Database Modeling

Read Chapters 3, 4 and 14

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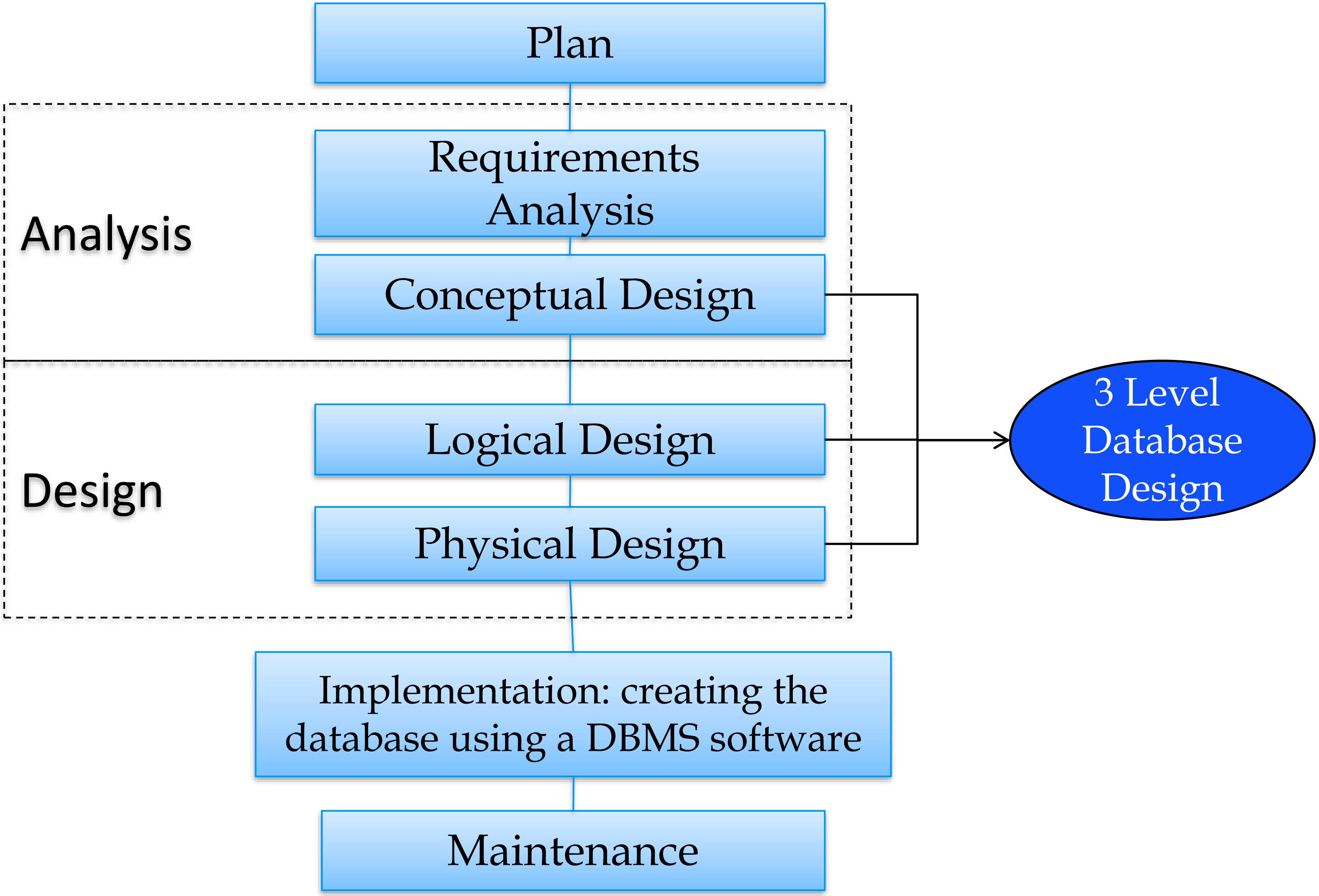
Conceptual Data Modeling using Entity-Relationship Diagram (ERD)

Database Development



→ Similar to software development

Database Design Steps in Practice

- Requirements Analysis
  - User needs; what must database do?
- Conceptual Design
  - Database `schema' in terms of entities and relationships
- Logical Design
  - Add attributes to entities and relationships
  - Schema Refinement: Normalization to reduce redundancy
  - Translate the ER into a database schema
- Physical Design - indexes, disk layout
- Security Design - who accesses what

Conceptual Database Design

- Use the Entity Relationship (ER) model to develop a high level description of the data
- Identify the entities and relationships in the enterprise
- Identify what information about these entities and relationships is to be stored in the database
- Draw an *Entity Relationship* diagram (ERD)
- Identify the integrity constraints that apply to the entities and relationships
- Check with the client that the ER model that has been developed is correct

Logical Database Design

- Determine which data model should be used to implement the database (the relational model is the most widely used)
- Determine which DBMS to use
  - In most cases this means deciding which existing DBMS product to purchase or license
- Map, or translate, the conceptual schema to a database schema of the chosen model
- There are two major problems to be avoided
  - ***Redundancy*** – information should not be repeated
  - ***Incompleteness*** – it should be possible to record all the desired information

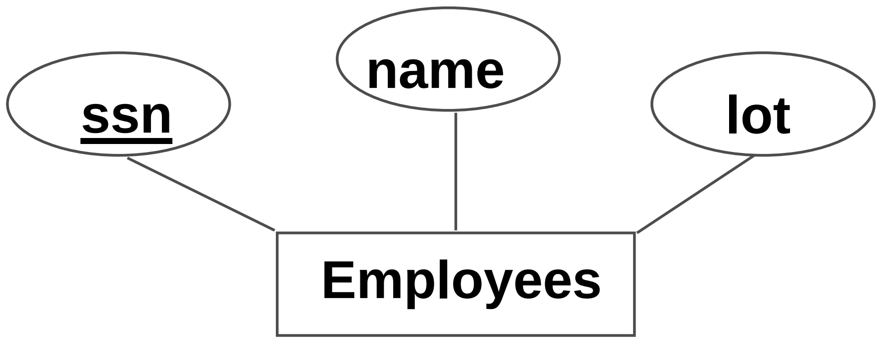
The Entity-Relationship Model

- The most common conceptual data model
- The major components of the ER Model are:
  - **Entity** – something in the real world that we wish to track and store data about (employee, item)
  - **Attribute** – A characteristic of an entity or relationship (EmployeeID, Item Description)
  - **Relationship** – A link that connect between entities (e.g. A customer (*entity*) buys (*relationship*) a product (*entity*)
  - **Constraints** which restrict relationships, e.g. an account *must be* owned by a customer

Entity-Relationship Diagram

- Entity-relationship diagram show the structure of a database graphically
  - Simple symbols: rectangles, diamonds, ovals and lines represent the components of the ER model
  - They are straightforward and easy to explain to users
- Dr. Peter Chen developed ERD. The ERD notation become a popular tool for relational database design
- There are many variations of ER diagrams
  - So don't expect the symbols in every ER diagram you see to be exactly the same!
  - Some common variations are discussed in this presentation

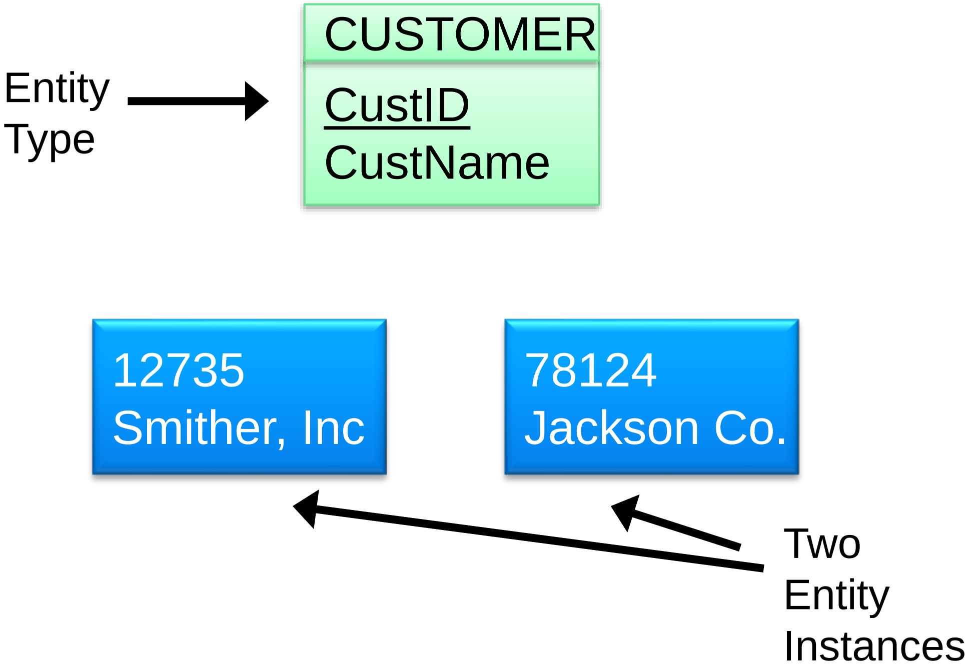
Entities and Entity Sets



- ***Entity:*** Real-world object, distinguishable from other objects. An entity is described using a set of ***attributes***.
- ***Entity Type (or Entity Set)***: A collection of similar entities. E.g., all employees.
  - Each entity set has a *key* *(underlined)*.
  - A *key* is a set of attributes whose values *uniquely* identify an entity in an entity set

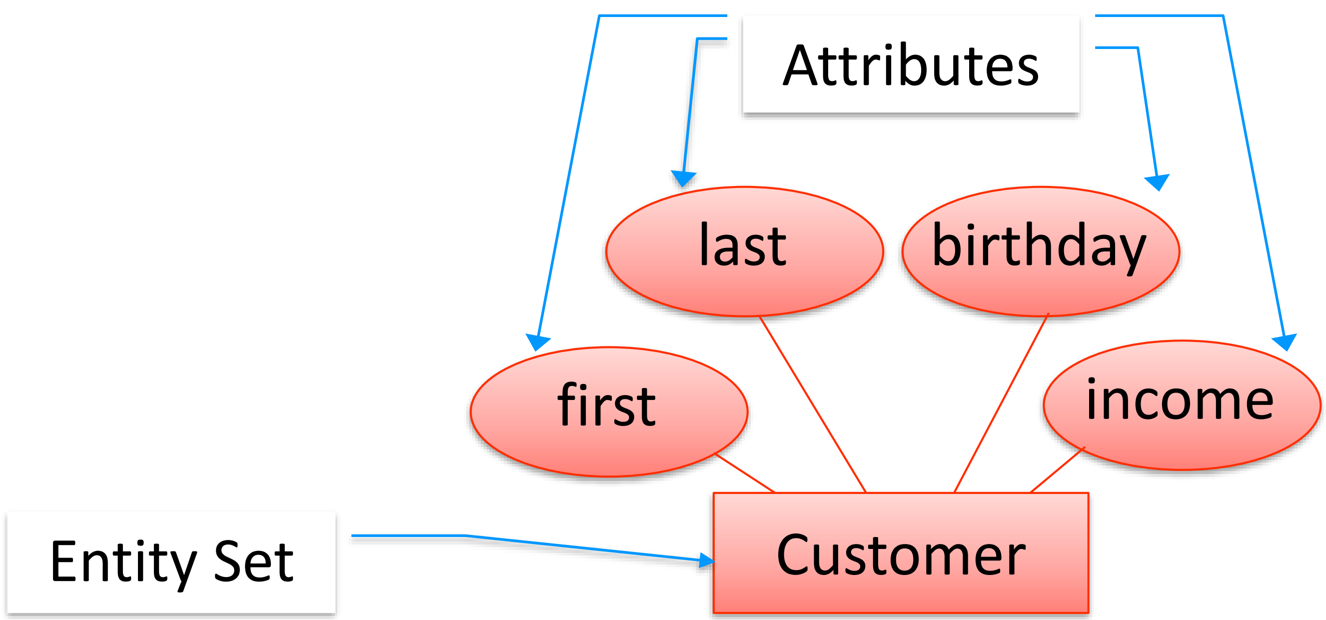
Instance versus Type

- An *entity type* is a description of the structure and format of the instance of the entity
- An *entity instance* is a specific occurrence of an entity type



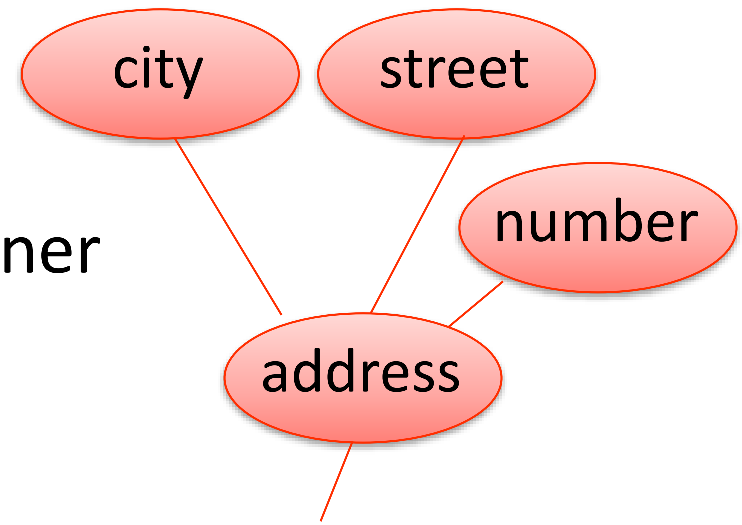
Attributes

- Attributes describe the properties of entities or relationships.
  - Each attribute has a domain: a set of all possible attribute values
  - Correspond to fields or columns of a table.
  - Avoid derived attribute, e.g., age



Composite Attributes

- Composite attributes are divided into subparts
  - e.g. address is composed of city, street and number
- They group related attributes together to make the model cleaner
- Some versions of the ER model disallow composite attributes
  - Replacing them with their subparts alone

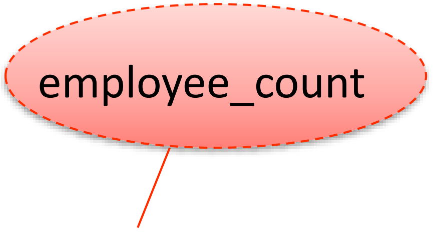


Multivalued Attributes

- A multivalued attribute is a set of values
  - All of the same type
  - e.g. phone numbers
- Some versions of the ER model disallow multivalued attributes
  - Replacing them with another entity

Derived Attributes

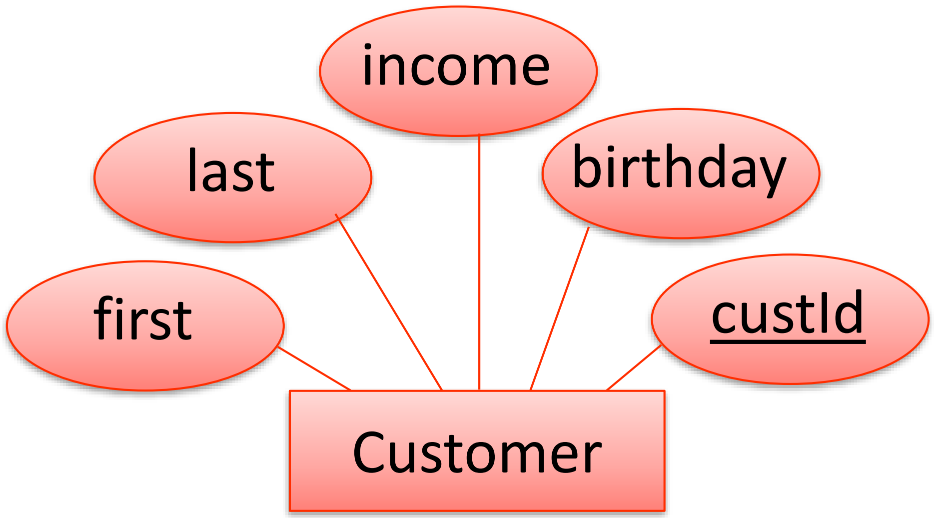
- The value of a derived attribute can be derived from other values
  - Belonging to related attributes or entities
  - e.g. employee_count for a department
    - Calculated by counting the number of employees in the department
- Derived attributes do not need to be stored in the database
  - They can be calculated when required



Selecting a Primary Key

- A *key* is a set of attributes whose values *uniquely* identify an entity in an entity set
- A primary key must be a candidate key
- The primary key should be chosen so that its attributes never (or very rarely) change
  - Including an address as part of a primary key is therefore not recommended
  - E.g., Qatari National ID make a good primary key
- It is sometimes useful to *generate* a unique primary key for entities

Primary Key



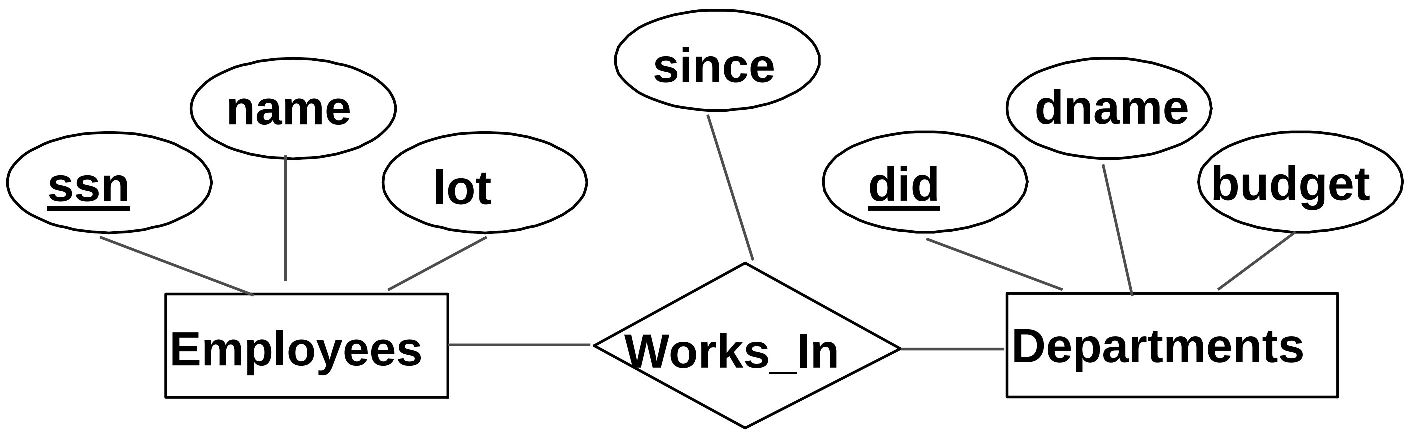
Candidate Key 1: {first, last, birthday}*

