Lecture 3. Relational Data Model (Chapter 5)

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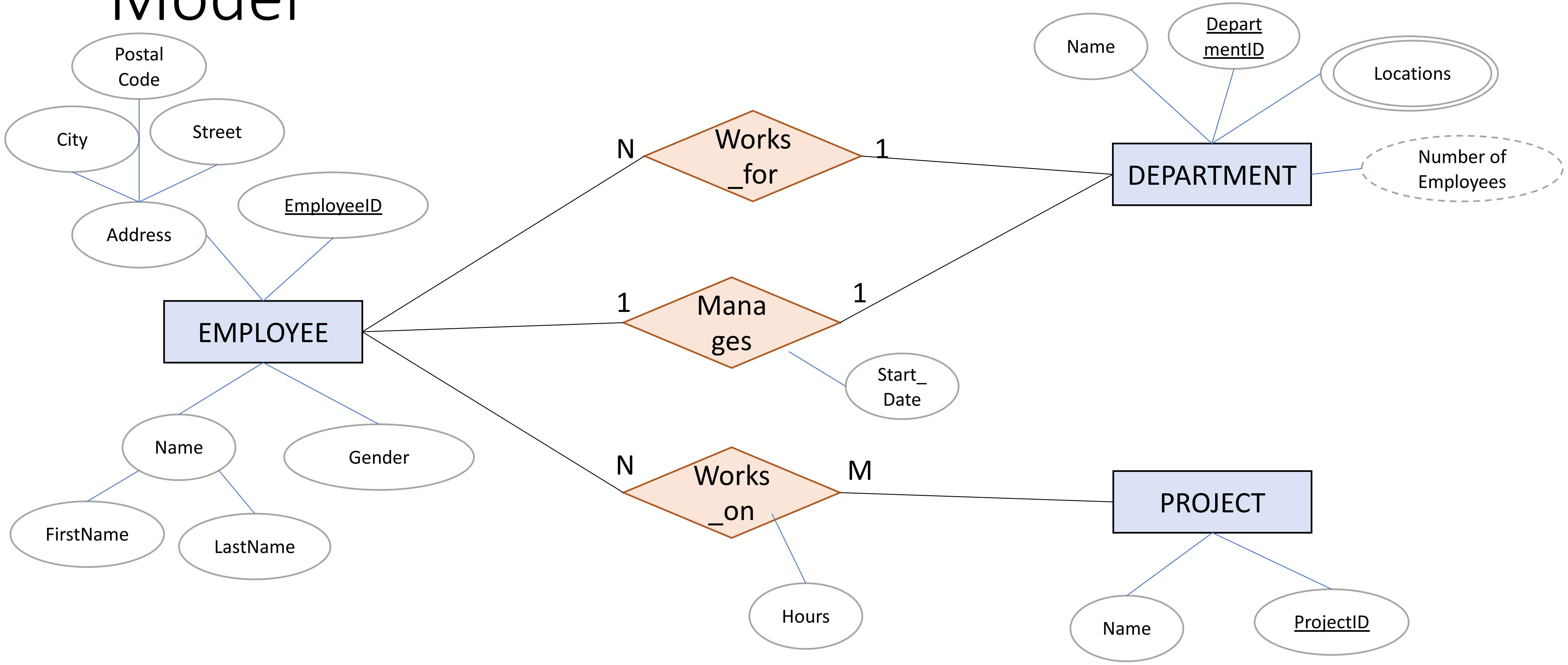
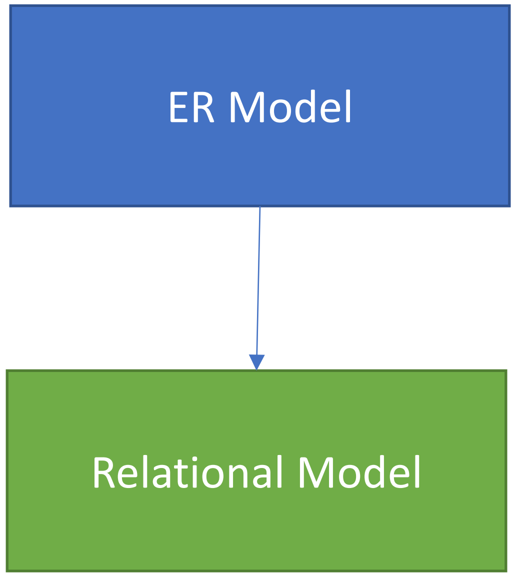
Outline

- From Conceptual Models to Physical Models (ER to Relational Model)
- Relational Model Concepts
- Relational Model Constraints and Relational Database Schemas
- Update Operations and Dealing with Constraint Violations

From ER (Conceptual model) to Relational Model



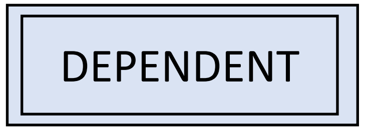
From ER (Conceptual model) to Relational Model



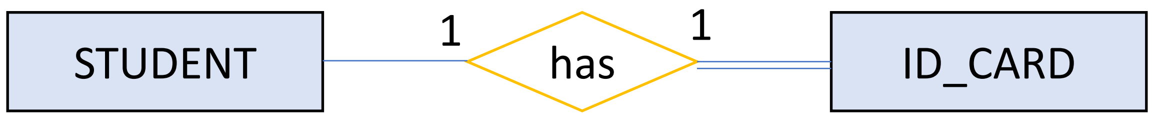
From ER to the Relational Model (Conventions)

- **Step 1 – Strong Entities**
  - Create a **table** that includes all the *simple* attributes
  - Include only the *simple components* of composite attributes
  - Choose a **primary key**
    - **Primary key** is the column or columns that contain values that uniquely identify each row in table. Primary keys must contain UNIQUE values, be static (or consistent), and cannot contain NULL values. The table can not have more then one primary key.

- **Step 2 – Weak Entities**
  - Create a table that includes all the simple attributes
  - Include the *primary key* from the ***owner*** entity, this will become a **foreign key**
    - **Foreign key** is a column (or columns) in one table that refers to the primary key in another table.



From ER to the Relational Model (Conversion Guide)



- **Step 3 – 1:1 Relations**
  - Choose one of the entities (right or left). It is better to choose the entity type with total participation (double line)
  - Copy the ***primary key*** from the first table into second table. It becomes a ***composite primary key*** in the second table.
  - Any attributes tied to the relationship goes to the table with the foreign key

Example:

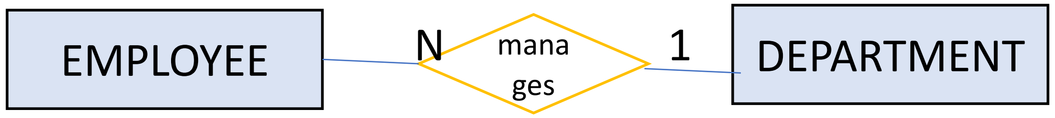
Student Table

ID	FirstName	LastName	….
1	Bob	Larsson	
2	Alice	Andresson	
….			

IdCards Table

ID	Date of Issue	Number	….	StudentID
1	2011.01.25	7805676F2 87654	….	1
	2011.01.25	7805676F2 87654		
..				

