UTS:ENGINEERING AND INFORMATION TECHNOLOGY

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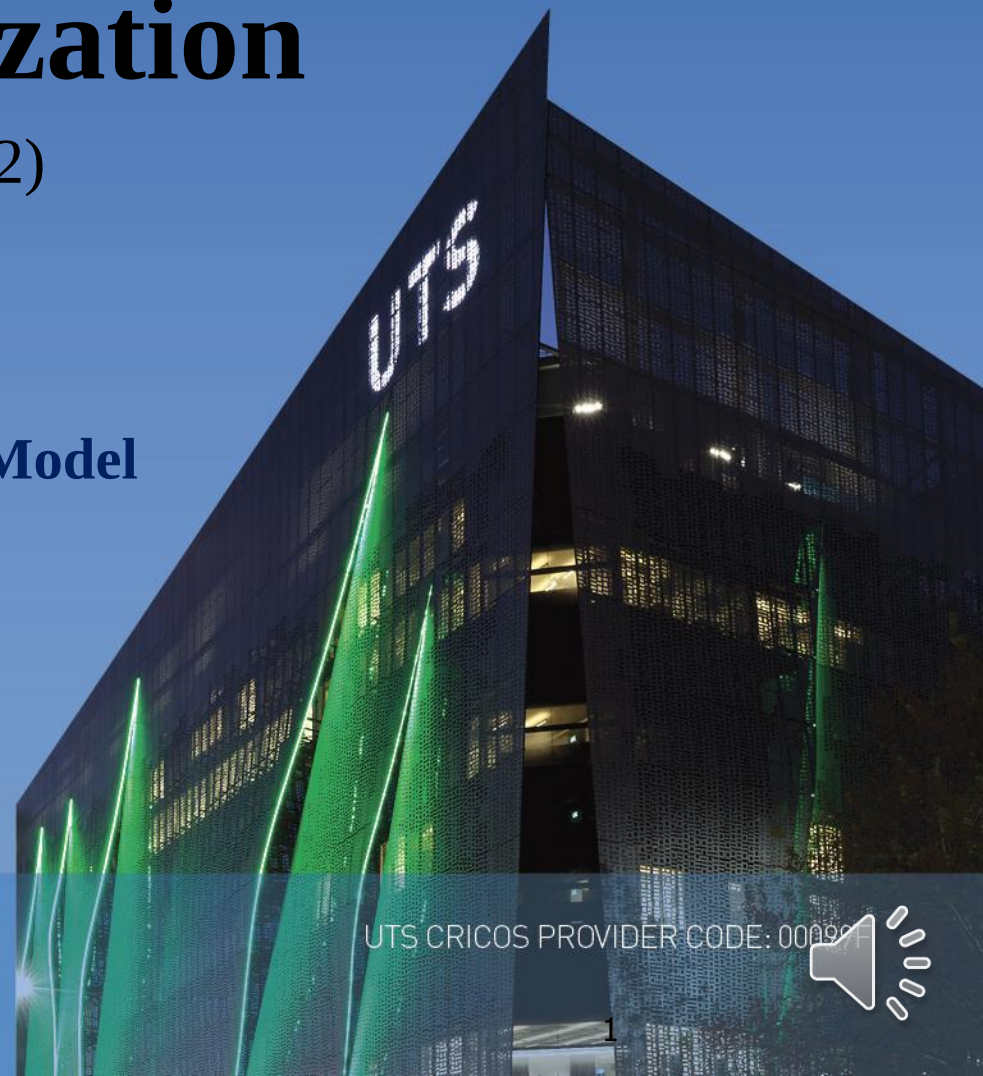
UNIVERSITY OF TECHNOLOGY, SYDNEY

lecture 6: Normalization

Combined File (Parts 1 & 2)

Main reference:

Modern Database Management, 11th Edition
Chapter 4: Logical Database Design and the Relational Model



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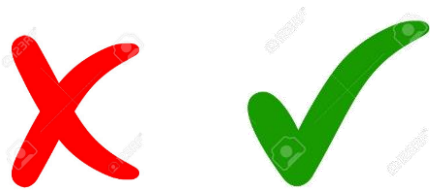
Participations and Discussions

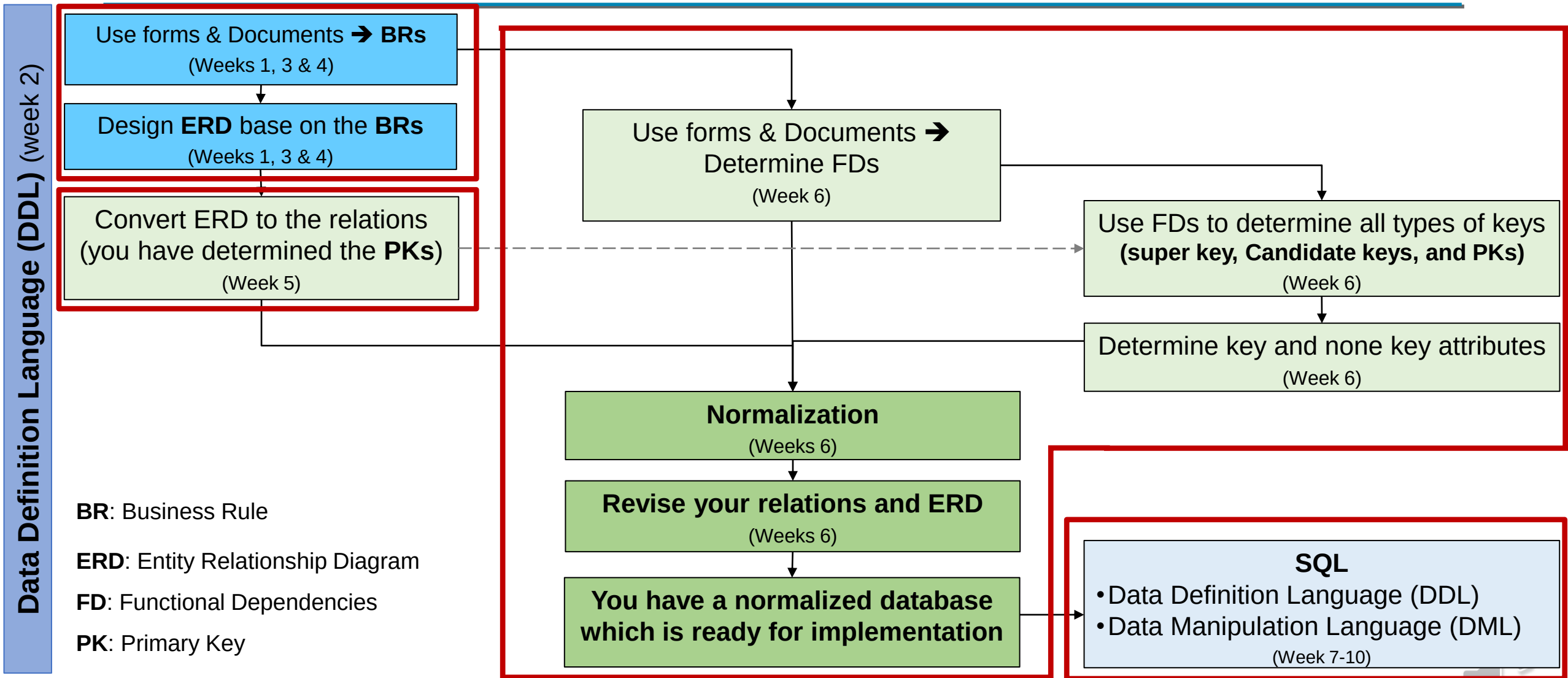
If you have any question and you don't want to share it now, send it to us via UTSOnline/Discussion Board.

However, it is better to speak out ☺

Please follow the following signs in the lecture slide ☺



Subject Flowchart



Subject Overview

- **Design Entity Relationship Diagram (ERD)**
  - **Week 1: Data Modelling I (Conceptual Level):** Entity, Attributes, PK, FK, …
  - **Week 2: Data Definition Language (DDL):** Create tables, constraints, insert, …
  - **Week 3: Data Modelling II (Conceptual Level):** Associative, Weak, …
  - **Week 4: Data Modelling III (Conceptual Level):** Subtype/Supertype
  - **Week 5: Convert ERD to Relations (Logical Level)**
  - **Week 6: Functional Dependencies, and Normalization**
- **Data manipulation**
  - **Week 7: Simple Query**
  - **Week 8: Multiple Table Queries**
  - **Week 9: Subquery**
  - **Week 10: Correlated Subquery**

Lecture Five Objectives:

Introduction: Why we need to do normalization and what are the anomalies?

1. **Terms to Know to Do Normalization**
   - 1.1. Functional Dependencies
   - 1.2. Keys: Super-key, Candidate key and Primary Key
   - 1.3. Determining Candidate Keys from Functional Dependencies (FDs)
   - 1.4. Partial Functional Dependencies
   - 1.5. Transitive Functional Dependencies
   - 1.6 Why Partial and Transitive FDS cause the anomalies?
2. **Well-Structured Relations and Data Normalization**
3. **Steps in normalization**
4. **First Normal Form**
5. **Second Normal Form**
6. **Third Normal Form**

Why we need to do normalization?

By now:

- **You have designed your ERD.**
- **You have converted your ERD to the relations.**

➢ **Questions:**

1. **Are your relations well-structured?**
2. **Will you have any redundant data in your relations?**
3. **Will you have any data inconsistency in your database?**

Example 1–Figure 4-2b

EMPLOYEE2

EmpID	Name	DeptName	Salary	CourseTitle	DateCompleted
100	Margaret Simpson	Marketing	48,000	SPSS	6/19/201X
100	Margaret Simpson	Marketing	48,000	Surveys	10/7/201X
140	Alan Beeton	Accounting	52,000	Tax Acc	12/8/201X
110	Chris Lucero	Info Systems	43,000	Visual Basic	1/12/201X
110	Chris Lucero	Info Systems	43,000	C++	4/22/201X
19 0	Lorenzo Davis	Finance	55,000		
15 0	Susan Martin	Marketing	42,000	SPSS	6/19/201X
15 0	Susan Martin	Marketing	42,000	Java	8/12/201X

Question–Is this a relation? Answer–Yes: Unique rows and no multivalued attributes

Question–What's the primary key? Answer–Composite: **EmpID, CourseTitle**

Is this relation (table) well-structured? Have a look at the **anomalies** in this Table:

EMPLOYEE2

EmpID	Name	DeptName	Salary	CourseTitle	DateCompleted
100	Margaret Simpson	Marketing	48,000	SPSS	6/19/201X
100	Margaret Simpson	Marketing	48,000	Surveys	10/7/201X
140	Alan Beeton	Accounting	52,000	Tax Acc	12/8/201X
110	Chris Lucero	Info Systems	43,000	Visual Basic	1/12/201X
110	Chris Lucero	Info Systems	43,000	C++	4/22/201X
19 0	Lorenzo Davis	Finance	55,000		
15 0	Susan Martin	Marketing	42,000	SPSS	6/19/201X
15 0	Susan Martin	Marketing	42,000	Java	8/12/201X

- **Insertion Anomaly:** can't enter a new employee without having the employee **take a class** (or at least empty fields of class information) → Why?
- **Deletion Anomaly :** if we remove employee **140**, we lose information about the existence of a **Tax Acc** class.
- **Modification Anomaly :** giving a **salary** increase to employee **100** forces us to update multiple records.

Note: The anomalies also happen after merging databases that are designed by the other database designers, or merging tables from different databases to create a new table.

