MODULE – 3

RELATIONAL DATABASE DESIGN

Data Dependency/Functional Dependency

A functional dependency is an association between two attributes of the same relational database table. One of the attributes is called the determinant and the other attribute is called the determined. For each value of the determinant there is associated one and only one value of the determined.

If A is the determinant and B is the determined then we say that *A functionally determines B* and graphically represent this as A -> B. The symbols A & B can also be expressed as *B is functionally determined by* A.

Since for each value of A there is associated one and only one value of B.

The following table illustrates A ⇨ B:

A	B
1	1
2	4
3	9
4	16
2	4
7	9

Data Dependency/Functional Dependency

A	B
1	1
2	4
3	9
4	16
2	4
3	11
7	9

In this table ***A does not functionally determine B.***

Since for A = 3 there is associated more than one value of B.

Functional dependency can also be defined as follows:
An attribute in a relational model is said to be functionally dependent on another attribute in the table if it can take only one value for a given value of the attribute upon which it is functionally dependent.

Data Dependency/Functional Dependency

A functional dependency denoted (FD) is denoted by $X \rightarrow Y$, between two sets of attributes X and Y that are subset of relation R specifies a constraint on the tuples that can form a relation state of r of R. The constraint is that, for any two tuple t1 and t2 in r that have t1[X] = t2[X], we must have t1[Y] = t2[Y].

It means that the values of the Y of a tuple in r depend upon or determined by, the value of X component. Alternatively, the values of X component of a tuple uniquely (or Functionally) determine the values of the Y component.

In other words, there is a functional dependency from X to Y or that Y is functionally dependent on X.

Thus, X functionally determines Y in a relation schema R if and only if, whenever two tuples of r(R) agree on their X-value, they must necessarily agree on their Y value.

Data Dependency/Functional Dependency

For example, in the relation schema PROJECT of the employees, the following functional dependencies should hold-

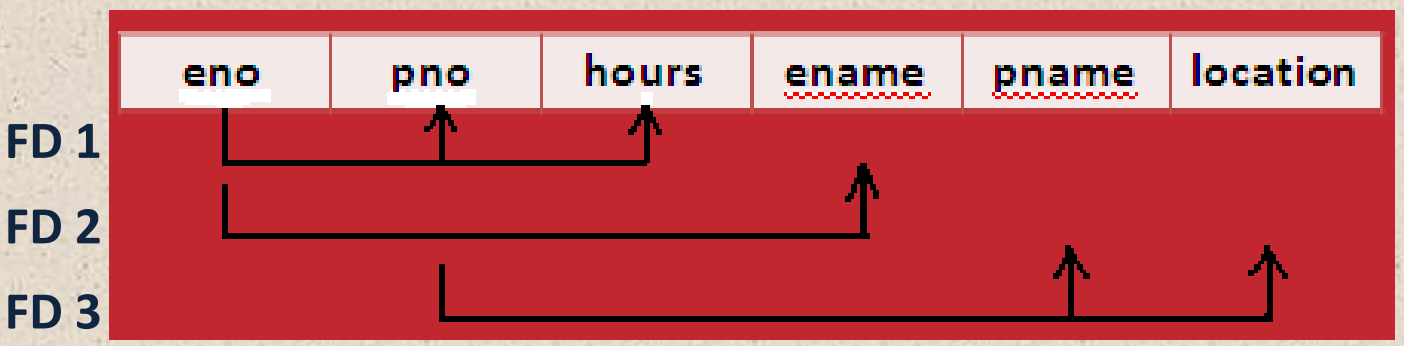
1. **eno → ename**
2. **pno → pname, location**
3. **Eno, pno → hours**

These functional dependencies specifies that

1. The value of an employee's number (eno) uniquely determines the employee name (ename).
2. The value of project number (pno) uniquely determines that project name (pname) and project location (location).
3. A combination of eno and pno values uniquely determines the number of hours the employee works on the project per week.

Alternatively, we can say that ename is functionally determined by eno and so on.

PROJECT SCHEMA



Data Dependency/Functional Dependency

Types of Functional Dependencies

There are many types of functional dependencies that depending on different criteria-

1. Full Functional Dependency
2. Partial Dependency
3. Transitive Dependency
4. Trivial and Non-trivial Dependency

- **Full Functional Dependency:**

  For a relation schema R and a FD, A $\rightarrow$ B, B is fully functionally dependent on A if there is no C, where C is proper subset of A, such that C $\rightarrow$ B.

  The Dependency A $\rightarrow$ B is left reduced, that is, there is no extraneous attributes in left side in the dependency.

- **Partial Dependency:**

  A functional dependency that holds in a relation is partial when removing one of the determining attributes gives a functional dependency that holds in the relation.

  E.g. if {A,B} → {C} but also {A} → {C} then {C} is partially functionally dependent on {A,B}.

Data Dependency/Functional Dependency

- **Partial Dependency:**

  Partial Dependency is a form of Functional dependency that holds on a set of attributes. It is about the complete dependency of a right hand side attribute on one of the left hand side attributes. In a functional dependency XY →Z, if Z (RHS attribute) can be uniquely identified by one of the LHS attributes, then the functional dependency is partial dependency.

  Example:

  Let us assume a relation R with attributes A, B, C, and D. Also, assume that the set of functional dependencies F that hold on R as follows;

  F = {A → B, D → C}.

  From set of attributes F, we can derive the primary key. For R, the key can be (A,D), a composite primary key. That means, AD → BC, AD can uniquely identify B and C. But, for this case A and D is not required to identify B or C uniquely. To identify B, attribute A is enough. Likewise, to identify C, attribute D is enough. The functional dependencies AD → B or AD → C are called as Partial functional dependencies.

Data Dependency/Functional Dependency

- **Transitive Dependency:** The functional dependency follows the mathematical property of *transitivity*, which states that if A=B and B=C, then A=C. Because ItemNo determines CategoryID, which in turn determines CategoryName and CategoryManager, the relation contains a transitive dependency.

ItemNo → Title, Price, CategoryID
CategoryId → CategoryName, CategoryManager

Transitive dependencies occur when there is an indirect relationship that causes a functional dependency.

Examples: For example, ”A -> C” is a transitive dependency when it is true only because both “A -> B” and “B -> C” are true.

Data Dependency/Functional Dependency

- **Trivial and Non-trivial Dependency:**

  Trivial: If an FD X → Y holds where Y subset of X, then it is called a trivial FD. Trivial FDs are always hold.

