Blockchain and Cryptocurrency

Reference Book

- There is enough material on the Internet and book as such is not required
- For readers interested to delve deeper: Arvind Narayanan, Joseph Bonneau, Edward Felten, Andrew Miller and Steven Goldfeder, **Bitcoin and Cryptocurrency Technologies**

What is Blockchain?

- Blockchain is a system comprised of..
  - Transactions
  - Immutable ledgers
  - Decentralized peers
  - Encryption processes
  - Consensus mechanisms
  - Optional Smart Contracts

- Let’s explore these concepts

Transactions

- As with enterprise transactions today, Blockchain is a historical archive of decisions and actions taken
- Proof of history, provides provenance

Notable transaction use cases
Land registration – Replacing requirements for research of Deeds (Sweden Land Registration)
Personal Identification – Replacement of Birth/Death certificates, Driver's Licenses, Social Security Cards (Estonia)
Transportation – Bills of Lading, tracking, Certificates of Origin, International Forms (Maersk/IBM)
Banking – Document storage, increased back office efficiencies (UBS, Russia's Sberbank)
Manufacturing – Cradle to grave documentation for any assembly or sub assembly
Food distribution – Providing location, lot, harvest date Supermarkets can pin point problematic food (Walmart)
Audits – Due to the decentralized and immutable nature of Blockchain, audits will fundamentally change.

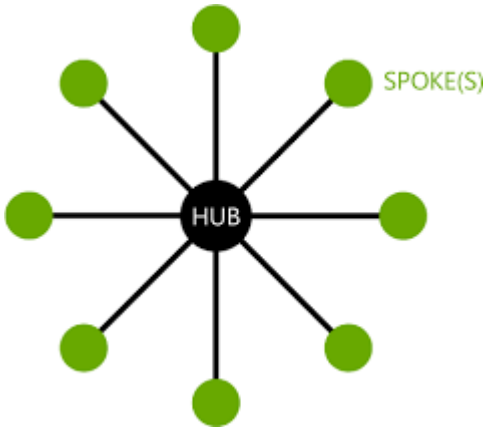
- Demo - https://anders.com/blockchain/blockchain.html

Decentralized Peers

- Rather than the centralized “Hub and Spoke” type of network, Blockchain is a decentralized peer to peer network. Where each NODE has a copy of the ledger.

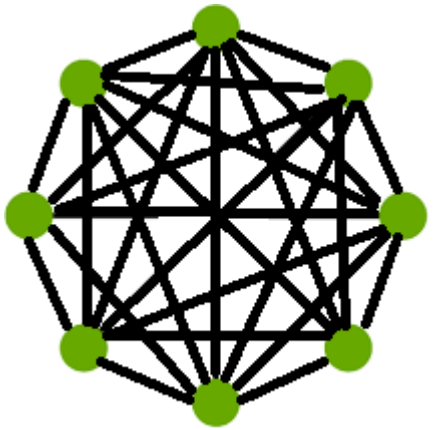
Legacy Network

Centralized DB



Blockchain Network

Distributed Ledgers



Consensus

- Ensures that the next block in a blockchain is the one and only version of the truth
- Keeps powerful adversaries from derailing the system and successfully forking the chain

Smart Contracts

- Computer code
- Provides business logic layer prior to block submission

Blockchain	Smart Contracts?	Language	
Bitcoin	No		
Ethereum	Yes	Solidity	
Hyperledger	Yes	Various	GoLang, C++, etc, depends
Others	Depends	Depends	

Blockchain Capabilities

A shared ledger technology allowing any participant in the business network to see the system of record (ledger)

Ensuring appropriate visibility; transactions are secure, authenticated & verifiable

All parties agree to network verified transaction

Business terms embedded in transaction database & executed with transactions

Blockchain Essentials

1. A business problem to be solved
   - That cannot be solved with more mature technologies
2. An identifiable business network
   - With Participants, Assets and Transactions
3. A need for trust
   - Consensus, Immutability, Finality or Provenance

Negative Indicators, Anti-Patterns

1. Need high performance (millisecond) transactions
2. Small organization (no business network)
3. Looking for a database replacement
4. Looking for a messaging replacement
5. Looking for transaction processing replacement
6. Process and metrics are not clear within the ecosystem
7. Value, velocity and/or variability are not present

Developing a Blockchain

Blockchain terminologies

- **Transaction & blocks**
  - A transaction is a value transfer; a block is a collection of transactions on the bitcoin network, gathered into a block that are hashed and added to the blockchain.

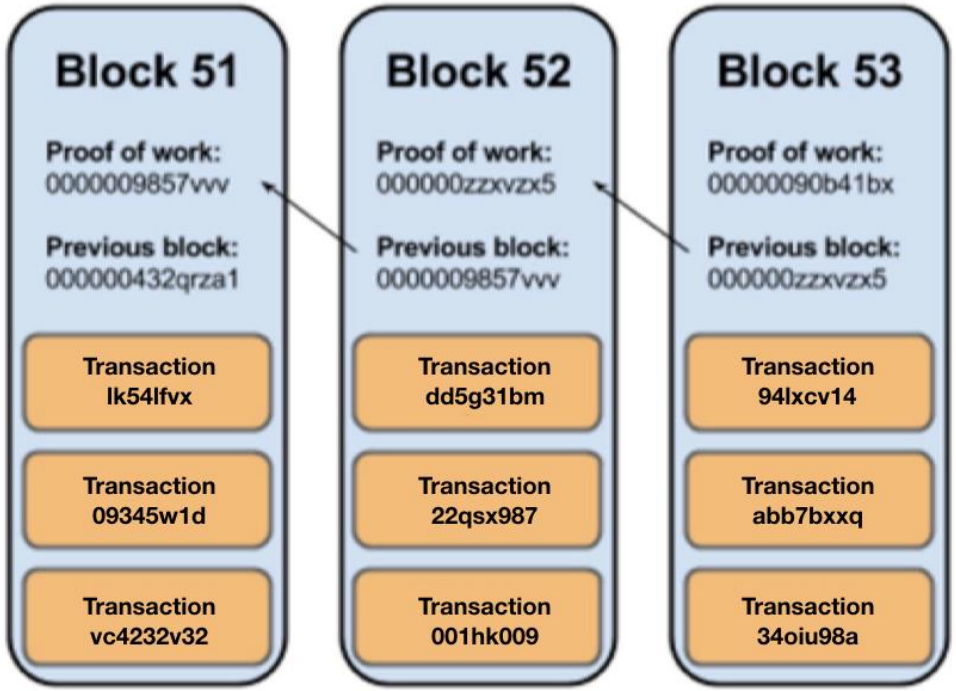
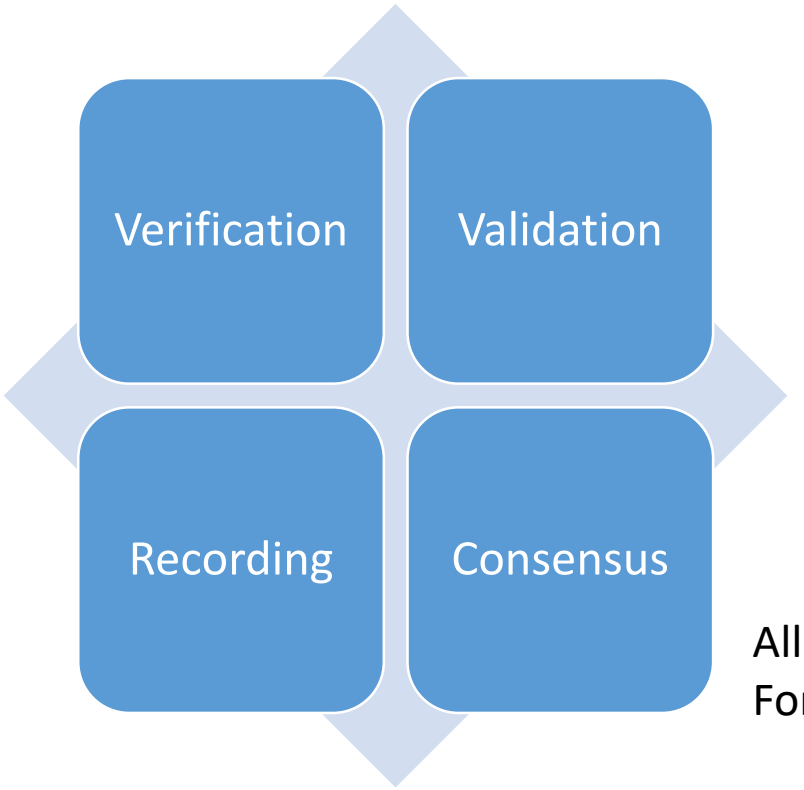
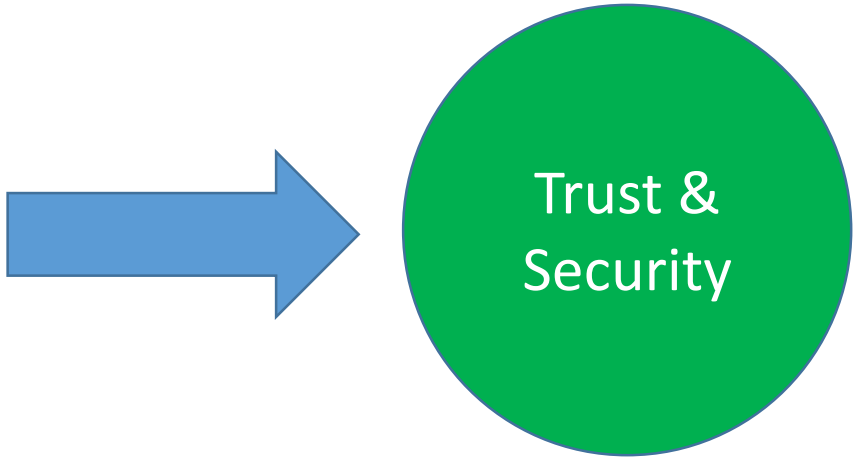


