Lecture 8
Relational Database Design

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Objectives

- Relational Model concepts
- Relational Model Constraints and Relational Database Schemas

- Ref.: Chapter 5

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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

- Note: There are several important differences between the *formal* model and the *practical* model, as we shall see

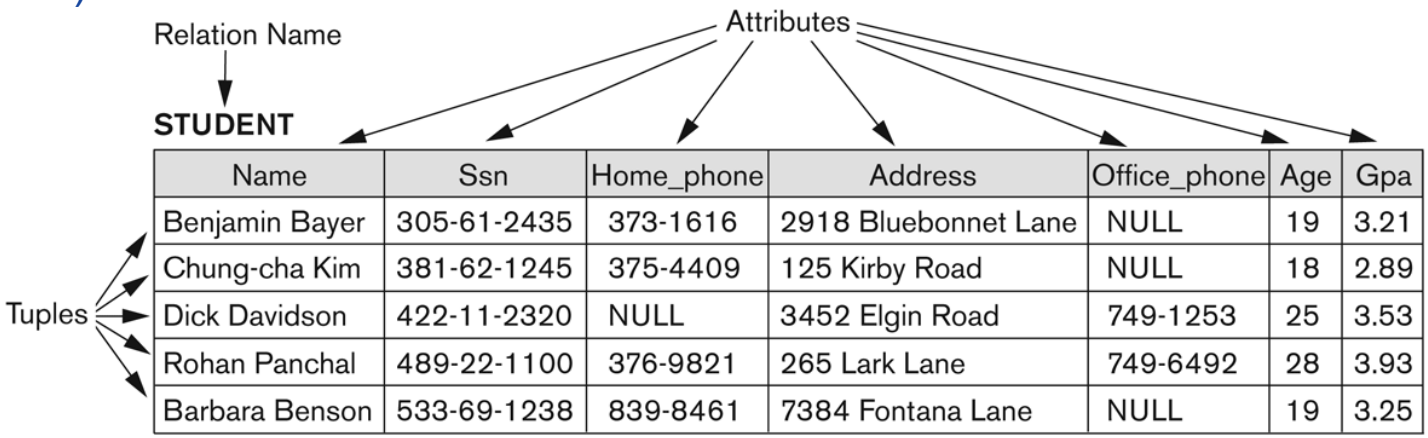
Relational Model Concepts

- 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**)



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

- 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 $R(A_1, A_2, ...A_n)$
  - R is the **name** of the relation
  - The **attributes** of the relation are $A_1, A_2, ..., A_n$
- Example:

  CUSTOMER (Cust-id, Cust-name, Address, PhoneNo)
  - CUSTOMER is the relation name
  - Defined over the four attributes: Cust-id, Cust-name, Address, PhoneNo

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

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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

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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*.

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Formal Definitions - Summary

- Formally,
  - Given $R(A_1, A_2, ..., A_n)$
  - $r(R) \subset dom(A_1) \times dom(A_2) \times ....X\ dom(A_n)$

- $R(A_1, A_2, \ldots, A_n)$ is the **schema** of the relation
  - R is the **name** of the relation
  - $A_1, A_2, \ldots, A_n$ 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)
  - $r(R) = \{t_1, t_2, \ldots, t_n\}$ where each t_i is an n-tuple
  - $ti = <v_1, v_2, \ldots, v_n>$ where each v_j *element-of* $dom(A_j)$

Formal Definitions - Example

- Let $R(A_1, A_2)$ be a relation schema:
  - Let $dom(A_1) = \{0,1\}$
  - Let $dom(A_2) = \{a,b,c\}$
  - Then: $dom(A_1)$ X $dom(A_2)$ is all possible combinations:

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

- The relation state $r(R) \subset dom(A_1)$ X $dom(A_2)$
- 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>

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 $R(A_1, A_2, ..., A_n)$ and the values in $t = <v_1, v_2, ..., v_n>$ to be ordered .
    - (However, a more general alternative definition of relation does not require this ordering).

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 = $<v_1, v_2, \ldots, v_n>$ 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 $dom(A_i)$
  - 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:
    - $t[A_i]$ or $t.A_i$
    - This is the value v_i of attribute A_i for tuple t
  - Similarly, $t[A_u, A_v, ..., A_w]$ refers to the subtuple of t containing the values of attributes $A_u, A_v, ..., A_w$, respectively in t

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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 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)

Key Constraints (2)

- Example: Consider the CAR relation schema:
  - CAR(State, RegNo, SerialNo, Make, Model, Year)
  - CAR has two keys:
    - Key_1 = {State, RegNo}
    - Key_2 = {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 (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, RegNo, 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

License_number	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**
  - $S = \{R_1, R_2, ..., R_n\}$
  - $R_1, R_2, \ldots, R_n$ 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

Fname	Minit	Lname	Ssn	Bdate	Address	Sex	Salary	Super_ssn	Dno

DEPARTMENT

Dname	Dnumber	Mgr_ssn	Mgr_start_date

DEPT_LOCATIONS

Dnumber	Dlocation

PROJECT

Pname	Pnumber	Plocation	Dnum

WORKS_ON

Essn	Pno	Hours

DEPENDENT

Essn	Dependent_name	Sex	Bdate	Relationship

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] $\neq$ 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.

