COMM1822

Term 2 2022

Introduction to Databases for Business Analytics

Week 4 Normalisation Part 1

Lecturer-in-Charge: Kam-Fung (Henry) Cheung
Email: kf.cheung@unsw.edu.au
Tutors: Theresa Tran
Liam Li Chen
Kathy Xu
PASS Leader: Srilekha Chandrashekara Kolaki

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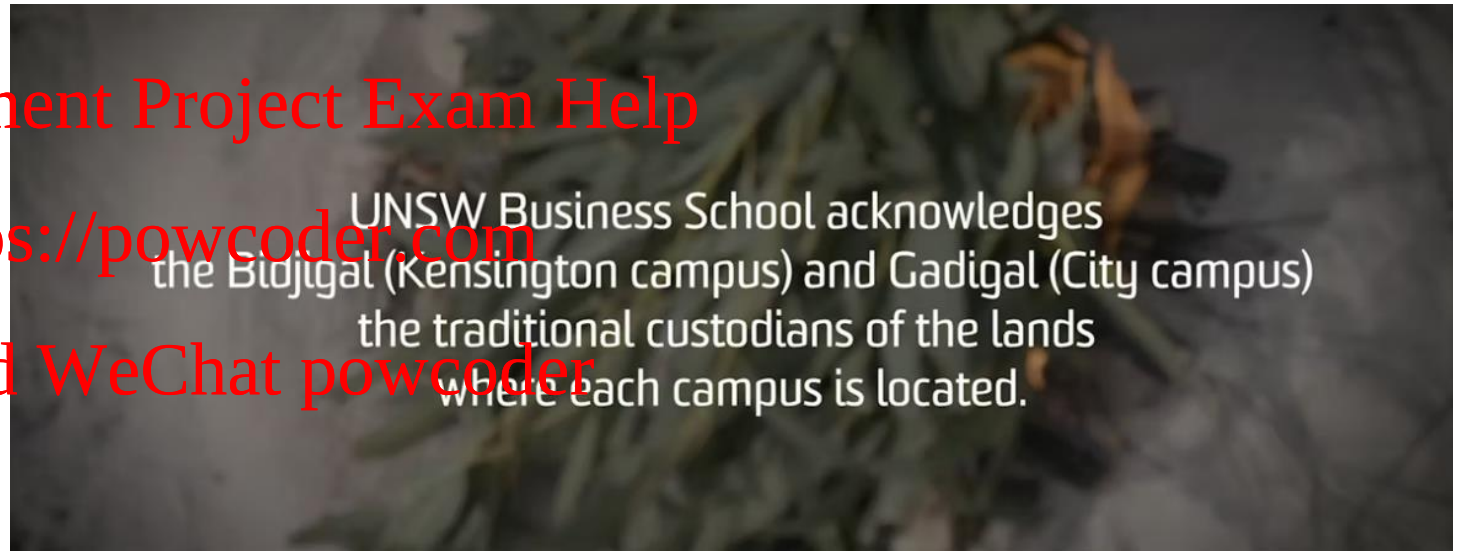

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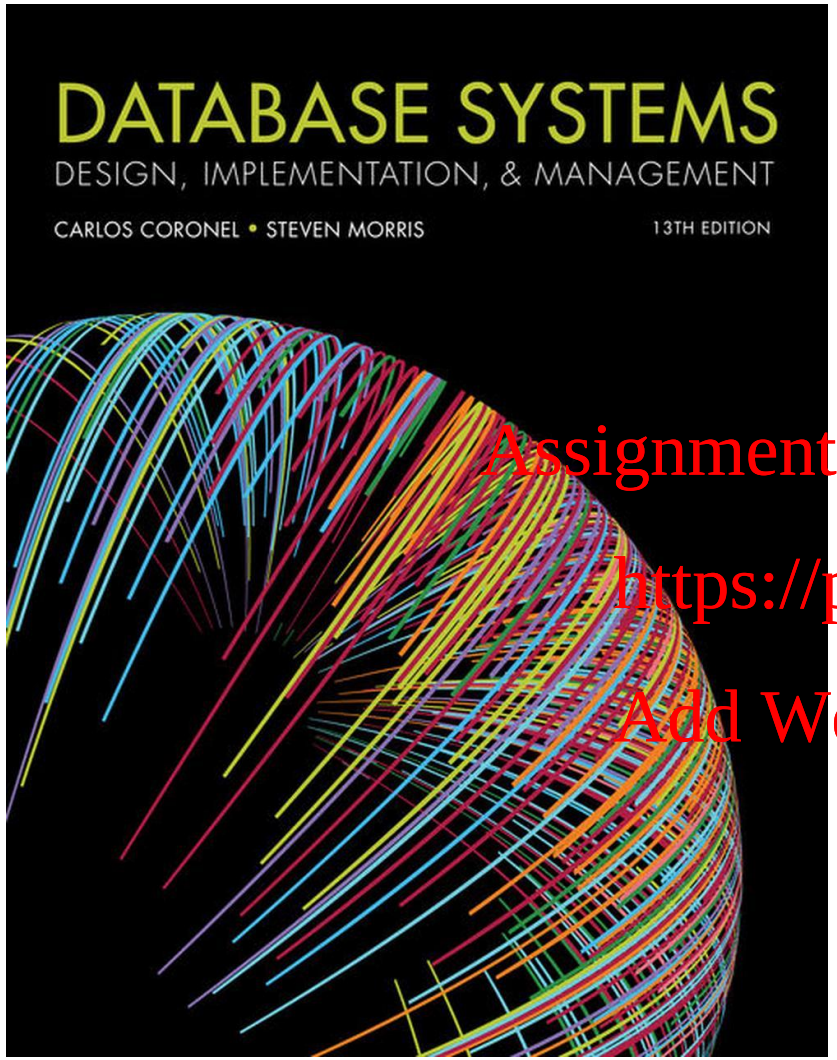

