Relational Data Base Management (RDBMS)

e-NOTES

B.Sc. Computer Science / B.C.A

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UNIT - III: Data Normalization

Pitfalls in relational database design – Decomposition – Functional dependencies – Normalization – First normal form – Second normal form – Third normal form – Boyce-codd normal form – Fourth normal form – Fifth normal form.

University Questions – April 2019 and Nov 2019

2marks (Q.No:5 & 6)

5. Why do we need Normalization? (April 2019)

Answer: "Normalization is a process to eliminate the flaws of a database with bad design". A poorly designed database is inconsistent and create issues while adding, deleting or updating information.

6. Define Referential Integrity.(April 2019)

A REFERENTIAL INTEGRITY is a database concept that is used to build and maintain logical relationships between tables to avoid logical corruption of data. It is a very useful and important part in RDBMS. Usually, referential integrity is made up of the combination of a primary key and a foreign key.

5. What is an integrity constraint? (Nov 2019)

Integrity constraints ensure that the data insertion, updating, and other processes have to be performed in such a way that data integrity is not affected. Thus, integrity constraint is used to guard against accidental damage to the database

6. Why we need normalization?

Answer: "Normalization is a process to eliminate the flaws of a database with bad design". A poorly designed database is inconsistent and create issues while adding, deleting or updating information.

5 marks (Q.No:13 a & b)

a) State BCNF .How does it differ from 3 NF?

b) Discuss the problems caused by redundancy

a) Write short notes on Boyce Codd Normal Form.

b) Find the highest normal form of relation R(A,B,C,D,E) with functional dependency set {A ->D, B->A, BC -> D, AC->BE}

10 Marks (Q.No: 18)

Describe any two normalization forms with necessary examples.

Explain 3NF and BCNF with examples.

Pitfalls in relational database design

Obviously, we can have good and bad designs. Among the undesirable design items are:

- Repetition of information
- Inability to represent certain information

The relation *lending* with the schema is an example of a bad design:

Lending-Schema=(branch-name, branch-city, assets, cutomer-name, loan-number, amount)

branch-name	branch-city	assets	customer-name	loan-number	amount
Downtown	Brooklyn	9000000	Jones	L-17	1000
Redwood	Palo Alto	2100000	Smith	L-23	2000
Perryridge	Horseneck	1700000	Hayes	L-15	1500
Downtown	Brooklyn	9000000	Jackson	L-14	1500
Mianus	Horseneck	400000	Jones	L-93	500
Round Hill	Horseneck	8000000	Turner	L-11	900
Pownal	Bennington	300000	Williams	L-29	1200
North Town	Rye	3700000	Hayes	L-16	1300
Downtown	Brooklyn	9000000	Johnson	L-23	2000
Perryridge	Horseneck	1700000	Glenn	L-25	2500
Brighton	Brooklyn	7100000	Brooks	L-10	2200

Looking at the Downtown and Perryridge, when a new loan is added, the branch-city and assets must be repeated. That makes updating the table more difficult, because the update must guarantee that all tuples are updated. Additional problems come from having two people take out one loan (L-23). More complexity is involved when Jones took out a loan at a second branch (maybe one near home and the other near work.) Notice that there is no way to represent information on a branch unless there is a loan.

Decomposition

Decomposition in DBMS removes redundancy, anomalies and inconsistencies from a database by dividing the table into multiple tables.

The following are the types −

Lossless Decomposition

Decomposition is lossless if it is feasible to reconstruct relation R from decomposed tables using Joins. This is the preferred choice. The information will not lose from the relation when decomposed. The join would result in the same original relation.

Let us see an example −

<EmpInfo>

Emp_ID	Emp_Name	Emp_Age	Emp_Location	Dept_ID	Dept_Name
E001	Jacob	29	Alabama	Dpt1	Operations
E002	Henry	32	Alabama	Dpt2	HR
E003	Tom	22	Texas	Dpt3	Finance

Decompose the above table into two tables:

<EmpDetails>

Emp_ID	Emp_Name	Emp_Age	Emp_Location
E001	Jacob	29	Alabama
E002	Henry	32	Alabama
E003	Tom	22	Texas

<DeptDetails>

Dept_ID	Emp_ID	Dept_Name
Dpt1	E001	Operations
Dpt2	E002	HR
Dpt3	E003	Finance

Now, Natural Join is applied on the above two tables −

The result will be −

Emp_ID	Emp_Name	Emp_Age	Emp_Location	Dept_ID	Dept_Name
E001	Jacob	29	Alabama	Dpt1	Operations
E002	Henry	32	Alabama	Dpt2	HR
E003	Tom	22	Texas	Dpt3	Finance

Therefore, the above relation had lossless decomposition i.e. no loss of information.

Lossy Decomposition

As the name suggests, when a relation is decomposed into two or more relational schemas, the loss of information is unavoidable when the original relation is retrieved.

Let us see an example −

<EmpInfo>

Emp_ID	Emp_Name	Emp_Age	Emp_Location	Dept_ID	Dept_Name
E001	Jacob	29	Alabama	Dpt1	Operations
E002	Henry	32	Alabama	Dpt2	HR
E003	Tom	22	Texas	Dpt3	Finance

Decompose the above table into two tables −

<EmpDetails>

Emp_ID	Emp_Name	Emp_Age	Emp_Location
E001	Jacob	29	Alabama
E002	Henry	32	Alabama
E003	Tom	22	Texas

<DeptDetails>

Dept_ID	Dept_Name
Dpt1	Operations
Dpt2	HR
Dpt3	Finance

Now, you won't be able to join the above tables, since **Emp_ID** isn't part of the **DeptDetails** relation.

Therefore, the above relation has lossy decomposition.

Functional dependencies

What is Functional Dependency?

