(ADVANCED) DATABASE SYSTEMS
(DATABASE MANAGEMENTS)

PROF. DR. HASAN HÜSEYİN BALIK

(4TH WEEK)

3. OUTLINE

3. Database Design

    3.1 Logical Database Design and the Relational Model

    3.2 Physical Database Design and Performance

3.1 LOGICAL DATABASE DESIGN AND THE RELATIONAL MODEL

OBJECTİVES

- Define 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 decompose anomalous relations to well-structured relations

COMPONENTS OF RELATIONAL MODEL

- Data structure
  - Tables (relations), rows, columns
- Data manipulation
  - Powerful SQL operations for retrieving and modifying data
- Data integrity
  - Mechanisms for implementing business rules that maintain integrity of manipulated data

RELATION

- A relation is a named, two-dimensional table of data.
- A 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.

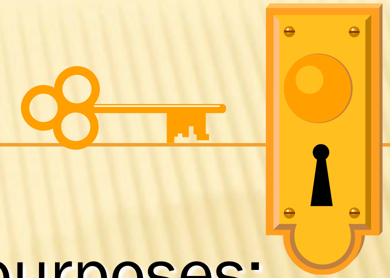
NOTE: All *relations* are in ***1st Normal form.***

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. Examples include employee numbers, social security numbers, etc. *This guarantees 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

Schema for four relations (Pine Valley Furniture Company)

CUSTOMER

CustomerID	CustomerName	CustomerAddress	CustomerCity*	CustomerState*	CustomerPostalCode

Primary Key

ORDER

OrderID	OrderDate	CustomerID

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

ORDER LINE

OrderID	ProductID	OrderedQuantity

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

ProductID	ProductDescription	ProductFinish	ProductStandardPrice	ProductLineID

* Not in Figure 2-22 for simplicity.

INTEGRITY CONSTRAINTS

- Domain Constraints
  - Allowable values for an attribute
  - Entity Integrity
  - No primary key attribute may be null. All primary key fields **MUST** contain data values.
- Referential Integrity
  - Rules that maintain consistency between the rows of two related tables.

TABLE 4-1 Domain Definitions for INVOICE Attributes

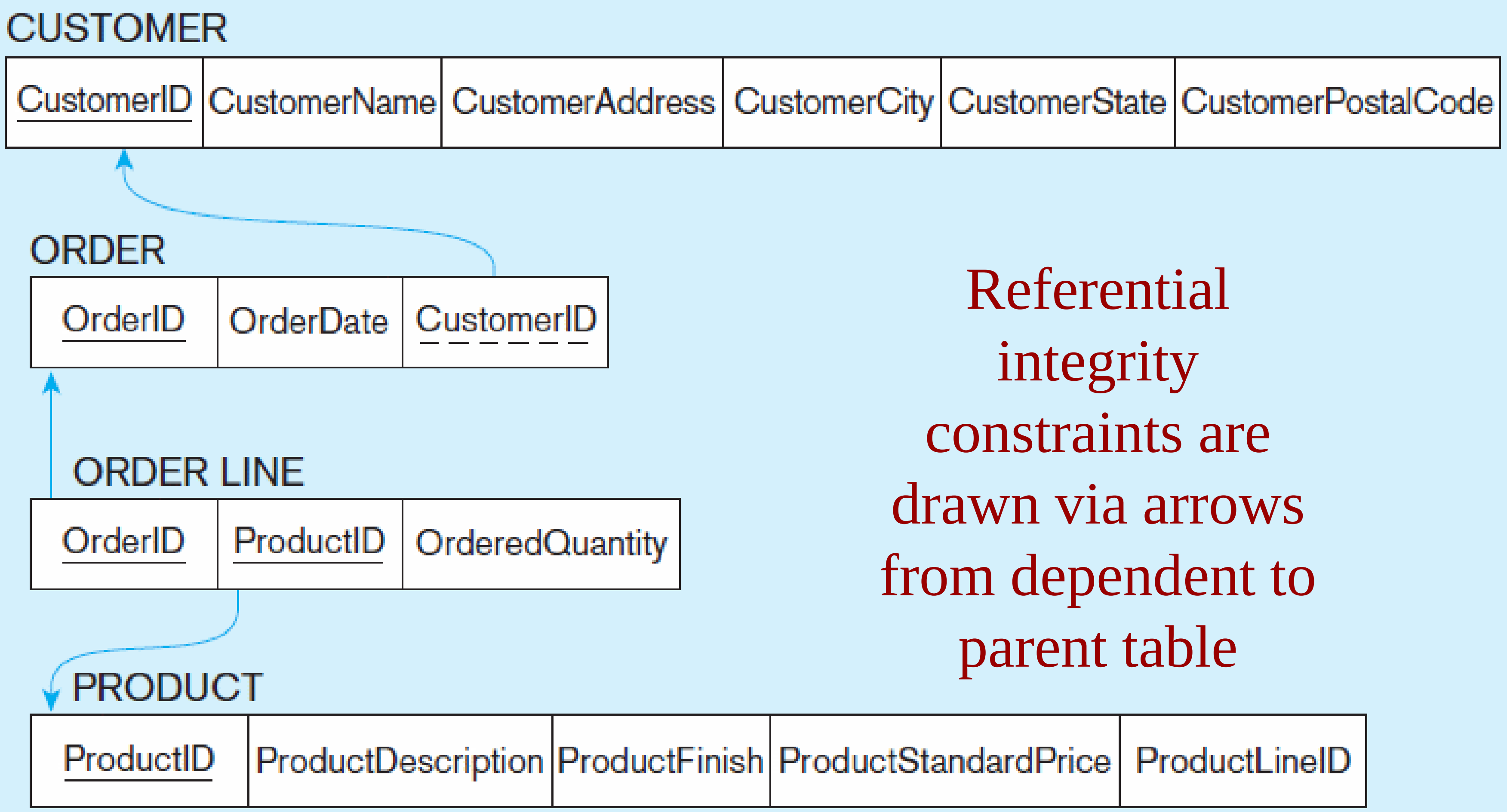
Attribute	Domain Name	Description	Domain
CustomerID	Customer IDs	Set of all possible customer IDs	character: size 5
CustomerName	Customer Names	Set of all possible customer names	character: size 25
CustomerAddress	Customer Addresses	Set of all possible customer addresses	character: size 30
CustomerCity	Cities	Set of all possible cities	character: size 20
CustomerState	States	Set of all possible states	character: size 2
CustomerPostalCode	Postal Codes	Set of all possible postal zip codes	character: size 10
OrderID	Order IDs	Set of all possible order IDs	character: size 5
OrderDate	Order Dates	Set of all possible order dates	date: format mm/dd/yy
ProductID	Product IDs	Set of all possible product IDs	character: size 5
ProductDescription	Product Descriptions	Set of all possible product descriptions	character: size 25
ProductFinish	Product Finishes	Set of all possible product finishes	character: size 15
ProductStandardPrice	Unit Prices	Set of all possible unit prices	monetary: 6 digits
ProductLineID	Product Line IDs	Set of all possible product line IDs	integer: 3 digits
OrderedQuantity	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

Referential integrity constraints (Pine Valley Furniture)



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

SQL table definitions

```
CREATE TABLE Customer_T
        (CustomerID                 NUMBER(11,0)      NOT NULL,
        CustomerName                VARCHAR2(25)      NOT NULL,
        CustomerAddress             VARCHAR2(30),
        CustomerCity                VARCHAR2(20),
        CustomerState               CHAR(2),
        CustomerPostalCode          VARCHAR2(9),
CONSTRAINT Customer_PK PRIMARY KEY (CustomerID));

CREATE TABLE Order_T
        (OrderID                    NUMBER(11,0)      NOT NULL,
        OrderDate                   DATE DEFAULT SYSDATE,
        CustomerID                  NUMBER(11,0),
CONSTRAINT Order_PK PRIMARY KEY (OrderID),
CONSTRAINT Order_FK FOREIGN KEY (CustomerID) REFERENCES Customer_T (CustomerID));

CREATE TABLE Product_T
        (ProductID                  NUMBER(11,0)      NOT NULL,
        ProductDescription          VARCHAR2(50),
        ProductFinish               VARCHAR2(20),
        ProductStandardPrice        DECIMAL(6,2),
        ProductLineID               NUMBER(11,0),
CONSTRAINT Product_PK PRIMARY KEY (ProductID));

CREATE TABLE OrderLine_T
        (OrderID                    NUMBER(11,0)      NOT NULL,
        ProductID                   NUMBER(11,0)      NOT NULL,
        OrderedQuantity             NUMBER(11,0),
CONSTRAINT OrderLine_PK PRIMARY KEY (OrderID, ProductID),
CONSTRAINT OrderLine_FK1 FOREIGN KEY (OrderID) REFERENCES Order_T (OrderID),
CONSTRAINT OrderLine_FK2 FOREIGN KEY (ProductID) REFERENCES Product_T (ProductID));
```

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

TRANSFORMING EER DIAGRAMS INTO RELATIONS

Mapping Regular Entities to Relations

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

Mapping a regular entity

(a) CUSTOMER entity type with simple attributes

CUSTOMER
<u>Customer ID</u>
Customer Name
Customer Address
Customer Postal Code

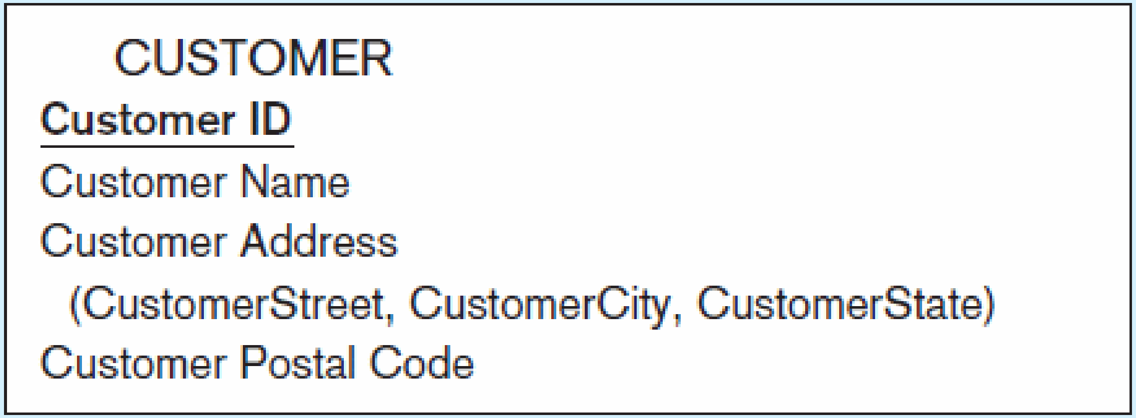
(b) CUSTOMER relation

CUSTOMER

<u>CustomerID</u>	CustomerName	CustomerAddress	CustomerPostalCode

Mapping a composite attribute

(a) CUSTOMER entity type with composite attribute



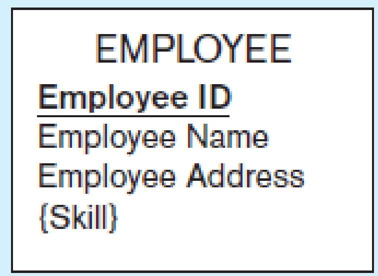
(b) CUSTOMER relation with address detail

