

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 this chapter
- In *practice*, there is a *standard model* based on SQL – this is described in Chapters 6 and 7 as a language
- 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:
 - "A Relational Model for Large Shared Data Banks," Communications of the ACM, June 1970
- The above paper caused a major revolution in the field of database management and earned Dr. Codd the coveted ACM Turing Award

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

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

Figure 5.1

The attributes and tuples of a relation STUDENT.

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 $R(A_1, A_2, \dots, A_n)$
 - R is the **name** of the relation
 - The **attributes** of the relation are A_1, A_2, \dots, A_n
- Example:
CUSTOMER (Cust-id, Cust-name, Address, Phone#)
 - CUSTOMER is the relation name
 - Defined over the four attributes: Cust-id, Cust-name, Address, Phone#
- 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 - Domain

- A **domain** has a logical definition:
 - Example: “USA_phone_numbers” are the set of 10 digit phone numbers valid in the U.S.
- A domain also has a data-type or a format defined for it.
 - The USA_phone_numbers may have a format: (ddd)ddd-dddd where each d is a decimal digit.
 - Dates have various formats such as year, month, date formatted as yyyy-mm-dd, or as dd mm,yyyy etc.
- The attribute name designates the role played by a domain in a relation:
 - Used to interpret the meaning of the data elements corresponding to that attribute
 - Example: The domain Date may be used to define two attributes named “Invoice-date” and “Payment-date” with different meanings

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

Formal Definitions - Example

- Let $R(A1, A2)$ be a relation schema:
 - Let $\text{dom}(A1) = \{0,1\}$
 - Let $\text{dom}(A2) = \{a,b,c\}$
- Then: $\text{dom}(A1) \times \text{dom}(A2)$ is all possible combinations:
 $\{ \langle 0,a \rangle, \langle 0,b \rangle, \langle 0,c \rangle, \langle 1,a \rangle, \langle 1,b \rangle, \langle 1,c \rangle \}$
- The relation state $r(R) \subset \text{dom}(A1) \times \text{dom}(A2)$
- For example: $r(R)$ could be $\{ \langle 0,a \rangle, \langle 0,b \rangle, \langle 1,c \rangle \}$
 - this is one possible state (or “population” or “extension”) r of the relation R , defined over $A1$ and $A2$.
 - It has three 2-tuples: $\langle 0,a \rangle, \langle 0,b \rangle, \langle 1,c \rangle$

Definition Summary

| <u>Informal Terms</u> | | <u>Formal Terms</u> |
|----------------------------|--|-----------------------|
| Table | | Relation |
| Column Header | | Attribute |
| All possible Column Values | | Domain |
| Row | | Tuple |
| | | |
| Table Definition | | Schema of a Relation |
| Populated Table | | State of the Relation |

Example – A relation STUDENT

Relation Name

STUDENT

Attributes

Name

Ssn

Home_phone

Address

Office_phone

Age

Gpa

Tuples

Benjamin Bayer

305-61-2435

373-1616

2918 Bluebonnet Lane

NULL

19

3.21

Chung-cha Kim

381-62-1245

375-4409

125 Kirby Road

NULL

18

2.89

Dick Davidson

422-11-2320

NULL

3452 Elgin Road

749-1253

25

3.53

Rohan Panchal

489-22-1100

376-9821

265 Lark Lane

749-6492

28

3.93

Barbara Benson

533-69-1238

839-8461

7384 Fontana Lane

NULL

19

3.25

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 $R(A_1, A_2, \dots, A_n)$ and the values in $t = \langle v_1, v_2, \dots, v_n \rangle$ to be ordered .
 - (However, a more general alternative definition of relation does not require this ordering. It includes both the name and the value for each of the attributes).
 - Example: $t = \{ \langle \text{name}, \text{"John"} \rangle, \langle \text{SSN}, 123456789 \rangle \}$
 - This representation may be called as “self-describing”.

Same state as previous Figure (but with different order of tuples)

Figure 5.2

The relation STUDENT from Figure 5.1 with a different order of tuples.

STUDENT

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

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 $t = \langle v_1, v_2, \dots, v_n \rangle$ is a tuple (row) in the relation state r of $R(A_1, A_2, \dots, A_n)$
 - Then each v_i must be a value from $dom(A_i)$
- A special **null** value is used to represent values that are unknown or not available or inapplicable in certain tuples.

Characteristics Of Relations

- Notation:

- We refer to **component values** of a tuple t by:
 - $t[A_i]$ or $t.A_i$
 - This is the value v_i of attribute A_i for tuple t
- Similarly, $t[A_u, A_v, \dots, A_w]$ refers to the subtuple of t containing the values of attributes A_u, A_v, \dots, A_w , respectively in t

CONSTRAINTS

Constraints determine which values are permissible and which are not in the database.