From ER to the Relational Model (Conversion Guide)



- **Step 4 – 1:N relations**
  - Choose the entity on the N-side and include copy of the primary key of the entity on the 1-side. The column becomes a foreign key in the table on the N-side
  - Any attributes tied to the relationship goes to the table with the foreign key

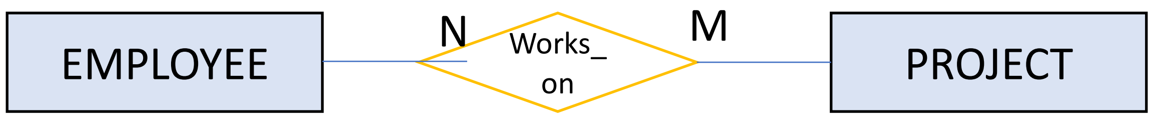
EMPLOYEE Table

ID	FirstName	LastName	….	DepartmentID
1	Bob	Larsson		
2	Alice	Andresson		
….				

DEPARTMENT Table

ID	Name	Location	….
1	Electronics	…	….
2	Economy	…	….
..	….	…	…

From ER to the Relational Model (Conversion Guide)



- **Step 5 – N:M Relations**
  - Create a new table and include the primary keys from the two participating entities
  - Both of these fields become foreign keys in the new table
  - Any attributes tied to the relationship goes to the new table

EMPLOYEE TABLE

ID	FirstName	LastName	….
1	Bob	Larsson	
2	Alice	Andresson	
….			

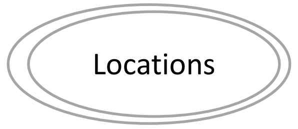
EMPLOYEE_PROJECT

Empl ID	ProjectID		
1	2	12	
1	3		
1	4		

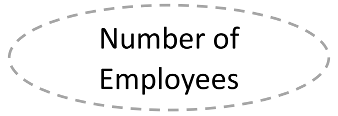
PROJECT TABLE

ID	Name	Location	….
1	Project A	…	…
2	Project B	…	…
….	…	…	..

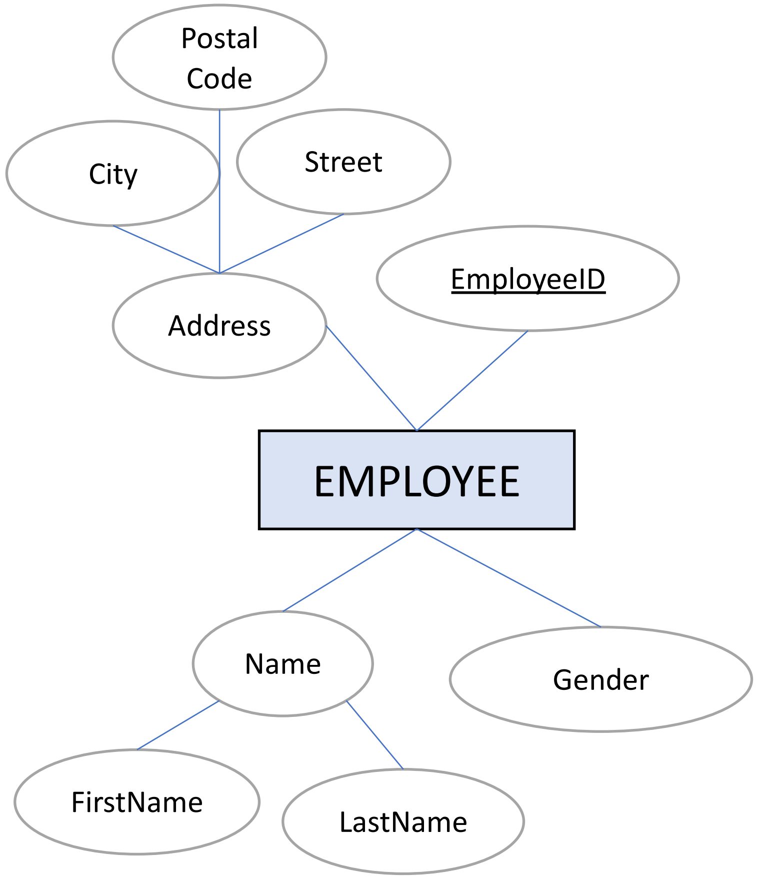
From ER to the Relational Model (Conversion Guide)

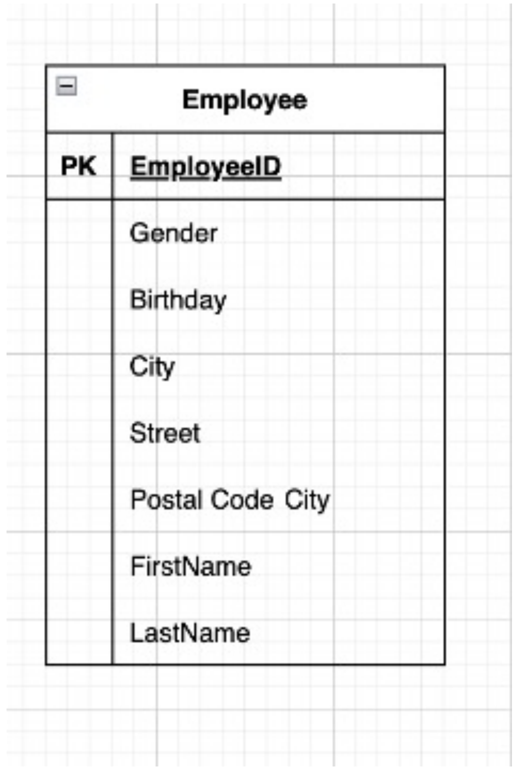


- **Step 6 – Multivalued Attributes**
  - For each multivalued attribute (A) create a new table and move the attribute (A) to this table
  - Include the primary key form the entity that originally had (A) as an attribute
  - The combination of these attributes will be the primary key of the new table
- **Step 7 – Derived Attributes**
  - Coded separately in SQL as a view. They are **not an attributes** in a relation table, because to minimize redundancy and ensure data consistency.



