IT486: Blockchains and Cryptocurrencies

Key management: wallets and exchanges

Digression: Quantum Resistance

- Signature schemes based on the integer factorization problem, the discrete logarithm problem, or the elliptic curve discrete logarithm problem
- Can be solved with Shor's algorithm with an enough powerful quantum computer
- Hash functions are considered to be relatively secure against quantum computers

Digression: Quantum Resistance

- If public key unknown, then bitcoins cannot be stolen. (If public, bitcoins are stolen)
- How do you prevent them from being stolen when you issue a transaction?
- If the quantum computer takes longer than 1-2 minutes to hack your private key, then you can transfer bitcoins if you always use a new address to transfer (to transfer, but also as a return address)
- In Bitcoin it is considered bad hygeine to reuse addresses. In a post-quantum world, it will get your funds stolen.

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  - Security: Making sure nobody else can spend your coins
  - Convenience: Managing your keys (and thus your coins)

Bitcoin wallets

- Provide a practical user interface for the generation and storage of private keys
- Keyring would have been a better name, since wallets don't store money directly!

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  - Note: cold storage retains the possibility of sending coins to it even if offline, however, as long as a valid address is known

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- Software on your device that keeps track of your keys, coins, makes transactions, etc.
- Think of it as the wallet in your pocket
  - simple to use and understand, but pickpockets are rife!

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Paper Wallets (Cold)

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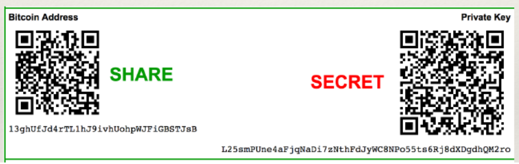
- QR codes for easy use



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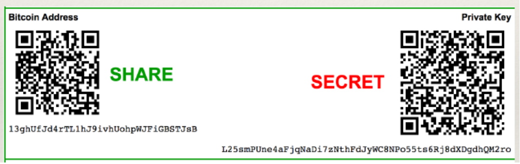

- Anyone who can see it can steal it!
- Availability: LOW, Convenience: MEDIUM, Security: MEDIUM/HIGH

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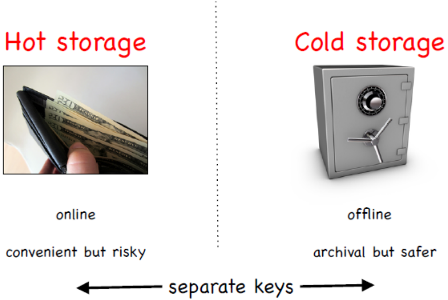
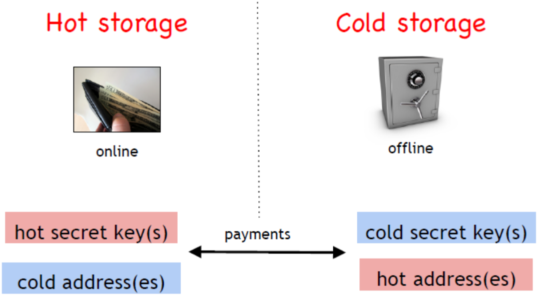
How to Store Bitcoins Safely

- Useful principle: keep limited amount of bitcoins in hot storage and majority of the reserve in cold storage



Transfers from hot storage to cold storage



- To move coins back and forth between the two sides, each side will need to know the other's addresses

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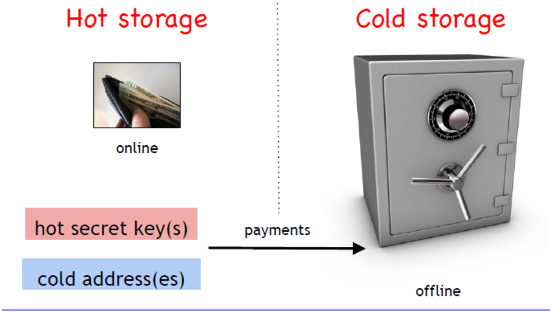

- Want to use a new address (and key) for each coin sent to cold storage. But, how can hot wallet learn new addresses if cold wallet is offline?