Example 2–Figure 4-26

OrderID	Order Date	Customer ID	Customer Name	Customer Address	ProductID	Product Description	Product Finish	Product StandardPrice	Ordered Quantity
1006	10/24/2010	2	Value Furniture	Plano, TX	7	Dining Table	Natural Ash	800.00	2
1006	10/24/2010	2	Value Furniture	Plano, TX	5	Writer's Desk	Cherry	325.00	2
1006	10/24/2010	2	Value Furniture	Plano, TX	4	Entertainment Center	Natural Maple	650.00	1
1007	10/25/2010	6	Furniture Gallery	Boulder, CO	11	4–Dr Dresser	Oak	500.00	4
1007	10/25/2010	6	Furniture Gallery	Boulder, CO	4	Entertainment Center	Natural Maple	650.00	3

FIGURE 4-26 INVOICE relation (1NF) (Pine Valley Furniture Company)

Question–Is this a relation? Answer–Yes: Unique rows and no multivalued attributes

Question–What's the primary key? Answer–Composite: **OrderID, ProductID**

Is this relation (table) well-structured? Have a look at the **anomalies** in this Table:

OrderID	Order Date	Customer ID	Customer Name	Customer Address	ProductID	Product Description	Product Finish	Product StandardPrice	Ordered Quantity
1006	10/24/2010	2	Value Furniture	Plano, TX	7	Dining Table	Natural Ash	800.00	2
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1007	10/25/2010	6	Furniture Gallery	Boulder, CO	4	Entertainment Center	Natural Maple	650.00	3

FIGURE 4-26 INVOICE relation (1NF) (Pine Valley Furniture Company)

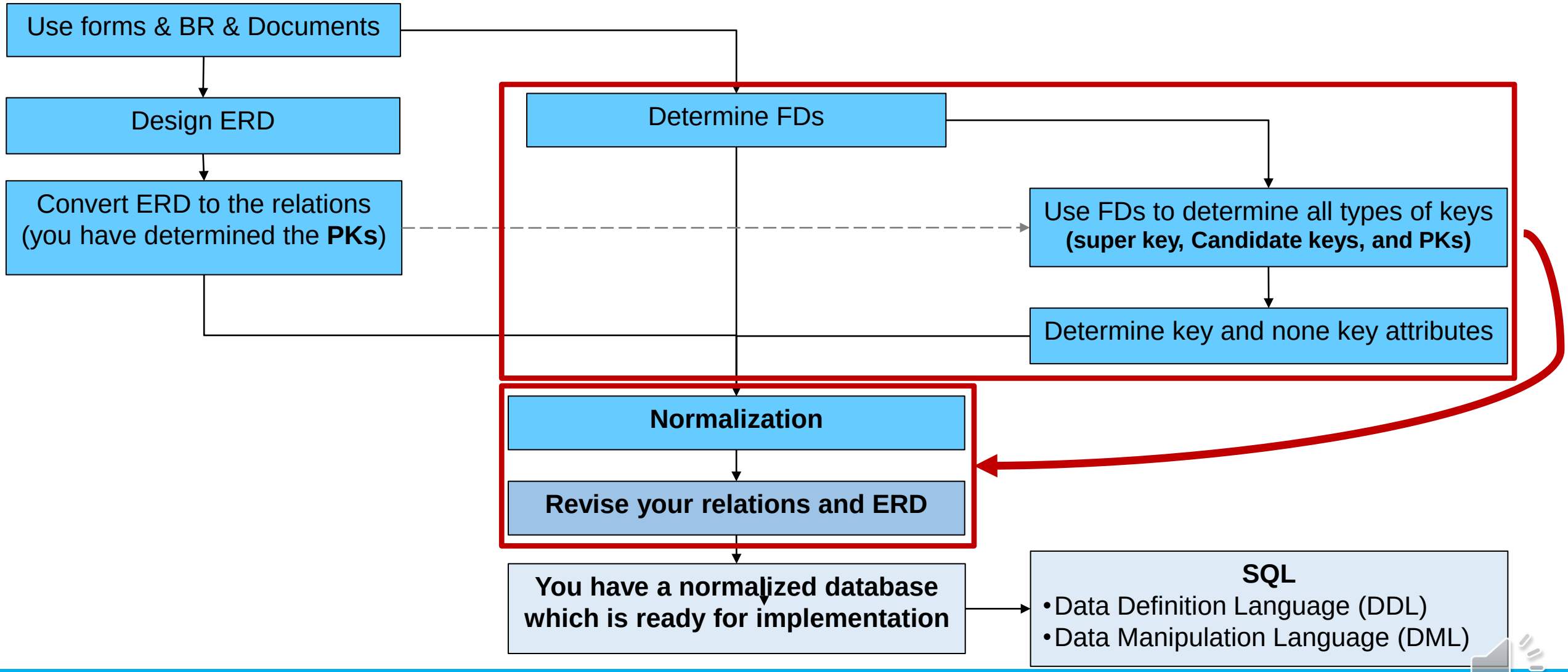
- **Insertion Anomaly**: if new product is ordered for order **1007** of existing customer, **customer data** must be re-entered, causing duplication
- **Deletion Anomaly** : if we delete the **Dining Table** from Order **1006**, we lose information concerning this item's finish and price
- **Update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

Note: The anomalies also happen after merging databases that are designed by the other database designers, or merging tables from different databases to create a new table.

Solution of these problems:

You need to normalize your relations to solve these problems

Subject Flowchart



1. Terms to Know for Normalization

1. Terms to Know for Normalization

1.1. Functional Dependencies

1.2. Keys: Super-key, Candidate key and Primary Key

1.3. Determining Candidate Keys from Functional Dependencies (FDs)

1.4. Partial Functional Dependencies

1.5. Transitive Functional Dependencies

1.6 Why Partial and Transitive FDS cause the anomalies?

1.1. Functional Dependencies

Functional Dependency: A constraint between two attributes in which the value of one attribute (**dependent**) is **uniquely** determined by the value of another attribute(s) (**determinant**).

- The value of attribute X (determinant) **uniquely** determines the value attribute(s) Y (dependent)

  X -> Y

- The value of attributes X and Z (determinants) **uniquely** determine the value attribute(s) Y and M and N (dependents)

  X, Z -> Y, M, N

Example:

EmpID -> FName, Lname, DeptName, Salary

Important Note

We determine Functional Dependencies based on the **Business Rules** and **Forms**.

NOT based on the designed ERD.

Note: in the next slide I used the stored data to illustrate Functional Dependencies between attributes.

CustomerID → CustomerName, Customer_Street, Customer_City, Customer_State, CustomerPostal_Code

OrderID → OrderDate, CustomerID, CustomerName, …..

PK

Customer_ID	Customer_Name	Customer_Street	Customer_City	Customer_State	CustomerPostal_Code
1	Contemporary Casuals	1355 S Hines Blvd	Gainesville	FL	32601-2871
2	Value Furnitures	15145 S.W. 17th St.	Plano	TX	75094-7743
3	Home Furnishings	1900 Allard Ave	Albany	NY	12209-1125
4	ern Furnitu	25 Beltline	Carteret	NJ	7008-3188
5	Impressions	5585 Westcott Ct.	Sacramento	CA	94206-4056
6	Furniture Gallery	325 Flatiron Dr.	Boulder	CO	80514-4432
7	New Furniture	Palace Ave	Farmington	NM	NULL

PK

Order_ID	Order_Date	Customer_ID
1001	8/09/2009	3
1002	4/10/2(	4
1003	19/07/2009	1
1004	1/11/2009	4

FK

Example

Let’s determine Functional Dependencies based on the following Business Rules:

BR1: Customers’ information, like name and address, need to be stored in the database.

BR2: Any customer can place many orders.

BR3: Company needs to store order date for each order.

BR1: Customers' information, like name and address, need to be stored in the database.
BR2: Any customer can place many orders.
BR3: Company needs to store order date for each order.

Question: which of the following FD set is correct?

A

CustomerID → CustomerName, Customer_Street, Customer_City, Customer_State, CustomerPostal_Code

OrderID → OrderDate, CustomerID

OR

B

CustomerID → CustomerName, Customer_Street, Customer_City, Customer_State, CustomerPostal_Code, OrderID

OrderID → OrderDate

Question: **OrderID** functionally determines **CustomerID or vice versa?**

A

OrderID → OrderDate, CustomerID

1002 → 4/10/2009, 4

B

CustomerID → CustomerName, …, OrderID

4 → Eastern Furniture, …, 1002 & 1004

PK

Customer_ID	Customer_Name	Customer_Street	Customer_City	Customer_State	CustomerPostal_Code
1	Contemporary Casuals	1355 S Hines Blvd	Gainesville	FL	32601-2871
2	Value Furnitures	15145 S.W. 17th St.	Plano	TX	75094-7743
3	Home Furnishings	1900 Allard Ave	Albany	NY	12209-1125
4	Eastern Furniture	1925 Beltline Rd.	Carteret	NJ	07008-3188
5	Impressions	5585 Westcott Ct.	Sacramento	CA	94206-4056
6	Furniture Gallery	325 Flatiron Dr.	Boulder	CO	80514-4432
7	New Furniture	Palace Ave	Farmington	NM	NULL

PK

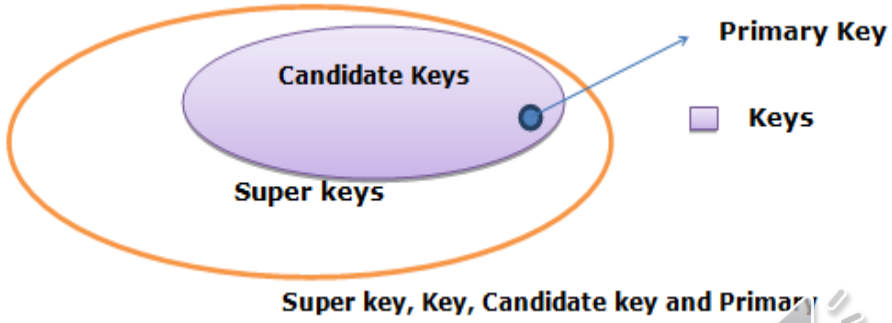
Order_ID	Order_Date	Customer_ID
1001	8/09/2009	3
1002	4/10/2009	4
1003	19/07/2009	1
1004	1/11/2009	4

