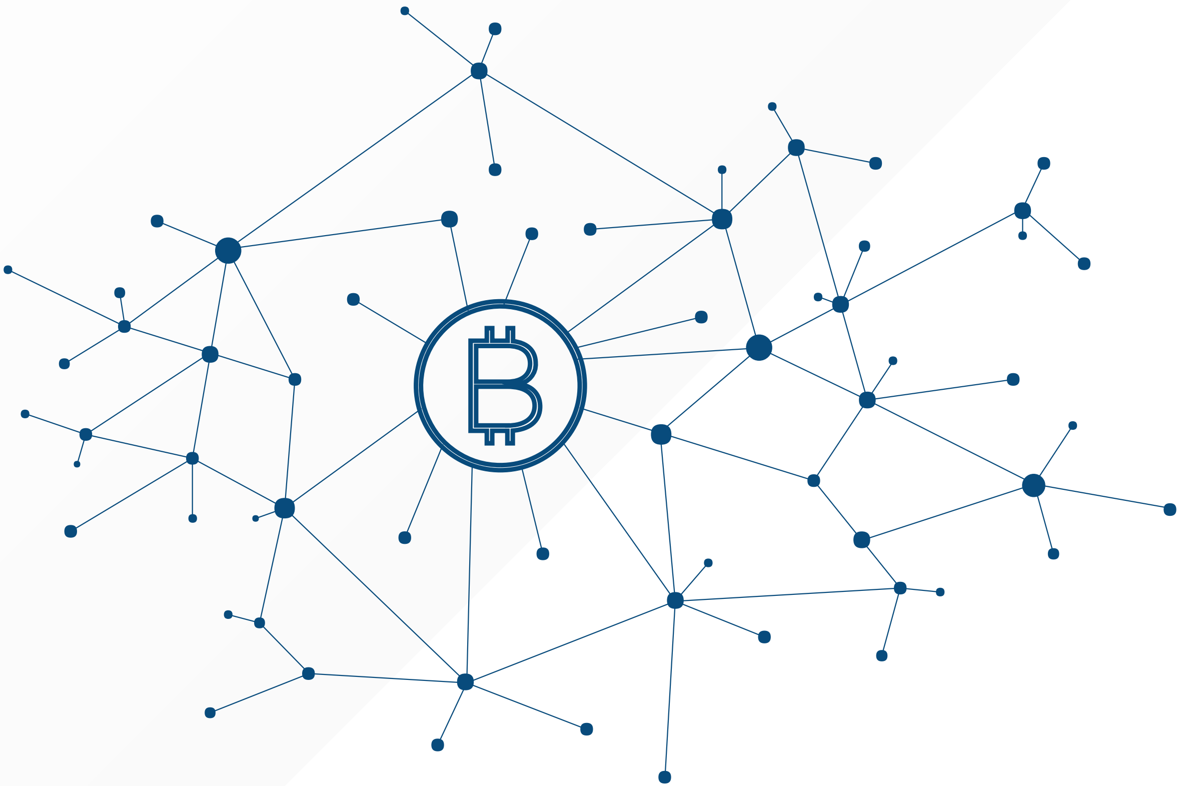
Large-scale Distributed Systems

Lecture 10: Blockchain

Today



Most of today's lecture slides are taken from Jonathan Jogenfors, "Cryptography Lecture 12: Bitcoin and friends".

Money vs the Internet

- Many everyday things have moved to the Internet.
- Communications, relations, entertainment, ... but not money.

Why do we still need these?

What about credit cards?

- Credit cards are inherently insecure.
- Entire model is backwards:
  - Merchant takes the customer's CC number.
  - Merchant goes to the bank.
  - Merchant gives CC number to the customer's bank.
  - Bank gives money from the customer's account to the merchant.
- Something like this would be better:
  - Customer tells bank to give money to merchant.
  - That's it!

Making money digital

- Why not create a currency based on cryptography?
- Our design goals should be a currency with the following properties:
    - Secure transfer in computer networks
    - Cannot be copied and reused
    - Anonymity
    - Offline transactions
    - Can be transferred to others
    - Can be subdivided

The failure of electronic cash

- There have been several proposals for digital money.
- Until a few years ago, all had failed.
- No gain over existing systems:
    - Still need a central point of trust
    - Privacy: who monitors the system?
    - Can we entrust a bank with managing an entire currency?