  Symbolically: A → B is trivial functional dependency if B is a subset of A.

  The following dependencies are also trivial:

  A → A

  AB → A

  AB → B

  B → B

  For example:

  Consider a table with two columns Student_id and Student_Name.

  {Student_Id, Student_Name} → Student_Id

  is a trivial functional dependency as Student_Id is a subset of {Student_Id, Student_Name}. That makes sense because if we know the values of Student_Id and Student_Name then the value of Student_Id can be uniquely determined. Also,

  Student_Id→Student_Id

  Student_Name→Student_Name

  are trivial dependencies too.

Data Dependency/Functional Dependency

- **Trivial and Non-trivial Dependency:**

  Non-trivial: If an FD X → Y holds where Y is not subset of X, then it is called non-trivial FD.

  For example:

  An employee table with three attributes:

  emp_id, emp_name, emp_address.

  The following functional dependencies are non-trivial:

  emp_id→ emp_name (emp_name is not a subset of emp_id)

  emp_id → emp_address (emp_address is not a subset of emp_id)

  On the other hand, the following dependencies are trivial:

  emp_id, emp_name → emp_name

  emp_name is a subset of {emp_id, emp_name}

  Completely non-trivial: If an FD X → Y holds where X intersect Y = Φ, is said to be completely non-trivial FD.

Data Dependency/Functional Dependency

Conclusion of Functional Dependency

Functional Dependencies:

- Data dependencies are constraints imposed on data in database.
- They are part of the scheme definition.
- FDs allow us to formally define keys.
- A conjecture (It has to be proven) is that a set of functional dependencies and one join dependency are enough to express the dependency structure of a relational database scheme.

Motivation:

Functional dependencies help in accomplishing the following two goals:

(a) controlling redundancy and
(b) enhancing data reliability.

Data Dependency/Functional Dependency

Problematic Issue:

Representing the set of all FDs for a relation R.

Solution:

- Find a basic set of FDs.
- Use axioms for inferring.
- Represent the set of all FDs as the set of FDs that can be inferred from the basic set of FDs.

Axioms:

An inference axiom is a rule that states if a relation satisfies certain FDs then it must satisfy certain other FDs.

Data Dependency/Functional Dependency

Armstrong's axioms are a set of axioms (or, more precisely, inference rules) used to infer all the functional dependencies on a relational database. They were developed by William W. Armstrong.

FD manipulations:
Soundness -- no incorrect FD's are generated
Completeness -- all FD's can be generated

Let R(U) be a relation scheme over the set of attributes U. We will use the letters X, Y, Z & W to represent any subset of and, for short, the union of two sets of attributes and by instead of the usual X U Y.

F1. Reflexivity/Self Determination $X \rightarrow X$
F2. Augmentation If ($Z \subseteq W$; $X \rightarrow Y$) then $XW \rightarrow YZ$, If $A \rightarrow B$ then $AC \rightarrow BC$
F3. Additivity/Union If { ($X \rightarrow Y$) ($X \rightarrow Z$)} then $X \rightarrow YZ$
F4. Projectivity/Decomposition If ($X \rightarrow YZ$) then $X \rightarrow Y$, $X \rightarrow Z$
F5. Transitivity If ($X \rightarrow Y$) and ($Y \rightarrow Z$) then ($X \rightarrow Z$)
F6. Pseudotransitivity If ($X \rightarrow Y$) and ($YZ \rightarrow W$) then $XZ \rightarrow W$

Data Dependency/Functional Dependency

Axiom Name	Axiom	Example
Reflexivity	if a is set of attributes, b ⊆ a, then a →b	SSN,Name → SSN
Augmentation	if a→ b holds and c is a set of attributes, then ca→cb	SSN → Name then SSN,Phone → Name, Phone
Transitivity	if a →b holds and b→c holds, then a→ c holds	SSN →Zip and Zip→City then SSN →City
Union or Additivity *	if a → b and a → c holds then a→ bc holds	SSN→Name and SSN→Zip then SSN→Name,Zip
Decomposition or Projectivity*	if a → bc holds then a → b and a → c holds	SSN→Name,Zip then SSN→Name and SSN→Zip
Pseudotransitivity*	if a → b and cb → d hold then ac → d holds	Address → Project and Date→Amount then Address,Date → Amount
(NOTE)	ab→ c does NOT imply a → b and b → c	

Data Dependency/Functional Dependency

Prove or disprove the following inference rules for functional dependencies-

i. $\{W \rightarrow Y, X \rightarrow Z\} \Rightarrow \{WX \rightarrow Y\}$

ii. $\{X \rightarrow Y\}$ and $Y \supseteq Z \Rightarrow \{X \rightarrow Z\}$

iii. $\{X \rightarrow Y, Y \rightarrow Z\} \Rightarrow \{X \rightarrow YZ\}$

iv. $\{X \rightarrow Z, Y \rightarrow Z\} \Rightarrow \{X \rightarrow Y\}$

v. $\{XY \rightarrow Z, Z \rightarrow W\} \Rightarrow \{X \rightarrow W\}$

i. $\{W \rightarrow Y, X \rightarrow Z\} \Rightarrow \{WX \rightarrow Y\}$

Given

$W \rightarrow Y$ --------- (a)

$X \rightarrow Z$ --------- (b)

by augmenting in (a) by X

$WX \rightarrow XY$ ------- (c)

by decomposing in (c)

$WX \rightarrow Y$ Hence, it is proved.

Data Dependency/Functional Dependency

Prove or disprove the following inference rules for functional dependencies-

ii. $\{X \rightarrow Y\}$ and $Y \supseteq Z \Rightarrow \{X \rightarrow Z\}$

Given

$X \rightarrow Y$ --------- (a)

$Y \supseteq Z$ and that two tuples t1 and t2 exist in some relation instance r of R such that t1[Y] = t2[Y]. Then t1[Z] = t2[Z] because $Y \supseteq Z$; hence $Y \rightarrow Z$ must hold.

by transitivity $X \rightarrow Y$ and $Y \rightarrow Z$ then $X \rightarrow Z$. Hence, it is proved.

iii. $\{X \rightarrow Y, Y \rightarrow Z\} \Rightarrow \{X \rightarrow YZ\}$

Given

$X \rightarrow Y$ --------- (a)

$Y \rightarrow Z$ --------- (b)

by augmentation rule on (b) by Y

$Y \rightarrow YZ$ --------- (c)

and by transitivity rule on (a) and (c)

$X \rightarrow Y$ and $Y \rightarrow YZ \Rightarrow \{X \rightarrow YZ\}$

Hence, it is proved.