FK

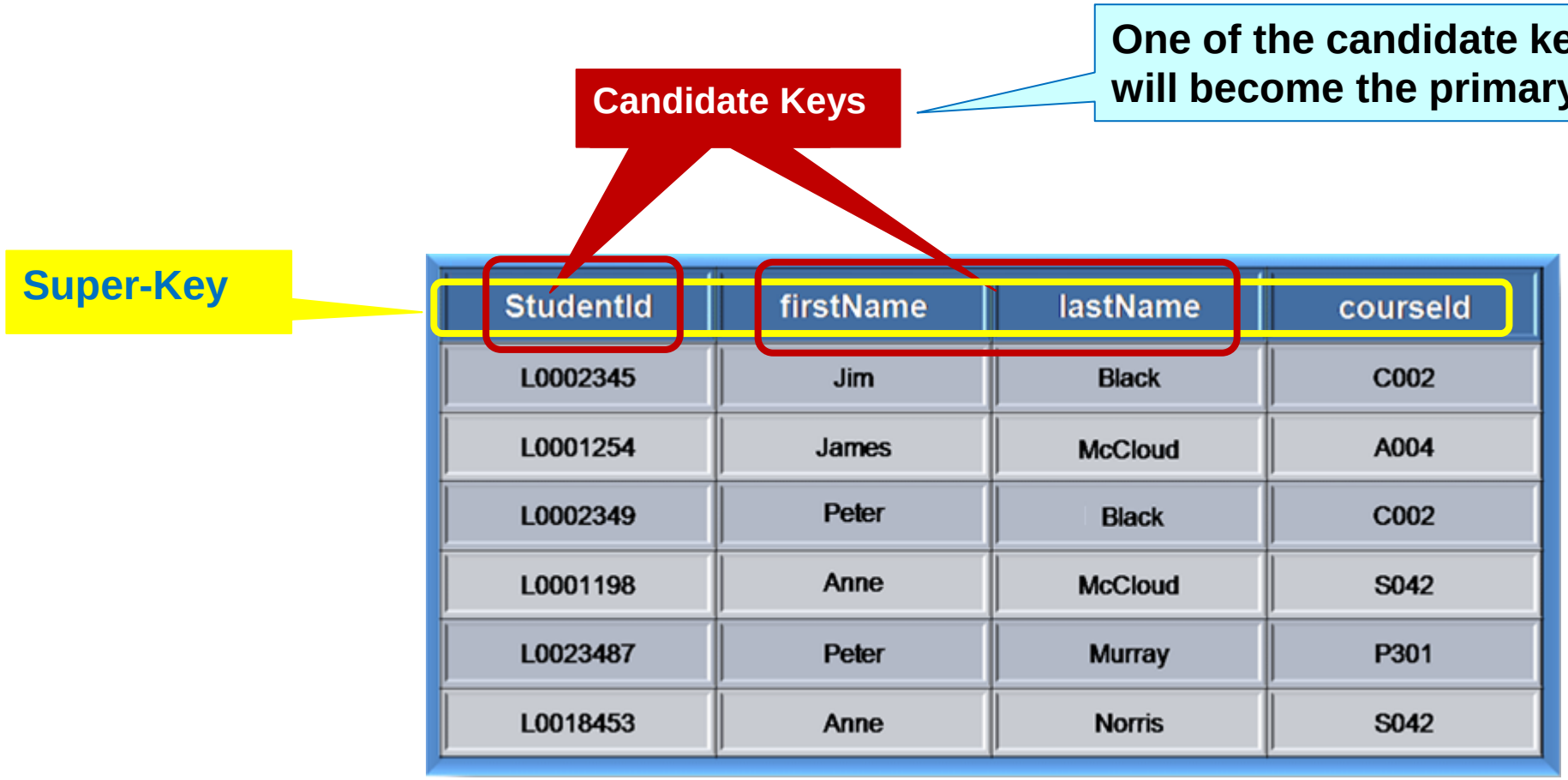
1.2. Keys of a Relation

- **Super-Key:**
  - Is a set of attributes within a table (relation) whose values can be used to uniquely identify a row in the relation.
- **Candidate Key:**
  - An attribute, or **minimal set** of attributes, that uniquely identifies a row in a relation (A unique identifier).
  - Each non-key field is functionally dependent on every candidate key.
  - One of the candidate keys will become the primary key

    E.g., perhaps there are both “credit card number” and “SS#” in a table. In this case both are candidate keys.
- **Primary Key:**
  - Is a unique identifier
  - It cannot contain null values
  - One of the candidate keys will become the primary key



Example: Super key, Candidate Key and PK



Note: Names are not a good choice to be a PK.

Class Activity 5.1 (3 minutes)

Explain two properties that must be satisfied by candidate keys?

a) Non-redundancy:

No attribute in the key can be deleted without destroying the property of unique identification.

StudentId	firstName	lastName	courseId
L0002345	Jim	Black	C002
L0001254	James	McCloud	A004
L0002349	Peter	Black	C002
L0001198	Anne	*Null*	S042
L0023487	Peter	Murray	P301
L0018453	Anne	*Null*	S042

b) Unique identification:

For every row, the value of the key must uniquely identify that row.

Class Activity 5.2 (2 minutes)

Explain the difference between candidate key and primary key.

Answer: A primary key is an attribute (or combination of attributes) that uniquely identifies a row in a relation. When a relation has more than one such attribute (or combination of attributes), each is called a candidate key. The primary key is then the one chosen by users to uniquely identify the rows in the relation.

Determining Candidate Keys

Using

Functional Dependencies (FDs)

1.3. Determining Candidate Keys Using Functional Dependencies (FDs)

- The candidate keys of a relation R can be defined using given FD set of the relation.

- To achieve this goal, the following concepts are discussed:

  1.3.1. Attribute Closure

  1.3.2. The Algorithm to Determine Candidate Keys Using FDs

1.3.1. Attribute Closure

- **Attribute Closure:**

  Attribute closure of an attribute set can be defined as a set of attributes which can be functionally determined from it.

  …

  Given FD set of a Relation R, If A is an attribute (or a combination of attributes), the set of attributes in relation R that are **functionally** dependent on A is called Attribute Closure of A and it can be represented as $\mathbf{A^+}$.

- **Steps to Find the Attribute Closure of A**

  Given FD set of a Relation R:

  1- Add A to the attribute closure set of A (A+)

  2- Recursively add attributes which can be functionally determined from attributes of the set A+ until done.

1.3.1. Example: Find the Attribute Closure of A

R (E-ID, E-Name, E-City, E-State)

FDs = { E-ID→ E-Name, E-ID → E-City, E-City → E-State }

The attribute closure of E-ID can be calculated as:

1. Add E-ID to the set

(E-ID)+ = {E-ID}

2. Add Attributes which can be derived (functionally determined) from **any attribute of set**.
   - In this case, E-Name and E-City can be derived from E-ID.
   - In addition, E-State can be derived from E-City. So these are also a part of closure.

(E-ID)+ = {E-ID, E-Name, E-City, E-State }

Similarly:

(E-Name)+ = {E-Name}

(E-City)+ = {E-City, E-State }

Reference: http://www.geeksforgeeks.org/finding-attribute-closure-and-candidate-keys-using-functional-dependencies/

1.3.2. The Algorithm to Determine Candidate Keys Using FDs

Step 1: Collect all related FDs to the relation R

Step 2: Create a table with three columns

Left	Middle	Right

Step 3: Write all attributes that only show up on the left side of some FDs under **Left** column

These attributes must be part of a key

Step 4: Write all attributes that only show up on the right side of some FDs under **Right** column

These attributes are not part of any key

Step 5: Write all attributes that show up on both left and right sides of some FDs under **Middle** column

These attributes may or may not be part of a key

Step 6: Determine the closure of attributes under **Left** and **Middle** columns to find which combination of those attributes **will functionally determine all other attributes**. Start from attributes under Left column.

Step 6.1. Add the attribute to the attribute closure set

Step 6.2. Add Attributes which can be derived from any attribute of the attribute closure set.

Step 7: The different combinations of attributes under Left and Middle columns that functionally determine **all other** attributes in relation R **are keys** for R i.e. **If A+ =R then A is a candidate key for R**

1.3.2. Example: Determining Candidate Keys Using FDs

R (ABCD)
FDs={AB→C,
C→B,
C→ D}

Steps 1, 2, 3, 4 and 5

Left	Middle	Right
A	BC	D

Note: Super Key is the combination of attributes under the Left and Middle columns (in this example ABC is the super key).

Step 6.1. **A+ ={A}**

Step 6.2. A+ is not equal to R. Therefore, we need to add another attribute under Middle column and find the attribute closure of the combination of A and B:

AB+ ={AB}

AB+ ={AB} and **AB→C** then **AB+ = {ABC}**

AB+ ={ABC} and **C→ D** then **AB+ = {ABCD} = R**

We need to try other combinations of attributes under Left and Middle columns to find all possible candidate key. Similarly:

AC+ = {ACBD}

Step 7: Determine the candidate keys:

AB+ equals to R. So AB is a candidate key for R.

AC+ also equals to R. So AC is another candidate key for R.

More Examples for Determining keys Using FDs:

There are more examples presented in the related video that is uploaded on UTSonline in Week 5 folder.

Class Activity 5.3: Determine the PK of the following relation (5 Minutes)

First Create the Left/Middle/Right Table

INVOICE (OrderID, ProductID, OrderDate, CustomerID, CustomerName, CustomerAddress, ProductDescription, ProductFinish, ProductStandardPrice, OrderQuantity)

- FDs:

OrderID, ProductID → OrderQuantity

ProductID → ProductDescription, ProductFinish, ProductStandardPrice

OrderID → OrderDate, CustomerID, CustomerName, CustomerAddress

CustomerID → CustomerName, CustomerAddress

Left	Middle	Right
OrderID **ProductID**	**CustomerID**	**OrderQuantity** **ProductDescription** **ProductFinish** **ProductStandardPrice** **OrderDate** **CustomerName** **CustomerAddress**

Which attributes may be part of a candidate key?

INVOICE (OrderID, ProductID, OrderDate, CustomerID, CustomerName, CustomerAddress, ProductDescription, ProductFinish, ProductStandardPrice, OrderQuantity)

OrderID, ProductID ➔ OrderQuantity
ProductID ➔ ProductDescription, ProductFinish, ProductStandardPrice
OrderID ➔ OrderDate, CustomerID, CustomerName, CustomerAddress
CustomerID ➔ CustomerName, CustomerAddress

Left	Middle	Right
OrderID **ProductID**	**CustomerID**	**OrderQuantity** **ProductDescription** **ProductFinish** **ProductStandardPrice** **OrderDate** **CustomerName** **CustomerAddress**

Now we need to find all possible candidate keys

OrderID+ = {OrderID, OrderDate, CustomerID, CustomerName, CustomerAddress}

ProductID+ = {ProductID, ProductDescription, ProductFinish, ProductStandardPrice}

{OrderID, ProductID}+ = {OrderID, ProductID, OrderQuantity, OrderDate, CustomerID, CustomerName, CustomerAddress, ProductDescription, ProductFinish, ProductStandardPrice} **= INVOICE**

Therefore "**OrderID, ProductID**" is the only composite candidate key and also the PK of the relation

Note: Considering that **{OrderID, ProductID}+ = INVOICE** we don't need to add another attribute to this combination to create a new candidate key. Because we are looking for minimal set of attributes to make a candidate key.

{ProductID, CustomerID} += {CustomerID, ProductId, ProductDescription, ProductFinish, ProductStandardPrice, CustomerName, CustomerAddress}

{OrderID, CustomerID} += { OrderID, OrderDate, CustomerId, CustomerName, CustomerAddress, CustomerID}

Partial and **Transitive**

Functional Dependencies

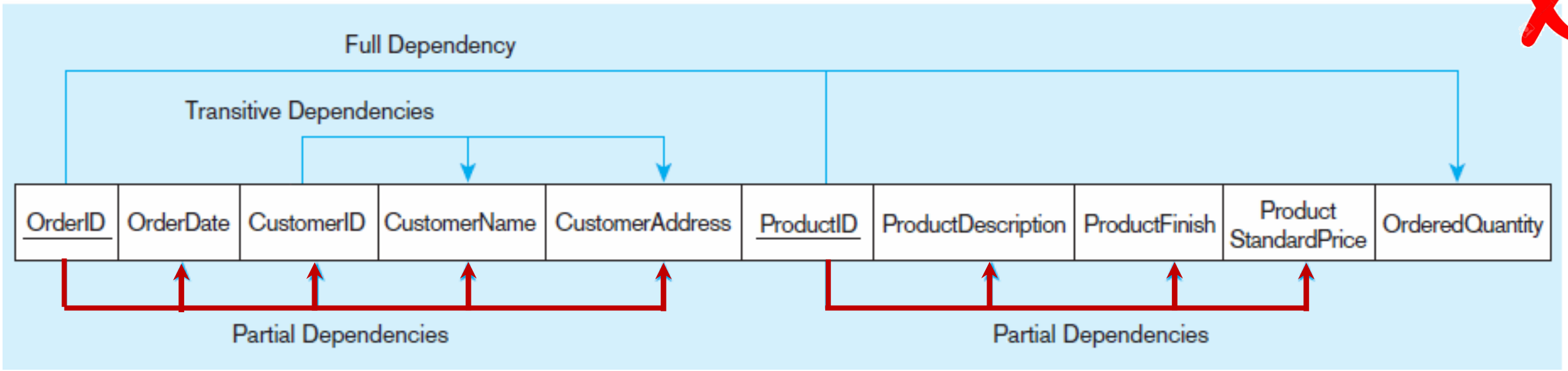
Important Note:

Partial and **Transitive** Functional Dependencies in a relation cause the insertion, deletion and modification **anomalies.**

- **What is Partial Functional Dependency?**
- **What is Transitive Functional Dependency?**
- **Why they cause the anomalies?**

1.4. Partial Functional Dependencies (Book format)

A functional dependency in which one or more non-key attributes are functionally dependent **on part (but not all)** of the primary key (**Composite primary Key**).