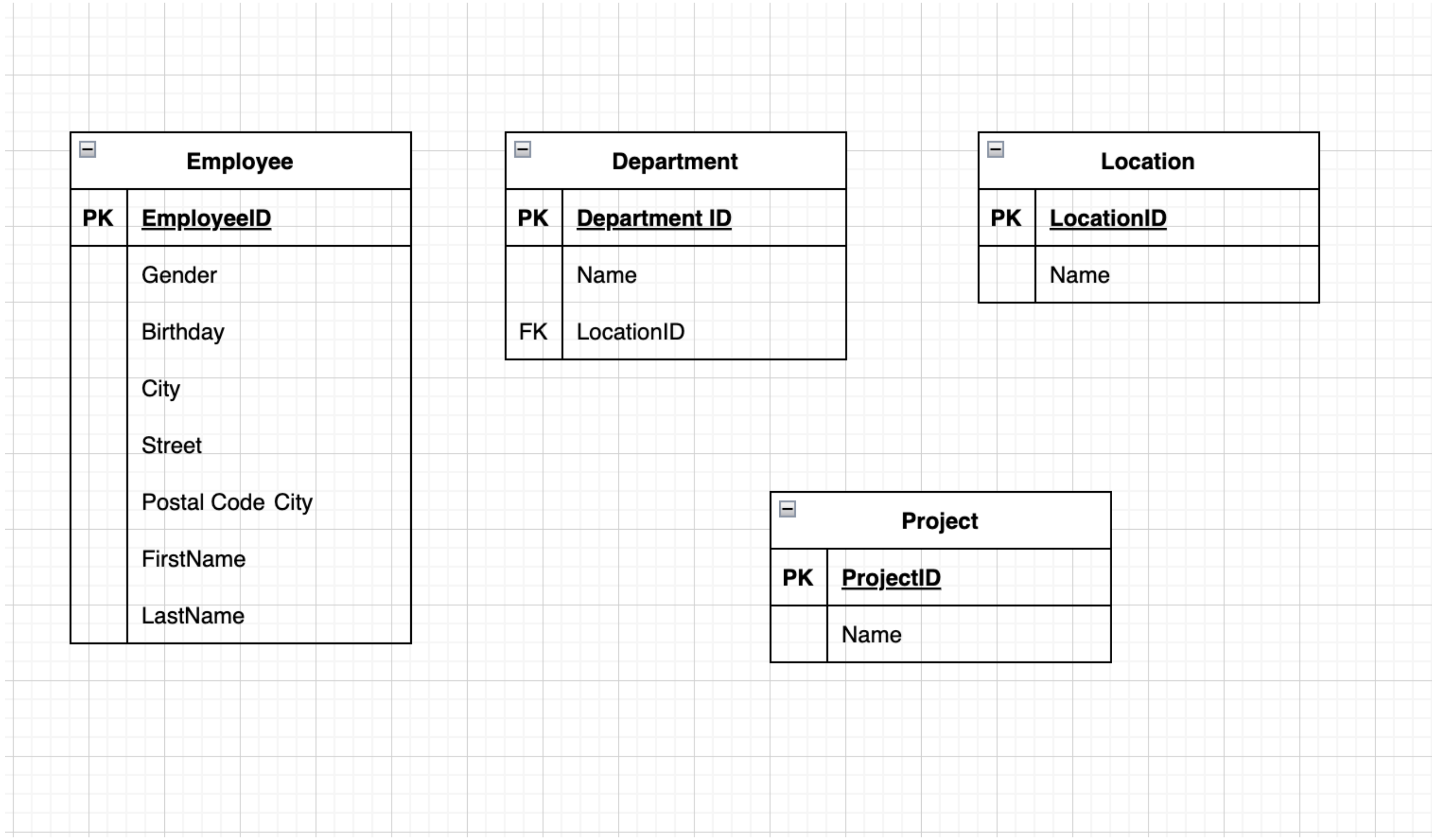
Step 1 - Strong Entities (1)



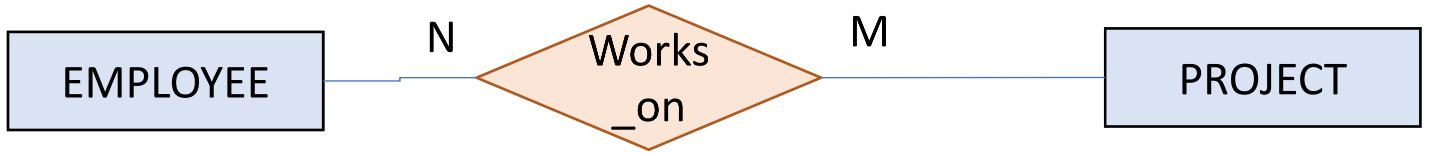


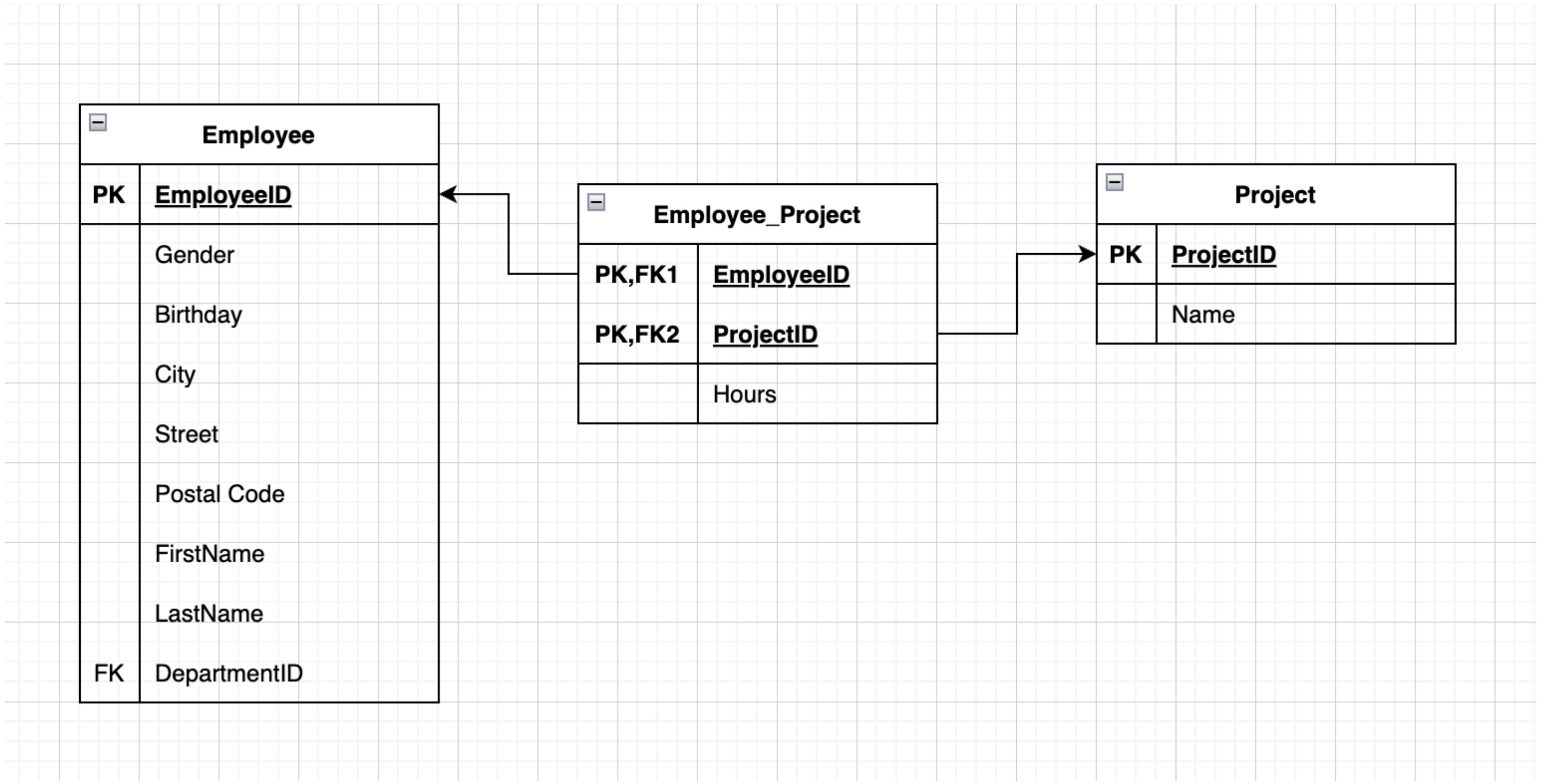
Employee	
PK	EmployeeID
	Gender
	Birthday
	City
	Street
	Postal Code City
	FirstName
	LastName