CUSTOMER

<u>CustomerID</u>	CustomerName	CustomerStreet	CustomerCity	CustomerState	CustomerPostalCode

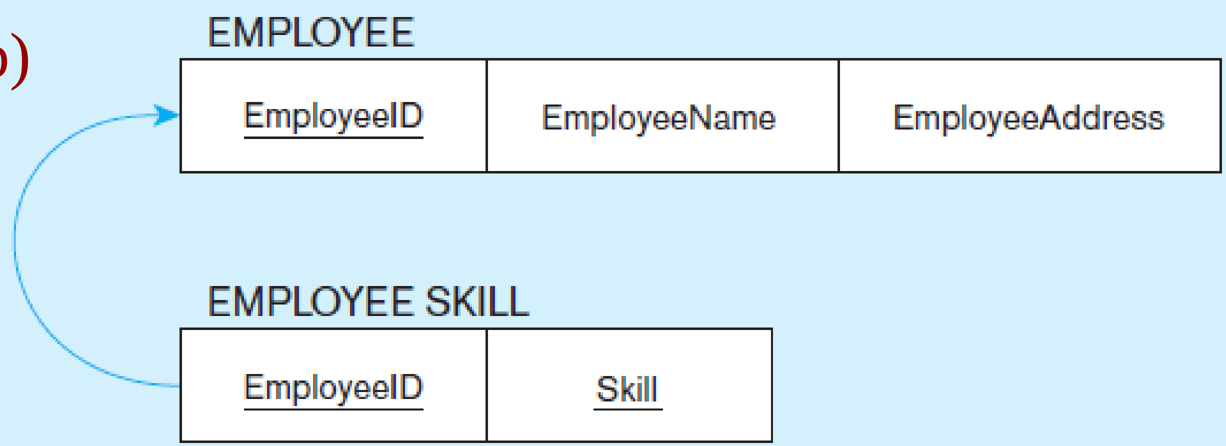
Mapping an entity with a multivalued attribute

(a)



Multivalued attribute becomes a separate relation with foreign key

(b)



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

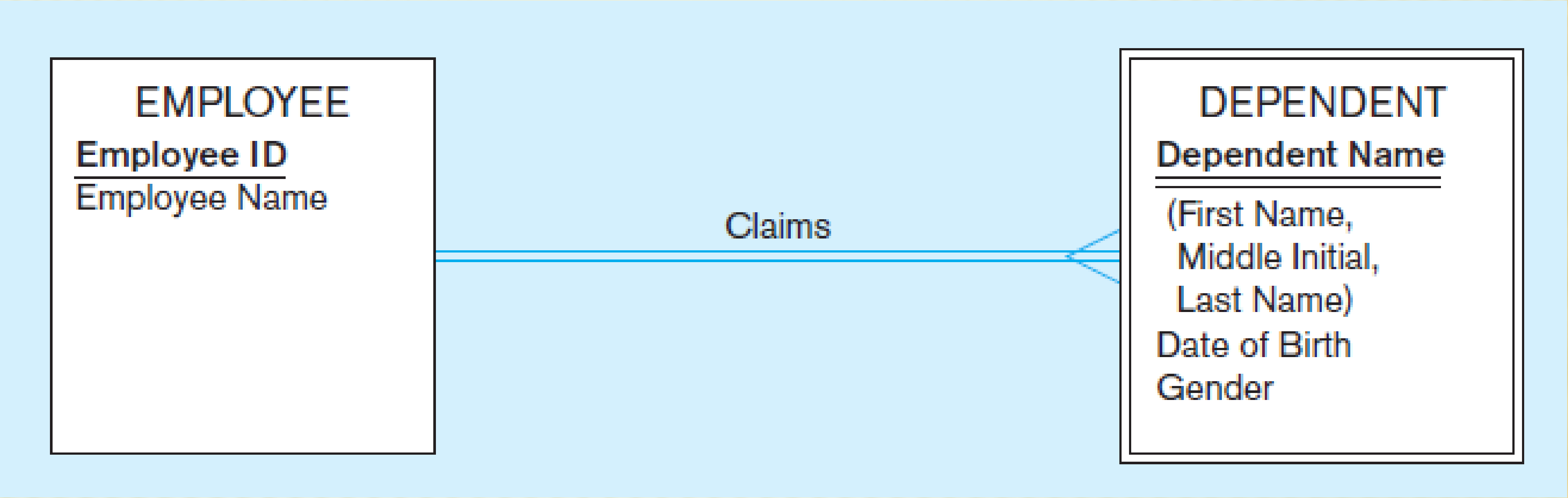
TRANSFORMING EER DIAGRAMS INTO RELATIONS (CONT.)

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)

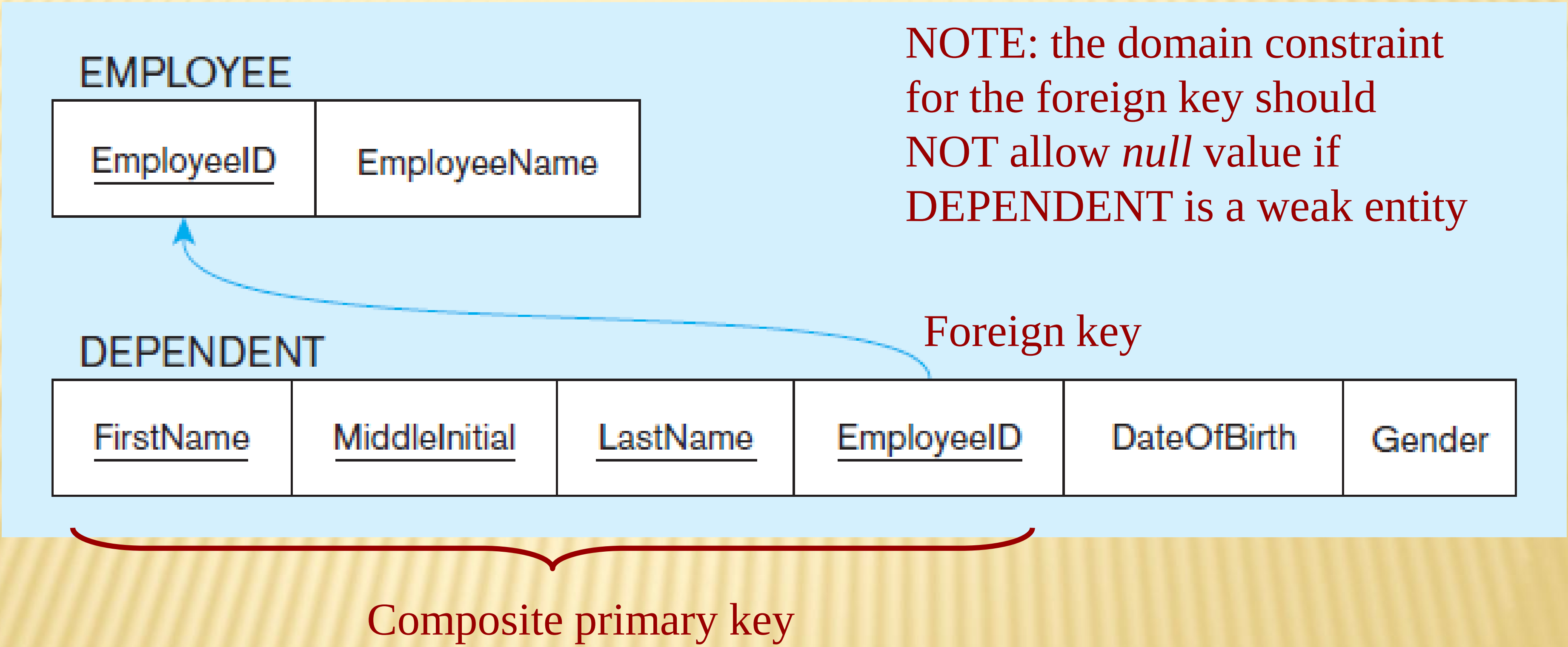
Example of mapping a weak entity

a) Weak entity DEPENDENT



Example of mapping a weak entity (cont.)

b) Relations resulting from weak entity



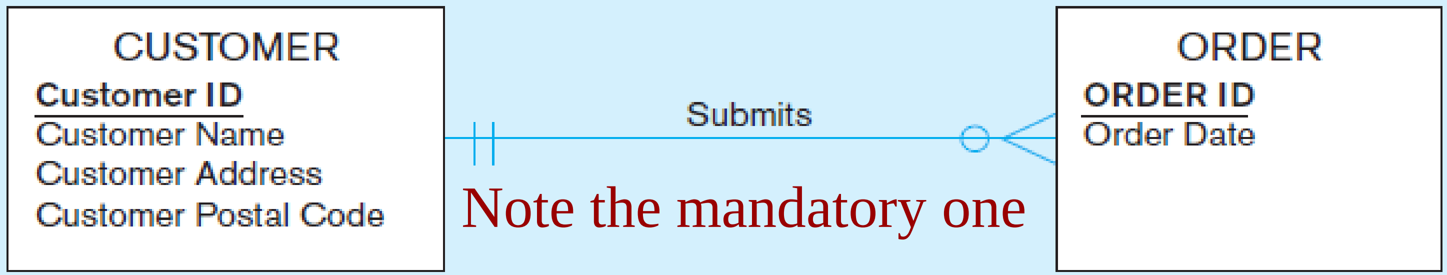
TRANSFORMING EER DIAGRAMS INTO RELATIONS (CONT.)

