Cryptography Fundamentals:

Encryption, Digital Signatures, Public-Key Cryptography, Private Key Cryptography, Distributed Denial-of-Service (DDoS) Attack, 51% Attack, Double spending problem, Merkel Tree, Security Threats to Blockchain nTechnology

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1. Encryption

- Definition: The process of converting plaintext (readable data) into ciphertext (scrambled data) to prevent unauthorized access.

- Types of Encryption:

    - Symmetric Encryption: The same key is used for both encryption and decryption. Example: AES (Advanced Encryption Standard).

    - Asymmetric Encryption: Uses a pair of keys (public and private) for encryption and decryption. Example: RSA (Rivest-Shamir-Adleman).

- Purpose: To ensure confidentiality, prevent data breaches, and protect information from unauthorized access.

Key Concepts

- Plaintext: Original, readable message
- Ciphertext: Encrypted, unreadable message
- Encryption Algorithm: Mathematical procedure used to convert plaintext to ciphertext
- Decryption Algorithm: Mathematical procedure used to recover plaintext from ciphertext
- Key: Secret value used by encryption/decryption algorithms

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2. Digital Signatures

- Definition: A cryptographic technique used to validate the authenticity and integrity of a message or document.

- How It Works:
    - A sender uses their private key to sign a message.
    - The receiver can use the sender's public key to verify the signature.
- Purpose: Provides proof of the origin and ensures that the message has not been tampered with.
- Applications: Used in blockchain transactions to verify the identity of users and transactions.

Characteristics

- Single shared secret key between parties
- Faster than public key cryptography
- Requires secure key exchange
- Suitable for encrypting large amounts of data

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3. Public-Key Cryptography

- Definition: A cryptographic system that uses a pair of keys—a public key and a private key.
- Public Key: Shared openly and used to encrypt data.
- Private Key: Kept secret and used to decrypt data encrypted with the corresponding public key.
- How It Works: Data encrypted with the public key can only be decrypted by the private key and vice versa.
- Advantages: Facilitates secure communication and digital signatures without the need for exchanging secret keys.
- Read More: https://www.geeksforgeeks.org/blockchain-public-key-cryptography/

4. Private Key Cryptography (Symmetric Cryptography)

- Definition: A type of cryptography where the same key is used for both encryption and decryption.
- Key Management: Both the sender and the receiver must have access to the same private key, which must remain secret.
- Examples: AES, DES (Data Encryption Standard).
- Challenges: Key distribution and management can be difficult, especially in large systems.
- Read More: https://www.geeksforgeeks.org/blockchain-private-key-cryptography/

Distributed Denial-of-Service (DDoS) Attack

- Definition: A cyberattack where multiple systems are used to flood a target server or network with excessive traffic, causing it to become overwhelmed and unavailable.
- Mechanism: Attackers typically use botnets (compromised devices) to initiate the attack.
- Impact: Disruption of services, downtime, and loss of access to services.
- Prevention: Anti-DDoS services, rate limiting, and network firewalls can help mitigate these attacks.

6. 51% Attack

- Definition: A situation where an attacker gains control of more than 50% of the computational power or hash rate of a blockchain network.
- Consequences: The attacker can:
    - Reverse transactions (double spend).
    - Prevent new transactions from being confirmed.
    - Disrupt the blockchain’s overall integrity.

- Prevention: Blockchain networks with higher decentralization (more miners/validators) are harder to attack.

  Read More in Detail here: https://nbx.com/crypto101/what-is-a-51-attack

7. Double Spending Problem

- Definition: The risk that a digital currency or asset can be spent more than once due to the lack of physical form.
- Example: In a blockchain, if a user sends a cryptocurrency to one party and then sends the same cryptocurrency to another party, the blockchain must prevent this.
- Solution: Blockchain technology prevents double spending by using consensus mechanisms like Proof of Work (PoW) or Proof of Stake (PoS) to validate transactions.

