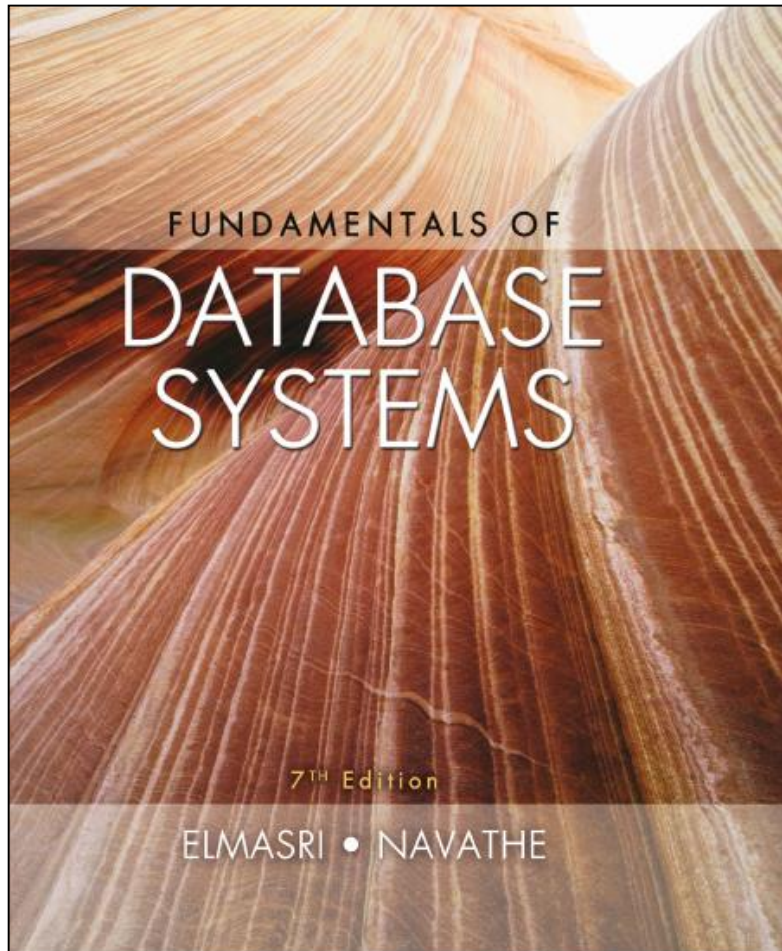


# Fundamentals of Database Systems

Seventh Edition



## Chapter 5

The Relational Data Model  
and Relational Database  
Constraints

# Learning Objectives

**5.1** Relational Model Concepts

**5.2** Relational Model Constraints and Relational Database Schemas

**5.3** Update Operations and Dealing with Constraint Violations

# Relational Model Concepts (1 of 2)

- 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 (2 of 2)

- 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 (1 of 2)

- 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

**Figure 5.1** The attributes and tuples of a relation STUDENT.

Relation Name

**STUDENT**

Attributes

Tuples

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

# Informal Definitions (2 of 2)

- 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  $R(A_1, A_2)$  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:  
 $\{ \langle 0,a \rangle, \langle 0,b \rangle, \langle 0,c \rangle, \langle 1,a \rangle, \langle 1,b \rangle, \langle 1,c \rangle \}$
- The relation state  $r(R) \subset \text{dom}(A_1) \times \text{dom}(A_2)$
- 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  $A_1$  and  $A_2$ .
  - It has three 2-tuples:  $\langle 0,a \rangle, \langle 0,b \rangle, \langle 1,c \rangle$

# Definition Summary

Informal Terms	Formal Terms
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

**Figure 5.1** The attributes and tuples 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

# Characteristics of Relations (1 of 3)

- 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 (2 of 3)

- 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 (3 of 3)

- 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 (1 of 3)

- **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  $t_1$  and  $t_2$  in  $r(R)$ ,  $t_1[SK] \neq t_2[SK]$
    - 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 (2 of 3)

- 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
  - {Serial No, 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 (3 of 3)

- 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

**Figure 5.4** The CAR relation, with two candidate keys: License\_number and Engine\_serial\_number.

**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

# 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

**Figure 5.5** Schema diagram for the COMPANY relational 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
-------------	-----------------------	-----	-------	--------------

# 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 (Figure 5.6) shows an example state for the COMPANY database schema shown in Figure 5.5 (see slide 28).