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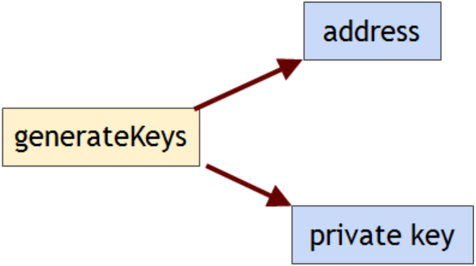
- Better solution: Hierarchical wallet

Recall: Regular key generation



Hierarchical key generation

generateKeysHier

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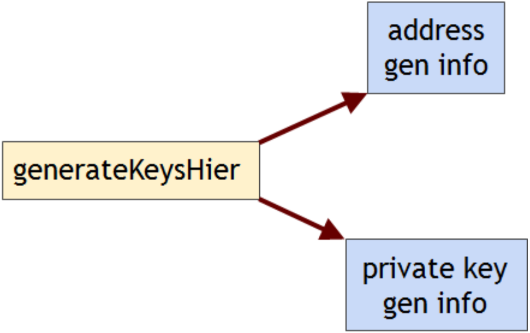

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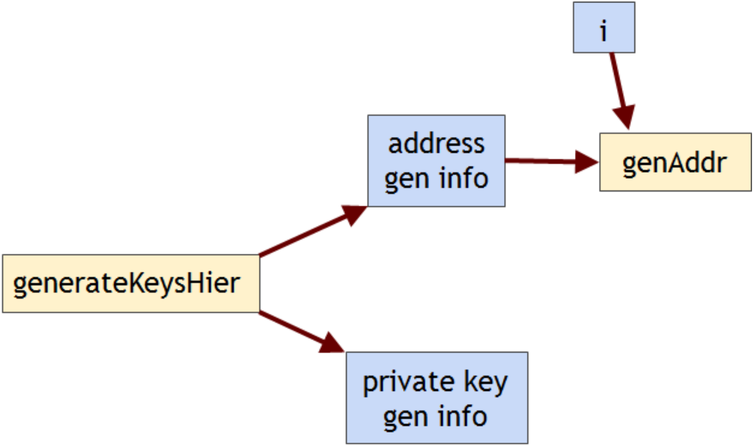

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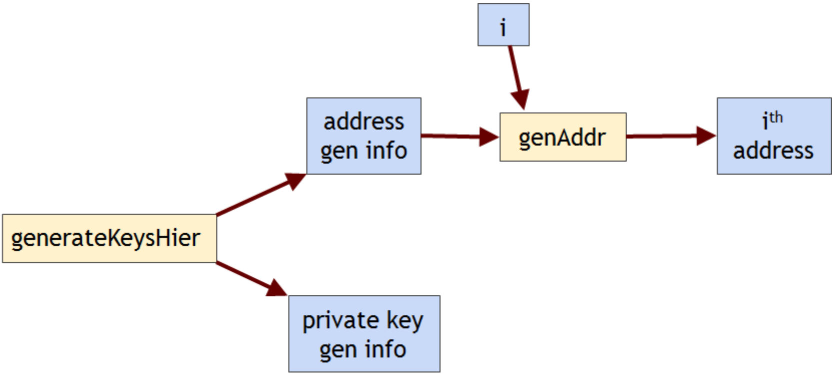

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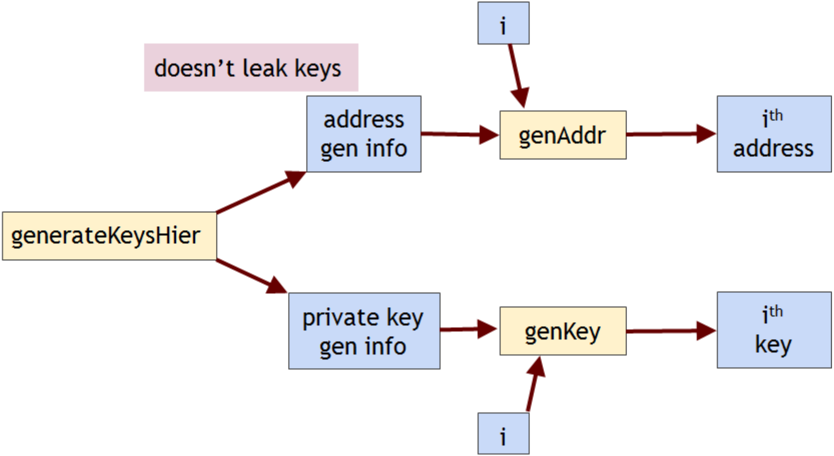
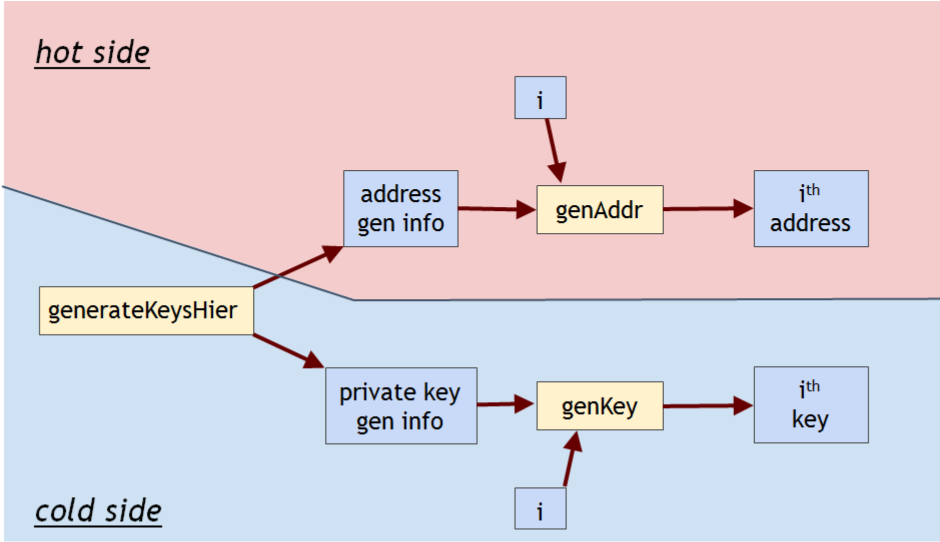


