Chapter 5

The Relational Data Model and Relational Database Constraints
Chapter Outline

- Relational Model Concepts
- Relational Model Constraints and Relational Database Schemas
- Update Operations and Dealing with Constraint Violations
Relational Model Concepts

- The relational Model of Data is based on the concept of a *Relation*
  - The strength of the relational approach to data management comes from the formal foundation provided by the theory of relations
- We review the essentials of the *formal relational model*
- In *practice*, there is a *standard model* based on SQL
- **Note:** There are several important differences between the *formal* model and the *practical* model, as we shall see
Relational Model Concepts

- A Relation is a mathematical concept based on the ideas of sets.
- The model was first proposed by Dr. E.F. Codd of IBM Research in 1970 in the following paper:
Informal Definitions

Informally, a relation looks like a table of values.

A relation typically contains a set of rows.

The data elements in each row represent certain facts that correspond to a real-world entity or relationship

- In the formal model, rows are called tuples

Each column has a column header that gives an indication of the meaning of the data items in that column

- In the formal model, the column header is called an attribute name (or just attribute)
Example of a Relation

The attributes and tuples of a relation STUDENT.

<table>
<thead>
<tr>
<th>Name</th>
<th>Ssn</th>
<th>Home_phone</th>
<th>Address</th>
<th>Office_phone</th>
<th>Age</th>
<th>Gpa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benjamin Bayer</td>
<td>305-61-2435</td>
<td>373-1616</td>
<td>2918 Bluebonnet Lane</td>
<td>NULL</td>
<td>19</td>
<td>3.21</td>
</tr>
<tr>
<td>Chung-cha Kim</td>
<td>381-62-1245</td>
<td>375-4409</td>
<td>125 Kirby Road</td>
<td>NULL</td>
<td>18</td>
<td>2.89</td>
</tr>
<tr>
<td>Dick Davidson</td>
<td>422-11-2320</td>
<td>NULL</td>
<td>3452 Elgin Road</td>
<td>749-1253</td>
<td>25</td>
<td>3.53</td>
</tr>
<tr>
<td>Rohan Panchal</td>
<td>489-22-1100</td>
<td>376-9821</td>
<td>265 Lark Lane</td>
<td>749-6492</td>
<td>28</td>
<td>3.93</td>
</tr>
<tr>
<td>Barbara Benson</td>
<td>533-69-1238</td>
<td>839-8461</td>
<td>7384 Fontana Lane</td>
<td>NULL</td>
<td>19</td>
<td>3.25</td>
</tr>
</tbody>
</table>
Informal Definitions

Key of a Relation:

- Each row has a value of a data item (or set of items) that uniquely identifies that row in the table
  - Called the *key*
- In the STUDENT table, SSN is the key
- Sometimes row-ids or sequential numbers are assigned as keys to identify the rows in a table
  - Called *artificial key* or *surrogate key*
Formal Definitions - Schema

➲ The **Schema** (or description) of a Relation:
- Denoted by \( R(A_1, A_2, \ldots, A_n) \)
- \( R \) is the **name** of the relation
- The **attributes** of the relation are \( A_1, A_2, \ldots, A_n \)

➲ Each attribute has a **domain** or a set of valid values.
- For example, the domain of Cust-id is 6 digit numbers.
Formal Definitions - Tuple

- A **tuple** is an ordered set of values (enclosed in angled brackets ‘< … >’)  
- Each value is derived from an appropriate **domain**.  
- A row in the CUSTOMER relation is a 4-tuple and would consist of four values, for example:
  - `<632895, "John Smith", "101 Main St. Atlanta, GA  30332", "(404) 894-2000">`  
  - This is called a 4-tuple as it has 4 values  
  - A tuple (row) in the CUSTOMER relation.  
- A relation is a **set** of such tuples (rows)
Formal Definitions - State

- The relation state is a subset of the Cartesian product of the domains of its attributes
  - each domain contains the set of all possible values the attribute can take.
- Example: attribute Cust-name is defined over the domain of character strings of maximum length 25
  - dom(Cust-name) is varchar(25)
- The role these strings play in the CUSTOMER relation is that of the name of a customer.
Formal Definitions - Summary

Formally,

- Given $R(A_1, A_2, \ldots, A_n)$
- $r(R) \subseteq \text{dom}(A_1) \times \text{dom}(A_2) \times \ldots \times \text{dom}(A_n)$