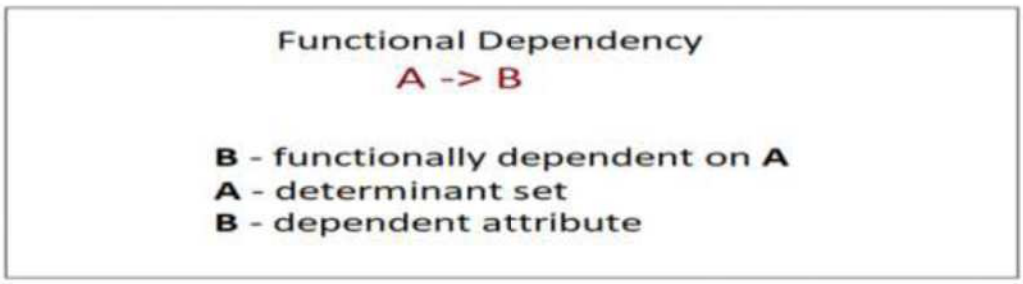
Functional dependency in DBMS, as the name suggests is a relationship between attributes of a table dependent on each other. Introduced by E. F. Codd, it helps in preventing data redundancy and gets to know about bad designs.

To understand the concept thoroughly, let us consider P is a relation with attributes A and B. Functional Dependency is represented by -> (arrow sign)

Then the following will represent the functional dependency between attributes with an arrow sign −

A -> B

Above suggests the following:



Example

The following is an example that would make it easier to understand functional dependency −

We have a **<Department>** table with two attributes − **DeptId** and **DeptName**.

DeptId = Department ID
DeptName = Department Name

The **DeptId** is our primary key. Here, **DeptId** uniquely identifies the **DeptName** attribute. This is because if you want to know the department name, then at first you need to have the **DeptId**.

DeptId	DeptName
001	Finance
002	Marketing
003	HR

Therefore, the above functional dependency between **DeptId** and **DeptName** can be determined as **DeptId** is functionally dependent on **DeptName** −

DeptId -> DeptName

Types of Functional Dependency

Functional Dependency has three forms −

- Trivial Functional Dependency
- Non-Trivial Functional Dependency
- Completely Non-Trivial Functional Dependency

Let us begin with Trivial Functional Dependency −

Trivial Functional Dependency

It occurs when B is a subset of A in −

A ->B

Example

We are considering the same **<Department>** table with two attributes to understand the concept of trivial dependency.

The following is a trivial functional dependency since **DeptId** is a subset of **DeptId** and **DeptName**

{ DeptId, DeptName } -> Dept Id

Non –Trivial Functional Dependency

It occurs when B is not a subset of A in −

A ->B

Example

```
DeptId ->  DeptName
```

The above is a non-trivial functional dependency since DeptName is a not a subset of DeptId.

Completely Non - Trivial Functional Dependency

It occurs when A intersection B is null in −

```
A ->B
```

Armstrong's Axioms Property of Functional Dependency

Armstrong's Axioms property was developed by William Armstrong in 1974 to reason about functional dependencies.

The property suggests rules that hold true if the following are satisfied:

- **Transitivity**
  If A->B and B->C, then A->C i.e. a transitive relation.
- **Reflexivity**
  A-> B, if B is a subset of A.
- **Augmentation**
  The last rule suggests: AC->BC, if A->B

Armstrong's Axioms:

If F is a set of functional dependencies then the closure of F, denoted as F^+, is the set of all functional dependencies logically implied by F. Armstrong's Axioms are a set of rules, that when applied repeatedly, generates a closure of functional dependencies.

- **Reflexive rule** − If alpha is a set of attributes and beta is_subset_of alpha, then alpha holds beta.
- **Augmentation rule** − If a → b holds and y is attribute set, then ay → by also holds. That is adding attributes in dependencies, does not change the basic dependencies.
- **Transitivity rule** − Same as transitive rule in algebra, if a → b holds and b → c holds, then a → c also holds. a → b is called as a functionally that determines b.

Trivial Functional Dependency

- **Trivial** − If a functional dependency (FD) X → Y holds, where Y is a subset of X, then it is called a trivial FD. Trivial FDs always hold.
- **Non-trivial** − If an FD X → Y holds, where Y is not a subset of X, then it is called a non-trivial FD.
- **Completely non-trivial** − If an FD X → Y holds, where x intersect Y = Φ, it is said to be a completely non-trivial FD.

Normalization

Normalization is a process to eliminate the flaws of a database with bad design. A poorly designed database is inconsistent and create issues while adding, deleting or updating information.

The following makes Database Normalization a crucial step in database design process −

Resolving the database anomalies

The forms of Normalization i.e. 1NF, 2NF, 3NF, BCF, 4NF and 5NF remove all the Insert, Update and Delete anomalies.

Insertion Anomaly occurs when you try to insert data in a record that does not exist.

Deletion Anomaly is when a data is to be deleted and due to the poor deign of database, other record also deletes.

Eliminate Redundancy of Data

Storing same data item multiple times is known as Data Redundancy. A normalized table do not have the issue of redundancy of data.

Data Dependency

The data gets stored in the correct table and ensures normalization.

Isolation of Data

A good designed database states that the changes in one table or field do not affect other. This is achieved through Normalization.

Data Consistency

While updating if a record is left, it can led to inconsistent data, Normalization resolves it and ensures Data Consistency.

First normal form (1-NF)

First Normal Form (1 NF)

First Normal Form is defined in the definition of relations (tables) itself. This rule defines that all the attributes in a relation must have atomic domains. The values in an atomic domain are indivisible units.

Course	Content
Programming	Java, c++
Web	HTML, PHP, ASP

We re-arrange the relation (table) as below, to convert it to First Normal Form.

Course	Content
Programming	Java
Programming	c++
Web	HTML
Web	PHP
Web	ASP

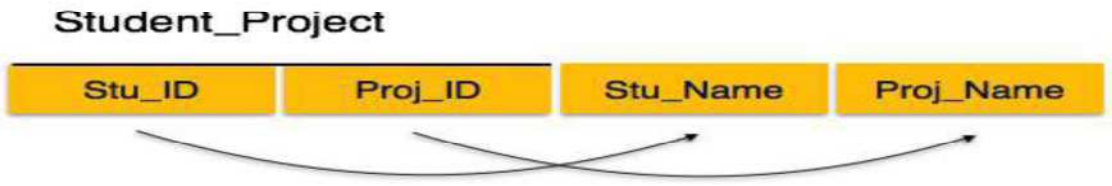
Each attribute must contain only a single value from its pre-defined domain.