Chapter 6
Normalisation of Database Tables

6-1 to 6-8

Plan: W4 Learnings

- **Normalisation** (or Normali**z**ation)
- **Functional Dependencies**
- **Normal Forms**
  - 1NF
  - 2NF
  - 3NF
  - BCNF
- **Denormalisation**

Conceptual Modelling and Logical Modelling

- A **conceptual data model** (e.g., ER model) represents the **conceptual view** of organisational data.
- A **logical data model** (e.g., relational model) describes the organisational data in a way to be used for **implementation** in a DBMS. (the logical model is still independent of any particular DBMS)
- So far,
  - We have learned how to develop ER models (conceptual).
  - We have learned how to convert ER models to relational schema (logical).
- **The question remains: How good are the attributes in the relational schema?**

The Needs and Outcomes of Normalisation

- **<u>Need</u> the process of normalisation is when you need to design a new database structure**
  - Analyse the relationship among the attributes within each entity
  - Determine if the structure can be improved
- **Improve the existing data structure and create an appropriate database design**

- **The <u>outcome</u> of normalisation will result in a well-structured relation.**

  A well-structured relation is:
  - a relation that contains minimal data redundancy and
  - allows users to insert, delete, and update rows without causing data inconsistencies and anomalies, i.e., reduce data anomalies.

Normalisation (1)

- **Normalisation** is a process for evaluating and correcting table structures to **minimise data redundancies**, thereby **reducing the likelihood of data anomalies**.
- **Normalisation** is …
  - a process for converting a relation to a **standard (normal) form**.
  - a **process** that is accomplished in **stages**.
  - a technique that is used to **define "goodness"** (or "badness") of a relation.
  - to minimise or **eliminate redundancy** (duplication of data).
  - to **prevent data inconsistencies** from update, deletion, and insertion **anomalies**.
  - to decompose a relation/table into **smaller components.**
  - to **recapture the precise content** of the original relation/table.
  - to build data structures that have some **desirable** ("good") **properties**.
  - Based on paper: **Codd (1971).**

Normalisation (2)

Table name: STUDENT

zID	…	Sec_Email

Table name: COURSE_ENROL

zID	CourseID	…	Sec_Email

Redundancy

- **Redundancy** occurs when data about a **one entity is recorded more than once** in a database.
- Database designers aim to **reduce redundancy** (i.e., database should not store same data several times) to save space and prevent problems.
- Evaluating and correcting table structures to minimise data redundancies.

If **data redundancy exists**, then **there will be anomalies**.

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

Normalisation (3)

A Normal Form…

- …is a certain **state** of a **relation**.
- …can be determined by applying **rules regarding dependencies**.
- …uses a concept called **functional dependency**…

Normal forms

- First normal form (1NF)
- Second normal form (2NF)
- Third normal form (3NF)
- Boyce-Codd normal form (BCNF)
- [Fourth normal form (4NF)]

Why denormalisation?

To improve greater performance with greater data redundancy. (More will be covered in Big Data)

Normal Forms

Table 6.2: Normal Forms		
Normal Form	**Characteristic**	**Section**
First normal form (1NF)	Table format, no repeating groups, and PK identified	6-3a
Second normal form (2NF)	1NF and no partial dependencies	6-3b
Third normal form (3NF)	2NF and no transitive dependencies	6-3c
Boyce-Codd normal form (BCNF)	Every determinant is a candidate key (special case of 3NF)	6-6a
Fourth normal form (4NF)	3NF and no independent multivalued dependencies	6-6b

Our focus

Functional Dependency

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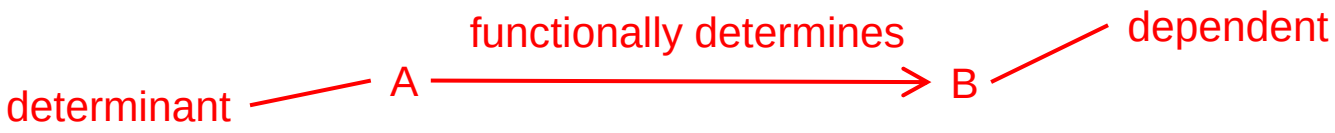
Functional Dependency (FD)

Functional Dependencies …

- …are **relationships between attributes** in a relation.
- …are the **semantics of the attributes** in a relation.
- …**can be inferred in a systematic way** by applying a set of **inference rules** (next slides).

Table 6.3: Functional Dependence Concepts	
Concept	**Definition**
Functional dependence	The attribute B is fully functionally dependent on the attribute A if each value of A determines one and only one value of B. Example: PROJ_NUM S PROJ_NAME (read as PROJ_NUM functionally determines PROJ_NAME) In this case, the attribute PROJ_NUM is known as the determinant attribute, and the attribute PROJ_NAME is known as the dependent attribute.
Functional dependence (generalised definition)	Attribute A determines attribute B (that is, B is functionally dependent on A) if all (generalised definition) of the rows in the table that agree in value for attribute A also agree in value for attribute B.
Fully functional dependence (composite key)	If attribute B is functionally dependent on a composite key A but not on any subset of that composite key, the attribute B is fully functionally dependent on A.