They are of three main types:

1. **Inherent or Implicit Constraints:** These are based on the data model itself. (E.g., relational model does not allow a list as a value for any attribute)
2. **Schema-based or Explicit Constraints:** They are expressed in the schema by using the facilities provided by the model. (E.g., max. cardinality ratio constraint in the ER model)
3. **Application based or semantic constraints:** These are beyond the expressive power of the model and must be specified and enforced by the application programs.

Relational Integrity Constraints

- Constraints are **conditions** that must hold on **all** valid relation states.
- There are three *main types* of (explicit schema-based) constraints that can be expressed in the relational model:
 - **Key** constraints
 - **Entity integrity** constraints
 - **Referential integrity** constraints
- Another schema-based 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 $r(R)$, $t1[SK] \neq t2[SK]$
 - 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)

- A Key is a Superkey but not vice versa

Key Constraints (continued)

- Example: Consider the CAR relation schema:
 - CAR(State, Reg#, SerialNo, Make, Model, Year)
 - CAR has two keys:
 - Key1 = {State, Reg#}
 - Key2 = {SerialNo}
 - Both are also superkeys of CAR
 - {SerialNo, Make} is a superkey but *not* a key.
- In general:
 - Any *key* is a *superkey* (but not vice versa)
 - Any set of attributes that *includes a key* is a *superkey*
 - A *minimal* superkey is also a key

Key Constraints (continued)

- If a relation has several **candidate keys**, one is chosen arbitrarily to be the **primary key**.
 - The primary key attributes are underlined.
- Example: Consider the CAR relation schema:
 - CAR(State, Reg#, SerialNo, Make, Model, Year)
 - We chose SerialNo as the primary key
- The primary key value is used to *uniquely identify* each tuple in a relation
 - Provides the tuple identity
- Also used to *reference* the tuple from another tuple
 - General rule: Choose as primary key the smallest of the candidate keys (in terms of size)
 - Not always applicable – choice is sometimes subjective

CAR table with two candidate keys – LicenseNumber chosen as Primary Key

CAR

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

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**
 - $S = \{R_1, R_2, \dots, R_n\}$ and a set IC of integrity constraints.
 - R_1, R_2, \dots, 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

| | | | | | | | | | |
|-------|-------|-------|------------|-------|---------|-----|--------|-----------|-----|
| Fname | Minit | Lname | <u>Ssn</u> | Bdate | Address | Sex | Salary | Super_ssn | Dno |
|-------|-------|-------|------------|-------|---------|-----|--------|-----------|-----|

DEPARTMENT

| | | | |
|-------|----------------|---------|----------------|
| Dname | <u>Dnumber</u> | Mgr_ssn | Mgr_start_date |
|-------|----------------|---------|----------------|

DEPT_LOCATIONS

| | |
|----------------|------------------|
| <u>Dnumber</u> | <u>Dlocation</u> |
|----------------|------------------|

PROJECT

| | | | |
|-------|----------------|-----------|------|
| Pname | <u>Pnumber</u> | Plocation | Dnum |
|-------|----------------|-----------|------|

WORKS_ON

| | | |
|-------------|------------|-------|
| <u>Essn</u> | <u>Pno</u> | Hours |
|-------------|------------|-------|

DEPENDENT

| | | | | |
|-------------|-----------------------|-----|-------|--------------|
| <u>Essn</u> | <u>Dependent_name</u> | Sex | Bdate | Relationship |
|-------------|-----------------------|-----|-------|--------------|

Figure 5.5
Schema diagram for
the COMPANY
relational database
schema.

Relational Database State

- A **relational database state** DB of S is a set of relation states $DB = \{r_1, r_2, \dots, r_m\}$ such that each r_i is a state of R_i and such that the r_i relation states satisfy the integrity constraints specified in IC.
- A relational database *state* is sometimes called a relational database *snapshot* or *instance*.
- We will not use the term *instance* since it also applies to single tuples.
- A database state that does not meet the constraints is an invalid state

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
- Next slide (Fig. 5.6) shows an example state for the COMPANY database schema shown in Fig. 5.5.

Populated database state for COMPANY

Figure 5.6

One possible database state for the COMPANY relational database schema.

