Database Systems

LESSON 02: RELATIONAL DATA MODEL

September 2019

Contents

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

This lesson reviews the essentials of the *formal relational model*

In *practice*, there is a *standard model* based on SQL – this is described as a language in later lessons

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**.

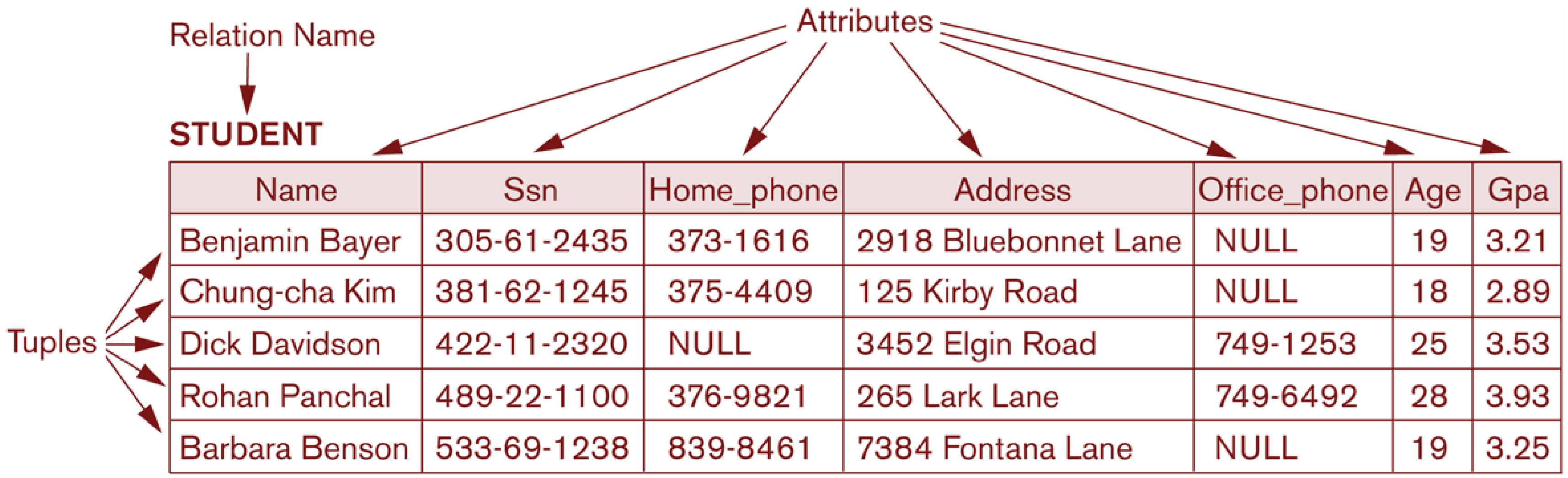
The data elements in each **row** represent certain facts that correspond to a real-world **entity** or **relationship**

- 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



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(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) $\subset$ dom (A1) X dom (A2) X ....X 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) $\subset$ dom(A1) X dom(A2)

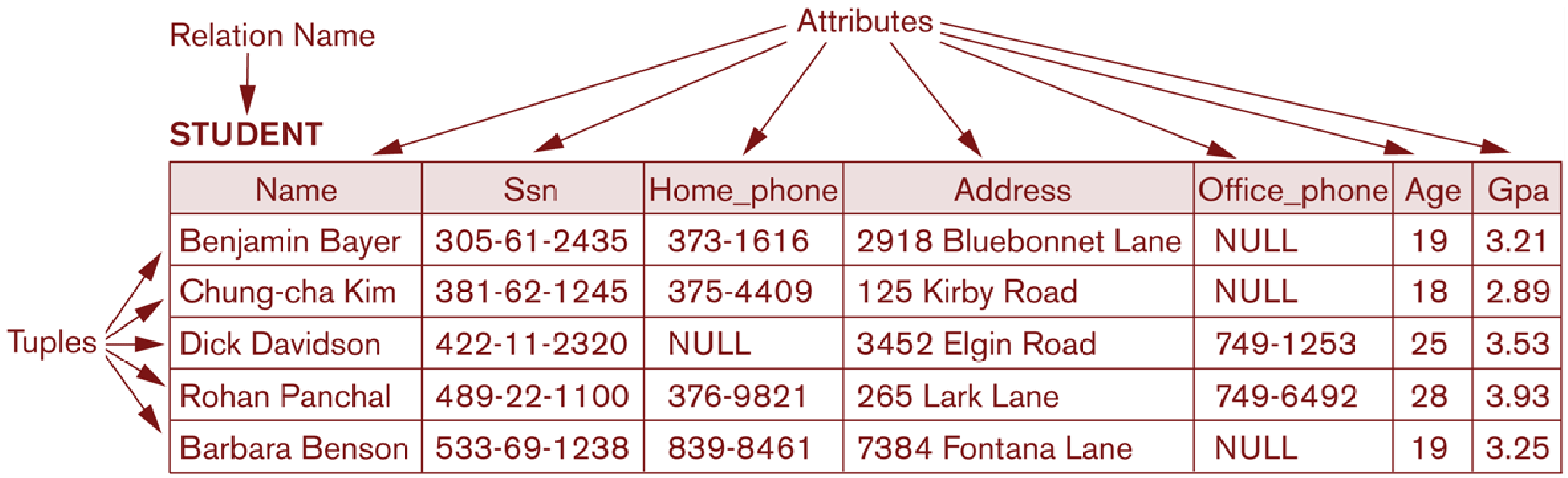
For example: r(R) could be {<0,a> , <0,b> , <1,c> }