Postcode → *State*; e.g., “2052” → “NSW”, but not “2052” → ”VIC”

Functional Dependence & Normalisation

Two types of functional dependencies:

- A **partial dependency** exists when there is a functional dependence in which **the determinant is only part of the primary key.**
  - For example, if $\{A, B\} \rightarrow \{C, D\}$, $B \rightarrow C$, and $\{A, B\}$ is the primary key, then the functional dependence $B \rightarrow C$ is a partial dependency because only part of the primary key B is needed to determine the value of C. Partial dependencies tend to be straightforward and easy to identify.
- A **transitive dependency** exists when there are functional dependencies such that $X \rightarrow Y$, $Y \rightarrow Z$, and X is the primary key. In that case, the dependency $X \rightarrow Z$ is a transitive dependency because X determines the value of Z via Y.
  - Unlike partial dependencies, transitive dependencies are more difficult to identify among a set of data.
  - Fortunately, there is an effective way to identify transitive dependencies: they occur only when a functional dependence exists among nonprime attributes.

nonkey to nonkey

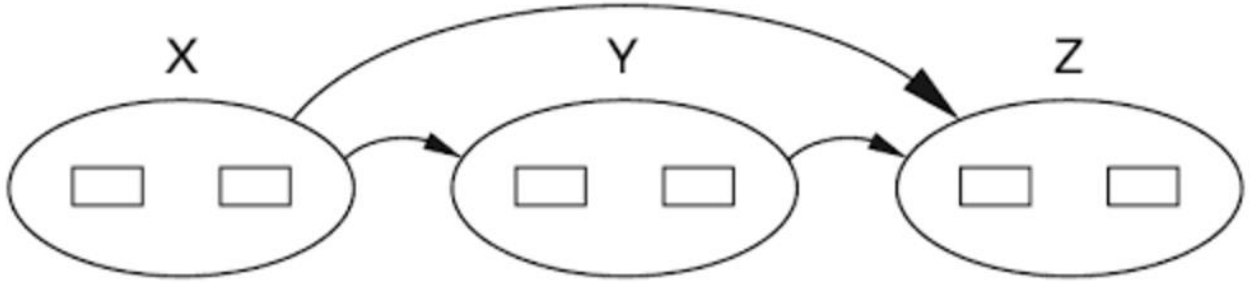
Transitivity and Transitive Dependency

If $X \rightarrow Y$ and $Y \rightarrow Z$, then $X \rightarrow Z$

Example

If zID → MobileNumber and MobileNumber → Name, then zID → Name

z1234567 → 0466 772 123 and 0466 772 123 → Kaiser, then z1234567 → Kaiser



Normalisation and Normal Forms

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Normalisation Process

- Objective is to ensure that each table conforms to the concept of well-formed relations
  - Each table represents a single subject
  - No data item will be unnecessarily stored in more than one table
  - All **nonprime** attributes in a table are dependent on the primary key
  - Each table is void of insertion, update, and deletion **anomalies**
- Ensures that all tables are in at least 3NF (rule of thumb)
- Works one relation at a time
- Starts by:
  - Identifying the dependencies of a relation (table)
  - Progressively breaking the relation into new set of relations/tables

Lossless Decomposition and Normal Forms

- Our aim is to **decompose** relations/tables so to **reduce size/redundancy**.

- We use **inferences rules** for this decomposition **process**.

- We need to be sure that the decomposed components (tables/relations) have the **lossless** join property (i.e., decomposed components could be joined back together to the original table/relation).

Decomposition Example

Which of the two decompositions of SUPPLIER relation is better? (i.e., which one could be joined back together to the original relation?)

SUPPLIER

SUP_ID	STATUS	CITY
S3	30	Paris
S5	30	Zurich

Relational Schema

SUPPLIER (SUP_ID, STATUS, CITY)

Option 1

S1

SUP_ID	STATUS
S3	30
S5	30

S2

STATUS	CITY
30	Paris
30	Zurich

Option 2

S1

SUP_ID	STATUS
S3	30
S5	30

S3

SUP_ID	CITY
S3	Paris
S5	Zurich

Construction Company Example

Scenario: database for reports for a **construction company.**

- Building project has: Project number, Name, Employees assigned to the project.
- Employee has: Employee number, Name, Job classification.
- The company charges its clients by billing the hours spent on each project.
- The hourly billing rate is dependent on the employee's position.

The following slide shows a table with contents correspond to the reporting requirements but is not "normalised".