Candidate Key 2: {custId}

Primary Key: {custId}

*assuming (unrealistically) that there are no two people with the same first name, last name and birthday

Relationship

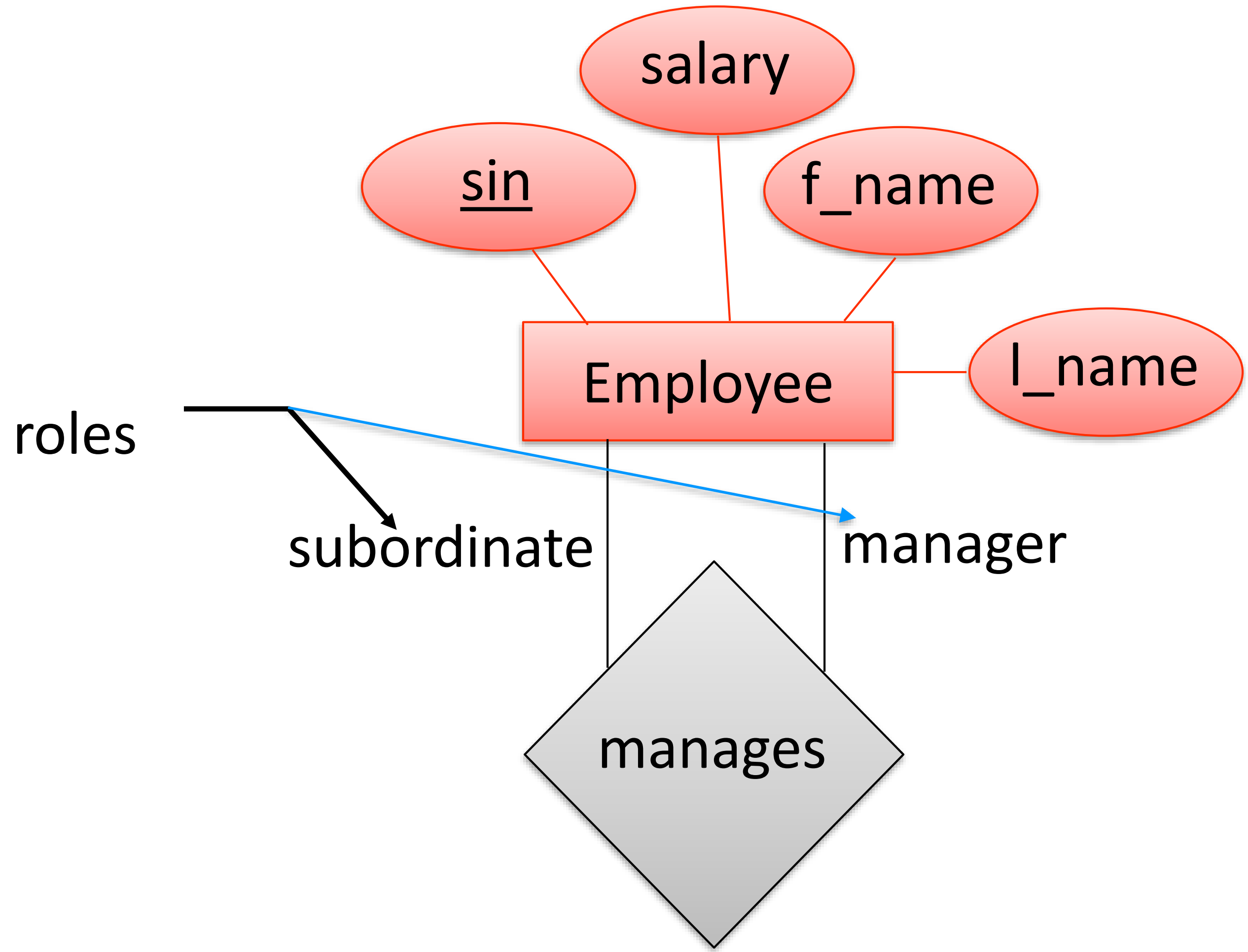


- *Relationship*: Association among two or more entities. E.g., Ali works in Pharmacy department.
  - relationships can have their own attributes.
- *Relationship Type (or Relationship Set)*: Collection of similar relationships.

Relationships (cont'd)

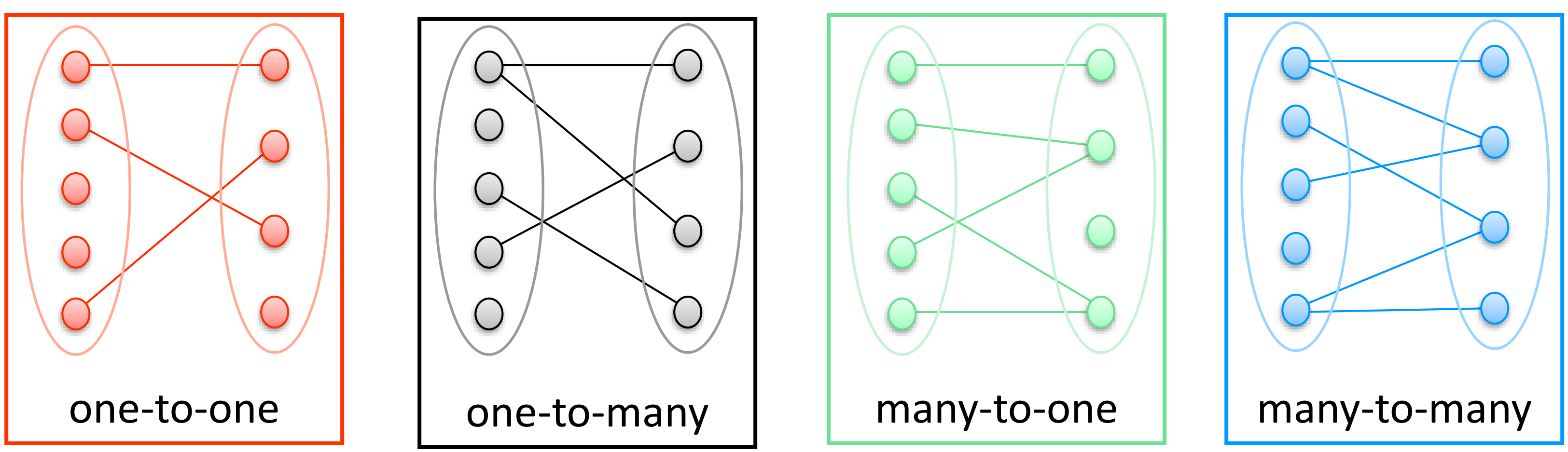
- Relationship participation
  - **Mandatory**: must have a corresponding occurrence
    - e.g., Every product must have a category
  - **Optional**: may not have a corresponding occurrence
    - e.g., A product may have an order
- Cardinality expresses number of <u>entity instances</u> associated with one instance of related entity
  - Minimum Cardinality: If zero, then optional; If one, then mandatory
  - Maximum Cardinality: stated as "many" (when greater than 1)
- Degree of the relationship
  - The number of <u>entity classes</u> in the relationship
  - Most common: binary relationship

And Another Relationship Set



Cardinalities

- Types of relationship in terms of the number of relationships that the participating entities may be involved in:
  - One-to-one (1:1)
  - One-to-many (1:N)
  - Many-to-many (M:N)

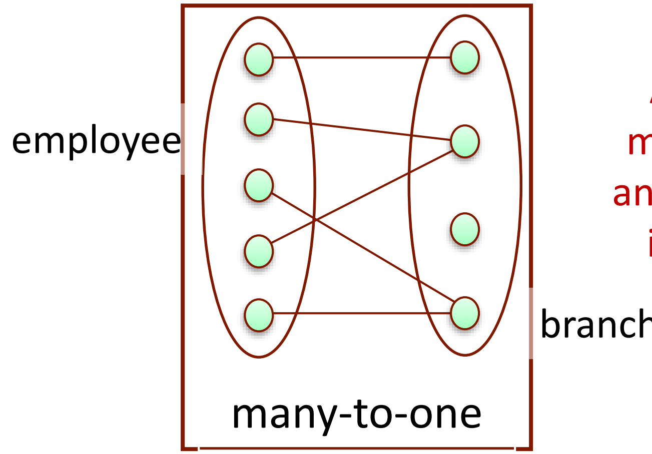


Cardinalities

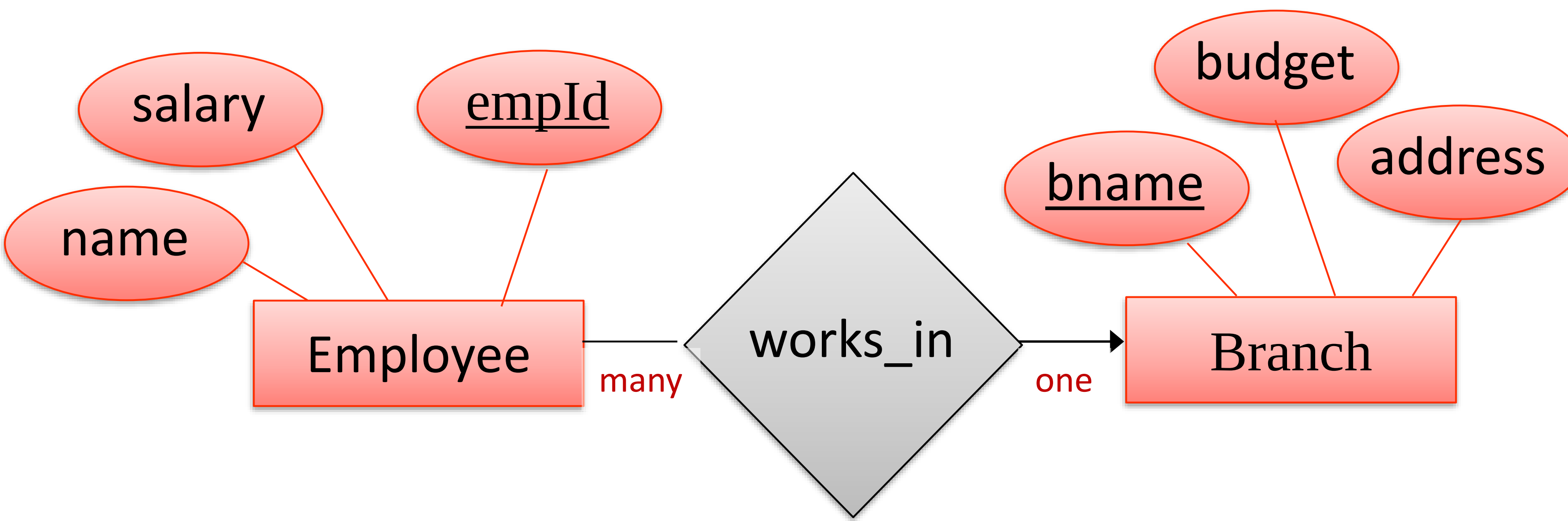
- Assume entity sets A and B
- One-to-one
  - An entity in A associates with *at most* one entity in B, an entity in B associates with *at most* one entity in A
- One-to-many (A to B)
  - An entity in A associates with *any number* of entities in B, an entity in B associates with at most one entity in A
- Many-to-many
  - An entity in A associates with *any number* of entities in B, an entity in B associates with *any number* of entities in A

Cardinalities Example

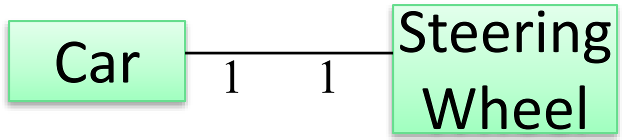
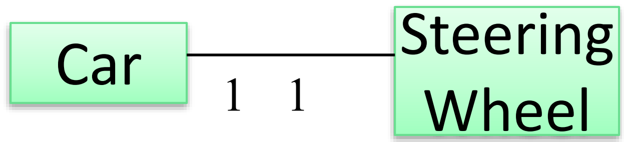
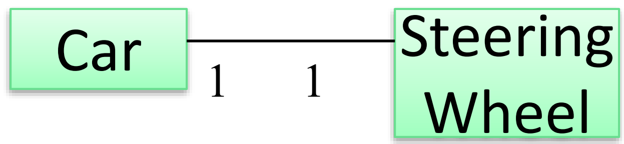
- An employee can work in only one branch
- A branch can have many employees working in it

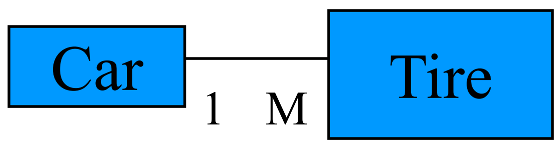
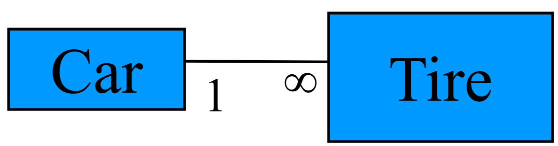
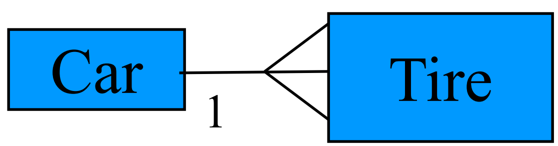