Image source: https://pplware.sapo.pt/informacao/monero-xmr-uma-moeda-segura-privada-e-sem-rasto/

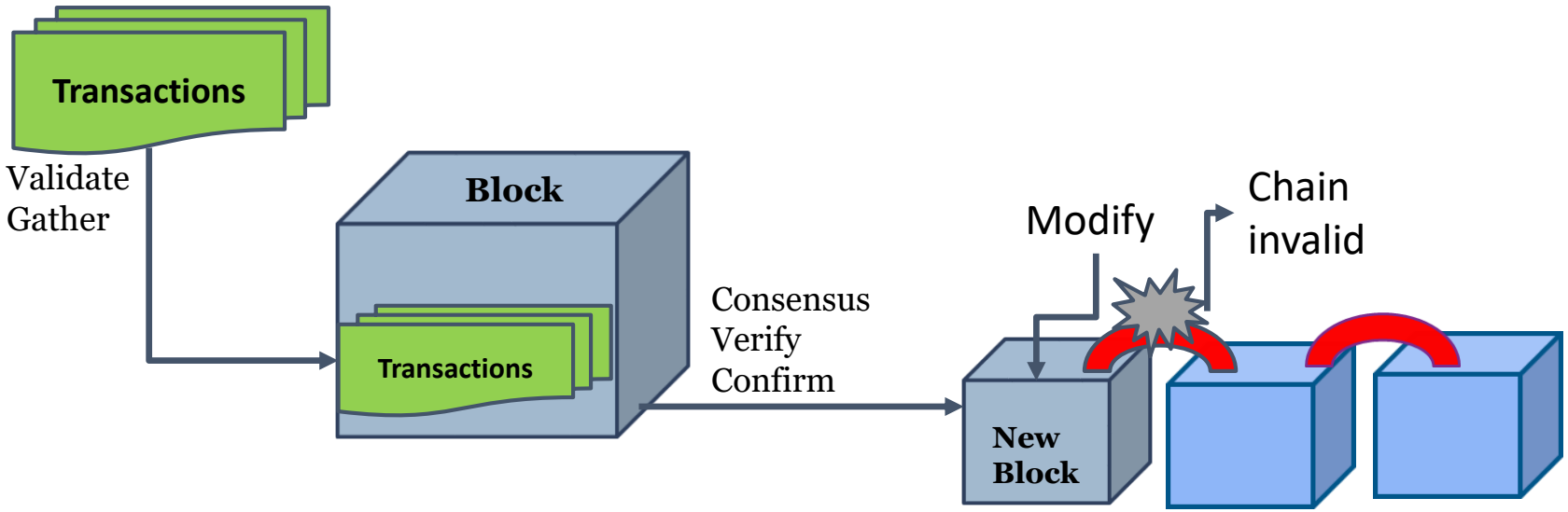
Blockchain





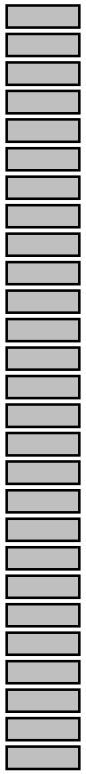
All defined by the blockchain protocol, and implemented.
For example, consider checking in for your flight at the airport.