Composite primary Key of this relation is: OrderID, ProductID

1.4. Partial Functional Dependencies (Tutorial format)

A functional dependency in which one or more non-key attributes are functionally dependent **on part (but not all)** of the primary key (**Composite primary Key**).

INVOICE (OrderID, ProductID, OrderDate, CustomerID, CustomerName, CustomerAddress, ProductDescription, ProductFinish, ProductStandardPrice, OrderQuantity)

- **FDs:**

OrderID, ProductID ➔ OrderQuantity

ProductID ➔ ProductDescription, ProductFinish, ProductStandardPrice

OrderID ➔ OrderDate, CustomerID, CustomerName, CustomerAddress

CustomerID → CustomerName, CustomerAddress

Class Activity 5.4: For the relation below:

a) Find partial functional dependencies, and

b) Explain if we need to check for partial functional dependencies in every relation.

C) Remove partial functional dependencies from the EMPLOYEE relation and provide new relations and the revised ERD.

EMPLOYEE (**Employee_ID, Skill_ID**, Emp_F_Name, Emp_L_Name, Emp_Date_Employed, Emp_DOB, Company_ID, Com_Name, Skill_Title, Skill_Type, Date_Completed)

FDs:

Employee_ID --> Emp_F_Name, Emp_L_Name, Emp_Date_Employed, Emp_DOB, Company_ID, Com_Name

Skill_ID --> Skill_Title, Skill_Type

Company_ID --> Com_Name

Employee_ID, Skill_ID --> Date_Completed

a) Considering the following FDs, there is a partial functional dependency in EMPLOYEE relation:

Employee_ID --> Emp_F_Name, Emp_L_Name, Emp_Date_Employed, Emp_DOB, Company_ID, Com_Name

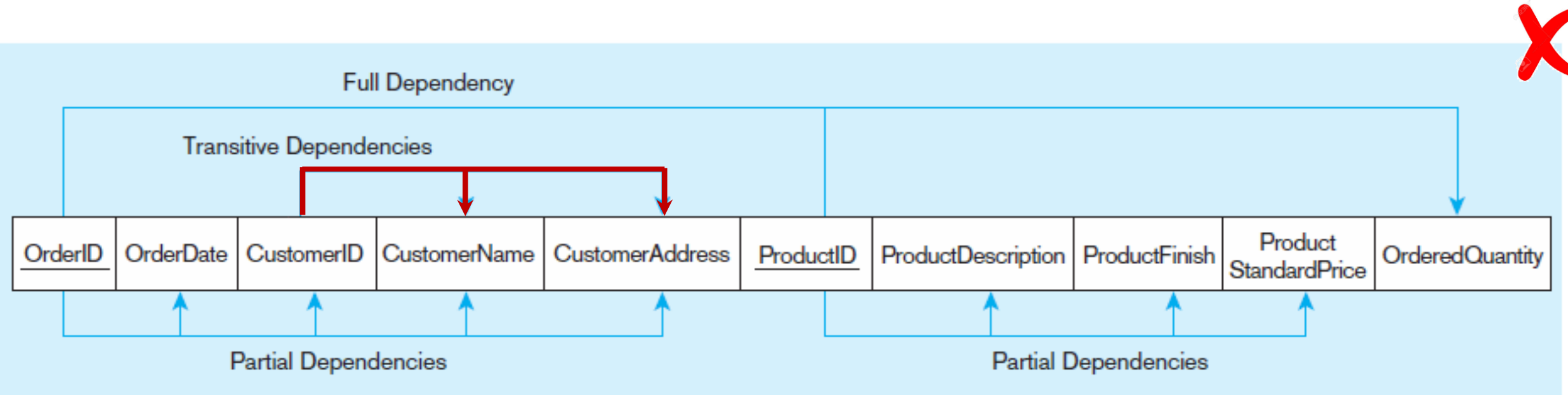
Skill_ID --> Skill_Title, Skill_Type

As you see, one or more non-key attributes are functionally dependent **on part (but not all)** of the primary key (**Composite primary Key**).

b) We just need to check the issue with partial functional dependency just for the relations with a **Composite** primary Key.

1.5. Transitive Functional Dependencies (Book format)

A functional dependency between the primary key and one or more non-key attributes that are dependent on the primary key **via another non-key attribute**.



Composite primary Key of this relation is: OrderID, ProductID

1.5. Transitive Functional Dependencies (Tutorial format)

A functional dependency between the primary key and one or more non-key attributes that are dependent on the primary key **via another non-key attribute**.

INVOICE (OrderID, ProductID, OrderDate, CustomerID, CustomerName, CustomerAddress, ProductDescription, ProductFinish, ProductStandardPrice, OrderQuantity)

- **FDs:**

OrderID, ProductID ➔ OrderQuantity

ProductID ➔ ProductDescription, ProductFinish, ProductStandardPrice

OrderID ➔ OrderDate, CustomerID, CustomerName, CustomerAddress

CustomerID → CustomerName, CustomerAddress

Class Activity 5.5: For the relation below:

a) Find transitive functional dependencies, and

b) Explain if we need to check for transitive functional dependencies in every relation.

C) Remove transitive functional dependencies from the EMPLOYEE relation and provide new relations and the revised ERD.

EMPLOYEE (**Employee_ID, Skill_ID**, Emp_F_Name, Emp_L_Name, Emp_Date_Employed, Emp_DOB, Company_ID, Com_Name, Skill_Title, Skill_Type, Date_Completed)

FDs:

Employee_ID --> Emp_F_Name, Emp_L_Name, Emp_Date_Employed, Emp_DOB, Company_ID, Com_Name

Skill_ID --> Skill_Title, Skill_Type

Company_ID --> Com_Name

Employee_ID, Skill_ID --> Date_Completed

a) Considering the following FDs, there is a transitive functional dependency in EMPLOYEE relation:

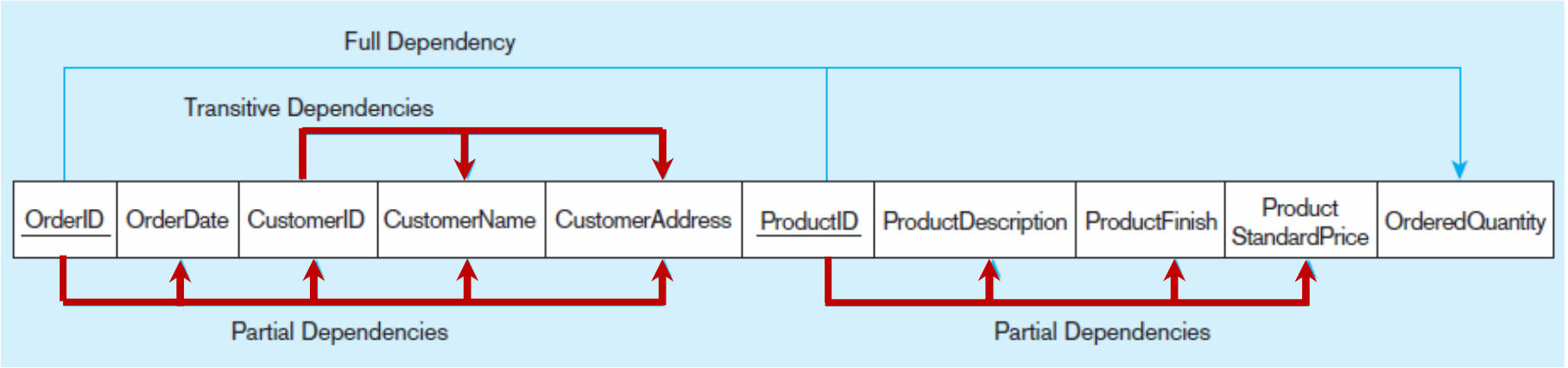
Company_ID --> Com_Name

As you see, one or more non-key attributes that are dependent on the primary key **via another non-key attribute**.

b) We just need to check the issue with transitive functional dependency just for the relations with more than one dependent attributes.

1.6. Why Partial and Transitive FDS cause the anomalies?

Functional Dependency Diagram for INVOICE (Figure 4-27)



INVOICE Relation

INVOICE (OrderID, ProductID, OrderDate, CustomerID, CustomerName, CustomerAddress, ProductDescription, ProductFinish, ProductStandardPrice, OrderQuantity)

FDs

OrderID, ProductID ➔ OrderQuantity

ProductID ➔ ProductDescription, ProductFinish, ProductStandardPrice

OrderID ➔ OrderDate, CustomerID, CustomerName, CustomerAddress

CustomerID → CustomerName, CustomerAddress

Have a look at the anomalies in INVOICE relation (table) that has partial and transitive FDs:

OrderID	Order Date	Customer ID	Customer Name	Customer Address	ProductID	Product Description	Product Finish	Product StandardPrice	Ordered Quantity
1006	10/24/2010	2	Value Furniture	Plano, TX	7	Dining Table	Natural Ash	800.00	2
1006	10/24/2010	2	Value Furniture	Plano, TX	5	Writer's Desk	Cherry	325.00	2
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FIGURE 4-26 INVOICE relation (1NF) (Pine Valley Furniture Company)

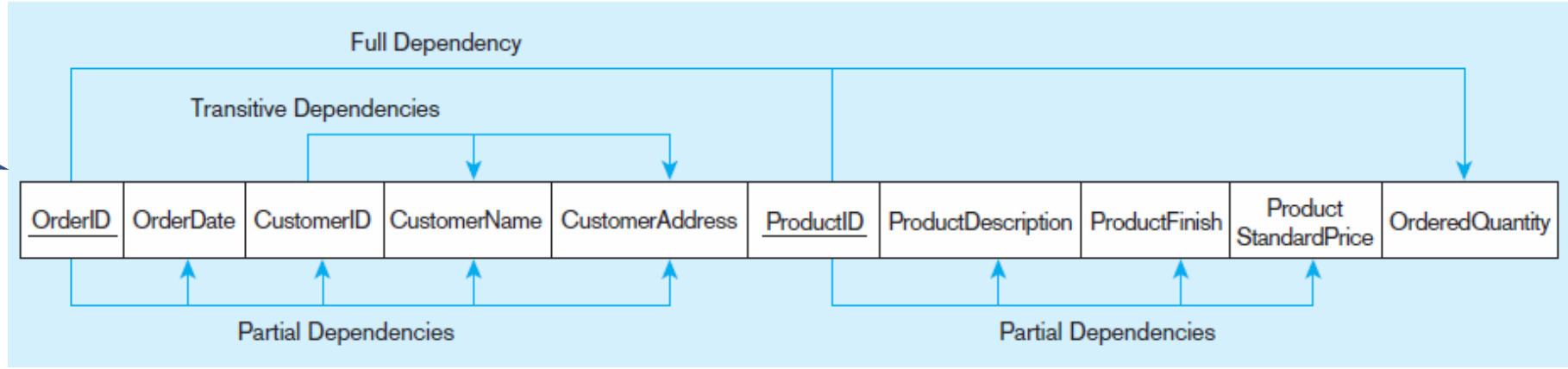
- **Insertion Anomaly**: if new product is ordered for order **1007** of existing customer, **customer data** must be re-entered, causing duplication
- **Deletion Anomaly** : if we delete the **Dining Table** from Order **1006**, we lose information concerning this item's finish and price
- **Update (Modification) Anomaly**: 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.

Have a look at the relation (in two formats) and review the answer to "Why Partial and Transitive FDS cause the anomalies?"