Bitcoin

- The bitcoin protocol was proposed in 2008.
- Takes care of:
  - Creation of new currency
  - Secure transactions
  - Protection against double-spending
  - Anybody can be a merchant or a customer
  - Pseudo-anonymity

Bitcoin: A Peer-to-Peer Electronic Cash System

Satoshi Nakamoto
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Abstract. A purely peer-to-peer version of electronic cash would allow online payments to be sent directly from one party to another without going through a financial institution. Digital signatures provide part of the solution, but the main benefits are lost if a trusted third party is still required to prevent double-spending. We propose a solution to the double-spending problem using a peer-to-peer network. The network timestamps transactions by hashing them into an ongoing chain of

Bitcoin from scratch

Step by step, we will build a peer-to-peer currency,
discussing strengths and weaknesses.

v1: Public, signed transactions

"I, Alice, send one coin to Bob."

- Alice publishes a signed message.
- Benefits:
  - Bob can verify the signature as being from Alice.
  - The transaction cannot be undone.
- Downsides:
  - No account balances.
  - Infinite number of coins. Very incomplete protocol.

v2: Serial numbers

"I, Alice, send coin no. 856034 to Bob."

- Duplicate transactions are easily spotted.
- How are the serial numbers created?
- Easy solution: Serial numbers are generated by a trusted source, like a bank.

No middleman?

- A bank works, but can we remove the central point of trust?
- We want a decentralized, self-governing network.
- Instead, we establish a list of all transactions ever made.
- Computing an account balance is done by summing over all previous transactions for that account.
- This list is called the blockchain and is shared by all users.

v3: The blockchain

"Bob checks his blockchain before accepting the transaction."

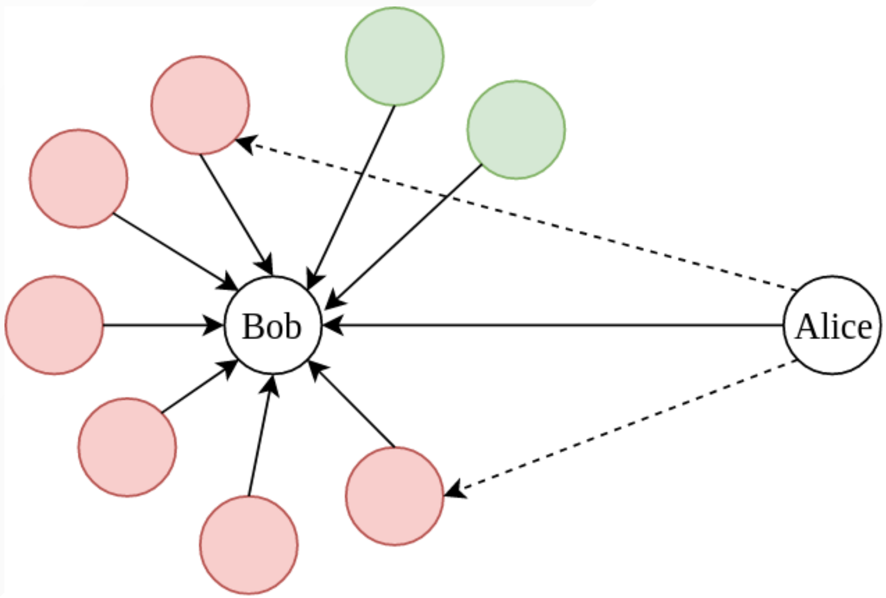
- If he sees that the coin is owned by Alice, he accepts it.
- After the transaction is complete, Bob broadcasts his acceptance.
  - Bitcoin relies on a gossiping protocol for the broadcast.
- As soon as the other peers hear this broadcast, they will not allow double-spending.

Double-spending

- Double-spending is still possible.
- Alice can perform a double-spend before the acceptance broadcast is hear by enough peers.
- To solve this problem, we make Bob ask everybody else to confirm the transaction validity.
- Double-spending will be noticed before payment is confirmed.