Step 1 - Strong Entities (2)

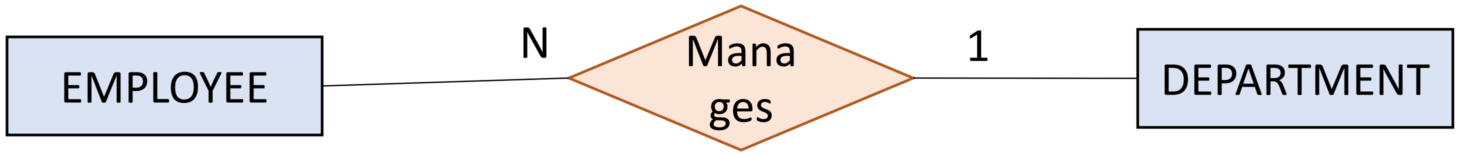


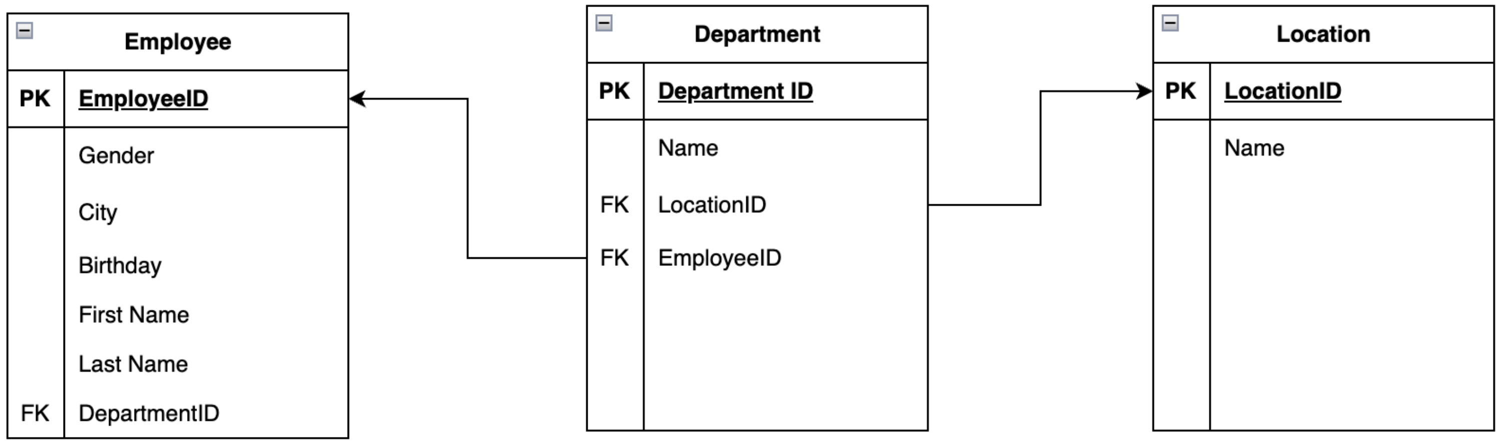
Step 2 – Relations (N:M)



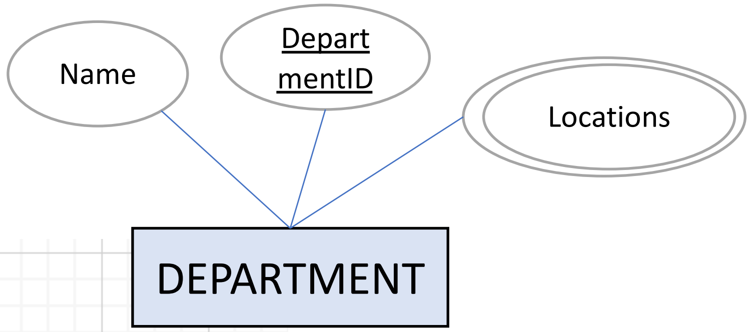


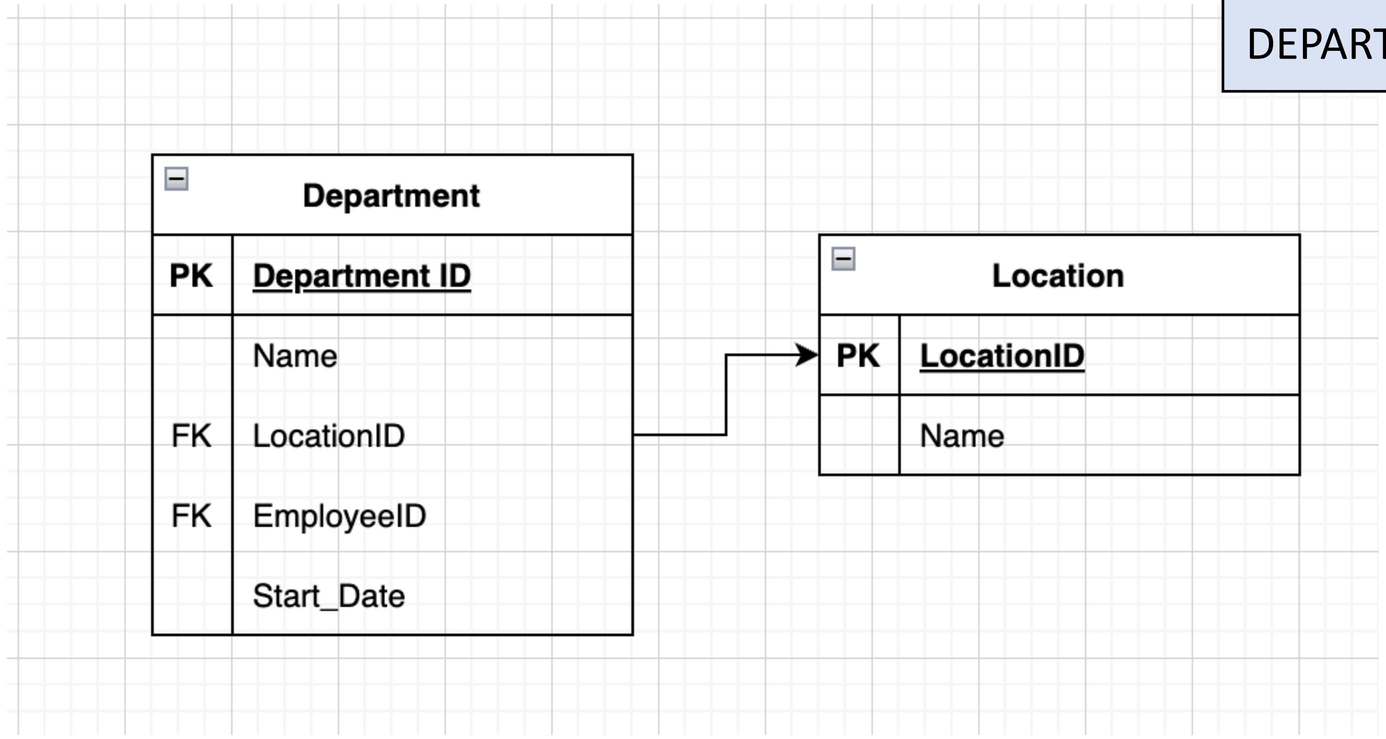
Step 3 –Relation (1:N or N:1)