Functional Dependency Diagram for INVOICE (Figure 4-27)



INVOICE Relation

INVOICE (OrderID, ProductID, OrderDate, CustomerID, CustomerName, CustomerAddress, ProductDescription, ProductFinish, ProductStandardPrice, OrderQuantity)

Why do these anomalies exist?

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

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

2. Well-Structured Relations and Data Normalization

2. 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 (update) Anomaly:** changing data in a row forces changes to other rows because of duplication

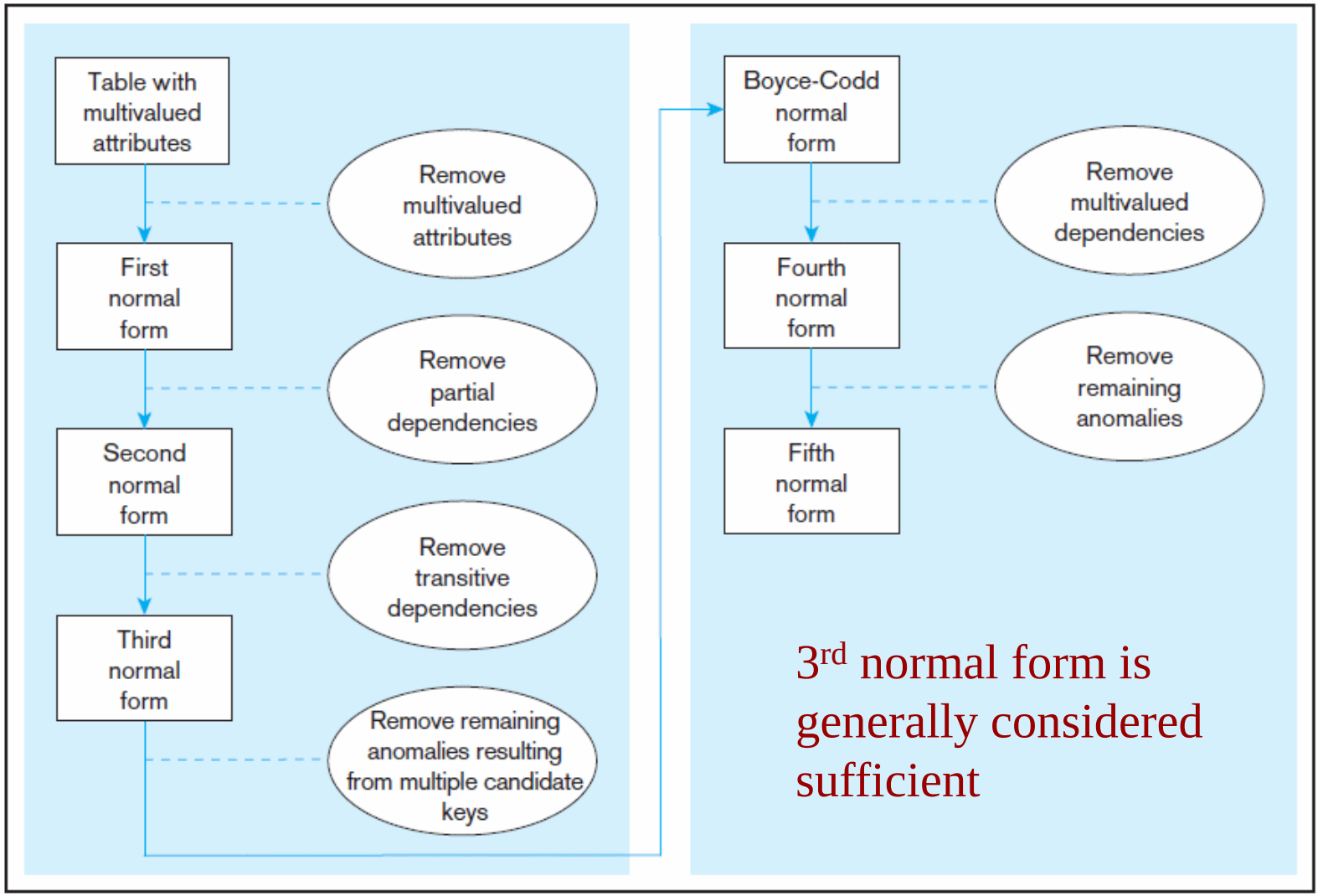
General rule of thumb: A table should not pertain to more than one entity type.

2. Data Normalization

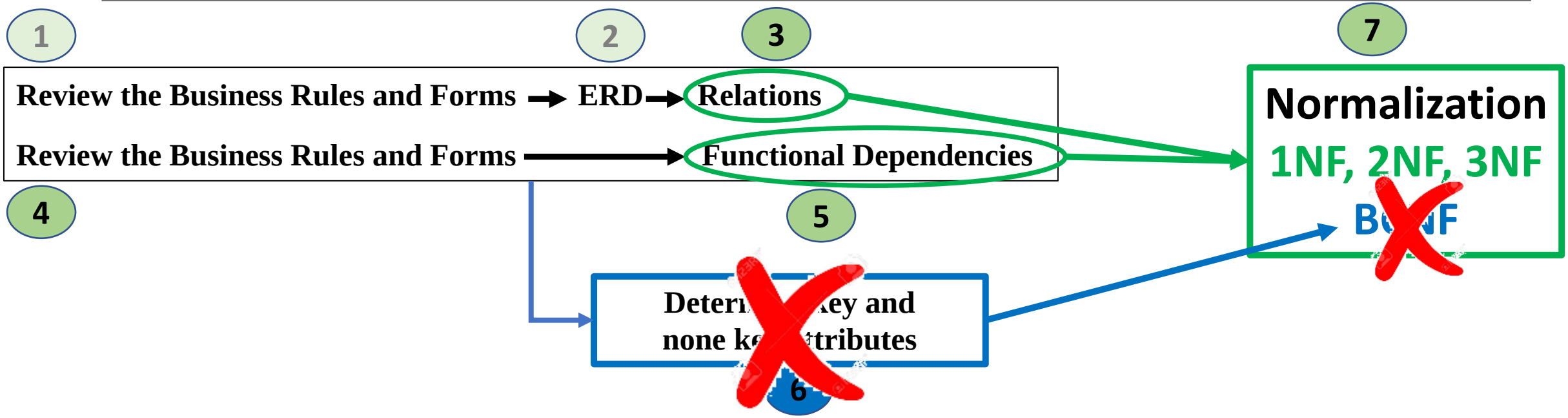
- Primarily a tool to validate and improve a logical design so that it satisfies certain constraints that **avoid unnecessary duplication of data**

- The process of decomposing relations with anomalies to produce smaller, **well-structured** relations

3. Steps in Normalization (Figure 4.22)



The Process of Designing and Normalizing an ERD:



NOTE: considering that BCNF is optional to learn for this subject, we don't need to determine all candidate keys of the relations to complete the normalization process. If you want to check your relation to make sure it is also in BCNF, then you need to determine all candidate keys of the relations.

NOTE: Please DO NOT use your ERD or Relations to determine FDs.

First Normal Form

4. First Normal Form

I. **No derived attribute** (Derived attribute can be calculated or derived using some business rule from other attributes)

- **Example:** In the following relation StuAge is a derived attribute and should be removed from the relation

- Student(StudentID, StuDateOfBirth, **StuAge**, StuAddress)
- Student(StudentID, StuDateOfBirth, StuAddress)

II. **Every attribute value is atomic** (Atomic attributes can't be divided into subparts)

- **Example:** In the following relation StuAddress is a non-atomic attribute and should be divided to smaller parts

- Student(StudentID, StuDateOfBirth, **StuAddress**)
- Student(StudentID, StuDateOfBirth, **StuUnitNumber, StuStreet, StuSuburb, StuState**)

Note: in the following slides "Customer Address" has been ASSUMED as an atomic attribute.

III. **No multivalued attributes** (Multivalued attributes can have more than one value at a time)

Based on this, a relation is in first normal form if:

- There are no repeating groups in the relation.
- A Primary key has been defined, which uniquely identifies each row in the relation

- **Example:** In the next slides

Table with multivalued attributes, not in 1st normal form

- **Multivalued attributes:** Attributes that can have more than one value at a time.
- **A relation is in first normal form (1NF) if:**
  - There are no repeating groups in the relation.
  - A Primary key has been defined, which uniquely identifies each row in the relation

OrderID	Order Date	Customer ID	Customer Name	Customer Address	ProductID	Product Description	Product Finish	Product StandardPrice	Ordered Quantity
1006	10/24/2010	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	10/25/2010	6	Furniture Gallery	Boulder, CO	11	4–Dr Dresser	Oak	500.00	4
					4	Entertainment Center	Natural Maple	650.00	3

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

Note: This is NOT a relation.

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

OrderID	Order Date	Customer ID	Customer Name	Customer Address	ProductID	Product Description	Product Finish	Product StandardPrice	Ordered Quantity
1006	10/24/2010	2	Value Furniture	Plano, TX	7	Dining Table	Natural Ash	800.00	2
1006	10/24/2010	2	Value Furniture	Plano, TX	5	Writer's Desk	Cherry	325.00	2
1006	10/24/2010	2	Value Furniture	Plano, TX	4	Entertainment Center	Natural Maple	650.00	1
1007	10/25/2010	6	Furniture Gallery	Boulder, CO	11	4–Dr Dresser	Oak	500.00	4
1007	10/25/2010	6	Furniture Gallery	Boulder, CO	4	Entertainment Center	Natural Maple	650.00	3

FIGURE 4-26 INVOICE relation (1NF) (Pine Valley Furniture Company)

Note: This is a relation and is in 1NF, but not a well-structured one.

This relation is still ✗

Anomalies in this Table (Review)

OrderID	Order Date	Customer ID	Customer Name	Customer Address	ProductID	Product Description	Product Finish	Product StandardPrice	Ordered Quantity
1006	10/24/2010	2	Value Furniture	Plano, TX	7	Dining Table	Natural Ash	800.00	2
1006	10/24/2010	2	Value Furniture	Plano, TX	5	Writer's Desk	Cherry	325.00	2
1006	10/24/2010	2	Value Furniture	Plano, TX	4	Entertainment Center	Natural Maple	650.00	1
1007	10/25/2010	6	Furniture Gallery	Boulder, CO	11	4–Dr Dresser	Oak	500.00	4
1007	10/25/2010	6	Furniture Gallery	Boulder, CO	4	Entertainment Center	Natural Maple	650.00	3

FIGURE 4-26 INVOICE relation (1NF) (Pine Valley Furniture Company)

- **Insertion Anomaly**: if new product is ordered for order **1007** of existing customer, **customer data** must be re-entered, causing duplication
- **Deletion Anomaly** : if we delete the **Dining Table** from Order **1006**, we lose information concerning this item's finish and price
- **Update (Modification) Anomaly**: 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.

Class Activity 5.6: Find the anomalies in the following relation with Employee_ID and Skill_ID as the composite PK.

Employee_ID	Emp_F_Name	Emp_L_Name	Emp_Date_Employed	Emp_DOB	Company_ID	Com_Name	Skill_ID	Skill_Title	Skill_Type	Date_Completed
1123	Sara	Brown	1/1/2014	1/1/1985	C12	Google	B86	C++	PL	2/5/2020
1123	Sara	Brown	1/1/2014	1/1/1985	C12	Google	V25	Visual Basic	PL	7/9/2019
1456	Jake	Cooper	5/8/2013	7/8/1990	C12	Google	C55	C#	CL	5/6/2006
1456	Jake	Cooper	5/8/2013	7/8/1990	C12	Google	A23	Java	PL	3/7/2020
1456	Jake	Cooper	5/8/2013	7/8/1990	C12	Google	C45	Python	PL	4/6/2007
7892	Fahimeh	Ramezani	2/3/2013	8/7/1987	C13	IBM	C45	Python	PL	8/9/2018
7892	Fahimeh	Ramezani	2/3/2013	8/7/1987	C13	IBM	B86	C++	PL	7/4/2016
8764	Ricky	Romanous	2/3/2015	4/3/1982	C14	SAS	B86	C++	PL	9/9/2009
8764	Ricky	Romanous	2/3/2015	4/3/1982	C14	SAS	C55	C#	CL	12/1/2005

- **Insertion Anomaly**: if new product is ordered for employee **7892** working in existing company, **company data** must be re-entered, causing duplication
- **Deletion Anomaly**: if we delete **Visual Basic** from the list of skills related to employee **1123**, we lose information concerning this skill's title and type.
- **Update (Modification) Anomaly**: updating the **skill type** of **skill ID C55** requires update in multiple records.