Blockchain: Distributed, Decentralized, Immutable

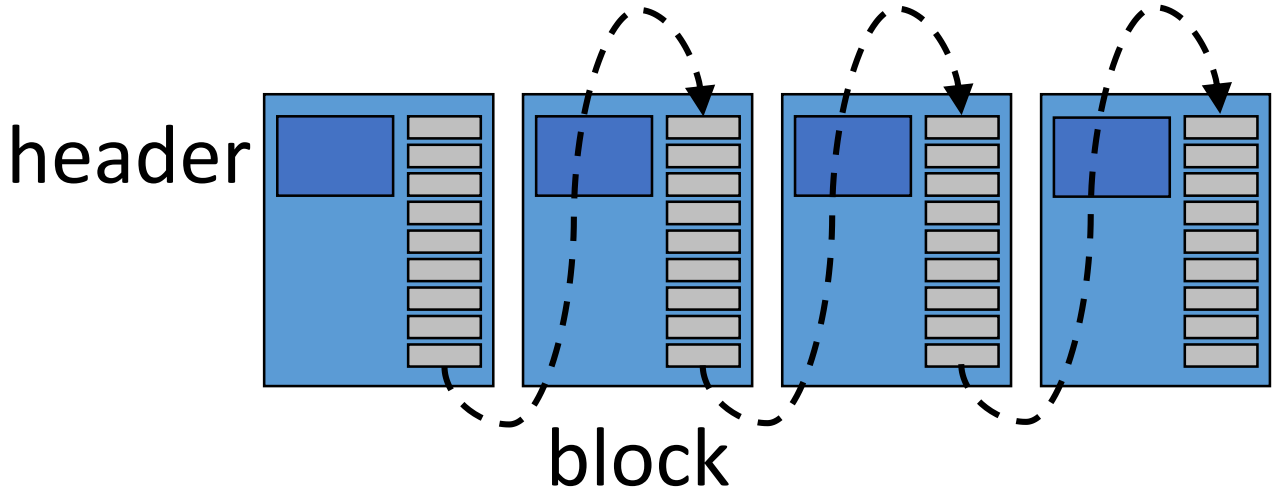


Blockchain

Log



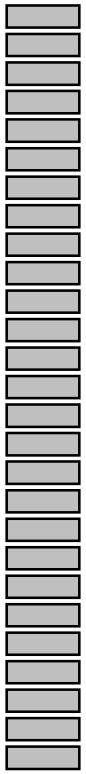
Blockchain



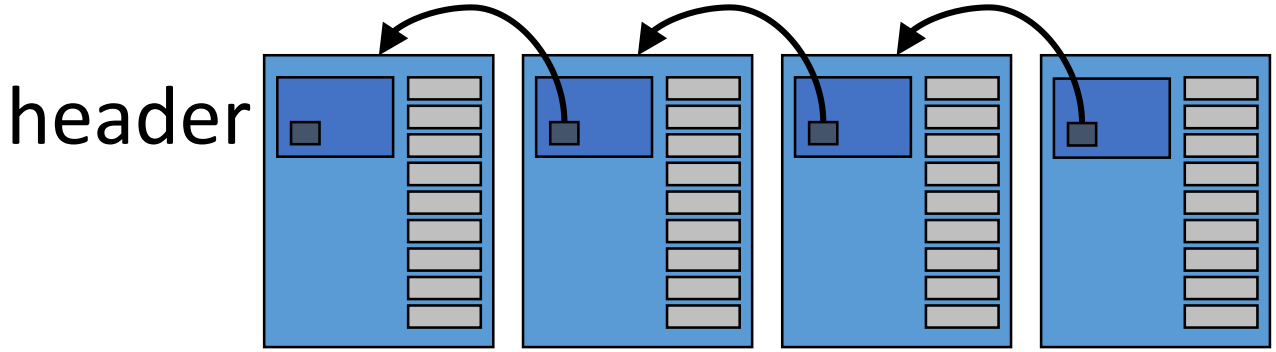
Slide courtesy of Ittay Eyal

Blockchain

Log



Blockchain



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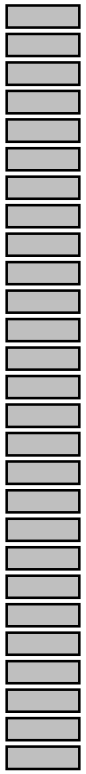
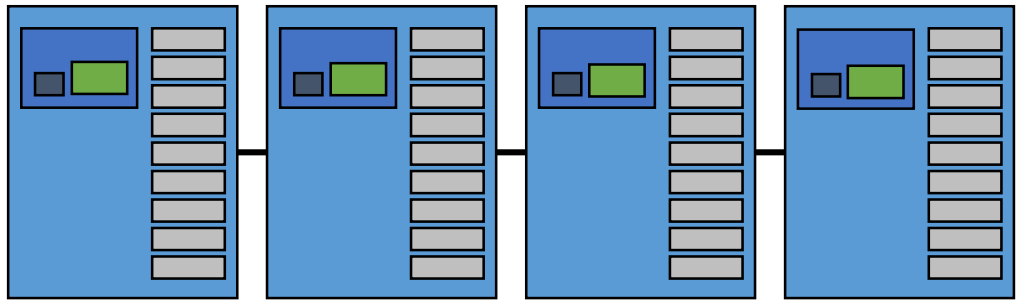
Slide courtesy of Ittay Eyal

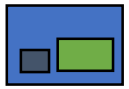
Nakamoto's Blockchain

Log



Blockchain

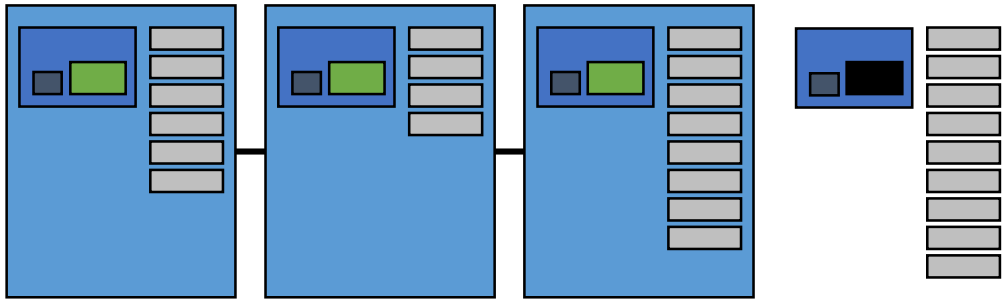


hash() < target*

* *target*: a deterministic function of previous blocks

Slide courtesy of Ittay Eyal

Nakamoto’s Blockchain



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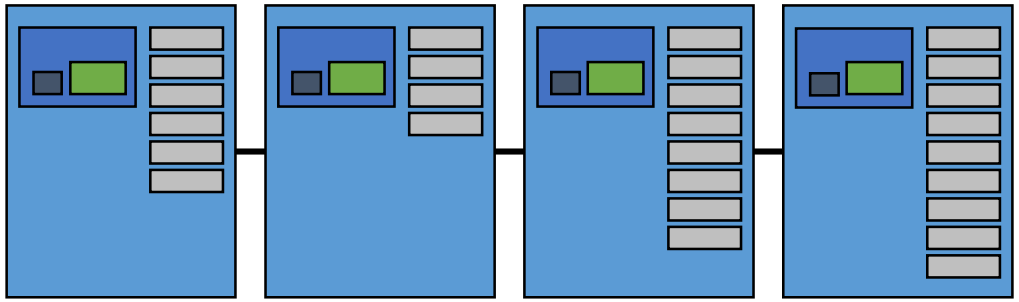
Nakamoto’s Blockchain