A branch can have many employees but an employee can work in only one branch

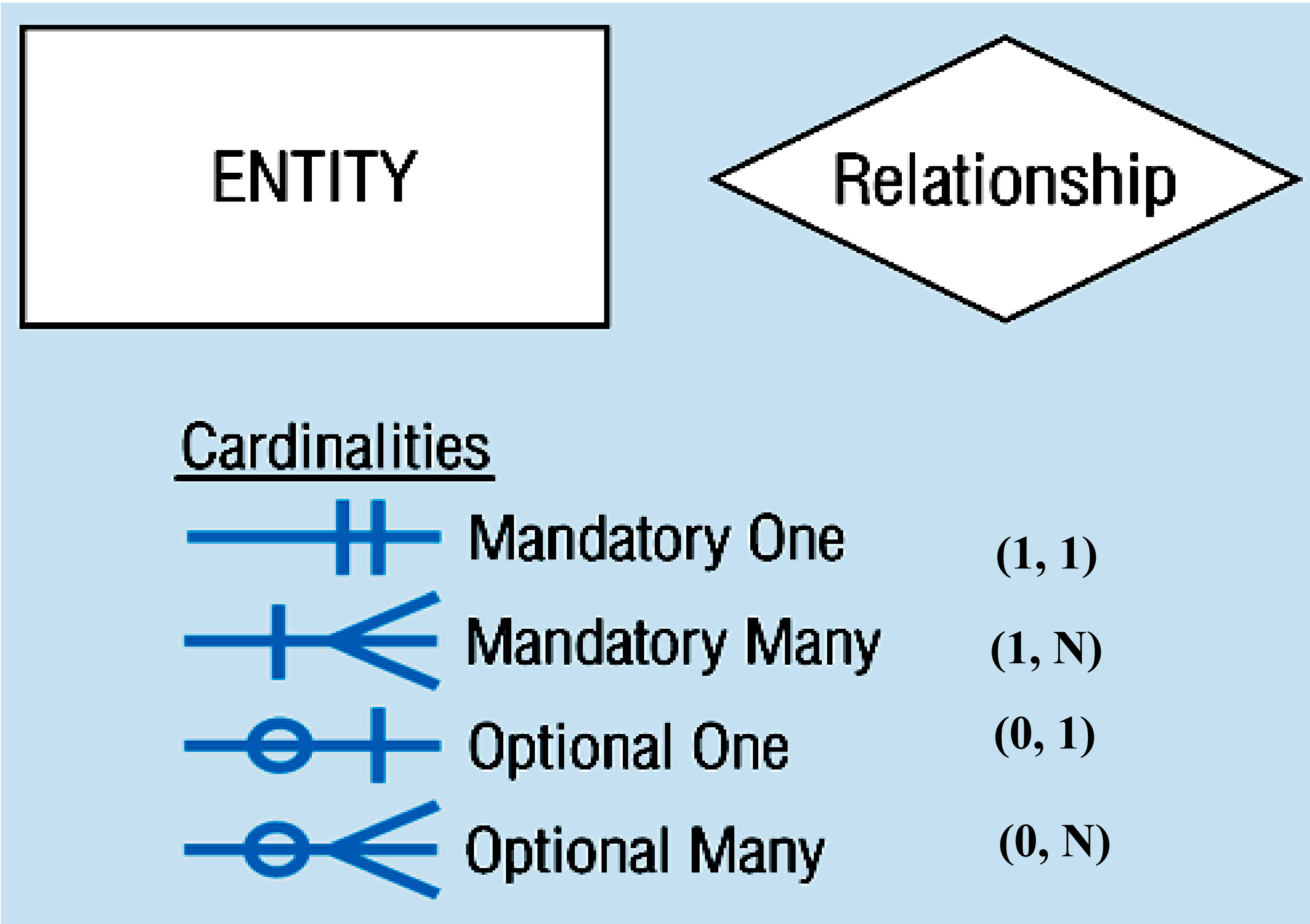


Example Cardinality Notations

Chen	
Infinity	
Crow's Feet	

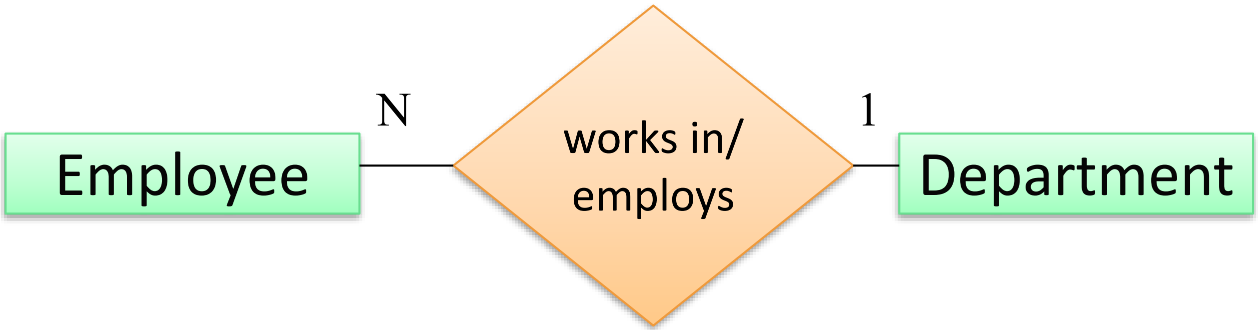
Chen	
Infinity	
Crow's Feet	

Chen(min/max) vs. Crows Feet

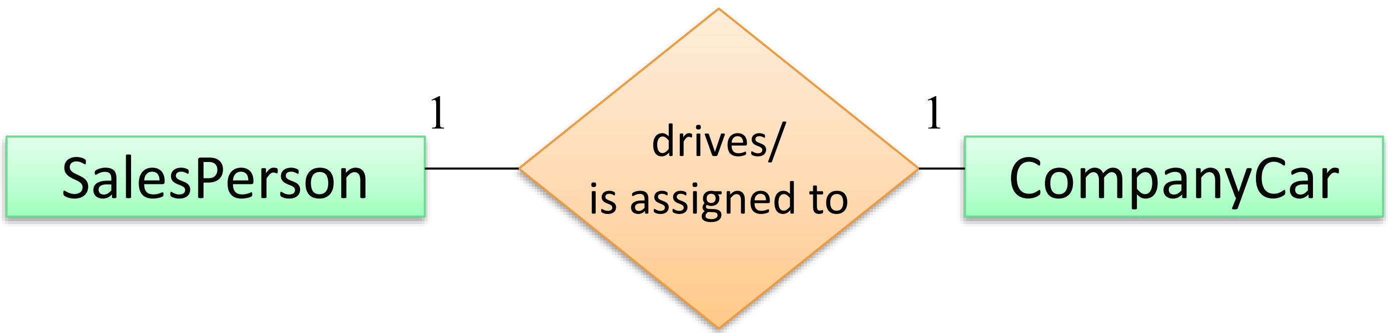


Relationship Examples

Binary
Many-to-One



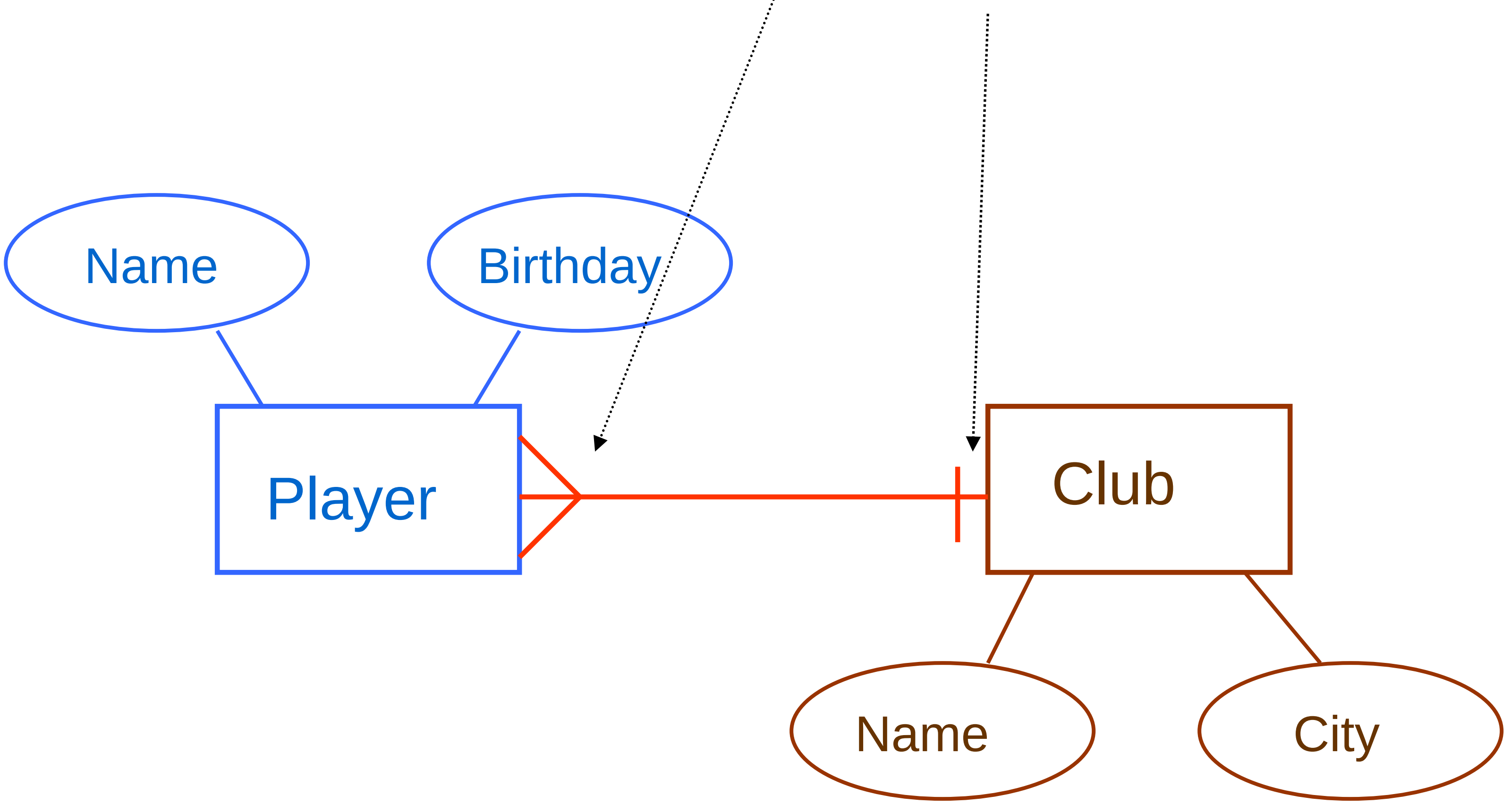
Binary
One-to-One



Binary
Many-to-Many

Relationship Example

- Each club hires many players
- Each player signs with only one club



Relationship Set Primary Keys

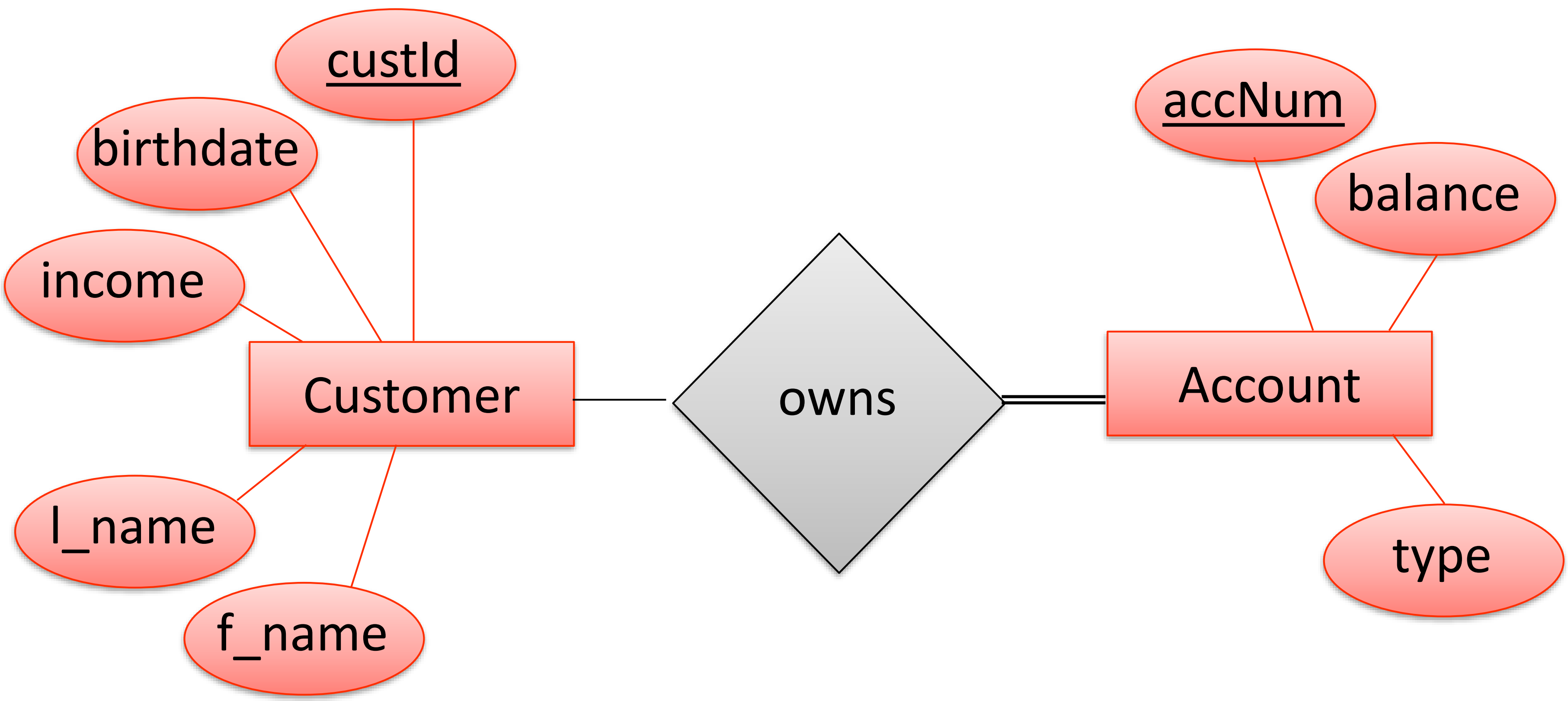
- The attributes of a relationship are
  - The attributes that comprise the primary keys of the participating entity sets and
  - Any descriptive attributes of the relationship set
- The primary key of a relationship depends on the key constraints in the relationship
  - *Many-to-many* – all the non-descriptive attributes of the relationship set
  - *One-to-many* – the primary key for the *many* entity
  - *One-to-one* – the primary key of *either* entity

Participation Constraints

- Indicate that each entity in an entity set *must* be involved in at least one relationship
- **Participation is said to be either *total*** (there is a constraint) **or *partial*** (no constraint)
  - If there is no participation constraint all the entities *may* still be involved in the relationship
- Total participation is indicated by a double line from the relationship to the entity
  - Or a thick line

Participation Example

- Each account must be owned by at least one customer

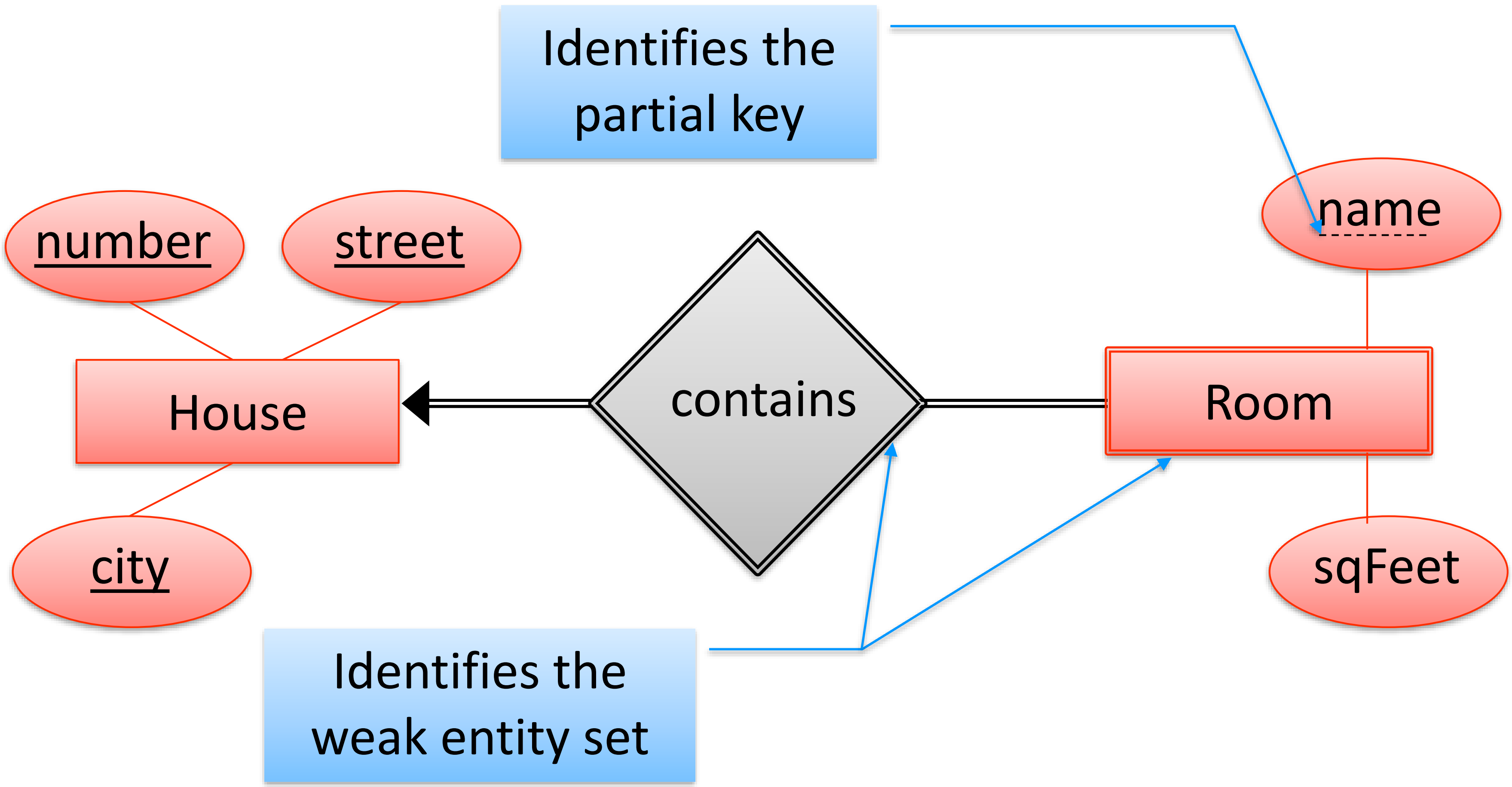


Extended ER Model

Weak Entity Sets

- A weak entity cannot be identified by its own attributes alone
  - A member of a weak entity set is identified by combining its *partial key* with the primary key of another entity set
  - The other entity set is referred to as the owner entity set
- Weak entity sets are permitted only when
  - The owner and weak entity set participate in a one-to-many *identifying* relationship set and
  - The weak entity set *must* have total participation in the identifying relationship

Weak Entity Set Example



Subclasses

- It may be useful to classify the entities in an entity set into subclasses
  - Similar to subclassing in Object Oriented Programming (OOP)
  - Each entity in a subclass is also an entity in the superclass
- The attributes of the superclass entity are *inherited* by the subclass entities
  - The subclass entity may also have additional attributes
- Class hierarchies can have multiple levels

Designing Subclasses

- The subclass relationship is sometimes referred to as an ***" is a" relationship***
  - A *"is a"* B (A is the subclass, B the superclass)
  - A *specializes* B or
  - B *generalizes* A
- ***Specialization*** is the process of identifying subsets with additional attributes from an existing entity set
- ***Generalization*** is the process of identifying common characteristics (attributes) of entity sets
  - And creating a new parent entity set with those attributes

Inheritance

- The attribute of parent entity sets are inherited by their subclasses
  - A subclass entity set is therefore described by its attributes and the attributes of its superclass(es)
- Subclass entity sets also inherit participation in relationship sets
  - Subclass entity sets can participate in any relationships that their superclasses participate in

Overlap Constraints

- It is often useful to specify whether or not an entity can belong to more than one subclass
- A *disjoint* constraint requires that an entity can only belong to one subclass
  - Can be specified on an ER diagram by writing *disjoint* next to the ISA triangle
  - e.g. The animal subclasses Bird and Mammal
- By default there is no disjoint constraint and subclasses are said to *overlap*
  - e.g. Person subclasses Customer and Employee

