INTRODUCTION TO SCHEMA REFINEMENT

The Schema Refinement refers to refine the schema by using some technique. The best technique of schema refinement is **decomposition.**

Normalization means "split the tables into small tables which will contain less number of attributes in such a way that table design must not contain any problem of inserting, deleting, updating anomalies and guarantees no redundancy".

Normalization or Schema Refinement is a technique of organizing the data in the database. It is a systematic approach of decomposing tables to eliminate data *redundancy* and undesirable characteristics like Insertion, Update and Deletion Anomalies.

Redundancy: refers to repetition of same data or duplicate copies of same data stored in different locations.

Anomalies: Anomalies refers to the problems occurred after poorly planned and normalized databases where all the data is stored in one table which is sometimes called a flat file database.

Anomalies or problems facing without normalization (problems due to redundancy):

Anomalies refers to the problems occurred after poorly planned and unnormalized databases where all the data is stored in one table which is sometimes called a flat file database. Let us consider such type of schema

SID	Sname	CID	Cname	FEE
S1	A	C1	C	5k
S2	A	C1	C	5k
S1	A	C2	C	10k
S3	B	C2	C	10k
S3	B	C2	JAVA	15k
Primary Key(SID,CID)				

Here all the data is stored in a single table which causes redundancy of data or say anomalies as SID and Sname are repeated once for same CID . Let us discuss anomalies one by one.

Due to redundancy of data we may get the following problems, those are-

1. **insertion anomalies :** It may not be possible to store some information unless some other information is stored as well.
2. **redundant storage:** some information is stored repeatedly
3. **update anomalies:** If one copy of redundant data is updated, then inconsistency is created unless all redundant copies of data are updated.

4.**deletion anomalies:** It may not be possible to delete some information without losing some other information as well.

Problem in updation / updation anomaly – If there is updation in the fee from 5000 to 7000, then we have to update FEE column in all the rows, else data will become inconsistent.

SID	Sname	CID	Cname	FEE
S1	A	C1	C	~~5k~~
S2	A	C1	C	~~5k~~
S1	A	C2	C	10k
S3	B	C2	C	10k
S3	B	C2	JAVA	15k

7k > 7k Costly Operation

More IO Cost

Insertion Anomaly and Deletion Anomaly- These anomalies exist only due to redundancy, otherwise they do not exist.

Insertion Anomalies: New course is introduced C4, But no student is there who is having C4 subject.

SID	Sname	CID	Cname	FEE
S1	A	C1	C	5k
S2	A	C1	C	5k
S1	A	C2	C	10k
S3	B	C2	C	10k
S3	B	C2	JAVA	15k

NULL	NULL	CA	DB	12k

To Insert that Row, It is Required to Put Dummy Data..

Therefore,

xx	xx	CA	DB	12k

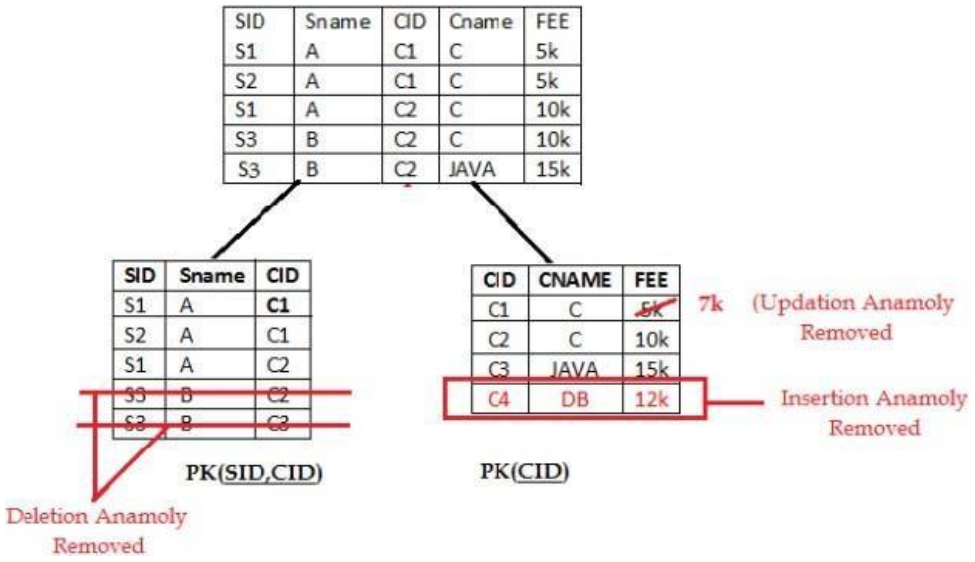
Because of insertion of some data, It is forced to insert some other dummy data.

Deletion Anomaly:

Deletion of S3 student cause the deletion of course. Because of deletion of some data forced to delete some other useful data.

SID	Sname	CID	Cname	FEE
S1	A	C1	C	5k
S2	A	C1	C	5k
S1	A	C2	C	10k
~~S3~~	~~B~~	~~C2~~	~~C~~	~~10k~~
~~S3~~	~~B~~	~~C2~~	~~JAVA~~	~~15k~~

Solutions To Anomalies : Decomposition of Tables – Schema Refinement, shown below.



Purpose of Normalization:

- Minimize the redundancy in data.
- Remove insert, update, and delete anomalies during the database activities.
- Reduce the need to organize the data when it is modified or enhanced.
- Normalization reduces a complex user view to a set of small and sub groups of fields or relations. This process helps to design a logical data model known as conceptual data model.

Advantages of Normalization:

1. Greater overall database organization will be gained.
2. The amount of unnecessary redundant data reduced.
3. Data integrity is easily maintained within the database.
4. The database & application design processes are much for flexible.
5. Security is easier to maintain or manage.

