EXPERIMENT NO 1

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Aim: Write a Python program to understand SHA and Cryptography in Blockchain, Merkle root tree hash.

Theory:

Cryptographic Hash Function in Blockchain

A cryptographic hash function is a special mathematical technique that converts any kind of input data—such as transaction details, files, or text—into a fixed-size string of characters known as a hash. In blockchain technology, this hash works like a unique digital identity for the data stored inside a block. Even the smallest modification in the input, like changing one letter, produces a completely new hash value. This makes hashing extremely useful for ensuring blockchain security and trust. Blockchains such as Bitcoin and Ethereum commonly rely on hashing algorithms like SHA-256 to secure transaction records.

Simply put, hashing guarantees that once information is stored on a blockchain, it cannot be secretly changed without everyone noticing.

Features of Cryptographic Hash Functions

● Consistency (Deterministic): The same input always results in the exact same hash. ● Constant Length Output: Regardless of how big or small the input is, the hash output remains the same fixed size (for example, 256 bits in SHA-256).
● Quick Processing: Hash calculations are efficient and can be done rapidly, which is necessary for blockchain systems handling many transactions.
● One-Way Nature (Pre-image Resistance): It is nearly impossible to retrieve the original input from its hash.
● Strong Uniqueness (Collision Resistance): Two different inputs should not generate an identical hash.
● Avalanche Property: A minor input change leads to a drastically different hash

result. Importance of Hashing in Blockchain

● It links blocks by embedding the previous block’s hash into the next one, creating a secure chain structure.
● It ensures immutability, since altering stored data would instantly change the hash and expose manipulation.
● It plays a major role in mining and transaction validation, helping networks confirm blocks before adding them.
● It strengthens protection of wallet addresses, digital signatures, and

sensitive user information against fraud and tampering.

Properties of SHA-256

SHA-256 (Secure Hash Algorithm – 256-bit) belongs to the SHA-2 family and is one of the most commonly used hashing algorithms in blockchain technology. It converts any input data into a secure 256-bit hash value, regardless of the input's original size.

- Fixed 256-bit Output: SHA-256 always produces a hash of exactly 256 bits, usually shown as 64 hexadecimal characters, no matter how large the input is.
- High Security Strength: It is widely trusted for modern cryptography and is a standard choice in blockchain networks for strong protection.
- Collision Resistance: The chance that two different pieces of data generate the same hash is extremely rare, ensuring reliable data integrity.
- Avalanche Property: Even the smallest change in input data results in a completely different hash output, making unauthorized modifications easy to detect.
- Irreversible (One-Way Function): It is practically impossible to reverse the hash and recover the original input data.

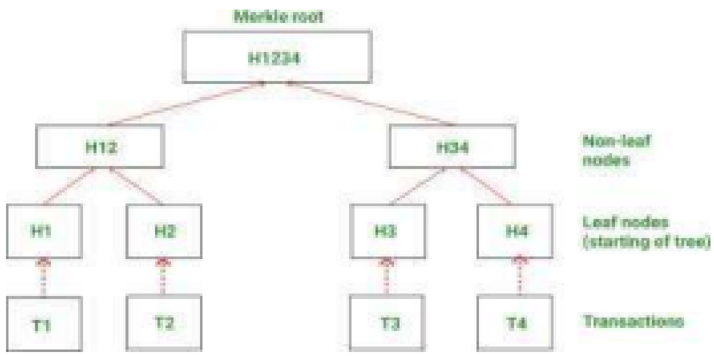
Merkle Tree (Hash Tree)

A Merkle Tree is a specialized binary tree structure used in blockchain to store and verify a large number of transactions efficiently. In this structure, every transaction is first converted into a hash, forming the leaf nodes. These hashes are then combined in pairs, hashed again, and repeated layer by layer until one final hash remains, called the Merkle Root.

The Merkle Root represents the complete set of transactions in a block. By storing only this single root hash inside the block header, blockchain systems can confirm that all transactions remain unchanged. If even one transaction is altered, the Merkle Root changes instantly, making fraud or tampering easy to detect.

Structure of a Merkle Tree

A Merkle Tree follows a layered hierarchical arrangement. It begins with individual transaction hashes at the bottom level. These hashes are merged pairwise to form parent nodes, continuing upward through multiple levels until reaching the topmost hash, the Merkle Root, which summarizes and secures all transactions within the block.



1. Leaf Nodes: These are the hashes of individual transactions in a block. Each transaction is first hashed to form a leaf node.
2. Intermediate (Parent) Nodes: Pairs of leaf nodes are combined and hashed again to form parent nodes. This process continues upward, combining child nodes at each level. 3. Root Node (Merkle Root): The topmost node of the tree, representing all transactions in the block. If any transaction changes, the Merkle Root changes, making tampering detectable.