Mapping Binary Relationships

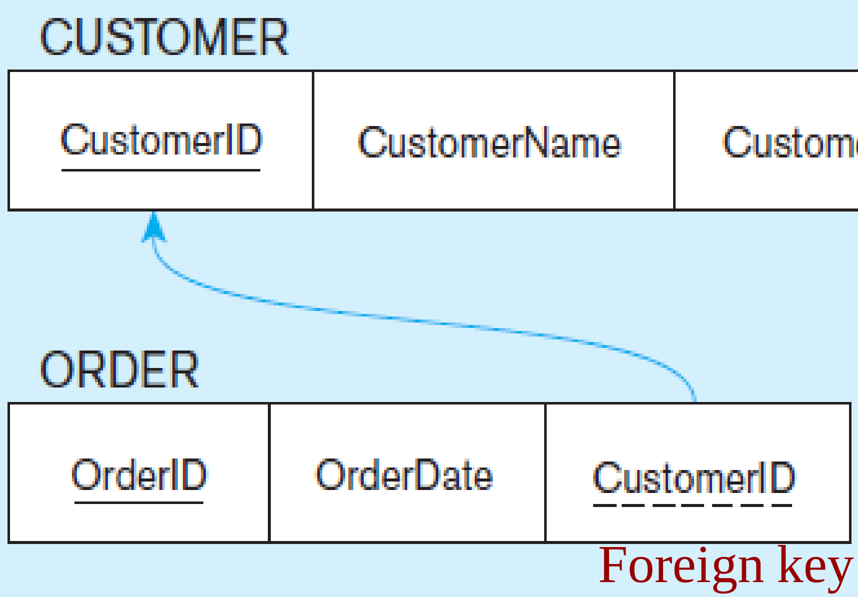
- **One-to-Many**–Primary key on the one side becomes a foreign key on the many side
- **Many-to-Many**–Create a ***new relation*** with the primary keys of the two entities as its primary key
- **One-to-One**–Primary key on mandatory side becomes a foreign key on optional side

Example of mapping a 1:M relationship

a) Relationship between customers and orders



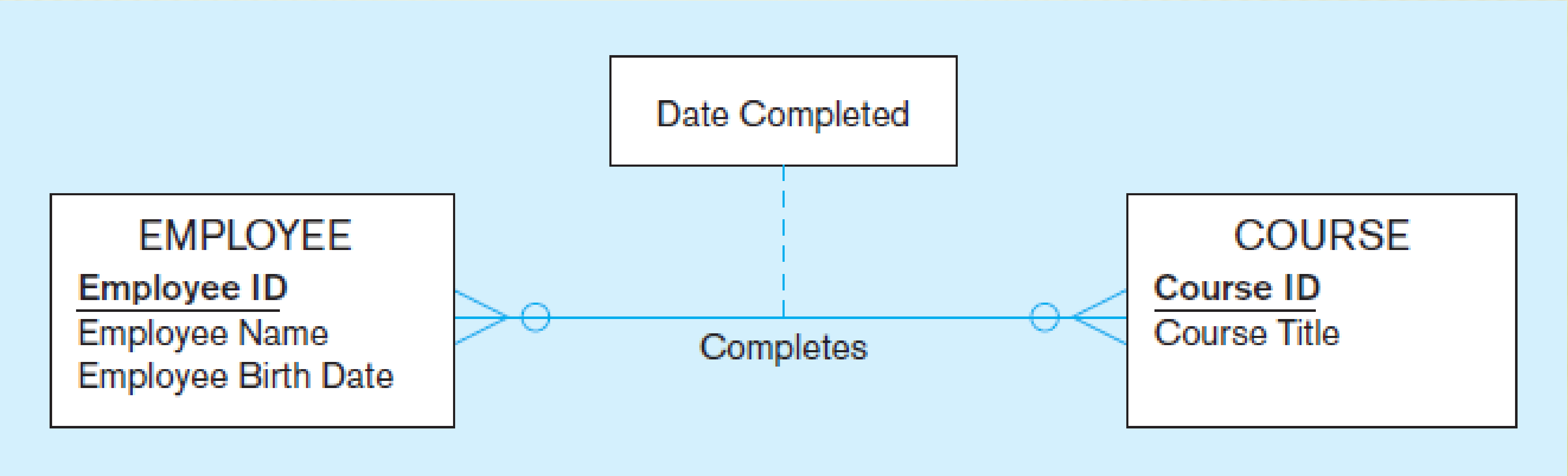
b) Mapping the relationship



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

Example of mapping an M:N relationship

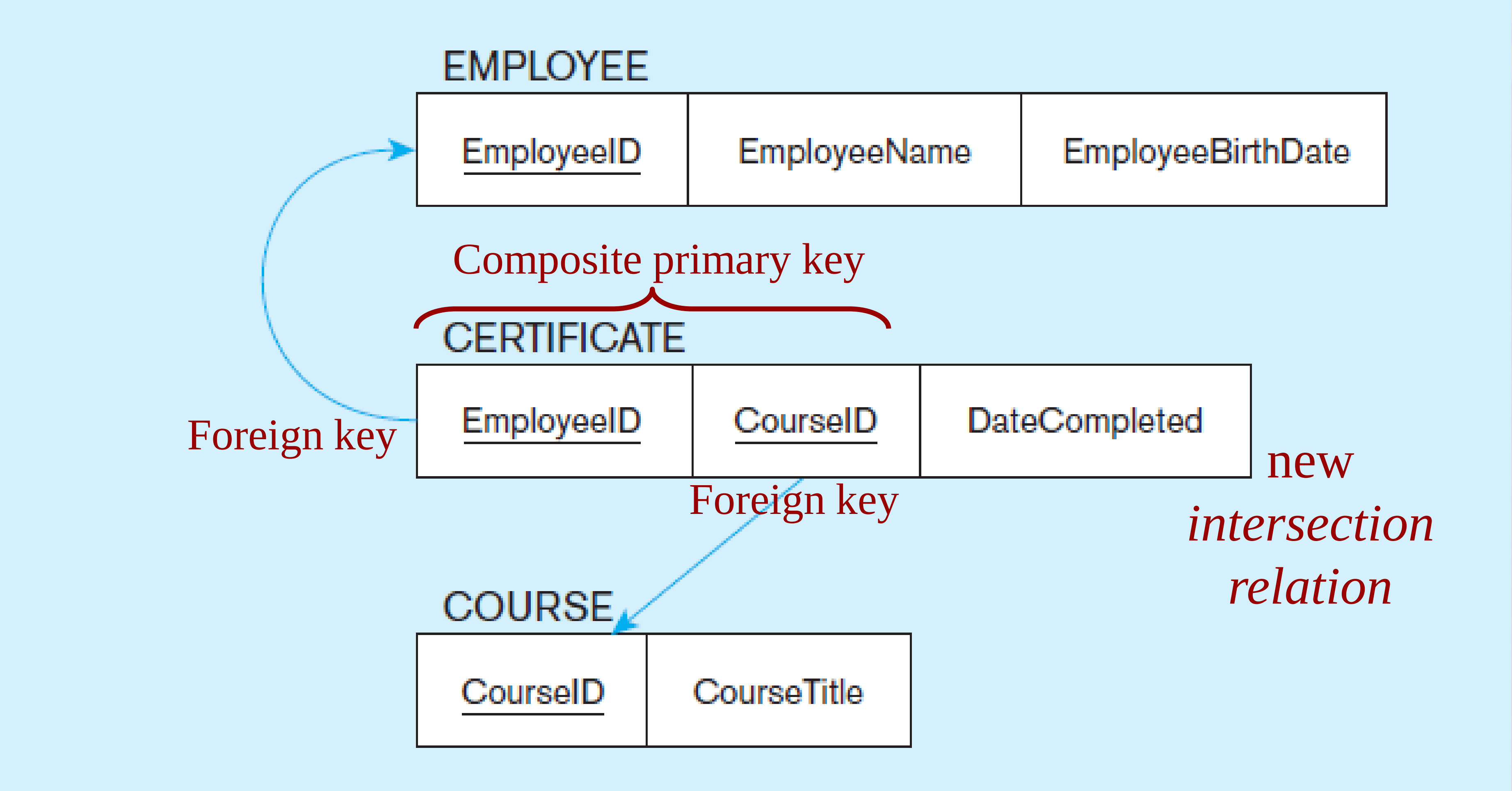
a) Completes relationship (M:N)



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

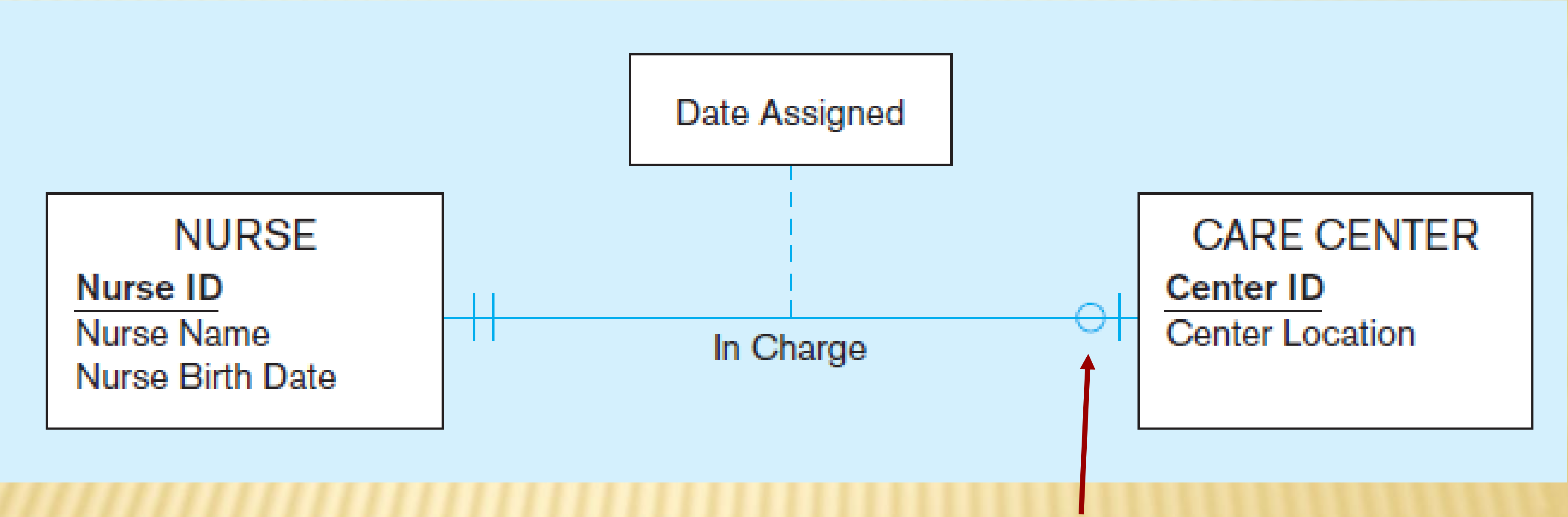
Example of mapping an M:N relationship (cont.)