- $R(A_1, A_2, \ldots, A_n)$ is the \textit{schema} of the relation
- $R$ is the \textit{name} of the relation
- $A_1, A_2, \ldots, A_n$ are the \textit{attributes} of the relation
- $r(R)$: a specific \textit{state} (or "value" or "population") of relation $R$ – this is a \textit{set of tuples} (rows)
- $r(R) = \{t_1, t_2, \ldots, t_n\}$ where each $t_i$ is an $n$-tuple
- $t_i = <v_1, v_2, \ldots, v_n>$ where each $v_j$ \textit{element-of} $\text{dom}(A_j)$
Let $R(A_1, A_2)$ be a relation schema:

- Let $\text{dom}(A_1) = \{0,1\}$
- Let $\text{dom}(A_2) = \{a,b,c\}$

Then: $\text{dom}(A_1) \times \text{dom}(A_2)$ is all possible combinations:

$\{<0,a>, <0,b>, <0,c>, <1,a>, <1,b>, <1,c>\}$

The relation state $r(R) \subset \text{dom}(A_1) \times \text{dom}(A_2)$

For example: $r(R)$ could be $\{<0,a>, <0,b>, <1,c>\}$

- this is one possible state (or “population” or “extension”) $r$ of the relation $R$, defined over $A_1$ and $A_2$.
- It has three 2-tuples: $<0,a>, <0,b>, <1,c>$
## Definition Summary

<table>
<thead>
<tr>
<th>Informal Terms</th>
<th>Formal Terms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table</td>
<td>Relation</td>
</tr>
<tr>
<td>Column header</td>
<td>Attribute</td>
</tr>
<tr>
<td>All possible column values</td>
<td>Domain</td>
</tr>
<tr>
<td>Row</td>
<td>Tuple</td>
</tr>
<tr>
<td>Table definition</td>
<td>Schema of a Relation</td>
</tr>
<tr>
<td>Populated table</td>
<td>State of the Relation</td>
</tr>
</tbody>
</table>
Example – A relation STUDENT

<table>
<thead>
<tr>
<th>Name</th>
<th>Ssn</th>
<th>Home_phone</th>
<th>Address</th>
<th>Office_phone</th>
<th>Age</th>
<th>Gpa</th>
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<tbody>
<tr>
<td>Benjamin Bayer</td>
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<td>7384 Fontana Lane</td>
<td>NULL</td>
<td>19</td>
<td>3.25</td>
</tr>
</tbody>
</table>

Figure 5.1
The attributes and tuples of a relation STUDENT.
Characteristics Of Relations

- Ordering of tuples in a relation r(R):
  - The tuples are *not considered to be ordered*, even though they appear to be in the tabular form.

- Ordering of attributes in a relation schema R (and of values within each tuple):
  - We will consider the attributes in R(A1, A2, ..., An) and the values in t=<v1, v2, ..., vn> to be ordered.
  - (However, a more general alternative definition of relation does not require this ordering).
**Figure 5.2**
The relation STUDENT from Figure 5.1 with a different order of tuples.

<table>
<thead>
<tr>
<th>Name</th>
<th>Ssn</th>
<th>Home_phone</th>
<th>Address</th>
<th>Office_phone</th>
<th>Age</th>
<th>Gpa</th>
</tr>
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<td>2918 Bluebonnet Lane</td>
<td>NULL</td>
<td>19</td>
<td>3.21</td>
</tr>
</tbody>
</table>
Characteristics Of Relations

Values in a tuple:

- All values are considered atomic (indivisible).
- Each value in a tuple must be from the domain of the attribute for that column.
  - If tuple \( t = \langle v_1, v_2, \ldots, v_n \rangle \) is a tuple (row) in the relation state \( r \) of \( R(A_1, A_2, \ldots, A_n) \)
  - Then each \( v_i \) must be a value from \( \text{dom}(A_i) \)
- A special null value is used to represent values that are unknown or inapplicable to certain tuples.
Characteristics Of Relations

➲ Notation:

• We refer to component values of a tuple t by:
  • t[Ai] or t.Ai
  • This is the value vi of attribute Ai for tuple t

• Similarly, t[Au, Av, ..., Aw] refers to the subtuple of t containing the values of attributes Au, Av, ..., Aw, respectively in t
Relational Integrity Constraints

- Constraints are **conditions** that must hold on all valid relation states.
- There are three *main types* of constraints in the relational model:
  - **Key** constraints
  - **Entity integrity** constraints
  - **Referential integrity** constraints
- Another implicit constraint is the **domain** constraint
  - Every value in a tuple must be from the *domain of its attribute* (or it could be **null**, if allowed for that attribute)
Key Constraints

➲ **Superkey** of R:
- Is a set of attributes SK of R with the following condition:
  - No two tuples in any valid relation state r(R) will have the same value for SK
  - That is, for any distinct tuples t1 and t2 in r(R), t1[SK] ≠ t2[SK]
  - This condition must hold in any valid state r(R)