EMPLOYEE

| Fname | Minit | Lname | Ssn | Bdate | Address | Sex | Salary | Super_ssn | Dno |
|----------|-------|---------|-----------|------------|--------------------------|-----|--------|-----------|-----|
| John | B | Smith | 123456789 | 1965-01-09 | 731 Fondren, Houston, TX | M | 30000 | 333445555 | 5 |
| Franklin | T | Wong | 333445555 | 1955-12-08 | 638 Voss, Houston, TX | M | 40000 | 888665555 | 5 |
| Alicia | J | Zelaya | 999887777 | 1968-01-19 | 3321 Castle, Spring, TX | F | 25000 | 987654321 | 4 |
| Jennifer | S | Wallace | 987654321 | 1941-06-20 | 291 Berry, Bellaire, TX | F | 43000 | 888665555 | 4 |
| Ramesh | K | Narayan | 666884444 | 1962-09-15 | 975 Fire Oak, Humble, TX | M | 38000 | 333445555 | 5 |
| Joyce | A | English | 453453453 | 1972-07-31 | 5631 Rice, Houston, TX | F | 25000 | 333445555 | 5 |
| Ahmad | V | Jabbar | 987987987 | 1969-03-29 | 980 Dallas, Houston, TX | M | 25000 | 987654321 | 4 |
| James | E | Borg | 888665555 | 1937-11-10 | 450 Stone, Houston, TX | M | 55000 | NULL | 1 |

DEPARTMENT

| Dname | Dnumber | Mgr_ssn | Mgr_start_date |
|----------------|---------|-----------|----------------|
| Research | 5 | 333445555 | 1988-05-22 |
| Administration | 4 | 987654321 | 1995-01-01 |
| Headquarters | 1 | 888665555 | 1981-06-19 |

DEPT_LOCATIONS

| Dnumber | Dlocation |
|---------|-----------|
| 1 | Houston |
| 4 | Stafford |
| 5 | Bellaire |
| 5 | Sugarland |
| 5 | Houston |

WORKS_ON

| Essn | Pno | Hours |
|-----------|-----|-------|
| 123456789 | 1 | 32.5 |
| 123456789 | 2 | 7.5 |
| 666884444 | 3 | 40.0 |
| 453453453 | 1 | 20.0 |
| 453453453 | 2 | 20.0 |
| 333445555 | 2 | 10.0 |
| 333445555 | 3 | 10.0 |
| 333445555 | 10 | 10.0 |
| 333445555 | 20 | 10.0 |
| 999887777 | 30 | 30.0 |
| 999887777 | 10 | 10.0 |
| 987987987 | 10 | 35.0 |
| 987987987 | 30 | 5.0 |
| 987654321 | 30 | 20.0 |
| 987654321 | 20 | 15.0 |
| 888665555 | 20 | NULL |

PROJECT

| Pname | Pnumber | Plocation | Dnum |
|-----------------|---------|-----------|------|
| ProductX | 1 | Bellaire | 5 |
| ProductY | 2 | Sugarland | 5 |
| ProductZ | 3 | Houston | 5 |
| Computerization | 10 | Stafford | 4 |
| Reorganization | 20 | Houston | 1 |
| Newbenefits | 30 | Stafford | 4 |

DEPENDENT

| Essn | Dependent_name | Sex | Bdate | Relationship |
|-----------|----------------|-----|------------|--------------|
| 333445555 | Alice | F | 1986-04-05 | Daughter |
| 333445555 | Theodore | M | 1983-10-25 | Son |
| 333445555 | Joy | F | 1958-05-03 | Spouse |
| 987654321 | Abner | M | 1942-02-28 | Spouse |
| 123456789 | Michael | M | 1988-01-04 | Son |
| 123456789 | Alice | F | 1988-12-30 | Daughter |
| 123456789 | Elizabeth | F | 1967-05-05 | Spouse |

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.
 - $t[PK] \neq \text{null}$ 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** R1 have attributes FK (called **foreign key** attributes) that reference the primary key attributes PK of the **referenced relation** R2.
 - A tuple t1 in R1 is said to **reference** a tuple t2 in R2 if $t1[FK] = t2[PK]$.
- A referential integrity constraint can be displayed in a relational database schema as a directed arc from R1.FK to R2.

Referential Integrity (or foreign key) Constraint

- Statement of the constraint
 - The value in the foreign key column (or columns) FK of the the **referencing relation** R1 can be **either**:
 - (1) a value of an existing primary key value of a corresponding primary key PK in the **referenced relation** R2, or
 - (2) a **null**.
- In case (2), the FK in R1 should **not** be a part of its own primary key.