Class Activity 5.7: Is the following relation in 1NF?

STAFF (staffID, staFName, staLName, staAddress, staGender, staPhone, staDOB, staAge, staSScale, staJType, staCSalary, staSDate, DocPager, DocSpecialty, NursePosition, StaffType)

STAFF is not in 1NF as we have a non-atomic attribute staAddress, and a drived attribute staAge.

Important Note

Please be aware that the **FKs should not be shown in the ERD** …

In the examples that are provided in the following slides, we have used the SQL server diagrams that have FKs included (we **did not** use the Crow's Foot notation)

Second Normal Form

5. 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

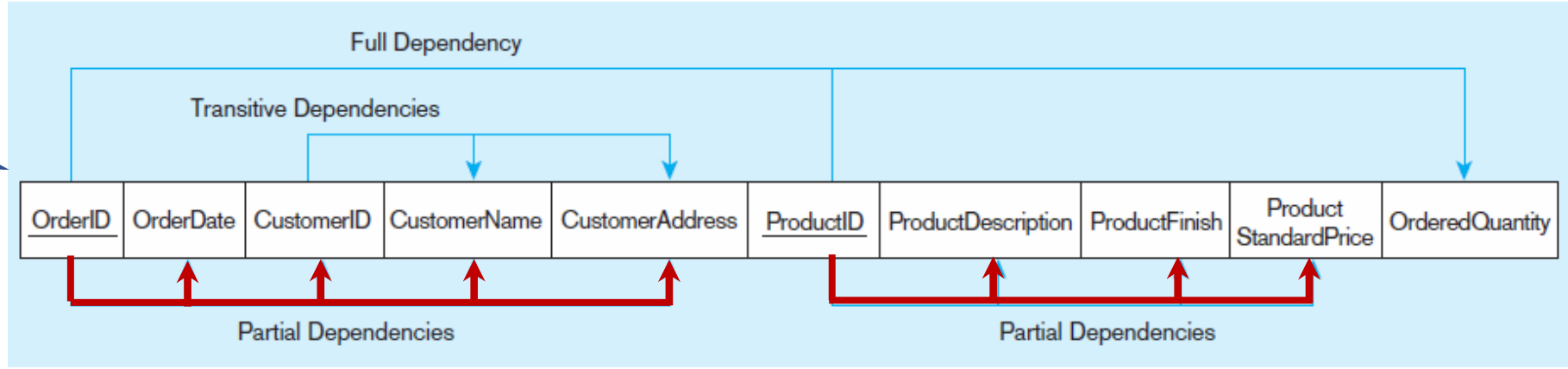
- **Solution:**

1. Create new relation for each Primary Key (PK) and move non-key attributes that are only dependent on this PK.

2. Consider this PK as a Foreign Key (FK) in the original table (relation)

Partial Functional Dependencies in INVOICE (Book and Tutorial Formats)

Functional Dependency Diagram for INVOICE (Figure 4-27)



INVOICE Relation

INVOICE (OrderID, ProductID, OrderDate, CustomerID, CustomerName, CustomerAddress, ProductDescription, ProductFinish, ProductStandardPrice, OrderQuantity)

FDs

OrderID, ProductID → OrderQuantity

ProductID → ProductDescription, ProductFinish, ProductStandardPrice

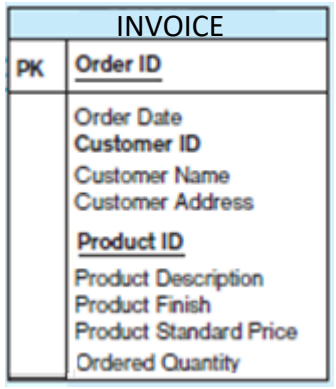
OrderID → OrderDate, CustomerID, CustomerName, CustomerAddress

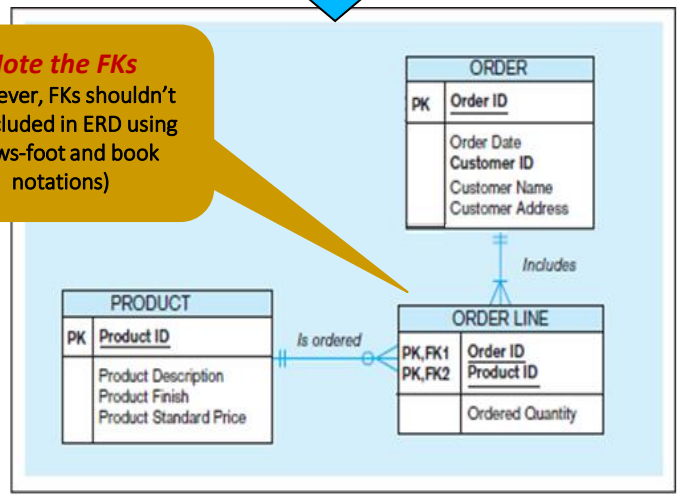
CustomerID → CustomerName, CustomerAddress

Based on the FDs there are partial functional dependencies in this relation → Therefore, This Relation (INVOICE) is NOT in 2nd Normal Form

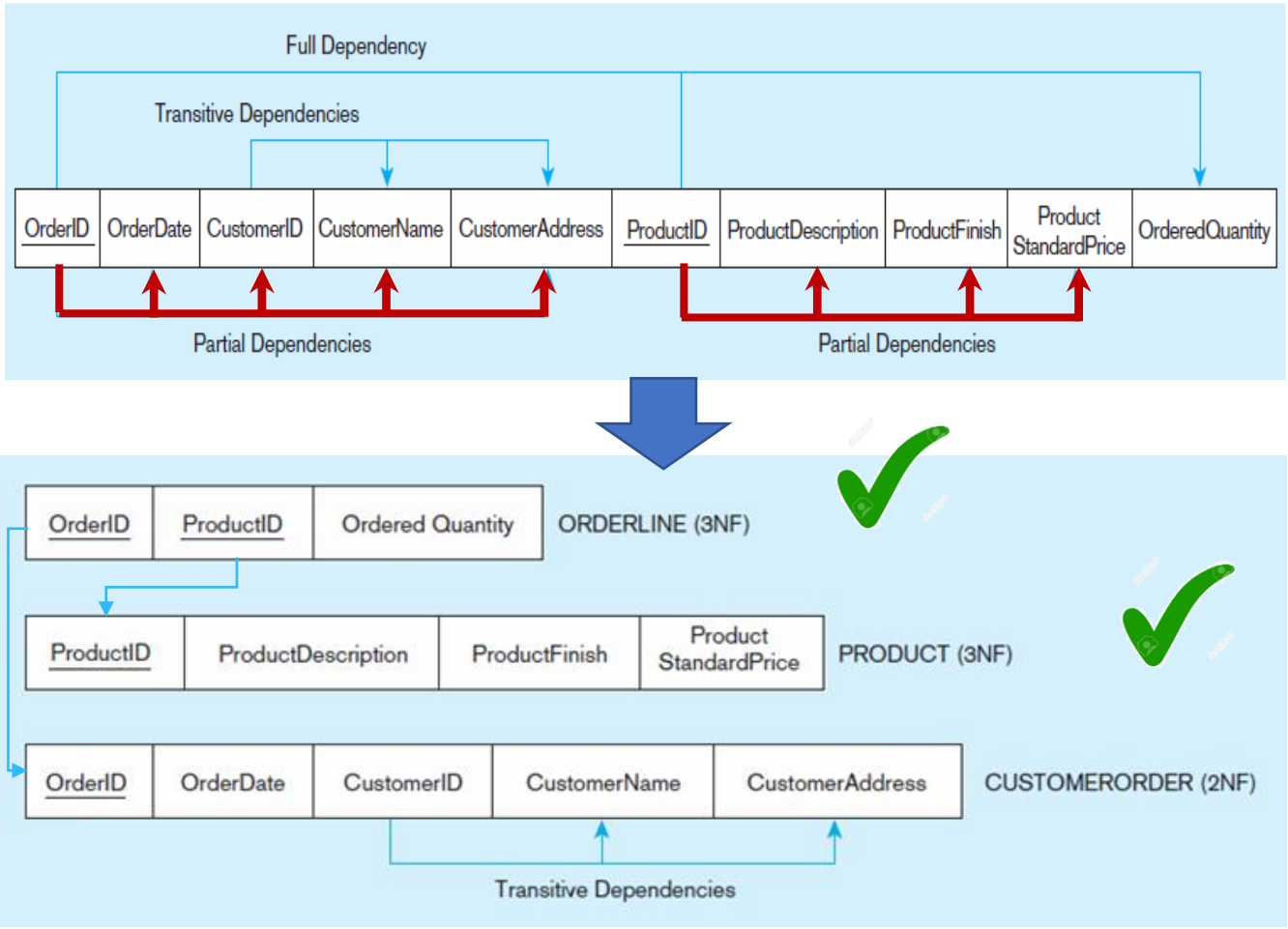
Removing Partial Dependencies (using Book Format in Figure 4-28)

1. Create new relation for each Primary Key (PK) and move non-key attributes that are only dependent on this PK.
2. Consider this PK as a Foreign Key (FK) in the original table (relation)





Note the FKs
(However, FKs shouldn't be included in ERD using crows-foot and book notations)

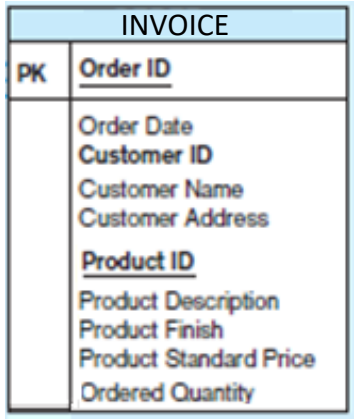


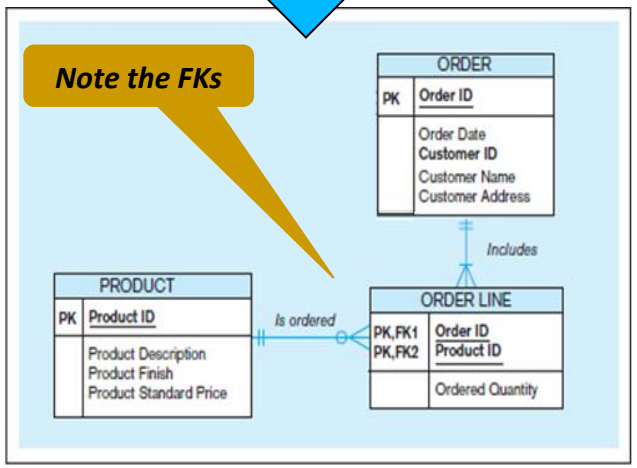
Getting it into Second Normal Form

Partial dependencies are removed, but there are still transitive dependencies

Removing Partial Dependencies (using Tutorial Format for Relations)

1. Create new relation for each Primary Key (PK) and move non-key attributes that are only dependent on this PK.
2. Consider this PK as a Foreign Key (FK) in the original table (relation)





INVOICE (OrderID, ProductID, OrderDate, CustomerID, CustomerName, CustomerAddress, ProductDescription, ProductFinish, ProductStandardPrice, OrderQuantity) ✗

OrderID, ProductID ➔ OrderQuantity

ProductID ➔ ProductDescription, ProductFinish, ProductStandardPrice

OrderID ➔ OrderDate, CustomerID, CustomerName, CustomerAddress

CustomerID → CustomerName, CustomerAddress

➢ **New Relations:** Getting it into Second Normal Form

PRODUCT (ProductID, ProductDescription, ProductFinish, ProductStandardPrice) ✓

ORDER (OrderID, OrderDate, CustomerID, CustomerName, CustomerAddress) ✗

ORDER-LINE (OrderID*, ProductID*, OrderQuantity) ✓

FK (OrderID) references ORDER

FK (ProductID) references PRODUCT

Note the FKs

Partial dependencies are removed, but there are still transitive dependencies in ORDER relation.