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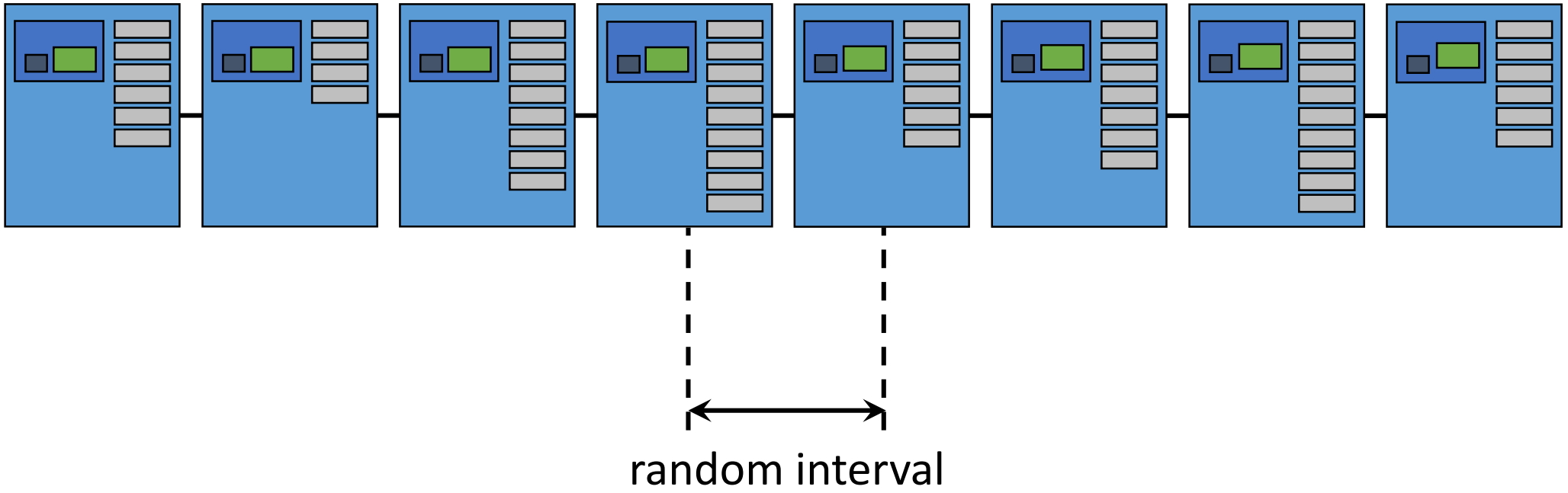

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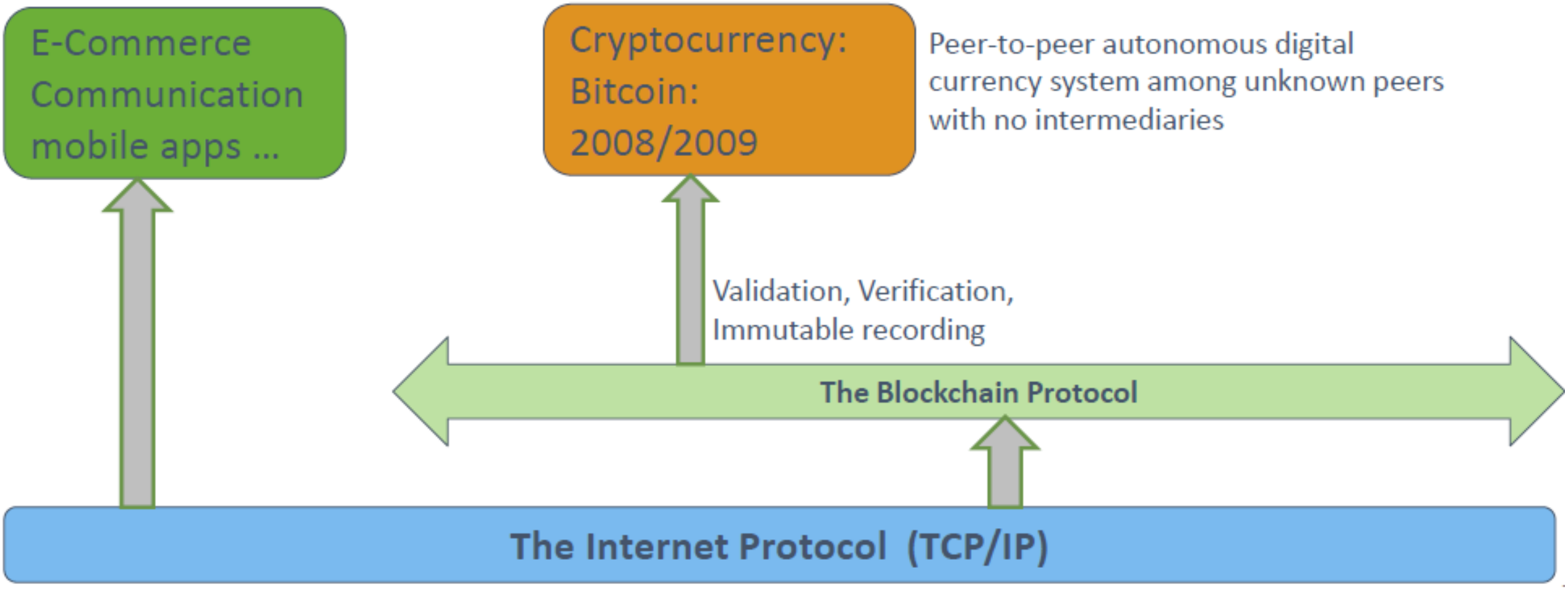
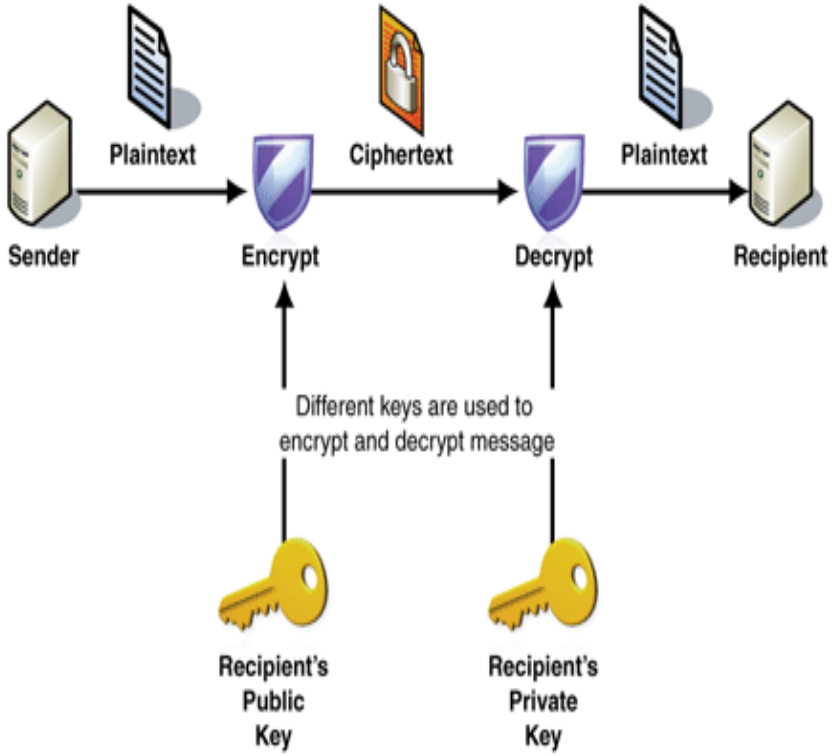
Bitcoin: Cryptocurrency