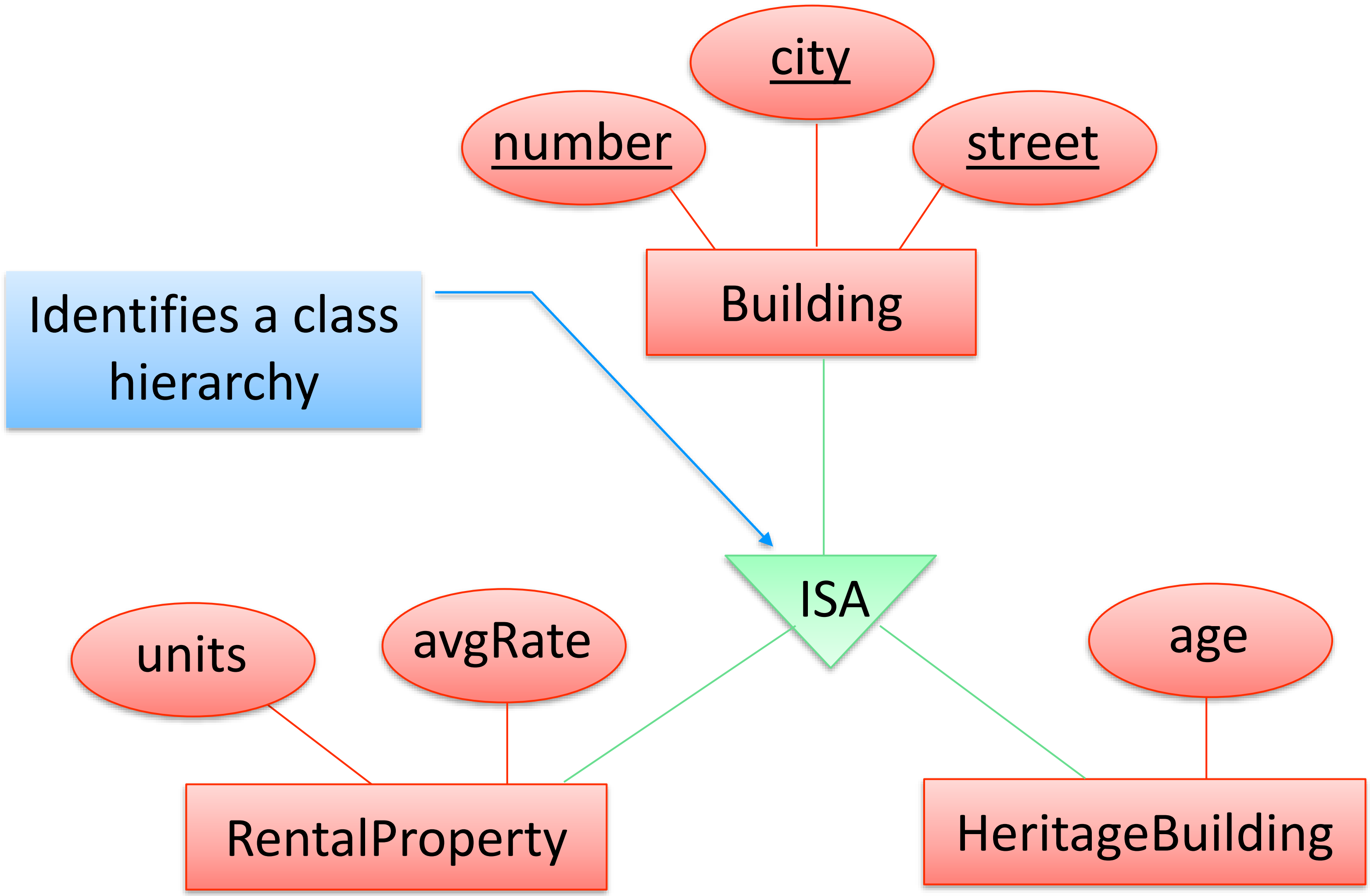
Completeness Constraints

- *Total* generalization or specialization
  - Each superclass entity *must* belong to a subclass
    - Can be specified on the ER diagram by drawing a double line from the superclass to the triangle
- *Partial* generalization or specialization
  - Superclass entities do not have to belong to a subclass
    - The default

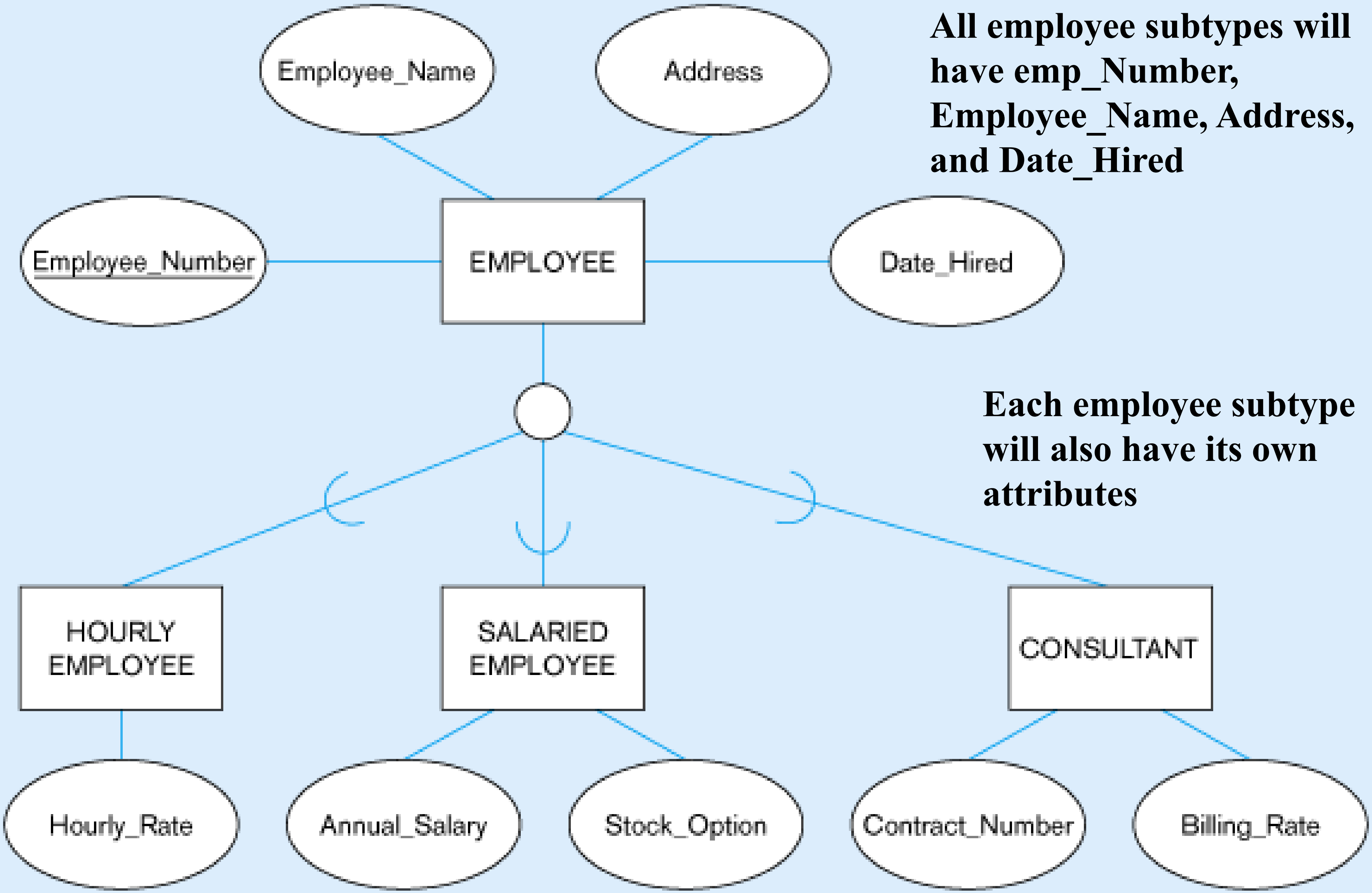
Why Use Class Hierarchies?

- So that attributes in common don’t have to be re-defined for each subclass
- So that additional descriptive attributes can be added to subclasses
- To identify the set of entities that participate in a particular relationship
  - i.e. subclasses can be created to identify a relationship with another entity set

Subclasses Example



Subclasses Example 2



All employee subtypes will have emp_Number, Employee_Name, Address, and Date_Hired

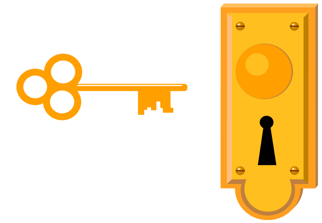
Each employee subtype will also have its own attributes

Mapping ER to Logical Model

Relation

- A database is collection of relations (or tables)
- Definition: A Relation is a **table**
  - Table is made up of rows (records), and columns (attribute or field)
- Characteristics of a Relation:
  - Every relation has a unique name.
  - Every attribute value is atomic (not multivalued, not composite)
  - Every row is unique (can’t have two rows with exactly the same values for all their fields)
  - Attributes (columns) in a table have unique names
  - The order of the columns is irrelevant
  - The order of the rows is irrelevant

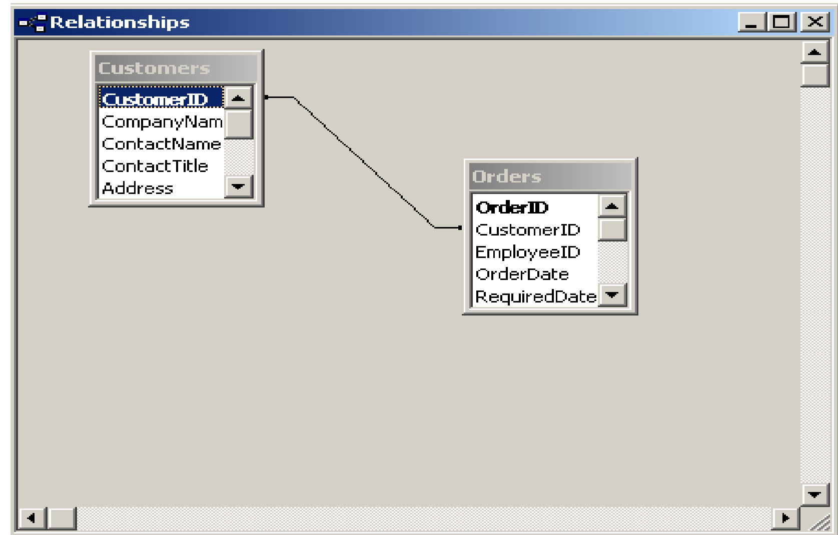
Key Fields

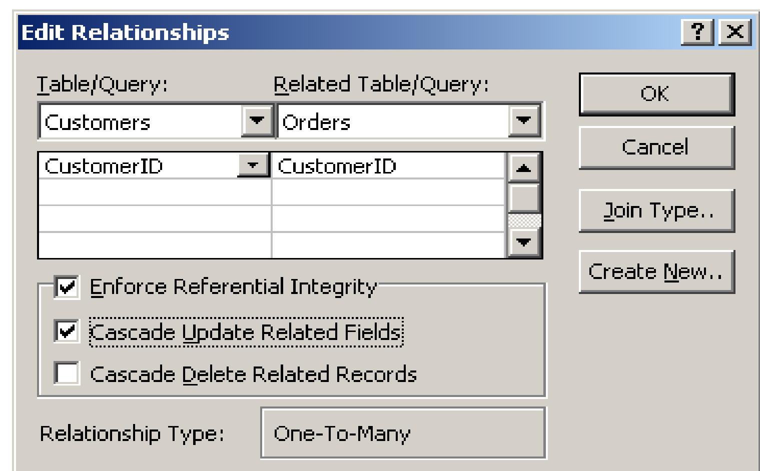


- Keys are special fields that serve two main purposes:
  - ***keys*** are unique identifiers a record. Examples include employee number, National Card number, etc.
  - ***keys*** are identifiers that enable a dependent relation (on the many side of a relationship) to refer to its parent relation (on the one side of the relationship)
- Keys can be ***simple*** (a single field) or ***composite*** (more than one field)
- ***Surrogate*** key (e.g., auto-incremented primary key)
- Keys usually are used as indexes to speed up the response to user queries

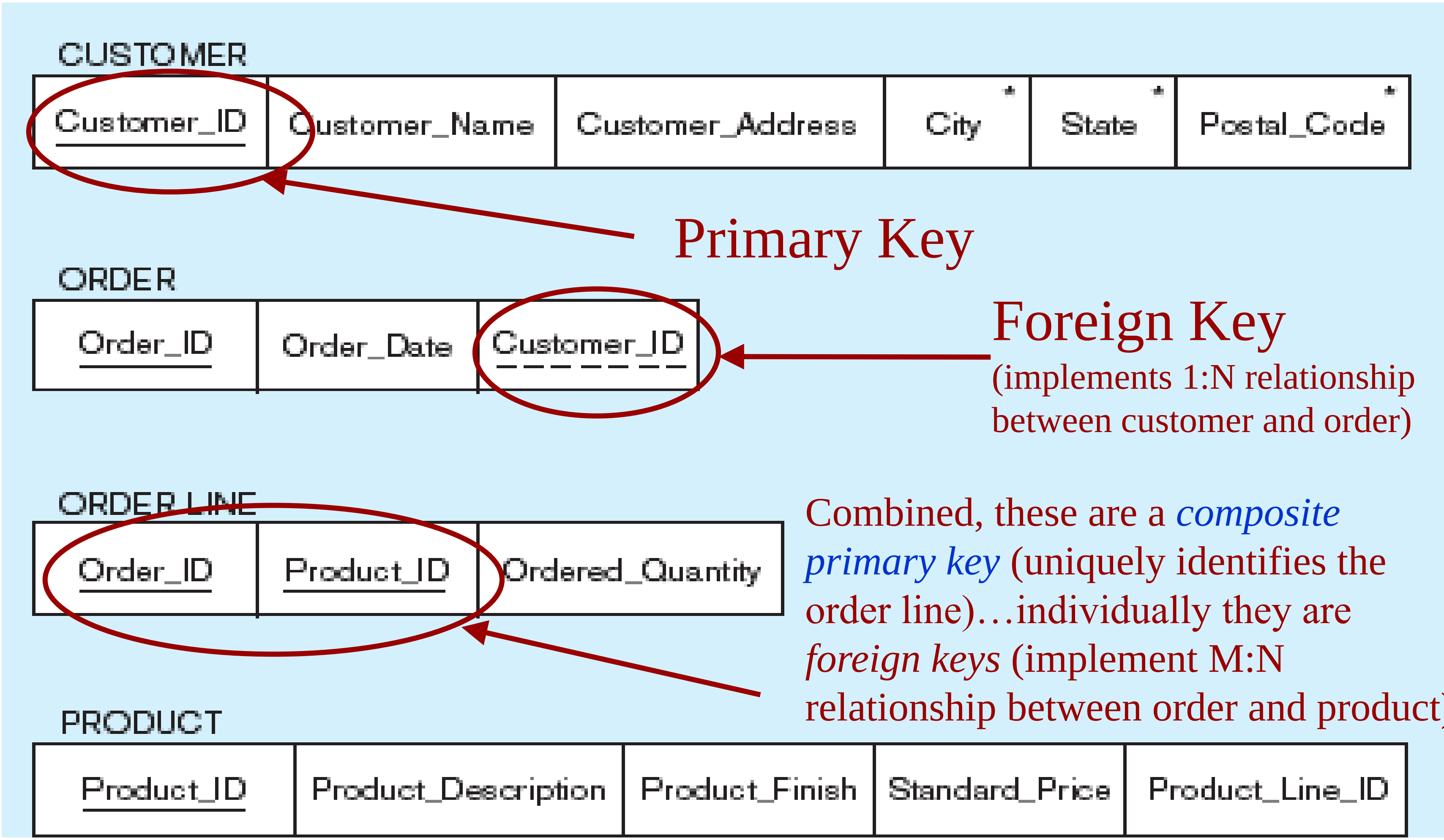
Referential Integrity

- Rules to preserve relationships
- Prevents orphan records
  - Cannot add record on many side
  - Cannot delete from one side
- Cascade Update
- Cascade Delete

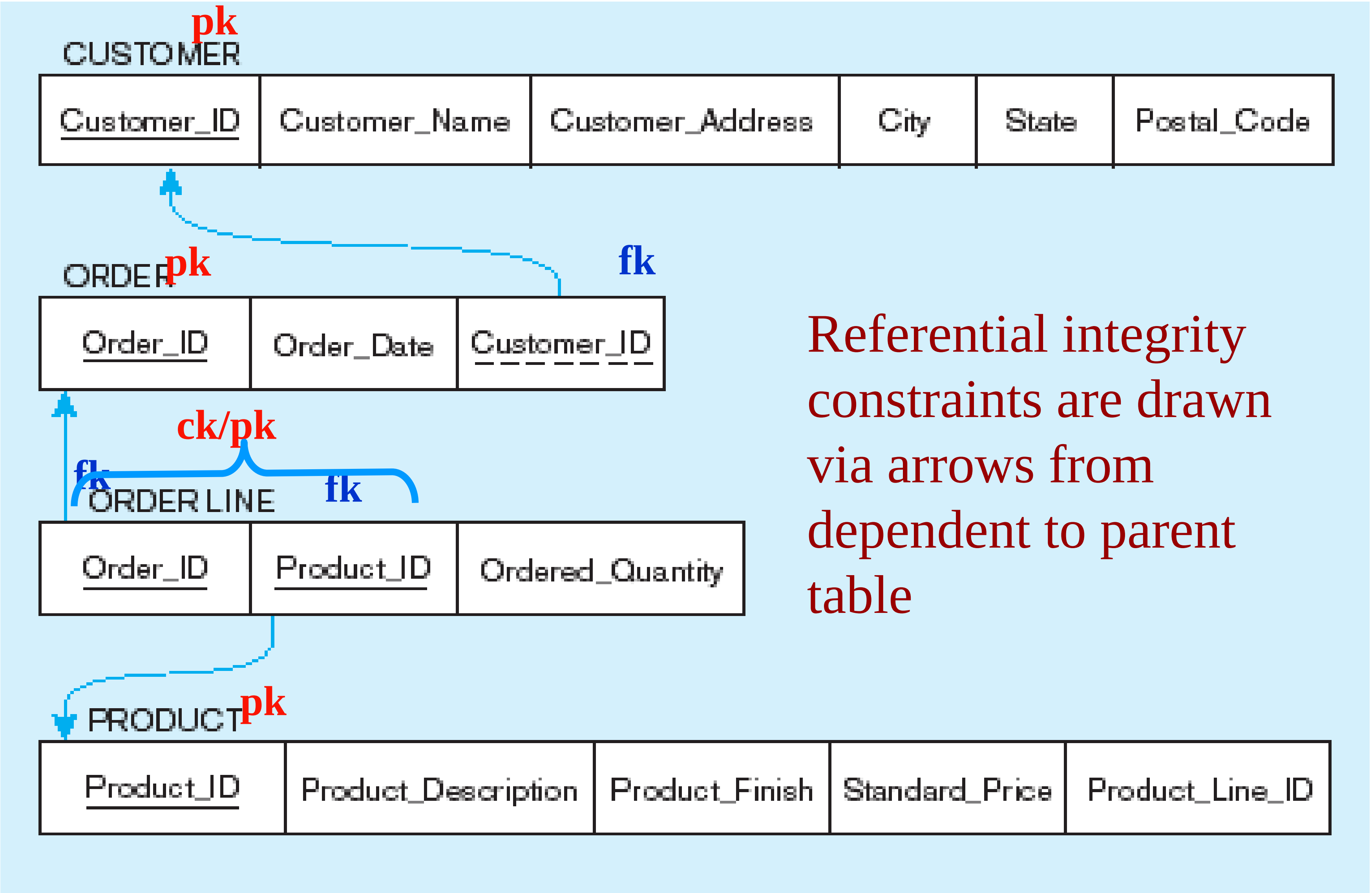




Example keys



Referential integrity constraints



Referential integrity constraints are drawn via arrows from dependent to parent table