➲ **Key** of R:
- A "minimal" superkey
- That is, a key is a superkey K such that removal of any attribute from K results in a set of attributes that is not a superkey (does not possess the superkey uniqueness property)
**CAR table with two candidate keys – LicenseNumber chosen as Primary Key**

<table>
<thead>
<tr>
<th>License_number</th>
<th>Engine_serial_number</th>
<th>Make</th>
<th>Model</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Texas ABC-739</td>
<td>A69352</td>
<td>Ford</td>
<td>Mustang</td>
<td>02</td>
</tr>
<tr>
<td>Florida TVP-347</td>
<td>B43696</td>
<td>Oldsmobile</td>
<td>Cutlass</td>
<td>05</td>
</tr>
<tr>
<td>New York MPO-22</td>
<td>X83554</td>
<td>Oldsmobile</td>
<td>Delta</td>
<td>01</td>
</tr>
<tr>
<td>California 432-TFY</td>
<td>C43742</td>
<td>Mercedes</td>
<td>190-D</td>
<td>99</td>
</tr>
<tr>
<td>California RSK-629</td>
<td>Y82935</td>
<td>Toyota</td>
<td>Camry</td>
<td>04</td>
</tr>
<tr>
<td>Texas RSK-629</td>
<td>U028365</td>
<td>Jaguar</td>
<td>XJS</td>
<td>04</td>
</tr>
</tbody>
</table>

**Figure 5.4**
The CAR relation, with two candidate keys: License_number and Engine_serial_number.
**Relational Database Schema**

- Relational Database Schema:
  - A set $S$ of relation schemas that belong to the same database.
  - $S$ is the name of the whole database schema
  - $S = \{R_1, R_2, \ldots, R_n\}$
  - $R_1, R_2, \ldots, R_n$ are the names of the individual relation schemas within the database $S$

- Following slide shows a COMPANY database schema with 6 relation schemas
COMPANY Database Schema

**EMPLOYEE**

<table>
<thead>
<tr>
<th>Fname</th>
<th>Minit</th>
<th>Lname</th>
<th>Ssn</th>
<th>Bdate</th>
<th>Address</th>
<th>Sex</th>
<th>Salary</th>
<th>Super_ssn</th>
<th>Dno</th>
</tr>
</thead>
</table>

**DEPARTMENT**

<table>
<thead>
<tr>
<th>Dname</th>
<th>Dnumber</th>
<th>Mgr_ssn</th>
<th>Mgr_start_date</th>
</tr>
</thead>
</table>

**DEPT_LOCATIONS**

<table>
<thead>
<tr>
<th>Dnumber</th>
<th>Dlocation</th>
</tr>
</thead>
</table>

**PROJECT**

<table>
<thead>
<tr>
<th>Pname</th>
<th>Pnumber</th>
<th>Plocation</th>
<th>Dnum</th>
</tr>
</thead>
</table>

**WORKS_ON**

<table>
<thead>
<tr>
<th>Essn</th>
<th>Pno</th>
<th>Hours</th>
</tr>
</thead>
</table>

**DEPENDENT**

<table>
<thead>
<tr>
<th>Essn</th>
<th>Dependent_name</th>
<th>Sex</th>
<th>Bdate</th>
<th>Relationship</th>
</tr>
</thead>
</table>
Entity Integrity

- Entity Integrity:
  - The *primary key attributes* PK of each relation schema R in S cannot have null values in any tuple of r(R).
  - This is because primary key values are used to *identify* the individual tuples.
  - t[PK] ≠ null for any tuple t in r(R)
  - If PK has several attributes, null is not allowed in any of these attributes
  - Note: Other attributes of R may be constrained to disallow null values, even though they are not members of the primary key.
Referential Integrity

- A constraint involving **two** relations
  - The previous constraints involve a single relation.
- Used to specify a **relationship** among tuples in two relations:
  - The **referencing relation** and the **referenced relation**.
Referential Integrity

- Tuples in the referencing relation $R_1$ have attributes $FK$ (called foreign key attributes) that reference the primary key attributes $PK$ of the referenced relation $R_2$.
  - A tuple $t_1$ in $R_1$ is said to reference a tuple $t_2$ in $R_2$ if $t_1[FK] = t_2[PK]$.