Data Dependency/Functional Dependency

Prove or disprove the following inference rules for functional dependencies-

iv. $\{X \rightarrow Z, Y \rightarrow Z\} \Rightarrow \{X \rightarrow Y\}$

Given $X \rightarrow Z$ i.e. $X \supseteq Z$ and that any two tuples t1 and t2 of relation R such that $t1[X] = t2[X]$ then $t1[Z] = t2[Z]$.

Also given $Y \rightarrow Z$ i.e. $Y \supseteq Z$ and that any two tuples t1 and t2 of relation R such that $t1[Y] = t2[Y]$ then $t1[Z] = t2[Z]$.

This implies that $X \supseteq Y$; i.e. $X \rightarrow Y$. Hence, it is proved.

iv. $\{XY \rightarrow Z, Z \rightarrow W\} \Rightarrow \{X \rightarrow W\}$

Given

$XY \rightarrow Z$ --------- (a)

$Z \rightarrow W$ --------- (b)

by transitivity rule on (a) and (c)

$XY \rightarrow Z$ and $Z \rightarrow W \Rightarrow \{XY \rightarrow W\}$ -------- (c)

by decomposition rule on (c)

$X \rightarrow W, Y \rightarrow W$

Hence, it is proved.

Data Dependency/Functional Dependency

Closure of Functional Dependencies

Suppose F is a Set of functional dependencies for a given relation R. Then,

Closure of F:

It is a set of all functional dependencies that include F as well as all dependencies that are inferred from F. It is denoted by

$$F^+$$

$X \rightarrow Y$ is inferred from F specified in R if $X \rightarrow Y$ holds in every legal relation state r of R.

By applying the following 6 inference rules, we can inferred FDs of F.

1. Reflexivity $X \rightarrow X$
2. Augmentation If ($Z \subseteq W$; $X \rightarrow Y$) then $XW \rightarrow YZ$
3. Additivity If { ($X \rightarrow Y$) ($X \rightarrow Z$)} then $X \rightarrow YZ$
4. Projectivity If ($X \rightarrow YZ$) then $X \rightarrow Y$
5. Transitivity If ($X \rightarrow Y$) and ($Y \rightarrow Z$) then ($X \rightarrow Z$)
6. Pseudotransitivity If ($X \rightarrow Y$) and ($YZ \rightarrow W$) then $XZ \rightarrow W$

Data Dependency/Functional Dependency

Example for Closure of F:

Suppose we are given a relation scheme $R=(A,B,C,G,H,I)$, and the set of functional dependencies:

$$A \rightarrow B$$
$$A \rightarrow C$$
$$CG \rightarrow H$$
$$CG \rightarrow I$$
$$B \rightarrow H$$

Applying the rules to the scheme and set *F* mentioned above, we can derive the following:

1. $A \rightarrow H$, as we saw by the transitivity rule.
2. $CG \rightarrow HI$ by the union rule.
3. $AG \rightarrow I$ by several steps:
   i. Note that $A \rightarrow C$ holds.
   ii. Then $AG \rightarrow CG$, by the augmentation rule.
   iii. Now by transitivity, $AG \rightarrow I$.

(You might notice that this is actually pseudotransivity if done in one step.)

Data Dependency/Functional Dependency

Example for Closure of F:

Assume that there are 4 attributes A, B, C, D, and that F = {A → B, B → C}. Then, F + includes all the following:

FDs: A → A, A → B, A → C, B → B, B → C, C → C, D → D, AB → A, AB → B, AB → C, AC → A, AC → B, AC → C, AD → A, AD → B, AD → C, AD → D, BC → B, BC → C, BD → B, BD → C, BD → D, CD → C, CD → D, ABC → A, ABC → B, ABC → C, ABD → A, ABD → B, ABD → C, ABD → D, BCD → B, BCD → C, BCD → D, ABCD → A, ABCD → B, ABCD → C, ABCD → D.

Data Dependency/Functional Dependency

Example for Closure of F:

Assume that there are 4 attributes A, B, C, D, and that F = {A → B, B → C}.

To compute F+,

we first get:

A+ = AB+ = AC+ = ABC+ = {A, B, C}

B+ = BC+ = {B, C}

C+ = {C}

D+ = {D}

AD+ = {A, D}

BC+ = {B, C}

BD+ = BCD+ = {B, C, D}

ABD+ = ABCD+ = {A, B, C, D}

ACD+ = {A, C, D}

It is easy to generate the FDs in F + from the closures of the above attribute sets.

Data Dependency/Functional Dependency

Closure of Attribute

Define the closure of α under F (denoted by α+) as the set of attributes that are functionally determined by α under F:

$\alpha \rightarrow \beta$ is in F+ $\Leftrightarrow \beta \subseteq \alpha+$

- Algorithm to compute α+, the closure of α under F

```
result := α;
while (changes to result) do
        for each β → γ in F do
                begin
                if β ⊆ result then result := result ∪ γ;
                end
```

Example:

R = (A, B, C, G, H, I) and F = {A → B A → C CG → H CG → I B → H}

- (AG+)
  1. result = AG
  2. result = ABCG (A → C and A ⊆ AGB)
  3. result = ABCGH (CG → H and CG ⊆ AGBC)
  4. result = ABCGHI (CG → I and CG ⊆ AGBCH)

Data Dependency/Functional Dependency

Finding Candidate Key

Let F be a set of FDs, and R a relation.

A candidate key is a set X of attributes in R such that

- X + includes all the attributes in R.
- There is no proper subset Y of X such that Y + includes all the attributes in R.

Note: A proper subset Y is a subset of X such that Y != X (i.e., X has at least one element not in Y).

Example.

Consider a table R(A, B, C, D), and that F = {A → B, B → C}.

A is not a candidate key, because A + = {A, B, C} which does not include D.
ABD is not a candidate key even though ABD+ = {A, B, C, D}.
This is because AD+ = {A, B, C, D}, namely, there is a proper subset AD of ABD such that AD+ includes all the attributes. AD is a candidate key.

Data Dependency/Functional Dependency

Finding Candidate Key

Example.

Consider a table R(A, B, C, D, E, F), and that F = {A → C, C → D, D → B, E → F}.
Find all the possible candidate key.