Disadvantages of Normalization:

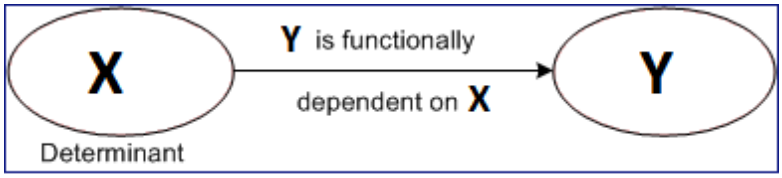
1. The disadvantage of normalization is that it produces a lot of tables with a relatively small number of columns. These columns then have to be joined using their primary/foreign key relationship.
2. This has two disadvantages.

Performance: all the joins required to merge data slow processing & place additional stress on your hardware.

Complex queries: developers have to code complex queries in order to merge data from different tables.

Concept of Functional Dependency:

Functional Dependencies are fundamental to the process of Normalization i.e., Functional Dependency plays key role in differentiating good database design from bad database designs. A functional dependency is a "**type of constraint that is a generalization of the notation of the key**".
Functional Dependency describes the **relationship between attributes (columns) in a table**.
Functional dependency is represented by an arrow sign **(→)**.
In other words, a dependency FD: "**X → Y"** means that the values of Y are determined by the values of X. Two tuples sharing the same values of X will necessarily have the same values of Y. An attribute on left hand side is known as "Determinant". Here X is a Determinant.



Functional dependency between X and Y

Example [Identifying the FD's]

A	B	C	D
A1	B1	C1	D1
A1	B2	C1	D2
A2	B2	C2	D2
A2	B2	C2	D3
A3	B3	C2	D4

Case1: A →B
Here A1 belongs to **B1 & B2.** So **A1** does not have unique value in **B**. So it is not in FD.
Case1: A →C
Here **A1→C1 and A2, A3→C2.** So **A** has unique values in **B**. So it is in FD.
Note: try to find all the possibilities. i.e., **A→D, B→C, B→D, and C→D**

Reasoning about functional dependencies:

Armstrong Axioms (Inference Rules) : The term Armstrong axioms refers to the sound and complete set of inference rules or axioms, introduced by William W. Armstrong, that is used to test logical implication of **functional dependencies**.

Armstrong axioms define the set of rules for reasoning about functional dependencies and also to infer all the functional dependencies on a relational database.

Various axioms rules or inference rules:

Primary axioms:

Rule 1	**Reflexivity** If A is a set of attributes and B is a subset of A, then A holds B. { A → B }
Rule 2	**Augmentation** If A hold B and C is a set of attributes, then AC holds BC. {AC → BC} It means that attribute in dependencies does not change the basic dependencies.
Rule 3	**Transitivity** If A holds B and B holds C, then A holds C. If {A → B} and {B → C}, then {A → C} A holds B {A → B} means that A functionally determines B.

Secondary or derived axioms:

Rule 1	**Union** If A holds B and A holds C, then A holds BC. If{A → B} and {A → C}, then {A → BC}
Rule 2	**Decomposition** If A holds BC and A holds B, then A holds C. If{A → BC} and {A → B}, then {A → C}
Rule 3	**Pseudo Transitivity** If A holds B and BC holds D, then AC holds D. If{A → B} and {BC → D}, then {AC → D}

Closure of a Set of Attributes:

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

The set of FD's that is logically implied by F is called the closure of F and written as F^+. And it is defined as "If F is a set FD's on a relation R, the F^+, the closure of F by using the inferences axioms that are not contained in F^+.

Example: R (A, B, C, D) and set of Functional Dependencies are **A→B, B→D, C→B** then what is the Closure of A, B, C, D?

Solution: A^+ is

A^+→ {A, B, D} i.e., A→B, B→D is exists and C is not FD on A. So it is eliminated.

B^+→ { B, D} i.e., B→D is exists and A, C is not FD on A. So it is eliminated.

C^+→ {C, B, D} i.e., C→B, B→D is exists and A is not FD on C. So it is eliminated.

The algorithm for computing the attribute closure of a set X of attributes is shown below

$closure = X;$
repeat until there is no change: {
    if there is an FD $U \rightarrow V$ in F such that $U \subseteq closure$,
        then set $closure = closure \cup V$
}

Types of functional dependencies:

1. **Fully Functional Dependency**: A functional dependency is said to be full dependency "if and only if the determinant of the functional dependency if either candidate key or super key, and the dependent can be either prime or non-prime attribute".

   (OR)

   Let's take the functional dependency **X → Y (**i.e., X determines y). Here Y is said to be fully determinant, if it cannot determine any subset of X.
   Example: Consider the following determinant **ABC → D** i.e., ABC determines D but D is not determined by any subset of A/ BC/C/B/AB i.e., **BC→D, C→D, A→D** Functional dependencies are **not exists. So D is Fully Functional Dependent.**

2. **Partial Functional Dependency**: If a non-prime attribute of the relation is getting derived by only a part of the candidate key, then such dependency is known as Partial Dependency.

   (OR)

   In a relation having more than one key field, a subset of non key fields may depend on all key fields but another subset or a particular non-key field may depend on only one of the key fields. Such dependency is defined as **Partial Dependency**.
   Example: Consider the following determinants **AC→P, A→D, D→P. From these determinants P is not fully FD on AC**. Because, If we find **A+** (means A's Closure) **A→D, D→P** i.e., **A→P.** But we don't have any requirement of **C**. **C** attribute is removed completely. So **P** is Partially Dependent on **AC.**
   Under the following conditions a table cannot have partial F.D
   (1) If primary key consists a single attribute
   (2) If table consists only two attributes
   (3) If all the attributes in the table are part of the primary key

3. **Transitive Functional Dependency:** If a non-prime attribute of a relation is getting derived by either another non-prime attribute or the combination of the part of the candidate key along with non-prime attribute, then such dependency is defined as **Transitive dependency**. i.e., in a relation, there may be dependency among non-key fields. Such dependency is called Transitive Functional Dependency.
   Example: X→Y, and **Y→Z** then we can determine **X→Z holds.**
   Under the following Circumstances, a table cannot have transitive F.D
   (1) If table consists only two attributes
   (2) If all the attributes in the table are part of the primary key.