Second normal form (2-NF)

Before we learn about the second normal form, we need to understand the following −

- **Prime attribute** − An attribute, which is a part of the candidate-key, is known as a prime attribute.
- **Non-prime attribute** − An attribute, which is not a part of the prime-key, is said to be a non-prime attribute.

If we follow second normal form, then every non-prime attribute should be fully functionally dependent on prime key attribute. That is, if X → A holds, then there should not be any proper subset Y of X, for which Y → A also holds true.



We see here in Student_Project relation that the prime key attributes are Stu_ID and Proj_ID. According to the rule, non-key attributes, i.e. Stu_Name and Proj_Name must be dependent upon both and not on any of the prime key attribute individually. But we find that Stu_Name can be identified by Stu_ID and Proj_Name can be identified by Proj_ID independently. This is called **partial dependency**, which is not allowed in Second Normal Form.

We broke the relation in two as depicted in the above picture. So there exists no partial dependency.

Third normal form (3-NF)

For a relation to be in Third Normal Form, it must be in Second Normal form and the following must satisfy −

- No non-prime attribute is transitively dependent on prime key attribute.
- For any non-trivial functional dependency, X → A, then either −
  - X is a superkey or,
  - A is prime attribute.

We find that in the above Student_detail relation, Stu_ID is the key and only prime key attribute. We find that City can be identified by Stu_ID as well as Zip itself. Neither Zip is a superkey nor is City a prime attribute. Additionally, Stu_ID → Zip → City, so there exists **transitive dependency**.

To bring this relation into third normal form, we break the relation into two relations as follows −

Boyce-codd normal form(BCNF)

Boyce-Codd Normal Form (BCNF) is an extension of Third Normal Form on strict terms. BCNF states that −

- For any non-trivial functional dependency, X → A, X must be a super-key.

In the above image, Stu_ID is the super-key in the relation Student_Detail and Zip is the super-key in the relation ZipCodes. So,

Stu_ID → Stu_Name, Zip

and

Zip → City

Which confirms that both the relations are in BCNF.

Boyce Codd normal form (BCNF)

- BCNF is the advance version of 3NF. It is stricter than 3NF.
- A table is in BCNF if 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_COUNTRY	EMP_DEPT	DEPT_TYPE	EMP_DEPT_NO
264	India	Designing	D394	283
264	India	Testing	D394	300
364	UK	Stores	D283	232
364	UK	Developing	D283	549

In the above table Functional dependencies are as follows:

1. EMP_ID → EMP_COUNTRY
2. 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
Testing	D394	300
Stores	D283	232
Developing	D283	549

EMP_DEPT_MAPPING table:

EMP_ID	EMP_DEPT
D394	283
D394	300
D283	232
D283	549

Functional dependencies:

1. EMP_ID → EMP_COUNTRY
2. EMP_DEPT → {DEPT_TYPE, EMP_DEPT_NO}

Candidate keys:

For the first table: EMP_ID
For the second table: EMP_DEPT
For the third table: {EMP_ID, EMP_DEPT}

Now, this is in BCNF because left side part of both the functional dependencies is a key.

Fourth normal form (4-NF)

What is 4NF?

The 4NF comes after 1NF, 2NF, 3NF, and Boyce-Codd Normal Form. It was introduced by Ronald Fagin in 1977.

To be in 4NF, a relation should be in Bouce-Codd Normal Form and may not contain more than one multi-valued attribute.

Example

Let us see an example −

<Movie>

Movie_Name	Shooting_Location	Listing
MovieOne	UK	Comedy
MovieOne	UK	Thriller
MovieTwo	Australia	Action
MovieTwo	Australia	Crime
MovieThree	India	Drama

The above is not in 4NF, since

- More than one movie can have the same listing
- Many shooting locations can have the same movie

Let us convert the above table in 4NF −

<Movie_Shooting>

Movie_Name	Shooting_Location
MovieOne	UK
MovieOne	UK
MovieTwo	Australia
MovieTwo	Australia
MovieThree	India

<Movie_Listing>

Movie_Name	Listing
MovieOne	Comedy

MovieOne	Thriller
MovieTwo	Action
MovieTwo	Crime
MovieThree	Drama

Now the violation is removed and the tables are in 4NF.

Fifth normal form (5-NF)

The 5NF (Fifth Normal Form) is also known as project-join normal form. A relation is in Fifth Normal Form (5NF), if it is in 4NF, and won't have lossless decomposition into smaller tables.

You can also consider that a relation is in 5NF, if the candidate key implies every join dependency in it.

Example

The below relation violates the Fifth Normal Form (5NF) of Normalization −

<Employee>

EmpName	**EmpSkills**	**EmpJob** (Assigned Work)
David	Java	E145
John	JavaScript	E146
Jamie	jQuery	E146
Emma	Java	E147

The above relation can be decomposed into the following three tables; therefore, it is not in 5NF −

<EmployeeSkills>

EmpName	**EmpSkills**
David	Java
John	JavaScript
Jamie	jQuery
Emma	Java

The following is the <EmployeeJob> relation that displays the jobs assigned to each employee −

<EmployeeJob>

EmpName	**EmpJob**
David	E145
John	E146
Jamie	E146
Emma	E147

Here is the skills that are related to the assigned jobs −

<JobSkills>

EmpSkills	EmpJob
Java	E145
JavaScript	E146
jQuery	E146
Java	E147

Our Join Dependency −

{(EmpName, EmpSkills), (EmpName, EmpJob), (EmpSkills, EmpJob)}

The above relations have join dependency, so they are not in 5NF. That would mean that a join relation of the above three relations is equal to our original relation **<Employee>**.

UNIT- V: Query Processing and Transaction Management

Query Processing - Transaction Concept - Concurrency Control - Locks based protocol Deadlock Handling -Recovery Systems.

Query Processing

Query processing refers to the range of activities involved in extracting data from a database. The activities include translation of queries in high-level database languages into expressions that can be used at the physical level of the file system, a variety of query-optimizing transformations, and actual evaluation of queries.