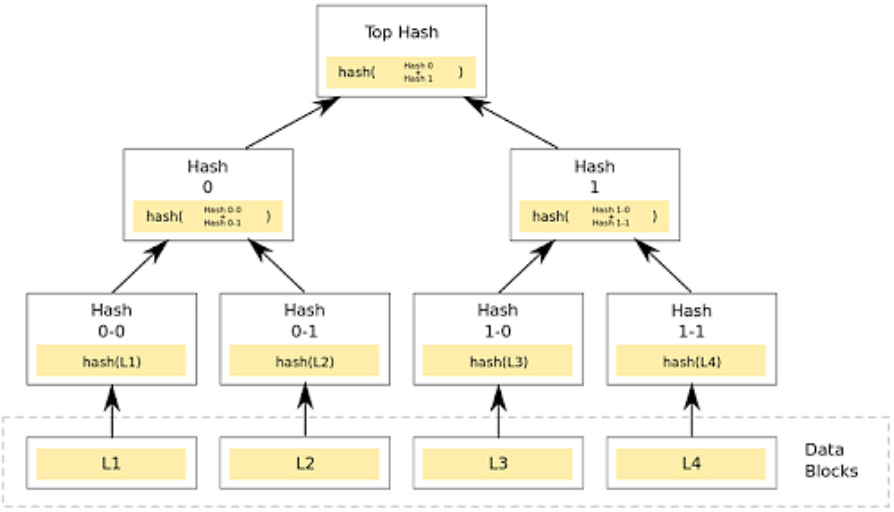
Security Threats to Blockchain Technology

- 51% Attack: As described above, when an attacker controls more than 50% of the network's mining or validation power.
- Sybil Attack: A type of attack where a malicious entity creates multiple fake identities to manipulate the network.
- Double Spending: A threat where digital assets can be spent more than once.
- Routing Attacks: Attacks that aim to manipulate or intercept the flow of blockchain data over the network.
- Smart Contract Vulnerabilities: Flaws in smart contracts that can be exploited to cause financial loss, such as reentrancy attacks.
- DDoS Attacks: Blockchain nodes can be targeted by distributed denial-of-service attacks, causing delays or shutdowns.
- Private Key Compromise: If private keys are compromised, the attacker can perform unauthorized actions such as transferring assets.

Merkle Tree in Blockchain: What It Is and How It Works

What Is a Merkle Tree?

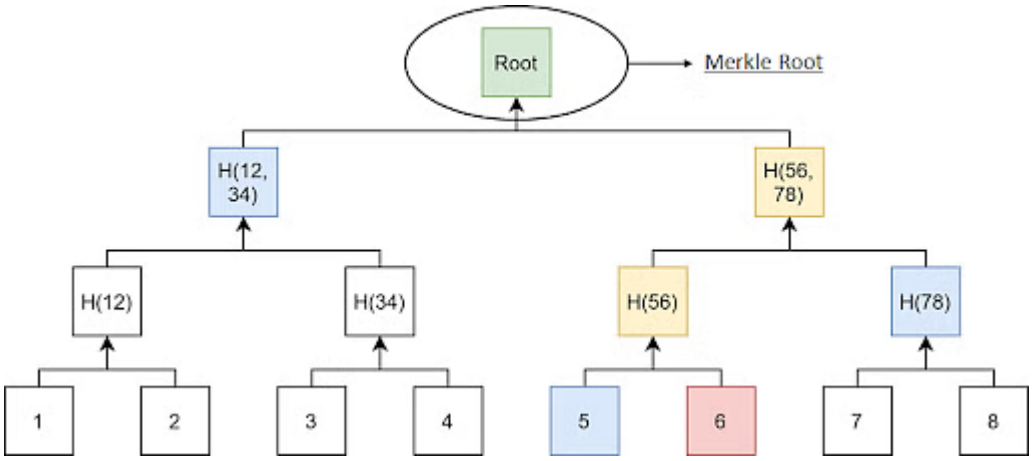
- Merkle trees, also known as Binary hash trees, are a prevalent sort of data structure in computer science.
- In bitcoin and other cryptocurrencies, they're used to encrypt blockchain data more efficiently and securely.
- It's a mathematical data structure made up of hashes of various data blocks that summarize all the transactions in a block.
- It also enables quick and secure content verification across big datasets and verifies the consistency and content of the data.



What Is a Merkle Root?

- A Merkle root is a simple mathematical method for confirming the facts on a Merkle tree.

- They're used in cryptocurrency to ensure that data blocks sent through a peer-to-peer network are whole, undamaged, and unaltered.
- They play a very crucial role in the computation required to keep cryptocurrencies like bitcoin and ether running.