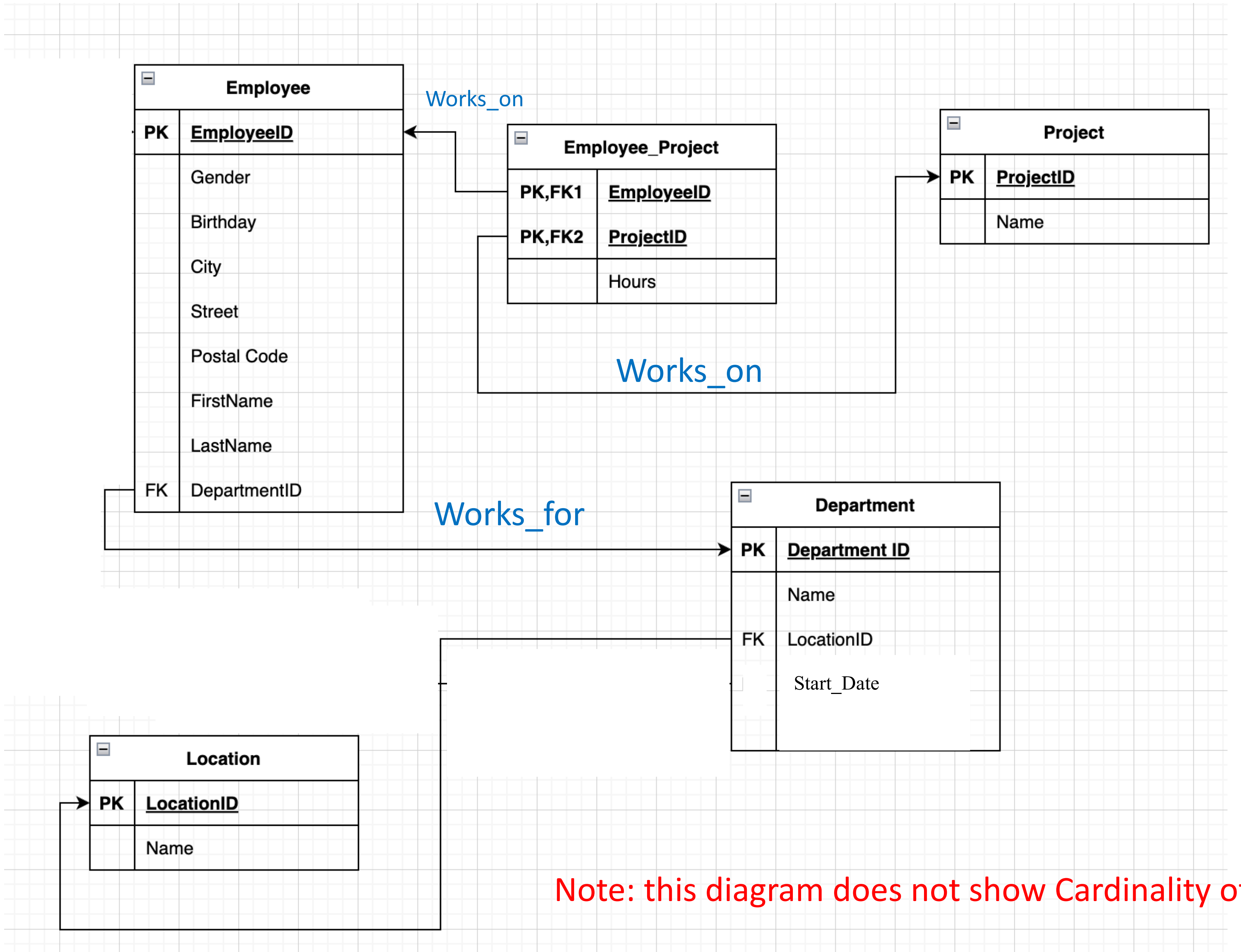


Step 4 – Multivalued Attributes





Relation Model



Note: this diagram does not show Cardinality of relationships

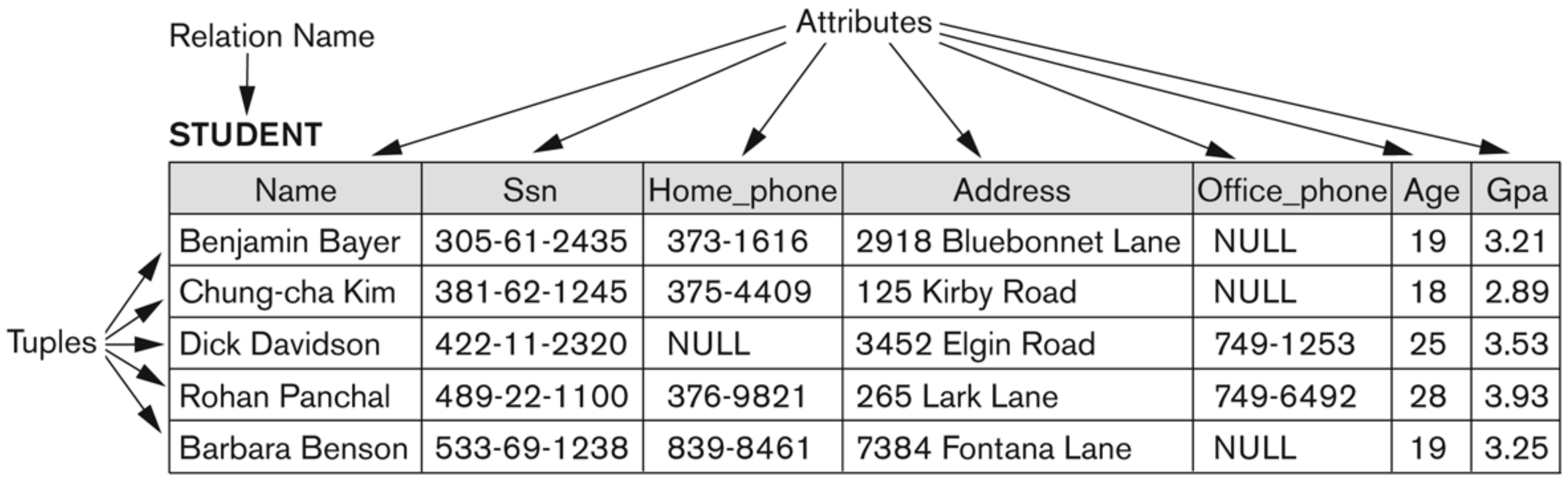
Terminology

Informal (Casual)	**Formal (DBMS)**
Table	Relation
Columns/fields/column header	Attributes
All possible column values	Domain
Row/Rows	Tuple/Tuples
Table definition	Schema of relation
Populated Table	State of relation

Relational Data Model Concepts

- Relation data model is used for data storage and processing.
- A relation represented as a table with ***columns*** (or *attributes*) and ***rows*** (or *tuples*)
  - It is based on the mathematical concept of relation based on the idea of sets proposed by Dr. E.F. Codd of IBM Research in 1970
- ***Relationships,*** defined as the associations or interactions between entities
- ***The degree of relation*** refers to number of columns/attributes in the table/relation
- Properties of a relation/table:
  - Should have a distinct relation name (or table name)
  - Each value attribute should contain exactly one value
  - The attribute names should be distinct names
  - Each tuple is distinct (no duplicate tuples)

Example of 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

Figure 5.1
The attributes and tuples of a relation STUDENT.