The steps involved in query processing is shown in the below Figure 12.1.The basic steps are:

1. Parsing and translation.
2. Optimization.
3. Evaluation.

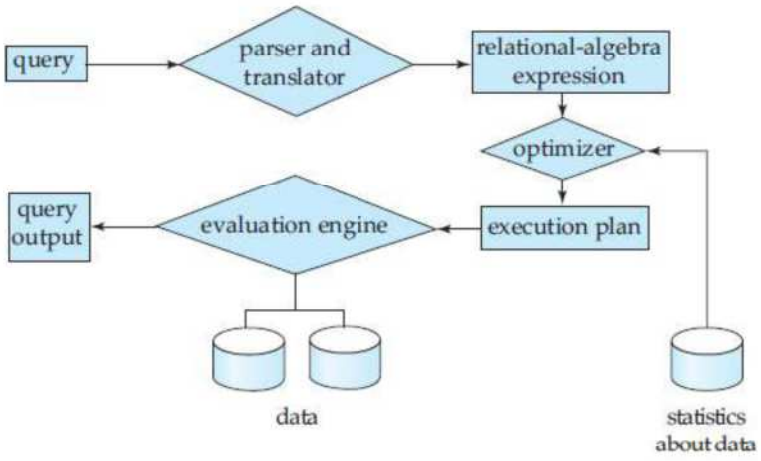


Figure 12.1 Steps in query processing.

Before query processing can begin, the system must translate the query into a usable form. A language such as SQL is suitable for human use, but is ill suited to be the system's internal representation of a query. A more useful internal representation is one based on the extended relational algebra.

Thus, the first action the system must take in query processing is to translate a given query into its internal form. This translation process is similar to the work performed by the parser of a compiler. In generating the internal form of the query, the parser checks the syntax of the user's query, verifies that the relation names appearing in the query are names of the relations in the database, and so on. The system constructs a parse-tree representation of the query, which it then translates into a relational-algebra expression.

If the query was expressed in terms of a view, the translation phase also replaces all uses of the view by the relational-algebra expression that defines the view. Most compiler texts cover parsing in detail.

Given a query, there are generally a variety of methods for computing the answer. For

example, we have seen that, in SQL, a query could be expressed in several different ways. Each SQL query can itself be translated into a relational- algebra expression in one of several ways. Furthermore, the relational-algebra representation of a query specifies only partially how to evaluate a query; there are usually several ways to evaluate relational-algebra expressions. As an illustration, consider the query:

select *salary* **from** *instructor* **where** *salary* < 75000;

This query can be translated into either of the following relational-algebra expressions:

$\sigma_{salary < 75000}(\Pi_{salary}(instructor))$
$\Pi_{salary}(\sigma_{salary < 75000}(instructor))$

Further, we can execute each relational-algebra operation by one of several different algorithms. For example, to implement the preceding selection, we can search every tuple in *instructor* to find tuples with salary less than 75000. If a B^+-tree index is available on the attribute *salary*, we can use the index instead to locate the tuples.

To specify fully how to evaluate a query, we need not only to provide the relational-algebra expression, but also to annotate it with instructions specifying how to evaluate each operation. Annotations may state the algorithm to be used for a specific operation, or the particular index or indices to use. A relational- algebra operation annotated with instructions on how to evaluate it is called an**evaluation primitive**.

A sequence of primitive operations that can be used to evaluate a query is a **query-execution plan** or **query-evaluation plan**. Figure 12.2illustrates an evaluation plan for our example query, in which a particular index (denoted in the figure as "index 1") is specified for the selection operation. The **query-execution engine** takes a query-evaluation plan, executes that plan, andreturns the answers to the query.

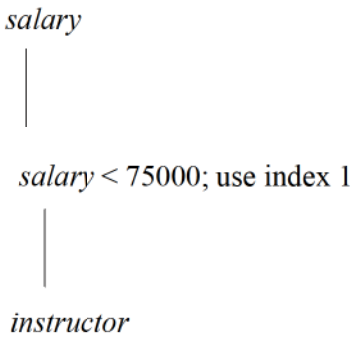


Figure 12.2 A query-evaluation plan.

The different evaluation plans for a given query can have different costs. We do not expect users to write their queries in a way that suggests the most efficient evaluation plan. Rather, it is the responsibility of the system to construct a query- evaluation plan that minimizes the cost of query evaluation; this task is called *query optimization*

Once the query plan is chosen, the query is evaluated with that plan, and the result of the Query is output

Transaction Concept

A **transaction** is a **unit** of program execution that accesses and possibly updates various data items.

Usually, a transaction is initiated by a user program written in a high-level data-manipulation language (typically SQL), or programming language (for example, C++, or Java), with embedded database accesses in JDBC or ODBC.

A transaction is delimited by statements (or function calls) of the form **begin transaction** and **end transaction**. The transaction consists of all operations executed between the **begin transaction** and **end transaction.**

This collection of steps must appear to the user as a single, indivisible unit. Since a transaction is indivisible, it either executes in its entirety or not at all. Thus, if a transaction begins to execute but fails for whatever reason, any changes to the database that the transaction may have made must be undone. This requirement holds regardless of whether the transaction itself failed (for example, if it divided by zero), the operating system crashed, or the computer itself stopped operating. As we shall see, ensuring that this requirement is met is difficult since some changes to the database may still be stored only in the main-memory variables of the transaction, while others may have been written to the database and storedon disk. This "all-or-none" property is referred to as **atomicity**.

Furthermore, since a transaction is a single unit, its actions cannot appear to be separated by other database operations not part of the transaction. While we wish to present this user-level impression of transactions, we know that reality is quite different. Even a single SQL statement involves many separate accesses to the database, and a transaction may consist of several SQL statements. Therefore, the database system must take special actions to ensure that transactions operate properly without interference from concurrently executing database statements. This property is referred to as **isolation**.

Even if the system ensures correct execution of a transaction, this serves little purpose if the system subsequently crashes and, as a result, the system "forgets" about the transaction. Thus, a transaction's actions must persist across crashes. This property is referred to as **durability**.