TABLE 6.1

A SAMPLE REPORT LAYOUT

PROJECT NUMBER	PROJECT NAME	EMPLOYEE NUMBER	EMPLOYEE NAME	JOB CLASS	CHARGE/ HOUR	HOURS BILLED	TOTAL CHARGE
15	Evergreen	103	June E. Arbough	Elec. Engineer	$ 84.50	23.8	$ 2,011.10
		101	John G. News	Database Designer	$105.00	19.4	$ 2,037.00
		105	Alice K. Johnson *	Database Designer	$105.00	35.7	$ 3,748.50
		106	William Smithfield	Programmer	$ 35.75	12.6	$ 450.45
		102	David H. Senior	Systems Analyst	$ 96.75	23.8	$ 2,302.65
				Subtotal			**$10,549.70**
18	Amber Wave	114	Annelise Jones	Applications Designer	$ 48.10	24.6	$ 1,183.26
		118	James J. Frommer	General Support	$ 18.36	45.3	$ 831.71
		104	Anne K. Ramoras *	Systems Analyst	$ 96.75	32.4	$ 3,134.70
		112	Darlene M. Smithson	DSS Analyst	$ 45.95	44.0	$ 2,021.80
				Subtotal			**$ 7,171.47**
22	Rolling Tide	105	Alice K. Johnson	Database Designer	$105.00	64.7	$ 6,793.50
		104	Anne K. Ramoras *	Systems Analyst	$96.75	48.4	$ 4,682.70
		113	Delbert K. Joenbrood *	Applications Designer	$48.10	23.6	$ 1,135.16
		111	Geoff B. Wabash	Clerical Support	$26.87	22.0	$ 591.14
		106	William Smithfield	Programmer	$35.75	12.8	$ 457.60
				Subtotal			**$13,660.10**
25	Starflight	107	Maria D. Alonzo	Programmer	$ 35.75	24.6	$ 879.45
		115	Travis B. Bawangi	Systems Analyst	$ 96.75	45.8	$ 4,431.15
		101	John G. News *	Database Designer	$105.00	56.3	$ 5,911.50
		114	Annelise Jones	Applications Designer	$ 48.10	33.1	$ 1,592.11
		108	Ralph B. Washington	Systems Analyst	$ 96.75	23.6	$ 2,283.30
		118	James J. Frommer	General Support	$ 18.36	30.5	$ 559.98
		112	Darlene M. Smithson	DSS Analyst	$ 45.95	41.4	$ 1,902.33
				Subtotal			**$17,559.82**
				Total			**$48,941.09**

Note: * indicates the project leader.

Example: Table Problems

- The project number is intended to be (part of) a **PK**, but it **contains NULLs**.
- The table **has data redundancies**.
- The table entries **invite data inconsistencies** and **anomalies** (addition, deletion, update anomalies).

1NF

Conversion to First Normal Form (1NF)

- **Aim**: creating a valid relation.

- A relation / table is in **1NF** if:

  - The key attributes are defined, i.e., PK attributes are defined and not NULL (i.e., **a valid PK**).
  - All attributes are dependent on the primary key
  - There are no repeating groups in the table
  - All attributes contain only atomic values (i.e., **no multivalued attributes**).

- Action to create/check 1NF:
  - Step 1: Cleaning & dealing with Repeating Groups and Multi-valued Attributes
  - Step 2: Identify the Primary Key
  - Step 3: Identify All Partial Dependencies

Steps to Follow for 1NF

- **Step 1: Cleaning & dealing with Repeating Groups and Multi-valued Attributes**
  - **Split multivalued attributes** and **split repeating groups of data** (i.e., transform multivalued attributes in additional columns, or, better, additional rows)
  - Add the **appropriate entry** in at least for the **primary keys column(s).**

- **Step 2: Identify the Primary Key**
  - All attributes are dependent on PROJ_NUM + EMP_NUM

- **Step 3: Identify All Dependencies**
  - Draw Dependency Diagram
  - Partial dependency: attributes are dependent on only a part of a composite PK
  - Transitive dependency: non-key (nonprime) attributes are dependent on another non-key attribute

TABLE 6.1

A SAMPLE REPORT LAYOUT

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		112	Darlene M. Smithson	DSS Analyst	$ 45.95	41.4	$ 1,902.33
				Subtotal			**$17,559.82**
				Total			**$48,941.09**

Note: * indicates the project leader.

So, which are the PK and dependencies?

Examine the Similarities and Differences of the Data

ALL_IN_ONE
(PROJ_NUM,
PROJ_NAME,
EMP_NUM,
EMP_NAME,
JOB_CLASS,
CHG_HOUR,
HOURS)

PROJ_NUM	PROJ_NAME	EMP_NUM	EMP_NAME	JOB_CLASS	CHG_HOUR	HOURS
15	Evergreen	103	June E. Arbough	Elect. Engineer	$84.50	23.8
15	Evergreen	101	John G. News	Database Designer	$105.00	19.4
15	Evergreen	105	Alice K. Johnson *	Database Designer	$105.00	35.7
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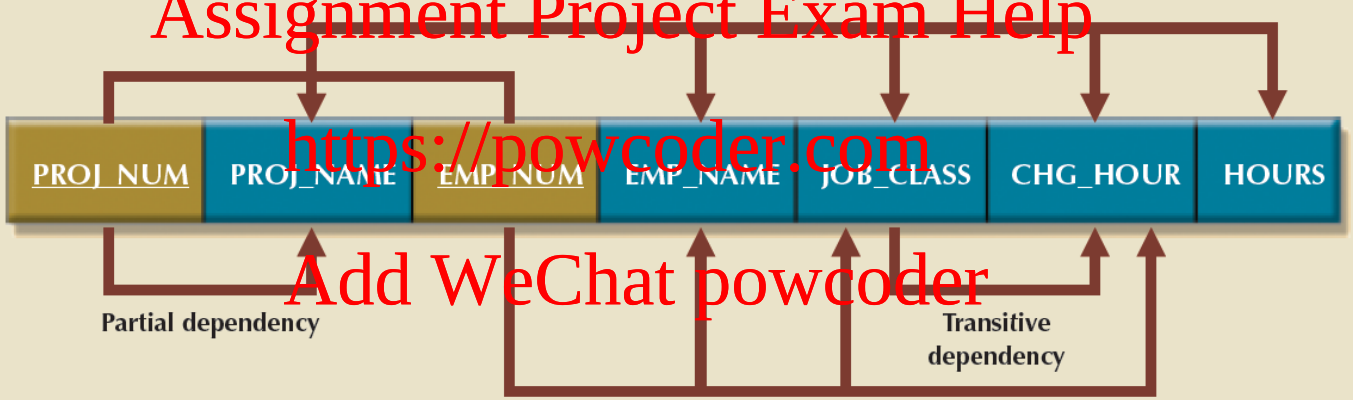
25	Starflight	101	John G. News *	Database Designer	$105.00	56.3
25	Starflight	114	Annelise Jones	Applications Designer	$48.10	33.1
25	Starflight	108	Ralph B. Washington	Systems Analyst	$96.75	23.9
25	Starflight	118	James J. Frommer	General Support	$18.36	30.2
25	Starflight	112	Darlene M. Smithson	DSS Analyst	$45.95	41.4