Mapping a composite attribute

(a) CUSTOMER entity type with composite attribute

CUSTOMER
Customer_ID
Customer_Name
Customer_Address (Street, City, State)
Postal_Code

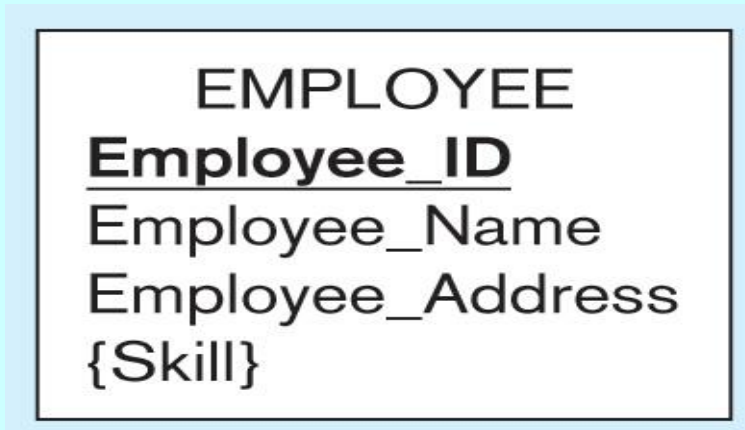
[Use only their simple, component attributes]

(b) CUSTOMER relation with address detail

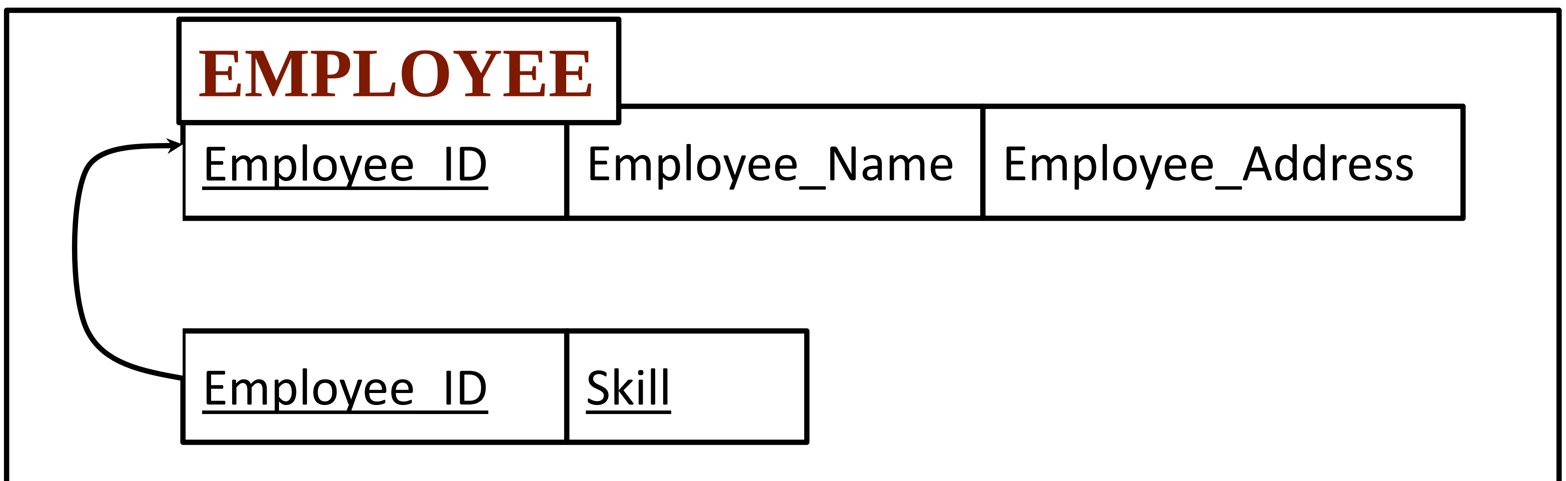
CUSTOMER

Customer_ID	Customer_Name	Street	City	State	Postal_Code

Mapping an entity with a multivalued attribute



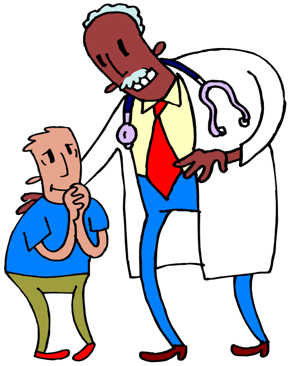
Multivalued attribute becomes a separate relation with foreign key



One–to–many relationship between original entity and new relation

[Two relations created with one containing all of the attributes except the multi-valued attribute, and the second one contains the pk (on the first one) and the multi-valued attribute]

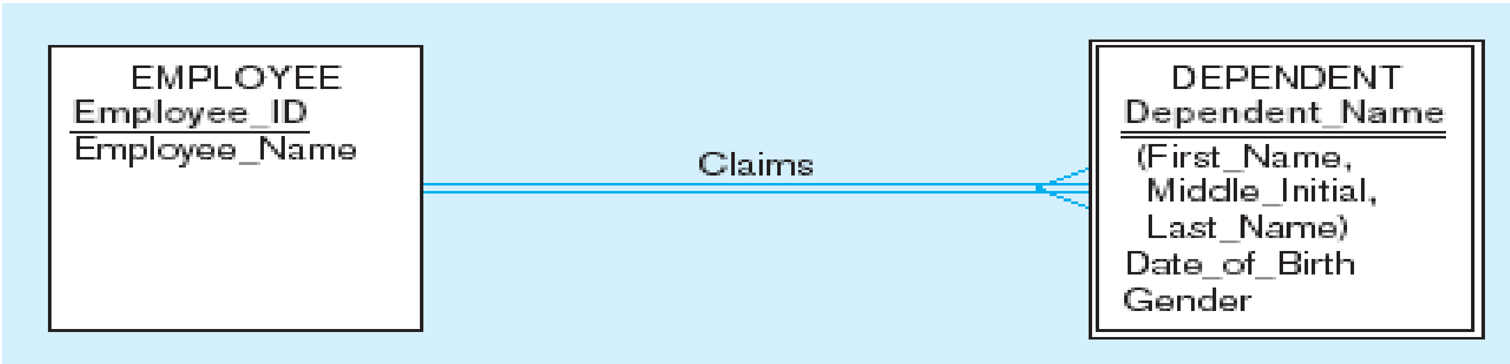
Mapping Weak Entities



- Week entity cannot exit on its own
- The OrderItem table stores weak entities precisely because an OrderItem has no meaning independent of the Order.
- Becomes a separate relation with a foreign key taken from the superior entity
- Primary key composed of:
    - Partial identifier of weak entity
    - Primary key of identifying relation (strong entity)

Example of mapping a weak entity

(a) Weak entity DEPENDENT



(b) Relations resulting from weak entity

EMPLOYEE

Employee_ID	Employee_Name

PK

[Becomes a separate relation with a foreign key taken from the superior entity]

NOTE: the domain constraint for the foreign key should NOT allow *null* value if DEPENDENT is a weak entity

CK

DEPENDENT

FK

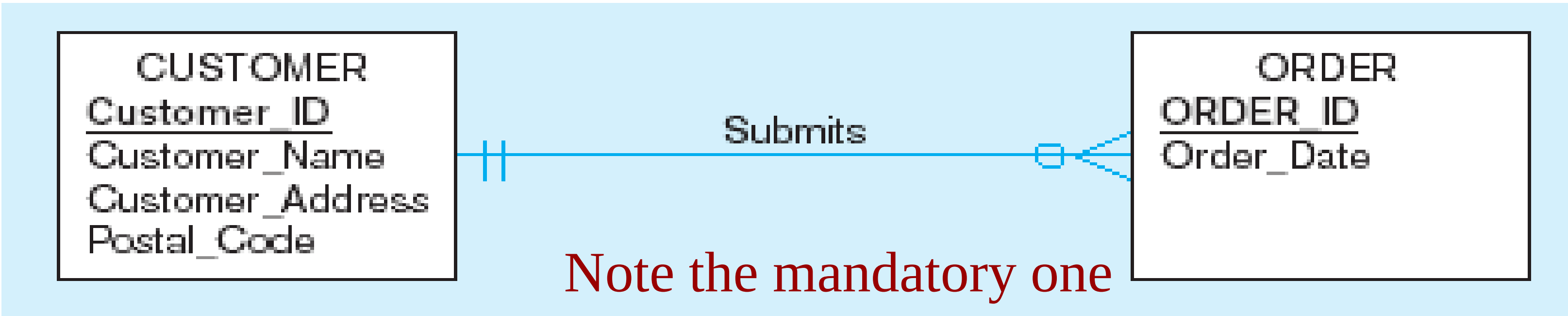
First_Name	Middle_Inital	Last_Name	Employee_ID	Date_of_Birth	Gender

Map Binary Relationships

- One-to-Many - Primary key on the one side becomes a foreign key on the many side
- Many-to-Many - Create a ***new relation*** with the primary keys of the two entities as its primary key
- One-to-One - Primary key on the mandatory side becomes a foreign key on the optional side

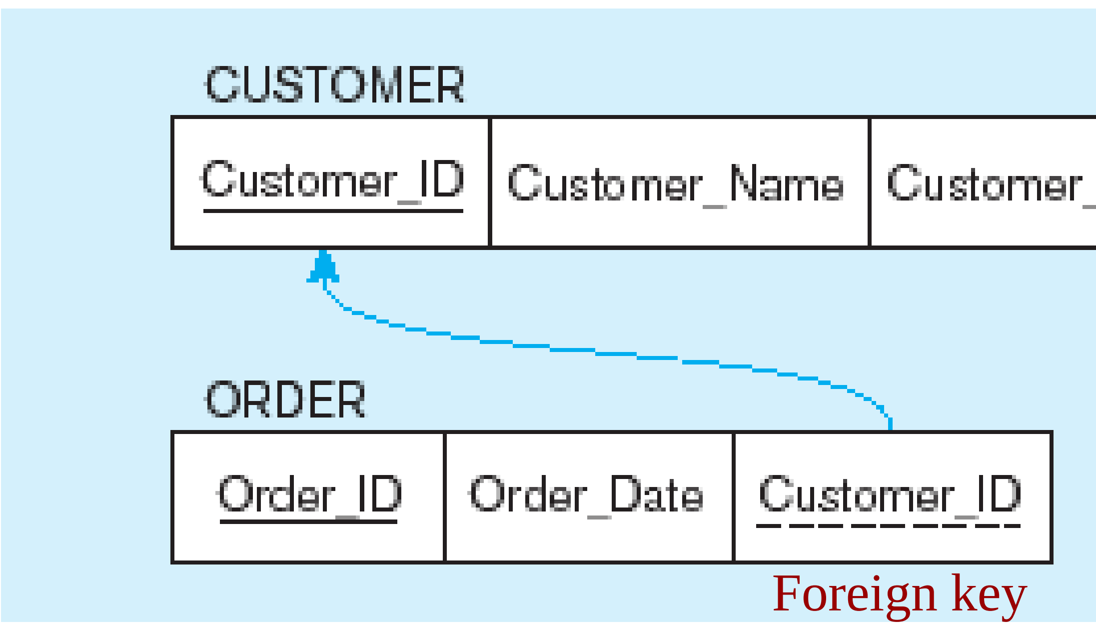
Mapping a 1:M relationship

(a) Relationship between customers and orders



(b) Mapping the relationship

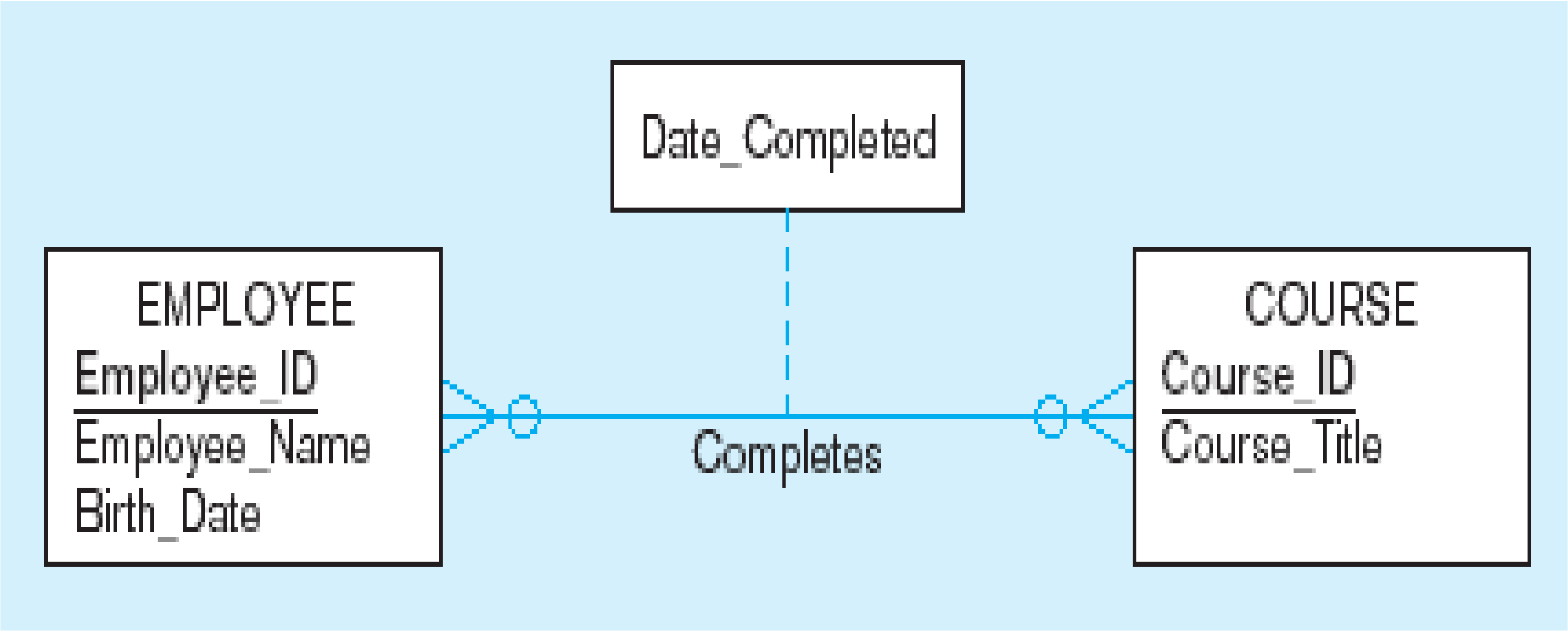
[Primary key on the one side becomes a foreign key on the many side]



Again, no null value in the foreign key…this is because of the mandatory minimum cardinality

Example of mapping an M:N relationship

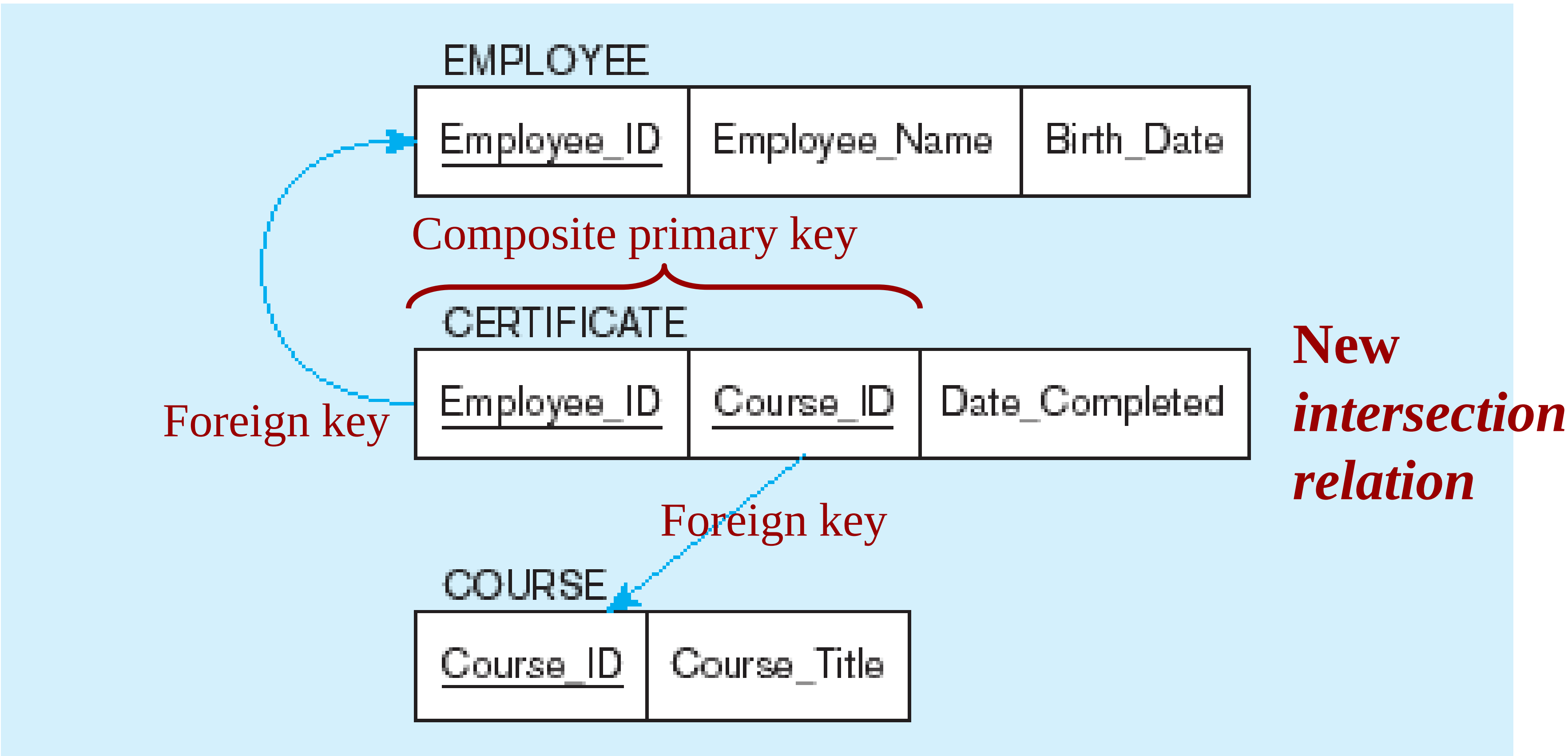
a) Completes relationship (M:N)