Because of the above three properties, transactions are an ideal way of struc- turing interaction with a database. This leads us to impose a requirement on transactions themselves. A transaction must preserve database consistency — if a transaction is run atomically in isolation starting from a consistent database, the database must again be consistent at the end of the transaction. This consistency requirement goes beyond the data integrity constraints we have seen earlier (such as primary-key constraints, referential integrity, **check** constraints, and the like). Rather, transactions are expected to go beyond that to ensure preservation of those application-dependent consistency constraints that are too complex to state using the SQL constructs for data integrity. How this is done is the

responsibility of the programmer who codes a transaction. This property is referred to as **consistency**

To restate the above more concisely, we require that the database system

maintain the following properties of the transactions:

- **Atomicity**. Either all operations of the transaction are reflected properly in the database, or none are.
- **Consistency**. Execution of a transaction in isolation (that is, with no other transaction executing concurrently) preserves the consistency of the database.
- **Isolation**. Even though multiple transactions may execute concurrently, the system guarantees that, for every pair of transactions T_i and T_j, it appears to T_i that either T_j finished execution before T_i started or T_j started execution after T_i finished. Thus, each transaction is unaware of other transactions executing concurrently in the system.
- **Durability**. After a transaction completes successfully, the changes it has made to the database persist, even if there are system failures

Concurrency Control

Concurrency control concept comes under the Transaction in database management system (DBMS). It is a procedure in DBMS which helps us for the management of two simultaneous processes to execute without conflicts between each other, these conflicts occur in multi user systems.

Concurrency can simply be said to be executing multiple transactions at a time. It is required to increase time efficiency. If many transactions try to access the same data, then inconsistency arises. Concurrency control required to maintain consistency data.

For example, if we take ATM machines and do not use concurrency, multiple persons cannot draw money at a time in different places. This is where we need concurrency.

Advantages

The advantages of concurrency control are as follows −

- Waiting time will be decreased.
- Response time will decrease.
- Resource utilization will increase.
- System performance & Efficiency is increased.

Control concurrency

The simultaneous execution of transactions over shared databases can create several data integrity and consistency problems.

For example, if too many people are logging in the ATM machines, serial updates and synchronization in the bank servers should happen whenever the transaction is done, if not it gives wrong information and wrong data in the database.

Main problems in using Concurrency

The problems which arise while using concurrency are as follows −

- **Updates will be lost** − One transaction does some changes and another transaction

deletes that change. One transaction nullifies the updates of another transaction.

- **Uncommitted Dependency or dirty read problem** − On variable has updated in one transaction, at the same time another transaction has started and deleted the value of the variable there the variable is not getting updated or committed that has been done

on the first transaction this gives us false values or the previous values of the variables this is a major problem.

- **Inconsistent retrievals** − One transaction is updating multiple different variables, another transaction is in a process to update those variables, and the problem occurs is inconsistency of the same variable in different instances.

Concurrency control techniques

The concurrency control techniques are as follows −

Locking

Lock guaranties exclusive use of data items to a current transaction. It first accesses the data items by acquiring a lock, after completion of the transaction it releases the lock.

Types of Locks

The types of locks are as follows −

- Shared Lock [Transaction can read only the data item values]
- Exclusive Lock [Used for both read and write data item values]

Time Stamping

Time stamp is a unique identifier created by DBMS that indicates relative starting time of a transaction. Whatever transaction we are doing it stores the starting time of the transaction and denotes a specific time.

This can be generated using a system clock or logical counter. This can be started whenever a transaction is started. Here, the logical counter is incremented after a new timestamp has been assigned.

Optimistic

It is based on the assumption that conflict is rare and it is more efficient to allow transactions to proceed without imposing delays to ensure serializability.

Locks based protocol

In this type of protocol, any transaction cannot read or write data until it acquires an appropriate lock on it. There are two types of lock:

1. Shared lock:

- It is also known as a Read-only lock. In a shared lock, the data item can only read by the transaction.
- It can be shared between the transactions because when the transaction holds a lock, then it can't update the data on the data item.

2. Exclusive lock:

- In the exclusive lock, the data item can be both reads as well as written by the transaction.
- This lock is exclusive, and in this lock, multiple transactions do not modify the same data simultaneously.

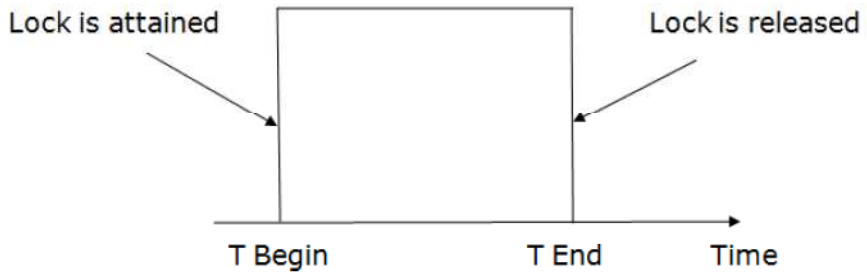
There are four types of lock protocols available:

1. Simplistic lock protocol

It is the simplest way of locking the data while transaction. Simplistic lock-based protocols allow all the transactions to get the lock on the data before insert or delete or update on it. It will unlock the data item after completing the transaction.

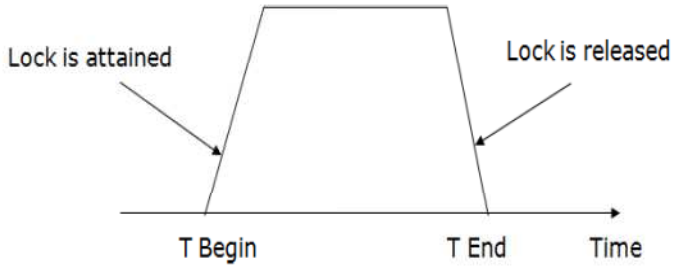
2. Pre-claiming Lock Protocol

- Pre-claiming Lock Protocols evaluate the transaction to list all the data items on which they need locks.
- Before initiating an execution of the transaction, it requests DBMS for all the lock on all those data items.
- If all the locks are granted then this protocol allows the transaction to begin. When the transaction is completed then it releases all the lock.
- If all the locks are not granted then this protocol allows the transaction to rolls back and waits until all the locks are granted.



