Aim : -

To implement a Merkle Tree in Java that generates a root hash by recursively hashing transaction data, ensuring secure and efficient verification of data integrity.

Merkle Tree : -

A **Merkle Tree** (also known as a **Hash Tree**) is a binary tree data structure in which:

- **Leaf nodes** contain the hash of individual data elements (e.g., transactions).
- **Non-leaf (internal) nodes** contain the hash of the concatenation of their child node hashes.

In this implementation:

- The input is a list of transactions (strings).
- Each transaction is hashed using **SHA-256** to create the leaf nodes.
- Pairs of hashes are concatenated and then hashed again to form parent nodes.
- This process continues recursively until a single root hash (Merkle Root) is produced.

Working Steps: -

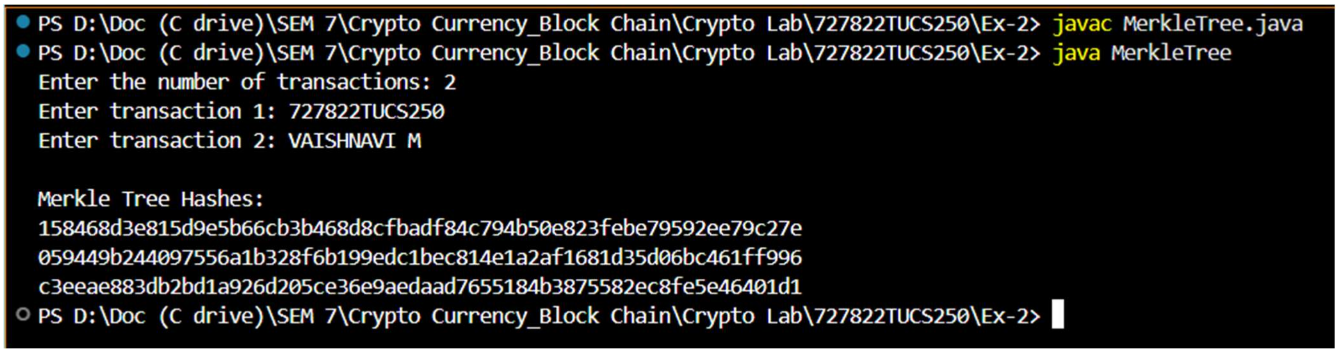
1. Accept a list of transactions as input.
2. Compute the SHA-256 hash of each transaction.
3. Group adjacent hashes in pairs.
4. Concatenate each pair and compute the SHA-256 hash again.
5. Repeat the process level by level until only one hash remains – the **Merkle Root**.
6. Store the entire Merkle Tree structure in a list for reference.

Source Code : -

```
import java.nio.charset.StandardCharsets;
import java.security.MessageDigest;
import java.security.NoSuchAlgorithmException;
import java.util.ArrayList;
import java.util.List;
import java.util.Scanner;
public class MerkleTree
{
   private List<String> transactions;
   private List<String> merkleTree;
   public MerkleTree(List<String> transactions)
   {
      this.transactions = buildInitialHashes(transactions);
      this.merkleTree = buildMerkleTree(this.transactions);
   }
   private List<String> buildInitialHashes(List<String> rawTransactions)
   {
      List<String> hashedTransactions = new ArrayList<>();
      for (String tx : rawTransactions)
      {
         hashedTransactions.add(calculateHash(tx));
      }
      return hashedTransactions;
   }
   private String calculateHash(String data)
   {
      try
```

```
        {
            MessageDigest digest = MessageDigest.getInstance("SHA-256");
            byte[] hashBytes = digest.digest(data.getBytes(StandardCharsets.UTF_8));
            StringBuilder hexString = new StringBuilder();
            for (byte hashByte : hashBytes)
            {
                String hex = Integer.toHexString(0xff & hashByte);
                if (hex.length() == 1) hexString.append('0');
                hexString.append(hex);
            }
            return hexString.toString();
        }
        catch (NoSuchAlgorithmException e)
        {
            e.printStackTrace();
        }
        return null;
    }
    private List<String> buildMerkleTree(List<String> hashedLeaves)
    {
        List<String> merkleTree = new ArrayList<>(hashedLeaves);
        int levelOffset = 0;
        for (int levelSize = hashedLeaves.size(); levelSize > 1; levelSize = (levelSize + 1) / 2)
        {
            for (int left = 0; left < levelSize; left += 2)
            {
                int right = Math.min(left + 1, levelSize - 1);
                String leftHash = merkleTree.get(levelOffset + left);
                String rightHash = merkleTree.get(levelOffset + right);
                String parentHash = calculateHash(leftHash + rightHash);
                merkleTree.add(parentHash);
            }
            levelOffset += levelSize;
        }
        return merkleTree;
    }
    public List<String> getMerkleTree()
    {
        return merkleTree;
    }
    public static void main(String[] args)
    {
        Scanner scanner = new Scanner(System.in);
        List<String> transactions = new ArrayList<>();
        System.out.print("Enter the number of transactions: ");
        int n = scanner.nextInt();
        scanner.nextLine();
        for (int i = 1; i <= n; i++)
        {
            System.out.print("Enter transaction " + i + ": ");
            transactions.add(scanner.nextLine());
        }
        MerkleTree tree = new MerkleTree(transactions);
        System.out.println("\nMerkle Tree Hashes:");
        for (String hash : tree.getMerkleTree())
        {
            System.out.println(hash);
        }
        scanner.close();
    }
}
```