- 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

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



STUDENT

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Characteristics Of Relations

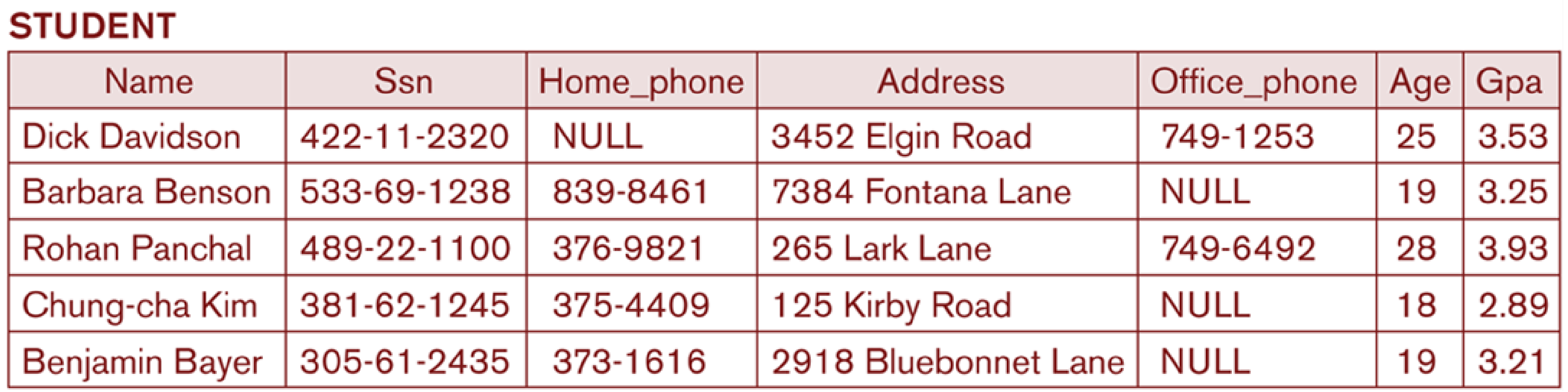
Ordering of tuples in a relation r(R):

- 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. It includes both the name and the value for each of the attributes).
  - Example: t= { <name, “John” >, <SSN, 123456789> }
  - This representation may be called as “self-describing”.

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



STUDENT

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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 not available or inapplicable in 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

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 (cont.)

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 (cont.)

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

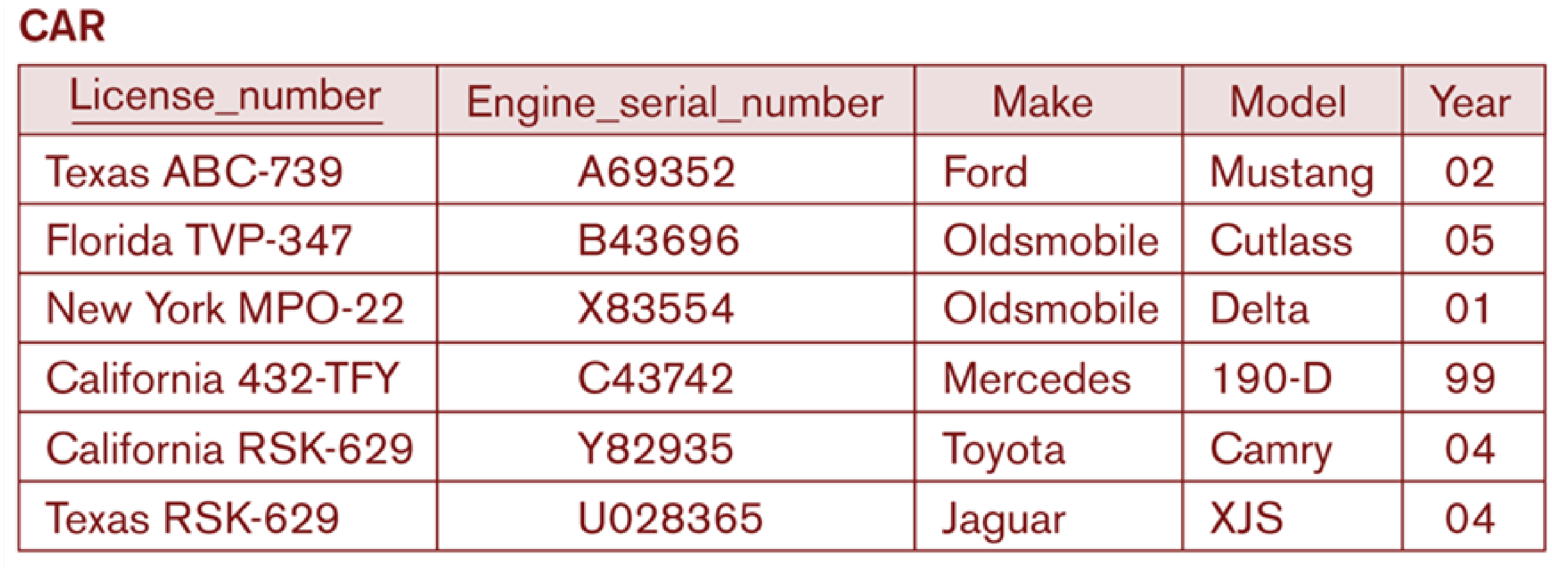
The primary key value is used to *uniquely identify* each tuple in a relation