2. Merkle Root

The Merkle Root is the topmost hash of the Merkle Tree. It acts as a summary of all transactions in a block.
If any transaction is changed, its hash changes, which affects the Merkle Root. Since the Merkle Root is stored in the block header, this makes tampering easy to detect.

3. Working of Merkle Tree

The Merkle Tree works by organizing and summarizing all transactions in a block into a single hash (the Merkle Root) so that data can be verified efficiently and securely.

The process follows these steps:

- Hashing Transactions: Each transaction in the block is first hashed using a cryptographic hash function, usually SHA-256. These hashes form the leaf nodes of the Merkle Tree.
  Example:
  Transactions: T1, T2, T3, T4
  Hashes: H(T1), H(T2), H(T3), H(T4)

- Pairing and Hashing: The leaf nodes are grouped in pairs. Each pair of hashes is concatenated (joined together) and then hashed again to create a parent node. If the number of transactions is odd, the last hash is duplicated to form a pair. This ensures that every level of the tree has an

even number of nodes.
Example:

- Pair 1: H(T1) + H(T2) → Hash = H12
- Pair 2: H(T3) + H(T4) → Hash = H34

- Building the Tree: The pairing and hashing process continues up the tree, combining parent nodes to create new higher-level nodes.
  Example:
  H12 + H34 → Hash = H1234
- Creating the Merkle Root: This process repeats until only one hash remains at the top of the tree. This top-level hash is called the Merkle Root, which represents all transactions in the block.

- Verification: To verify that a transaction exists in a block, a Merkle Proof is used. Instead of checking every transaction, only a small number of hashes along the path from the transaction leaf to the Merkle Root are needed. This makes verification fast and efficient, even for large blocks of data. Example:
  To verify T1: Use H(T2) and H34 along with H(T1) to recalculate H1234. If it matches the Merkle Root, T1 is valid.

- Tamper Detection: If any transaction is modified, its hash changes. This change propagates up the tree and alters the Merkle Root. Since the Merkle Root is stored in the block header, any tampering becomes immediately obvious.
  Example:
  If T3 changes → H(T3) changes → H34 changes → H1234 changes → Merkle Root mismatch.

4. Benefits of Merkle Tree

- Efficient Verification: Only a small number of hashes are needed to verify a transaction using a Merkle Proof, so checking data is fast even for large blocks.
- Data Integrity: Any change in a transaction alters the Merkle Root, making it easy to detect tampering.
- Reduced Storage: Instead of storing all transaction data in the block header, only the Merkle Root is stored, saving space.
- Scalability: Merkle Trees allow blockchains to handle a large number of transactions without slowing down verification.
- Security: The structure ensures that transactions cannot be altered without being noticed, keeping the blockchain secure.

5. Use of Merkle Tree in Blockchain

- Efficient Transaction Verification: Nodes can verify a single transaction without downloading the entire block, using a Merkle Proof.

- Ensures Data Integrity: Any change in a transaction immediately changes the Merkle Root, helping detect tampering.
- Reduces Storage Needs: Only the Merkle Root is stored in the block header, instead of all transaction data, saving space.
- Supports Lightweight Nodes: Simple Payment Verification (SPV) nodes can confirm transactions securely without holding the full blockchain.

Applications of Merkle Tree

Merkle Trees are an important data structure used not only in blockchain but also in many digital security systems. Their main advantage is that they can verify huge amounts of data quickly without needing to store or process everything. Below are some common practical uses:

1. Blockchain Block Transaction Management

In cryptocurrencies such as Bitcoin, thousands of transactions may exist inside a single block. Merkle Trees help compress this information efficiently.

- Example: Instead of keeping the entire transaction list in the block header, only one hash value—the Merkle Root—is stored.
- If any transaction is modified, the Merkle Root changes instantly.

Why useful: Ensures block integrity and makes transaction verification

simpler.

2. Lightweight Wallet Verification (SPV Method)

Many mobile wallets and small devices cannot store complete blockchain data. They use Merkle Trees for fast checking.

- Example: A phone wallet can verify a payment by downloading only the transaction proof path, not the entire block.

Benefit: Saves internet bandwidth, storage space, and still

maintains trust.

3. Software Development and File Tracking

Merkle Trees are widely used in systems that need reliable tracking of file changes.

- Example: In software platforms, every file version can be hashed, and any update changes the root hash, clearly showing that the content was altered.