Output : -



```
● PS D:\Doc (C drive)\SEM 7\Crypto Currency_Block Chain\Crypto Lab\727822TUCS250\Ex-2> javac MerkleTree.java
● PS D:\Doc (C drive)\SEM 7\Crypto Currency_Block Chain\Crypto Lab\727822TUCS250\Ex-2> java MerkleTree
  Enter the number of transactions: 2
  Enter transaction 1: 727822TUCS250
  Enter transaction 2: VAISHNAVI M

  Merkle Tree Hashes:
  158468d3e815d9e5b66cb3b468d8cfbadf84c794b50e823febe79592ee79c27e
  059449b244097556a1b328f6b199edc1bec814e1a2af1681d35d06bc461ff996
  c3eeae883db2bd1a926d205ce36e9aedaad7655184b3875582ec8fe5e46401d1
○ PS D:\Doc (C drive)\SEM 7\Crypto Currency_Block Chain\Crypto Lab\727822TUCS250\Ex-2>
```

AIM:

To create a block structure that securely stores transaction data in a blockchain system. Each block holds a set of recent transactions that are yet to be validated. Once validated, the block is closed and linked to the previous block, forming a chain. New blocks are generated when validators or miners successfully verify the encrypted information in the block header.

Block : -

A **Block** is a fundamental component of a blockchain. It is a data structure that securely stores information such as transactions, timestamps, and a reference to the previous block. Each block is uniquely identified using a cryptographic hash.

In this implementation:

- Each block has an **index**, **timestamp**, **data**, **previous hash**, and a **nonce** (used in mining).
- The **SHA-256** hashing algorithm is used to calculate the block's hash based on its contents.
- A **mining** process is included to simulate Proof-of-Work, where the hash must meet a specified difficulty (number of leading zeros).

Working Steps : -

1. Initialize the block with index, previous hash, and data.
2. Generate a timestamp and set nonce to 0.
3. Calculate the initial hash using SHA-256.
4. Mine the block by adjusting the nonce until the hash starts with the required number of zeros (difficulty).