b) Three resulting relations



Example of mapping a binary 1:1 relationship

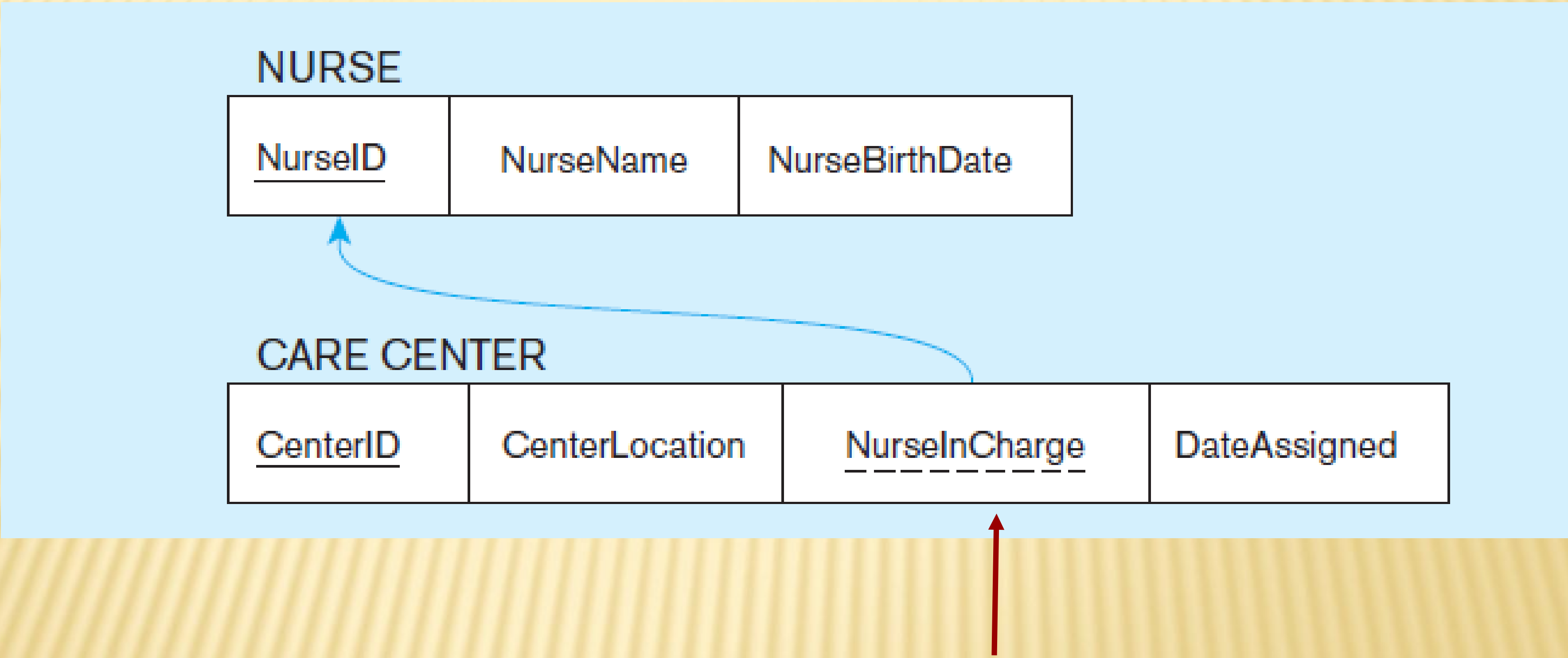
a) In charge relationship (binary 1:1)



Often in 1:1 relationships, one direction is optional

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

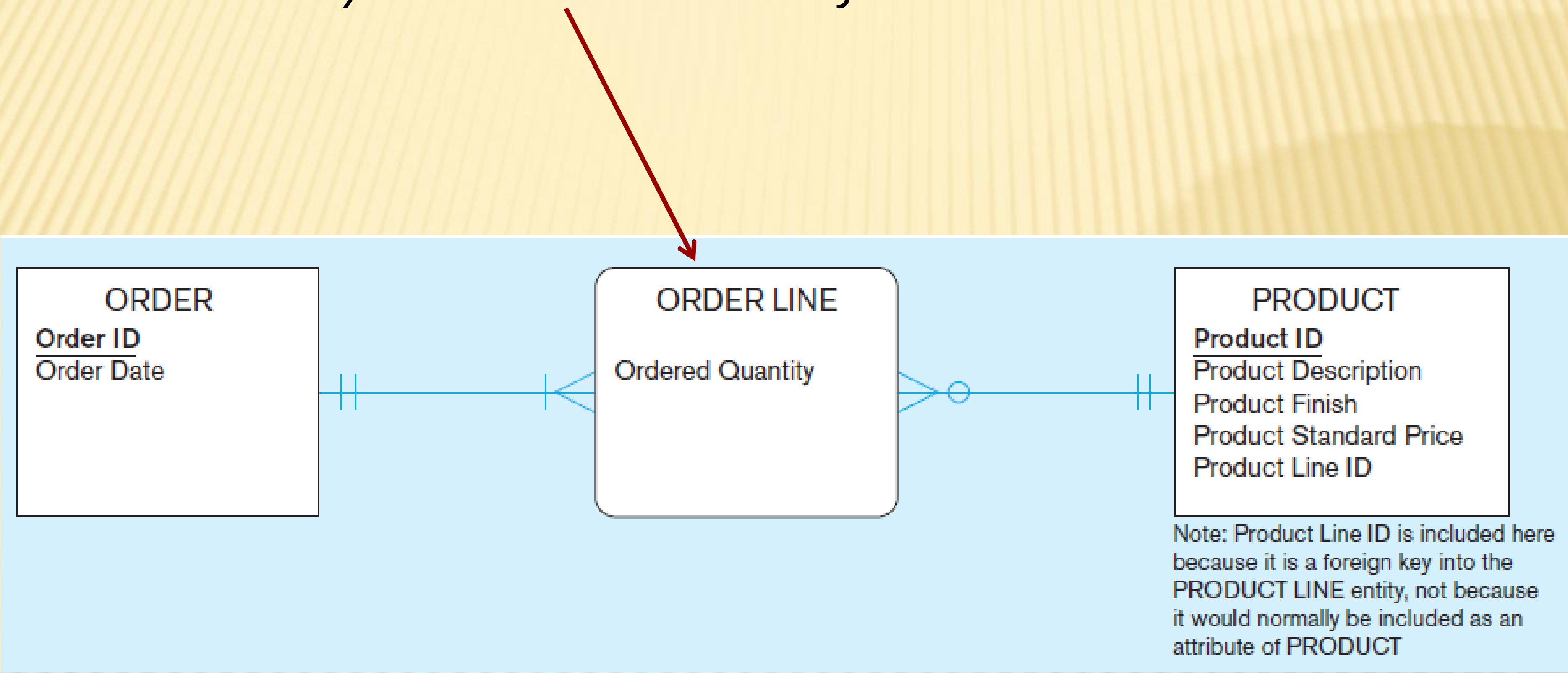
TRANSFORMING EER DIAGRAMS INTO RELATIONS (CONT.)

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

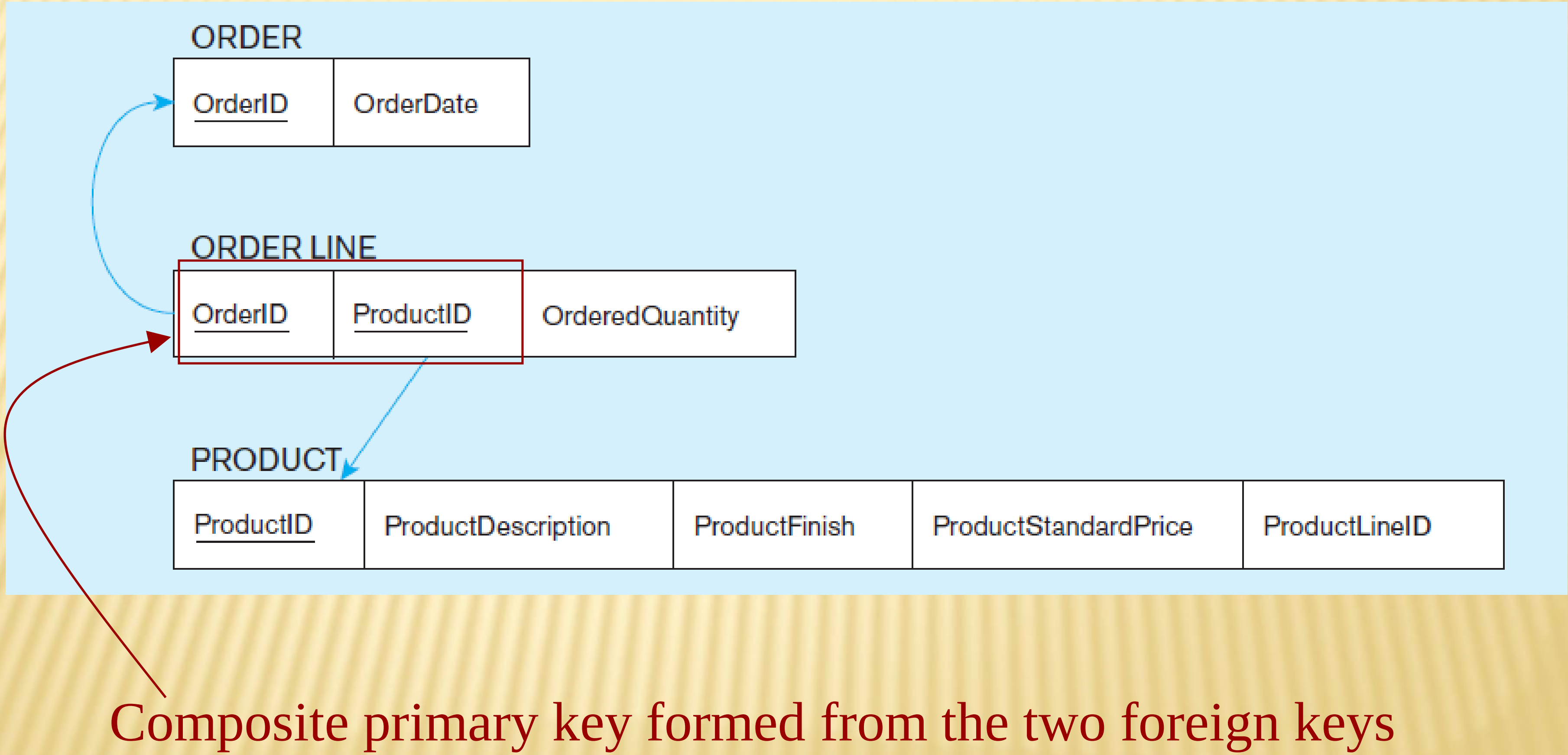
Example of mapping an associative entity