- 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

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 = {R1, R2, ..., Rn} and a set IC of integrity constraints.
- 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	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

Relational Database State

A **relational database state** DB of *S* is a set of relation states DB = {r_1, r_2, ..., 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

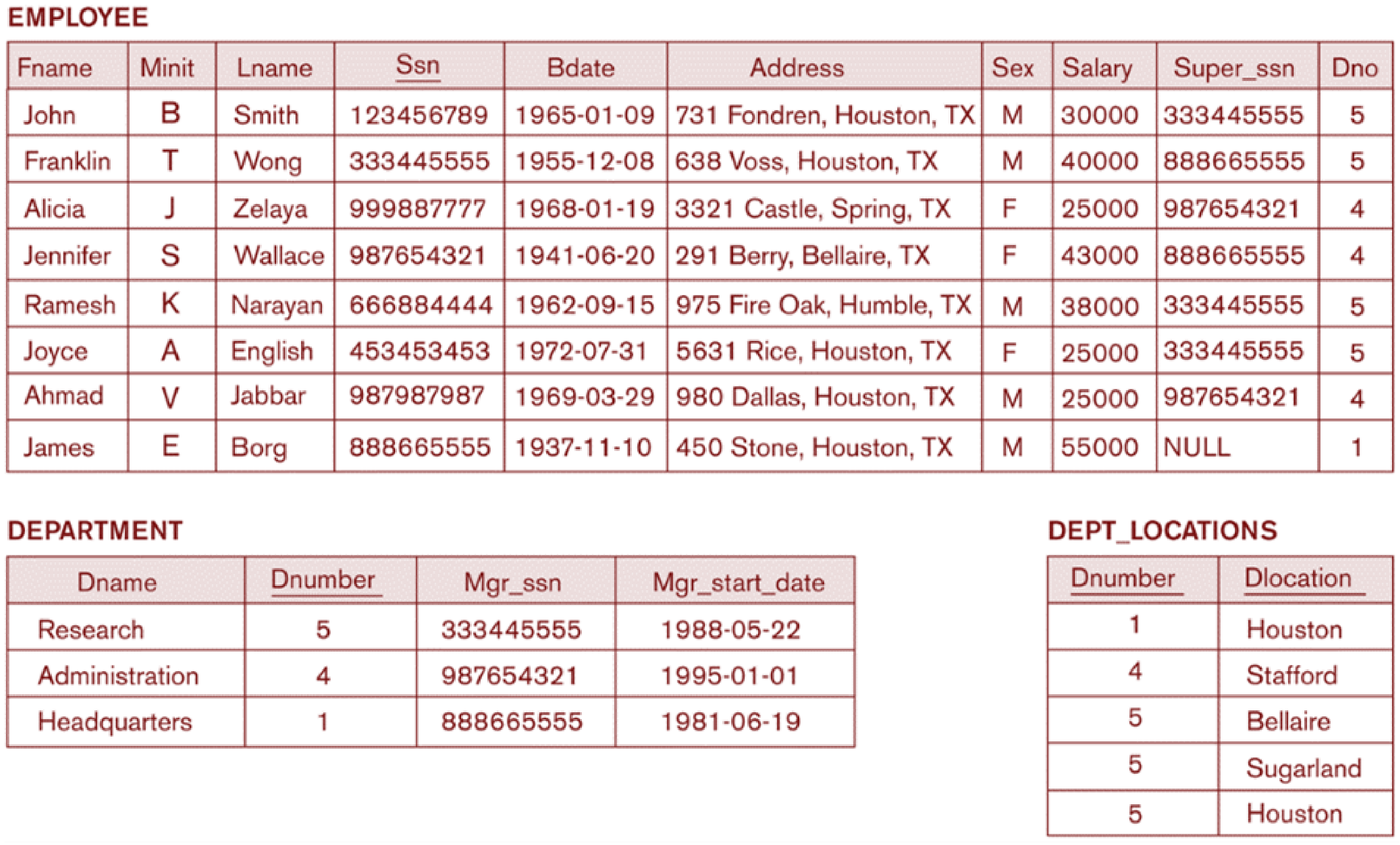
Whenever the database is changed, a new state arises