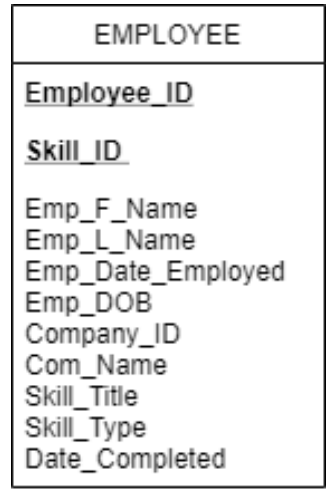
Class Activity 5.4: For the relation below:

a) Find partial functional dependencies, and

b) Explain if we need to check for partial functional dependencies in every relation.

C) Remove partial functional dependencies from the EMPLOYEE relation and provide new relations and the revised ERD.

EMPLOYEE (**Employee_ID, Skill_ID**, Emp_F_Name, Emp_L_Name, Emp_Date_Employed, Emp_DOB, Company_ID, Com_Name, Skill_Title, Skill_Type, Date_Completed)



FDs:

Employee_ID --> Emp_F_Name, Emp_L_Name, Emp_Date_Employed, Emp_DOB, Company_ID, Com_Name

Skill_ID --> Skill_Title, Skill_Type

Company_ID --> Com_Name

Employee_ID, Skill_ID --> Date_Completed

EMPLOYEE (**Employee_ID**, Emp_F_Name, Emp_L_Name, Emp_Date_Employed, Emp_DOB, Company_ID, Com_Name)

SKILL (**Skill_ID**, Skill_Title, Skill_Type)

EMPLOYEE_SKILL (**Employee_ID*, Skill_ID***, Date_Completed)

FK (Employee_ID) references EMPLOYEE
FK (Skill_ID) references SKILL

Class Activity 5.4: For the relation below:

a) Find partial functional dependencies, and

b) Explain if we need to check for partial functional dependencies in every relation.

C) Remove partial functional dependencies from the EMPLOYEE relation and provide new relations and the revised ERD.

EMPLOYEE (**Employee_ID**, Emp_F_Name, Emp_L_Name, Emp_Date_Employed, Emp_DOB, Company_ID, Com_Name)

SKILL (**Skill_ID**, Skill_Title, Skill_Type)

EMPLOYEE_SKILL (**Employee_ID*, Skill_ID***, Date_Completed)

Third Normal Form

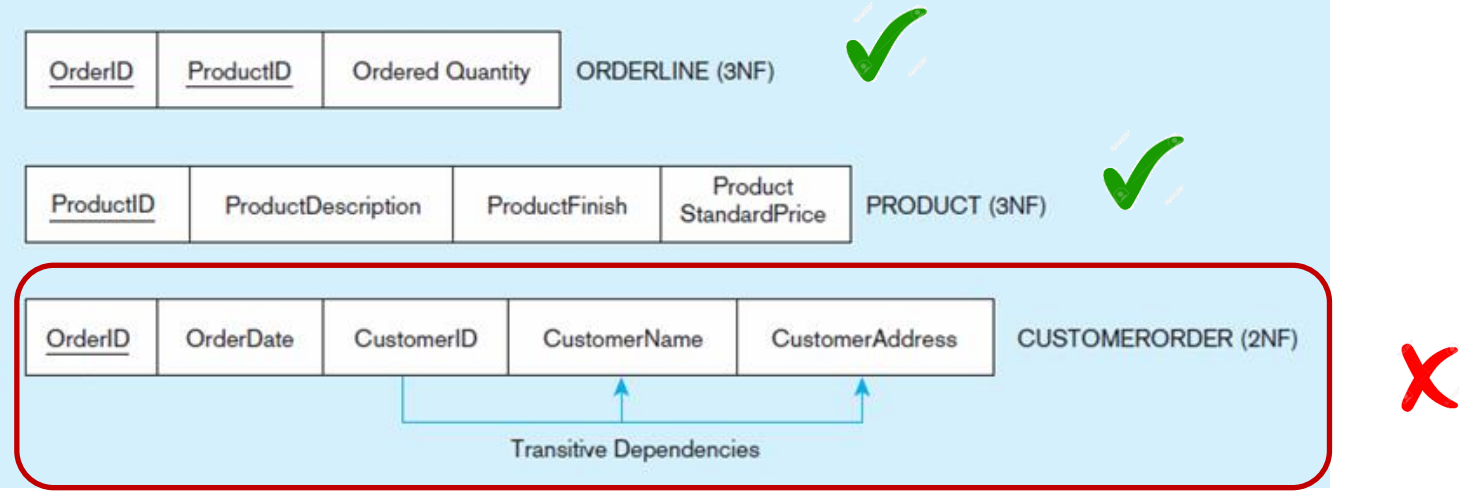
6. Third Normal Form

- **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.
- (If it is **non-transitive** then each non-key attribute is not dependent on, or a determinant for, any other non-key attributes).

- **Solution:**

1. Non-key determinant with transitive dependencies go into a new table;
2. Non-key determinant becomes primary key in the new table, and
3. Stays as foreign key in the old table (relation)

By now …
we have converted INVOICE relation to three new relations as follows:



OrderID, ProductID ➔ OrderQuantity

ProductID ➔ ProductDescription, ProductFinish, ProductStandardPrice

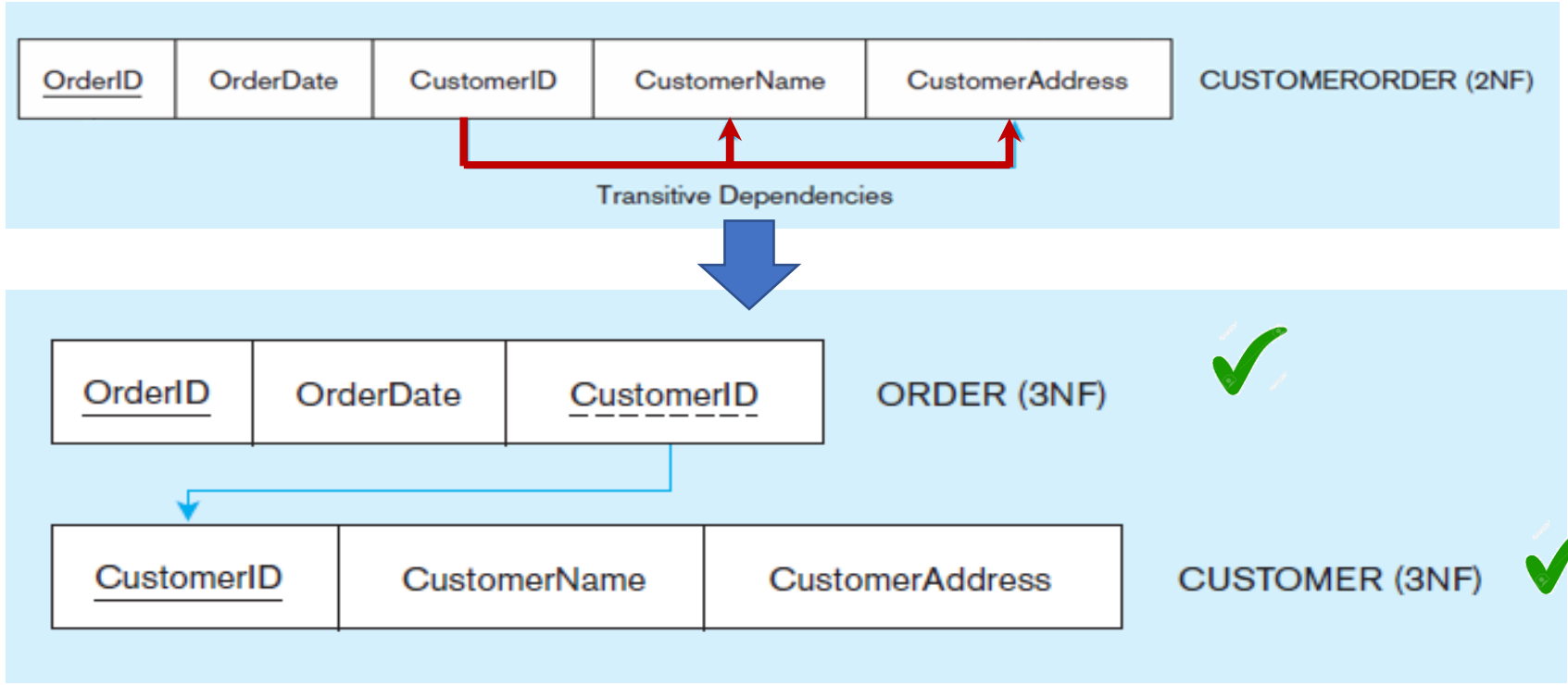
OrderID ➔ OrderDate, CustomerID, CustomerName, CustomerAddress

CustomerID → CustomerName, CustomerAddress

You can see there is a transitive functional dependencies in ORDER relation.

Removing Transitive Dependencies (Book Format in Figure 4-29)

- **Solution:**
  1. Non-key determinant with transitive dependencies go into a new table;
  2. Non-key determinant becomes primary key in the new table, and
  3. Stays as foreign key in the old table



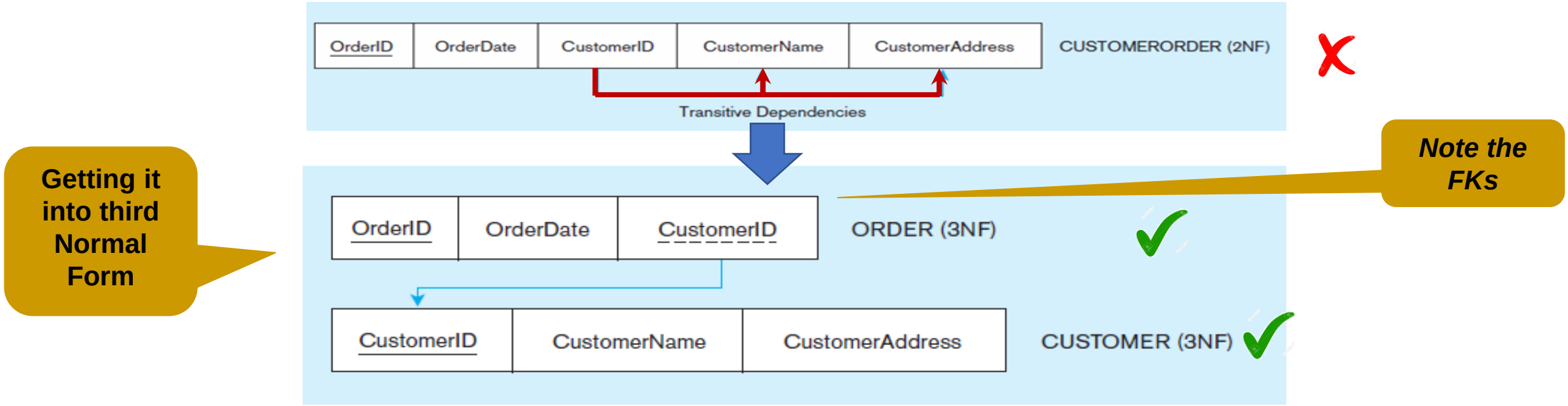
Getting it into third Normal Form

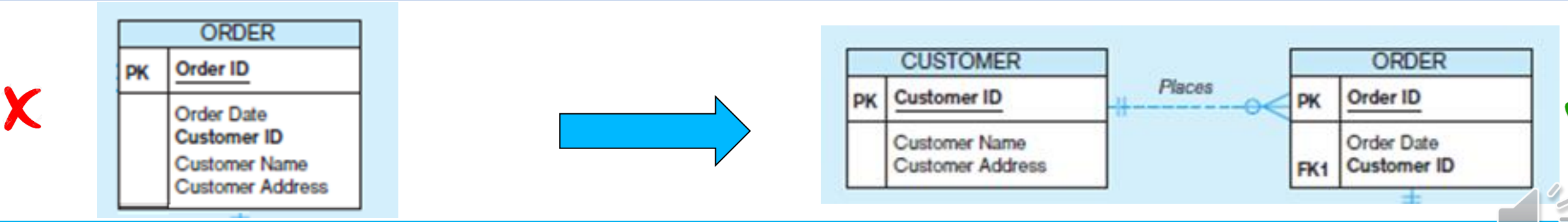
OrderID ➔ OrderDate, CustomerID, CustomerName, CustomerAddress