Advantage: Helps in managing project history and preventing unnoticed modifications. 4. Cloud Storage Validation

Cloud providers must guarantee that stored files are not corrupted over time.

- Example: A Merkle Tree can be built from file chunks, allowing users to verify that their uploaded data remains unchanged.

Result: Secure storage and easy corruption detection.

5. Secure Data Sharing in P2P Systems

Peer-to-peer networks often share data in fragments, making verification necessary.

- Example: When downloading a large video split into parts, Merkle Trees allow users to confirm each part is authentic before assembling the full file.

Benefit: Prevents fake or tampered file pieces from spreading.

6. Digital Auditing and Record Security

Merkle Trees are also useful in financial audits and secure record-keeping.

- Example: Banks or companies can store transaction logs in a Merkle Tree so that auditors can later confirm no records were changed.

Importance: Ensures transparency and long-term trust in stored logs.

Colab Notebook:

https://colab.research.google.com/drive/1vjNukEc8h5Qt5kMXuuQSc8EA1KfsGmtI#scrollTo=W9PpRO6cI77h

Code & Output:

1. Hash Generation using SHA-256: Developed a Python program to compute a SHA-256 hash for any given input string using the hashlib library.

```
import hashlib

data_string = 'hi kartik bhat'

encoded_data = data_string.encode('utf-8')

sha256_hash = hashlib.sha256()

sha256_hash.update(encoded_data)

hex_digest = sha256_hash.hexdigest()

print(f"Original string: '{data_string}'")
```

```
print(f"SHA-256 Hash: {hex_digest}")
```

```
Original string: 'hi kartik bhat'
SHA-256 Hash: 8a7d15add595397aaf9135e69bdde6a4a5de8d1140dbb527b9dd77a16ede239e
```

2. Target Hash Generation with Nonce: Created a program to generate a hash code by concatenating a user input string and a nonce value to simulate the mining process.

```
import hashlib
data = input("Enter the input string: ")
nonce = int(input("Enter nonce value: "))
combined_data = data + str(nonce)
hash_with_nonce = hashlib.sha256(combined_data.encode()).hexdigest()
print("Hash with Nonce:", hash_with_nonce)
```

```
Enter the input string: i am kartik
Enter nonce value: 16
Hash with Nonce: 9a3b650fd50827526166bb5d2c82bbc166502683750f3b34a166280a2788c7d6
```

3. Proof-of-Work Puzzle Solving: Implemented a program to find the nonce that, when combined with a given input string, produces a hash starting with a specified number of leading zeros.

```
import hashlib
data = input("Enter the input string: ")
difficulty = int(input("Enter number of leading zeros required: "))
prefix = '0' * difficulty
nonce = 0
while True:
    text = data + str(nonce)
    hash_result = hashlib.sha256(text.encode()).hexdigest()
    if hash_result.startswith(prefix):
        break
    nonce += 1
print("Nonce found:", nonce)
print("Valid Proof-of-Work Hash:", hash_result)
```

```
Enter the input string: dhoni is the best batsmen
Enter number of leading zeros required: 6
Nonce found: 6861255
Valid Proof-of-Work Hash: 000000e4fa3306fbbad22c1c9734e1f8bb23dfec112416a5565da15bc1454066
```

4. Merkle Tree Construction: Built a Merkle Tree from a list of transactions by

recursively hashing pairs of transaction hashes, doubling up last nodes if needed, and generated the Merkle Root hash for blockchain transaction integrity.

```
import hashlib

def sha256(data):
    return hashlib.sha256(data.encode()).hexdigest()

def merkle_root(transactions):
    hashes = [sha256(tx) for tx in transactions]
    while len(hashes) > 1:
        if len(hashes) % 2 != 0:
            hashes.append(hashes[-1])
        new_level = []
        for i in range(0, len(hashes), 2):
            combined_hash = hashes[i] + hashes[i + 1]
            new_level.append(sha256(combined_hash))
        hashes = new_level
    return hashes[0]

transactions = [
    "dhoni gives 5 runs",
    "kohli gives 2 runs",
    "pandya takes a wicket",
    "sharma drops a catch"
]

print("Merkle Root Hash:", merkle_root(transactions))
```

```
Merkle Root Hash: 21f1fce3ec2e102fb2fdb56b08fe4159ba7e934934e53f56f59bed5a937cbfb8
```

Conclusion:

Cryptographic hash functions like SHA-256 help keep blockchain data safe, secure, and unchangeable. Merkle Trees organize transactions in a way that makes it easy to verify them quickly and detect any tampering. Together, they make blockchain trustworthy, capable of handling large amounts of data without compromising security. These concepts help us understand how blockchain maintains security, efficiency even with large amounts of data.