Blockchain Implementation

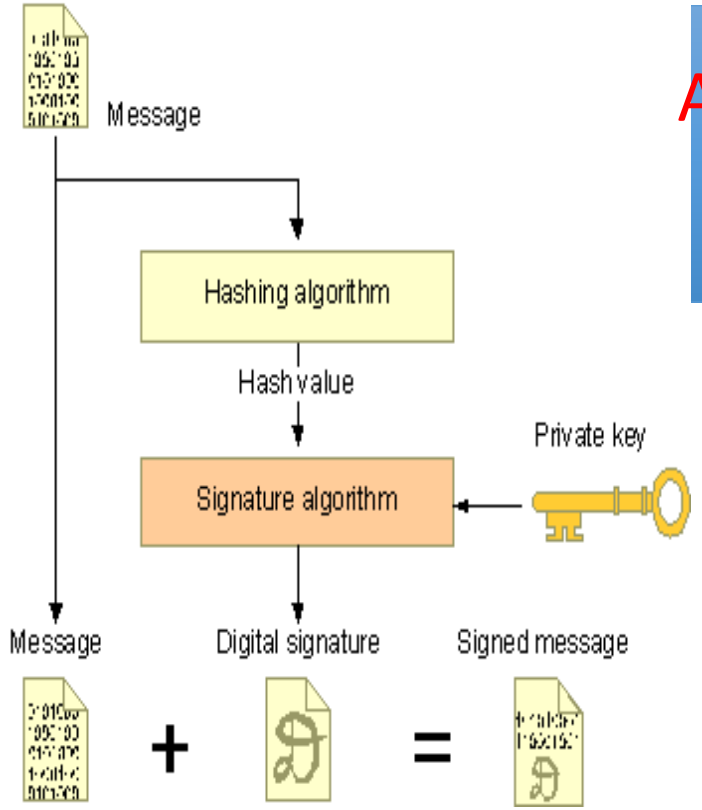
Public Key Crypto: Encryption

- Key pair: public key and private key



Public Key Crypto: Digital Signature

- First, create a message digest using a cryptographic hash
- Then, encrypt the message digest with your private key



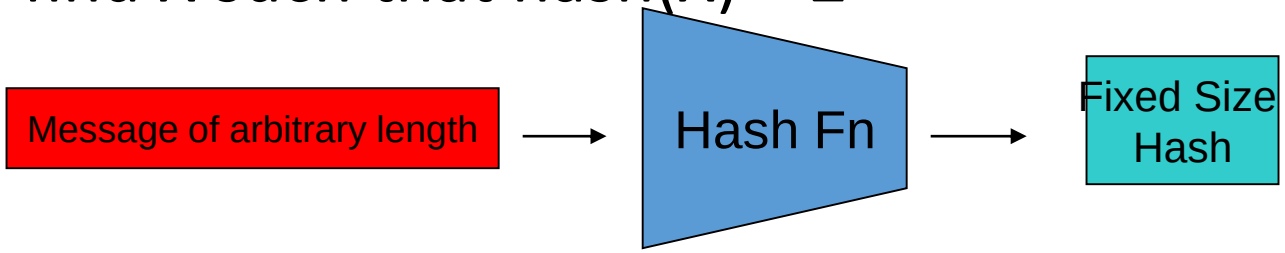
Authentication

Integrity

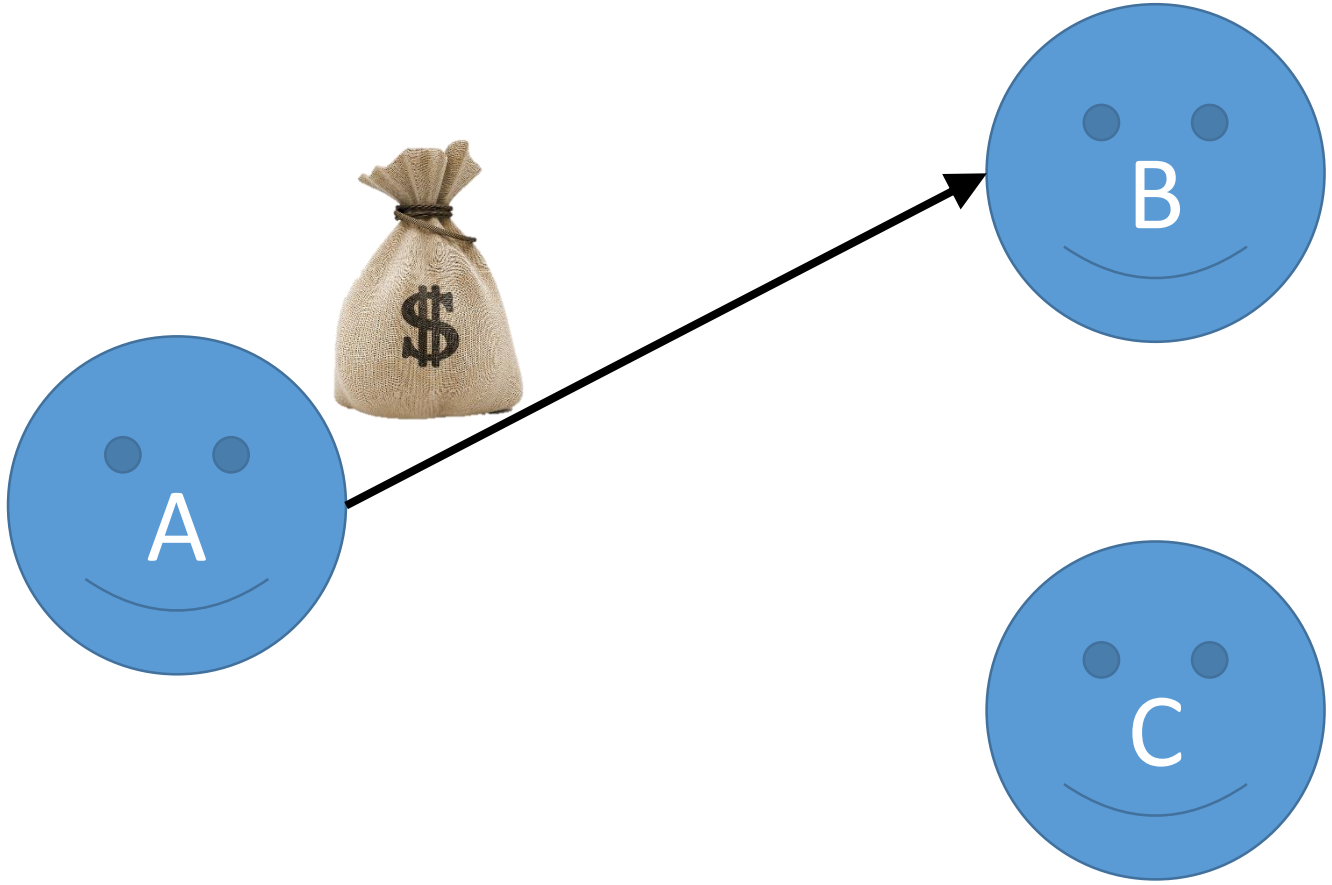
Non-repudiation

Cryptographic Hash Functions

- **Consistent:** hash(X) always yields same result
- **One-way:** given Y, hard to find X s.t. hash(X) = Y
- **Collision resistant:** given hash(W) = Z, hard to find X such that hash(X) = Z



Key Challenges



1. **No stealing: Only Alice can move her money**
2. Minting: Fair money creation
3. No double-spending: Alice cannot duplicate her money

