Chapter 5:

Logical Database Design and the Relational Model

Objectives

- Definition of terms
- List five properties of relations
- State two properties of candidate keys
- Define first, second, and third normal form
- Describe problems from merging relations
- Transform E-R and EER diagrams to relations
- Create tables with entity and relational integrity constraints
- Use normalization to convert anomalous tables to well-structured relations

Relation

- Definition: A relation is a named, two-dimensional table of data
- Table consists of rows (records) and columns (attribute or field)
- Requirements for a table to qualify as a relation:
  - It must have a unique name
  - Every attribute value must be atomic (not multivalued, not composite)
  - Every row must be unique (can't have two rows with exactly the same values for all their fields)
  - Attributes (columns) in tables must have unique names
  - The order of the columns must be irrelevant
  - The order of the rows must be irrelevant

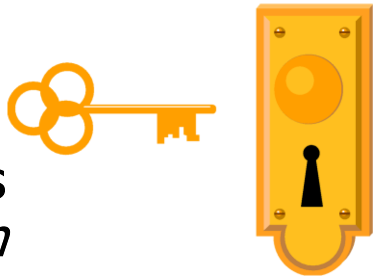
NOTE: all *relations* are in ***1st Normal form***

Correspondence with E-R Model

- Relations (tables) correspond with entity types and with many-to-many relationship types
- Rows correspond with entity instances and with many-to-many relationship instances
- Columns correspond with attributes

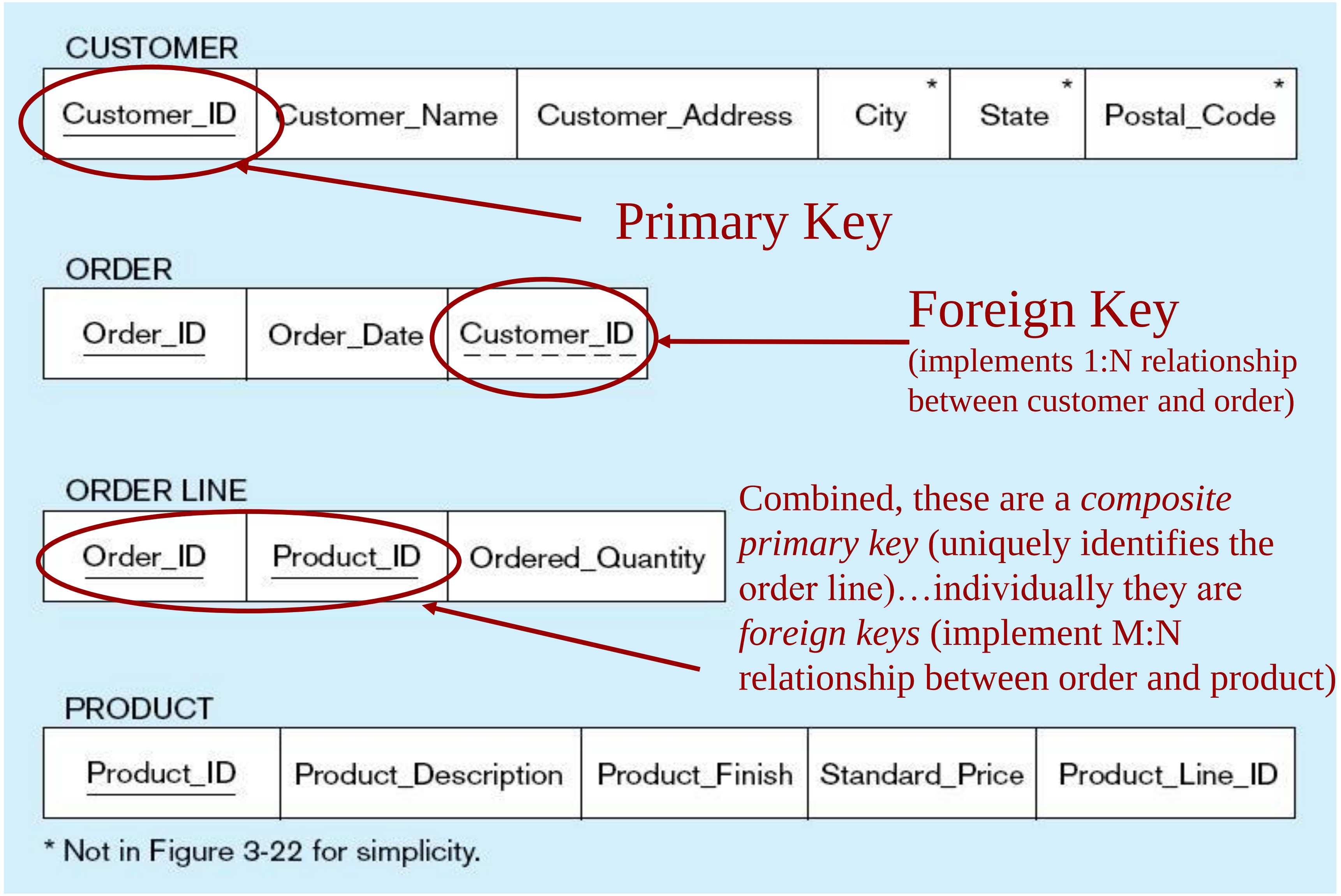
- NOTE: The word ***relation*** (in relational database) is NOT the same as the word ***relationship*** (in E-R model)

Key Fields



- Keys are special fields that serve two main purposes:
  - ***Primary keys*** are unique identifiers of the relation in question. Examples include employee numbers, social security numbers, etc. *This is how we can guarantee that all rows are unique*
  - ***Foreign 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)
- Keys usually are used as indexes to speed up the response to user queries (More on this in Chapter 6)

Figure 5-3 Schema for four relations (Pine Valley Furniture Company)



CUSTOMER

Customer_ID	Customer_Name	Customer_Address	City *	State *	Postal_Code *

Primary Key

ORDER

Order_ID	Order_Date	Customer_ID

Foreign Key
(implements 1:N relationship between customer and order)

ORDER LINE

Order_ID	Product_ID	Ordered_Quantity

Combined, these are a *composite primary key* (uniquely identifies the order line)…individually they are *foreign keys* (implement M:N relationship between order and product)

PRODUCT

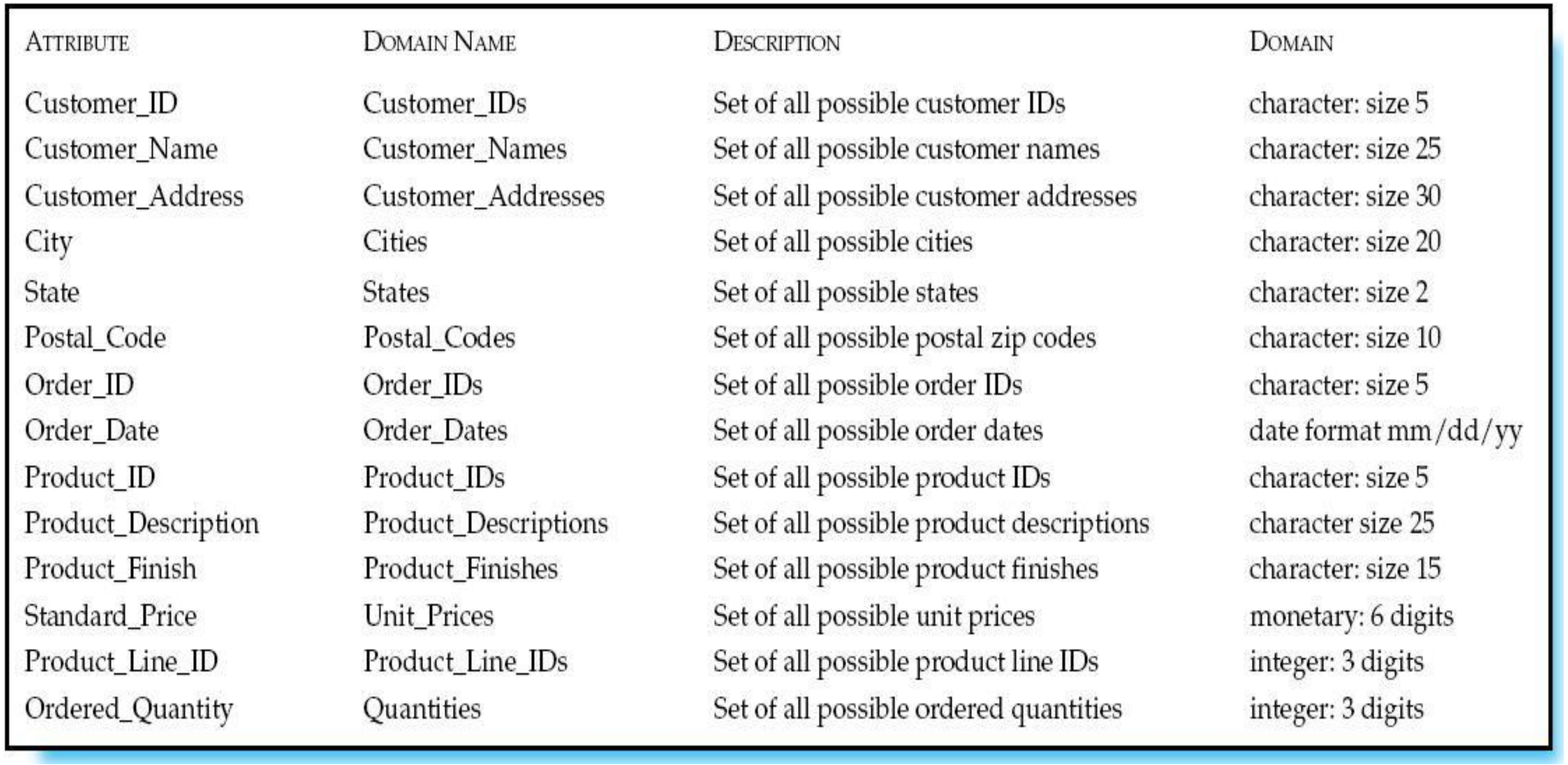
Product_ID	Product_Description	Product_Finish	Standard_Price	Product_Line_ID

* Not in Figure 3-22 for simplicity.

Integrity Constraints

- Domain Constraints
  - Allowable values for an attribute. See Table 5-1
- Entity Integrity
  - No primary key attribute may be null. All primary key fields **MUST** have data
- Action Assertions
  - Business rules. Recall from Chapter 4

Table 5-1 Domain Definitions for INVOICE Attributes



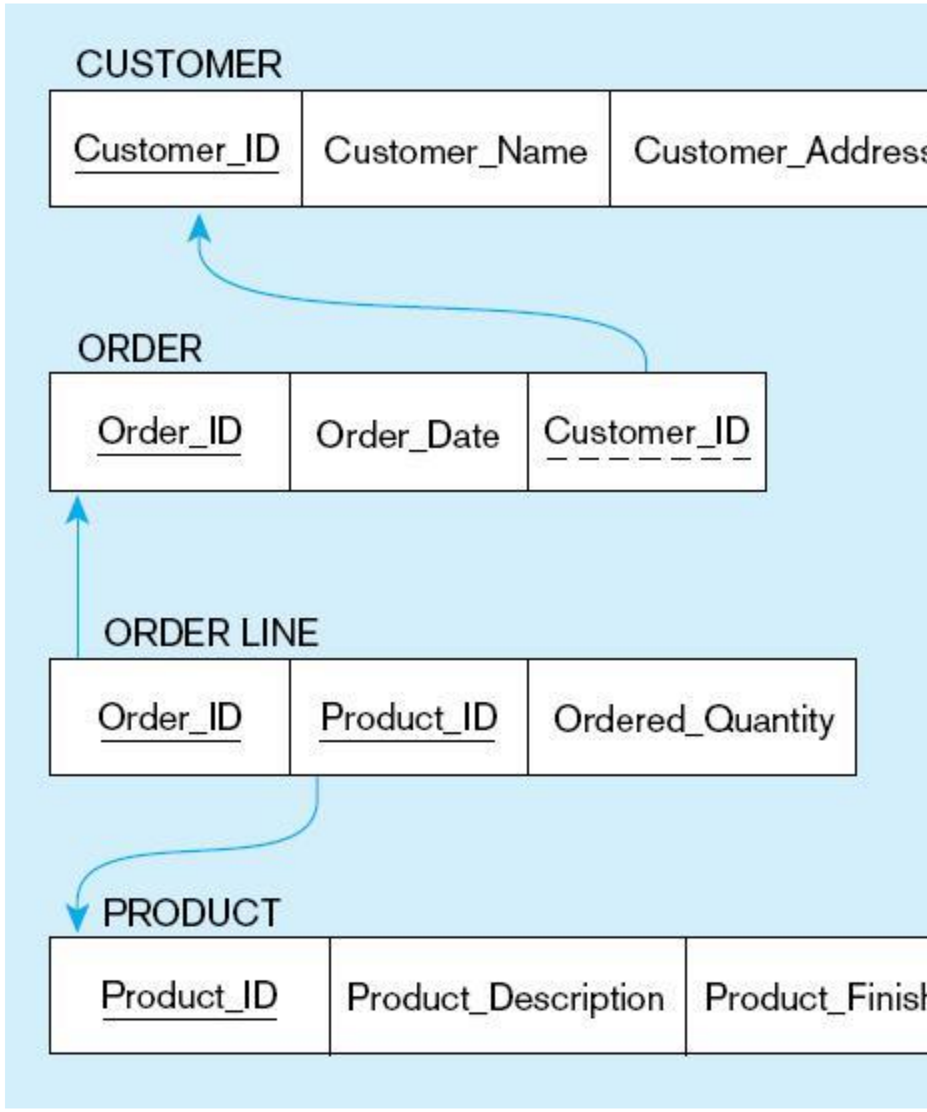
Attribute	Domain Name	Description	Domain
Customer_ID	Customer_IDs	Set of all possible customer IDs	character: size 5
Customer_Name	Customer_Names	Set of all possible customer names	character: size 25
Customer_Address	Customer_Addresses	Set of all possible customer addresses	character: size 30
City	Cities	Set of all possible cities	character: size 20
State	States	Set of all possible states	character: size 2
Postal_Code	Postal_Codes	Set of all possible postal zip codes	character: size 10
Order_ID	Order_IDs	Set of all possible order IDs	character: size 5
Order_Date	Order_Dates	Set of all possible order dates	date format mm/dd/yy
Product_ID	Product_IDs	Set of all possible product IDs	character: size 5
Product_Description	Product_Descriptions	Set of all possible product descriptions	character size 25
Product_Finish	Product_Finishes	Set of all possible product finishes	character: size 15
Standard_Price	Unit_Prices	Set of all possible unit prices	monetary: 6 digits
Product_Line_ID	Product_Line_IDs	Set of all possible product line IDs	integer: 3 digits
Ordered_Quantity	Quantities	Set of all possible ordered quantities	integer: 3 digits