The *Completes* relationship will need to become a separate relation

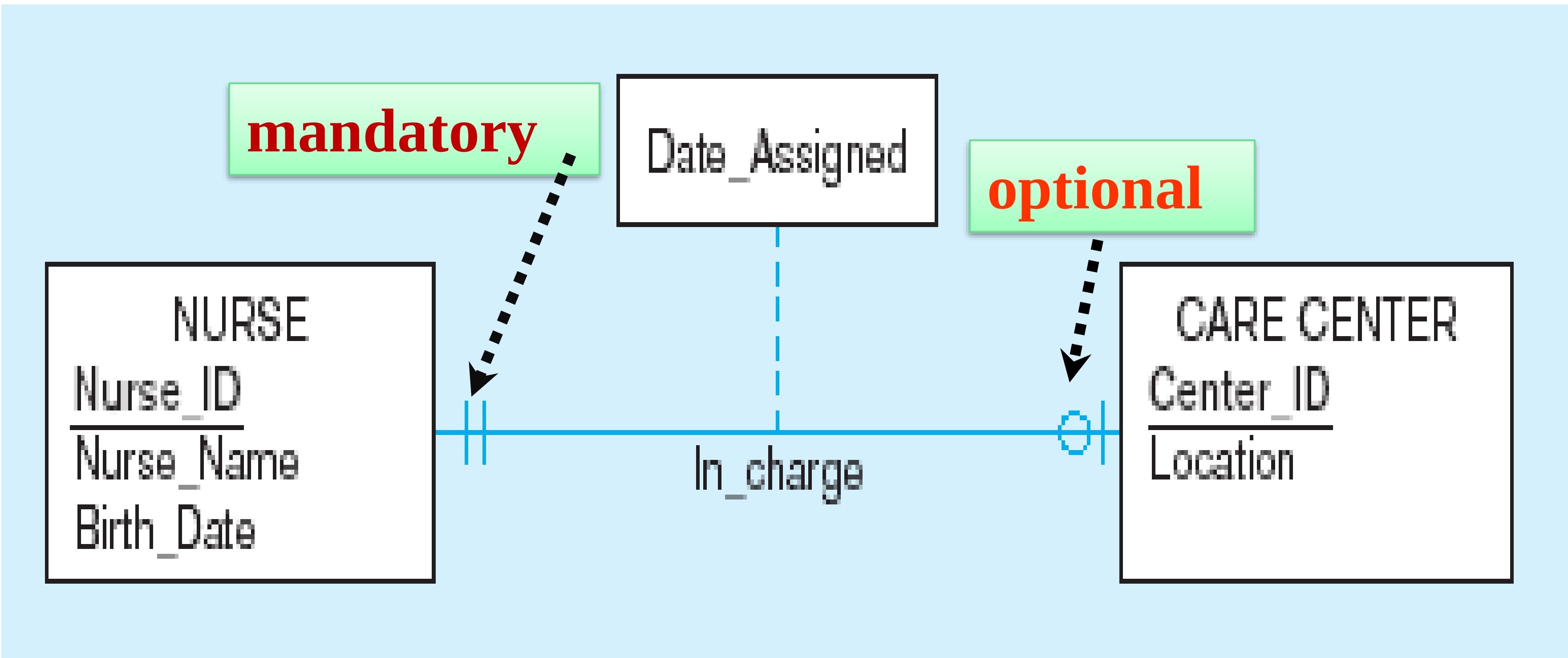
Mapping an M:N relationship (cont.)

b) Three resulting relations



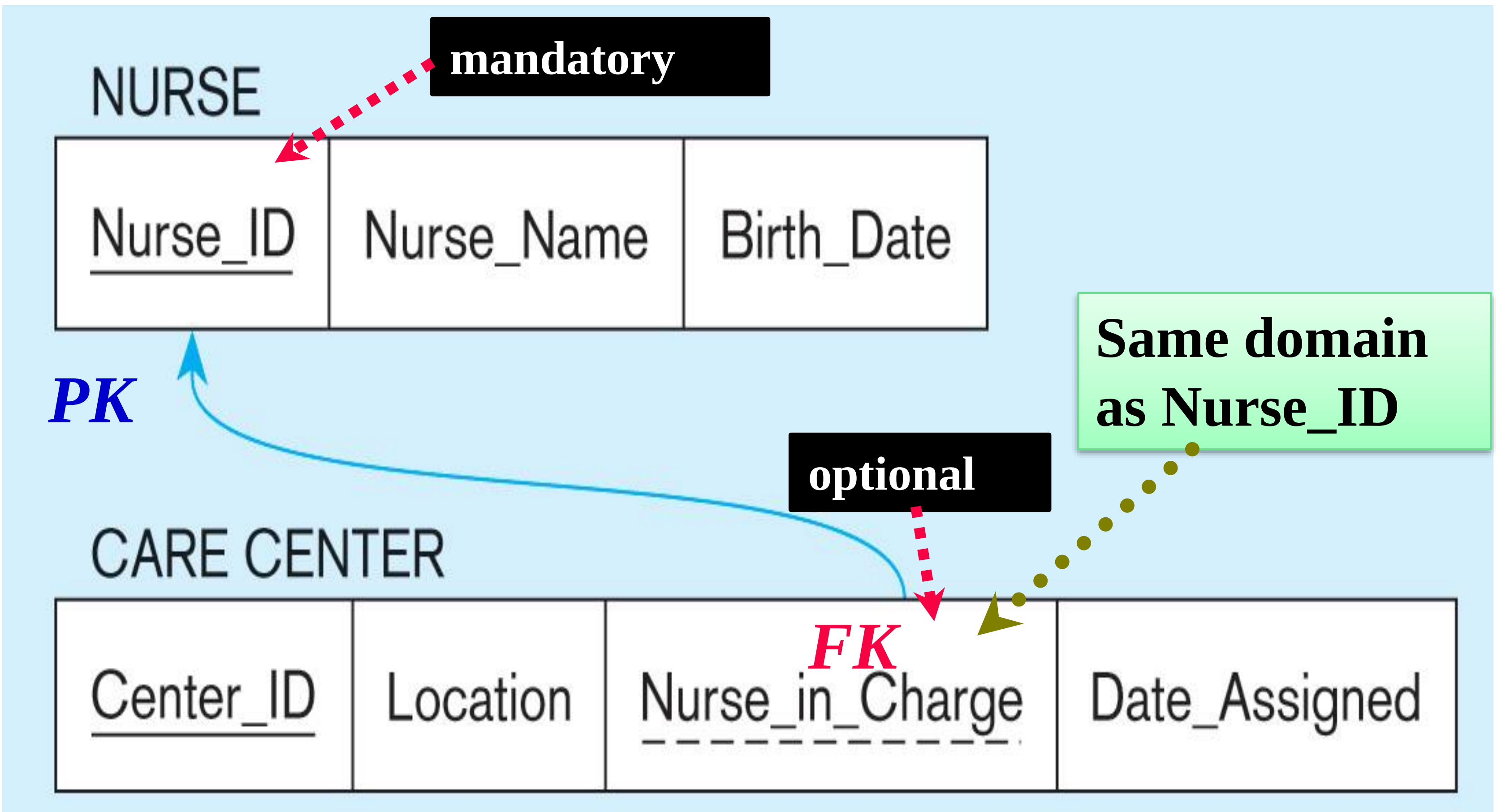
Mapping a binary 1:1 relationship

In_charge relationship (1:1)



Often in 1:1 relationships, one direction is optional.

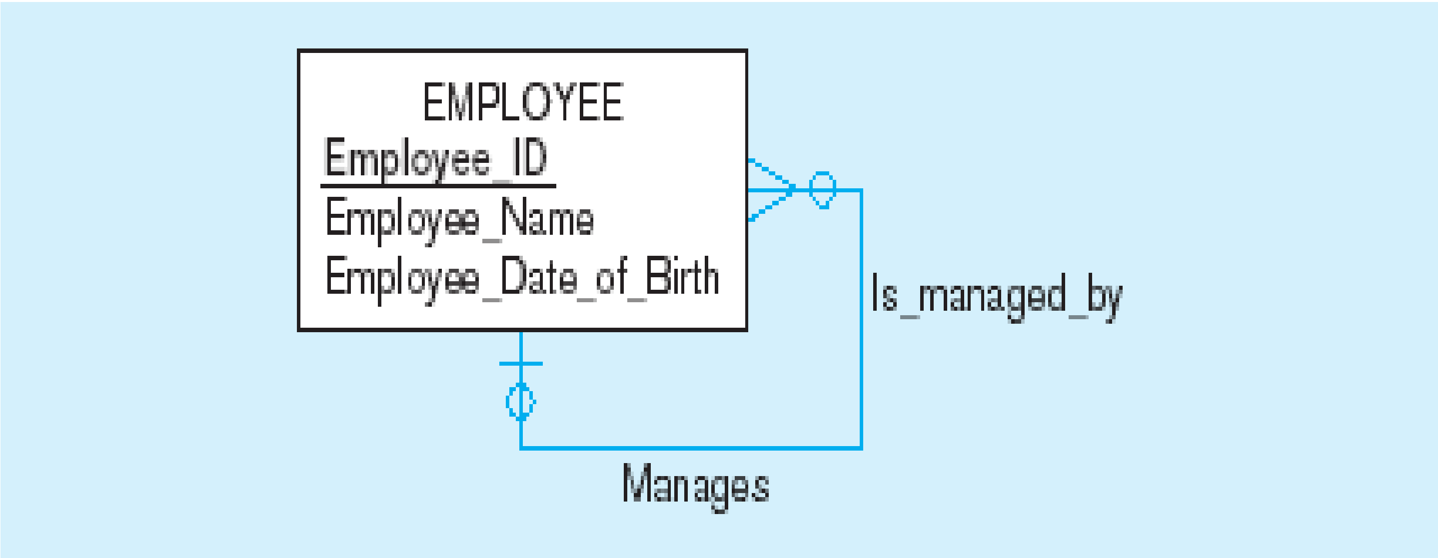
Mapping 1:1 relationship - Resulting relations



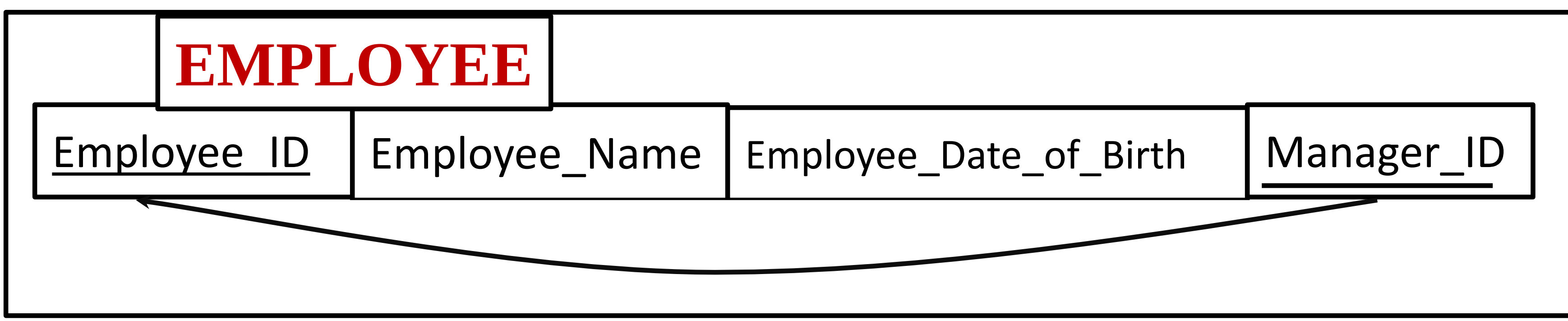
[Primary key on the mandatory side becomes a foreign key on the optional side]

Mapping a unary 1:N relationship

(a) EMPLOYEE entity with unary relationship



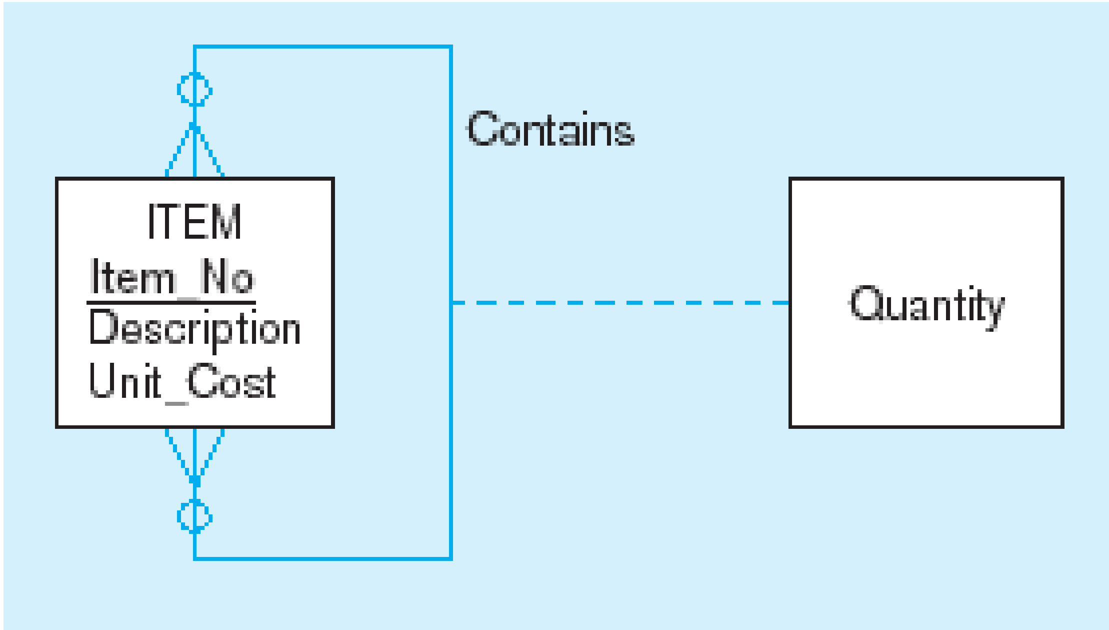
(b) EMPLOYEE relation with recursive foreign key



A recursive FK is a FK in a relation that references the PK values of that same relation. It must have the same domain as the PK.

Mapping a unary M:N relationship

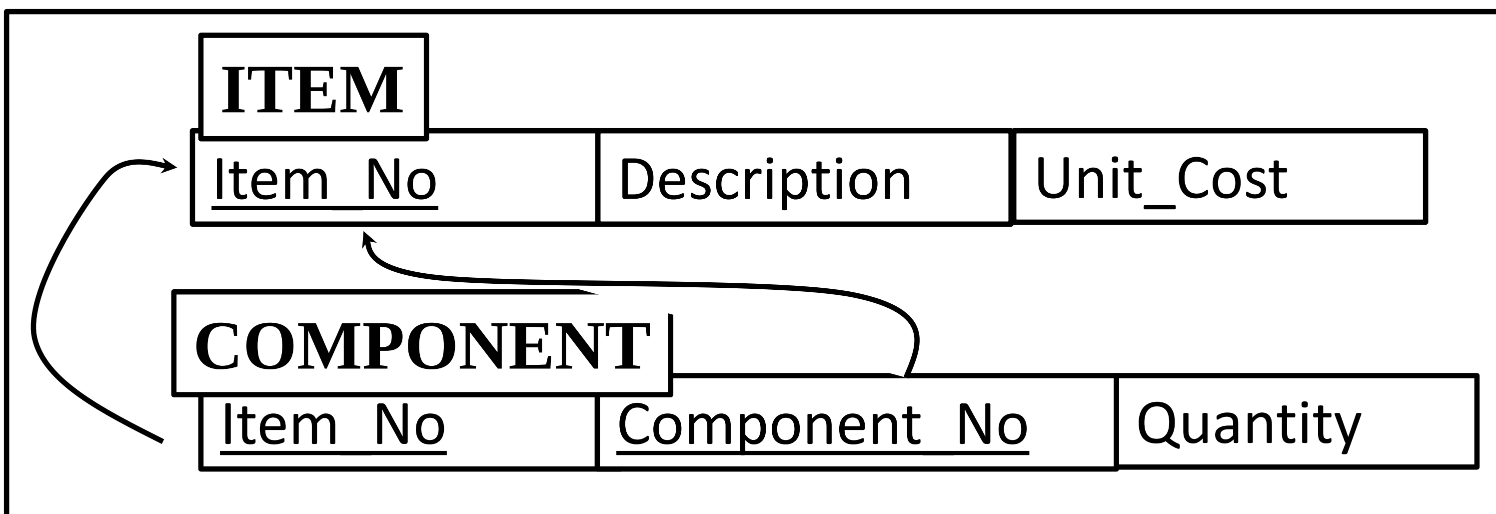
(a) Bill-of-materials relationships (M:N)



One for the entity type.