3. Two-phase locking (2PL)

- The two-phase locking protocol divides the execution phase of the transaction into three parts.
- In the first part, when the execution of the transaction starts, it seeks permission for the lock it requires.
- In the second part, the transaction acquires all the locks. The third phase is started as soon as the transaction releases its first lock.
- In the third phase, the transaction cannot demand any new locks. It only releases the acquired locks.



There are two phases of 2PL:

Growing phase: In the growing phase, a new lock on the data item may be acquired by the transaction, but none can be released.

Shrinking phase: In the shrinking phase, existing lock held by the transaction may be released, but no new locks can be acquired.

In the below example, if lock conversion is allowed then the following phase can happen:

1. Upgrading of lock (from S(a) to X (a)) is allowed in growing phase.
2. Downgrading of lock (from X(a) to S(a)) must be done in shrinking phase.

Example:

	T1	T2
0	LOCK-S(A)	
1		LOCK-S(A)
2	LOCK-X(B)	
3	——	——
4	UNLOCK(A)	
5		LOCK-X(C)
6	UNLOCK(B)	
7		UNLOCK(A)
8		UNLOCK(C)
9	——	——

The following way shows how unlocking and locking work with 2-PL.

Transaction T1:

- **Growing phase:** from step 1-3

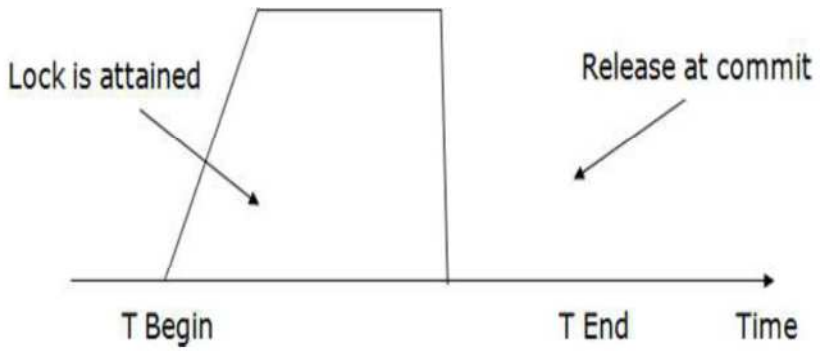
- **Shrinking phase:** from step 5-7
- **Lock point:** at 3

Transaction T2:

- **Growing phase:** from step 2-6
- **Shrinking phase:** from step 8-9
- **Lock point:** at 6

4. Strict Two-phase locking (Strict-2PL)

- The first phase of Strict-2PL is similar to 2PL. In the first phase, after acquiring all the locks, the transaction continues to execute normally.
- The only difference between 2PL and strict 2PL is that Strict-2PL does not release a lock after using it.
- Strict-2PL waits until the whole transaction to commit, and then it releases all the locks at a time.
- Strict-2PL protocol does not have shrinking phase of lock release.



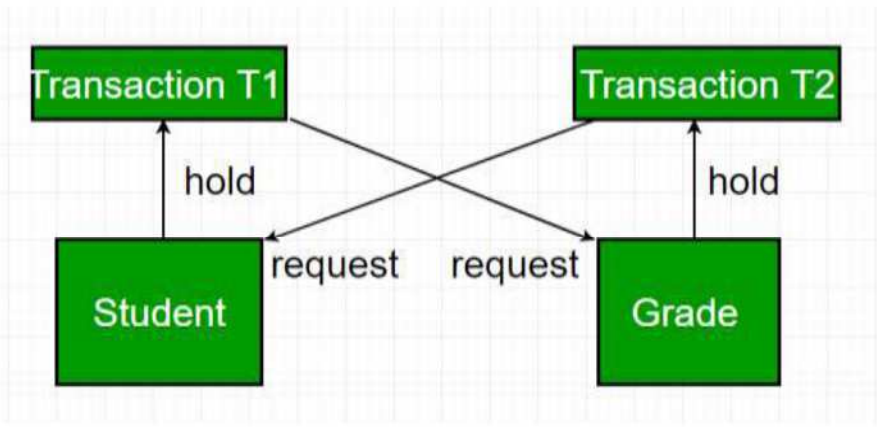
It does not have cascading abort as 2PL does.

Deadlock Handling

In a database, a deadlock is an unwanted situation in which two or more transactions are waiting indefinitely for one another to give up locks. Deadlock is said to be one of the most feared complications in DBMS as it brings the whole system to a Halt.

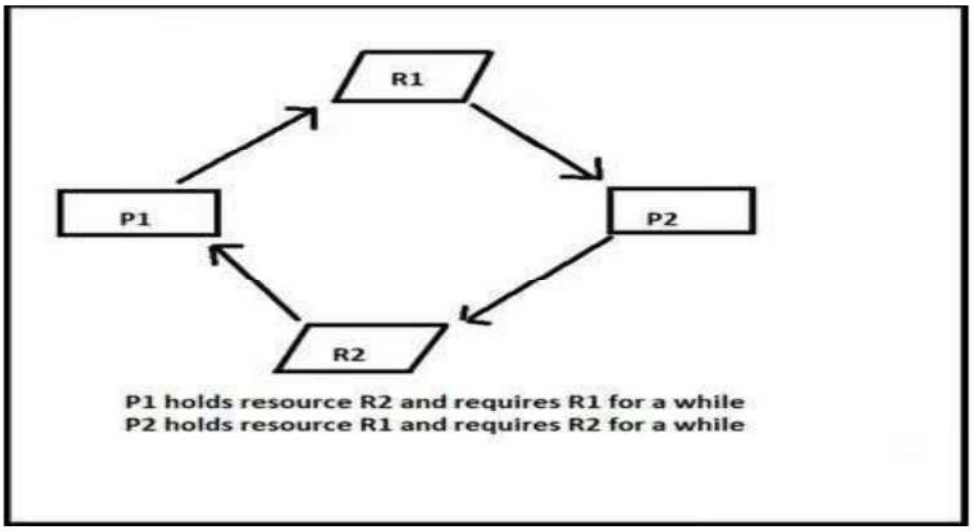
Example – let us understand the concept of Deadlock with an example :
Suppose, Transaction T1 holds a lock on some rows in the Students table and **needs to update** some rows in the Grades table. Simultaneously, Transaction **T2 holds** locks on those very rows (Which T1 needs to update) in the Grades table **but needs** to update the rows in the Student table **held by Transaction T1**.