Key Challenges

1. No stealing: Only Alice can move her money

   Cryptographic signatures
2. No double-spending: Alice cannot duplicate her money

   Global ledger
3. Minting: Fair money creation

   Mint for proof of work

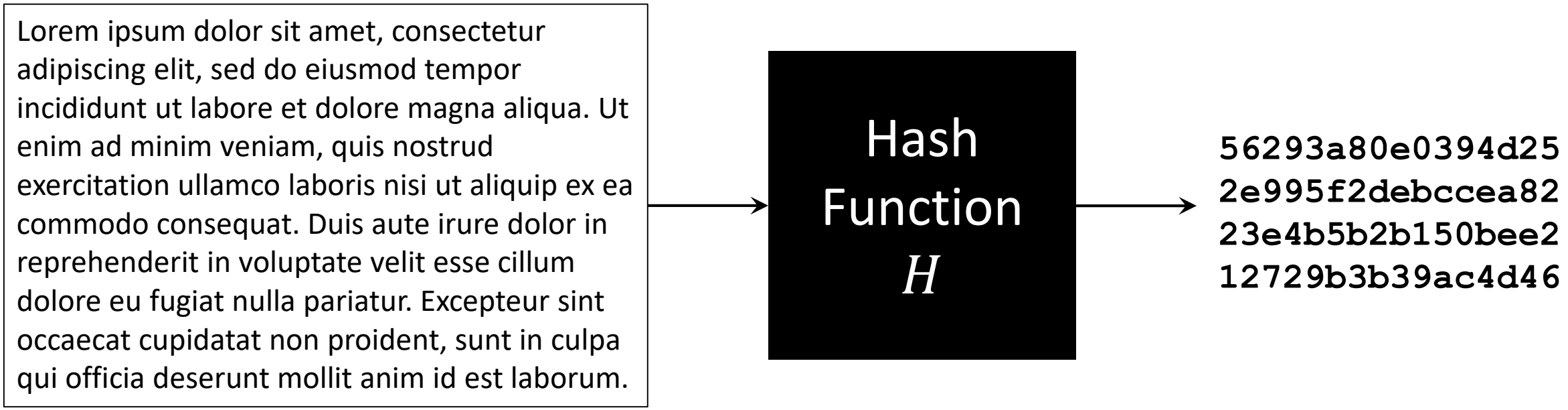
Security in Bitcoin

- Authentication
  - Am I paying the right person? Not some other impersonator?
- Integrity
  - Is the coin double-spent?
  - Can an attacker reverse or change transactions?
- Availability
  - Can I make a transaction anytime I want?
- Confidentiality
  - Are my transactions private? Anonymous?

Security in Bitcoin

- Authentication → Public Key Crypto: Digital Signatures
  - Am I paying the right person? Not some other impersonator?
- Integrity → Digital Signatures and Cryptographic Hash
  - Is the coin double-spent?
  - Can an attacker reverse or change transactions?
- Availability→ Broadcast messages to the P2P network
  - Can I make a transaction anytime I want?
- Confidentiality→ Pseudonymity
  - Are my transactions private? Anonymous?

60 Seconds on Cryptographic Hashing



String input

256 bit number (for example)

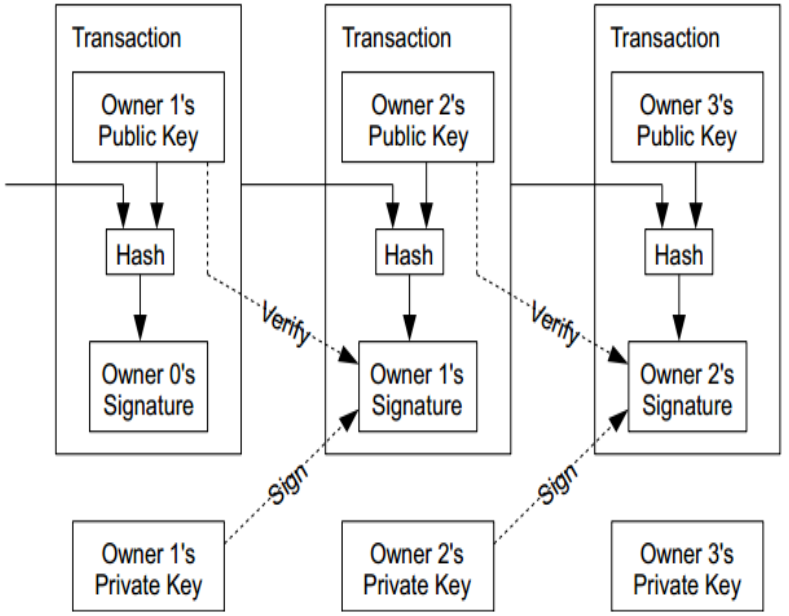
Given a 256bit number h, one cannot find an input string that results in h faster than repeatedly guessing inputs x and calculating $H(x)$.

Slide courtesy of Ittay Eyal

Bitcoin

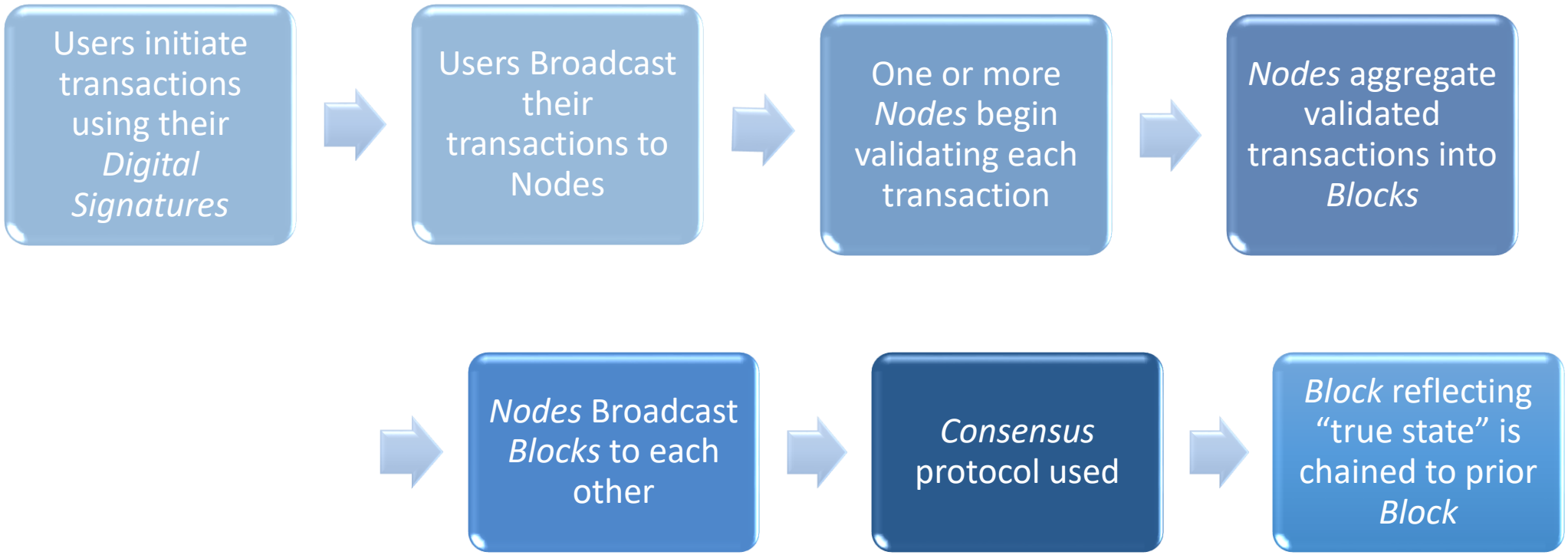
- Electronic coin == chain of digital signatures
- BitCoin transfer: Sign(Previous transaction + New owner's public key)
- Anyone can verify (n-1)th owner transferred this to the nth owner.
- Anyone can follow the history