Given A → C, A determines C
C → D, C determines D
D → B, D determines B
E → F E determines F

Now, the easiest way is to find which attributes are not determined. In this example, A and E are not determined. Then, find out the closure of (AE)+.

(AE)+ = AE
= ACE
= ACDE
= ACDBE
= ACDBEF

Closure of AE has all the attributes. Thus, AE is a candidate key. In this way, we can find out more candidate keys for this problem.

Normalization

While designing a database out of an entity–relationship model, the main problem existing in that “raw” database is redundancy. Redundancy is storing the same data item in more one place. A redundancy creates several problems like the following:

- Extra storage space: storing the same data in many places takes large amount of disk space.
- Entering same data more than once during data insertion.
- Deleting data from more than one place during deletion.
- Modifying data in more than one place.
- Anomalies may occur in the database if insertion, deletion, modification etc are no done properly. It creates inconsistency and unreliability in the database.

To solve this problem, the “raw” database needs to be normalized. This is a step by step process of removing different kinds of redundancy and anomaly at each step. At each step a specific rule is followed to remove specific kind of impurity in order to give the database a slim and clean look.

Normalization

Normalization of Database

Database Normalization is a technique of organizing the data in the database. Normalization is a systematic approach of decomposing tables to eliminate data redundancy and undesirable characteristics like Insertion, Update and Deletion Anomalies. It is a multi-step process that puts data into tabular form by removing duplicated data from the relation tables.

Normalization is the process of organizing data in a database to reduce redundancy and improve data integrity. It involves decomposing large tables into smaller ones and establishing relationships between them to ensure efficient data management.

Normalization

Why Normalization of Database?

1. *Eliminates Data Redundancy*
   - Reduces duplicate data, saving storage space.
   - Ensures consistency, as data is stored only in one place.

2. *Improves Data Integrity and Consistency*
   - Avoids anomalies (insertion, update, and deletion anomalies).
   - Ensures that any change in data reflects across related tables correctly.

3. *Enhances Data Retrieval Efficiency*
   - Structured tables improve query performance.
   - Indexing becomes more efficient.

4. *Reduces Anomalies in Database Operations*
   - Insertion Anomaly: Prevents unnecessary storage of null values.
   - Update Anomaly: Ensures that updates occur at a single place.
   - Deletion Anomaly: Avoids unintentional data loss due to deletion.

5. *Maintains Data Dependencies*
   - Ensures that attributes are logically related.
   - Helps in enforcing referential integrity.

Normalization

Un-Normalized Form (UNF)

If a table contains non-atomic values at each row, it is said to be in UNF. An **atomic value** is something that can not be further decomposed. A **non-atomic value**, as the name suggests, can be further decomposed and simplified. Consider the following table:

Emp-Id	Emp-Name	Month	Sales	Bank-Id	Bank-Name
E01	AA	Jan	1000	B01	SBI
		Feb	1200		
		Mar	850		
E02	BB	Jan	2200	B02	UTI
		Feb	2500		
E03	CC	Jan	1700	B01	SBI
		Feb	1800		
		Mar	1850		
		Apr	1725		

In the sample table above, there are multiple occurrences of rows under each key Emp-Id. Although considered to be the primary key, Emp-Id cannot give us the unique identification facility for any single row. Further, each primary key points to a variable length record (3 for E01, 2 for E02 and 4 for E03).

Normalization

Problems without Normalization

If a database design is not perfect, it may contain anomalies, which are like a bad dream for any database administrator. Managing a database with anomalies is next to impossible.

Update anomalies − If data items are scattered and are not linked to each other properly, then it could lead to strange situations. For example, when we try to update one data item having its copies scattered over several places, a few instances get updated properly while a few others are left with old values. Such instances leave the database in an inconsistent state.

Deletion anomalies − We tried to delete a record, but parts of it was left undeleted because of unawareness, the data is also saved somewhere else.

Insert anomalies − We tried to insert data in a record that does not exist at all.

Normalization is a method to remove all these anomalies and bring the database to a consistent state.

Normalization

Normalization Forms

Normalization is performed in stages known as **Normal Forms (NF)**:

- **First Normal Form (1NF)** – Eliminates duplicate columns, ensures atomicity.
- **Second Normal Form (2NF)** – Removes partial dependencies.
- **Third Normal Form (3NF)** – Eliminates transitive dependencies.
- **Boyce-Codd Normal Form (BCNF)** – Strengthens 3NF to handle special cases.
- **Fourth (4NF) and Fifth Normal Form (5NF)** – Deals with multi-valued dependencies and complex relationships.

First Normal Form (1NF)

A relation is in first normal form if it meets the definition of a relation:

- Each attribute (column) value must be a single value only.
- All values for a given attribute (column) must be of the same type.
- Each attribute (column) name must be unique.
- The order of attributes (columns) is insignificant
- No two tuples (rows) in a relation can be identical.
- The order of the tuples (rows) is insignificant.

If you have a *key* defined for the relation, then you can meet the *unique row* requirement.

Normalization

First Normal Form (1NF)

A relation is said to be in 1NF if it contains no non-atomic values and each row can provide a unique combination of values. The above table in UNF can be processed to create the following table in 1NF.

Emp-Id	Emp-Name	Month	Sales	Bank-Id	Bank-Name
E01	AA	Jan	1000	B01	SBI
E01	AA	Feb	1200	B01	SBI
E01	AA	Mar	850	B01	SBI
E02	BB	Jan	2200	B02	UTI
E02	BB	Feb	2500	B02	UTI
E03	CC	Jan	1700	B01	SBI
E03	CC	Feb	1800	B01	SBI
E03	CC	Mar	1850	B01	SBI
E03	CC	Apr	1725	B01	SBI

As you can see now, each row contains unique combination of values. Unlike in UNF, this relation contains only atomic values, i.e. the rows can not be further decomposed, so the relation is now in 1NF.

Normalization

Un-Normal Form Table

Company	Symbol	Headquarters	Date	Close Price
Microsoft	MSFT	Redmond, WA	09/07/2013	23.96
			09/08/2013	23.93
			09/09/2013	24.01
Oracle	ORCL	Redwood Shores, CA	09/07/2013	24.27
			09/08/2013	24.14
			09/09/2013	24.33

Table in First Normal Form

Company	Symbol	Headquarters	Date	Close Price
Microsoft	MSFT	Redmond, WA	09/07/2013	23.96
Microsoft	MSFT	Redmond, WA	09/08/2013	23.93
Microsoft	MSFT	Redmond, WA	09/09/2013	24.01
Oracle	ORCL	Redwood Shores, CA	09/07/2013	24.27
Oracle	ORCL	Redwood Shores, CA	09/08/2013	24.14
Oracle	ORCL	Redwood Shores, CA	09/09/2013	24.33

n can be removed into another related relation, it would come to 2NF.