4. **Trivial Functional Dependency:** It is basically related to Reflexive rule. i.e., if X is a set of attributes, and Y is subset of X then **X→Y** holds.
   Example: ABC→BC is a Trivial Dependency.

5. **Multi-Valued Dependency:** Consider 3 fields X, Y, and Z in a relation. If for each value of X, there is a well-defined set of values Y and Well-defined set of values of Z and set of values of Y is independent of the set values of Z. This dependency is Multi-valued Dependency. **i.e., X →Y / Z.**

Prime and non-prime attributes

Attributes which are parts of any candidate key of relation are called as prime attribute, others are non-prime attributes.

Candidate Key:

Candidate Key is minimal set of attributes of a relation which can be used to identify a tuple uniquely.
Consider student table: student(**sno**, sname,sphone,age)
we can take **sno** as candidate key. we can have more than 1 candidate key in a table.
types of candidate keys:
1. simple(having only one attribute)
2. composite(having multiple attributes as candidate key)

Super Key:

Super Key is set of attributes of a relation which can be used to identify a tuple uniquely.

- Adding zero or more attributes to candidate key generates super key.
- A candidate key is a super key but vice versa is not true.

Consider student table: student(sno, sname,sphone,age)
we can take **sno**, (**sno, sname**) as super key

Operations performed functional dependencies (applications of closure set of attributes):

(1) To identify the additional F.D's.
(2) To identify the keys.
(3) To identify the equivalences of the F.D's
(4) To identify irreducible set (minimal set) of F.D's or canonical forms of F.D's or standard form of F.D's.

(1) To identify the additional F.D's :

To check any F.D's like A→B can be determined from F1 or not. Complete A^+ from F1 is A^+ includes B also then; A→B can be derived as a F.D in F1.

Examples:

1. **In a schema with attributes A,B,C,D and E the following set of attributes are given A→B, A→C, CD→E, B→D, E→A. Find CD→AC determines from the given FDs or not.**

Sol: Given FD is CD→AC find the closure set of CD.

$CD^+ = CDE$ ($\because CD \rightarrow E$)

$= CDEA$ ($\because E \rightarrow A$)

$= CDEAB$ ($\because A \rightarrow B$)

From the closure set the attributes AC are determined by CD so CD→ AC.

2. **Check D→A can be derived from the following FDs or not AB→C, BC→AD, D→E, CF→B.**

(2) Identification of key by using closure set as attributes:

A key attribute: An attribute that is capable of identifying all other attributes in a given table.

(i) **Primary key:** It is an unique value attribute in a table to enforce entity integrity and ti identify rows in the table uniquely.

(ii) **Composite Primary Key:** Sometimes single attribute is not sufficient to identify uniquely the rows in the table so, we combine 2 or more attributes to identify the rows uniquely.

(iii) **Candidate keys:** Sometimes 2 or more independent attribute or attributes can be used to identify the rows uniquely Eg :(vech no,veng no,purchase date) Either vehicle no or vehicle engine no can be used as a key attribute then they are called as candidate keys one of the candidate key can be elected as primary key.

Example 1: Find candidate keys for the relation R(ABCD) having following FD's AB→CD, C→A, D→A.

Sol: From the given FD's, the attribute B is key attribute because it is not in RHS of functional dependency.

$B^+ = B$ (not a candidate key, find the combinations of B)

$AB^+ = ABCD$ ($\because AB \rightarrow CD$)

$BC^+ = BCAD$ ($\because C \rightarrow A, AB \rightarrow CD$)

$BD^+ = BDA$ ($\because D \rightarrow A$)

$CD^+ = CDA$ ($\because D \rightarrow A$)

$AC^+ = AC$

$AD^+ = AD$

From the above attributes AB and BC determines all attributes.

AB, BC are candidate keys.

Example 2: Find candidate keys for the relation R(ABCDE) having following FD's A→BC, CD→E, B→D, E→A.

Sol: From the given FD's, no attribute is key attribute because all are in RHS of functional dependency. So check for all attributes of LHS.

A^+ = ABC (∵ A→ BC)
= ABCD (∵ B→ D)
= ABCDE (∵ CD→ E)

B^+ = BD (∵ B→ D)

E^+ = EA (∵ E→ A)
= EABC (∵ A→ BC)
= EABCD (∵ B→ D)

C^+ = C

D^+ = D

CD^+ = CDE (∵ CD→ E)
= CDEA (∵ E→ A)
= CDEAB (∵ A→ BC)

BC^+ = BCD (∵ B→ D)
= BCDE (∵ CD→ E)
= BCDEA (∵ E→ A)

From the above attributes A, E, CD and BC determines all attributes.

A, E, CD, BC are candidate keys.

Question 2: Given a relation R(ABCDEF) having FDs {AB → C, C → DE , E → F, C → B} Identify the prime attributes and non prime attributes.

Solution :
$(AB)^+$: {A B C D E F}
$(A)^+$: {A}
$(B)^+$: {B}
(AB) ⇒ (AC), $(AC)^+$: {ABCDEF}
$(C)^+$: {DECBF}
⇒ Candidate Keys {AB, AC}
⇒ Prime Attributes {A,B,C}
⇒ Non Prime Attributes {D,E,F}

Question 1 : Given a relation R(ABCDEF) having FDs {AB→C, C→D, D→E , F→B, E→F} Identify the prime attributes and non prime attributes .