First Normal Form (1NF) Dependency Diagram

Partial dependency: attributes are dependent on only a part of a composite PK
Transitive dependency: non-key (nonprime) attributes are dependent on another non-key attribute

FIGURE 6.3 FIRST NORMAL FORM (1NF) DEPENDENCY DIAGRAM



Primary Key

1NF (PROJ_NUM, EMP_NUM, PROJ_NAME, EMP_NAME, JOB_CLASS, CHG_HOURS, HOURS)

PARTIAL DEPENDENCIES:
(PROJ_NUM → PROJ_NAME)
(EMP_NUM → EMP_NAME, JOB_CLASS, CHG_HOUR)

TRANSITIVE DEPENDENCY:
(JOB_CLASS → CHG_HOUR)

Please note the notation

All attributes depend on the primary key.

30

2NF

Conversion to Second Normal Form (2NF)

- **Aim**: remove **partial dependencies** (no repeating values in non-key fields).

- A relation / table is in **2NF** if:
  - No partial dependencies (Each non-key field is functionally dependent on the entire PK).
  - The relation/table must be in 1NF.

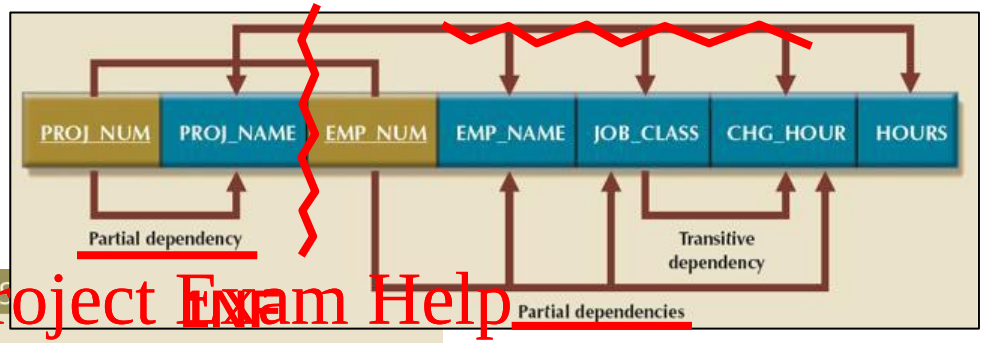
Hint: Look for values that occur multiple times in *non-key fields*. This tells you that you have to many fields in a single table. *In a well-designed database, the only data that is duplicated is in key fields used to connect tables.*

- Action to create/check **2NF**:
  - Step 1: **Analyse FDs, especially partial dependencies, and assign corresponding dependent attributes.**
  - Step 2: Make new tables by eliminating **partial dependencies** (attributes not functionally dependent on the entire primary key) by separating the data items into a separate relation using appropriate PKs (may need bridge/junction table).

Steps to Follow for 2NF

Step 1: Identify all key FDs components, especially partial dependency before breaking into smaller tables.

Step 2: Eliminate partial dependency



2NF

FIGURE 6.4 SECOND NORMAL FORM (2NF) CONVERSION RESULTS

Table name: PROJECT

PROJECT (PROJ_NUM, PROJ_NAME)

PROJ_NUM | PROJ_NAME

Table name: EMPLOYEE

EMPLOYEE (EMP_NUM, EMP_NAME, JOB_CLASS, CHG_HOUR)

TRANSITIVE DEPENDENCY
(JOB_CLASS → CHG_HOUR)

EMP_NUM | EMP_NAME | JOB_CLASS | CHG_HOUR

Transitive dependency

Table name: ASSIGNMENT

ASSIGNMENT (PROJ_NUM, EMP_NUM, ASSIGN_HOURS)

PROJ_NUM | EMP_NUM | ASSIGN_HOURS

HOURS

3NF

Conversion to Third Normal Form (3NF)

❑ **Aim**: **remove non-key dependencies**, data that is not dependent on other keys.

❑ A relation / table is in 3**NF** if:

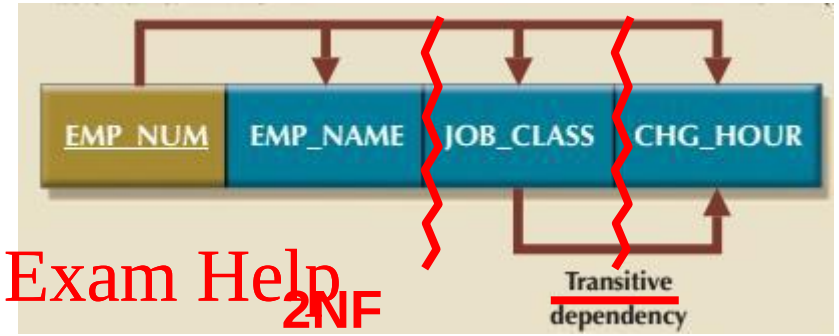
- It has **no transitive dependencies** (no non-key attributes determined by other non-candidate-key attributes).
- The relation/table must be in 2NF