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 shows an example state for the COMPANY database schema shown in previous slides.

Populated database state for COMPANY



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

Populated database state for COMPANY (cont.)

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] ≠ 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, <u>or</u>
  - (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

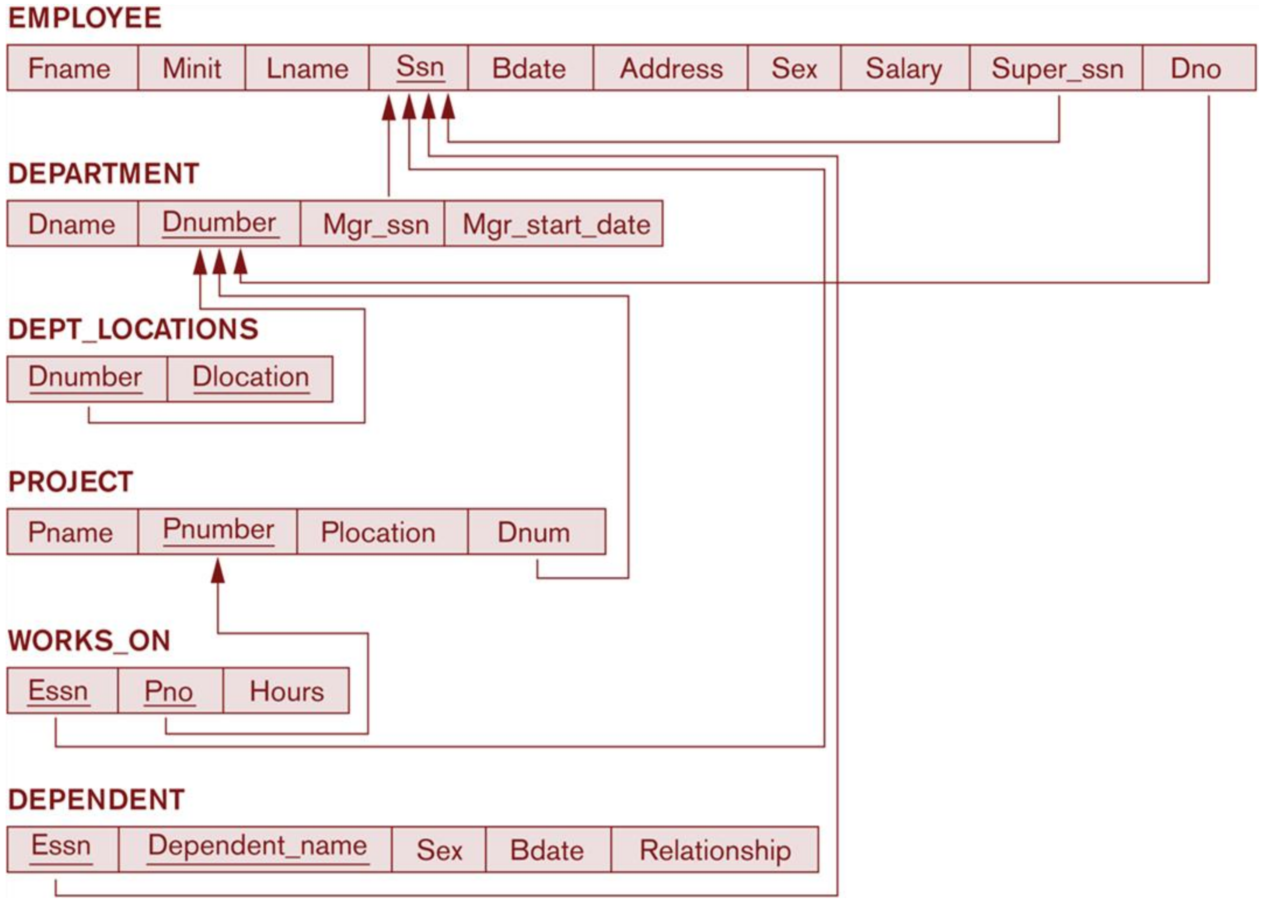
The primary key attribute (or attributes) will be underlined

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



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.