Now, look at a little example of a Merkle Tree in Blockchain to help you understand the concept.

Consider the following scenario: A, B, C, and D are four transactions, all executed on the same block. Each transaction is then hashed, leaving you with:

- Hash A
- Hash B
- Hash C
- Hash D

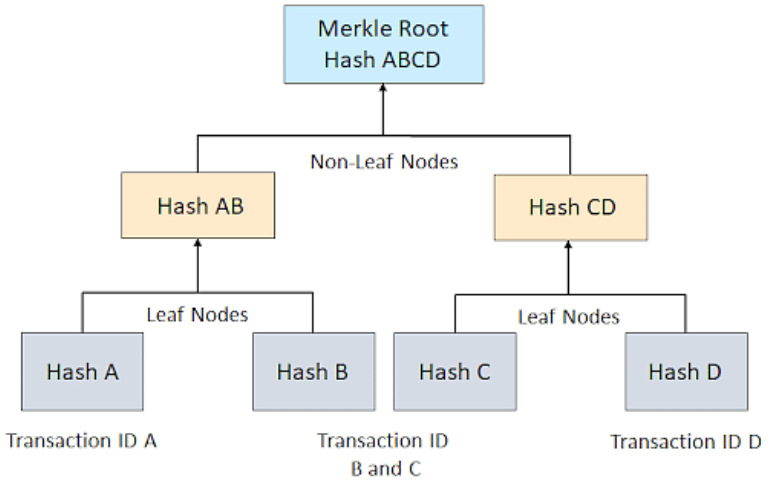
The hashes are paired together, resulting in:

- Hash AB

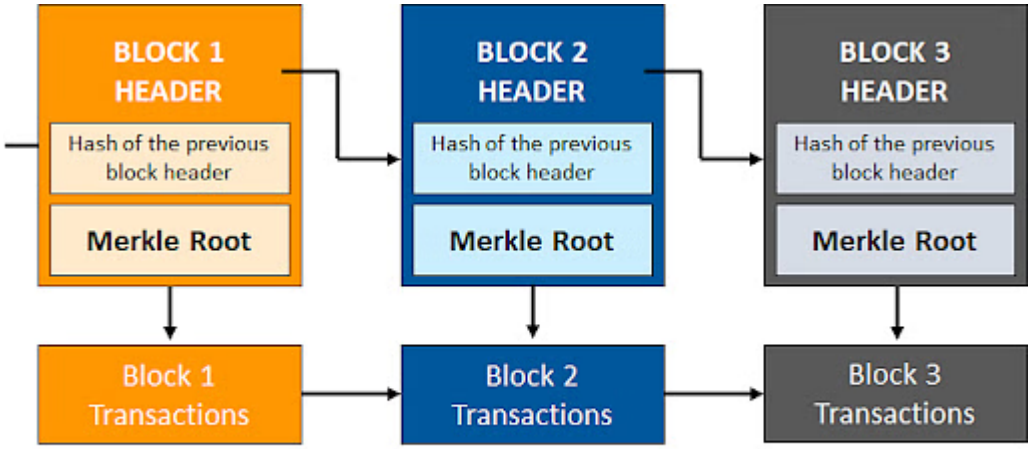
and

- Hash CD

And therefore, your Merkle Root is formed by combining these two hashes: Hash ABCD.



Benefits of Merkle Tree in Blockchain



Merkle Tree breaking the data into tiny parts of information

Merkle trees provide four significant advantages -

- Validate the data's integrity: It can be used to validate the data's integrity effectively.
- Takes little disk space: Compared to other data structures, the Merkle tree takes up very little disk space.
- Tiny information across networks: Merkle trees can be broken down into small pieces of data for verification.
- Efficient Verification: The data format is efficient, and verifying the data's integrity takes only a few moments.

Key Takeaways

- Merkle trees are a structured way of encoding data for easy verification and better security.
- Blockchains use Merkle trees to generate hashes that are used to verify transactions and secure the blocks.
- Visual representations of Merkle trees resemble upside-down trees with the root at the top.
- The repeated hashing technique used in blockchain Merkle trees is one of the mechanics that contribute to their immutability.