Normalization

Second Normal Form (2NF)

A relation is said to be in 2NF f if it is already in 1NF and each and every attribute fully depends on the primary key of the relation. Speaking inversely, if a table has some attributes which is not dependant on the primary key of that table, then it is not in 2NF.

Let us explain. Emp-Id is the primary key of the above relation. Emp-Name, Month, Sales and Bank-Name all depend upon Emp-Id. But the attribute Bank-Name depends on Bank-Id, which is not the primary key of the table. So the table is in 1NF, but not in 2NF. If this position can be removed into another related relation, it would come to 2NF.

Emp-Id	Emp-Name	Month	Sales	Bank-Id
E01	AA	JAN	1000	B01
E01	AA	FEB	1200	B01
E01	AA	MAR	850	B01
E02	BB	JAN	2200	B02
E02	BB	FEB	2500	B02
E03	CC	JAN	1700	B01
E03	CC	FEB	1800	B01
E03	CC	MAR	1850	B01
E03	CC	APR	1726	B01

Bank-Id	Bank-Name
B01	SBI
B02	UTI

After removing the portion into another relation we store lesser amount of data in two relations without any loss information. There is also a significant reduction in redundancy.

Normalization

The following example relation *is not* in 2NF:
STOCKS (Company, Symbol, Headquarters, Date, Close_Price)

To start the normalization process, list the functional dependencies (FD):

FD1: Symbol, Date → Company, Headquarters, Close Price
FD2: Symbol → Company, Headquarters

Consider that Symbol, Date → Close Price. So we might use Symbol, Date as our key.
However we also see that: Symbol → Headquarters

- This violates the rule for 2NF in that a *part of our key*. key determines a non-key attribute.
- Another name for this is a *Partial key dependency*. Symbol is only a "part" of the key and it determines a non-key attribute.
- Also, consider the insertion and deletion anomalies.

One Solution:
Split this up into two new relations:
COMPANY (Company, Symbol, Headquarters)
STOCK_PRICES (Symbol, Date, Close_Price)

Normalization

- At this point we have two new relations in our relational model. The original "STOCKS" relation we started with is removed form the model.
- Sample data and functional dependencies for the two new relations:
- COMPANY Relation:

Company	Symbol	Headquarters	Date	Close Price
Microsoft	MSFT	Redmond, WA	09/07/2013	23.96
Microsoft	MSFT	Redmond, WA	09/08/2013	23.93
Microsoft	MSFT	Redmond, WA	09/09/2013	24.01
Oracle	ORCL	Redwood Shores, CA	09/07/2013	24.27
Oracle	ORCL	Redwood Shores, CA	09/08/2013	24.14
Oracle	ORCL	Redwood Shores, CA	09/09/2013	24.33

FD1: Symbol, Date → Company, Headquarters, Close Price

Symbol	Date	Close Price
MSFT	09/07/2013	23.96
MSFT	09/08/2013	23.93
MSFT	09/09/2013	24.01
ORCL	09/07/2013	24.27
ORCL	09/08/2013	24.14
ORCL	09/09/2013	24.33

FD2: Symbol → Company, Headquarters

Company	Symbol	Headquarters
Microsoft	MSFT	Redmond, WA
Oracle	ORCL	Redwood Shores, CA

n can be removed into another related relation, it would come to 2NF.

Normalization

Third Normal Form (3NF)

A relation is in third normal form (3NF) if it is in second normal form and it contains no *transitive dependencies*.

Consider relation R containing attributes A, B and C. R(A, B, C)

If A → B and B → C then A → C

Transitive Dependency: Three attributes with the above dependencies.

Example: At CUNY:

Course_Code → Course_Number, Section

Course_Number, Section → Classroom, Professor

Consider one of the new relations we created in the STOCKS example for 2nd normal form:

The functional dependencies we can see are:

FD1: Symbol → Company

FD2: Company → Headquarters

so therefore: Symbol → Headquarters

This is a transitive dependency.

What happens if we remove Oracle?

We loose information about 2 different facts.

Company	**Symbol**	**Headquarters**
Microsoft	MSFT	Redmond, WA
Oracle	ORCL	Redwood Shores, CA

Normalization

The solution again is to split this relation up into two new relations:

STOCK_SYMBOLS(Company, Symbol)

COMPANY_HEADQUARTERS(Company, Headquarters)

This gives us the following sample data and FD for the new relations

FD1: Symbol → Company

Company	**Symbol**
Microsoft	MSFT
Oracle	ORCL

FD2: Company → Headquarters

Company	**Headquarters**
Microsoft	Redmond, WA
Oracle	Redwood Shores, CA

Normalization

Boyce-Codd Normal Form (BCNF)

- A relation is in BCNF if every determinant is a candidate key.
- Recall that not all determinants are keys.
- Those determinants that are keys we initially call *candidate keys*.
- Eventually, we select a single candidate key to be *the key* for the relation.
- Consider the following example:
  - Funds consist of one or more Investment Types.
  - Funds are managed by one or more Managers
  - Investment Types can have one more Managers
  - Managers only manage one type of investment.

Relation: FUNDS (FundID, InvestmentType, Manager)

FD1: FundID, InvestmentType → Manager

FD2: FundID, Manager → InvestmentType

FD3: Manager → InvestmentType

FundID	InvestmentType	Manager
99	Common Stock	Smith
99	Municipal Bonds	Jones
33	Common Stock	Green
22	Growth Stocks	Brown
11	Common Stock	Smith

Normalization

- In this case, the combination FundID and InvestmentType form a *candidate key* because we can use FundID,InvestmentType to uniquely identify a tuple in the relation.
- Similarly, the combination FundID and Manager also form a *candidate key* because we can use FundID, Manager to uniquely identify a tuple.
- Manager by itself is not a candidate key because we cannot use Manager alone to uniquely identify a tuple in the relation.
- Is this relation FUNDS(FundID, InvestmentType, Manager) in 1NF, 2NF or 3NF ? Given we pick FundID, InvestmentType as the *Primary Key:*
  - ✓ 1NF for sure.
  - ✓ 2NF because all of the non-key attributes (Manager) is dependant on all of the key.
  - ✓ 3NF because there are no transitive dependencies.