- A referential integrity constraint can be displayed in a relational database schema as a directed arc from $R_1.FK$ to $R_2$. 
Displaying a relational database schema and its constraints

- Each relation schema can be displayed as a row of attribute names
- The name of the relation is written above the attribute names
- The primary key attribute (or attributes) will be underlined
- A foreign key (referential integrity) constraints is displayed as a directed arc (arrow) from the foreign key attributes to the referenced table
  - Can also point the the primary key of the referenced relation for clarity
- Next slide shows the COMPANY relational schema diagram
Referential Integrity Constraints for COMPANY database

Figure 5.7
Referential integrity constraints displayed on the COMPANY relational database schema.
Other Types of Constraints

▫ Semantic Integrity Constraints:
  • based on application semantics and cannot be expressed by the model
  • Example: “the max. no. of hours per employee for all projects he or she works on is 56 hrs per week”

▫ SQL-99 allows triggers and **ASSERTIONS** to express for some of these
**Populated database state**

- Each *relation* will have many tuples in its current relation state
- The *relational database state* is a union of all the individual relation states
- Whenever the database is changed, a new state arises
- Basic operations for changing the database:
  - INSERT a new tuple in a relation
  - DELETE an existing tuple from a relation
  - MODIFY an attribute of an existing tuple
### Populated database state for COMPANY

#### Figure 5.6
One possible database state for the COMPANY relational database schema.

#### EMPLOYEE

<table>
<thead>
<tr>
<th>Name</th>
<th>Ssn</th>
<th>Birthdate</th>
<th>Address</th>
<th>Sex</th>
<th>Salary</th>
<th>Super_ssn</th>
<th>Dno</th>
</tr>
</thead>
<tbody>
<tr>
<td>John</td>
<td>123456789</td>
<td>1965-01-09</td>
<td>731 Fondren, Houston, TX</td>
<td>M</td>
<td>30000</td>
<td>333445555</td>
<td>5</td>
</tr>
<tr>
<td>Franklin</td>
<td>333445555</td>
<td>1955-12-08</td>
<td>838 Voss, Houston, TX</td>
<td>M</td>
<td>40000</td>
<td>888665555</td>
<td>5</td>
</tr>
<tr>
<td>Alicia</td>
<td>999878777</td>
<td>1968-01-19</td>
<td>3321 Castle, Spring, TX</td>
<td>F</td>
<td>25000</td>
<td>987654321</td>
<td>4</td>
</tr>
<tr>
<td>Jennifer</td>
<td>987654321</td>
<td>1941-06-20</td>
<td>291 Berry, Bellaire, TX</td>
<td>F</td>
<td>43000</td>
<td>888665555</td>
<td>4</td>
</tr>
<tr>
<td>Ramesh</td>
<td>666884444</td>
<td>1962-09-15</td>
<td>075 Fire Oak, Humble, TX</td>
<td>M</td>
<td>38000</td>
<td>333445555</td>
<td>5</td>
</tr>
<tr>
<td>Joyce</td>
<td>453453453</td>
<td>1972-07-31</td>
<td>5631 Rice, Houston, TX</td>
<td>F</td>
<td>25000</td>
<td>333445555</td>
<td>5</td>
</tr>
<tr>
<td>Ahmad</td>
<td>987987987</td>
<td>1969-03-29</td>
<td>980 Dallas, Houston, TX</td>
<td>M</td>
<td>25000</td>
<td>987654321</td>
<td>4</td>
</tr>
<tr>
<td>James</td>
<td>888665555</td>
<td>1937-11-10</td>
<td>450 Stone, Houston, TX</td>
<td>M</td>
<td>55000</td>
<td>NULL</td>
<td>1</td>
</tr>
</tbody>
</table>

#### DEPARTMENT

<table>
<thead>
<tr>
<th>Name</th>
<th>Dnumber</th>
<th>Mgr_ssn</th>
<th>Mgr_start_date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research</td>
<td>5</td>
<td>333445555</td>
<td>1988-05-22</td>
</tr>
<tr>
<td>Administration</td>
<td>4</td>
<td>987654321</td>
<td>1995-01-01</td>
</tr>
<tr>
<td>Headquarters</td>
<td>1</td>
<td>888665555</td>
<td>1981-06-19</td>
</tr>
</tbody>
</table>

#### WORKS_ON

<table>
<thead>
<tr>
<th>Project</th>
<th>Hours</th>
<th>Ssn</th>
</tr>
</thead>
<tbody>
<tr>
<td>123456789</td>
<td>32.5</td>
<td>1</td>
</tr>
<tr>
<td>123456789</td>
<td>7.5</td>
<td>2</td>
</tr>
<tr>
<td>666884444</td>
<td>40.0</td>
<td>3</td>
</tr>
<tr>
<td>453453453</td>
<td>20.0</td>
<td>4</td>
</tr>
<tr>
<td>333445555</td>
<td>10.0</td>
<td>5</td>
</tr>
</tbody>
</table>