Solution :
(AB)$^+$: {ABCDEF} ⇒ Super Key
(A)$^+$: {A} ⇒ Not Super Key
(B)$^+$: {B} ⇒ Not Super Key
Prime Attributes : {A,B}
(AB) → Candidate Key
↓ (as F → B)
(AF)$^+$: {AFBCDE}
(A)$^+$: {A} ⇒ Not Super key
(F)$^+$: {FB} ⇒ Not Super Key
(AF) → Candidate Key
↓
(AE)$^+$: {AEFBCD}
(A)$^+$: {A} ⇒ Not Super key
(E)$^+$: {EFB} ⇒ Not Super key
(AE) → Candidate Key
↓
(AD)$^+$: {ADEFBC}
(A)$^+$: {A} ⇒ Not Super key
(D)$^+$: {DEFB} ⇒ Not Super key
(AD) → Candidate Key
↓
(AC)$^+$: {ACDEFB}
(A)$^+$: {A} ⇒ Not Super Key
(C)$^+$: {DCEFB} ⇒ Not Super Key
⇒ Candidate Keys {AB, AF, AE, AD, AC}
⇒ Prime Attributes {A,B,C,D,E,F}
⇒ Non Prime Attributes {}

(3) To identify equivalence of F.D's :

Different database designers may define different F.D's sets from the same requirements. To evaluate whether they are equivalent if we are able to derive all F.D's in G from F and vice-versa.

Q1 Consider the following two sets of FDs

$$F = \{A \to C,\ AC \to D,\ E \to AD,\ E \to H\}$$

$$G = \{A \to CD,\ E \to AH\}$$

Find the equivalence of two sets of FDs.

Sol:

Step 1: Take set F and enclose all FD's in G that can be derived from F.

$A \rightarrow CD$

A^+ from F

$=A$

$=AC$ ($\because A \rightarrow C$)

$=ACD$ ($\because AC \rightarrow D$)

$\therefore A \rightarrow CD$ can be derived from F

$E \rightarrow AH$

E+ from F

$=E$

$=EAD$

$=EADH$

$\therefore E \rightarrow AH$ can be derived from F

Step 2: Take set G and enclose all F.D's in F that can be derived from G. $A \rightarrow C$

A+ from G

$=A$

$=ACD$

$A \rightarrow C$ can be derived from G

$E \rightarrow AD$

E^+ from G

$=E$

$=EAH$

$=EAHCD$

$E \rightarrow AH$ & $E \rightarrow AD$ can be derived from G

$\therefore$ G and F are equivalent.

Q2 Consider two sets of FDs on the attributes ABCDE

$$F = \{ B \rightarrow CD,\ AD \rightarrow E,\ B \rightarrow A \}$$

$$G = \{ B \rightarrow CDE,\ B \rightarrow ABC,\ AD \rightarrow E \}$$

Find whether they are equivalent or not

(4) To identify the irreducible form of FD's /canonical Form (minimal cover):

We try to minimize the functional dependency. The minimize FD should be equivalent to original FD,

Procedure to find minimal set:

Step 1: Have single attributes on the RHS for every FD.

Step 2: Evaluate all F.D's in step 1 for their necessity. If they are not necessary, remove them from the list.

Step 3: Evaluate the necessity of the LHS attributes in FD's obtained from step 2.If they are not necessary remove from FD.

Step 4: Apply the union rule for common to LHS attribute in the FD's obtained from step 3.Then we will get irreducible set.

Q1 Find the irreducible set from the following FDs

F=

$A \rightarrow B$
$C \rightarrow B$
$D \rightarrow ABC$
$AC \rightarrow D$

Sol:

Step 1:

(l) $A \rightarrow B$
(2) $C \rightarrow B$
(3) $D \rightarrow A$
(4) $D \rightarrow B$
(5) $D \rightarrow C$
(6) $AC \rightarrow D$

Step 2:

Remove 1 & compute A^+ from2, 3,4,5,6

$A^+=A$

∴We need 1

Remove 2 and compute 1, 3, 4, 5&6

$C^+=C$

∴We need 2.

Remove 3 and compute D^+ from 1, 2, 4, 5&6

$D^+=DBC$

∴We need 3.

Remove 3 and compute D^+ from 1, 2, 4, 5&6

Remove 4 and compute D+ from 1, 2, 4, 5&6

D^+=ADCB

∴D→B can be removed.

Remove 5 and compute D^+ from 1, 2, 3,4&6

D^+=ABD

∴We need 5.

Remove 6 and compute D^+ from 1, 2,3, 4, 5

AC^+=ACB

∴We need 6.

Step 3:

$A \rightarrow B$
$C \rightarrow B$
$D \rightarrow A$
$D \rightarrow C$
$AC \rightarrow D$

Remove A

$A \rightarrow B$	$A \rightarrow B$
$C \rightarrow B$	$C \rightarrow B$
$D \rightarrow A$	$D \rightarrow A$
$D \rightarrow C$	$D \rightarrow C$
$C \rightarrow D$	$AC \rightarrow D$
C^+=CDAB	C^+=CB

$\therefore C^+ \not\equiv C^+$

Remove C

$A \rightarrow B$	$A \rightarrow B$
$C \rightarrow B$	$C \rightarrow B$
$D \rightarrow A$	$D \rightarrow A$
$D \rightarrow C$	$D \rightarrow C$
$A \rightarrow D$	$AC \rightarrow D$
A^+=ADCB	A^+=AB

$A^+ \not\equiv A^+$

Step 4:

$A \rightarrow B$
$C \rightarrow B$
$D \rightarrow A$
$D \rightarrow C$
$AC \rightarrow D$

$A \rightarrow B$
$C \rightarrow B$
$D \rightarrow AC$
$AC \rightarrow D$

Therefore, it is an irreducible F.D.