Given a BitCoin



Blockchain terminologies

- **Distributed ledger – How it works?**

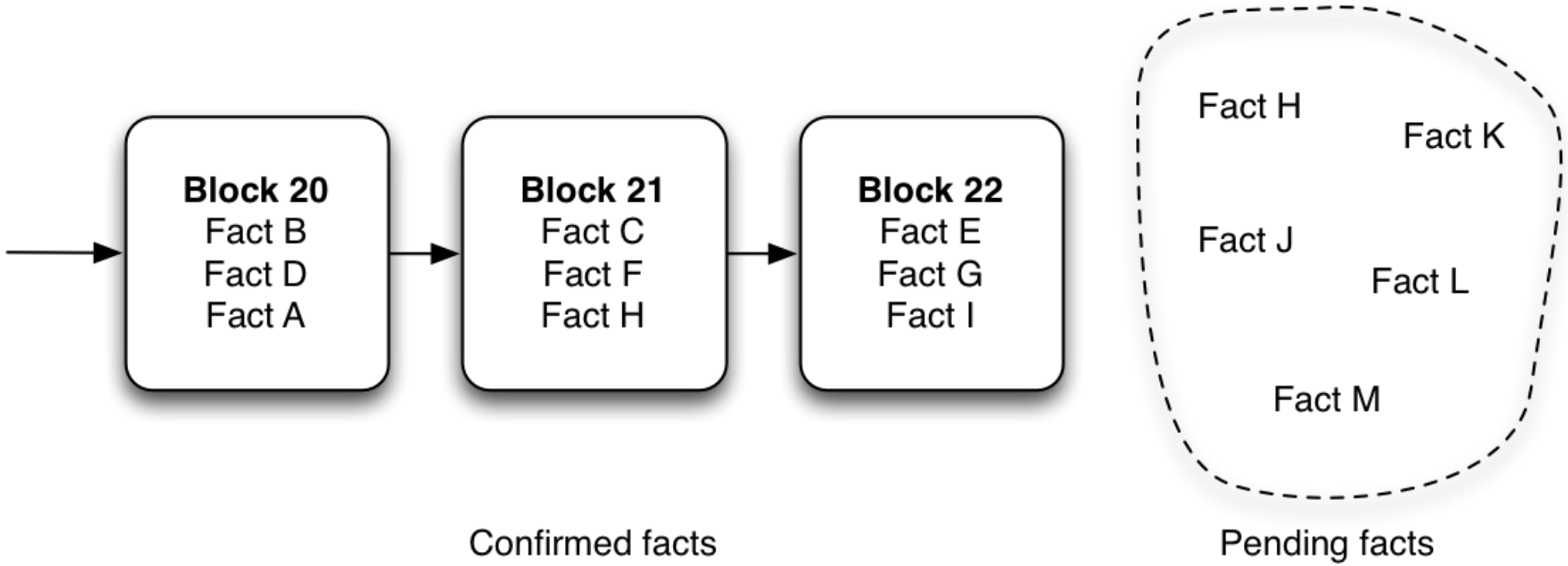


Source:
https://ccl.yale.edu/sites/default/files/files/A%20Brief%20Introduction%20to%20Blockchain%20(Final%20without%20Notes).pdf

Specific issues

Blockchain terminologies

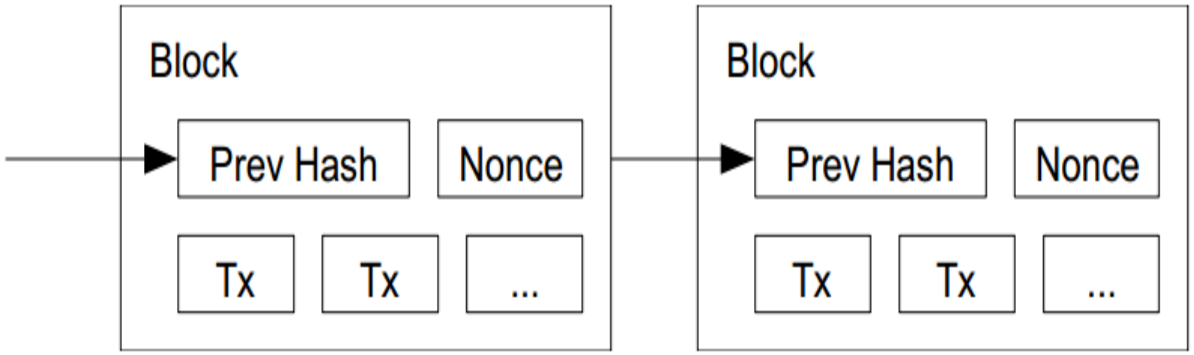
- **Mining**
  - This process of solving cryptographic problems using computing hardware also triggers the release of cryptocurrencies



Source: https://marmelab.com/blog/2016/05/12/blockchain-expliquee-aux-

Use of Cryptographic Hashes

- Proof-of-work
  - Block contains transactions to be validated and previous hash value.
  - Pick a nouce such that **H(prev hash, nounce, Tx) < E**. E is a variable that the system specifies. Basically, this amounts to finding a hash value who's leading bits are zero. The work required is exponential in the number of zero bits required.
  - Verification is easy. But proof-of-work is hard.



BitCoin

- Validation
  - Is the coin legit? (proof-of-work) → Use of Cryptographic Hashes
  - How do you prevent a coin from double-spending? → consensus based verification
- Creation of a virtual coin/note
  - How is it created in the first place? → Provide incentives for miners
  - How do you prevent inflation? (What prevents anyone from creating lots of coins?) → Limit the creation rate of the BitCoins

Preventing Double-spending

- The only way is to be aware of all transactions.
- Each node (miner) verifies that this is the first spending of the Bitcoin by the payer.
- Only when it is verified it generates the proof-of-work and attach it to the current chain.

Key Challenges

1. No stealing: Only Alice can move her money

   Cryptographic signatures
2. No double-spending: Alice cannot duplicate her money

   Global ledger
3. Minting: Fair money creation

   Mint for proof of work

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Who runs the public key infrastructure?

Who maintains the public ledger?

Who gives money for puzzles?