- However consider what happens if we delete the tuple with FundID 22. We loose the fact that Brown manages the InvestmentType “Growth Stocks.”

Normalization

- Therefore, while FUNDS relation is in 1NF, 2NF and 3NF, it is in BCNF because not all determinants (Manager in FD3) are candidate keys.
- The following are steps to normalize a relation into BCNF:
  - ✓ List all of the determinants.
  - ✓ See if each determinant can act as a key (candidate keys).
  - ✓ For any determinant that is *not* a candidate key, create a new relation from the functional dependency. Retain the determinant in the original relation.
- For our example:FUNDS (FundID, InvestmentType, Manager)
- The determinants are:FundID, InvestmentType FundID, Manager Manager
- Which determinants can act as keys?

  FundID, InvestmentType *YES*

  FundID, Manager *YES*

  Manager *NO*
- Create a new relation from the functional dependency:

  MANAGERS(Manager, InvestmentType),

  FUND_MANAGERS(FundID, Manager)

In this last step, we have retained the determinant "Manager" in the original relation MANAGERS.Each of the new relations should be checked to ensure they meet the definitions of 1NF, 2NF, 3NF and BCNF

Normalization

- For our example:FUNDS (FundID, InvestmentType, Manager)
- The determinants are:FundID, InvestmentType FundID, Manager Manager
- Which determinants can act as keys?

  FundID, InvestmentType *YES*

  FundID, Manager *YES*

  Manager *NO*
- Create a new relation from the functional dependency:

  MANAGERS(Manager, InvestmentType),

  FUND_MANAGERS(FundID, Manager)

In this last step, we have retained the determinant "Manager" in the original relation MANAGERS. Each of the new relations should be checked to ensure they meet the definitions of 1NF, 2NF, 3NF and BCNF

FundID	Manager
99	Smith
99	Jones
33	Green
22	Brown
11	Smith

InvestmentType	Manager
Common Stock	Smith
Municipal Bonds	Jones
Common Stock	Green
Growth Stocks	Brown
Common Stock	Smith

Normalization

Fourth Normal Form (4NF)

A relation is in fourth normal form if it is in BCNF and it contains no *multivalued dependencies*.

Multivalued Dependency: A type of functional dependency where the determinant can determine more than one value.

More formally, there are 3 criteria:

- There must be at least 3 attributes in the relation. call them A, B, and C, for example.
- Given A, one can determine multiple values of B.
- Given A, one can determine multiple values of C.
- B and C are independent of one another.

Normalization

Example (Before 4NF - Table with Multi-Valued Dependency)

Consider a **STUDENT_SKILLS_PROJECTS** table where a student can have multiple skills and work on multiple projects:

Student_ID	Skill	Project
101	Python	AI Model
101	Java	AI Model
101	Python	Web App
101	Java	Web App
102	C++	IoT System
102	C	IoT System

Problem: Multi-Valued Dependency (MVD)

- A **student's skills** are independent of the **projects** they work on.
- **(Student_ID →→ Skill)** and **(Student_ID →→ Project)** are two independent multi-valued dependencies.
- This causes **redundancy** because every combination is stored multiple times.

Normalization

Example (After Applying 4NF - Removing Multi-Valued Dependency)
We split the table into two:

Table 1: STUDENT_SKILLS Table (Stores student skills)

Student_ID	Skill
101	Python
101	Java
102	C++
102	C

Table 2: STUDENT_PROJECTS Table (Stores student projects)

Student_ID	Project
101	AI Model
101	Web App
102	IoT System

- **Eliminates multi-valued dependencies** by separating independent data.
- **Reduces redundancy and anomalies** in data storage.
- **Ensures that attributes depend only on the primary key.**

Normalization

A few characteristics:

- No regular functional dependencies
- All three attributes taken together form the key.
- Later two attributes are independent of one another.
- Insertion anomaly: Cannot add a stock fund without adding a bond fund (NULL Value). Must always maintain the combinations to preserve the meaning.

Stock Fund and Bond Fund form a multivalued dependency on Portfolio ID.

PortfolioID →→ Stock Fund

PortfolioID →→ Bond Fund

Portfolio ID	Stock Fund	Bond Fund
999	Janus Fund	Municipal Bonds
999	Janus Fund	Dreyfus Short-Intermediate Municipal Bond Fund
999	Scudder Global Fund	Municipal Bonds
999	Scudder Global Fund	Dreyfus Short-Intermediate Municipal Bond Fund
888	Kaufmann Fund	T. Rowe Price Emerging Markets Bond Fund

Normalization

Resolution: Split into two tables with the common key:

Portfolio ID	Stock Fund
999	Janus Fund
999	Scudder Global Fund
888	Kaufmann Fund

Portfolio ID	Bond Fund
999	Municipal Bonds
999	Dreyfus Short-Intermediate Municipal Bond Fund
888	T. Rowe Price Emerging Markets Bond Fund

Normalization

Fifth Normal Form (5NF)

- Also called “Projection Join” Normal form.

A table is in **Fifth Normal Form (5NF)** if:

- It is already in **Fourth Normal Form (4NF)**.
- It does **not have join dependencies** that lead to **lossless decomposition** (i.e., a table should not be broken into smaller tables unless it ensures correct data reconstruction when joined back).

❖ **5NF focuses on eliminating redundancy caused by complex relationships between multiple entities.**

Normalization

Example (Before 5NF - Table with Join Dependency)

Consider a **STUDENT_COURSE_PROFESSOR** table where:

- A student can enroll in multiple courses.
- A professor can teach multiple courses.
- A student can learn from multiple professors.

Student_ID	Course_ID	Professor_ID
101	C01	P01
101	C02	P02
102	C01	P01
102	C03	P03

Issue (Join Dependency):

- This table is **not in 5NF** because there is a **many-to-many relationship** between Students, Courses, and Professors.

- If a professor no longer teaches a course, deleting a row might remove information about the student's enrollment, leading to **data loss**.