Now, the main problem arises. Transaction T1 will wait for transaction T2 to give up the lock, and similarly, transaction T2 will wait for transaction T1 to give up the lock. As a consequence, All activity comes to a halt and remains at a standstill forever unless the DBMS detects the deadlock and aborts one of the transactions.



Deadlock in DBMS

Deadlock : deadlock is a condition wherein two or more tasks are waiting for each other in order to be finished but none of the task is willing to give up the resources that other task needs. In this situation no task ever gets finished and is in waiting state forever.



Example of Deadlock

- A real-world example would be traffic, which is going only in one direction.
- Here, a bridge is considered a resource.
- So, when Deadlock happens, it can be easily resolved if one car backs up (Preempt resources and rollback).
- Several cars may have to be backed up if a deadlock situation occurs.So starvation is possible.

Deadlock Avoidance : When a database is stuck in a deadlock state, then it is better to avoid the database rather than aborting or restating the database. This is a waste of time and resource.

Deadlock avoidance mechanism is used to detect any deadlock situation in advance. A method like "wait for graph" is used for detecting the deadlock situation but this method is

suitable only for the smaller database. For the larger database, deadlock prevention method can be used.

Another method for avoiding deadlock is to apply both row level locking mechanism and READ COMMITTED isolation level. However, It does not guarantee to remove deadlocks completely.

Deadlock can be avoided if resources are allocated in such a way that it avoids the deadlock occurrence. There are two algorithms for deadlock avoidance.

- Wait/Die
- Wound/Wait

Here is the table representation of resource allocation for each algorithm. Both of these algorithms take process age into consideration while determining the best possible way of resource allocation for deadlock avoidance.

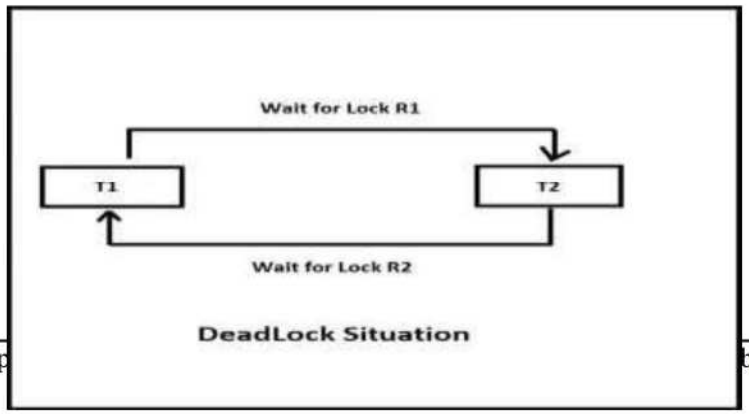
	Wait Die	**Wound Wait**
Older process needs a resource held by younger process	Older process waits	Younger process dies
Younger process needs a resource held by older process	Younger process dies	Younger process waits

Deadlock Detection : When a transaction waits indefinitely to obtain a lock, The database management system should detect whether the transaction is involved in a deadlock or not.

Resource scheduler is one that keeps the track of resources allocated to and requested by processes. Thus, if there is a deadlock it is known to the resource scheduler. This is how a deadlock is detected. Once a deadlock is detected it is being corrected by following methods:

- **Terminating processes involved in deadlock:** Terminating all the processes involved in deadlock or terminating process one by one until deadlock is resolved can be the solutions but both of these approaches are not good. Terminating all processes cost high and partial work done by processes gets lost. Terminating one by one takes lot of time because each time a process is terminated, it needs to check whether the deadlock is resolved or not. Thus, the best approach is considering process age and priority while terminating them during a deadlock condition.
- **Resource Preemption :** Another approach can be the Preemption of resources and allocation of them to the other processes until the deadlock is resolved.

Wait-for-graph is one of the methods for detecting the deadlock situation. This method is suitable for smaller database. In this method a graph is drawn based on the transaction and their lock on the resource. If the graph created has a closed loop or a cycle, then there is a deadlock.



Deadlock Prevention : Deadlock prevention method is suitable for a large database. If the resources are allocated in such a way that deadlock never occurs, then the deadlock can be prevented.

- **Mutual Exclusion** - At least one resource must be held in a non-sharable mode; If any other process requests this resource, then that process must wait for the resource to be released.
- **Hold and Wait** - A process must be simultaneously holding at least one resource and waiting for at least one resource that is currently being held by some other process.
- **No preemption** - Once a process is holding a resource (i.e. once its request has been granted), then that resource cannot be taken away from that process until the process voluntarily releases it.
- **Circular Wait** - A set of processes { P0, P1, P2, . . ., PN } must exist such that every P[i] is waiting for P[(i + 1) % (N + 1)]. (Note that this condition implies the hold-and-wait condition, but it is easier to deal with the conditions if the four are considered separately.)

Wait-Die scheme: In this scheme, if a transaction requests for a resource which is already held with a conflicting lock by another transaction then the DBMS simply checks the timestamp of both transactions. It allows the older transaction to wait until the resource is available for execution.

Let's assume there are two transactions Ti and Tj and let TS(T) is a timestamp of any transaction T. If T2 holds a lock by some other transaction and T1 is requesting for resources held by T2 then the following actions are performed by DBMS:

1. Check if TS(Ti) < TS(Tj) - If Ti is the older transaction and Tj has held some resource, then Ti is allowed to wait until the data-item is available for execution. That means if the older transaction is waiting for a resource which is locked by the younger transaction, then the older transaction is allowed to wait for resource until it is available.

2. Check if TS(Ti) < TS(Tj) - If Ti is older transaction and has held some resource and if Tj is waiting for it, then Tj is killed and restarted later with the random delay but with the same timestamp.

Wound wait scheme : In wound wait scheme, if the older transaction requests for a resource which is held by the younger transaction, then older transaction forces younger one to kill the transaction and release the resource. After the minute delay, the younger transaction is restarted but with the same timestamp. If the older transaction has held a resource which is requested by the Younger transaction, then the younger transaction is asked to wait until older releases it.