#### DEPENDENT

<table>
<thead>
<tr>
<th>Ssn</th>
<th>Dependent_name</th>
<th>Sex</th>
<th>Birthdate</th>
<th>Relationship</th>
</tr>
</thead>
<tbody>
<tr>
<td>333445555</td>
<td>Alice</td>
<td>F</td>
<td>1986-04-05</td>
<td>Daughter</td>
</tr>
<tr>
<td>333445555</td>
<td>Theodore</td>
<td>M</td>
<td>1983-10-25</td>
<td>Son</td>
</tr>
<tr>
<td>333445555</td>
<td>Joy</td>
<td>F</td>
<td>1958-05-03</td>
<td>Spouse</td>
</tr>
<tr>
<td>987654321</td>
<td>Abner</td>
<td>M</td>
<td>1942-02-28</td>
<td>Spouse</td>
</tr>
<tr>
<td>123456789</td>
<td>Michael</td>
<td>M</td>
<td>1988-01-04</td>
<td>Son</td>
</tr>
<tr>
<td>123456789</td>
<td>Alice</td>
<td>F</td>
<td>1988-12-30</td>
<td>Daughter</td>
</tr>
<tr>
<td>123456789</td>
<td>Elizabeth</td>
<td>F</td>
<td>1967-05-05</td>
<td>Spouse</td>
</tr>
</tbody>
</table>

#### PROJECT

<table>
<thead>
<tr>
<th>Project</th>
<th>Dnumber</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>ProductX</td>
<td>1</td>
<td>Bellaire</td>
</tr>
<tr>
<td>ProductY</td>
<td>2</td>
<td>Sugarland</td>
</tr>
<tr>
<td>ProductZ</td>
<td>3</td>
<td>Houston</td>
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<tr>
<td>Computerization</td>
<td>10</td>
<td>Stafford</td>
</tr>
<tr>
<td>Reorganization</td>
<td>20</td>
<td>Houston</td>
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<td>30</td>
<td>Stafford</td>
</tr>
</tbody>
</table>

#### DEPT_LOCATIONS

<table>
<thead>
<tr>
<th>Dnumber</th>
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<tbody>
<tr>
<td>1</td>
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</tr>
<tr>
<td>4</td>
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</tr>
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</tr>
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</tr>
<tr>
<td>5</td>
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</table>
Update Operations on Relations

- INSERT a tuple.
- DELETE a tuple.
- MODIFY a tuple.
- Integrity constraints should not be violated by the update operations.
- Updates may **propagate** to cause other updates automatically. This may be necessary to maintain integrity constraints.
Update Operations on Relations

In case of integrity violation, several actions can be taken:

• Cancel the operation that causes the violation (RESTRICT or REJECT option)
• Perform the operation but inform the user of the violation
• Trigger additional updates so the violation is corrected (CASCADE option, SET NULL option)
• Execute a user-specified error-correction routine
Possible violations for each operation

- INSERT may violate any of the constraints:
  - Domain constraint:
    - if one of the attribute values provided for the new tuple is not of the specified attribute domain
  - Key constraint:
    - if the value of a key attribute in the new tuple already exists in another tuple in the relation
  - Referential integrity:
    - if a foreign key value in the new tuple references a primary key value that does not exist in the referenced relation
  - Entity integrity:
    - if the primary key value is null in the new tuple
Possible violations for each operation

- DELETE may violate only referential integrity:
  - If the primary key value of the tuple being deleted is referenced from other tuples in the database
  - Can be remedied by several actions: RESTRICT, CASCADE, SET NULL (see Chapter 8 for more details)
    - RESTRICT option: reject the deletion
    - CASCADE option: propagate the new primary key value into the foreign keys of the referencing tuples
    - SET NULL option: set the foreign keys of the referencing tuples to NULL
  - One of the above options must be specified during database design for each foreign key constraint
Possible violations for each operation

- UPDATE may violate domain constraint and NOT NULL constraint on an attribute being modified.
- Any of the other constraints may also be violated, depending on the attribute being updated:
  - Updating the primary key (PK):
    - Similar to a DELETE followed by an INSERT
    - Need to specify similar options to DELETE
  - Updating a foreign key (FK):
    - May violate referential integrity
  - Updating an ordinary attribute (neither PK nor FK):
    - Can only violate domain constraints
Summary

- Presented Relational Model Concepts
  - Definitions
  - Characteristics of relations
- Discussed Relational Model Constraints and Relational Database Schemas
  - Domain constraints’
  - Key constraints
  - Entity integrity
  - Referential integrity
- Described the Relational Update Operations and Dealing with Constraint Violations