a) An associative entity



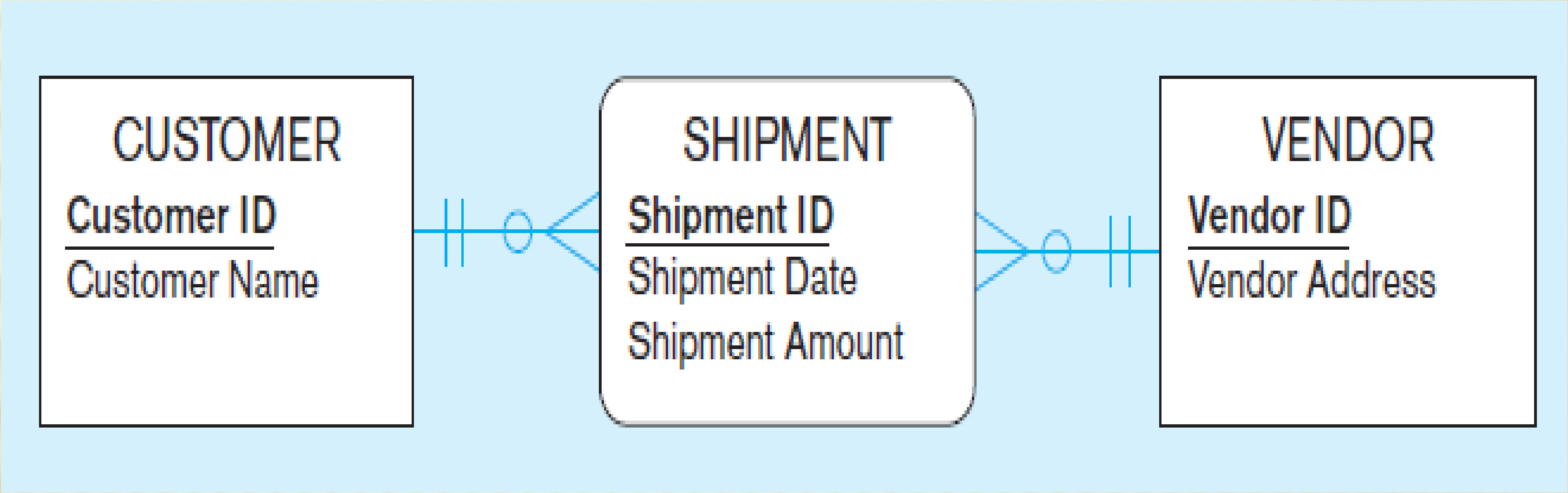
Example of mapping an associative entity (cont.)

b) Three resulting relations



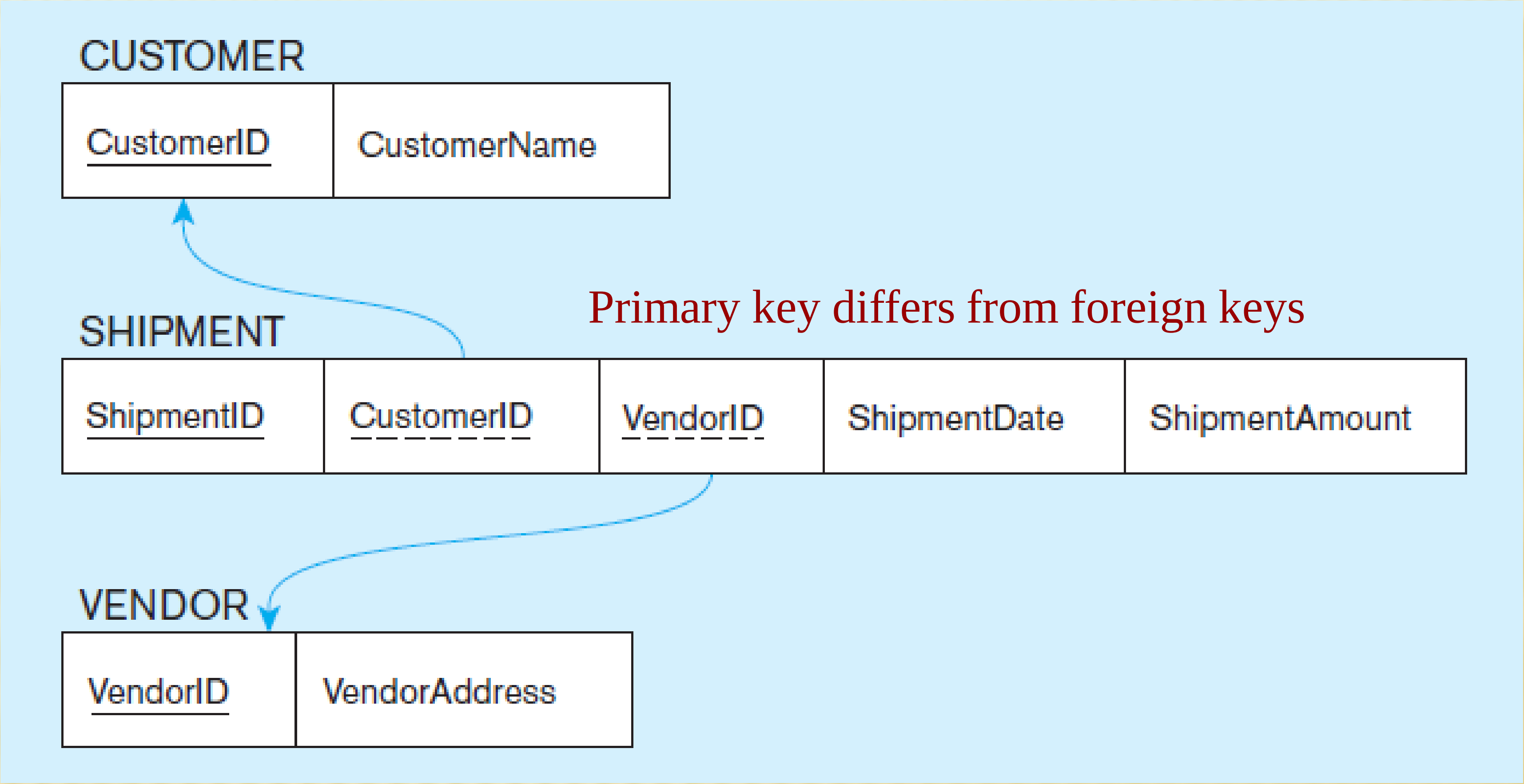
Example of mapping an associative entity with an identifier

a) SHIPMENT associative entity



Example of mapping an associative entity with an identifier (cont.)

b) Three resulting relations

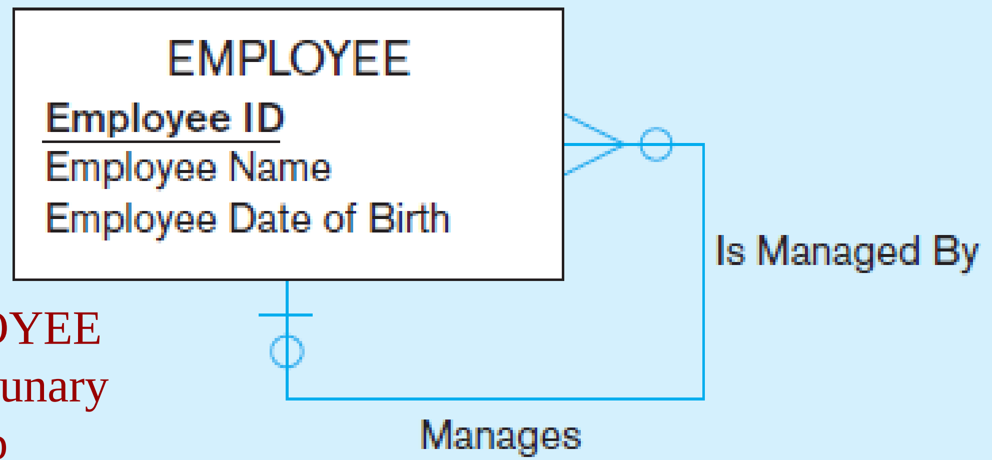


TRANSFORMING EER DIAGRAMS INTO RELATIONS (CONT.)

Mapping Unary Relationships

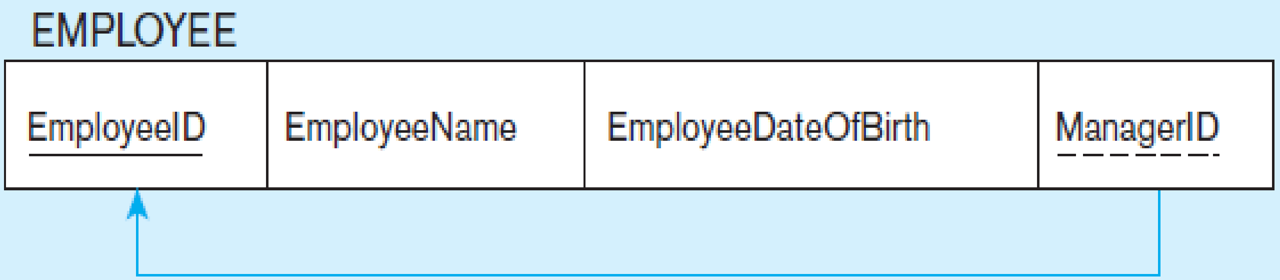
- One-to-Many–Recursive foreign key in the same relation
- Many-to-Many–Two relations:
  - One for the entity type
  - One for an associative relation in which the primary key has two attributes, both taken from the primary key of the entity