Recovery Systems

Database recovery is the process of restoring the database to a correct (consistent) state in the event of a failure. In other words, it is the process of restoring the database to the most recent consistent state that existed shortly before the time of system failure. The failure may be the result of a system crash due to hardware or software errors, a media failure such as head crash, or a software error in the application such as a logical error in the program that

is accessing the database. Recovery restores a database form a given state, usually inconsistent, to a previously consistent state.

Crash Recovery

DBMS is a highly complex system with hundreds of transactions being executed every second. The durability and robustness of a DBMS depends on its complex architecture and its underlying hardware and system software. If it fails or crashes amid transactions, it is expected that the system would follow some sort of algorithm or techniques to recover lost data.

Failure Classification

To see where the problem has occurred, we generalize a failure into various categories, as follows −

Transaction failure

A transaction has to abort when it fails to execute or when it reaches a point from where it can't go any further. This is called transaction failure where only a few transactions or processes are hurt.

Reasons for a transaction failure could be −

- **Logical errors** − Where a transaction cannot complete because it has some code error or any internal error condition.
- **System errors** − Where the database system itself terminates an active transaction because the DBMS is not able to execute it, or it has to stop because of some system condition. For example, in case of deadlock or resource unavailability, the system aborts an active transaction.

System Crash

There are problems − external to the system − that may cause the system to stop abruptly and cause the system to crash. For example, interruptions in power supply may cause the failure of underlying hardware or software failure.

Examples may include operating system errors.

Disk Failure

In early days of technology evolution, it was a common problem where hard-disk drives or storage drives used to fail frequently.

Disk failures include formation of bad sectors, unreachability to the disk, disk head crash or any other failure, which destroys all or a part of disk storage.

Storage Structure

We have already described the storage system. In brief, the storage structure can be divided into two categories −

- **Volatile storage** − As the name suggests, a volatile storage cannot survive system crashes. Volatile storage devices are placed very close to the CPU; normally they are embedded onto the chipset itself. For example, main memory and cache memory are examples of volatile storage. They are fast but can store only a small amount of information.

- **Non-volatile storage** − These memories are made to survive system crashes. They are huge in data storage capacity, but slower in accessibility. Examples may include hard-disks, magnetic tapes, flash memory, and non-volatile (battery backed up) RAM.

Recovery and Atomicity

When a system crashes, it may have several transactions being executed and various files opened for them to modify the data items. Transactions are made of various operations, which are atomic in nature. But according to ACID properties of DBMS, atomicity of transactions as a whole must be maintained, that is, either all the operations are executed or none.

When a DBMS recovers from a crash, it should maintain the following −

- It should check the states of all the transactions, which were being executed.
- A transaction may be in the middle of some operation; the DBMS must ensure the atomicity of the transaction in this case.
- It should check whether the transaction can be completed now or it needs to be rolled back.
- No transactions would be allowed to leave the DBMS in an inconsistent state.

There are two types of techniques, which can help a DBMS in recovering as well as maintaining the atomicity of a transaction −

- Maintaining the logs of each transaction, and writing them onto some stable storage before actually modifying the database.
- Maintaining shadow paging, where the changes are done on a volatile memory, and later, the actual database is updated.

Log-based Recovery

Log is a sequence of records, which maintains the records of actions performed by a transaction. It is important that the logs are written prior to the actual modification and stored on a stable storage media, which is failsafe.

Log-based recovery works as follows −

- The log file is kept on a stable storage media.
- When a transaction enters the system and starts execution, it writes a log about it.

<T_n, Start>

- When the transaction modifies an item X, it write logs as follows −

<T_n, X, V_1, V_2>

It reads T_n has changed the value of X, from V_1 to V_2.

- When the transaction finishes, it logs −

<T_n, commit>

The database can be modified using two approaches −

- **Deferred database modification** − All logs are written on to the stable storage and the database is updated when a transaction commits.
- **Immediate database modification** − Each log follows an actual database modification. That is, the database is modified immediately after every

operation.

Recovery with Concurrent Transactions

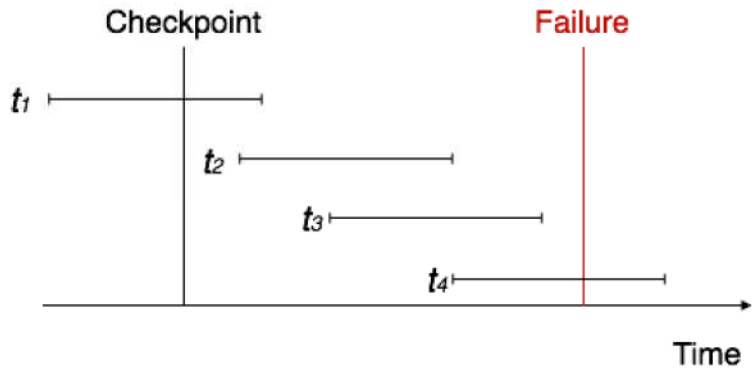
When more than one transaction are being executed in parallel, the logs are interleaved. At the time of recovery, it would become hard for the recovery system to backtrack all logs, and then start recovering. To ease this situation, most modern DBMS use the concept of 'checkpoints'.

Checkpoint

Keeping and maintaining logs in real time and in real environment may fill out all the memory space available in the system. As time passes, the log file may grow too big to be handled at all. Checkpoint is a mechanism where all the previous logs are removed from the system and stored permanently in a storage disk. Checkpoint declares a point before which the DBMS was in consistent state, and all the transactions were committed.

Recovery

When a system with concurrent transactions crashes and recovers, it behaves in the following manner −



- The recovery system reads the logs backwards from the end to the last checkpoint.
- It maintains two lists, an undo-list and a redo-list.
- If the recovery system sees a log with <T_n, Start> and <T_n, Commit> or just <T_n, Commit>, it puts the transaction in the redo-list.
- If the recovery system sees a log with <T_n, Start> but no commit or abort log found, it puts the transaction in undo-list.

All the transactions in the undo-list are then undone and their logs are removed. All the transactions in the redo-list and their previous logs are removed and then redone before saving their logs.