Domain definitions enforce domain integrity constraints

Integrity Constraints

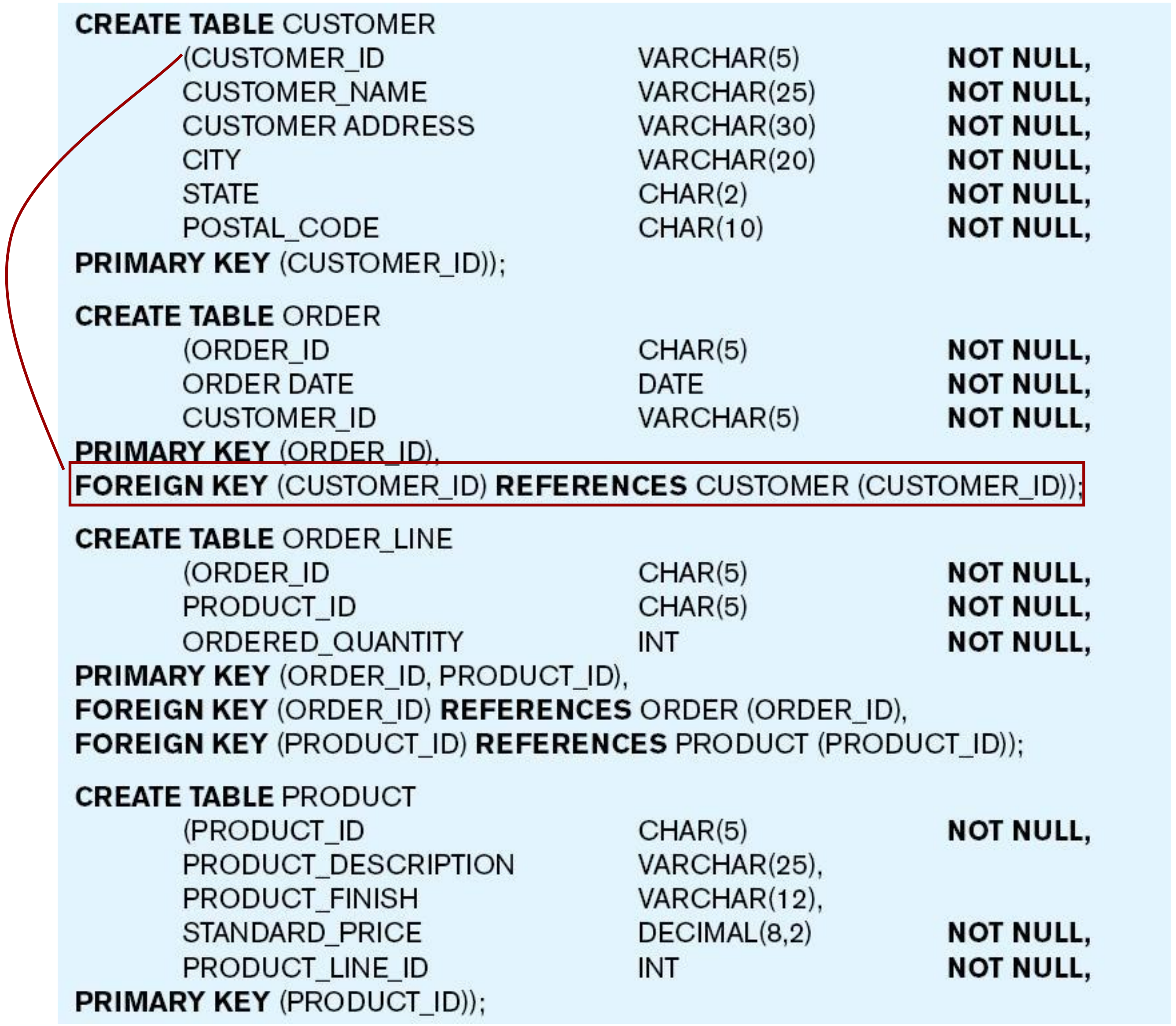
- Referential Integrity–rule states that any foreign key value (on the relation of the many side) MUST match a primary key value in the relation of the one side. (Or the foreign key can be null)
  - For example: Delete Rules
    - Restrict–don't allow delete of "parent" side if related rows exist in "dependent" side
    - Cascade–automatically delete "dependent" side rows that correspond with the "parent" side row to be deleted
    - Set-to-Null–set the foreign key in the dependent side to null if deleting from the parent side not allowed for weak entities

Figure 5-5 Referential integrity constraints (Pine Valley Furniture)



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

Figure 5-6 SQL table definitions



```
CREATE TABLE CUSTOMER
        (CUSTOMER_ID            VARCHAR(5)      NOT NULL,
        CUSTOMER_NAME           VARCHAR(25)     NOT NULL,
        CUSTOMER ADDRESS        VARCHAR(30)     NOT NULL,
        CITY                    VARCHAR(20)     NOT NULL,
        STATE                   CHAR(2)         NOT NULL,
        POSTAL_CODE             CHAR(10)        NOT NULL,
PRIMARY KEY (CUSTOMER_ID));

CREATE TABLE ORDER
        (ORDER_ID               CHAR(5)         NOT NULL,
        ORDER DATE              DATE            NOT NULL,
        CUSTOMER_ID             VARCHAR(5)      NOT NULL,
PRIMARY KEY (ORDER_ID),
FOREIGN KEY (CUSTOMER_ID) REFERENCES CUSTOMER (CUSTOMER_ID));

CREATE TABLE ORDER_LINE
        (ORDER_ID               CHAR(5)         NOT NULL,
        PRODUCT_ID              CHAR(5)         NOT NULL,
        ORDERED_QUANTITY        INT             NOT NULL,
PRIMARY KEY (ORDER_ID, PRODUCT_ID),
FOREIGN KEY (ORDER_ID) REFERENCES ORDER (ORDER_ID),
FOREIGN KEY (PRODUCT_ID) REFERENCES PRODUCT (PRODUCT_ID));

CREATE TABLE PRODUCT
        (PRODUCT_ID             CHAR(5)         NOT NULL,
        PRODUCT_DESCRIPTION     VARCHAR(25),
        PRODUCT_FINISH          VARCHAR(12),
        STANDARD_PRICE          DECIMAL(8,2)    NOT NULL,
        PRODUCT_LINE_ID         INT             NOT NULL,
PRIMARY KEY (PRODUCT_ID));
```

Referential integrity constraints are implemented with foreign key to primary key references

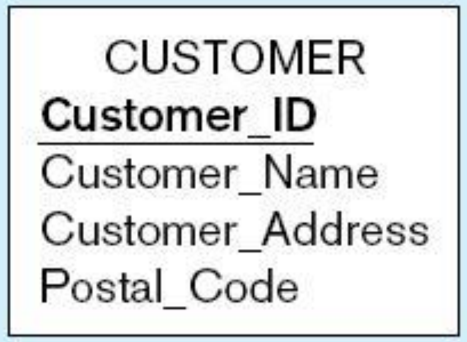
Transforming EER Diagrams into Relations

Mapping Regular Entities to Relations

1. Simple attributes: E-R attributes map directly onto the relation
2. Composite attributes: Use only their simple, component attributes
3. Multivalued Attribute: Becomes a separate relation with a foreign key taken from the superior entity

Figure 5-8 Mapping a regular entity

(a) CUSTOMER entity type with simple attributes



(b) CUSTOMER relation

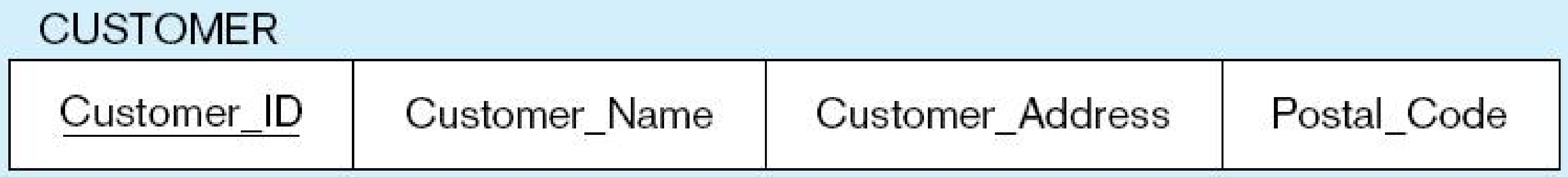
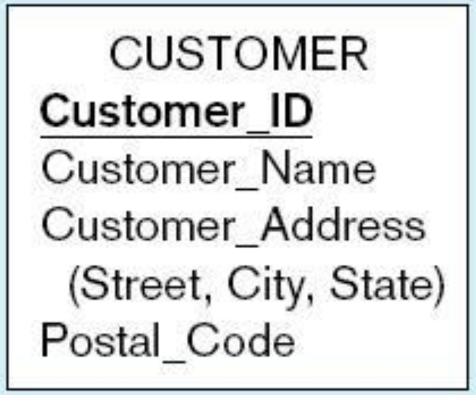
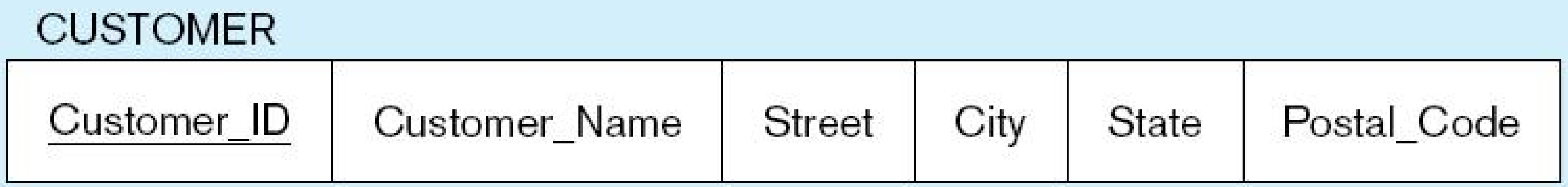


Figure 5-9 Mapping a composite attribute

(a) CUSTOMER entity type with composite attribute


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

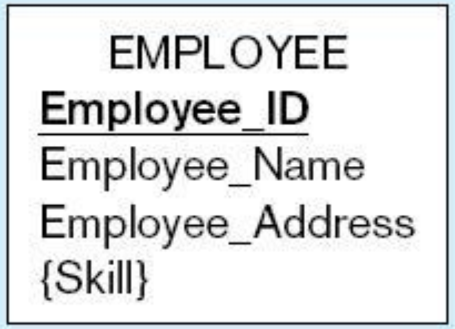
(b) CUSTOMER relation with address detail


CUSTOMER

Customer_ID	Customer_Name	Street	City	State	Postal_Code

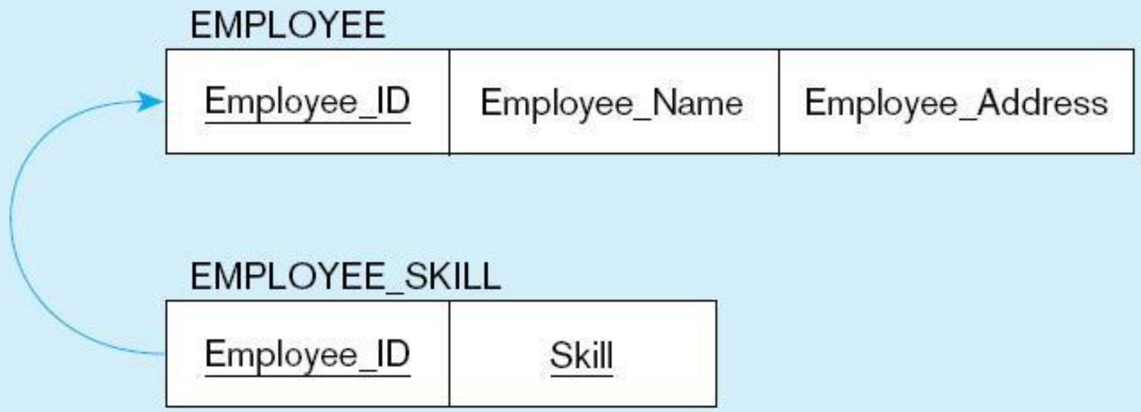
Figure 5-10 Mapping an entity with a multivalued attribute

(a)



Multivalued attribute becomes a separate relation with foreign key

(b)



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

Transforming EER Diagrams into Relations (cont.)