Values inside of the table, called **domains** *D*

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 a set of values (enclosed in angled brackets ‘< … >’)
- Each value is derived from an appropriate *domain*.
- A row in the CUSTOMER relation (or table) is a 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 tuple (row) as it has 4 values
  - A tuple (row) in the CUSTOMER relation (table).
- A relation (table) is a **set** of such tuples (rows)

Formal Definitions - Domain

- A **domain** is a set of acceptable values that an attribute is allowed to contain

  Examples:
  - "Swedish_phone_numbers" are the set of 11 digit phone numbers including country code.
  - Swedish Personal Number. The set of valid 12 digits personal numbers
  - Grade_points. Possible values for grade A (95-100 points), for grade B (86-94), etc.
  - Marital Status has a set of possible values: {Married, Single, Divorced..}

- A domain also has a *data-type* or a *format* defined for it.
  - The Swedish_phone_numbers may have a format: "(+dd)dd-ddd dd dd" 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.
- It is possible for several attributes to have the same domain:
  - Example: Invoice_Date, Order_Date, Shipment_Date can have the same domain type (Date) and the same format (yy-mm-dd)

NULL values

- A NULL is a special symbol, independent of data type, which means either unknown or inapplicable. It does not mean zero or blank.
- Can represent:
  - An unknown attribute value
  - A known, but missing, attribute value
  - A not applicable value
- Issues with NULL values:
  - Can create problems when functions such as COUNT, AVERAGE, SUM are used
  - Can create logical problems when relational tales are linked/connected

  NOTE: The result of a comparison operation is null when either argument is null. The result of an arithmetic operation is null when either argument is null (except functions that ignore nulls).

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 .
    - The ordering of values in a tuple in relation schema is important
    - 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> }
- *Values* in a tuple:
  - All values are considered ***atomic*** (indivisible) or ***Simple*** type. Composite and multi-valued attributes are not allowed in relation model. Multivalued attributes must be presented by separate relations (and/or weak entities), and composite attributes are represented only by their simple component attributes.
  - 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.
  - During database design, it is best to avoid NULL values as much as possible

CONSTRAINTS

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

There are of three main types:

1. **Inherent or Implicit Constraints**: These are based on the data model itself.

For example: relational model does not allow a list as a value for any attribute, the table names are unique, no duplicated tuples in a table, the primary key can not be NULL.

2. **Schema-based or Explicit Constraints**: They are expressed in the schema by using the facilities provided by the model.

For example: key constrains, constrains on NULLs

```
CREATE TABLE Employees (
   EmployeeID INT PRIMARY KEY,  ///Primary key constraint, each employee id must be unique, and not NULL
   Email VARCHAR(100) UNIQUE,   //// Unique constraint on the email column ensures that each email address must be unique
);
```

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. For example: data validation, conditions, business rules, enum constrains, security constrains, or temporal constrains

```
 Age DECIMAL(16,80) CHECK (Age>=16 AND Age<=80) /// CHECK constraint ensures that the Age column must be between 16 and 80 year.
```

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:
  - **Domain** constraints
  - **Key** constraints
  - **Entity integrity** constraints
  - **Referential integrity** constraints

Domain Constraints

- Every value in a tuple must be from the *domain of its attribute* (or it could be **null**, if allowed for that attribute):
  - Data Type Constraint
  - Length Constraint, e.g., ProductName VARCHAR(100)
  - Check Constraint, e.g., Age INT, CONSTRAINT CHK_Age CHECK (Age >= 18)
- Domain constraints specify that within each tuple, the value of each attribute *A* must be an atomic value from the domain *dom(A):*
  - Standard numeric data types for ***integers*** (short integer, integer, long integer)
  - And ***real*** numbers (float and double-precision float)
  - Characters, Booleans, fixed-length strings, date, time, timestamp, enumerated data type, a subrange of values, etc.

Key Constraints (1)

- **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 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)
- Any superkey formed from a single attribute is also a key. A key with multiple attributes must require *all* its attributes together to have the uniqueness property.

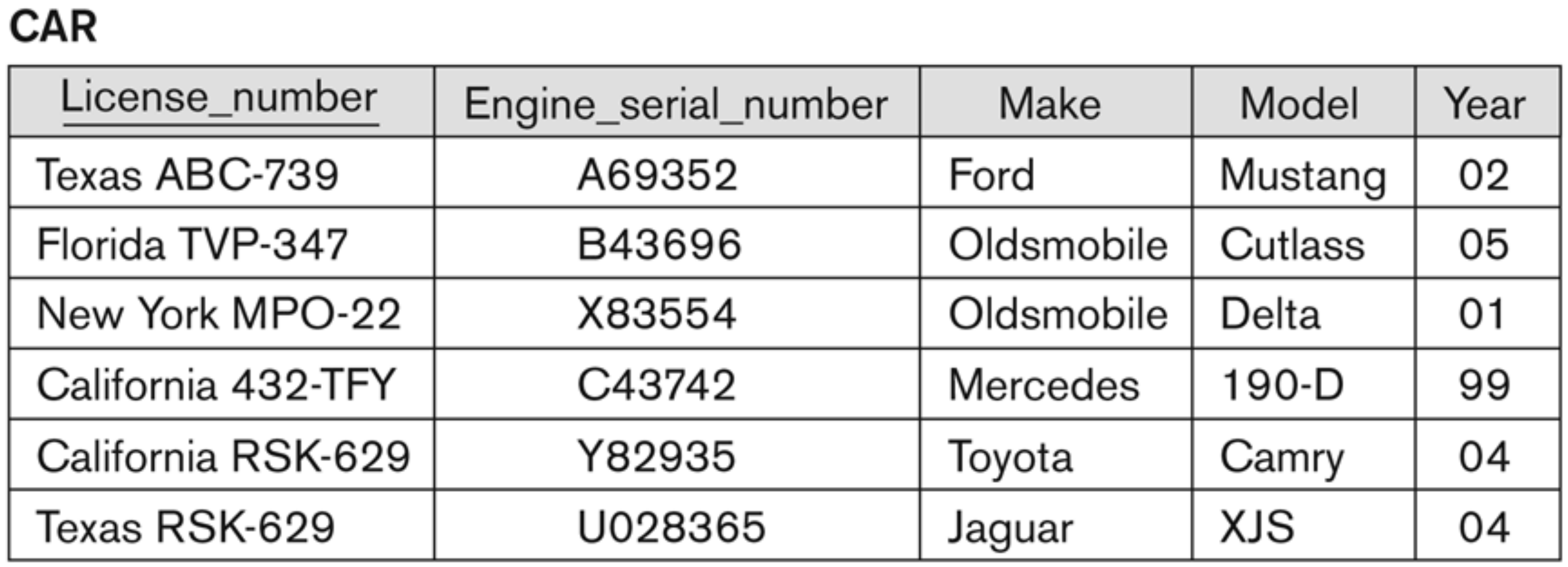
Key Constraints (2)

