The Relational Model

Chapter 3
Why Study the Relational Model?

- Most widely used model.
  - Vendors: IBM, Informix, Microsoft, Oracle, Sybase, etc.
- “Legacy systems” in older models
  - E.G., IBM’s IMS
- Recent competitor: object-oriented model
  - ObjectStore, Versant, Ontos
  - A synthesis emerging: object-relational model
    - Informix Universal Server, UniSQL, O2, Oracle, DB2
Relational Database: Definitions

- **Relational database**: a set of relations
- **Relation**: made up of 2 parts:
  - *Instance*: a table, with rows and columns. 
    \#Rows = cardinality, \#fields = degree / arity.
  - *Schema*: specifies name of relation, plus name and type of each column.
- Can think of a relation as a set of rows or tuples (i.e., all rows are distinct).
## Example Instance of Students Relation

<table>
<thead>
<tr>
<th>sid</th>
<th>name</th>
<th>login</th>
<th>age</th>
<th>gpa</th>
</tr>
</thead>
<tbody>
<tr>
<td>53666</td>
<td>Jones</td>
<td>jones@cs</td>
<td>18</td>
<td>3.4</td>
</tr>
<tr>
<td>53688</td>
<td>Smith</td>
<td>smith@eecs</td>
<td>18</td>
<td>3.2</td>
</tr>
<tr>
<td>53650</td>
<td>Smith</td>
<td>smith@math</td>
<td>19</td>
<td>3.8</td>
</tr>
</tbody>
</table>

- Cardinality = 3, degree = 5, all rows distinct
- Do all columns in a relation instance have to be distinct?
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 efficient evaluation.
  - The key: precise semantics for relational queries.
  - Allows the optimizer to extensively re-order operations, and still ensure that the answer does not change.
The SQL Query Language

- Developed by IBM (system R) in the 1970s
- Need for a standard since it is used by many vendors
- Standards:
  - SQL-86
  - SQL-89 (minor revision)
  - SQL-92 (major revision, current standard)
  - SQL-99 (major extensions)
The SQL Query Language

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

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

<table>
<thead>
<tr>
<th>sid</th>
<th>name</th>
<th>login</th>
<th>age</th>
<th>gpa</th>
</tr>
</thead>
<tbody>
<tr>
<td>53666</td>
<td>Jones</td>
<td>jones@cs</td>
<td>18</td>
<td>3.4</td>
</tr>
<tr>
<td>53688</td>
<td>Smith</td>
<td>smith@ee</td>
<td>18</td>
<td>3.2</td>
</tr>
</tbody>
</table>

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

```sql
SELECT S.name, S.login
```
What does the following query compute?

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

Given the following instance of Enrolled (is this possible if the DBMS ensures referential integrity?):

<table>
<thead>
<tr>
<th>sid</th>
<th>cid</th>
<th>grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>53831</td>
<td>Carnatic101</td>
<td>C</td>
</tr>
<tr>
<td>53831</td>
<td>Reggae203</td>
<td>B</td>
</tr>
<tr>
<td>53650</td>
<td>Topology112</td>
<td>A</td>
</tr>
<tr>
<td>53666</td>
<td>History105</td>
<td>B</td>
</tr>
</tbody>
</table>

we get:

<table>
<thead>
<tr>
<th>S.name</th>
<th>E.cid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smith</td>
<td>Topology112</td>
</tr>
</tbody>
</table>
Creating Relations in SQL

- Creates the Students relation. Observe that the type (domain) of each field is specified, and enforced by the DBMS whenever tuples are added or modified.

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

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

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

  \[
  \text{INSERT INTO Students (sid, name, login, age, gpa) VALUES (53688, 'Smith', 'smith@ee', 18, 3.2)}
  \]

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

  \[
  \text{DELETE FROM Students S WHERE S.name = 'Smith'}
  \]

* Powerful variants of these commands are available; more later!
**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 should not allow illegal instances.

- If the DBMS checks ICs, stored data is more faithful to real-world meaning.
  - Avoids data entry errors, too!
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’s >1 key for a relation, one of the keys is chosen (by DBA) to be the primary key.

- E.g., sid is a key for Students. (What about name?) The set \{sid, gpa\} is a superkey.
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!

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

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

```sql
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.
  - Can you name a data model w/o referential integrity?
    - Links in HTML!
Foreign Keys in SQL

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

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

<table>
<thead>
<tr>
<th>Enrolled</th>
<th>Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>sid</td>
<td>cid</td>
</tr>
<tr>
<td>53666</td>
<td>Carnatic101</td>
</tr>
<tr>
<td>53666</td>
<td>Reggae203</td>
</tr>
<tr>
<td>53650</td>
<td>Topology112</td>
</tr>
<tr>
<td>53666</td>
<td>History105</td>
</tr>
</tbody>
</table>
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?
  - Also delete all Enrolled tuples that refer to it.
  - Disallow deletion of a Students tuple that is referred to.
  - Set sid in Enrolled tuples that refer to it to a default sid.
  - *(In SQL, also: 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.
SQL/92 supports 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)

```sql
CREATE TABLE Enrolled
(sid CHAR(20),
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.
- 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.
Views

- A view is just a relation, but we store a definition, rather than a set of tuples.

```
CREATE VIEW YoungActiveStudents (name, grade)
AS SELECT S.name, E.grade
FROM Students S, Enrolled E
WHERE S.sid = E.sid and S.age<21
```

- Views can be dropped using the DROP VIEW command.
  - How to handle DROP TABLE if there’s a view on the table?
    - DROP TABLE command has options to let the user specify this.
Views and Security

- Views can be used to present necessary information (or a summary), while hiding details in underlying relation(s).
  - Given YoungStudents, but not Students or Enrolled, we can find students s who have are enrolled, but not the cid’s of the courses they are enrolled in.
Logical DB Design: ER to Relational

- Entity sets to tables.