Mapping a unary 1:N relationship

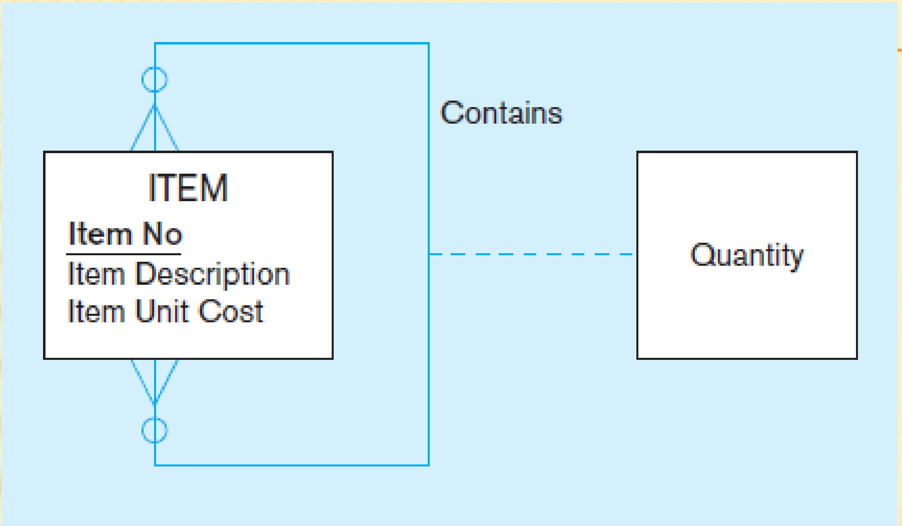


(a) EMPLOYEE entity with unary relationship

(b) EMPLOYEE relation with recursive foreign key

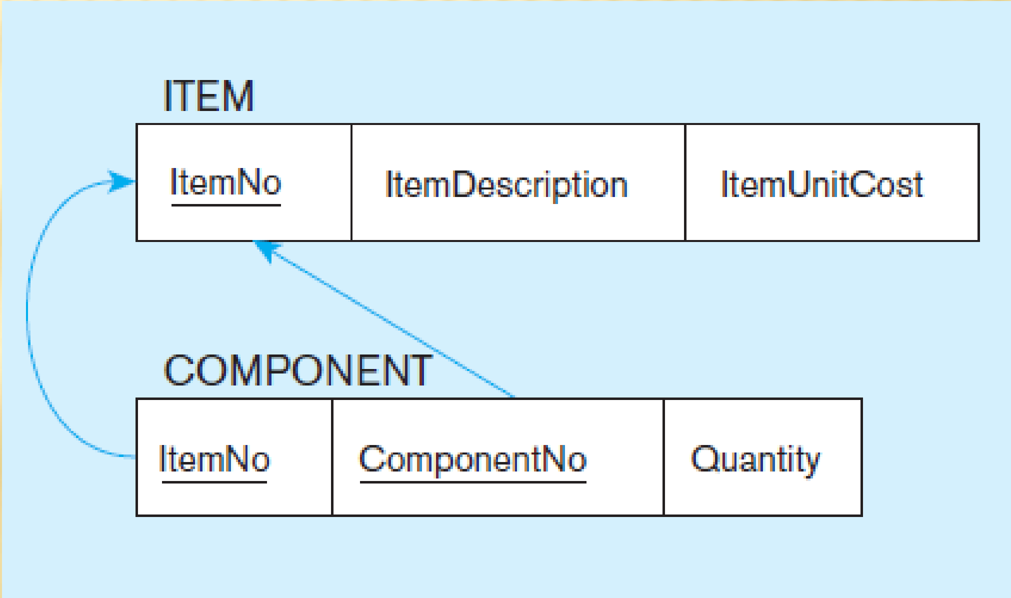


Mapping a unary M:N relationship



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

(b) ITEM and COMPONENT relations



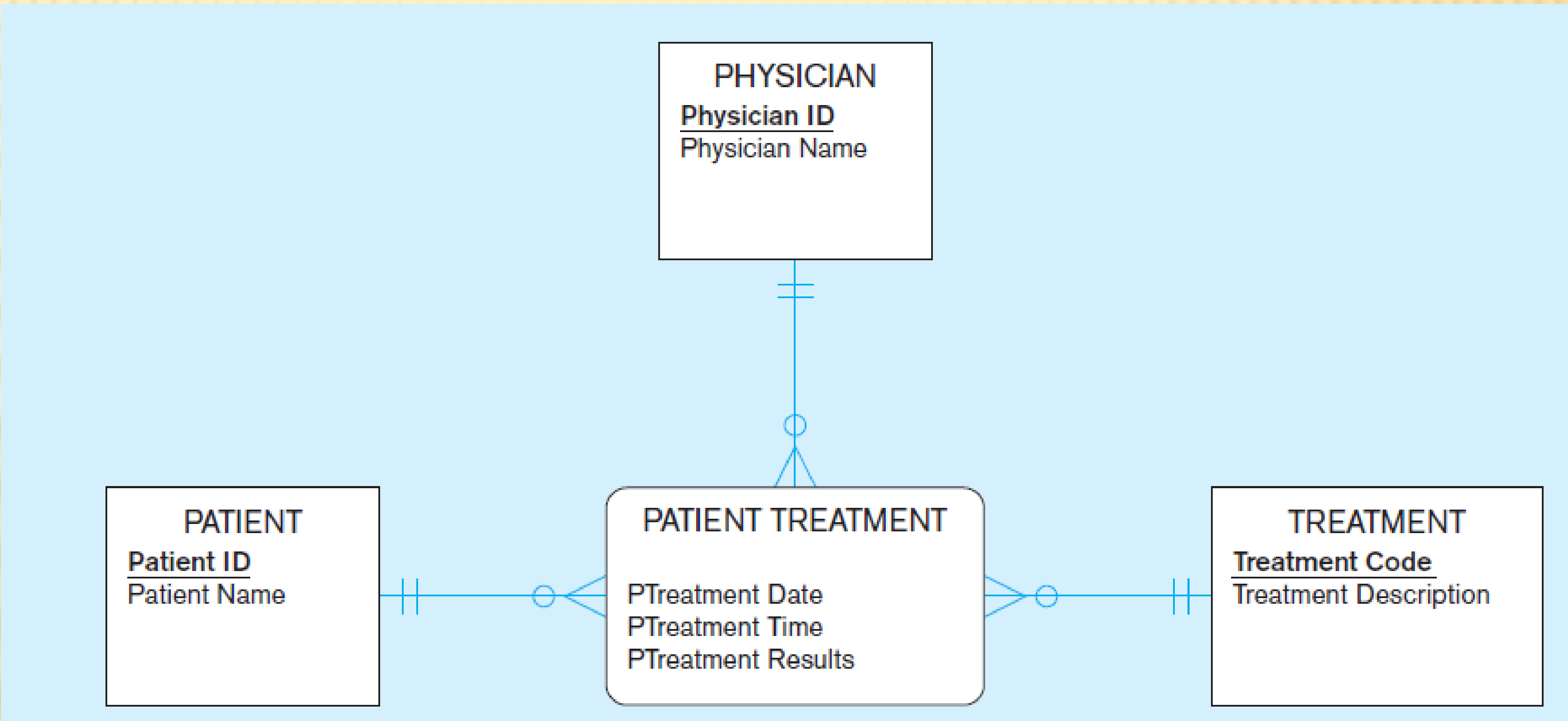
TRANSFORMING EER DIAGRAMS INTO RELATIONS (CONT.)