Q2 Consider Universal relation with attributes ABC and FDs

$AB \rightarrow C$

$C \rightarrow B$

$A \rightarrow B$

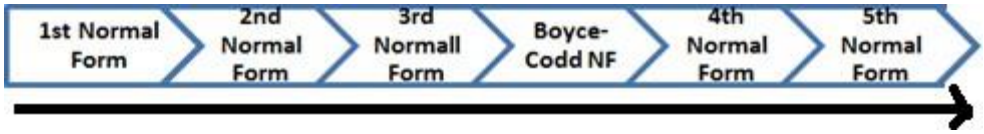
Find the Irreducible set

Normal forms based on functional dependency (1NF, 2NF and 3 NF, Boyce-Codd normal form (BCNF), 4NF)

Normalization *means "split the tables into small tables which will contain less number of attributes in such a way that table design must not contain any problem of inserting, deleting, updating anomalies and guarantees no redundancy".*

The **evolution of Normalization theories / Steps of Normalization / Different Normal Forms** is illustrated below-

1. **First Normal Form (1NF)**
2. **Second Normal Form (2NF)**
3. **Third Normal Form (3NF)**
4. **Boyce-Codd Normal Form (BCNF)**
5. **Fourth Normal Form (4NF)**
6. **Fifth Normal Form (5NF).**



Points to be Remember

- 1 NF is a mandatory NF and remaining are the optional
- If you construct E-R diagrams in to the tables, then 4 NF and 5 NF need not be applied on the table.
- Practically applied normalization is upto 3NF and very rarely we will go beyond that.
- 2 NF dealing with the partial dependencies and 3NF is dealing with transitive dependencies.

First Normal Form (1NF): A relation is said to in the 1NF if it is already in un-normalized form and it satisfies the following conditions or rules or qualifications are:

1. Each attribute name must be unique.
2. Each attribute value must be single or atomic i.e., Single Valued Attributes.
3. Each row / record must be unique.
4. There is no repeating group's.

Example: How do we bring an un-normalized table into first normal form? Consider the following relation:

TABLE_PRODUCT

Product ID	Color	Price
1	red, green	15.99
2	yellow	23.99
3	green	17.50
4	yellow, blue	9.99
5	red	29.99

Solution: This table is not in first normal form because the [Color] column can contain multiple values. For example, the first row includes values "red" and "green." To bring this table to first normal form, we split the table into two tables and now we have the resulting tables:

TABLE_PRODUCT_PRICE

Product ID	Price
1	15.99
2	23.99
3	17.50
4	9.99
5	29.99

TABLE_PRODUCT_COLOR

Product ID	Color
1	red
1	green
2	yellow
3	green
4	yellow
4	blue
5	red

Second Normal Form (2NF): A relation is said to be in 2NF, if it is already in 1st NF and it has no Partial Dependency i.e., no non-prime attribute is dependent on the only a part of the candidate key.

(OR)

A relation is in second normal form if it satisfies the following conditions:

- It is in first normal form
- All non-key attributes are fully functional dependent on the primary key.

Note: <u>Partial Functional Dependency:</u> If a non-prime attribute of the relation is getting derived by only a part of the candidate key, then such dependency is known as Partial Dependency

Example: Consider the following relation

TABLE_PURCHASE_DETAIL

Customer ID	Store ID	Purchase Location
1	1	Los Angeles
1	3	San Francisco
2	1	Los Angeles
3	2	New York
4	3	San Francisco

➔ This table has a composite primary key [Customer ID, Store ID]. The non-key attribute is [Purchase Location]. In this case, [Purchase Location] only depends on [Store ID], which is only part of the primary key. Therefore, this table does not satisfy second normal form.

➔ To bring this table to second normal form, we break the table into two tables, and now we have the following:

TABLE_PURCHASE

Customer ID	Store ID
1	1
1	3
2	1
3	2
4	3

TABLE_STORE

Store ID	Purchase Location
1	Los Angeles
2	New York
3	San Francisco

Q1 Given relation R(ABCD) and F:{AB→C, B→D} Decompose in into 2NF.

from the given FDs determine primary key. Necessary attributes to include in the key are A, B (because this attributes are not in RHS of FD).

Find the closure set of AB

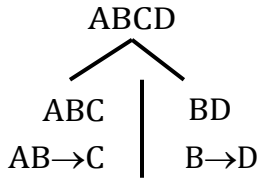
$AB^+ = ABC$

$= ABCD \quad (\because B \rightarrow D)$

$\therefore$ AB is a primary key.

From the FDs B→D is partially depending on AB. So decompose the table.

(D is a non-prime attribute derived by a part of the key)



Q2 Consider the relation R=ABCDEF and set of FDs are A→ FC, C→D, B→ E Find the key and normalize into 2NF.

Third Normal Form (3NF): A database is in third normal form if it satisfies the following conditions:

- It is in 2NF.
- There is no transitive functional dependency
  - By **transitive functional dependency**, we mean we have the following relationships in the table: A is functionally dependent on B, and B is functionally dependent on C. In this case, C is transitively dependent on A via B. and **A non-key attribute is depending on a non-key attribute.**

Example: Consider the following relation.

TABLE_BOOK_DETAIL

Book ID	Genre ID	Genre Type	Price
1	1	Gardening	25.99
2	2	Sports	14.99
3	1	Gardening	10.00
4	3	Travel	12.99
5	2	Sports	17.99

➔ In the table able, [Book ID] determines [Genre ID], and [Genre ID] determines [Genre Type]. Therefore, [Book ID] determines [Genre Type] via [Genre ID] and we have transitive functional dependency, and this structure does not satisfy third normal form.

➔ To bring this table to third normal form, we split the table into two as follows:

TABLE_BOOK

Book ID	Genre ID	Price
1	1	25.99
2	2	14.99
3	1	10.00
4	3	12.99
5	2	17.99

TABLE_GENRE

Genre ID	Genre Type
1	Gardening
2	Sports
3	Travel

Q1 Given relation R(ABCDE) and F:{AB→C, B→D, D→E} Decompose in into 3NF.

from the given FDs determine primary key. Necessary attributes to include in the key are A, B (because this attributes are not in RHS of FD).