# 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

- 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.
  - $t[\text{PK}] \neq \text{null}$  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 (1 of 2)

- 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 (2 of 2)

- 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  $t_1[\text{FK}] = t_2[\text{PK}]$ .
- A referential integrity constraint can be displayed in a relational database schema as a directed arc from  $R_1.\text{FK}$  to  $R_2$ .

# Referential Integrity (or Foreign Key) Constraint

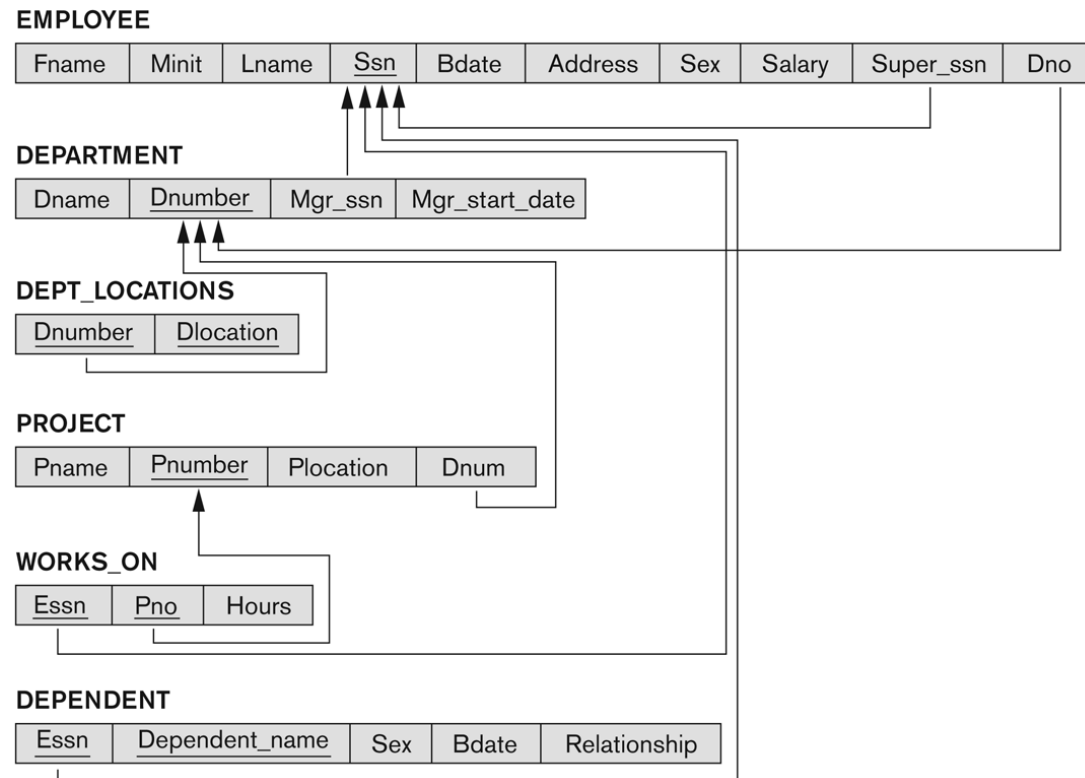
- Statement of the constraint
  - The value in the foreign key column (or columns) FK of the **referencing relation**  $R_1$  can be either:
    - (1) a value of an existing primary key value of a corresponding primary key PK in the **referenced relation**  $R_2$ , or
    - (2) a **null**.
- In case (2), the FK in  $R_1$  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 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 maximum number 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 (1 of 2)

- 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 (2 of 2)

- 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 (1 of 3)

- 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 (2 of 3)

- 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 (3 of 3)

- 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

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.**

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