LSRC D344, Wednesdays 1:30-2:30 pm

Recap: Lecture 1

- Why use a DBMS
- Structured data model: Relational data model
  - table, schema, instance, tuples, attributes
  - bag and set semantic
- Logical and physical data independence

Today's topic

- Overview of XML

- SQL in a nutshell
  - Reading material: [RG] Chapters 3 and 5
  - Additional reading for practice: [GUW] Chapter 6

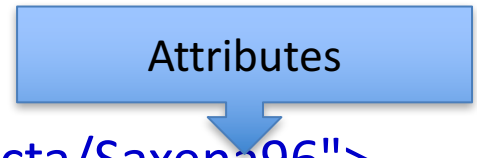
Acknowledgement:
The following slides have been created adapting the instructor material of the [RG] book provided by the authors Dr. Ramakrishnan and Dr. Gehrke.

XML: an overview

Semi-structured Data and XML

- XML: Extensible Markup Language
- Will not be covered in detail in class, but many datasets available to download are in this form
  - You will download the DBLP dataset in XML format and transform into relational form (in HW1)
- Data does not have a fixed schema
  - "Attributes" are part of the data
  - The data is "self-describing"
  - Tree-structured

XML: Example




```
<article mdate="2011-01-11” key="journals/acta/Saxena96">
    <author>Sanjeev Saxena</author>
    <title>Parallel Integer Sorting and Simulation Amongst CRCW
        Models.</title>
    <pages>607-619</pages>
    <year>1996</year>
    <volume>33</volume>
    <journal>Acta Inf.</journal>
    <number>7</number>
    <url>db/journals/acta/acta33.html#Saxena96</url>
    <ee>http://dx.doi.org/10.1007/BF03036466</ee>
</article>
```

Attribute vs. Elements

- Elements can be repeated and nested
- Attributes are unique and atomic

XML vs. Relational Databases

+ Serves as a model suitable for integration of databases containing similar data with different schemas
  - e.g. try to integrate two student databases: S1(sid, name, gpa) and S2(sid, dept, year)
  - Many "nulls" if done in relational model, very easy in XML
- NULL = A keyword to denote missing or unknown values

+ Flexible – easy to change the schema and data

- Makes query processing more difficult

Which one is easier?

- XML (semi-structured) to relational (structured)

or

- relational (structured) to XML (semi-structured)?

XML to Relational Model

- Problem 1: Repeated attributes

```
<book>
    <author>Ramakrishnan</author>
    <author>Gehrke</author>
    <title>Database Management Systems</title>
    <publisher> McGraw Hill
</book>
```

What is a good relational schema?

XML to Relational Model

- Problem 1: Repeated attributes

```
<book>
    <author>Ramakrishnan</author>
    <author>Gehrke</author>
    <title>Database Management Systems</title>
    <pubisher> McGraw Hill</publisher>
</book>
```

Title	Publisher	Author1	Author2

What if the paper has a single author?

XML to Relational Model

- Problem 1: Repeated attributes

```
<book>
    <author>Garcia-Molina</author>
    <author>Ullman</author>
    <author>Widom</author>
    <title>Database Systems – The Complete Book</title>
    <pubisher>Prentice Hall</publisher>
</book>
```

Does not work

Title	Publisher	Author1	Author2

XML to Relational Model

Book

BookId	Title	Publisher
b1	Database Management Systems	McGraw Hill
b2	Database Systems – The Complete Book	Prentice Hall

BookAuthoredBy

BookId	Author
b1	Ramakrishnan
b1	Gehrke
b2	Garcia-Molina
b2	Ullman
b2	Widom

XML to Relational Model

- Problem 2: Missing attributes

```
<book>
        <author>Ramakrishnan</author>
        <author>Gehrke</author>
        <title>Database Management Systems</title>
        <pubisher> McGraw Hill
        <edition>Third</edition>
</book>
<book>
        <author>Garcia-Molina</author>
        <author>Ullman</author>
        <author>Widom</author>
        <title>Database Systems – The Complete
Book</title>
        <pubisher>Prentice Hall</publisher>
</book>
```

BookId	Title	Publisher	Edition
b1	Database Management Systems	McGraw Hill	Third
b2	Database Systems – The Complete Book	Prentice Hall	null

Summary: Data Models

- Relational data model is the most standard for database managements
  - and is the main focus of this course
- Semi-structured model/XML is also used in practice – you will use them in hw assignments
- Unstructured data (text/photo/video) is unavoidable, but won't be covered in this class

SQL
(Stuctured Query Language)

Relational Query Languages

- A major strength of the relational model: supports simple, powerful querying of data.

- Queries can be written intuitively, and the DBMS is responsible for an efficient evaluation
  - The key: precise semantics for relational queries
  - Based on a sound theory!
  - Allows the optimizer to extensively re-order operations, and still ensure that the answer does not change.

The SQL Query Language

- Developed by IBM (systemR) in the 1970s based on Ted Codd's relational model
  - First called "SEQUEL" (Structured English Query Language)
- First commercialized by Oracle (then Relational Software)in 1979
- Standards by ANSI and ISO since it is used by many vendors
  - SQL-86, -89 (minor revision), -92 (major revision), -96, -99 (major extensions), -03, -06, -08, -11, -16

Purposes of SQL

- Data Manipulation Language (DML)
  - Querying: SELECT-FROM-WHERE
  - Modifying: INSERT/DELETE/UPDATE
- Data Definition Language (DDL)
  - CREATE/ALTER/DROP

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
```

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

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

- Part 2 false? 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."
- 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,cid) )
```

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

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

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

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

Next…

- Querying using SQL
  - semantic
  - joins
  - group bys and aggregates
  - nested queries

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!

Can see 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

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

A Note on "Range Variables"

- Really needed only if the same relation appears twice in the FROM clause
  - 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!

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
```

- Would adding DISTINCT to this query make a difference?

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 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