❑ Action to create/check **3NF**:

- Step 1: **Analyse FDs, especially transitive dependencies, and reassign corresponding dependent attributes**
- Step 2: Make new tables to eliminate all **transitive dependencies**
  - **Determinant**: Any attribute whose value determines other values within a row

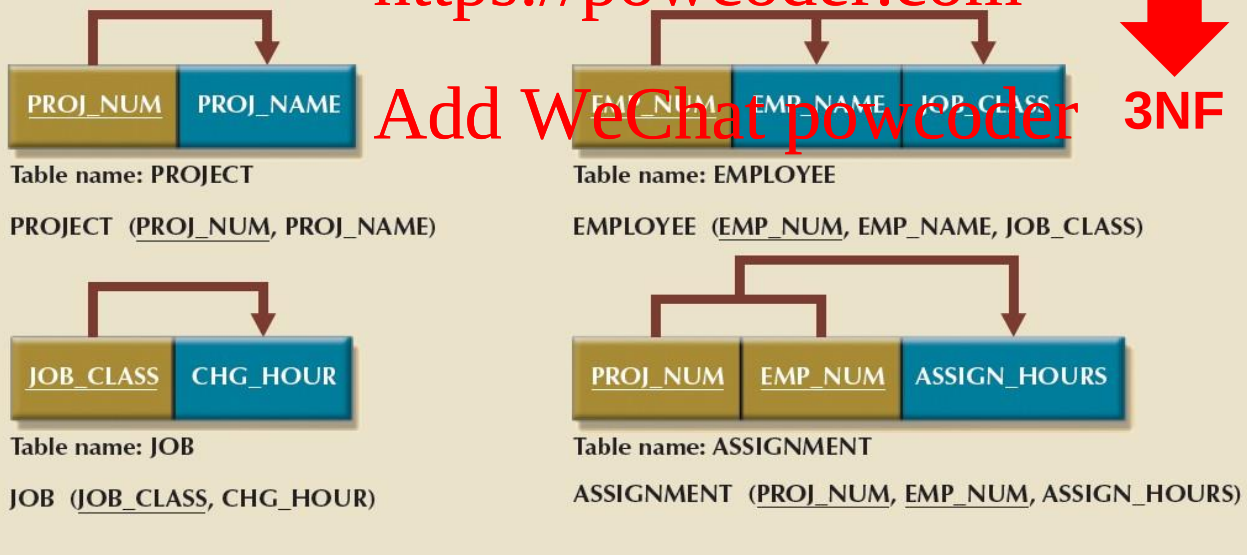
Steps to Follow for 3NF

Step 1: Analyse FDs, especially transitive dependencies (from 2NF)



Step 2: Remove transitive dependency.

FIGURE 6.5 THIRD NORMAL FORM (3NF) CONVERSION RESULTS



BCNF

Boyce-Codd Normal Form (BCNF)

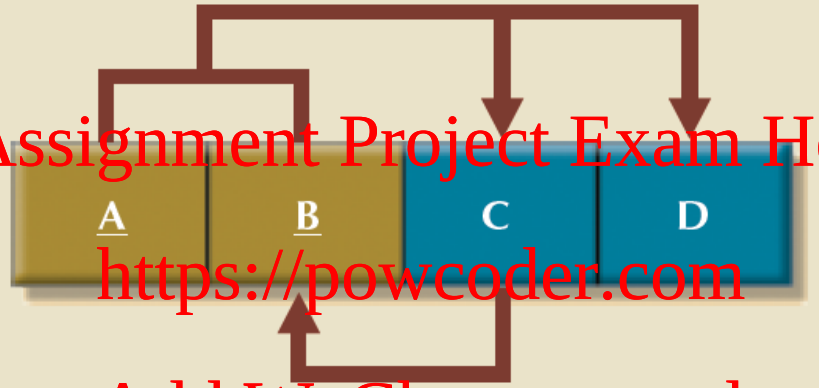
- **Aim: higher normal forms** such as BCNF do cover some specific aspects and problems with the 3NF
  - Based on paper **Codd (1974)**.
  - Sometimes called **3.5NF**
  - 3NF is always achievable, **BCNF is not always achievable (Beeri & Bernstein 1979)**.

- Candidate Key: Every determinant in the table should be a candidate key
  - Same characteristics as primary key but not chosen to be the primary key
  - Equivalent to 3NF when the table contains only one candidate key
  - Violated only when the table contains more than one candidate key
  - Considered to be a special case of 3NF

- A relation/table is in **BCNF** if, for every one of its dependencies X → Y, one of the following conditions holds true:
  - X → Y is a TRIVIAL FUNCTIONAL DEPENDENCY (i.e., Y is a subset of X)
  - X is a SUPERKEY

A Table That is in 3NF and NOT in BCNF

FIGURE 6.8 A TABLE THAT IS IN 3NF BUT NOT IN BCNF



A **partial dependency:** The determinant is only part of the primary key.

Transitive dependency: An attribute functionally depends on another nonkey attribute (i.e., nonkey to nonkey)

Why is $C \rightarrow B$ not partial or transitive?