Mapping Weak Entities

- 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)

Figure 5-11 Example of mapping a weak entity

a) Weak entity DEPENDENT

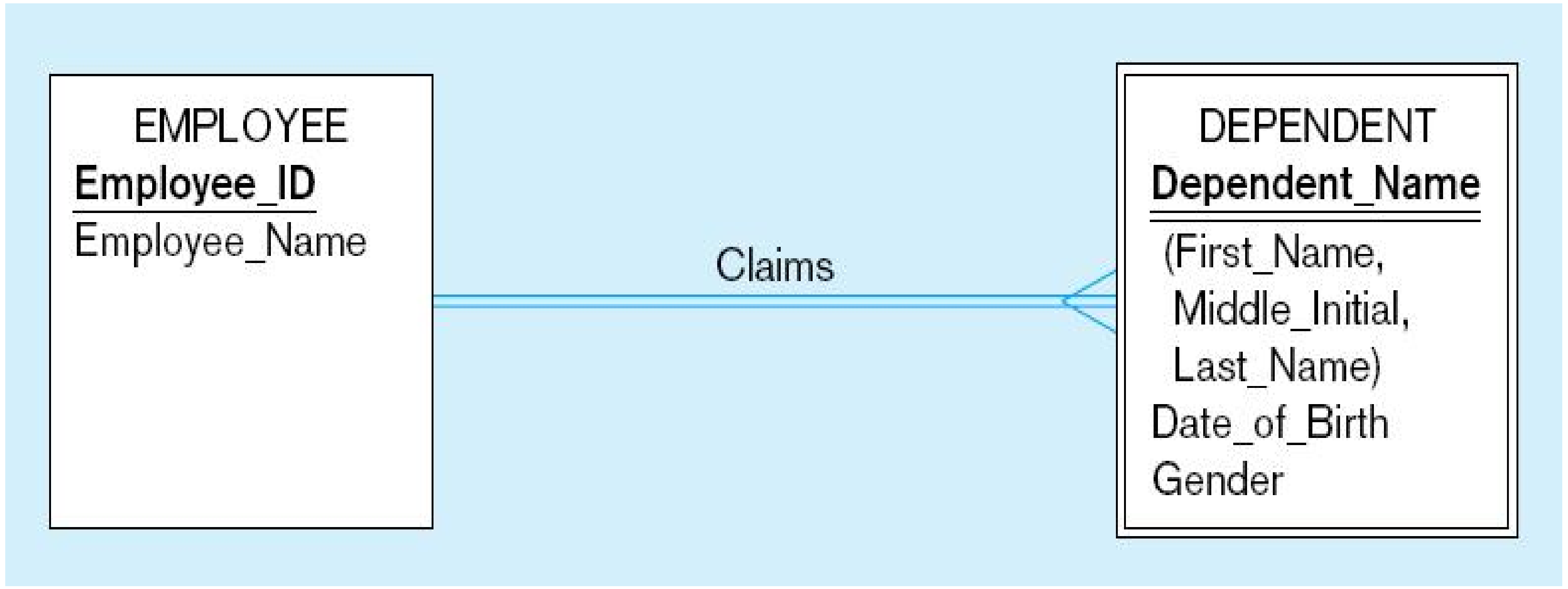
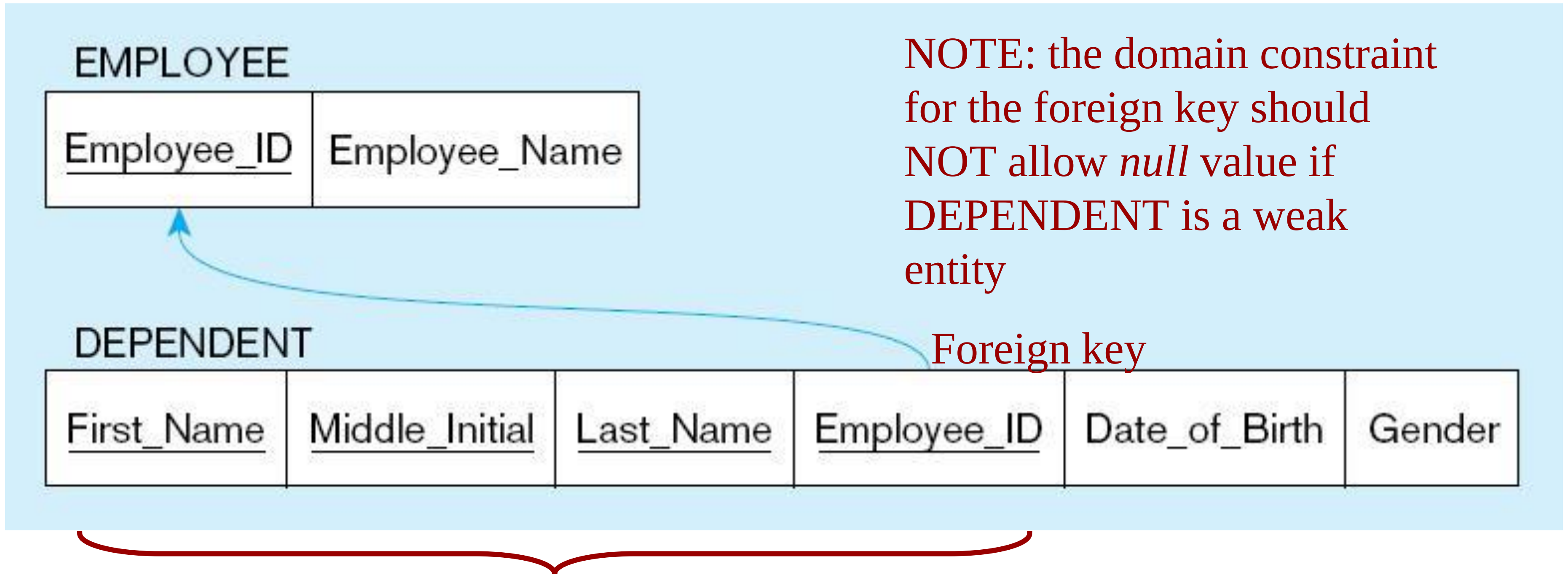


Figure 5-11 Example of mapping a weak entity (cont.)

b) Relations resulting from weak entity



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

Composite primary key

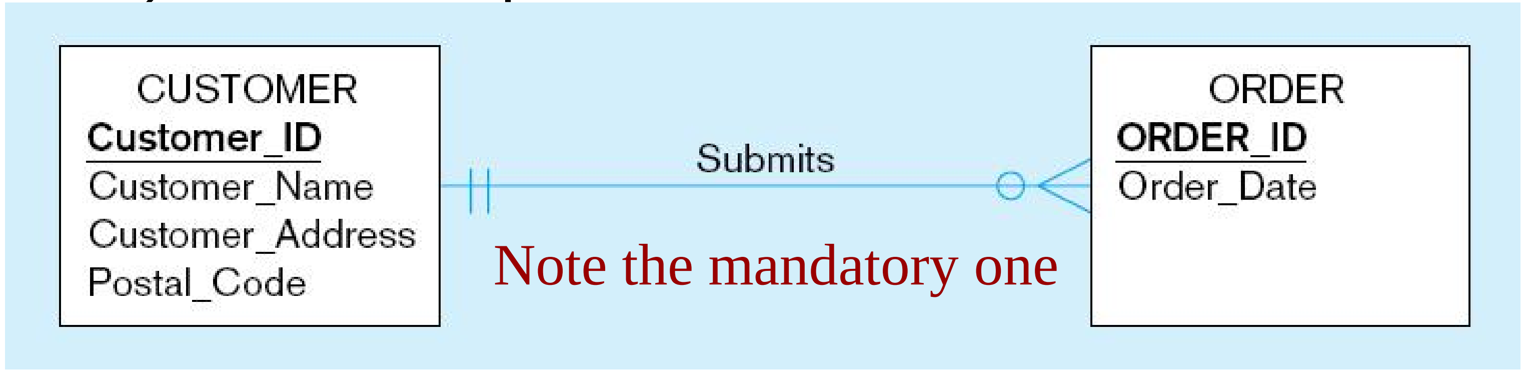
Transforming EER Diagrams into Relations (cont.)

Mapping 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

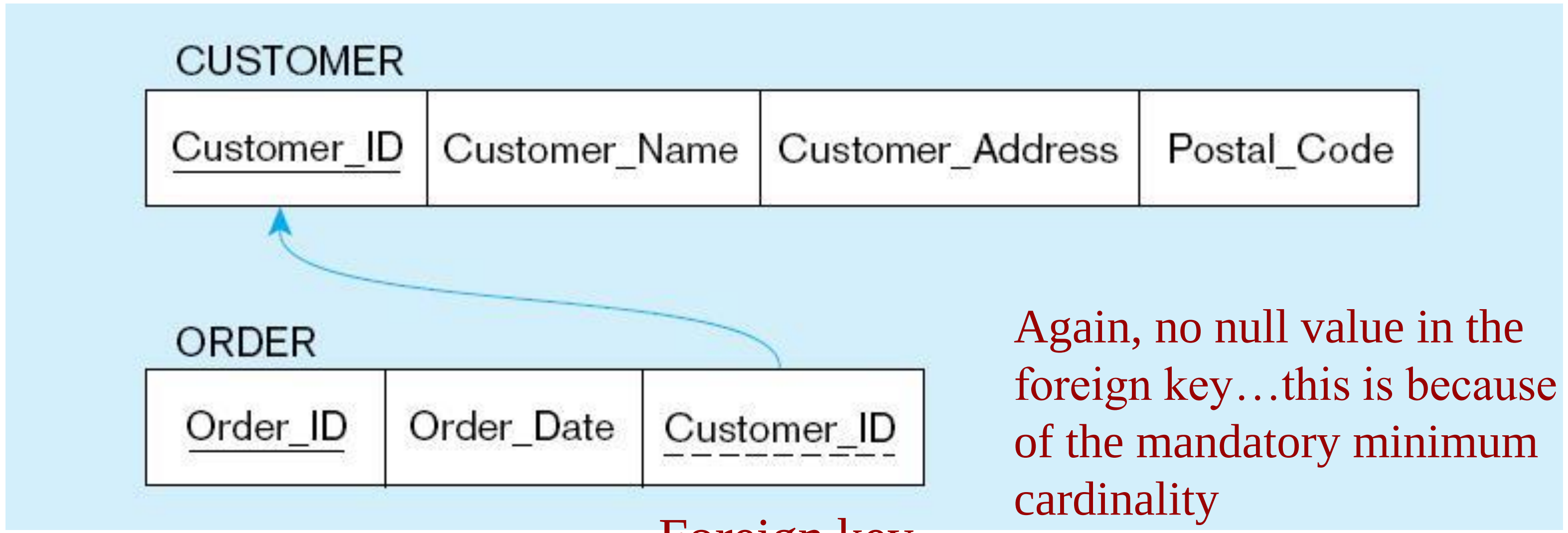
Figure 5-12 Example of mapping a 1:M relationship

a) Relationship between customers and orders



Note the mandatory one

b) Mapping the relationship

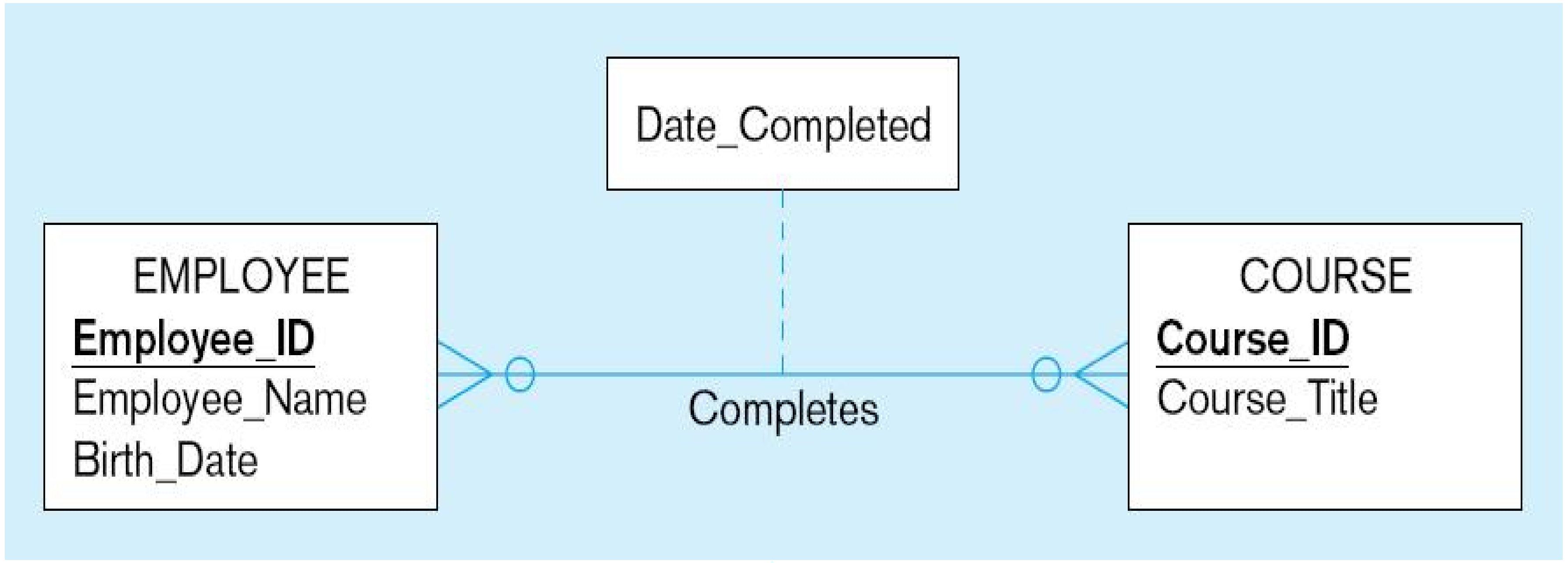


Again, no null value in the foreign key…this is because of the mandatory minimum cardinality