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

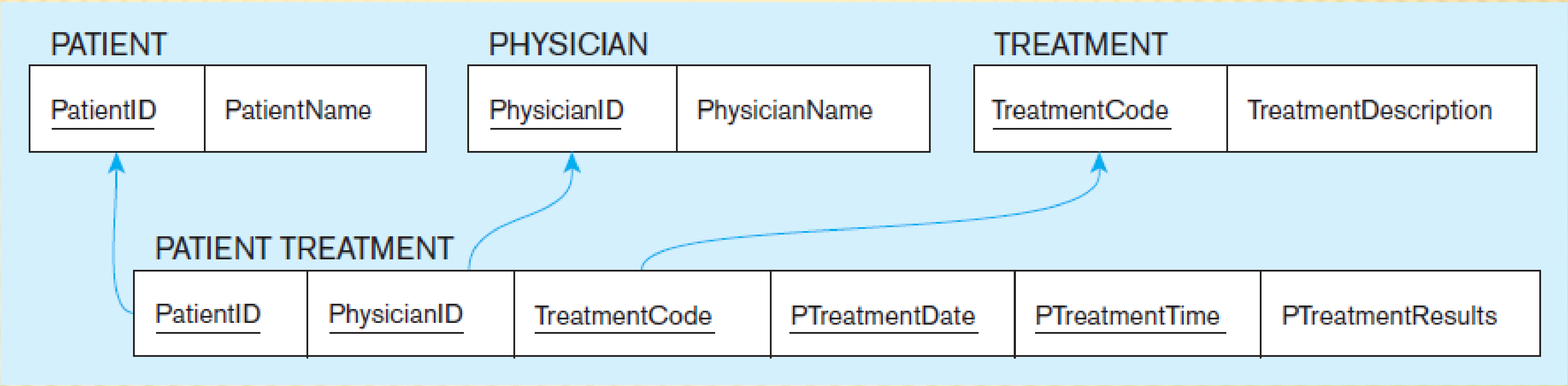
Mapping a ternary relationship

a) PATIENT TREATMENT Ternary relationship with associative entity



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…

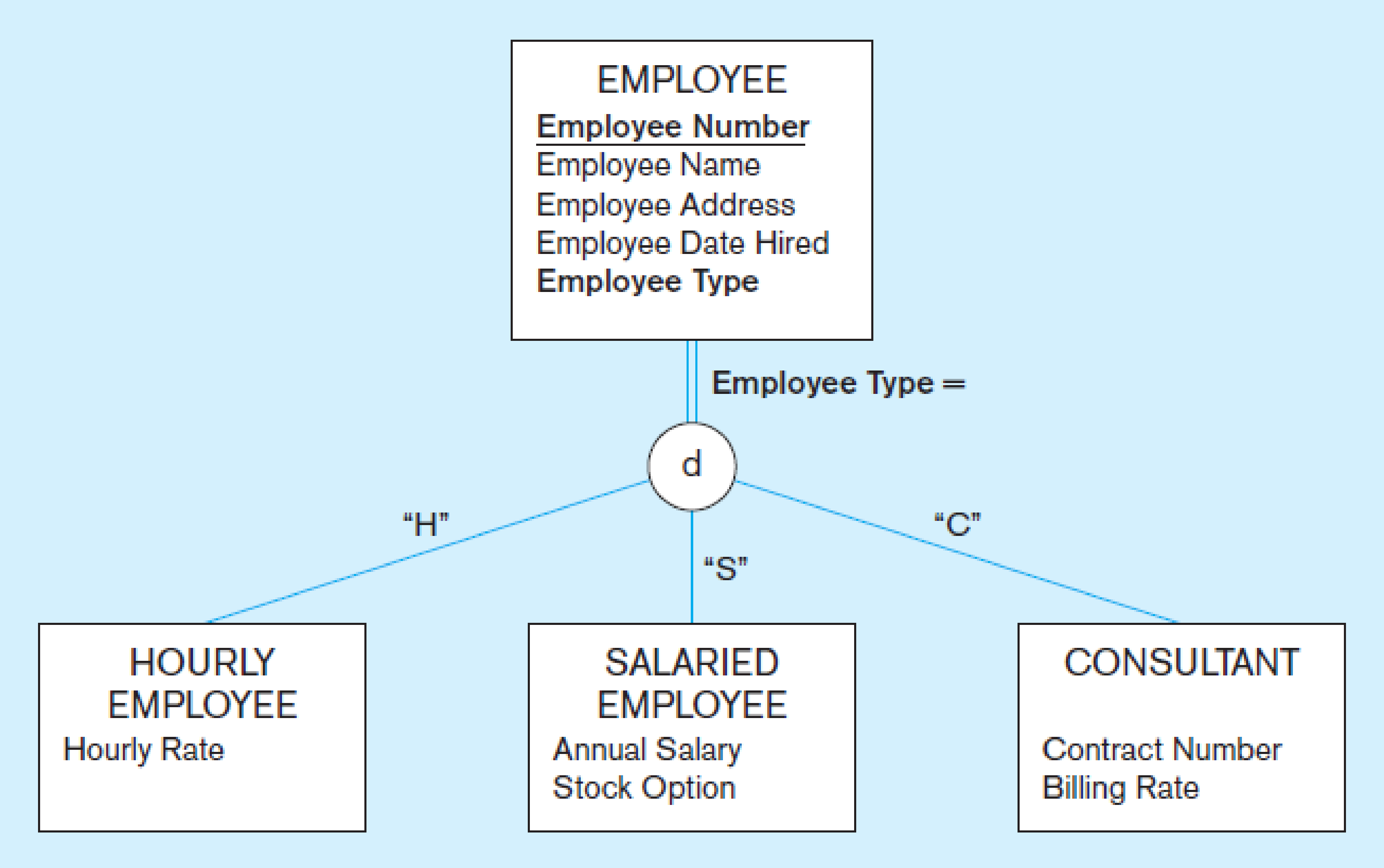
It would be better to create a surrogate key like Treatment#.

TRANSFORMING EER DIAGRAMS INTO RELATIONS (CONT.)

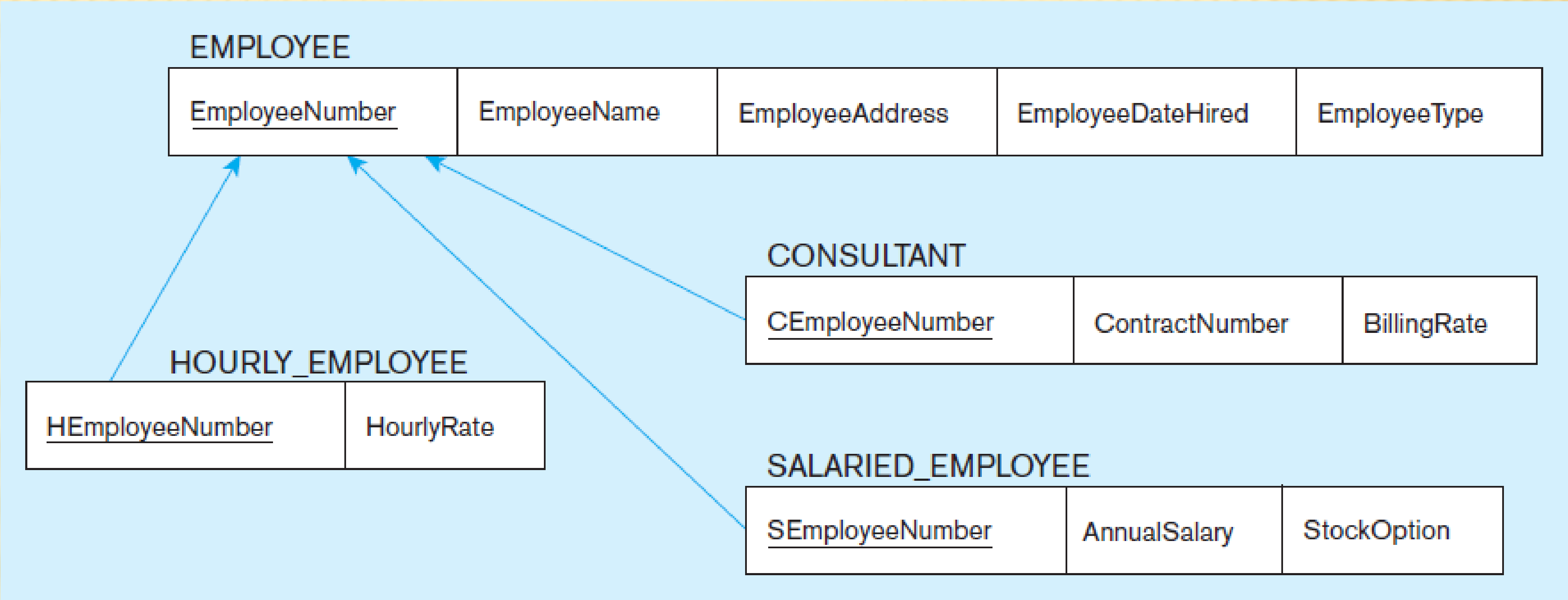
Mapping Supertype/Subtype Relationships

- 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

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

EMPLOYEE2

EmpID	Name	DeptName	Salary	CourseTitle	DateCompleted
100	Margaret Simpson	Marketing	48,000	SPSS	6/19/2015
100	Margaret Simpson	Marketing	48,000	Surveys	10/7/2015
140	Alan Beeton	Accounting	52,000	Tax Acc	12/8/2015
110	Chris Lucero	Info Systems	43,000	Visual Basic	1/12/2015
110	Chris Lucero	Info Systems	43,000	C++	4/22/2015
190	Lorenzo Davis	Finance	55,000		
150	Susan Martin	Marketing	42,000	SPSS	6/19/2015
150	Susan Martin	Marketing	42,000	Java	8/12/2015

Question–Is this a relation?

Answer–Yes: Unique rows and no multivalued attributes

Question–What's the primary key?

Answer–Composite: EmpID, CourseTitle

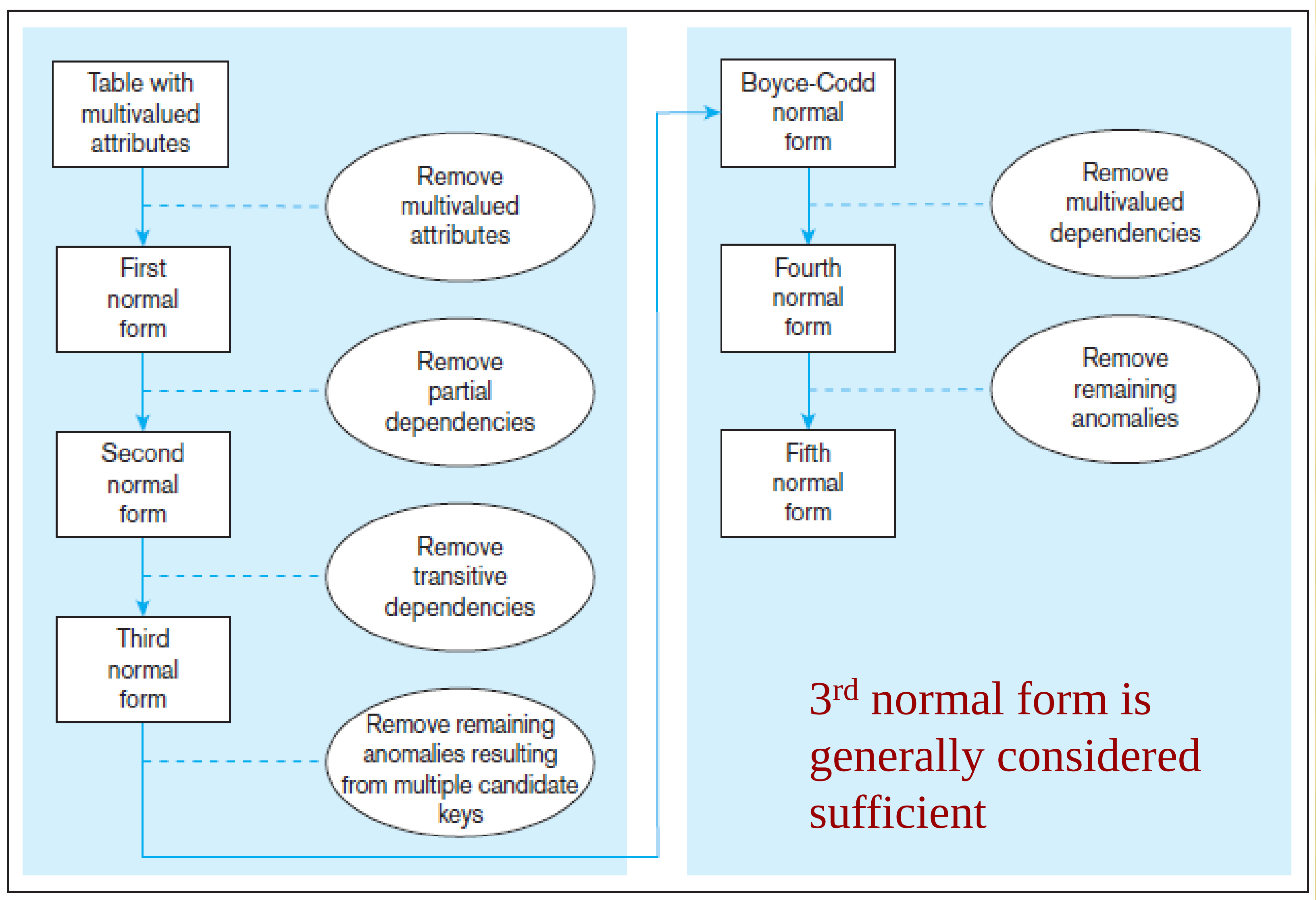
ANOMALIES IN THIS TABLE

- **Insertion**–can't enter a new employee without having the employee take a class (or at least empty fields of class information)
- **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.

Steps in normalization



3rd normal form is generally considered sufficient

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.