- Example: Consider the CAR relation schema:
  - CAR(State, Reg#, SerialNo, Make, Model, Year)
  - CAR has two keys:
    - Key 1 = {SerialNo, Reg#}
    - Key 2 = {SerialNo}
    - Key 3 = {Reg#}
  - All are also superkeys of CAR
  - {SerialNo, Reg#} 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 superkeys they called a **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 of attributes)
  - Not always applicable – choice is sometimes subjective

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



CAR

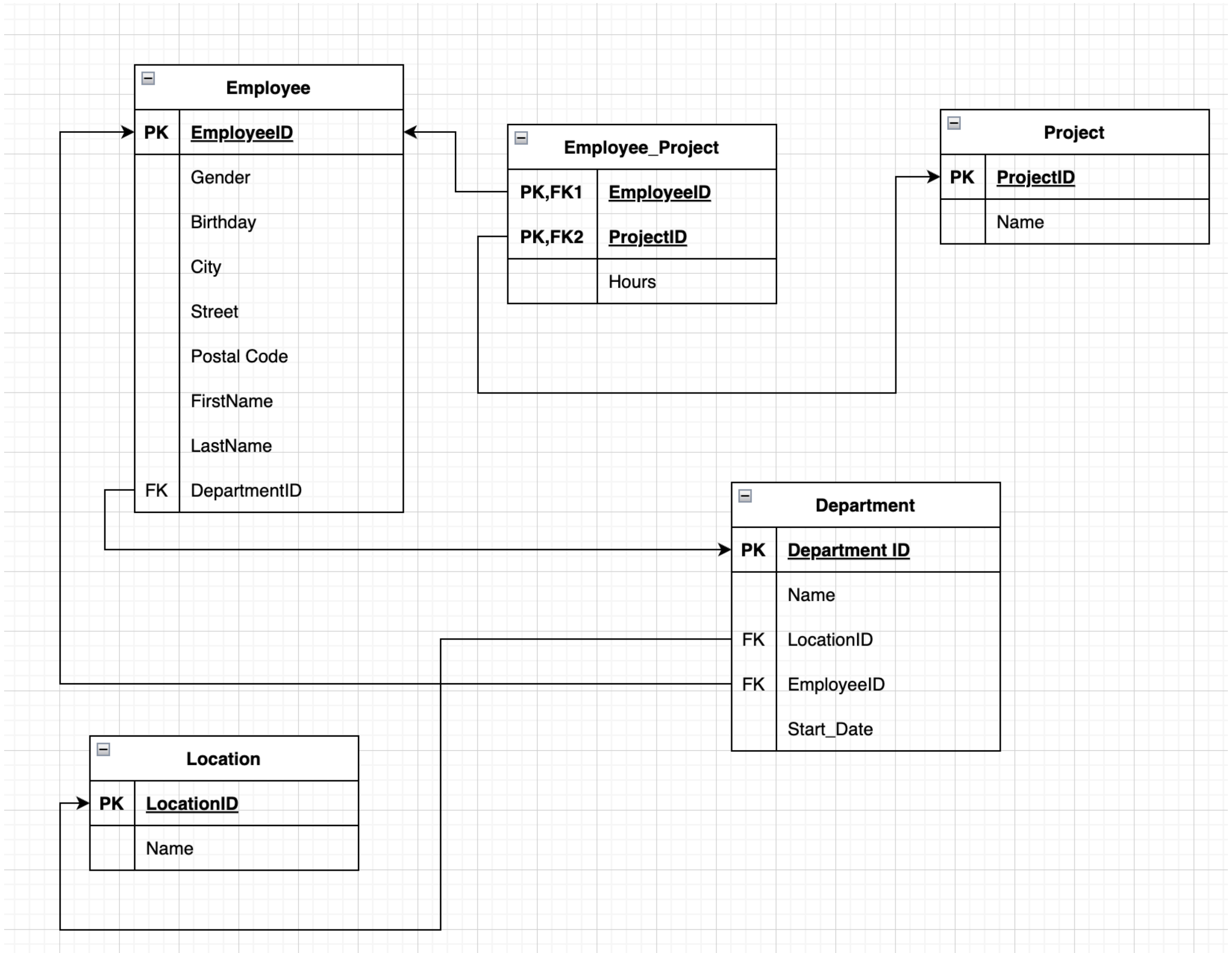
License_number	Engine_serial_number	Make	Model	Year
Texas ABC-739	A69352	Ford	Mustang	02
Florida TVP-347	B43696	Oldsmobile	Cutlass	05
New York MPO-22	X83554	Oldsmobile	Delta	01
California 432-TFY	C43742	Mercedes	190-D	99
California RSK-629	Y82935	Toyota	Camry	04
Texas RSK-629	U028365	Jaguar	XJS	04

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

Referential Integrity

- The referential integrity is specified between the two relations (tables) is used to maintain the consistency among tuples in the two relations (tables).
- A set of of attributes FK in relation schema R1 is a ***foreign key*** of R1 that references relation R2 if it is satisfies the following rules:
  - The attributes in FK have the same domain(s) as the primary key attributes PK of R2;
  - A value of FK in a tuple t1 can occurs as a value of PK for some tuple t2 or is NULL.

PK and FK


Employee
PK | EmployeeID
Gender
Birthday
City
Street
Postal Code
FirstName
LastName
FK | DepartmentID
Employee_Project
PK,FK1 | EmployeeID
PK,FK2 | ProjectID
Hours
Project
PK | ProjectID
Name
Department
PK | Department ID
Name
FK | LocationID
FK | EmployeeID
Start_Date
Location
PK | LocationID
Name

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.
- Note: whenever we apply the above operations to the relational table, the constrains should not get violated

Update Operations on Relations (Tables)

- 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 (e,g., we insert value 15 for employee’s age attribute which should not be less than 16)
    - 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

Examples INSERT operation violated

- Operation 1:
  - Insert <‘Cecilia’, ‘F’, ‘Kolonsky’, NULL, ‘2000-04-05’, ‘Linnea gatan 1, 355 63 Växjö’>
  - *Result*: this insertion violates the entity integrity constrain (NULL for the personal number), so it is rejected.
- Operation 2:
  - Insert <‘’Alicia’, ‘J’, ‘Zelaya’, ‘123456789’, ‘Linnea gatan 1, 355 63 Växjö’>
  - *Result*: This insertion violates the key constrain because another tuple (row) with the same personal number value already exists in the EMPLOYEE table, so it is rejected
- Operation 3
  - Insert <‘Cecilia’, ‘F’, ‘Kolonsky’, NULL, ‘2000-04-05’, ‘Linnea gatan 1, 355 63 Växjö’, 7>
  - *Result*: This insertion violates the referential integrity constrain specified on Dno in EMPLOYEE because no corresponding referenced tuple exists in DEPARTMENT with Dnumber = 7. So it is rejected
- Operation 4:
  - Insert <‘Cecilia’, ‘F’, ‘Kolonsky’, ‘20000334-2389’, ‘2000-04-05’, ‘Linnea gatan 1, 355 63 Växjö’>
  - Result: This insertion violates the domain constrain on personal number because the birth day 34 can not be specified in personal number format ‘’yyyymmdd-dddd’