One for an associative relation in which the primary key has two attributes, both taken from the primary key of the entity.

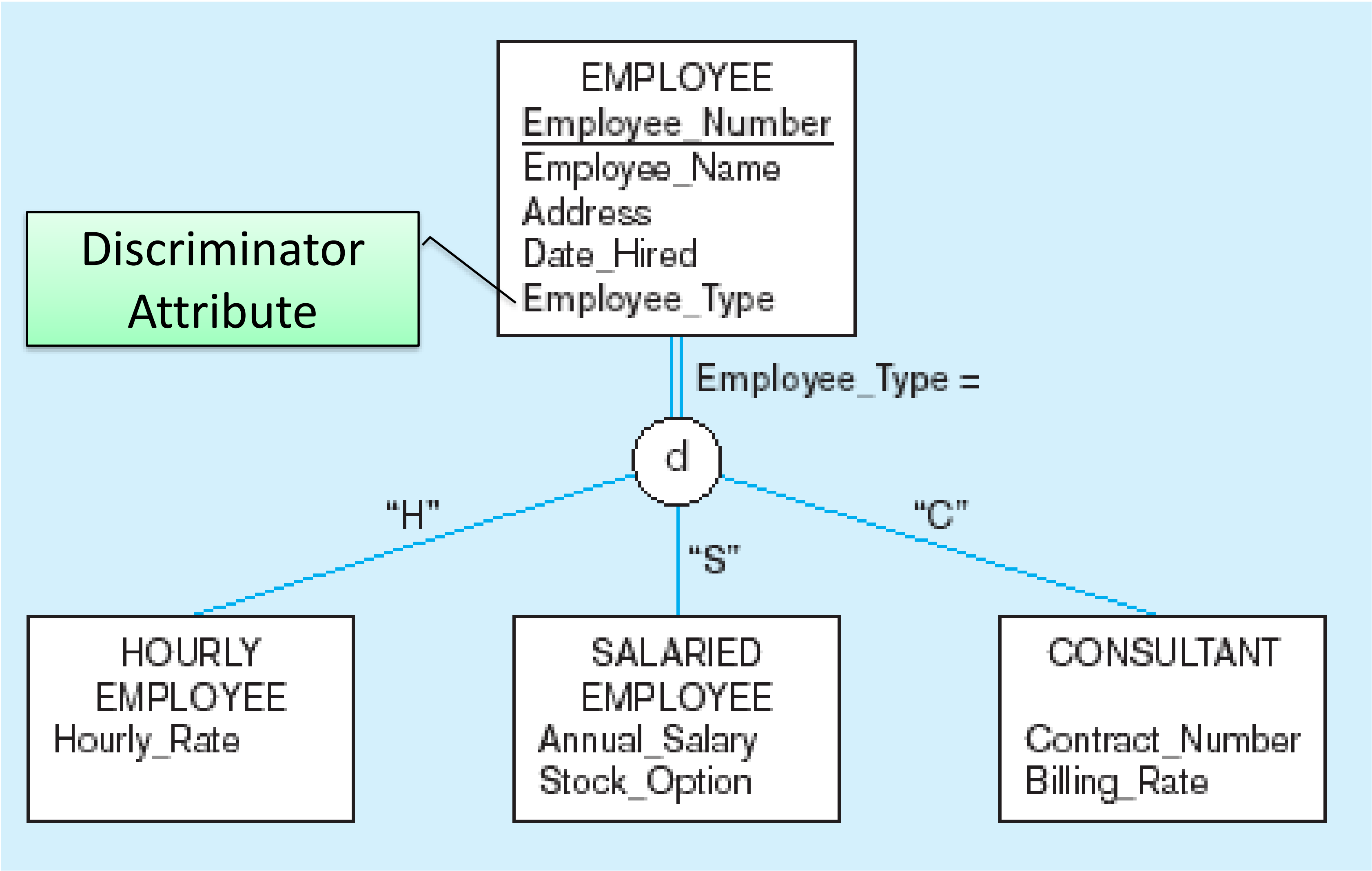
(b) ITEM and COMPONENT relations



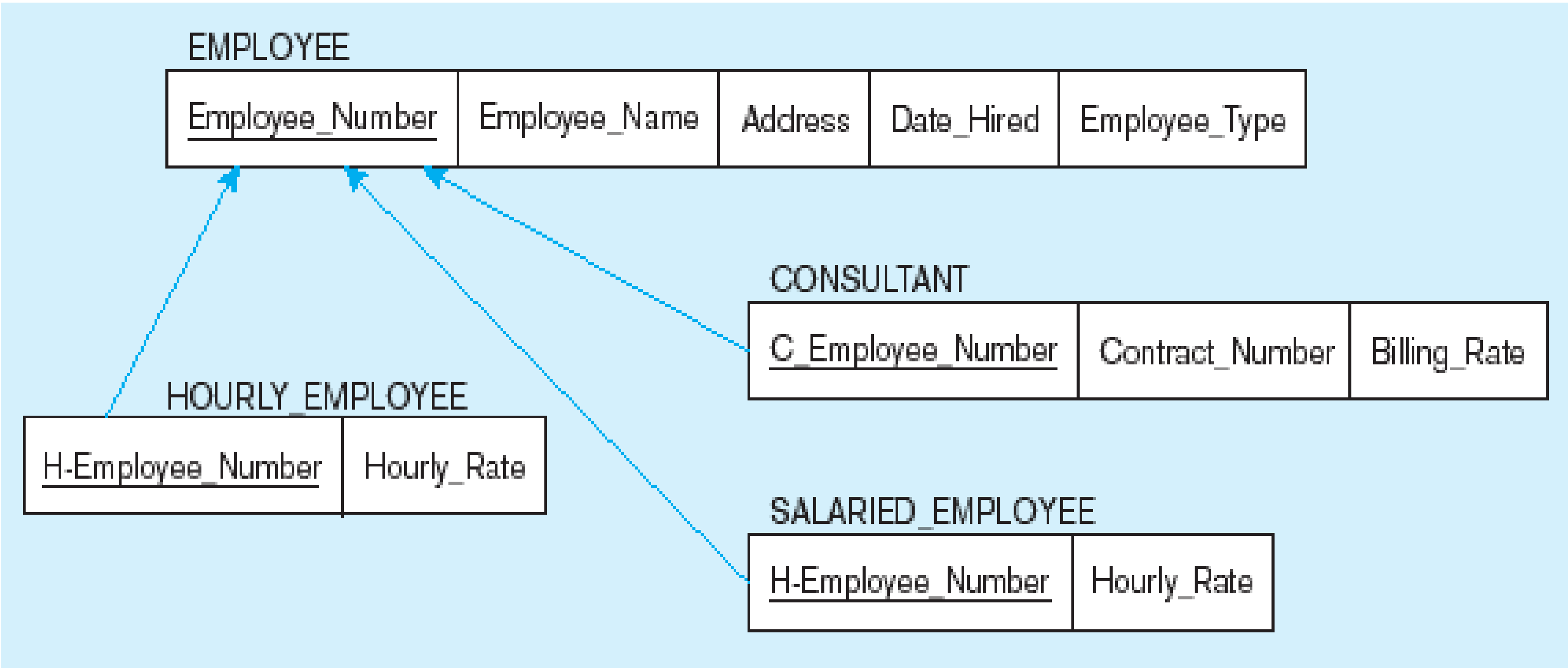
Mapping Supertype/Subtype Relationships

- One relation for supertype and for each subtype
- Supertype attributes (including identifier and subtype discriminator) go into supertype relation
- Subtype attributes go into each subtype; primary key of supertype relation also becomes primary key of subtype relation
- 1:1 relationship established between supertype and each subtype, with supertype as primary table

Supertype/subtype relationships



Mapping Supertype/subtype relationships to relations



These are implemented as one-to-one relationships

Normalization

Data Normalization

- The process of decomposing relations with anomalies to produce smaller, well ***structured*** relations free of redundancy:
  - A relation that contains minimal data redundancy allows users to insert, delete, and update rows **without causing data inconsistencies**
- Normalization is a primarily tool to validate and improve a logical design so that it satisfies certain constraints that ***avoid unnecessary duplication of data***
- Goal is to avoid anomalies
  - **Insertion Anomaly** – adding new rows forces user to create duplicate data
  - **Deletion Anomaly** – deleting rows may cause a loss of data that would be needed for other future rows
  - **Modification Anomaly** – changing data in a row forces changes to other rows because of duplication

Student#	Advisor	Adv-Room
1022	Jones	412
4123	Smith	216
4124	Smith	216

Anomalies in this Table

- **Insertion** – can't enter a new student without having the Advisor Room
- **Deletion** – if we remove Student# 1022, we lose information about the room of the Advisor Jones
- **Modification** – Changing the room of the advisor Smith forces us to update multiple records

Why do these anomalies exist?

Because are two entity types were combined. This results in duplication, and an **unnecessary dependency between the entities**

First Normal Form

- No multivalued attributes
  - A table is in first normal form (1NF) if it does not contain a repeating group
- Every attribute value is atomic (singled-value)

Normalized Relations from Employee

EMPLOYEE

Emp_ID	Name	Dept_Name	Salary	Course_ Title	Date_ Completed
100	Margaret Simpson	Marketing	48,000	SPSS	6/19/2010
100	Margaret Simpson	Marketing	48,000	Surveys	10/7/2010
140	Allen Beeton	Accounting	52,000	Tax Acc	12/8/2010
110	Chris Lucero	Info. System	43,000	SPSS	1/12/2010
110	Chris Lucero	Info. System	43,000	C++	4/22/2010
190	Lorenzo Davis	Finance	55,000		
150	Susan Martin	Marketing	42,000	SPSS	6/16/2010
150	Susan Martin	Marketing	42,000	Java	8/12/2010

EMPLOYEE

Emp_ID	Name	Dept_Name	Salary
100	Margaret Simpson	Marketing	48,000
140	Allen Beet	Accounting	52,000
110	Chris Lucero	Info. System	43,000
190	Lorenzo Davis	Finance	55,000
150	Sususan Martin	Marketing	42,000

Is there any ano-maly?

EMP_COURSE

Emp_ID	Course_ Title	Date_ Completed
100	SPSS	6/19/2010
100	Surveys	10/7/2010
140	Tax Acc	12/8/2010
110	SPSS	1/12/2010
110	C++	4/22/2010
150	SPSS	6/19/2010
150	Java	8/12/2010

Second Normal Form

- 1NF and **every** non-key attribute is functionally dependent on the entire primary key.
- No partial functional dependencies: Every non-key attribute must be defined by the entire key not by only part of the key.

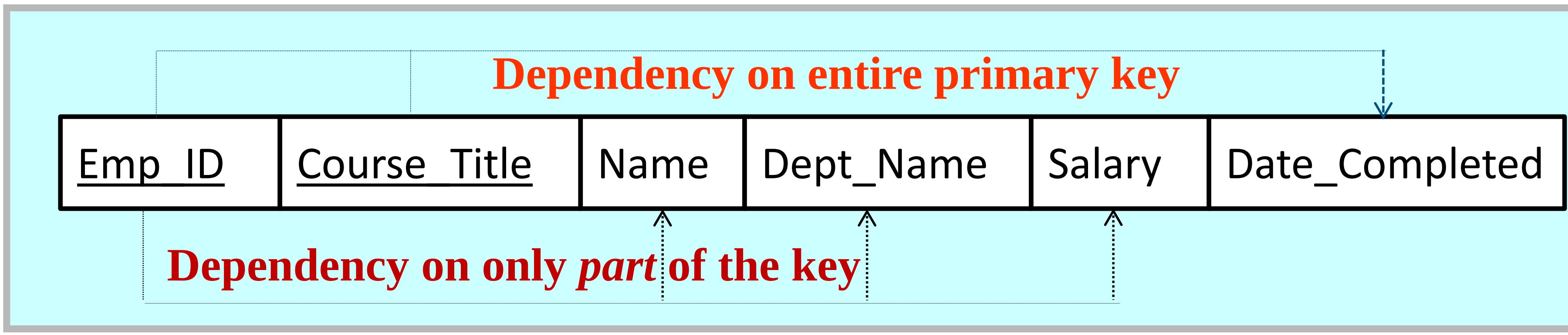
EXAMPLE OF FUNCTIONAL DEPENDENCY

EMPLOYEE NUMBER	PROJECT CODE	EMPLOYEE NAME	PROJECT NAME	TOTAL DAYS ON PROJECT

EMPLOYEE NAME	is functionally dependent on EMPLOYEE NUMBER but not on PROJECT CODE
PROJECT NAME	is functionally dependent on PROJECT CODE but not on EMPLOYEE NUMBER
TOTAL DAYS ON PROJECT	is functionally dependent on the concatenated key of EMPLOYEE NUMBER and PROJECT CODE

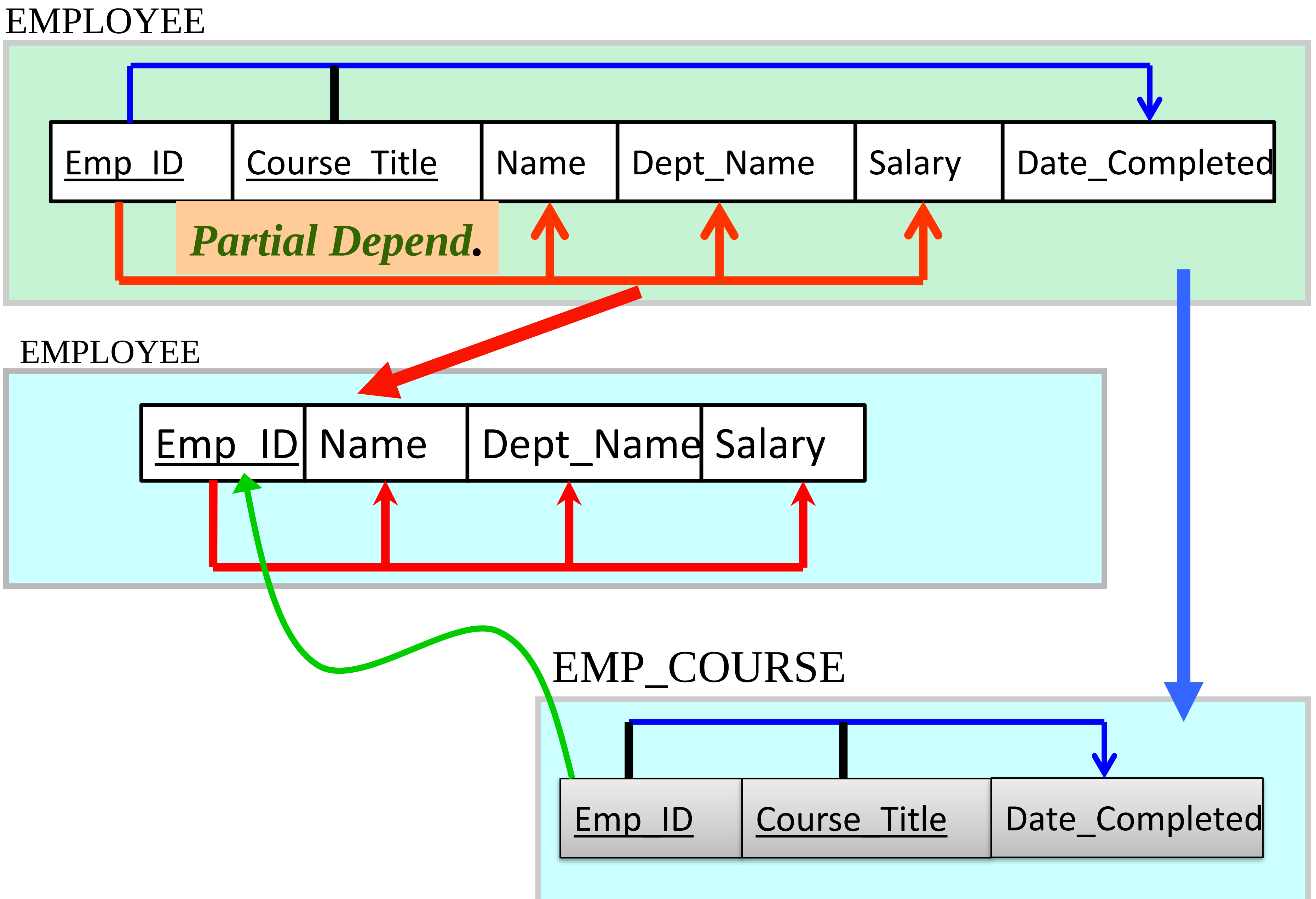
Functional Dependencies in EMPLOYEE

Functional Dependencies in EMPLOYEE



Therefore, NOT in 2nd Normal Form!!