Foreign key

Figure 5-13 Example of mapping an M:N relationship

a) Completes relationship (M:N)



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

Figure 5-13 Example of mapping an M:N relationship (cont.)

b) Three resulting relations

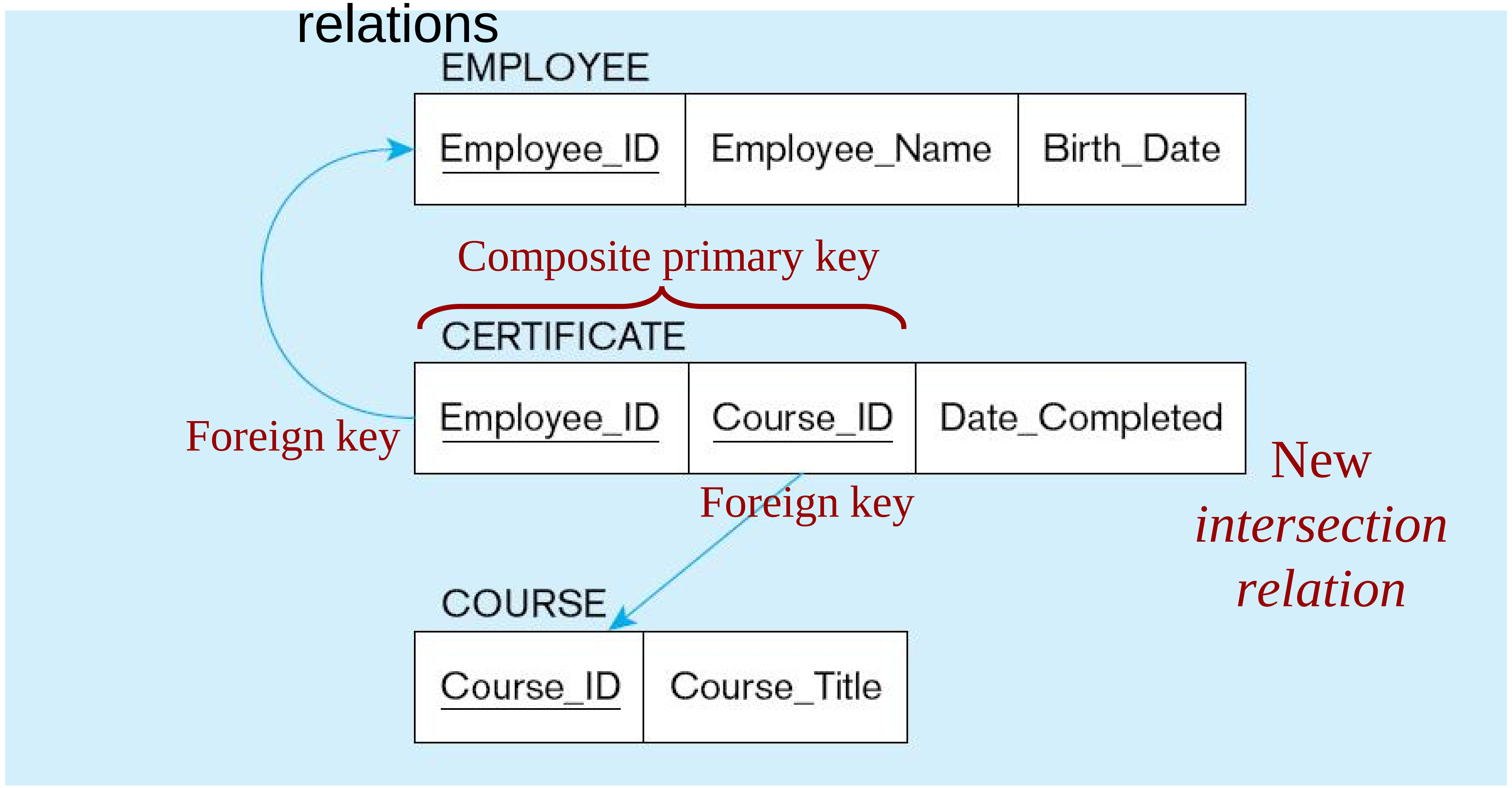
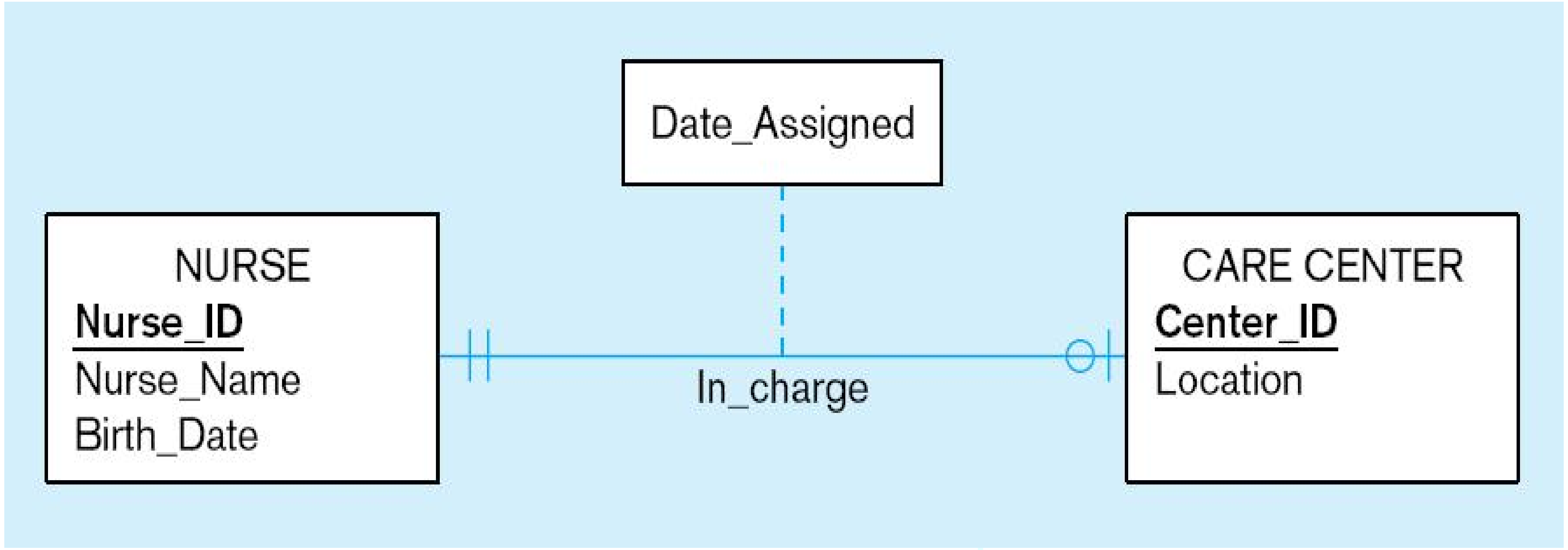


Figure 5-14 Example of mapping a binary 1:1 relationship

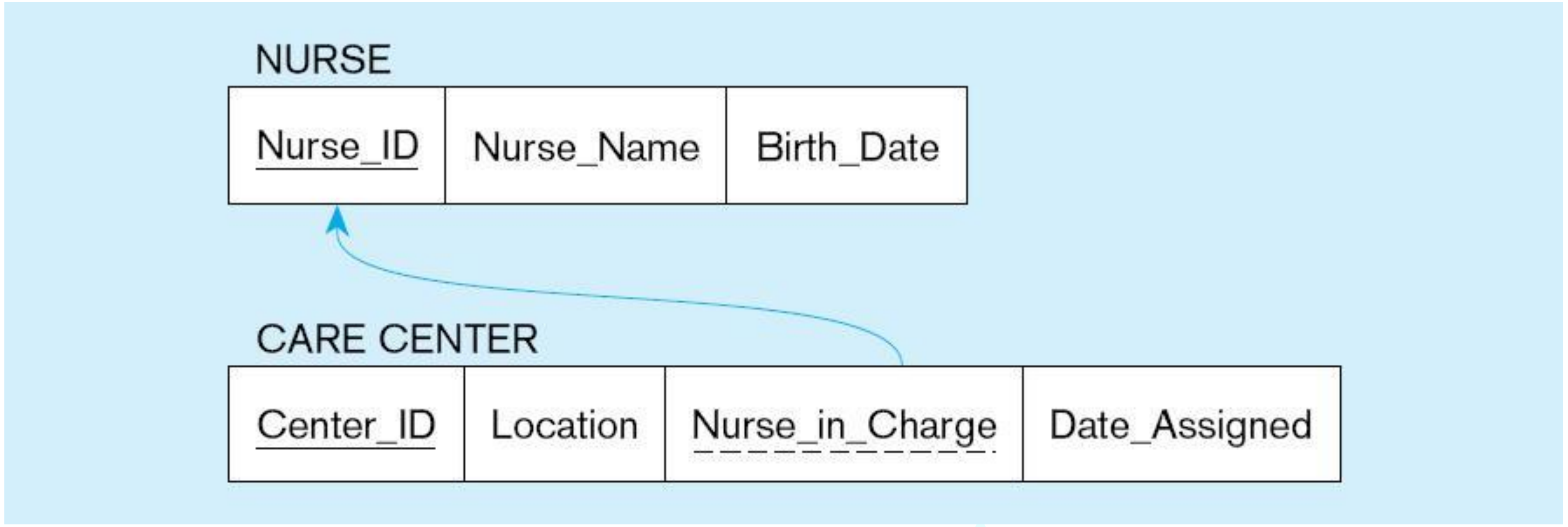
a) In_charge relationship (1:1)



Often in 1:1 relationships, one direction is optional

Figure 5-14 Example of mapping a binary 1:1 relationship (cont.)

b) Resulting relations



Foreign key goes in the relation on the optional side, matching the primary key on the mandatory side

Transforming EER Diagrams into Relations (cont.)

Mapping Associative Entities

- Identifier Not Assigned
  - Default primary key for the association relation is composed of the primary keys of the two entities (as in M:N relationship)
- Identifier Assigned
  - It is natural and familiar to end-users
  - Default identifier may not be unique

Figure 5-15 Example of mapping an associative entity

a) An associative entity

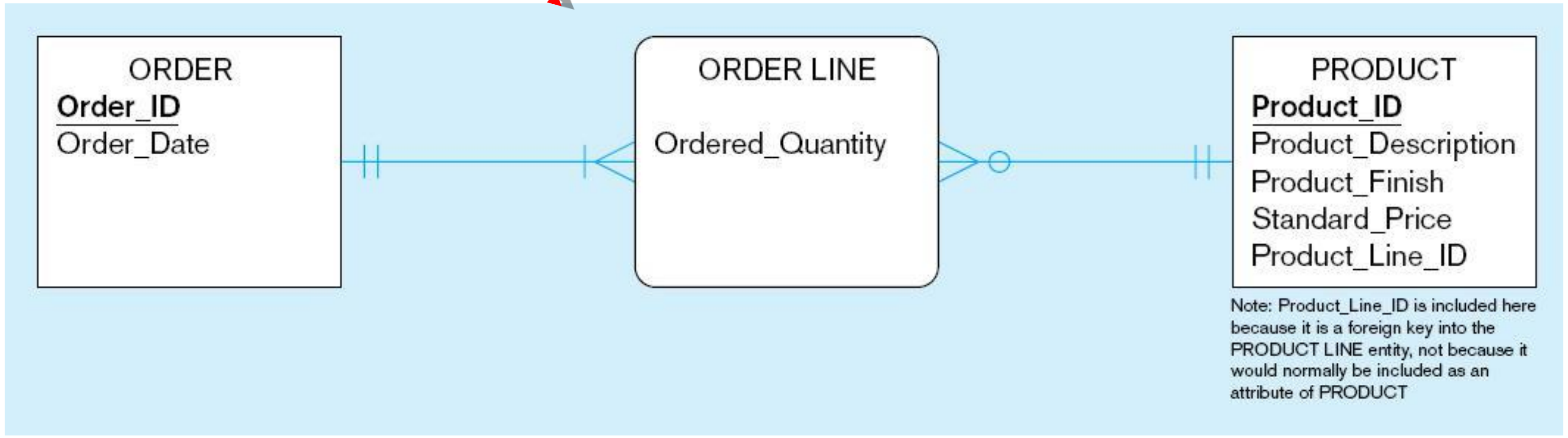
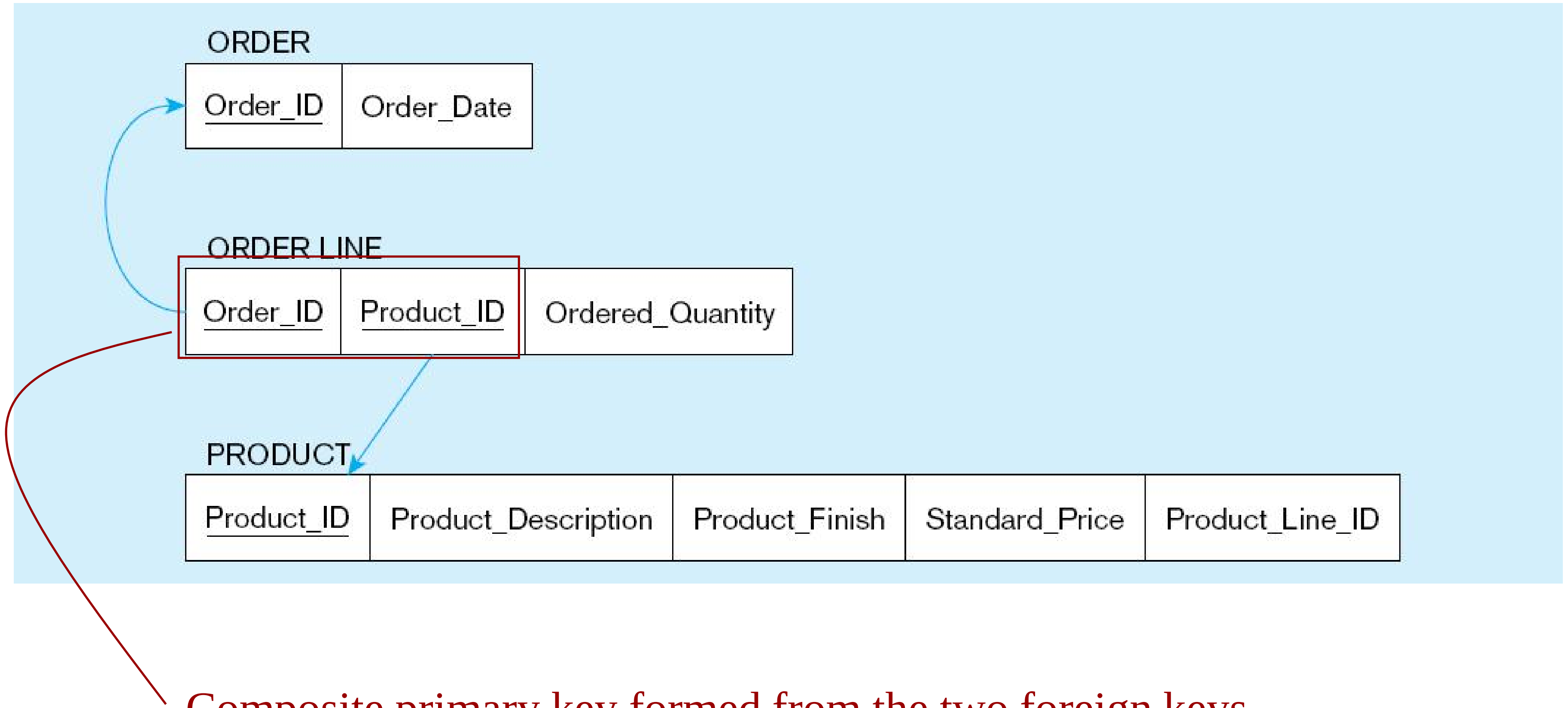