Properties

- Given an initial address generation info, there is a function that generates a sequence of public and private keys
  - For any integer i, the function generates the i-th address
  - and the i-private key in the sequence
  - Knowing the list of public keys does not reveal any private key

Hierarchical wallet



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  - typically, bank invests the money
  - keeps some around to meet withdrawals ("fractional reserve")

Bitcoin Exchanges

- Online wallet plus place to buy/sell bitcoin (like a stock exchange)
- Help connect BTC economy to fiat currency economy
- Exchange knows private keys for your assets
- Just like real banks, exchanges promise to give you your bitcoin when you ask for it, but may not actually have it!

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    - Only effect: Exchange is making a different promise now

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- More people try to cash out, exacerbating problem

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- "Exit scam"
- Ponzi scheme: paying people who ask for bitcoin with newcomer's bitcoin

Risk 3: Security Breach

- Exchanges hold big amounts of coins and are a popular target for hackers
- A hacker who breaks into the exchange's software can move all of their bitcoin
- Many bitcoin thefts can be attributed to a security breach of exchanges
  - Mt. Gox roughly lost US$450M

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- Bitcoin is not regulated like this!

What is Solvency?

- Solvency is the ability of an exchange to meet its financial commitments (i.e. assets $\geq$ obligations)
- Unlike conventional banks, bitcoin exchanges are expected to be fully solvent at all times

Proof of Solvency

- Proof-of-reserve
  - this proves that exchange holds at least X amount of bitcoins (assets)
- Proof-of-liabilities
  - this proves that exchange owes its customers no more that Y amount of bitcoins (obligations)
- Solvency is proved if X $\geq$ Y

Proof-of-Reserve Problem

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    - Publish a valid payment-to-self of claimed amount
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- Proof of reserve $\neq$ willingness to pay

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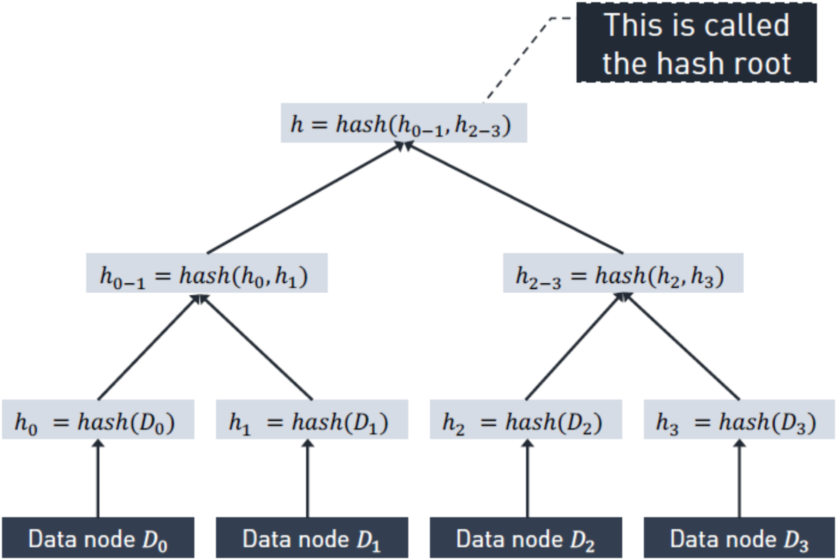
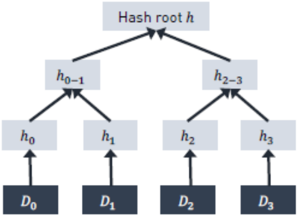
- Exchange may create fake users, but this only overstates liabilities