Normalization from 1NF to 2NF

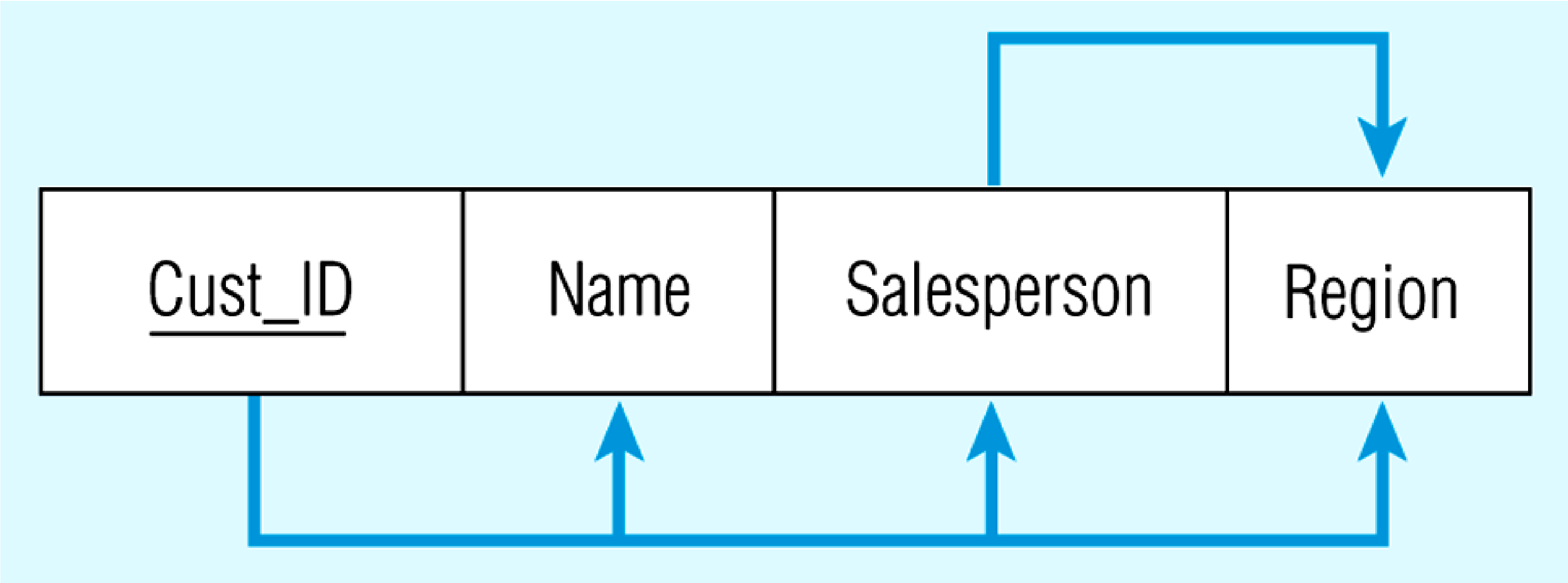


Third Normal Form

- 2NF and no transitive dependencies (no functional dependency between non-key attributes)

=> all fields are functionally dependent ONLY on the primary key

Relation with transitive dependency

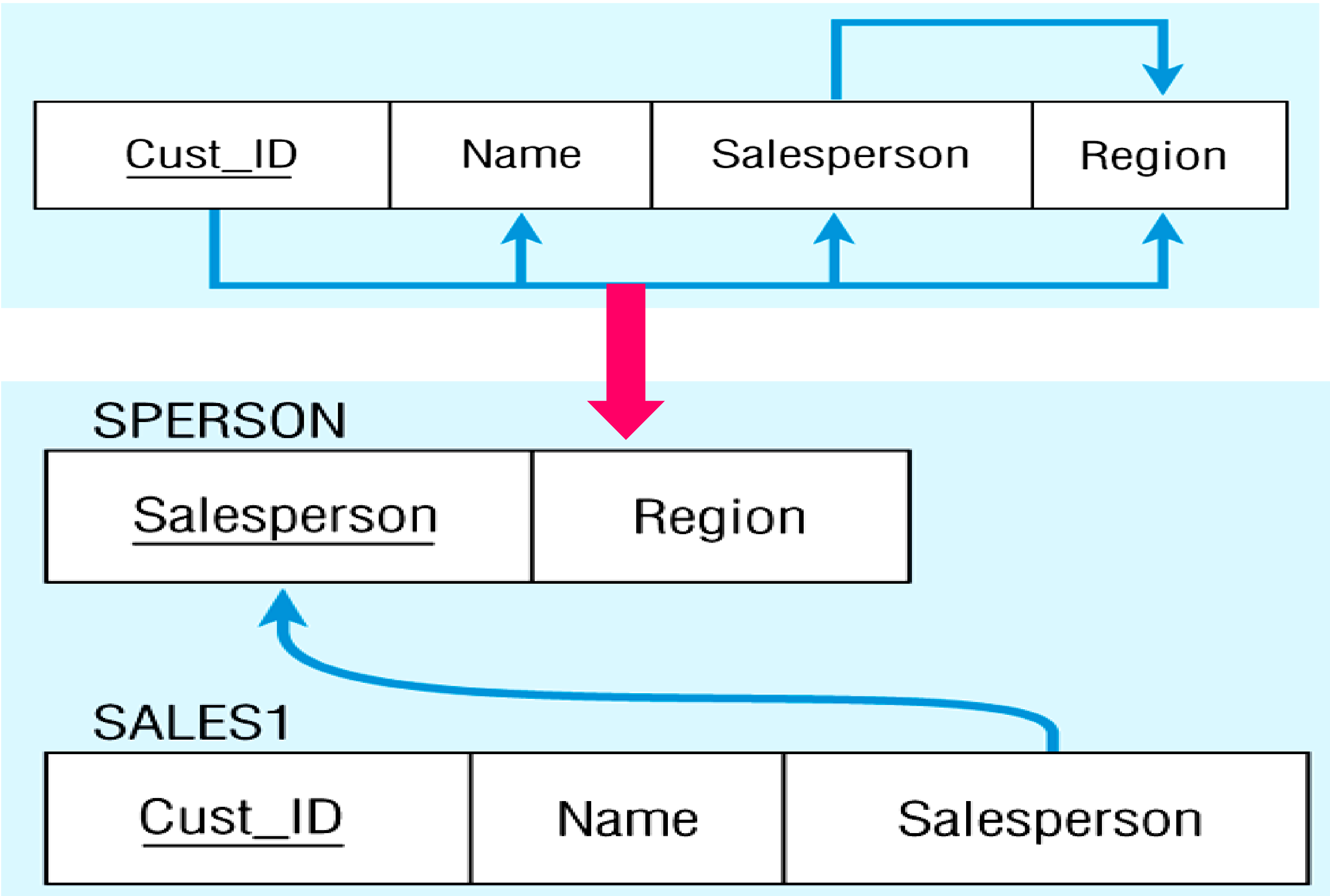


CustID → Name
CustID → Salesperson
CustID → Region
and
Salesperson → Region
All this is OK
(2nd NF)

BUT
CustID → Salesperson → Region
implies
CustID → Region
Transitive dependency
(not in 3rd NF)

Relations in 3NF

Remove a transitive dependency



Removing a transitive dependency

(a) Decomposing the SALES relation

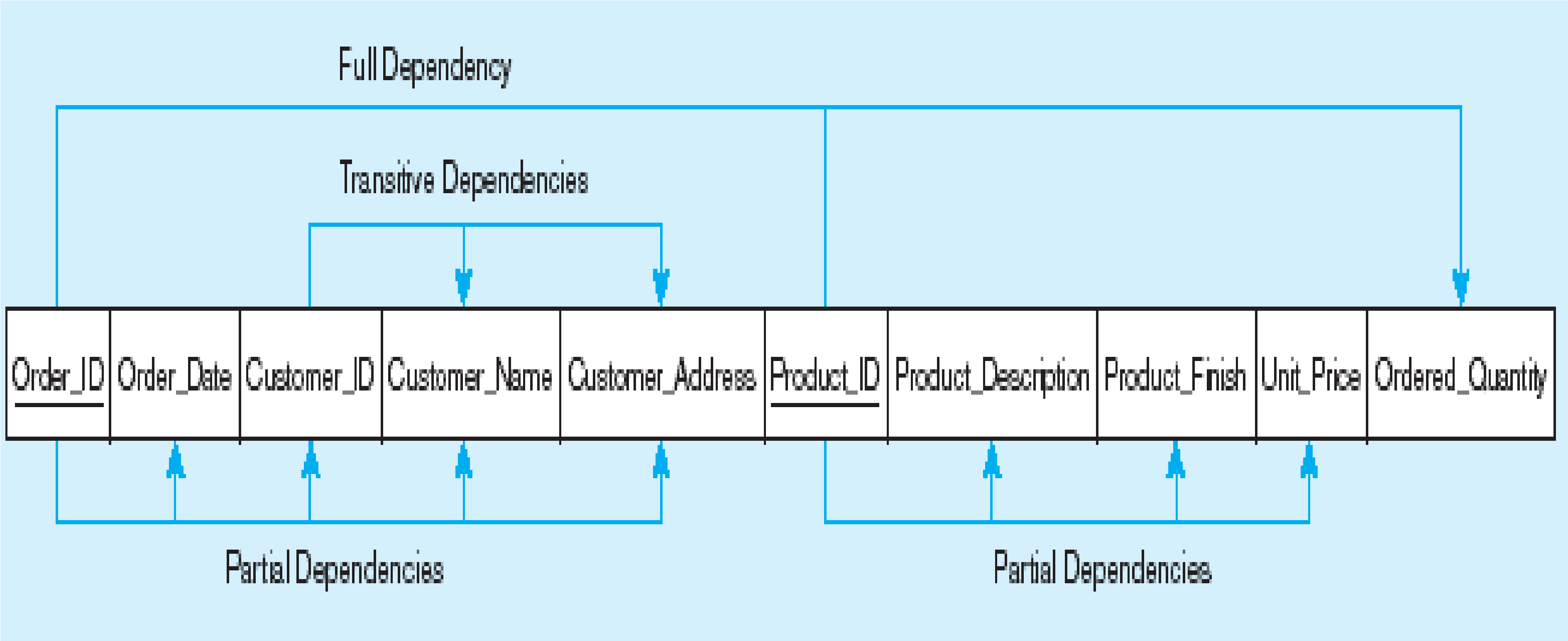
SALES1

Cust_ID	**Name**	**Salesperson**
8023	Anderson	101
9167	Bancroft	102
7924	Hobbs	101
6837	Tucker	103
8596	Eckersley	102
7018	Arnold	104

S_PERSON

Salesperson	**Region**
101	South
102	West
103	East
104	North

Functional dependency diagram for INVOICE



Order_ID → Order_Date, Customer_ID, Customer_Name, Customer_Address

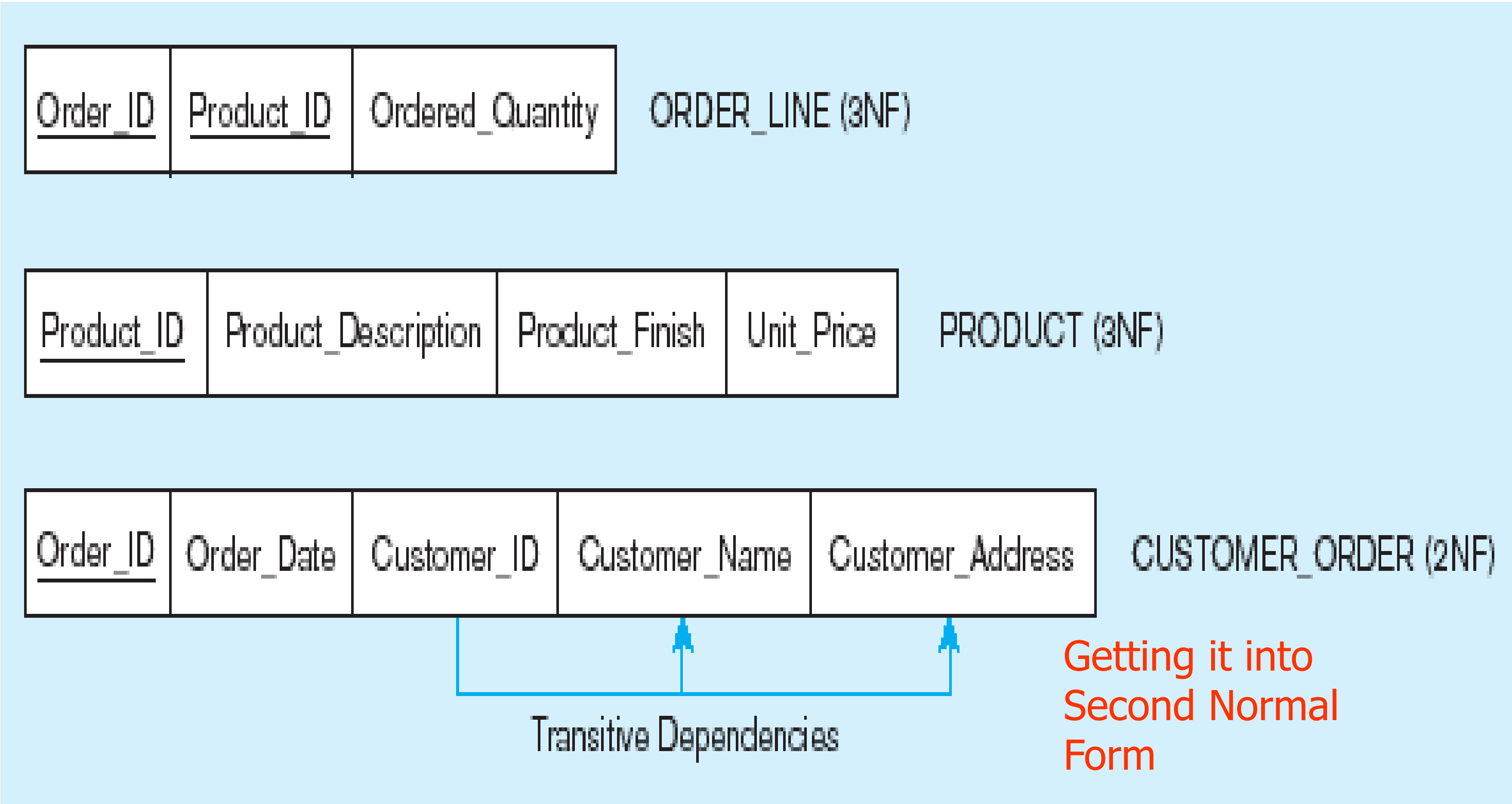
Customer_ID → Customer_Name, Customer_Address

Product_ID → Product_Description, Product_Finish, Unit_Price

Order_ID, Product_ID → Order_Quantity

Therefore, NOT in 2nd Normal Form

Partial Dependencies were Removed (2NF)



Partial dependencies are removed, but there are still transitive dependencies

Transitive Dependencies were Removed (3NF)

Order_ID	Product_ID	Ordered_Quantity

ORDER_LINE (3NF)

Product_ID	Product_Description	Product_Finish	Unit_Price

PRODUCT (3NF)

Two Relations Remained

Order_ID	Order_Date	Customer_ID	Customer_Name	Customer_Address

CUSTOMER_ORDER (2NF)

Transitive Dependencies

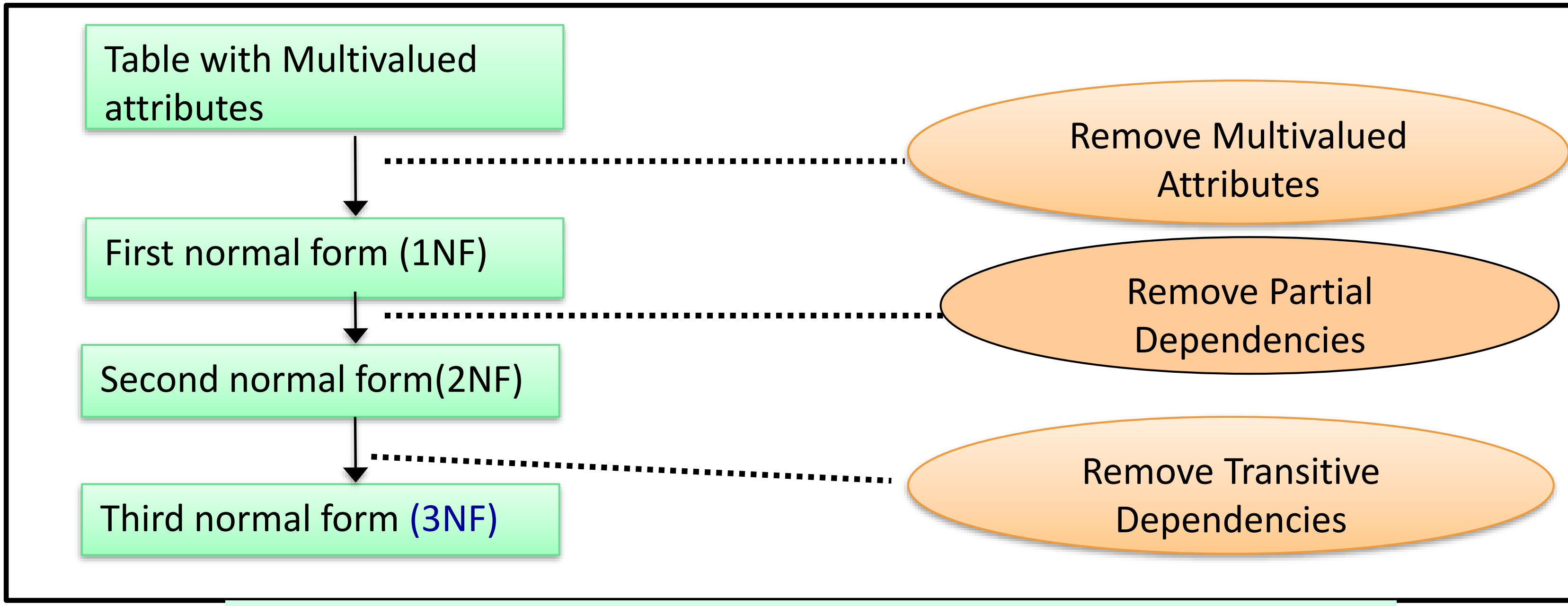
Order_ID	Order_Date	Customer_ID

ORDER (3NF)

Getting it into Third Normal Form

Customer_ID	Customer_Name	Customer_Address

CUSTOMER (3NF)



The Normalisation Process

Normalisation

1. *Check for multi-valued attributes*
   If you find any, restructure table to remove them
   table is now in 1st NF
2. *Check for partial dependencies*
   If you find any, restructure table to remove them
   table is now in 2nd NF
3. *Check for transitive dependencies*
   If you find any, restructure table to remove them
   table is now in 3rd NF