Not partial! Because C is the determinant of B, and not part of PK.
Not transitive! Because it involves a PK, i.e., B.
Thus, in 3NF

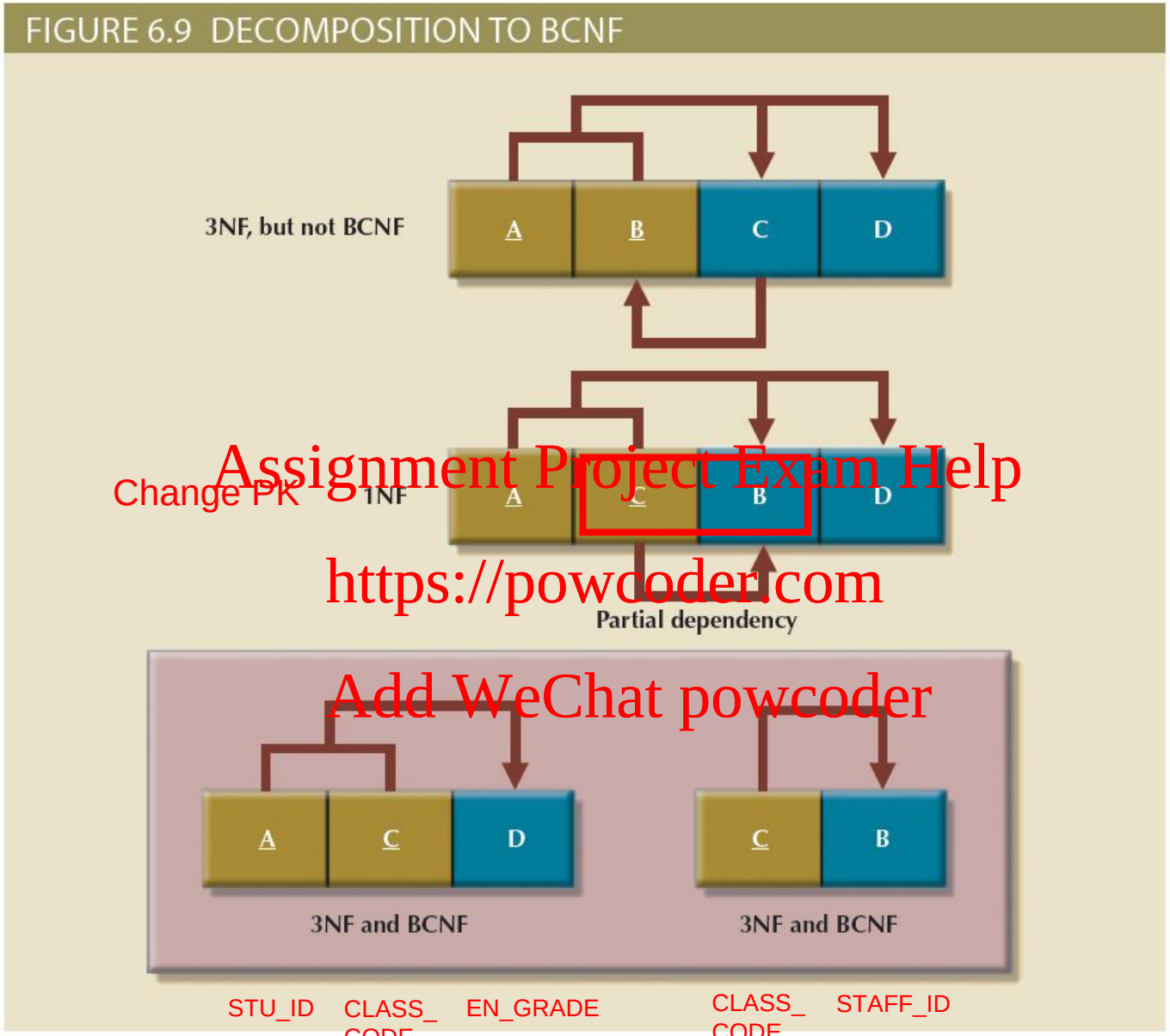
BCNF if, for every one of its dependencies $X \rightarrow Y$, one of the following conditions holds true:

- $X \rightarrow Y$ is a TRIVIAL functional dependency, i.e., Y is a subset of X
- X is a SUPERKEY

Why not in BCNF? (Hint: Look at $C \rightarrow B$)

- B is not part of C, i.e., B is NOT a subset of C
- C is not a superkey, as C CANNOT determines A or D on its own

A: STU_ID
B: STAFF_ID
C: CLASS_CODE
D: EN_GRADE



Normalisation and Database Design

- Normalisation should be part of the design process
- Proposed entities must meet the required normal form before table structures are created
- Principles and normalisation procedures to be understood to redesign and modify databases
  - ERD is created through an iterative process
  - Normalisation focuses on the characteristics of specific entities

Denormalisation

UNSW SYDNEY

Denormalisation

Data is redundant but access will be much faster – this is in big data!

- Design goals
  - Creation of normalized relations
  - Processing requirements and speed
- Number of database tables expands when tables are decomposed to conform to normalisation requirements
  - Joining a larger number of tables:
    - Takes additional input/output (I/O) operations and processing logic
    - Reduces system speed
- Defects in unnormalized tables
  - **Data updates are less efficient because tables are larger**
  - Indexing is more cumbersome
  - No simple strategies for creating virtual tables known as views (will be covered later)