Merkle trees



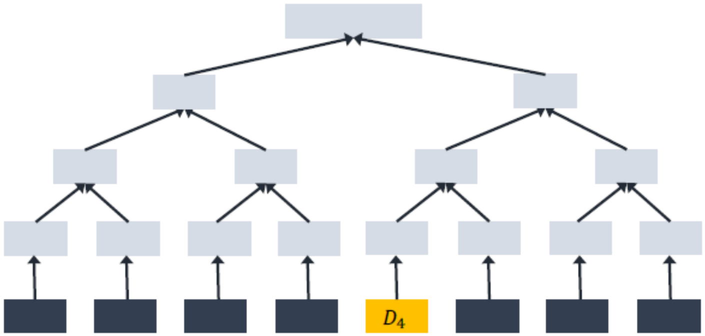
Uses of Merkle trees



Data integrity verification

- The hash root is typically obtained from a trusted source
- One can verify the integrity of the data elements D_0, D_1, D_2, D_3 by reconstructing the hash root and comparing it to the trusted root

Membership verification



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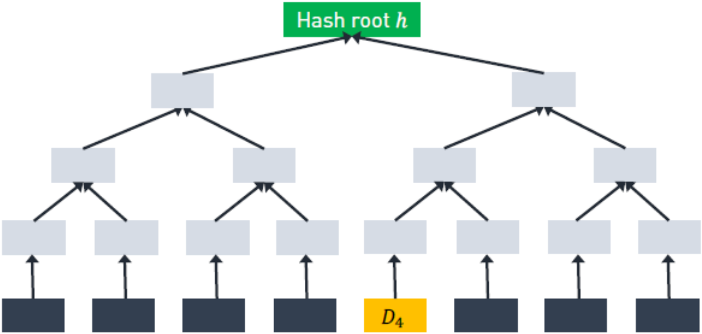

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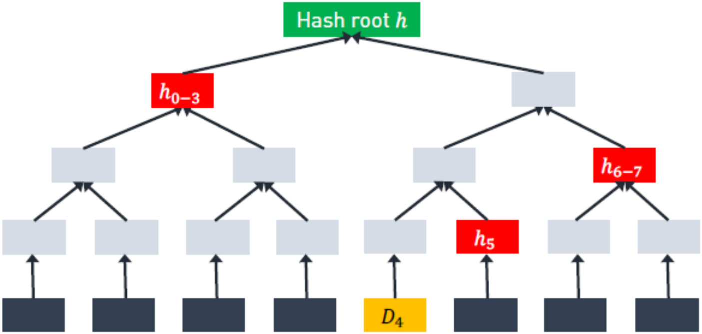

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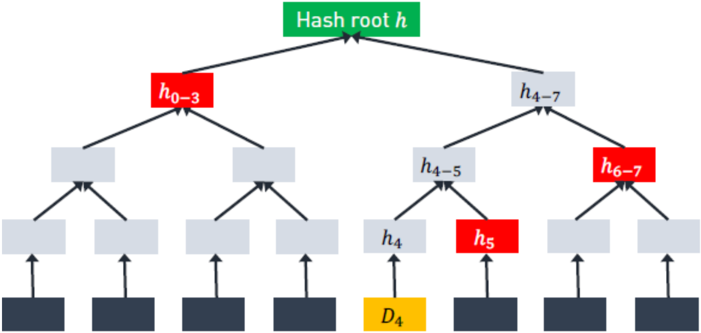

- Obtain the hash root h from a trusted source
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- Compute h_4, h_{4-5}, h_{4-7}, h' and check whether $h = h'$