CustomerID → CustomerName, CustomerAddress

Removing Transitive Dependencies (Using Book Format in Figure 4-29)

1. Non-key determinant with transitive dependencies go into a new table;
2. Non-key determinant becomes primary key in the new table, and
3. Stays as foreign key in the old table





Removing Transitive Dependencies (Using Tutorial Format for Relations)

1. Non-key determinant with transitive dependencies go into a new table;
2. Non-key determinant becomes primary key in the new table, and
3. Stays as foreign key in the old table

ORDER (OrderID, OrderDate, CustomerID, CustomerName, CustomerAddress) ✗

➢ **FDs:**

OrderID ➔ OrderDate, CustomerID, CustomerName, CustomerAddress

CustomerID → CustomerName, CustomerAddress

➢ **New Relations that are in 3NF:**

CUSTOMER (CustomerID, CustomerName, CustomerAddress) ✓

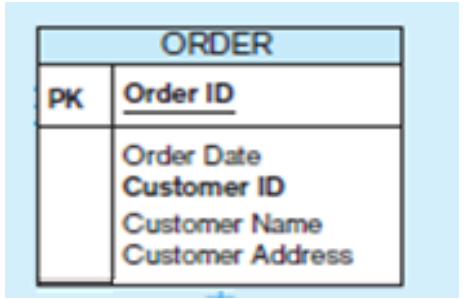
ORDER (OrderID, OrderDate, CustomerID*) ✓

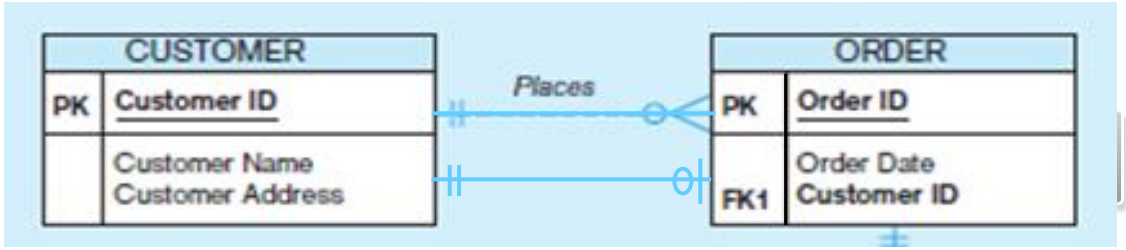
FK (CustomerID) references CUSTOMER

ORDER

OrderID	OrderDate	CustomerID
1001	18/04/1983	1233
1003	12/01/1988	1233
…	…	…

✗





✓

Normalized logical Design

OrderID	Order Date	Customer ID	Customer Name	Customer Address	ProductID	Product Description	Product Finish	Product StandardPrice	Ordered Quantity
1006	10/24/2010	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	10/25/2010	6	Furniture Gallery	Boulder, CO	11	4–Dr Dresser	Oak	500.00	4
					4	Entertainment Center	Natural Maple	650.00	3

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

ProductID ➔ ProductDescription, ProductFinish, ProductStandardPrice

CustomerID ➔ CustomerName, CustomerAddress

OrderID ➔ OrderDate, CustomerID

OrderID, ProductID ➔ OrderQuantity

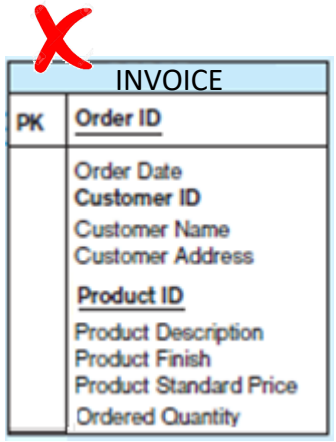
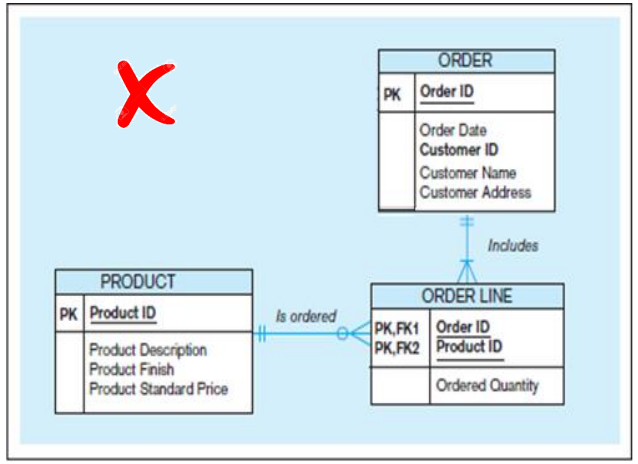
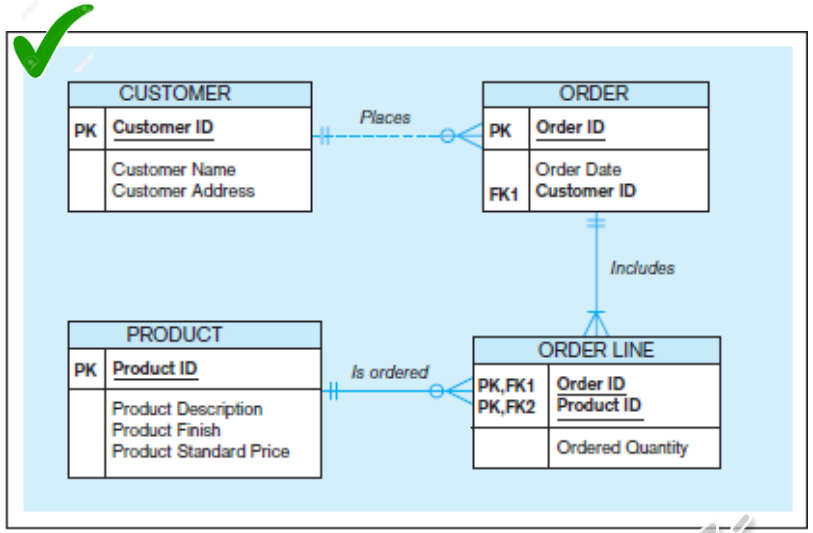


Figure 4-30 shows the result of normalization, yielding four separate relations where initially there was only one.





Class Activity 5.5: For the relation below:

a) Find transitive functional dependencies, and

b) Explain if we need to check for transitive functional dependencies in every relation.

C) Remove transitive functional dependencies from the EMPLOYEE relation and provide new relations and the revised ERD.

EMPLOYEE (**Employee_ID, Skill_ID**, Emp_F_Name, Emp_L_Name, Emp_Date_Employed, Emp_DOB, Company_ID, Com_Name, Skill_Title, Skill_Type, Date_Completed)

FDs:

Employee_ID --> Emp_F_Name, Emp_L_Name, Emp_Date_Employed, Emp_DOB, Company_ID, Com_Name

Skill_ID --> Skill_Title, Skill_Type

Company_ID --> Com_Name

Employee_ID, Skill_ID --> Date_Completed

EMPLOYEE (**Employee_ID**, Emp_F_Name, Emp_L_Name, Emp_Date_Employed, Emp_DOB, Company_ID, Com_Name)

EMPLOYEE (**Employee_ID**, Emp_F_Name, Emp_L_Name, Emp_Date_Employed, Emp_DOB, Company_ID*)

FK (Company_ID) references COMPANY

COMPANY (**Company_ID**, Com_Name)

Class Activity 5.5: For the relation below:

a) Find transitive functional dependencies, and

b) Explain if we need to check for transitive functional dependencies in every relation.

C) Remove transitive functional dependencies from the EMPLOYEE relation and provide new relations and the revised ERD.

EMPLOYEE (**Employee_ID**, Emp_F_Name, Emp_L_Name, Emp_Date_Employed, Emp_DOB, Company_ID*)

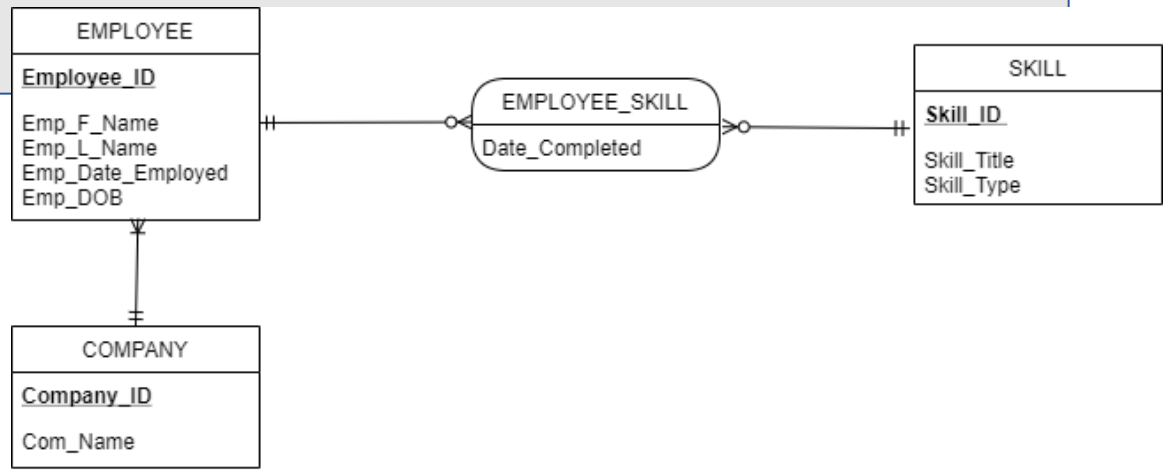
FK (Company_ID) references COMPANY

COMPANY (**Company_ID**, Com_Name)

SKILL (**Skill_ID**, Skill_Title, Skill_Type)

EMPLOYEE_SKILL (**Employee_ID*, Skill_ID***, Date_Completed)

FK (Employee_ID) references EMPLOYEE
FK (Skill_ID) references SKILL



Summary

- State two properties of candidate keys
- Determining keys from FDs
- Define first, second, and third normal form
- Use normalization to decompose anomalous relations to well-structured relations

Next Lecture…

1. **Review of 1NF, 2NF and 3NF.**
2. **Boyce Codd Normal Form (BCNF) → Optional**
   - 1.1. BCNF Example 1
   - 1.2. BCNF Example 2
3. **Creating New Relations in a Higher Normal Form → Optional**
4. **Role of Normalization → Optional**
5. **Advantages of Refinement (Top-Down) Approach → Optional**
6. **Tutorial 6 – Section one**