Common Denormalisation Examples

TABLE 6.6

COMMON DENORMALIZATION EXAMPLES

CASE	EXAMPLE	RATIONALE AND CONTROLS
Redundant data (ZIP, CITY)	Storing ZIP and CITY attributes in the AGENT table when ZIP determines CITY (see Figure 2.2)	Avoid extra join operations Program can validate city (drop-down box) based on the zip code
Derived data (Course, Credit)	Storing STU_HRS and STU_CLASS (student classification) when STU_HRS determines STU_CLASS (see Figure 3.28)	Avoid extra join operations Program can validate classification (lookup) based on the student hours
Preaggregated data (also derived data) storing WAM	Storing the student grade point average (STU_GPA) aggregate value in the STUDENT table when this can be calculated from the ENROLL and COURSE tables (see Figure 3.28)	Avoid extra join operations Program computes the GPA every time a grade is entered or updated STU_GPA can be updated only via administrative routine
Information requirements	Using a temporary denormalized table to hold report data; this is required when creating a tabular report in which the columns represent data that are stored in the table as rows (see Figures 6.17 and 6.18)	Impossible to generate the data required by the report using plain SQL No need to maintain table Temporary table is deleted once report is done Processing speed is not an issue

Summary

- **Normalisation** is a **table design technique** aimed at minimising data redundancies.
- First three normal forms (**1NF, 2NF**, and **3NF**) are most commonly used.
- Normalisation is an important part—but **only a part**—of the design process.
- Best practice: continue the iterative ER process until all entities and their attributes are defined and all equivalent **tables are in 3NF**.

W4 Learnings

- **Normalisation** (or Normalization)
- **Functional Dependencies**
- **Normal Forms**
  - 1NF
  - 2NF
  - 3NF
  - BCNF
- **Denormalisation**

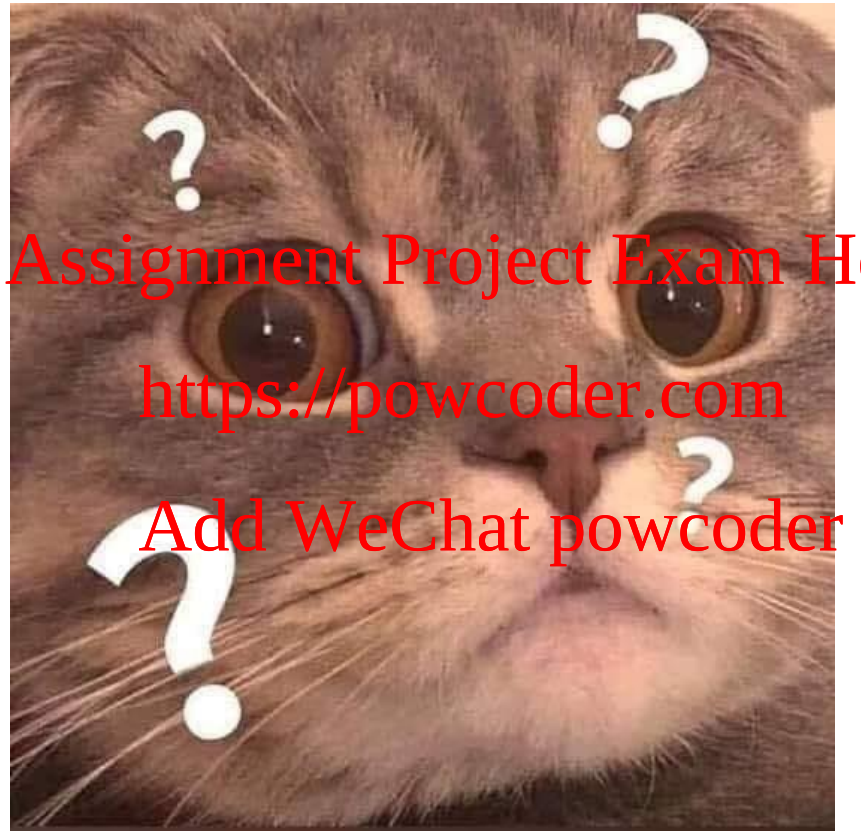
Reference (Harvard)

Beeri, C. & Bernstein, P.A., 1979. 'Computational problems related to the design of normal form relational schemas', *ACM Transactions on Database Systems (TODS)*, vol. 4, no. 1, pp.30-59.

Codd, E.F., 1971. 'Normalized data base structure: A brief tutorial', In *Proceedings of the 1971 ACM SIGFIDET (now SIGMOD) Workshop on Data Description, Access and Control* (pp. 1-17).

Codd, E.F., 1974. 'Recent investigations into relational data base', *Information Processing 74*, pp.1017-1021.

Questions



Source: keepmeme.com

Take-Home Exercise

A librarian has created the above table in an effort to create a “database”. However, there are several issues with the design.

1. Argue what potential problems there are with the table design.
2. Identify the PK(s) and draw the dependencies diagrams.
3. Normalise the relational model the 3NF.
4. Draw the ER diagram based on the 3NF.

Memb ID	Memb Name	Call No	Copy ID	Book Title	Book Author	Author ID	Date Borrow	Date Return
24	A. Hope	SQ231.215	4	Jack Sprat's Hat – was it for real?	JK Spratt	A1	1/2/04	17/3/04
42	B. Marcy	S14.143	1C	Knowing what you know and knowing what to do with it.	K Nowles	A4	2/2/99	12/2/99
		AV127.143	5	Life and Times of the Iguana	IG Uana	A7	2/2/99	12/2/99
		S14.143	3C	Knowing what you know and knowing what to do with it.	K Nowles	A4	1/5/03	
24	C. Sam	PJ234.234	4	The Tech Heads guide to Technology	IM Smart	A9	3/4/99	
		S14.143	1C	Knowing what you know and knowing what to do with it.	K Nowles	A4	3/4/99	
56	E. Bronwyn	SQ231.215	2	Jack Sprat's Hat – was it for real?	JK Spratt	A1	3/3/99	5/3/04
67	F. Mac	AV127.143	5	Life and Times of the Iguana	IG Uana	A7	4/4/99	