Find the closure set of AB

$AB^+ = ABC$

$= ABCD \quad (\because B \rightarrow D)$

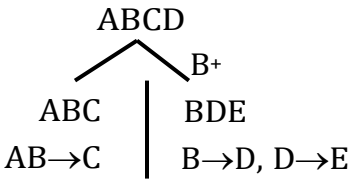
$= ABCDE \quad (\because D \rightarrow E)$

$\therefore$ AB is a primary key.

From the FDs B→D is partially depending on AB. So decompose the table.

(D is a non-prime attribute derived by a part of the key)

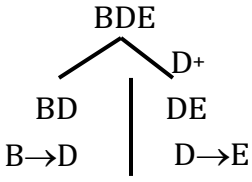
$B^+ = BDE$



$\therefore$ table is in 2NF but not in 3NF. Because D→E is transitive dependency.

(No non-key attribute should determining a non-key attribute)

$D^+ = DE$



$\therefore$ Table is 3NF.

The relations after decomposing into 3NF.

R1: ABC

R2: BD

R3: DE

Q2 Given relation R=ABCDEFGHIJ and the set of FDs are AB→ C, A→DE, B→F, F→GH, D→ IJ Decompose R into 3NF.

Q3(a) Given a set of FDs for the relation schema R(ABCD) with primary key AB under which R is 1NF but not in 2NF

(b) Find FDs such that R is in 2NF but not in 3NF

Sol: R=ABCD
Key=AB

(a) Atomic values are allowed in 1NF and partial dependency is not allowed in 2NF.

The following FDs are allowed.

B→ C, A→C, B→ D, A→ D

(show the FDs which is having partial dependency)

(b) According to question partial dependencies are not allowed and transitivity dependency is allowed. The following FDs are allowed.

C→ D, D→C

Boyce-Codd normal form (BCNF): A relation is said to be in BCNF, if and only if every determinant should be a candidate key.

✓ BCNF is the advance version of 3NF. It is stricter than 3NF.

✓ A table is in 3NF if for every functional dependency X → Y, X is the super key of the table.

✓ For BCNF, the table should be in 3NF and for every FD, LHS is super key.

Example: Let's assume there is a company where employees work in more than one department. EMPLOYEE table:

emp_id	emp_nationality	emp_dept	dept_type	dept_no_of_emp
1001	Austrian	Production and planning	D001	200
1001	Austrian	stores	D001	250
1002	American	design and technical support	D134	100
1002	American	Purchasing department	D134	600

➔ In the above table Functional dependencies are as follows: EMP_ID → EMP_COUNTRY and EMP_DEPT → {DEPT_TYPE, EMP_DEPT_NO} Candidate key: {EMP-ID, EMP-DEPT}

➔ The table is not in BCNF because neither EMP_DEPT nor EMP_ID alone are keys. To convert the given table into BCNF, we decompose it into three tables:

EMP_COUNTRY table:

EMP_ID	EMP_COUNTRY
264	India
264	India

EMP_DEPT table:

EMP_DEPT	DEPT_TYPE	EMP_DEPT_NO
Designing	D394	283
283	D394	300
Stores	D283	232
549	D283	549

EMP_DEPT_MAPPING table:

EMP_ID	EMP_DEPT
D394	283
D394	300
D283	232
D283	549

FOR BCNF problems refer your note book.

Q1 Consider the relation schema R(A,B,C), which has the FD B → C. If A is a candidate key for R, is it possible for R to be in BCNF? If so, under what conditions? If not, explain why not.

Sol : The only way R could be in BCNF is if B includes a key, i.e. B is a key for R

Fourth Normal Form (4NF): A relation said to be in 4NF if it is in Boyce Codd normal form and should have no multi-valued dependency.

✓ For a dependency A→ B, if for a single value of A, multiple value of B exists then the relation will be multi-valued dependency.

✓ **Note: Multi Valued Dependency:** A table is said to have multi-valued dependency, if the following conditions are true,

1. For a dependency A → B, if for a single value of A, multiple value of B exists, then the table may have multi-valued dependency.
2. Also, a table should have at-least 3 columns for it to have a multi-valued dependency.
3. And, for a relation R (A, B, C), if there is a multi-valued dependency between, A and B, then B and C should be independent of each other.

■ If all these conditions are true for any relation (table), it is said to have multi-valued dependency.

Example

STU_ID	COURSE	HOBBY
21	Computer	Dancing
21	Math	Singing
34	Chemistry	Dancing
74	Biology	Cricket
59	Physics	Hockey

- The given STUDENT table is in 3NF but the COURSE and HOBBY are two independent entity. Hence, there is no relationship between COURSE and HOBBY. In the STUDENT relation, student with STU_ID, 21 contains two courses, Computer and Math and two hobbies, Dancing and Singing. So there is a Multi-valued dependency on STU_ID, which leads to un-necessary repetition of data.
- So to make the above table into 4NF, we can decompose it into two tables: STUDENT_COURSE

STU_ID	COURSE
21	Computer
21	Math
34	Chemistry
74	Biology
59	Physics

STUDENT_HOBBY

STU_ID	HOBBY
21	Dancing
21	Singing
34	Dancing
74	Cricket
59	Hockey

Concept of Surrogate Key:

✓ Alternate of Primary Key that allows duplication of data's/records.

✓ Surrogate key is a unique identification key, it is like an artificial key to production key, because the production key may be alphanumeric or composite key but the surrogate key is always single numeric key.

✓ A surrogate key has the following characteristics:

i. The value is never reused and is unique within the whole system.

ii. It is system generated and an integer.

iii. The value cannot be manipulated by the user or application.

iv. The value is not an amalgam of different values from multiple domains.

✓ A Surrogate Keys can be generated in a variety of ways, and most databases offers ways to generate surrogate keys.

Example: Oracle uses **SEQUENCE**,
MYSQL uses **Auto_Increment**,
and SQL Server uses **IDENTITY**.

Lossless join and Dependency preserving decomposition:

Decomposition: Decomposition of a relation is done when a relation in relational model is not in appropriate normal form. Relation R is decomposed into two or more relations if decomposition is lossless join as well as dependency preserving.