ORDER
Order_ID
Order_Date
ORDER LINE
Ordered_Quantity
PRODUCT
Product_ID
Product_Description
Product_Finish
Standard_Price
Product_Line_ID
Note: Product_Line_ID is included here because it is a foreign key into the PRODUCT LINE entity, not because it would normally be included as an attribute of PRODUCT

Figure 5-15 Example of mapping an associative entity (cont.)

b) Three resulting relations



Composite primary key formed from the two foreign keys

Figure 5-16 Example of mapping an associative entity with an identifier

a) SHIPMENT associative entity

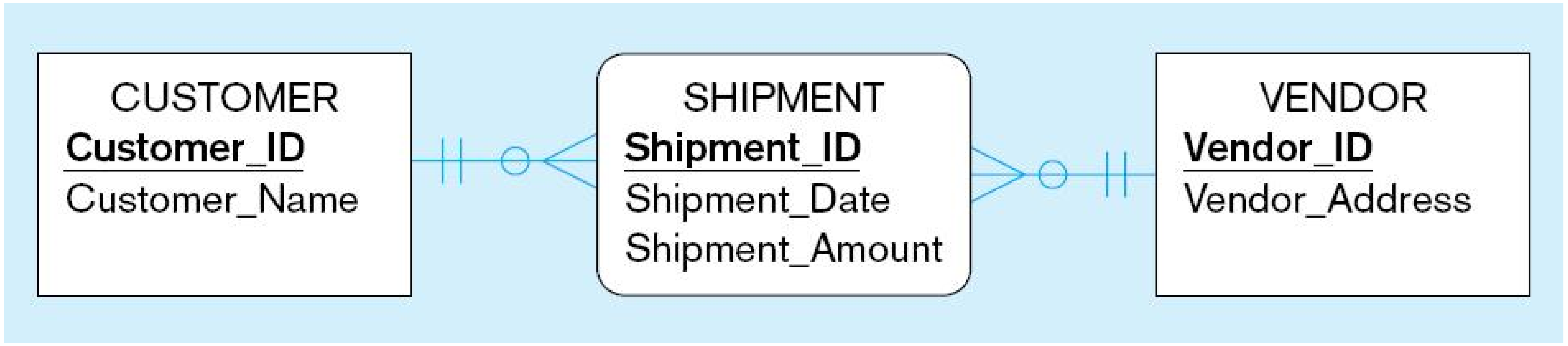
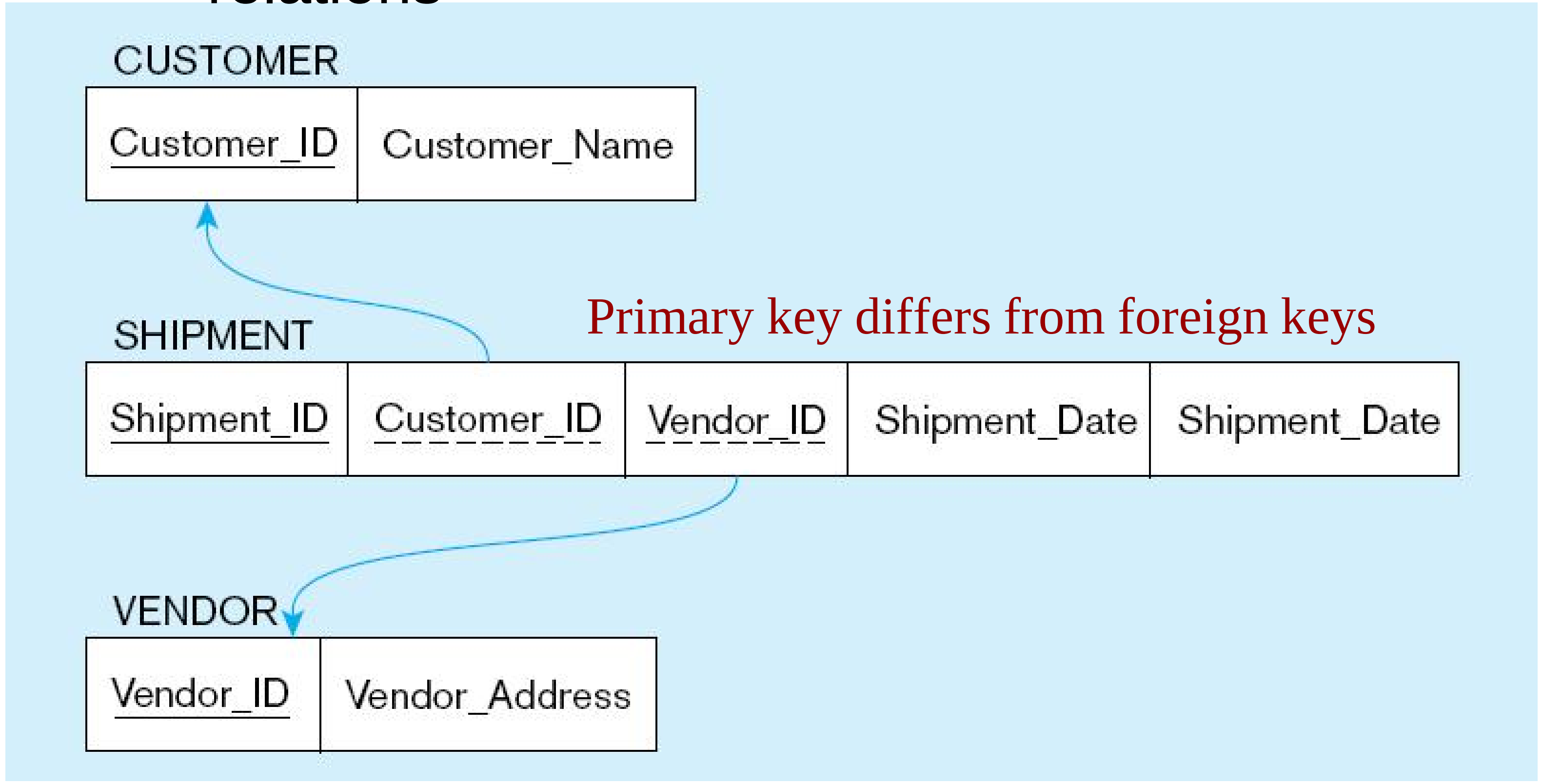


Figure 5-16 Example of mapping an associative entity with an identifier (cont.)

b) Three resulting relations

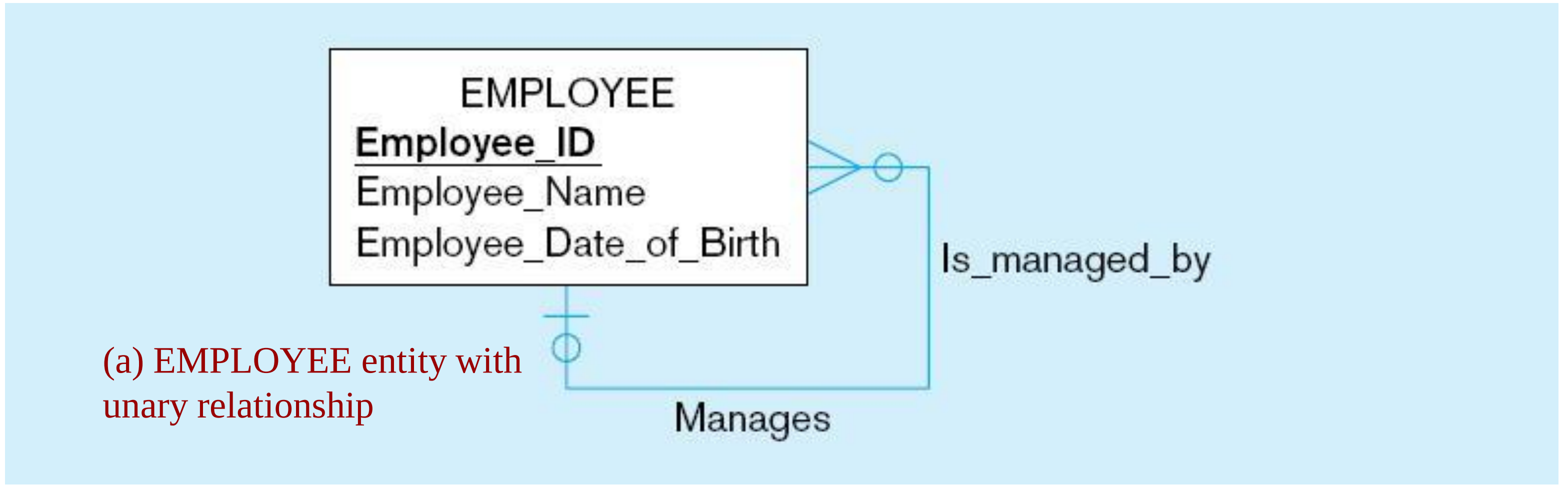


Transforming EER Diagrams into Relations (cont.)

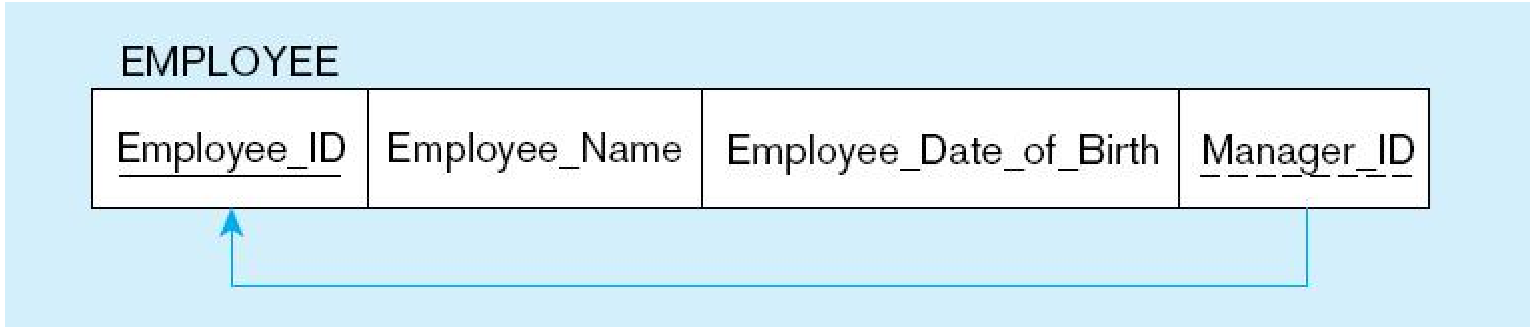
Mapping Unary Relationships

- One-to-Many–Recursive foreign key in the same relation
- Many-to-Many–Two relations:
  - 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