FIRST NORMAL FORM

- No multivalued attributes
- Every attribute value is atomic
- Fig. in slide 49 *is not* in 1st Normal Form (multivalued attributes) → it is not a relation.
- Fig. İn slide 50 *is* in 1st Normal form.
- ***All relations* are in 1st Normal Form.**

Table with multivalued attributes, not in 1st normal form

FIGURE 4-25 **INVOICE data (Pine Valley Furniture Company)**

OrderID	Order Date	Customer ID	Customer Name	Customer Address	ProductID	Product Description	Product Finish	Product StandardPrice	Ordered Quantity
1006	10/24/2015	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	10/25/2015	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 4-26 INVOICE relation (1NF) (Pine Valley Furniture Company)

OrderID	Order Date	Customer ID	Customer Name	Customer Address	ProductID	Product Description	Product Finish	Product StandardPrice	Ordered Quantity
1006	10/24/2015	2	Value Furniture	Plano, TX	7	Dining Table	Natural Ash	800.00	2
1006	10/24/2015	2	Value Furniture	Plano, TX	5	Writer's Desk	Cherry	325.00	2
1006	10/24/2015	2	Value Furniture	Plano, TX	4	Entertainment Center	Natural Maple	650.00	1
1007	10/25/2015	6	Furniture Gallery	Boulder, CO	11	4–Dr Dresser	Oak	500.00	4
1007	10/25/2015	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 multiple records

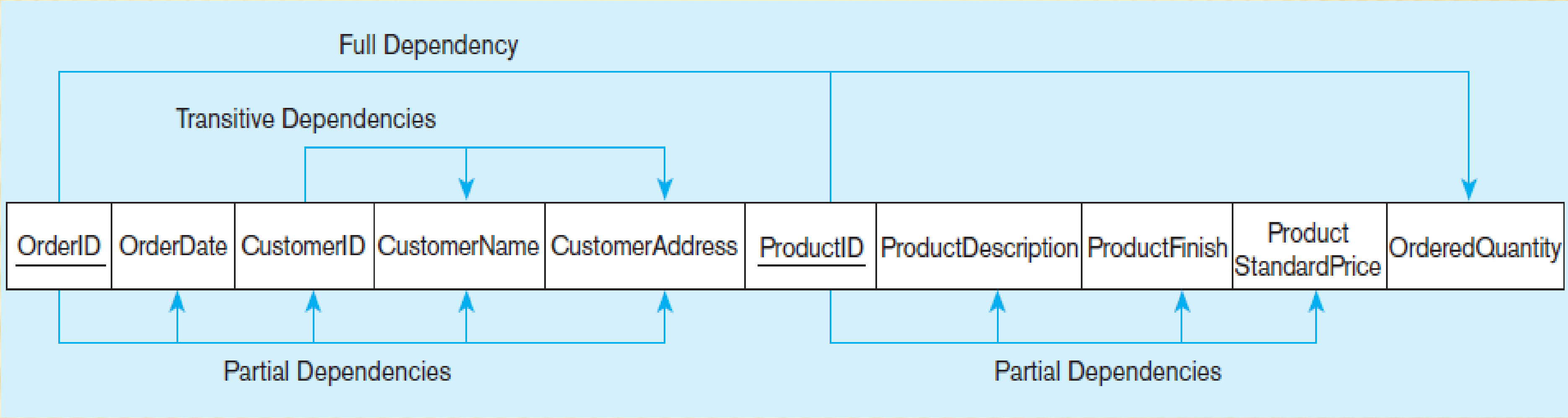
Why do these anomalies exist?

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

Functional dependency diagram for INVOICE



OrderID ➔ OrderDate, CustomerID, CustomerName, CustomerAddress

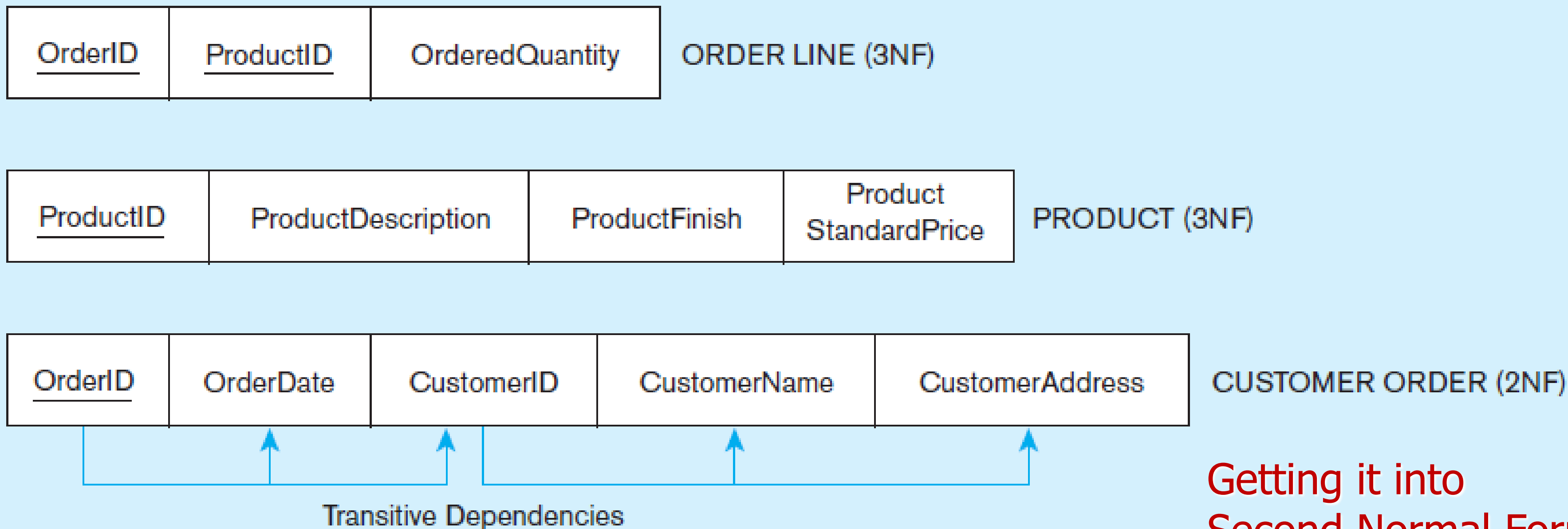
CustomerID ➔ CustomerName, CustomerAddress

ProductID ➔ ProductDescription, ProductFinish, ProductStandardPrice

OrderID, ProductID ➔ OrderQuantity

Therefore, NOT in 2nd Normal Form

Removing partial dependencies



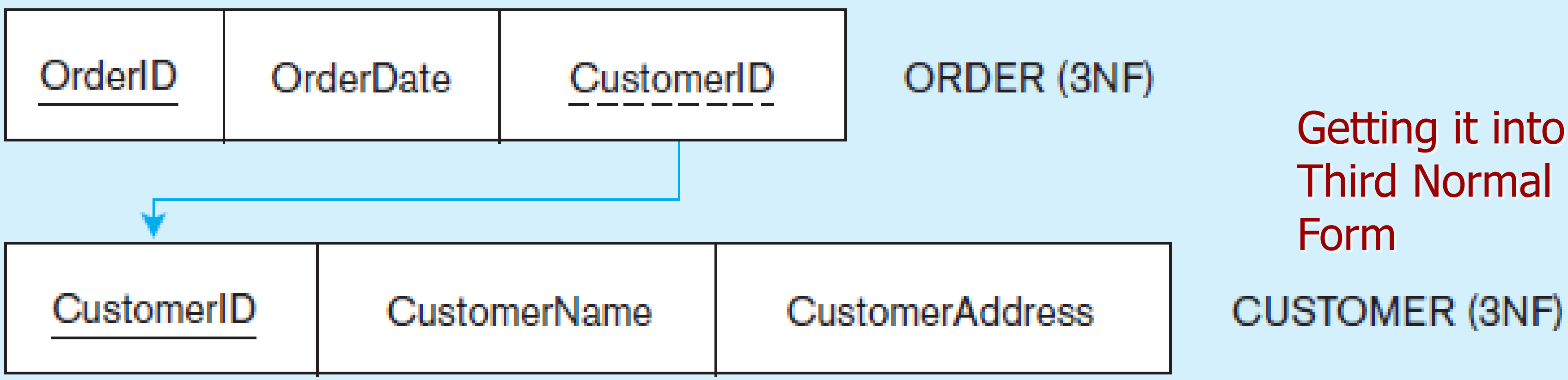
Getting it into Second Normal Form

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

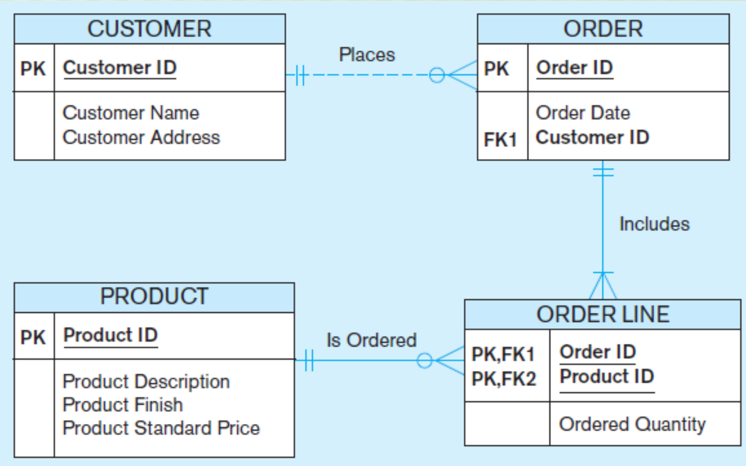
Removing partial dependencies



Getting it into Third Normal Form

Transitive dependencies are removed.

Figure shows the result of normalization, yielding four separate relations where initially there was only one.



MERGING RELATIONS

- View Integration–Combining entities from multiple ER models into common relations
- Issues to watch out for when merging entities from different ER models:
  - Synonyms–two or more attributes with different names but same meaning
  - Homonyms–attributes with same name but different meanings
  - Transitive dependencies–even if relations are in 3NF prior to merging, they may not be after merging
  - Supertype/subtype relationships–may be hidden prior to merging

Enterprise keys

OBJECT (OID, ObjectType)
EMPLOYEE (OID, EmpID, EmpName, DeptName, Salary)
CUSTOMER (OID, CustID, CustName, Address)

a) Relations with enterprise key

b) Sample data with enterprise key

OBJECT

OID	ObjectType
1	EMPLOYEE
2	CUSTOMER
3	CUSTOMER
4	EMPLOYEE
5	EMPLOYEE
6	CUSTOMER
7	CUSTOMER

EMPLOYEE

OID	EmpID	EmpName	DeptName	Salary
1	100	Jennings, Fred	Marketing	50000
4	101	Hopkins, Dan	Purchasing	45000
5	102	Huber, Ike	Accounting	45000

CUSTOMER

OID	CustID	CustName	Address
2	100	Fred's Warehouse	Greensboro, NC
3	101	Bargain Bonanza	Moscow, ID
6	102	Jasper's	Tallahassee, FL
7	103	Desks 'R Us	Kettering, OH