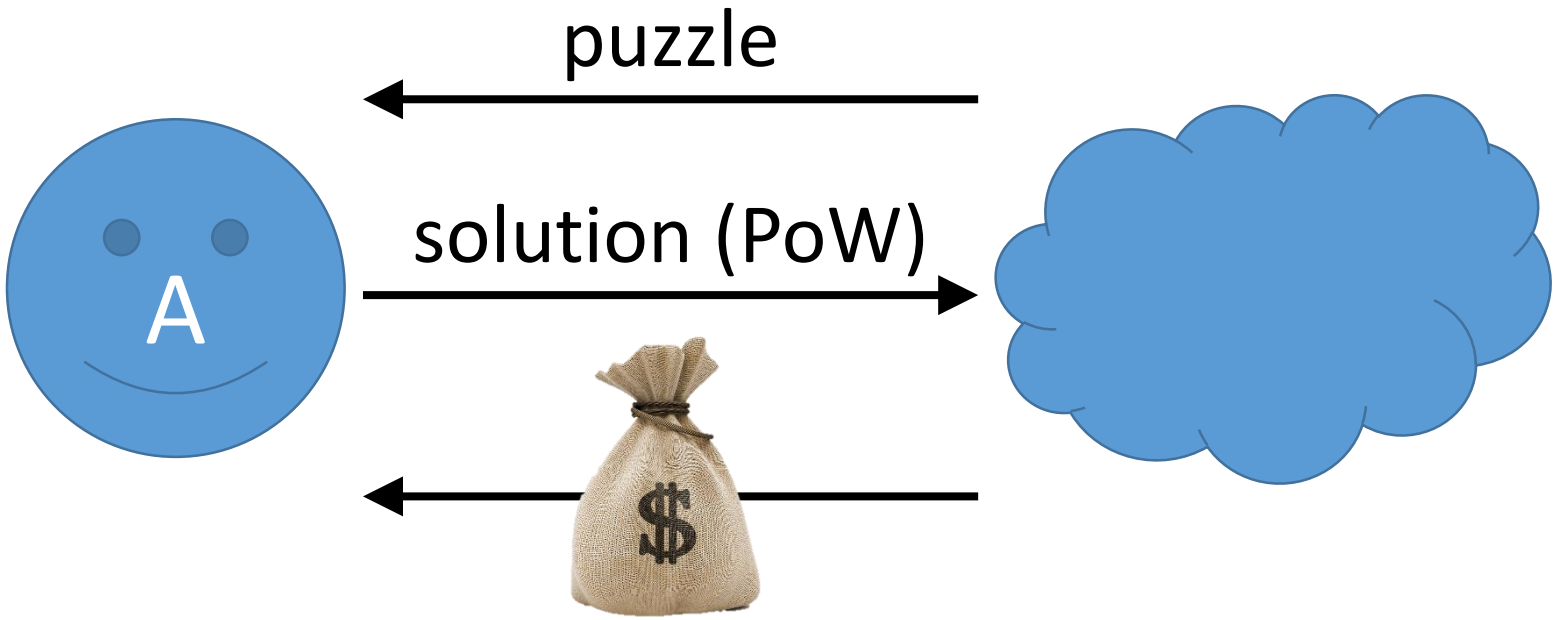
Can this be decentralized?

Slide courtesy of Ittay Eyal

BitCoin Economics

- Rate limiting on the creation of a new block
  - Adapt to the “network’s capacity”
  - A block created every 10 mins (six blocks every hour)
    - How? Difficulty is adjusted every two weeks to keep the rate fixed as capacity/computing power increases
- N new Bitcoins per each new block: credited to the miner → incentives for miners
  - N was 50 initially. In 2013, N=25.
  - Halved every 210,000 blocks (every four years)
  - Thus, the total number of BitCoins will not exceed 21 million. (After this miner takes a fee)

Mining – Minting for Proof of Work



Mining – Minting for Proof of Work

Computationally difficult puzzle:

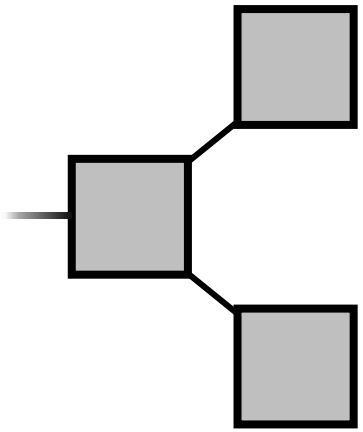
$$\text{Find } x \text{ such that } H(x|y) < t$$

Solver guesses values for x until finding a valid one

- Different strings y for different puzzles
- The target t determines the difficulty, average time to solve

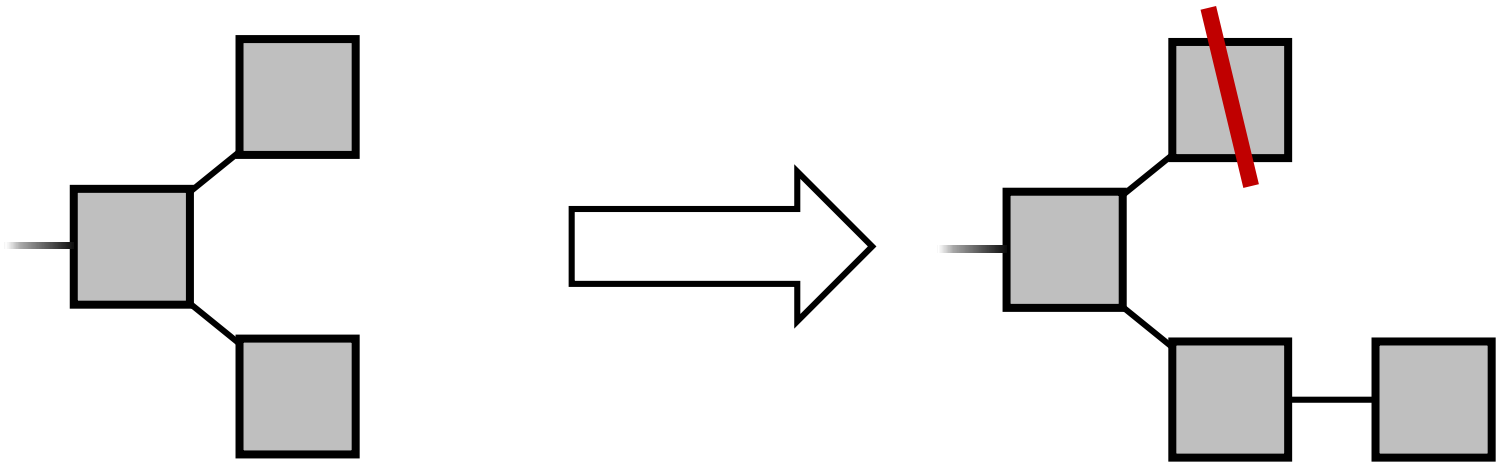
Slide courtesy of Ittay Eyal

Forks



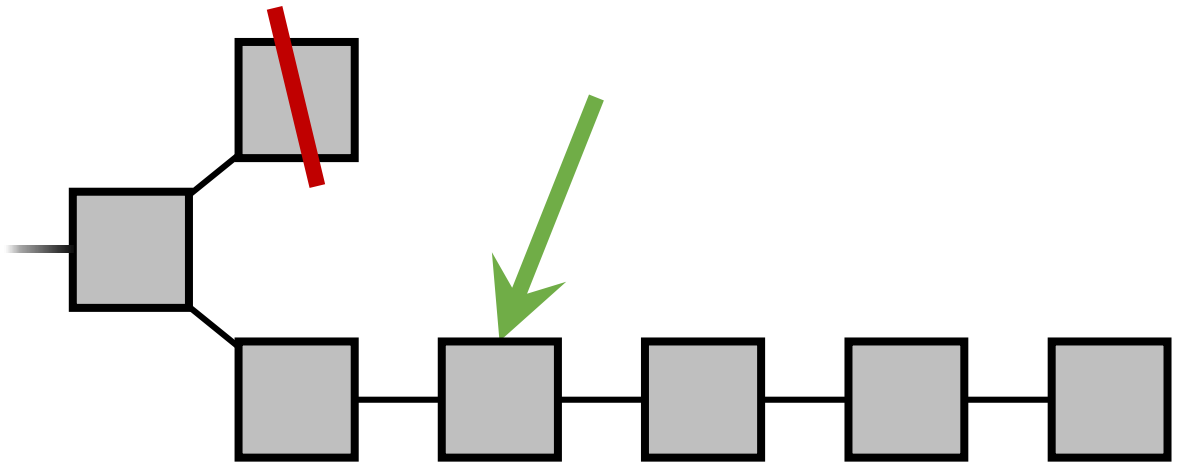
- Natural in a distributed system

Fork Resolution



- **Longest** chain wins
- Transactions are reverted
- Double-spending a threat

Fork Resolution



A transaction is **confirmed** when
it is **buried** deep enough