Figure 5-17 Mapping a unary 1:N relationship

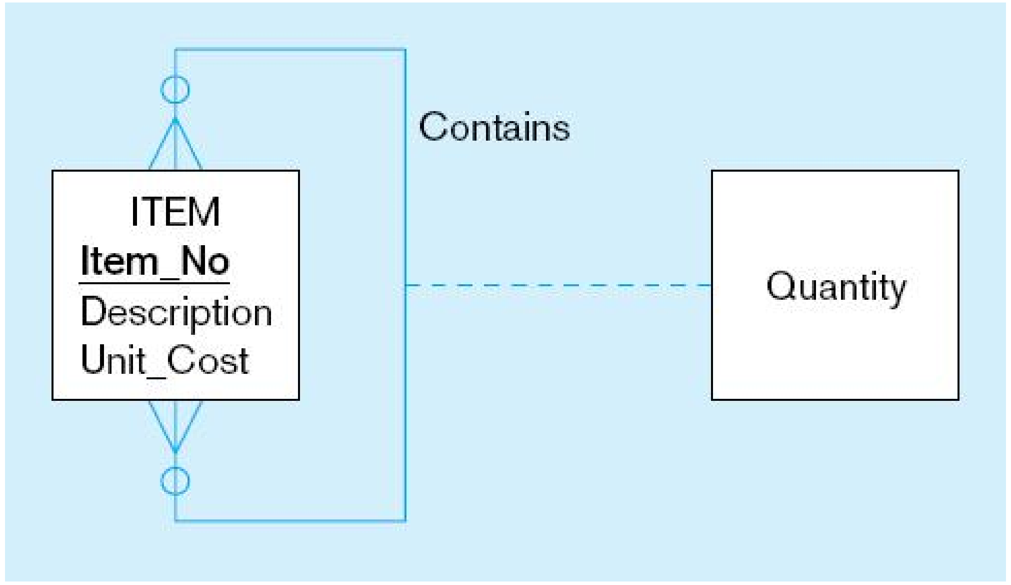


(a) EMPLOYEE entity with unary relationship



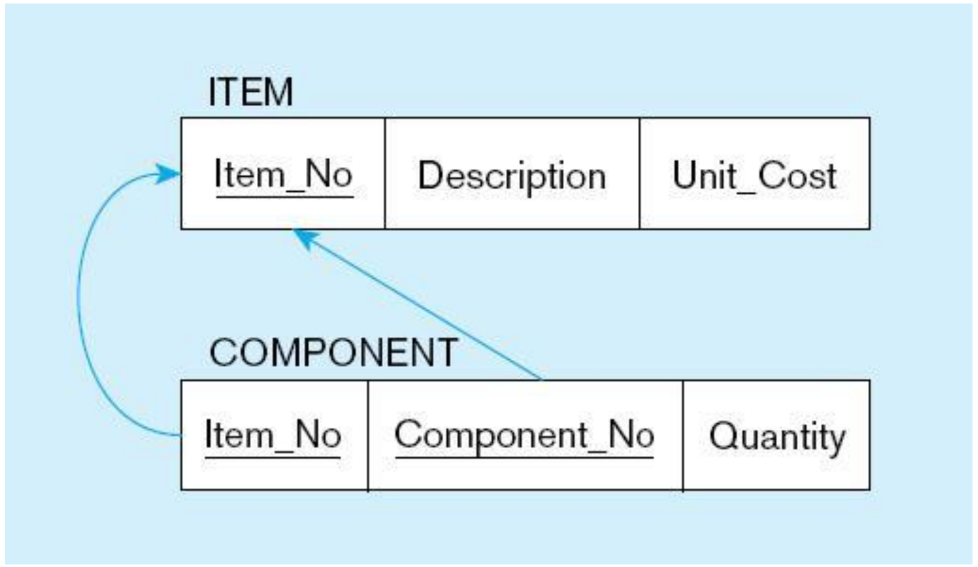
(b) EMPLOYEE relation with recursive foreign key

Figure 5-18 Mapping a unary M:N relationship



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

(b) ITEM and COMPONENT relations



Transforming EER Diagrams into Relations (cont.)

Mapping Ternary (and n-ary) Relationships

- One relation for each entity and one for the associative entity
- Associative entity has foreign keys to each entity in the relationship

Figure 5-19 Mapping a ternary relationship

a) PATIENT TREATMENT Ternary relationship with associative entity

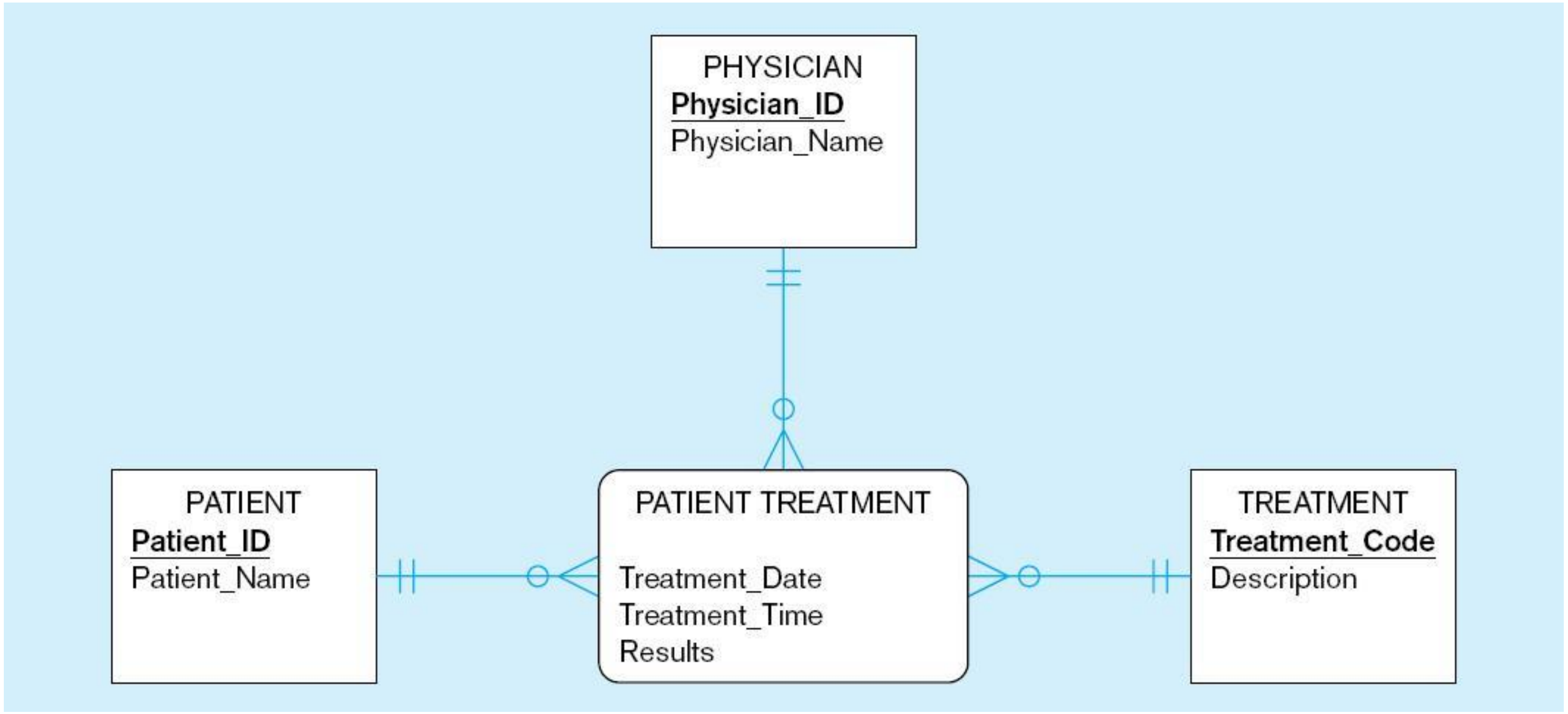
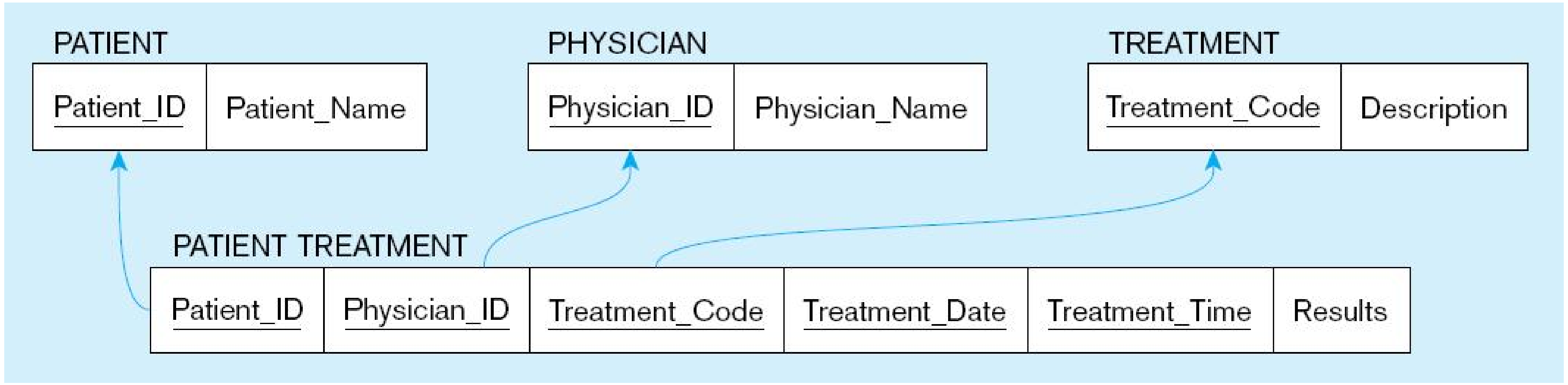


Figure 5-19 Mapping a ternary relationship (cont.)

b) Mapping the ternary relationship PATIENT TREATMENT



Remember that the primary key MUST be unique

This is why treatment date and time are included in the composite primary key

But this makes a very cumbersome key…

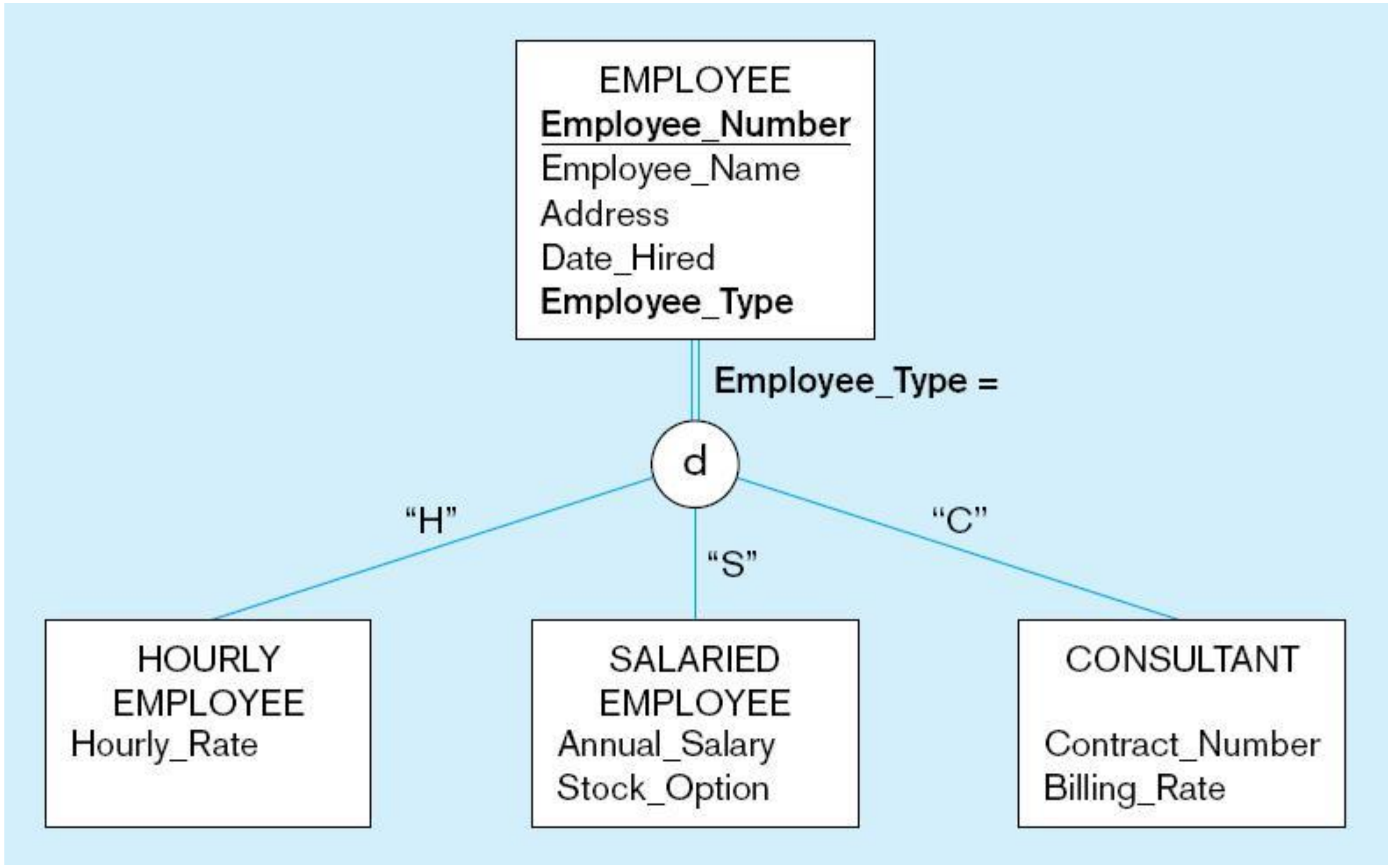
It would be better to create a surrogate key like Treatment#

Transforming EER Diagrams into Relations (cont.)