Normalization

Example (After Applying 5NF - Removing Join Dependency)

We decompose the table into three smaller tables:

STUDENT_COURSE Table

Course_ID	Professor_ID
C01	P01
C02	P02
C03	P03

COURSE_PROFESSOR Table

Student_ID	Course_ID
101	C01
101	C02
102	C01
102	C03

STUDENT_PROFESSOR Table

Student_ID	Professor_ID
101	P01
101	P02
102	P01
102	P03

- **Eliminates redundancy by breaking down complex many-to-many relationships.**
- **Ensures lossless join decomposition** (We can reconstruct the original table by joining these tables).
- **Avoids unnecessary duplication of data.**

Normalization

What is Lossless Decomposition?

Lossless decomposition ensures that when a table is split into smaller tables, no data is lost, and we can reconstruct the original table by joining the decomposed tables.

A decomposition is lossless if the natural join of the decomposed tables results in the original table without any extra or missing tuples.

To verify that this decomposition is lossless, we join the decomposed tables:

Performing Natural Joins

- Join STUDENT_COURSE and COURSE_PROFESSOR on Course_ID:
  - This gives us a table with (Student_ID, Course_ID, Professor_ID), but it might have extra rows.
- Join the result with STUDENT_PROFESSOR on (Student_ID, Professor_ID).

If we get back the original STUDENT_COURSE_PROFESSOR table exactly as it was, the decomposition is lossless.

Since our decomposition maintains all relationships and allows perfect reconstruction of the original table, this decomposition is lossless.

Minimal/Canonical Cover (Fc) of FDs

Minimal Cover/Canonical Cover (also called **Minimal Basis**) of a set of **functional dependencies (FDs)** is an **equivalent** set of FDs that is:

- **Minimal** – It has the smallest number of FDs.
- **Canonical** – The right-hand side of each FD contains **only one attribute**.
- **Irredundant** – No FD is unnecessary (i.e., no FD can be derived from others).

Steps to Find Minimal Cover

To find the minimal cover for a set of functional dependencies, follow these steps:

- **Make RHS Atomic** – Ensure that each FD has a **single attribute** on the right-hand side.
- **Remove Extraneous Attributes** – Eliminate unnecessary attributes from the left-hand side.
- **Remove Redundant FDs** – Delete redundant functional dependencies.

Minimal/Canonical Cover (Fc) of FDs

Example 1

Consider a relation R(A, B, C, D) with the following functional dependencies:

$F=\{A \rightarrow BC, B \rightarrow C, A \rightarrow B, AB \rightarrow C\}$

Step 1: Make RHS Atomic

Each FD should have only one attribute on the right-hand side.

A → BC can be split into:

A → B

A → C

Now, our set becomes:

$F=\{A \rightarrow B, A \rightarrow C, B \rightarrow C, A \rightarrow B, AB \rightarrow C\}$

(Remove duplicate A → B)$F=\{A \rightarrow B, A \rightarrow C, B \rightarrow C, AB \rightarrow C\}$

Minimal/Canonical Cover (Fc) of FDs

Step 2: Remove Extraneous Attributes

A left-side attribute is extraneous if removing it does not change the closure of the set.

Check if **AB → C** can be simplified:

Compute A+ (closure of A):

A → B (so, **A+ = {A, B}**)

B → C (so, **A+ = {A, B, C}**)

Since A+ already contains C, AB → C is redundant.

Remove AB → C, leaving: $F=\{A \rightarrow B, A \rightarrow C, B \rightarrow C\}$

Step 3: Remove Redundant FDs

An FD **X → Y** is redundant if **Y** can be derived from other FDs.

Check if **A → C** is redundant:

Compute **A+** using **A → B** and **B → C**:

A → B (so, **A+ = {A, B}**)

B → C (so, **A+ = {A, B, C}**)

Since **C** is already in **A+**, **A → C** is redundant.

Remove **A → C**, leaving:

F_{min}={A→B,B→C}

Minimal/Canonical Cover (Fc) of FDs

Example 2

Consider a relation R(X, Y, Z, W, V) with the following functional dependencies:

F={XZ→YW, Y→W, X→Y, XW→V}

Find the **Minimal Cover F_{min}** by following these steps:

1. Make RHS atomic (Each FD should have only one attribute on the right-hand side).
2. Remove extraneous attributes from LHS.
3. Remove redundant FDs to get the minimal cover.

Step 1: Make RHS Atomic

Each FD should have only one attribute on the right-hand side.

XZ → YW can be split into:

XZ → Y

XZ → W

Now, the new set of **F** is:

F={XZ→Y, XZ→W, Y→W, X→Y, XW→V}

Now, all FDs have atomic RHS.

Minimal/Canonical Cover (Fc) of FDs

Step 2: Remove Extraneous Attributes from LHS

Now, check if any attribute in LHS is unnecessary.

Check if Z is extraneous in XZ → Y:

Compute $\mathbf{X^+}$ (closure of X) using remaining FDs:

X → Y (Given)

Y → W (Given)

$\mathbf{X^+ = \{X, Y, W\}}$

Since X alone can determine Y, **XZ → Y** can be reduced to **X → Y**.

Updated FDs after removal:

F={X→Y, XZ→W, Y→W, XW→V}

Check if Z is extraneous in XZ → W:

Compute $\mathbf{X^+}$:

X → Y

Y → W

$\mathbf{X^+ = \{X, Y, W\}}$

Since X alone can determine W, **XZ → W** is redundant and can be removed.

Updated FDs after removal:

F={X→Y,Y→W,XW→V}

Now, no extraneous attributes in LHS.

Minimal/Canonical Cover (Fc) of FDs

Step 3: Remove Redundant FDs

Check if X → Y is redundant:

We need **Y** to determine **W**, so **X → Y** is required.

Not redundant.

Check if Y → W is redundant:

If we remove **Y → W**, then we can't derive W from X.

Not redundant.

Check if XW → V is redundant:

If we remove **XW → V**, then V cannot be derived.

Not redundant.

No redundant FDs left.

Final Minimal Cover F_{min}

F_{min}={X→Y, Y→W, XW→V}

Dangling Tuple

A dangling tuple in DBMS refers to a tuple (row) in a database that does not have a valid reference in another related table due to referential integrity violations. This typically happens in foreign key constraints, where a foreign key in one table refers to a primary key in another table, but the referenced primary key does not exist.

Causes of Dangling Tuples:

- **Deletion of a Referenced Tuple** – If a referenced row (primary key) in the parent table is deleted, but the foreign key in the child table still refers to it.
- **Insertion of an Invalid Foreign Key** – If a tuple with a foreign key is inserted into a table, but the referenced primary key does not exist in the parent table.
- **Update Anomalies** – If the value of the referenced primary key is updated, making existing foreign key references invalid.