CREATE TABLE Employees
(ssn CHAR(11),
name CHAR(20),
lot INTEGER,
PRIMARY KEY (ssn))
In translating a relationship set to a relation, attributes of the relation must include:

- Keys for each participating entity set (as foreign keys).
  - This set of attributes forms a superkey for the relation.
- All descriptive attributes.

```sql
CREATE TABLE Works_In(
    ssn  CHAR(1),
    did  INTEGER,
    since  DATE,
    PRIMARY KEY (ssn, did),
    FOREIGN KEY (ssn)
        REFERENCES Employees,
    FOREIGN KEY (did)
        REFERENCES Departments
)
```
Review: Key Constraints

- Each dept has at most one manager, according to the key constraint on Manages.

Translation to relational model?

1-to-1  1-to Many  Many-to-1  Many-to-Many
Translating ER Diagrams with Key Constraints

- Map relationship to a table:
  - Note that did is the key now!
  - Separate tables for Employees and Departments.

- Since each department has a unique manager, we could instead combine Manages and Departments.

CREATE TABLE Manages(
  ssn CHAR(11),
  did INTEGER,
  since DATE,
  PRIMARY KEY (did),
  FOREIGN KEY (ssn) REFERENCES Employees,
  FOREIGN KEY (did) REFERENCES Departments)

CREATE TABLE Dept_Mgr(
  did INTEGER,
  dname CHAR(20),
  budget REAL,
  ssn CHAR(11),
  since DATE,
  PRIMARY KEY (did),
  FOREIGN KEY (ssn) REFERENCES Employees)

Better!
Review: Participation Constraints

- Does every department have a manager?
  - If so, this is a participation constraint: the participation of Departments in Manages is said to be total (vs. partial).
    - Every did value in Departments table must appear in a row of the Manages table (with a non-null ssn value!)
Participation Constraints in SQL

- We can capture participation constraints involving one entity set in a binary relationship, but little else (without resorting to CHECK constraints).

```sql
CREATE TABLE Dept_Mgr(
    did INTEGER,
    dname CHAR(20),
    budget REAL,
    ssn CHAR(11) NOT NULL,
    since DATE,
    PRIMARY KEY (did),
    FOREIGN KEY (ssn) REFERENCES Employees,
    ON DELETE NO ACTION)
```
A weak entity can be identified uniquely only by considering the primary key of another (owner) entity.
- Owner entity set and weak entity set must participate in a one-to-many relationship set (1 owner, many weak entities).
- Weak entity set must have total participation in this identifying relationship set.
Translating Weak Entity Sets

- Weak entity set and identifying relationship set are translated into a single table.
  - When the owner entity is deleted, all owned weak entities must also be deleted.

```sql
CREATE TABLE Dep_Policy (  
  pname CHAR(20),  
  age INTEGER,  
  cost REAL,  
  ssn CHAR(11) NOT NULL,  
  PRIMARY KEY (pname, ssn),  
  FOREIGN KEY (ssn) REFERENCES Employees,  
  ON DELETE CASCADE)
```
Review: ISA Hierarchies

- As in C++, or other PLs, attributes are inherited.
- If we declare $A$ ISA $B$, every $A$ entity is also considered to be a $B$ entity.
- **Overlap constraints**: Can Joe be an Hourly_Emps as well as a Contract_Emps entity? *(Allowed/disallowed)*
- **Covering constraints**: Does every Employees entity also have to be an Hourly_Emps or a Contract_Emps entity? *(Yes/no)*
Translating ISA Hierarchies to Relations

- **General approach:**
  - 3 relations: Employees, Hourly_Emps and Contract_Emps.
    - *Hourly_Emps:* Every employee is recorded in Employees. For hourly emps, extra info recorded in Hourly_Emps (*hourly_wages, hours_worked, ssn*); must delete Hourly_Emps tuple if referenced Employees tuple is deleted).
    - Queries involving all employees easy, those involving just Hourly_Emps require a join to get some attributes.
  - Alternative: Just Hourly_Emps and Contract_Emps.
    - *Hourly_Emps:* *ssn, name, lot, hourly_wages, hours_worked.*
    - Each employee must be in one of these two subclasses.
Review: Binary vs. Ternary Relationships

- If each policy is owned by just 1 employee:
  - Key constraint on Policies would mean policy can only cover 1 dependent!

- What are the additional constraints in the 2nd diagram?
**Binary vs. Ternary Relationships (Contd.)**

- The key constraints allow us to combine Purchaser with Policies and Beneficiary with Dependents.
- Participation constraints lead to **NOT NULL** constraints.
- What if Policies is a weak entity set?

```sql
CREATE TABLE Policies (  
  policyid INTEGER,  
  cost REAL,  
  ssn CHAR(11) NOT NULL,  
  PRIMARY KEY (policyid).  
  FOREIGN KEY (ssn) REFERENCES Employees,  
  ON DELETE CASCADE)
```

```sql
CREATE TABLE Dependents (  
  pname CHAR(20),  
  age INTEGER,  
  policyid INTEGER,  
  PRIMARY KEY (pname, policyid).  
  FOREIGN KEY (policyid) REFERENCES Policies,  
  ON DELETE CASCADE)
```
Relational Model: Summary

- A tabular representation of data.
- Simple and intuitive, currently the most widely used.
- Integrity constraints can be specified by the DBA, based on application semantics. DBMS checks for violations.
  - Two important ICs: primary and foreign keys
  - In addition, we always have domain constraints.
- Powerful and natural query languages exist.
- Rules to translate ER to relational model