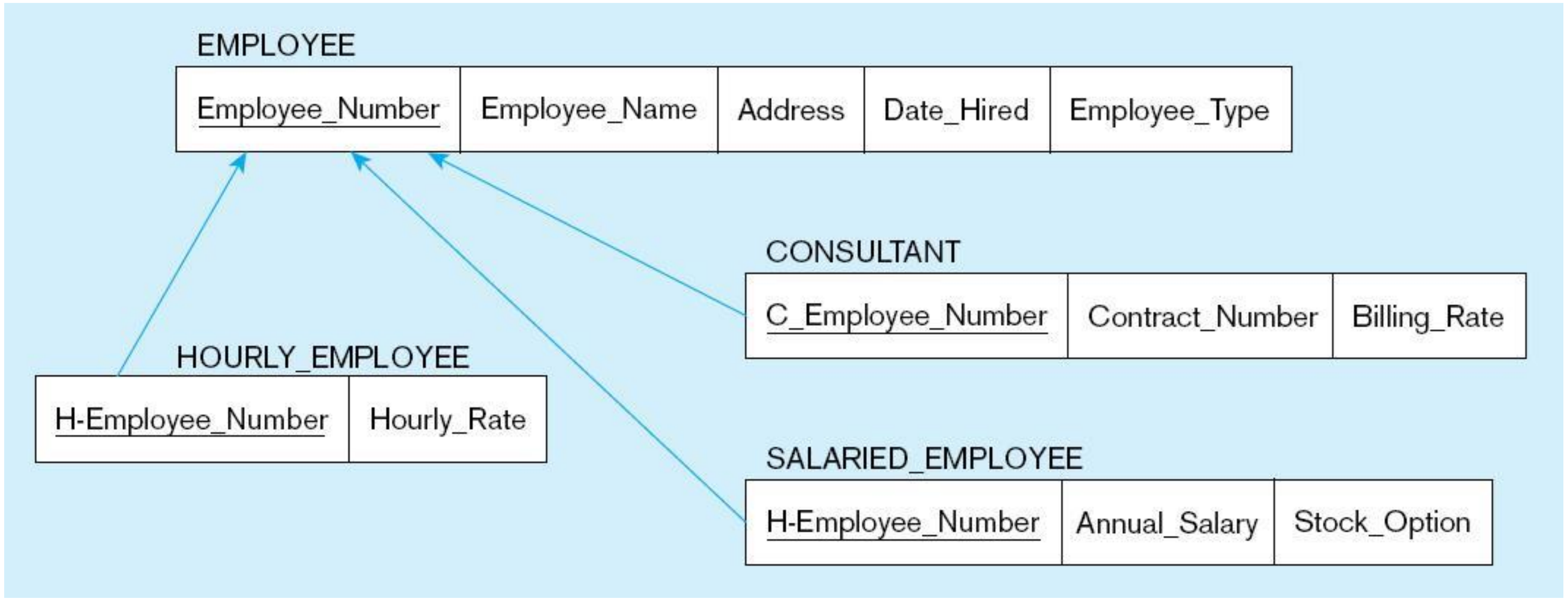
Mapping Supertype/Subtype Relationships

- 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

Figure 5-20 Supertype/subtype relationships



Mapping Supertype/subtype relationships to relations



These are implemented as one-to-one relationships

Data Normalization

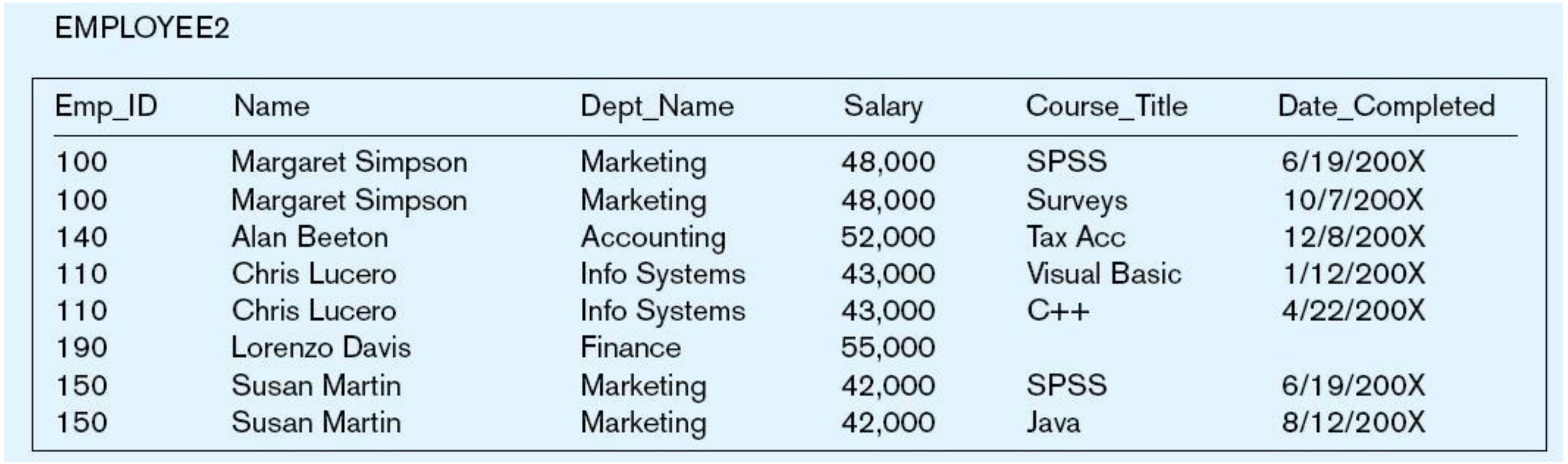
- Primarily a tool to validate and improve a logical design so that it satisfies certain constraints that ***avoid unnecessary duplication of data***
- The process of decomposing relations with anomalies to produce smaller, ***well-structured*** relations

Well-Structured Relations

- A relation that contains minimal data redundancy and allows users to insert, delete, and update rows without causing data inconsistencies
- 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

General rule of thumb: A table should not pertain to more than one entity type

Example–Figure 5-2b



EMPLOYEE2

Emp_ID	Name	Dept_Name	Salary	Course_Title	Date_Completed
100	Margaret Simpson	Marketing	48,000	SPSS	6/19/200X
100	Margaret Simpson	Marketing	48,000	Surveys	10/7/200X
140	Alan Beeton	Accounting	52,000	Tax Acc	12/8/200X
110	Chris Lucero	Info Systems	43,000	Visual Basic	1/12/200X
110	Chris Lucero	Info Systems	43,000	C++	4/22/200X
190	Lorenzo Davis	Finance	55,000		
150	Susan Martin	Marketing	42,000	SPSS	6/19/200X
150	Susan Martin	Marketing	42,000	Java	8/12/200X

Question–Is this a relation?

Answer–Yes: Unique rows and no multivalued attributes

Question–What’s the primary key?

Answer–Composite: Emp_ID, Course_Title

Anomalies in this Table

- **Insertion**–can't enter a new employee without having the employee take a class
- **Deletion**–if we remove employee 140, we lose information about the existence of a Tax Acc class
- **Modification**–giving a salary increase to employee 100 forces us to update multiple records

Why do these anomalies exist?

Because there are two themes (entity types) in this one relation. This results in data duplication and an unnecessary dependency between the entities

Functional Dependencies and Keys

- Functional Dependency: The value of one attribute (the ***determinant***) determines the value of another attribute
- Candidate Key:
  - A unique identifier. One of the candidate keys will become the primary key
    - E.g. perhaps there is both credit card number and SS# in a table…in this case both are candidate keys
  - Each non-key field is functionally dependent on every candidate key

Figure 5.22 Steps in normalization

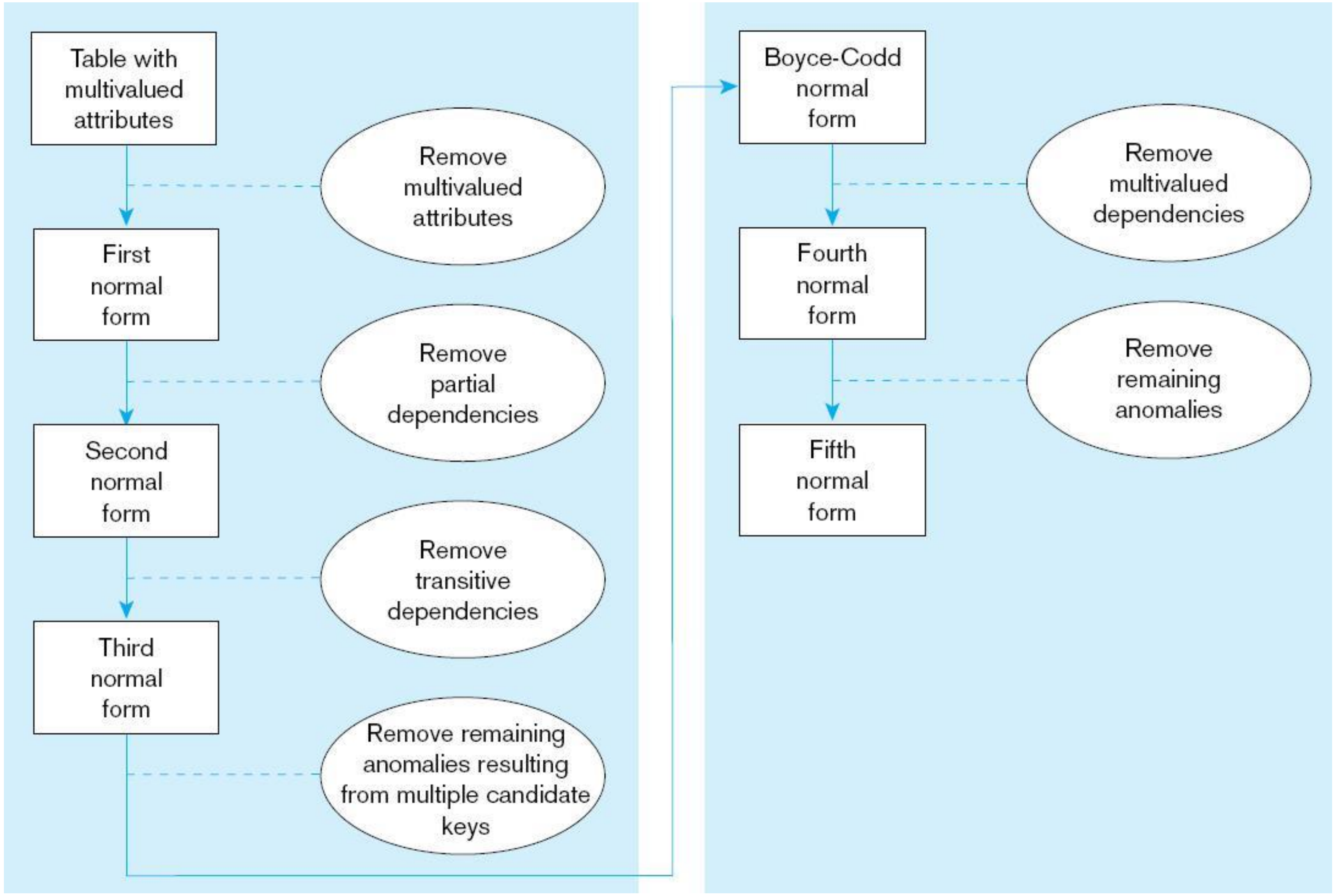


Table with multivalued attributes
Remove multivalued attributes
First normal form
Remove partial dependencies
Second normal form
Remove transitive dependencies
Third normal form
Remove remaining anomalies resulting from multiple candidate keys
Boyce-Codd normal form
Remove multivalued dependencies
Fourth normal form
Remove remaining anomalies
Fifth normal form

First Normal Form

- No multivalued attributes
- Every attribute value is atomic
- Fig. 5-25 *is not* in 1st Normal Form (multivalued attributes) it is not a relation
- Fig. 5-26 *is* in 1st Normal form
- ***All relations* are in 1st Normal Form**