➔ If we decompose a relation R into relations R1 and R2, There are 2 types of decomposition:

1. **Decomposition is lossy**, if **R1 ⋈ R2 ⊃ R.**
   - ✓ The decomposition of relation R into R1 and R2 is **lossy** when the join of R1 and R2 does not yield the same relation as in R." One of the disadvantages of decomposition into two or more relational schemes (or tables) is that some information is lost during retrieval of original relation or table.
   - ✓ Consider that we have table STUDENT with three attribute roll_no , sname and department.

Roll_no	Sname	Dept
111	parimal	COMPUTER
222	parimal	ELECTRICAL

- ✓ This relation is decomposed into two relation no_name and name_dept:

Roll_no	Sname
111	parimal
222	parimal

Sname	Dept
parimal	COMPUTER
parimal	ELECTRICAL

- ✓ In lossy decomposition, spurious tuples are generated when a natural join is applied to the relations in the decomposition.

stu_joined :

Roll_no	Sname	Dept
111	parimal	COMPUTER
111	parimal	ELECTRICAL
222	parimal	COMPUTER
222	parimal	ELECTRICAL

- ✓ The above decomposition is a bad decomposition or Lossy decomposition.

2. **Lossless Join Decomposition:** Decomposition is lossless if **R1 ⋈ R2 = R**
   - ✓ This is also referred as **non-additive decomposition.**
   - ✓ The lossless-join decomposition is always defined with respect to a specific set F of dependencies
   - ✓ **To check for lossless join decomposition using FD set, following conditions must hold:**
     1. Union of Attributes of R1 and R2 must be equal to attribute of R. Each attribute of R must be either in R1 or in R2.

        Att(R1) U Att(R2) = Att(R).
     2. Intersection of Attributes of R1 and R2 must not be NULL.

        Att(R1) ∩ Att(R2) ≠ Φ.
     3. Common attribute must be a key for at least one relation (R1 or R2)

        Att(R1) ∩ Att(R2) -> Att(R1) or Att(R1) ∩ Att(R2) -> Att(R2).

   - ✓ **Example 1:,** A relation R (A, B, C, D) with FD set{A->BC} is decomposed into R1(ABC) and R2(AD) which is a lossless join decomposition as:
     1. First condition holds true as Att(R1) U Att(R2) = (ABC) U (AD) = (ABCD) = Att(R).
     2. Second condition holds true as Att(R1) ∩ Att(R2) = (ABC) ∩ (AD) ≠ Φ
     3. Third condition holds true as Att(R1) ∩ Att(R2) = A is a key of R1(ABC) because A->BC is given.

✓ **Example 2:** Consider that we have table STUDENT with three attribute roll_no, sname and department.
STUDENT:

Roll_no	Sname	Dept
111	parimal	COMPUTER
222	parimal	ELECTRICAL

This relation is decomposed into two relation Stu_name and Stu_dept:

Roll_no	Sname
111	parimal
222	parimal

Roll_no	Dept
111	COMPUTER
222	ELECTRICAL

Now, when these two relations are joined on the comman column 'roll_no' ,the resultant relation will look like stu_joined.

Roll_no	Sname	Dept
111	parimal	COMPUTER
222	parimal	ELECTRICAL

In lossless decomposition, no any spurious tuples are generated when a natural joined is applied to the relations in the decomposition.

➢ **Dependency Preserving Decomposition:**

- ✓ If we decompose a relation R into relations R1 and R2, All dependencies of R either must be a part of R1 or R2 or must be derivable from combination of FD's of R1 and R2.
- ✓ The dependency preservation decomposition is another property of decomposed relational database schema D in which each functional dependency X -> Y specified in F either appeared directly in one of the relation schemas R_i in the decomposed D or could be inferred from the dependencies that appear in some R_i.
- ✓ Decomposition D = {R_1, R_2, R_3,.., ,R_n} of R is said to be dependency-preserving with respect to F if the union of the projections of F on each R_i , in D is equivalent to F. In other words, R ⊂ join of R_1, R_2 over X. The dependencies are preserved because each dependency in F represents a constraint on the database. If decomposition is not dependency-preserving, some dependency is lost in the decomposition.
- ✓ **Example 1:** A relation R (A, B, C, D) with FD set {A->BC} is decomposed into R1(ABC) and R2(AD) which is dependency preserving because FD A->BC is a part of R1(ABC).
- ✓ **Example 2:** Let a relation R(A,B,C,D) and set a FDs F = { A -> B , A -> C , C -> D} are given. A relation R is decomposed into –

```
R1 = (A, B, C) with FDs F1 = {A -> B, A -> C}, and
R2 = (C, D) with FDs F2 = {C -> D}.
     F' = F1 ∪ F2 = {A -> B, A -> C, C -> D}
      So, F' = F.
     And so, F'+ = F+.
```

Thus, the decomposition is dependency preserving decomposition.

Fifth Normal Form (5NF) in DBMS?

Normalization is a process that involves removing or decreasing the redundancy present in the database. Normalization mainly focuses on removing duplicate data from the database and making it more consistent.
There are various types of normalization such as 1NF,2NF, 3NF, BCNF, 4NF, and 5NF. 5NF is one of the highest levels of normalization form present in database normalization.
Fifth Normal Form (5NF)

- A Relation is said to be in 5NF if both conditions are satisfied.

1) Relation should be already in 4NF 2) It cannot be further non-loss decomposed (Joined Dependency should not be present)

- The Fifth Normal Form (5NF) is also known as the Project-Join Normal Form (PJNF).
- 5NF gets satisfied when the table is broken down into as many parts as possible to avoid data redundancy.

Let's have a look at the above 2 conditions for 5NF.

