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
- A synthesis emerged: object-relational model
  - Informix Universal Server, UniSQL, O2, Oracle, DB2
- Recent developments in NoSQL systems
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.
    - E.G. Students(
      - sid: string,
      - name: string,
      - login: string,
      - age: integer,
      - gpa: real).
- 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)
  - SQL-99 (major extensions)
  - SQL-2011 (Latest)
The SQL Query Language

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

\[
\text{SELECT } * \text{ FROM Students S WHERE S.age=18}
\]

<table>
<thead>
<tr>
<th>sid</th>
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<th>gpa</th>
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<tbody>
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<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:

\[
\text{SELECT S.name, S.login}
\]
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:

<table>
<thead>
<tr>
<th>sid</th>
<th>name</th>
<th>login</th>
<th>age</th>
<th>gpa</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Jones</td>
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<td>Smith</td>
<td>smith@math</td>
<td>19</td>
<td>3.8</td>
</tr>
</tbody>
</table>

we get:

<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>

<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.

```sql
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))
```
Destroys the relation Students. The schema information \textit{and} the tuples are deleted.

The schema of Students is altered by adding a new field; every tuple in the current instance is extended with a \textit{null} value in the new field.
Adding and Deleting Tuples

- Can insert a single tuple using:

  ```sql
  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):

  ```sql
  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),
    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.

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>sid</th>
<th>cid</th>
<th>grade</th>
<th></th>
<th></th>
</tr>
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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 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)
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.
Logical DB Design: ER to Relational

- Entity sets to tables:

CREATE TABLE Employees (ssn CHAR(11), name CHAR(20), lot INTEGER, PRIMARY KEY (ssn))
Example: Works_in relationship set
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(11),
  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?

<table>
<thead>
<tr>
<th>1-to-1</th>
<th>1-to Many</th>
<th>Many-to-1</th>
<th>Many-to-Many</th>
</tr>
</thead>
</table>

Database Management Systems 3ed, R. Ramakrishnan and J. Gehrke
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)
```
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!)

![Database Management Systems 3ed, R. Ramakrishnan and J. Gehrke 25](image-url)
We can capture participation constraints involving one entity set in a binary relationship, but little else (without resorting to CHECK constraints).

```
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)
```
**Review: Weak Entities**

- 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.

Diagram:

```
    employees: ssn, name, lot
        <------------------------>        cost
          Policy

    dependents: pname, age
        <------------------------>        policy
          employees
```

Database Management Systems 3ed, R. Ramakrishnan and J. Gehrke 27
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

- What are the additional constraints in the 2nd diagram?

Bad design

Better design
**Binary vs. Ternary Relationships (Contd.)**

- The key constraints allow us to combine Purchaser with Policies and Beneficiary with Dependants.
- 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
)

CREATE TABLE Dependents (
    pname CHAR(20),
    age INTEGER,
    policyid INTEGER,
    PRIMARY KEY (pname, policyid),
    FOREIGN KEY (policyid) REFERENCES Policies,
    ON DELETE CASCADE
)
```
Views

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

```sql
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.
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