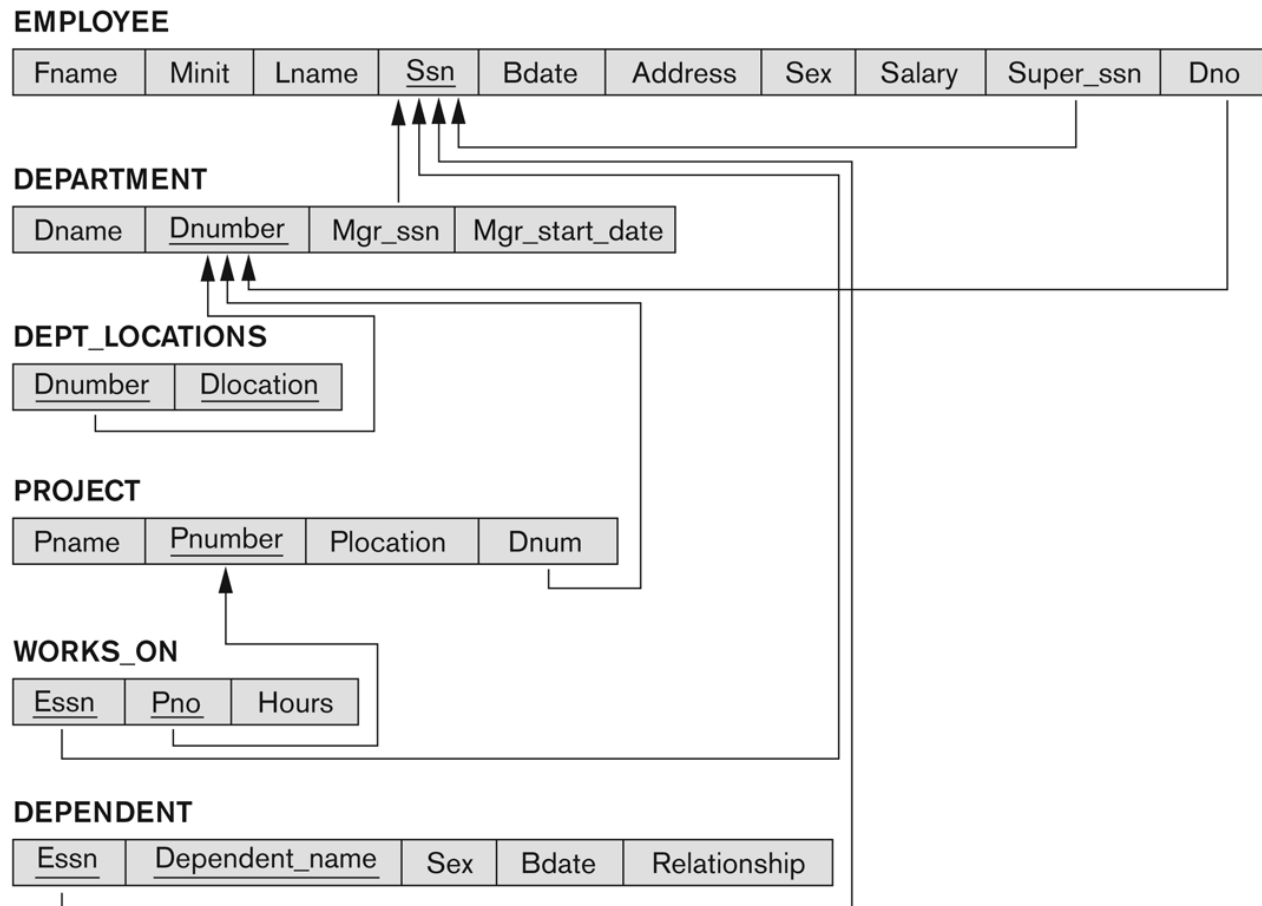
Displaying a relational database schema and its constraints

- 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 with referential integrity constraints

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 per se
 - Example: “the max. no. of hours per employee for all projects he or she works on is 56 hrs per week”
- A **constraint specification** language may have to be used to express these
- SQL-99 allows **CREATE TRIGGER** and **CREATE ASSERTION** to express some of these semantic constraints
- Keys, Permissibility of Null values, Candidate Keys (Unique in SQL), Foreign Keys, Referential Integrity etc. are expressed by the **CREATE TABLE** statement in SQL.

Update Operations on Relations

- INSERT a tuple.
- DELETE a tuple.
- MODIFY a tuple.
- Integrity constraints should not be violated by the update operations.
- Several update operations may have to be grouped together.
- 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 6 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

In-Class Exercise

(Taken from Exercise 5.15)

Consider the following relations for a database that keeps track of student enrollment in courses and the books adopted for each course:

STUDENT(SSN, Name, Major, Bdate)

COURSE(Course#, Cname, Dept)

ENROLL(SSN, Course#, Quarter, Grade)

BOOK_ADOPTION(Course#, Quarter, Book_ISBN)

TEXT(Book_ISBN, Book_Title, Publisher, Author)

Draw a relational schema diagram specifying the foreign keys for this schema.