Dangling Tuple

Example:

Parent Table (Department)

Dept_ID (Primary Key)	Dept_Name
101	CSE
102	ECE

Child Table (Student)

Student_ID	Name	Dept_ID (Foreign Key)
1	Alex	101
2	Bob	103

In the above example, the Student table has a **dangling tuple** because **Dept_ID = 103 does not exist** in the Department table.

Dangling Tuple

Causes of Dangling Tuples

1. **Deletion of the referenced row** in the parent table (DELETE FROM Departments WHERE Dept_ID = 101;).

2. **Insertion of an invalid foreign key** in the child table (INSERT INTO Students VALUES (3, 'Charlie', 104); where 104 does not exist).

3. **Updating the primary key** in the parent table, making foreign key references invalid.

Prevention Methods:

1. **ON DELETE CASCADE** – Automatically deletes dependent rows when the referenced row is deleted.
2. **ON DELETE SET NULL** – Sets foreign key values to NULL if the referenced row is deleted.
3. **Foreign Key Constraints** – Ensure referential integrity by preventing invalid insertions.
4. **Triggers** – Custom database triggers can be used to handle integrity checks.

Canonical Cover (Fc) of FDs

Consider two sets of FDs

F = { A→B, AB →C, D→AC, D→E}

G= { A→BC, D→AB}

Which one is true?

a) F covers G

b) G covers F

c) F & G are equal

d) None

Let us consider first set of FDs F = { A→B, AB →C, D→AC, D→E}

1. Here given D→AC apply decompose rule D→A, D→C
2. After this FDs are F = { A→B, AB →C, D→A, D→C, D→E}
   Only one FD is a partial FD AB →C where B is extraneous. Because, A+ = AB & B+ = B.

Canonical Cover (Fc) of FDs

3. Now find out redundant FDs

F = { A→B, A →C, D→A, D→C, D→E}

redundant FD can be find out by finding closure of each attribute set of FD, without any help of that FD.

for example:

A→B For this FD calculate A+ and try to derive B from A without help of A→B is it possible? No, then it is non-redundant.

A+ = AC

A→C For this FD calculate A+ and try to derive C from A without help of A→C is it possible? No, then it is non-redundant.

A+ = AB

D→A For this FD calculate D+ and try to derive A from D without help of D→A is it possible? No, then it is non-redundant.

D+ = DCE

D→C For this FD calculate D+ and try to derive C from D without help of D→C is it possible? **Yes, then it is redundant.**

D+ = DAEBC

D→E For this FD calculate D+ and try to derive E from D without help of D→E is it possible? No, then it is non-redundant.

D+ = DACB

Canonical Cover (Fc) of FDs

Hence Fc for given FD set F = { A→B, A →C, D→A, D→C, D→E} is

Fc = { A→B, A →C, D→A, D→E}

Similarly, we'll consider G = { A→BC, D→AB}

1. Here given A→BC, D→AB apply decompose rule A→B, A →C, D→A, D→B
2. After this FDs are G = {A→B, A →C, D→A, D→B}
   Here, No FD has extraneous attribute. Follow third step
3. Now find out redundant FDs
   G = {A→B, A →C, D→A, D→B}
   A→B For this FD calculate A+ and try to derive B from A without help of A→B is it possible? No, then it is non-redundant.
   A+ = AC
   A→C For this FD calculate A+ and try to derive C from A without help of A→C is it possible? No, then it is non-redundant.
   A+ = AB
   D→A For this FD calculate D+ and try to derive A from D without help of D→A is it possible? No, then it is non-redundant.
   D+ = DB
   D→ B For this FD calculate D+ and try to derive C from D without help of D→B is it possible? **Yes, then it is redundant.**
   D+ = DABC

Canonical Cover (Fc) of FDs

Hence Gc for given FD set G = { A→B, A →C, D→A, D→B} is

Gc = { A→B, A →C, D→A}

Now, Compare Fc and Gc

Fc = { A→B, A →C, D→A, D→E}

Gc = { A→B, A →C, D→A}

a) F covers G
b) G covers F
c) F & G are equal
d) None

Answer is d) None

Relational Database Design

The **algorithm for relational database design** involves a series of steps to ensure that the database is well-structured, follows normalization principles, and maintains **data integrity**. The goal is to minimize redundancy, prevent anomalies, and optimize query performance.

Algorithm for Relational Database Design

Step 1: Requirement Analysis

- Identify the data that needs to be stored.
- Determine the relationships among different data entities.
- Understand business rules and constraints.

Step 2: Construct an Entity-Relationship (ER) Model

- Identify **entities** and **attributes**.
- Define **primary keys** for each entity.
- Establish **relationships** (one-to-one, one-to-many, many-to-many).
- Draw an **ER diagram** to visualize data organization.

Step 3: Convert ER Model to Relational Schema

- Convert **entities** into tables.
- Convert **relationships** into foreign key constraints.
- Handle **many-to-many** relationships using bridge tables.

Relational Database Design

Step 4: Define Functional Dependencies

- Identify **functional dependencies** (FDs) among attributes.
- Determine how attributes depend on primary keys.

Step 5: Normalize the Database

- **First Normal Form (1NF)** – Remove duplicate columns and ensure atomicity.
- **Second Normal Form (2NF)** – Ensure no partial dependency on primary keys.
- **Third Normal Form (3NF)** – Ensure no transitive dependencies.
- **Boyce-Codd Normal Form (BCNF)** – Strengthen 3NF if necessary.
- Further normalization (**4NF, 5NF**) if required.

Step 6: Define Integrity Constraints

- **Primary Key Constraint** – Ensure unique identification.
- **Foreign Key Constraint** – Enforce referential integrity.
- **Unique, Not Null, and Check Constraints** – Enforce business rules.

Relational Database Design

Step 7: Indexing and Query Optimization

- Create **indexes** on frequently searched columns.
- Use **denormalization** if necessary for performance tuning.
- Optimize SQL queries for faster execution.

Step 8: Implement the Database

- Use SQL commands (CREATE TABLE, ALTER TABLE, etc.) to implement the schema.
- Load initial data into tables.

Step 9: Test and Validate

- Insert sample data and test constraints.
- Check for anomalies in insertion, deletion, and updates.
- Verify data integrity and consistency.