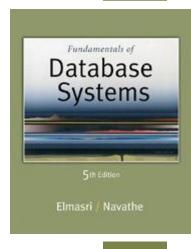


5th Edition

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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 8 and 9
- 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

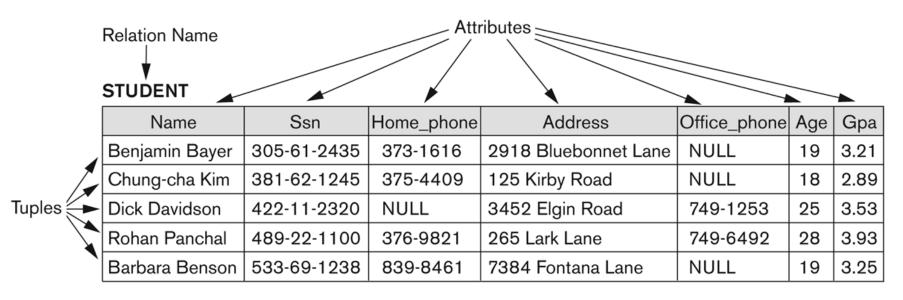


Figure 5.1

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(A1, A2,An)
 - R is the name of the relation
 - The attributes of the relation are A1, A2, ..., An
- 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
 - 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(A1, A2,, An)
 - r(R) ⊂ dom (A1) X dom (A2) XX dom(An)
- R(A1, A2, ..., An) is the **schema** of the relation
- R is the name of the relation
- A1, A2, ..., An 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) = {t1, t2, ..., tn} where each ti is an n-tuple
 - ti = <v1, v2, ..., vn> where each vj element-of dom(Aj)

Formal Definitions - Example

- Let R(A1, A2) be a relation schema:
 - Let dom(A1) = {0,1}
 - Let dom(A2) = {a,b,c}
- Then: dom(A1) X dom(A2) is all possible combinations:

```
{<0,a>, <0,b>, <0,c>, <1,a>, <1,b>, <1,c>}
```

- The relation state r(R) ⊂ dom(A1) X dom(A2)
- 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 A1 and A2.
 - It has three 2-tuples: <0,a> , <0,b> , <1,c>

Definition Summary

<u>Informal Terms</u>	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

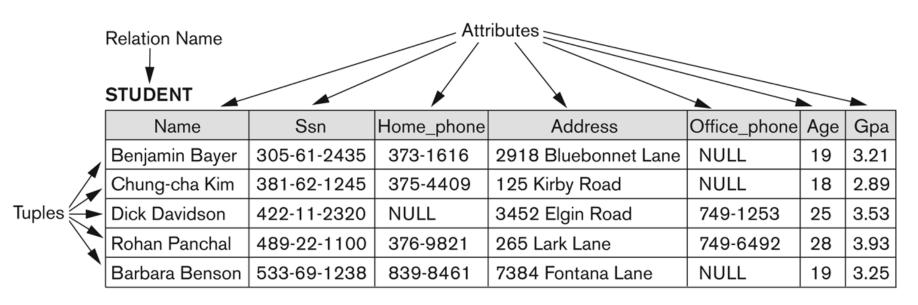


Figure 5.1

The attributes and tuples of a relation STUDENT.

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).

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 = <v1, v2, ..., vn> is a tuple (row) in the relation state r of R(A1, A2, ..., An)
 - Then each *vi* must be a value from *dom(Ai)*
 - 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)

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 <u>underlined</u>.
- Example: Consider the CAR relation schema:
 - CAR(State, Reg#, <u>SerialNo</u>, 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

Figure 5.4 The CAR relation, with two candidate keys: License_number and Engine_serial_number.

<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 = {R1, R2, ..., Rn}
- R1, R2, ..., Rn 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 Lna	Ssn	Ssn B	Bdate Address	Sex	Salary	Super_ssn	Dno
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DEPARTMENT

Dname	Dnumber	Mgr_ssn	Mgr_start_date
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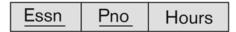
DEPT_LOCATIONS



PROJECT

Pname	<u>Pnumber</u>	Plocation	Dnum
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WORKS_ON



DEPENDENT

Essn Dependent_n	ne Sex	Bdate	Relationship
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Figure 5.5

Schema diagram for the COMPANY relational database schema.

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 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

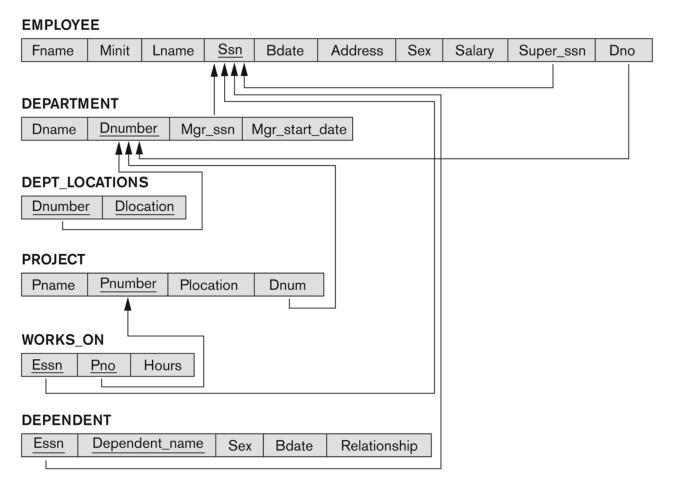
- Statement of the constraint
 - The value in the foreign key column (or columns) FK of the the referencing relation R1 can be either:
 - (1) a value of an existing primary key value of a corresponding primary key PK in the referenced relation R2, or
 - (2) a **null**.
- In case (2), the FK in R1 should **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

Referential Integrity Constraints for COMPANY database

Figure 5.7Referential 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 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
- Next slide shows an example state for the COMPANY database

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	В	Smith	123456789	1965-01-09	731 Fondren, Houston, TX	М	30000	333445555	5
Franklin	Т	Wong	333445555	1955-12-08	638 Voss, Houston, TX	М	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	М	38000	333445555	5
Joyce	Α	English	453453453	1972-07-31	5631 Rice, Houston, TX	F	25000	333445555	5
Ahmad	٧	Jabbar	987987987	1969-03-29	980 Dallas, Houston, TX	М	25000	987654321	4
James	Е	Borg	888665555	1937-11-10	450 Stone, Houston, TX	М	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	<u>Pno</u>	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	М	1983-10-25	Son
333445555	Joy	F	1958-05-03	Spouse
987654321	Abner	М	1942-02-28	Spouse
123456789	Michael	М	1988-01-04	Son
123456789	Alice	F	1988-12-30	Daughter
123456789	Elizabeth	F	1967-05-05	Spouse

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 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

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(<u>SSN</u>, Name, Major, Bdate)

COURSE(Course#, Cname, Dept)

ENROLL(SSN, Course#, Quarter, Grade)

BOOK_ADOPTION(Course#, Quarter, Book_ISBN)

TEXT(<u>Book_ISBN</u>, Book_Title, Publisher, Author)

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