Table with multivalued attributes, not in 1st normal form

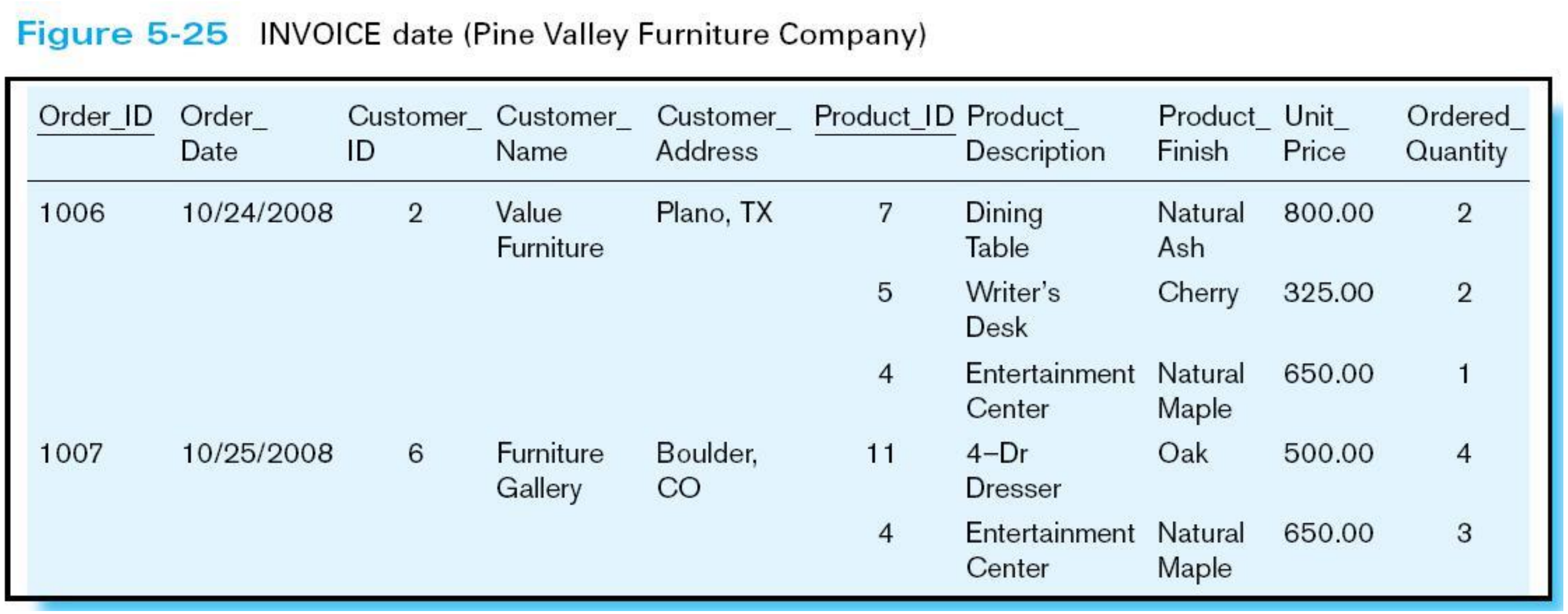


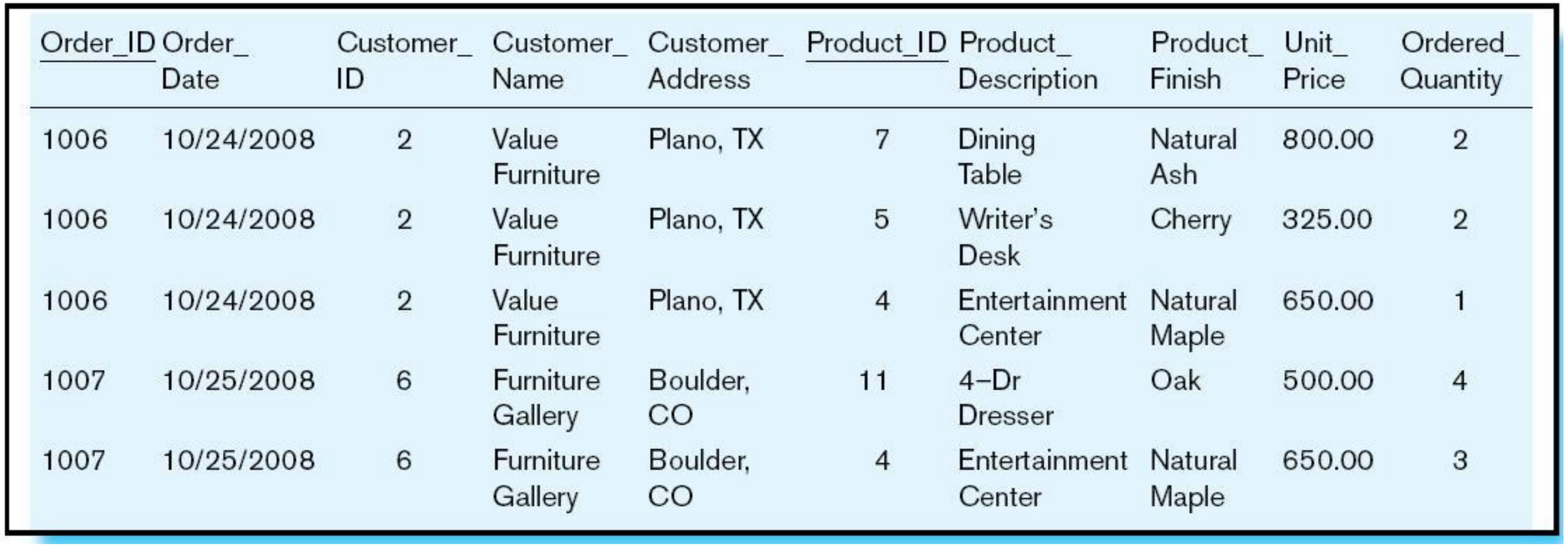
Figure 5-25 INVOICE date (Pine Valley Furniture Company)

Order_ID	Order_ Date	Customer_ ID	Customer_ Name	Customer_ Address	Product_ID	Product_ Description	Product_ Finish	Unit_ Price	Ordered_ Quantity
1006	10/24/2008	2	Value Furniture	Plano, TX	7	Dining Table	Natural Ash	800.00	2
					5	Writer's Desk	Cherry	325.00	2
					4	Entertainment Center	Natural Maple	650.00	1
1007	10/25/2008	6	Furniture Gallery	Boulder, CO	11	4–Dr Dresser	Oak	500.00	4
					4	Entertainment Center	Natural Maple	650.00	3

Note: this is NOT a relation

Table with no multivalued attributes and unique rows, in 1st normal form

Figure 5-26 INVOICE relation (1NF) (Pine Valley Furniture Company)



Order_ID	Order_ Date	Customer_ ID	Customer_ Name	Customer_ Address	Product_ID	Product_ Description	Product_ Finish	Unit_ Price	Ordered_ Quantity
1006	10/24/2008	2	Value Furniture	Plano, TX	7	Dining Table	Natural Ash	800.00	2
1006	10/24/2008	2	Value Furniture	Plano, TX	5	Writer's Desk	Cherry	325.00	2
1006	10/24/2008	2	Value Furniture	Plano, TX	4	Entertainment Center	Natural Maple	650.00	1
1007	10/25/2008	6	Furniture Gallery	Boulder, CO	11	4–Dr Dresser	Oak	500.00	4
1007	10/25/2008	6	Furniture Gallery	Boulder, CO	4	Entertainment Center	Natural Maple	650.00	3

Note: this is a relation, but not a well-structured one

Anomalies in this Table

- **Insertion**–if new product is ordered for order 1007 of existing customer, customer data must be re-entered, causing duplication
- **Deletion**–if we delete the Dining Table from Order 1006, we lose information concerning this item's finish and price
- **Update**–changing the price of product ID 4 requires update in several records

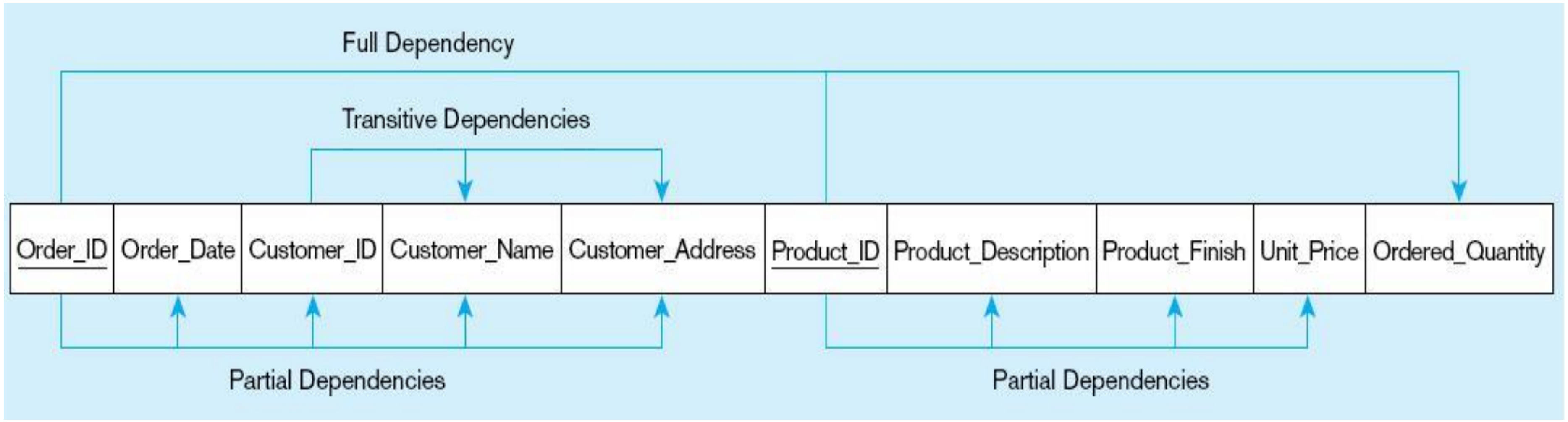
Why do these anomalies exist?

Because there are multiple themes (entity types) in one relation. This results in duplication and an unnecessary dependency between the entities

Second Normal Form

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

Figure 5-27 Functional dependency diagram for INVOICE



Order_ID → Order_Date, Customer_ID, Customer_Name, Customer_Address

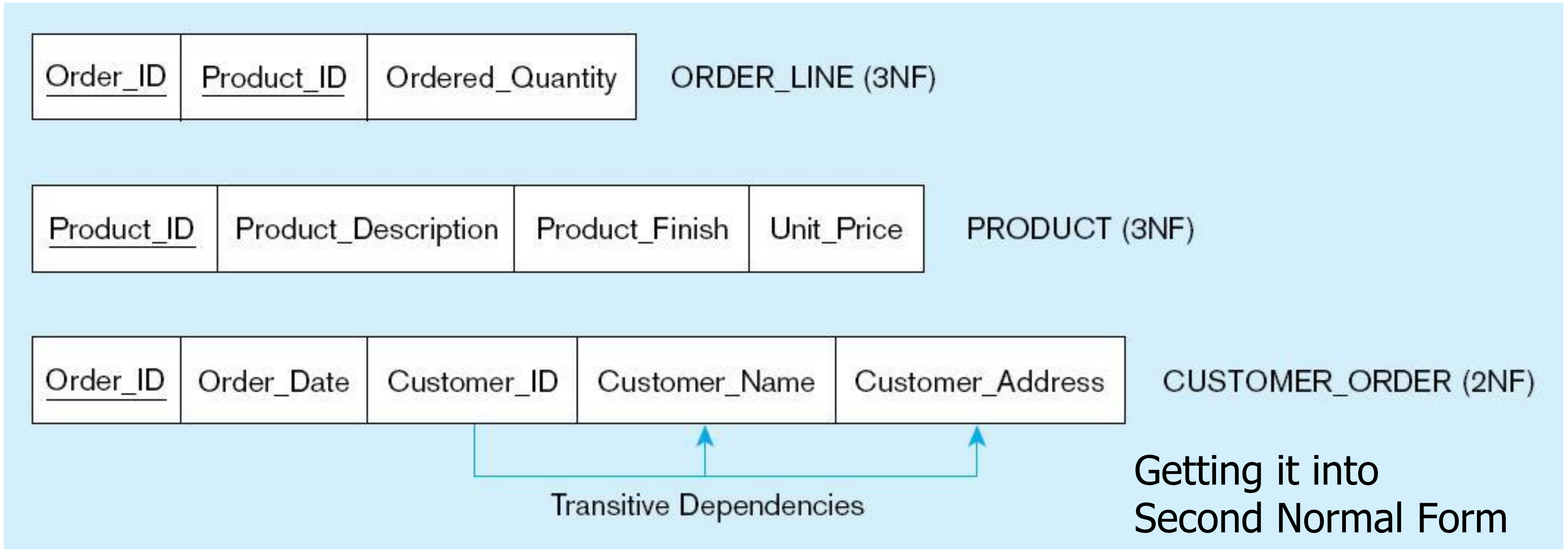
Customer_ID → Customer_Name, Customer_Address

Product_ID → Product_Description, Product_Finish, Unit_Price

Order_ID, Product_ID → Order_Quantity

Therefore, NOT in 2nd Normal Form

Figure 5-28 Removing partial dependencies

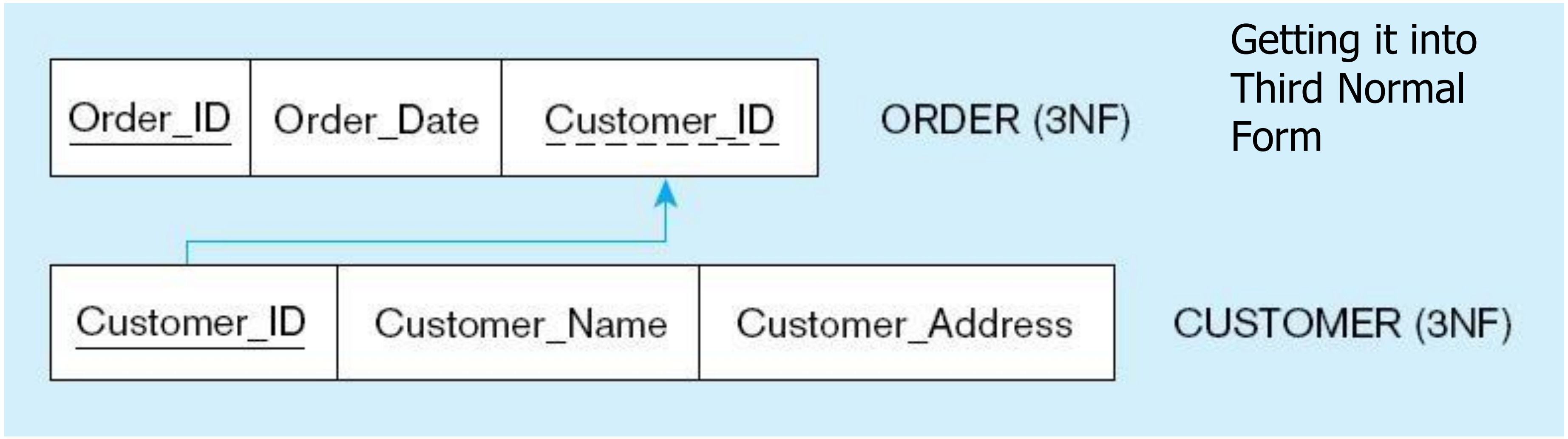


Partial dependencies are removed, but there are still transitive dependencies

Third Normal Form

- 2NF PLUS ***no transitive dependencies*** (functional dependencies on non-primary-key attributes)
- Note: This is called transitive, because the primary key is a determinant for another attribute, which in turn is a determinant for a third
- Solution: Non-key determinant with transitive dependencies go into a new table; non-key determinant becomes primary key in the new table and stays as foreign key in the old table

Figure 5-29 Removing partial dependencies



Getting it into Third Normal Form

Transitive dependencies are removed