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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**.

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Referential Integrity (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 $t_1[FK] = t_2[PK]$.

- A referential integrity constraint can be displayed in a relational database schema as a directed arc from R_1.FK to R_2.PK

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** 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.

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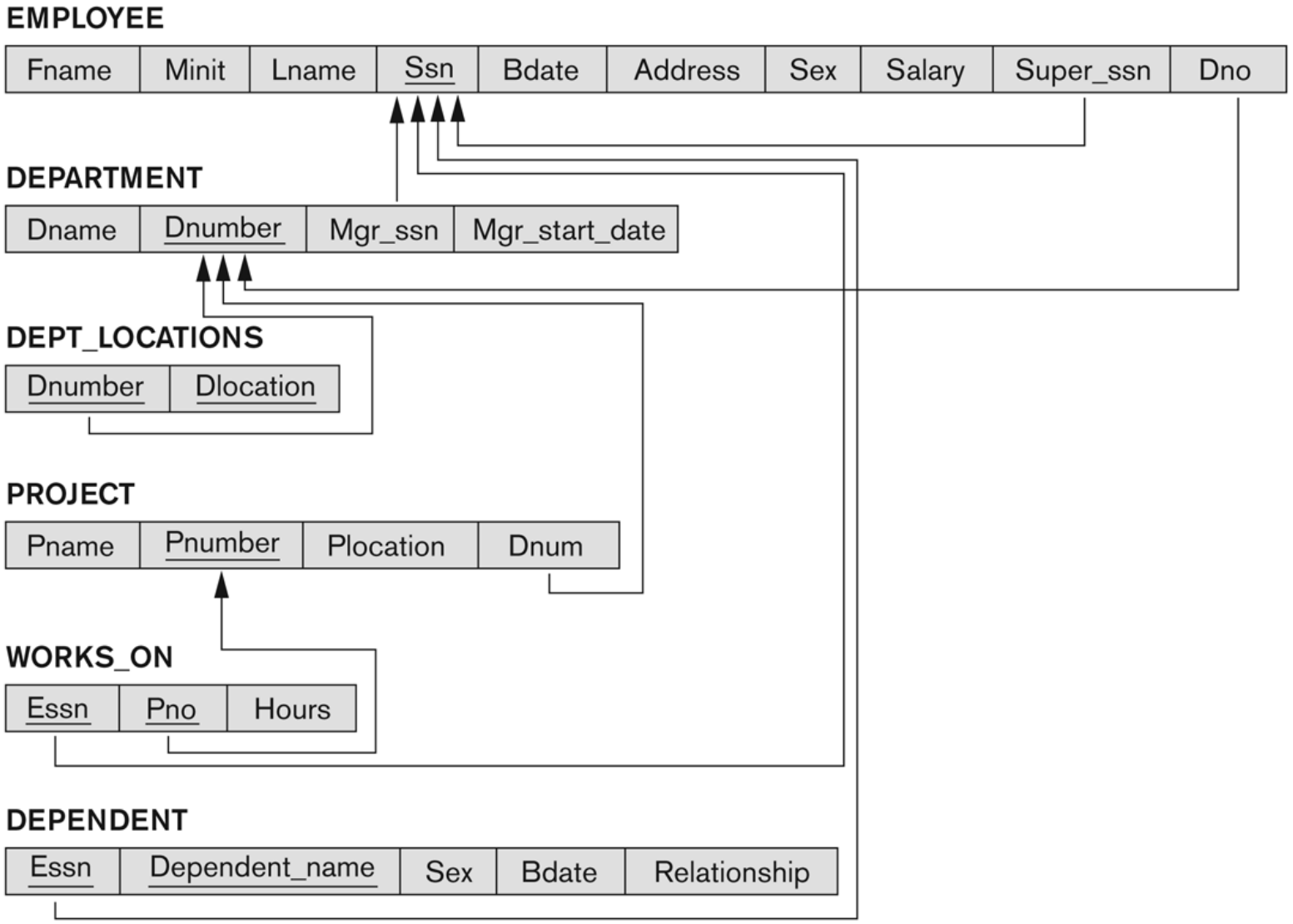
Displaying a relational database schema and its constraints

- 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

Referential Integrity Constraints for COMPANY DB



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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

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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

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.

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Update Operations on Relations (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 - Insert

- 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

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Possible violations for each operation - Delete

- 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
      - 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

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Possible violations for each operation - Update

- 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

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Q & A