5. Print the mined block details: index, timestamp, previous hash, current hash, and data.

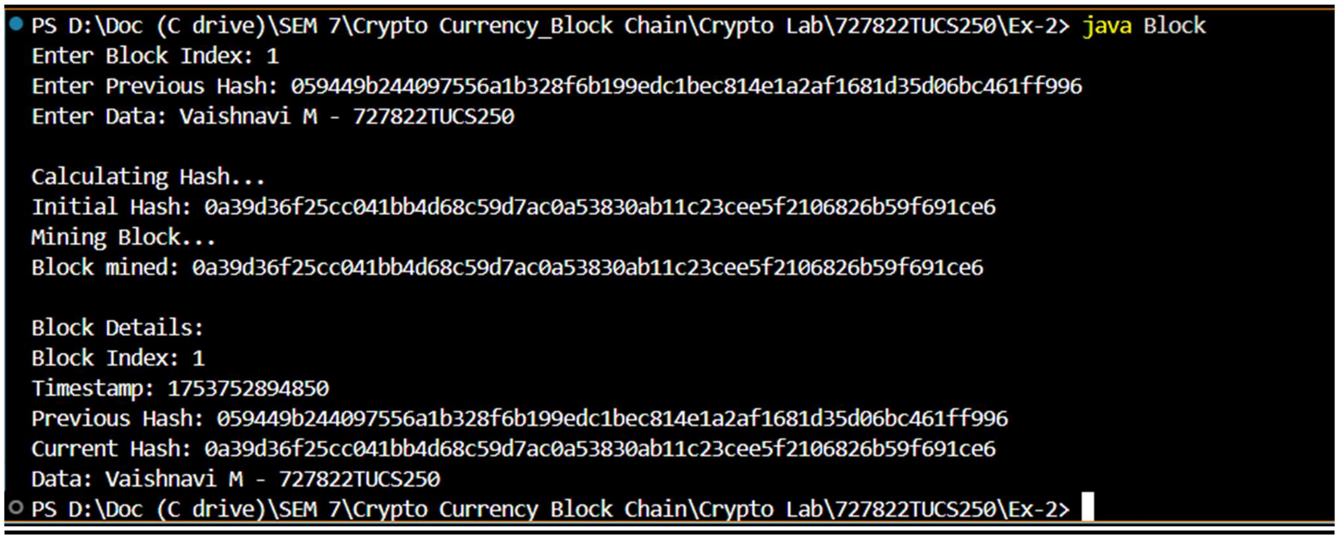
Source Code : -

```
import java.security.MessageDigest;
import java.security.NoSuchAlgorithmException;
import java.util.Date;
import java.util.Scanner;
public class Block
{
    private int index;
    private long timestamp;
    private String previousHash;
    private String hash;
    private String data;
    private int nonce;
    public Block(int index, String previousHash, String data)
    {
        this.index = index;
        this.timestamp = new Date().getTime();
        this.previousHash = previousHash;
        this.data = data;
        this.nonce = 0;
        this.hash = calculateHash();
```

```
}
public String calculateHash()
{
    try
    {
        MessageDigest digest = MessageDigest.getInstance("SHA-256");
        String input = index + timestamp + previousHash + data + nonce;
        byte[] hashBytes = digest.digest(input.getBytes());
        StringBuilder hexString = new StringBuilder();
        for (byte hashByte : hashBytes)
        {
            String hex = Integer.toHexString(0xff & hashByte);
            if (hex.length() == 1) hexString.append('0');
            hexString.append(hex);
        }
        return hexString.toString();
    }
    catch (NoSuchAlgorithmException e)
    {
        e.printStackTrace();
    }
    return null;
}
public void mineBlock(int difficulty)
{
    String target = new String(new char[difficulty]).replace('\0', '0');
    while (!hash.substring(0, difficulty).equals(target))
    {
        nonce++;
        hash = calculateHash();
    }
    System.out.println("Block mined: " + hash);
}

public static void main(String[] args)
{
    Scanner scanner = new Scanner(System.in);
    System.out.print("Enter Block Index: ");
    int index = scanner.nextInt();
    scanner.nextLine();
    System.out.print("Enter Previous Hash: ");
    String prevHash = scanner.nextLine();
    System.out.print("Enter Data: ");
    String data = scanner.nextLine();
    Block block = new Block(index, prevHash, data);
    System.out.println("\nCalculating Hash...");
    System.out.println("Initial Hash: " + block.calculateHash());
    System.out.println("Mining Block...");
    block.mineBlock(1);
    System.out.println("\nBlock Details:");
    System.out.println("Block Index: " + block.index);
    System.out.println("Timestamp: " + block.timestamp);
    System.out.println("Previous Hash: " + block.previousHash);
    System.out.println("Current Hash: " + block.hash);
    System.out.println("Data: " + block.data);
    scanner.close();
}
}
```

<u>Output : -</u>



```
PS D:\Doc (C drive)\SEM 7\Crypto Currency_Block Chain\Crypto Lab\727822TUCS250\Ex-2> java Block
Enter Block Index: 1
Enter Previous Hash: 059449b244097556a1b328f6b199edc1bec814e1a2af1681d35d06bc461ff996
Enter Data: Vaishnavi M - 727822TUCS250

Calculating Hash...
Initial Hash: 0a39d36f25cc041bb4d68c59d7ac0a53830ab11c23cee5f2106826b59f691ce6
Mining Block...
Block mined: 0a39d36f25cc041bb4d68c59d7ac0a53830ab11c23cee5f2106826b59f691ce6

Block Details:
Block Index: 1
Timestamp: 1753752894850
Previous Hash: 059449b244097556a1b328f6b199edc1bec814e1a2af1681d35d06bc461ff996
Current Hash: 0a39d36f25cc041bb4d68c59d7ac0a53830ab11c23cee5f2106826b59f691ce6
Data: Vaishnavi M - 727822TUCS250
PS D:\Doc (C drive)\SEM 7\Crypto Currency_Block Chain\Crypto Lab\727822TUCS250\Ex-2>
```

<u>Result : -</u>

Thus, the implementation of the **Merkle Tree** and **Block** has been successfully completed.