Relation should be Already in 4NF

- It should satisfy all the conditions of 4NF

1. It should be in BCNF.
2. No multi-valued dependency should exist.

Non-Loss Decomposition

- When the table does not contain any join dependency then it is called a lossless /non-loss decomposition.
- In other words, we can say that
- A database is in 5NF when there is **no join dependency** present in the table / database.
- When we decompose the given table to remove redundancy in the data and then compose it again to create the original table , we should not lose any data, and the original table should be obtained as a loss should happen after the decomposition of the table.
- Join dependency for relation R can be stated as
- R=(R1 𝔚 R2 𝔚 R3 𝔚 .....Rn) where R1,R2,R3.....Rn are sub-relation of R and 𝔚 is Natural Join Operator.
- Here R1, R2, R3, ... Rn are the sub-relation of relation R.

Example

- let's, take **of** Table R which has 3 columns i.e. subject, class, and teacher where each subject can be taught by many teachers in many classes, and a teacher can teach more than 1 subject.

Subject	Class	Teacher
math	class 10	kartik
math	class 9	yash
math	class 10	yash
science	class 10	yash

- Here the subject of math is taught by both teachers kartik and yash. Also yash can teach math and science. Yash teaches math to both class 9 and class 10.
- As there is redundancy in data we will decompose it into two tables R1 and R2 such that R1 will have attribute Subject and Class and R2 will have attribute class and teacher.

Table R1

Subject	Class
math	class 9
math	class 10
science	class 10

- Here we removed the redundancy in the table by removing the extra tuple with the same values i.e. subject math taught in class 10. This tuple is repeated 2 times in the main table but in table R1 this redundancy is removed.

Table R2

Class	Teacher
class 10	kartik
class 9	yash
class 10	yash

- Here we removed the redundancy in the table by removing the extra tuple with the same values i.e. yash is teaching for class 10. This tuple is repeated 2 times in the main table but in table R2 this redundancy is removed.

- After combining both tables R1 and R2 we will get as mentioned below:

Table (R1 ⋈ R2)

Subject	Class	Teacher
math	class 9	yash
math	class 10	kartik
math	class 10	yash
science	class 10	kartik
science	class 10	yash

Uses of Fifth Normal Form (5NF)

- 5NF ensures that there will be no redundancy present in the database. Removing the redundancy in the database helps the data to remain more optimized and easy to perform database actions.
- It also ensures that there will be non-lossy decomposition only which will result in data consistency and data integrity.
- As data redundancy and anomalies are removed, the database performance gets enhanced.

Limitation of Fifth Normal Form (5NF)

- One of the biggest limitations**is** of 5Nf is the complexity of the database. Due to 5Nf large number of tables and relation gets created which eventually increases the complexity of the database.
- Slow exhibition due to large number of tables.
- The cost of implementation of 5NF is also high as it increases the complexity of the database.

Multivalued Dependency

Multivalued dependency occurs when two attributes in a table are independent of each other but, both depend on a third attribute.

A multivalued dependency consists of at least two attributes that are dependent on a third attribute that's why it always requires at least three attributes.

Mutiivalued dependencies are consequences of 1NF which did not allow an attribute in a tuple to have a set of values.

In a relation, the functional dependency A -> B relates a value of A to a value of B while multivalued dependency represented A ->-> B represents a relationship that defines a relationship in which attribute B are determined by a single value of A. The multivalued dependency is the result of 1NF that prohibits an attribute from having a set of values.

Example: Suppose there is a bike manufacturer company which produces two colors(white and black) of each model every year.

BIKE_MODEL	MANUF_YEAR	COLOR
M2011	2008	White
M2001	2008	Black
M3001	2013	White
M3001	2013	Black
M4006	2017	White
M4006	2017	Black

Here columns COLOR and MANUF_YEAR are dependent on BIKE_MODEL and independent of each other.

In this case, these two columns can be called as multivalued dependent on BIKE_MODEL. The representation of these dependencies is shown below:

BIKE_MODEL $\rightarrow\rightarrow$ MANUF_YEAR

BIKE_MODEL $\rightarrow\rightarrow$ COLOR

This can be read as "BIKE_MODEL multidetermined MANUF_YEAR" and "BIKE_MODEL multidetermined COLOR".

A Multivalued dependency can be defined as:

Multivalued dependencies occur when two or more independent multivalued facts about an attribute occur are in the same table.

In other words, R(X, Y, Z) in a relation where it will be assumed that X, Y, Z are pair wise disjoint.

X = {x1, x2.....xn)

Y = { y1, y2.....yn)

Z = { z1, z2.....zn)

Then the multi-valued dependency X ->->Y holds at any point in time, then Yxz depends only on X i.e. Yxz = Yxz and both are non empty for each value of x, y and z.

Consider another example of STAFF relation that holds information about staff, the equipment they have been allocated and the languages in which they are fluent as shown below.

STAFF Relation: STAFF (@S_Name + @Equipment + @Language)

S_Name	Equipment	Language
Anurag	PC	English
Anurag	PC	French
Anurag	Mainframe	English
Anurag	Mainframe	French
Kapil	PC	English
Kapil	PC	French
Kapil	PC	Japanese

We assume that a staff can have more than one value for the equipment as well as for the language. The Staff's Equipment and Language attribute are independent of each other, so we must have a separate tuple to represent every combination of a Staff's Equipment and Staff's Language. So a Staff has multivalued facts about his equipment and language or in other words Staff multidetermines Equipment and Language.

It can be represented as:

Staff ->-> Equipment

Staff ->-> Language

So, Equipment and Language are multivalued dependent on Staff.

Properties of Multivalued Dependency:

Multivalued Dependency consists of the following properties:

- For a relation to maintain multivalued dependency, it must have atleast three attributes. Since Multivalued Dependency always occurs in pairs i.e. A->->C also holds in a relation R (A, B, C).
- The attributes giving rise to the multivalued facts must be independent of each other.
- Functional dependency is a special case of multivalued dependency. If we restrict the set determined by multivalued dependency to a single set then multivalued dependency reduces to a functional dependency.