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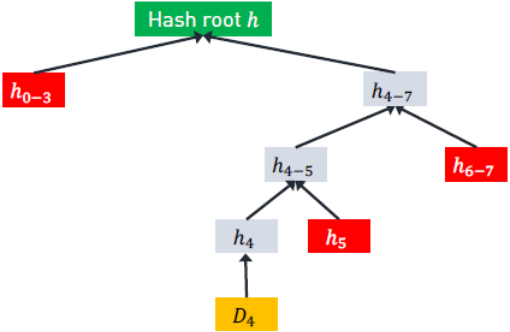
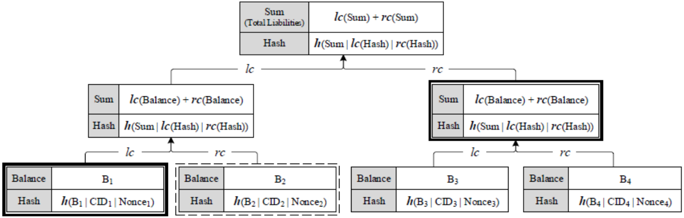


- Membership verification requires $\log n$ elements
- Useful when the set of data elements is large

Maxwell protocol

- The exchange privately computes a modified Merkle tree that accumulates the account balances of depositors
- The tree below records four accounts:



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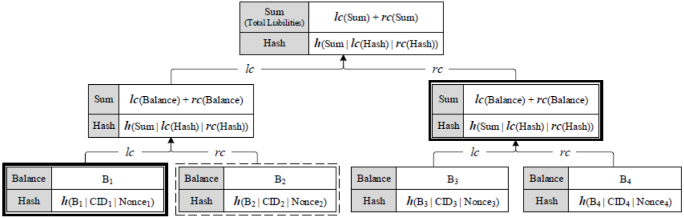

- The root node is publicly broadcast by exchange as its total liabilities

Maxwell protocol

- Balance verification:
  - A customer requests the exchange to send a proof that her balance is included in the total liabilities
  - The exchange sends to the customer her nonce and the sibling node of each node on the unique path from the customer's leaf node to the root node
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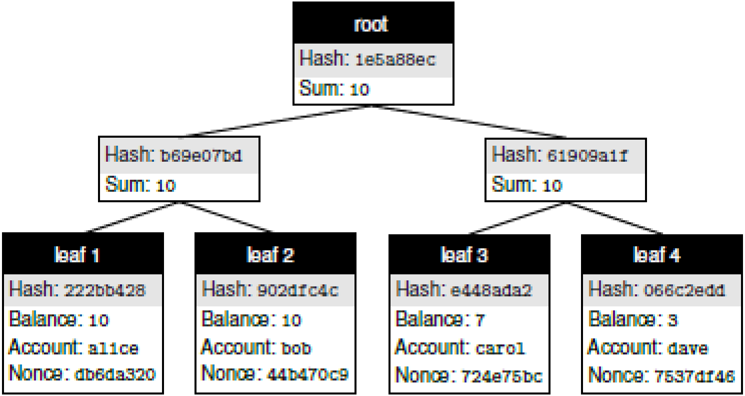
- It is required that each customer performs the verification regularly

Flaw in Maxwell protocol

- Recorded by malicious exchange



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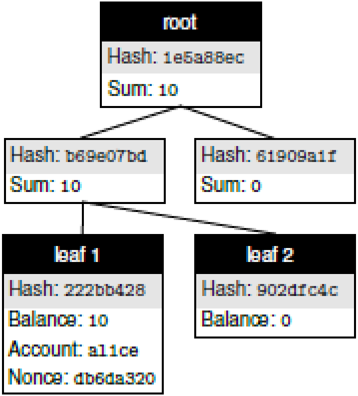
- The exchange gives Alice this tree:



Flaw in Maxwell protocol

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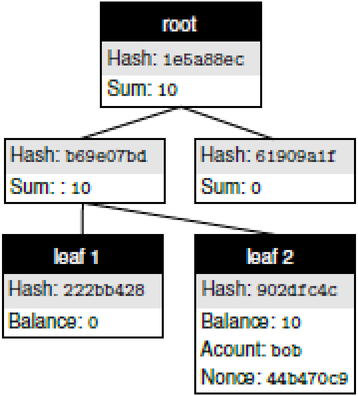

Attack result

- Both users are assured their balance is declared in the tree yet the exchange only needs to prove assets of 10 (instead of 20)

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  - Each sibling node revealed in a given users' path to the root node reveals the total holdings of each customer in that neighboring subtree.

ZeroLedge

- ZeroLedge: Proving Solvency with Privacy
  - Jack Doerner, Abhi Shelat, David Evans [unpublished]
- no account can be fraudulently reduced or omitted
- Proof of solvency by inequality
  - proves only that the the total liability is less than some publicly stated value