Company Database Example

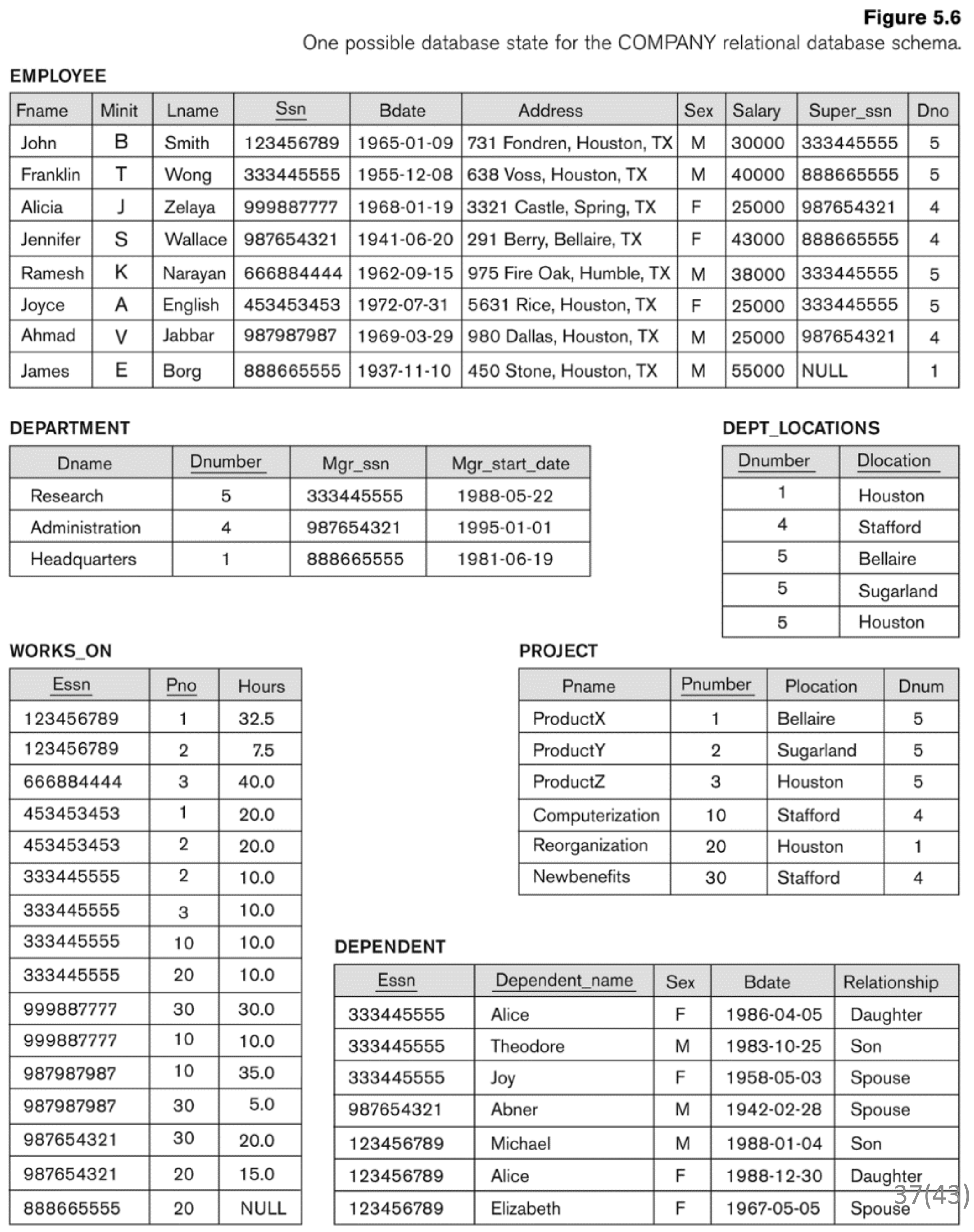


Figure 5.6
One possible database state for the COMPANY relational database schema.

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

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

Examples DELETE Violations

- Operation 1:
  - Delete the WORKS_ON tuple with Esnn = ‘999887777’ and Pno=10
  - *Result*: This deletion is acceptable and deletes exactly one tuple
- Operation 2:
  - Delete the EMPLOYEE tuple with Ssn =‘999887777’
  - *Result*: This deletion is not acceptable, because there are tuples in WORKS_ON that refer to this tuple. Hence, if the tuple in EMPLOYEE is deleted, referential integrity violations will result. Solution: use CASCADE option
- Operation 3:
  - Delete the EMLOYEE tuple with Ssn=‘333445555’
  - *Result*: This deletion will result in even worse referential integrity violations, because the tuple involved in referenced by tuples from the EMPLOYEE, DEPARTMENT, WORKS_ON, and DEPENDENT relations. Solution: use CASCADE option

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. Solution: use CASCADE option on UPDATE
  - 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

Additional Video Tutorials

- Relation Data Model (https://www.youtube.com/watch?v=-CuY5ADwn24)
- Relational Database Concepts (https://www.youtube.com/watch?v=NvrpuBAMddw)

Lecture 3 Key Terms/Concepts for the Exam

- **Constraints** determine which values are permissible and which are not in the database.
- **NULL value**: a special value, independent of data type, which means either unknown or inapplicable; it does not mean zero or blank
- A **domain** is a set of acceptable values that an attribute is allowed to contain
- **integrity constraints**: logical statements that state what data values are or are not allowed and which format is suitable for an attribute
- **referential integrity**: requires that a foreign key must have a matching primary key or it must be null
- **Schema-based constrains**: constrains that can be directly expressed in the schemas of the data model. They are domain constraints, key constrains, constrains on NULL, integrity and referential integrity constraints
- **Application-based constrains:** Constraints that cannot be directly expressed in the schemas of the data model, and hence must be expressed and enforced by the application programs

Lecture 3 Key Terms/Concepts for the Exam

- A **Superkey** is a single key or a group of multiple keys that can uniquely identify tuples in a table. Super keys can contain redundant attributes that might not be important for identifying tuples
- A **key:** an attribute or group of attributes whose values can be used to uniquely identify an individual entity in an entity set
- A **composite key**: composed of two or more attributes, but it must be minimal
- A **foreign key (FK)**: an attribute in a table that references the primary key in another table OR it can be null
- A **primary key** is a minimal set of attribute (or set of attributes) that is used to uniquely identifies all attributes in a relation
- Possible violations for UPDATE operation: key constrains, domain constrains
- Possible violations for INSERT operation: domain, key, integrity, and referential integrity
- Possible violations for DELETE operation: key constrains