Verifying transactions

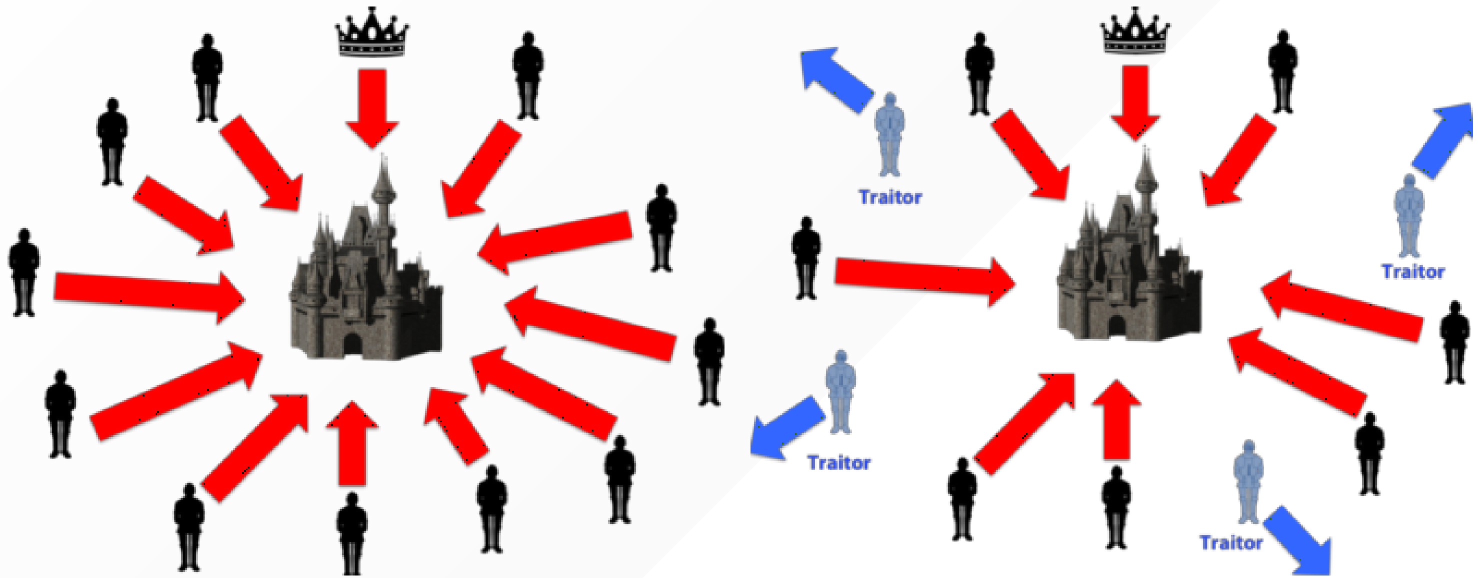
- How many answers should Bob require? How can answers be trusted?
- A majority vote is impossible.
  - What if Alice controls other peers and spams Bob with false confirmations?
- But Bitcoin will not work if transactions cannot be reliably verified...



A sybil attack from Alice

We need consensus, in the presence of malicious peers!

The Byzantine Generals Problem



The Byzantine Generals Problem

- Each division of the Byzantine army is directed by its own general.
- Generals, some of which are traitors, communicate with each other by messengers.
- Requirements:
  - All loyal generals must decide upon the same plan of action (attack or retreat).
  - A small number of traitors cannot cause the loyal generals to adopt a bad plan.
- Impossibility result:
  - No solution exists if $\leq 2/3$ generals are loyal.

v4 (final): Proof of work

- To verify transactions, the Bitcoin protocol uses Proof of Work (PoW).
- Basic idea: We only trust solutions that are accompanied by a proof of someone having committed a large amount of resources to a problem.
- That is, we do not authenticate a user, but we authenticate the fact time/money/energy/etc has been spent.
- In order for Alice to make a double-spend, she first has to spend energy before Bob trusts here.
- Even better: we turn proof-of-work into a competition.

The PoW challenge

- We want a problem that...
  - is difficult to solve
  - has solutions that are easy to verify
  - has scalable difficulty
- Finding (partial) hash collision as proof-of-work:
  - A one-way hash function $h(x)$ has the following properties:
    - Easy to compute $h(x)$ from x.
    - Given $h(x)$, it is difficult to find x' such that $h(x') = h(x)$.
  - Finding pre-images is the perfect proof-of-work!
  - Bitcoin uses $h(x) = \mathrm{SHA256}(\mathrm{SHA256}(x))$

Mining

- Blocks of transactions are verified by special peers called miners.
- Assume that Alice's transaction message m is broadcast:
  - "I, Alice, send coin no. 856034 to Bob."
- Mining algorithm:
  - A miner selects a random nonce k and computes $h(m+k)$.
  - If $h(m+k) > T$, the miner chooses a new k and tries again.
  - After a long time, a miner eventually finds k such that $h(m+k) < T$ and broadcasts k.
  - Bob receives k and checks that $h(m+k) < T$ to accept the transaction.

Example

- Let the threshold T be so that the hash value $h(m+k)$ needs five leading zeros and let m="AAA".

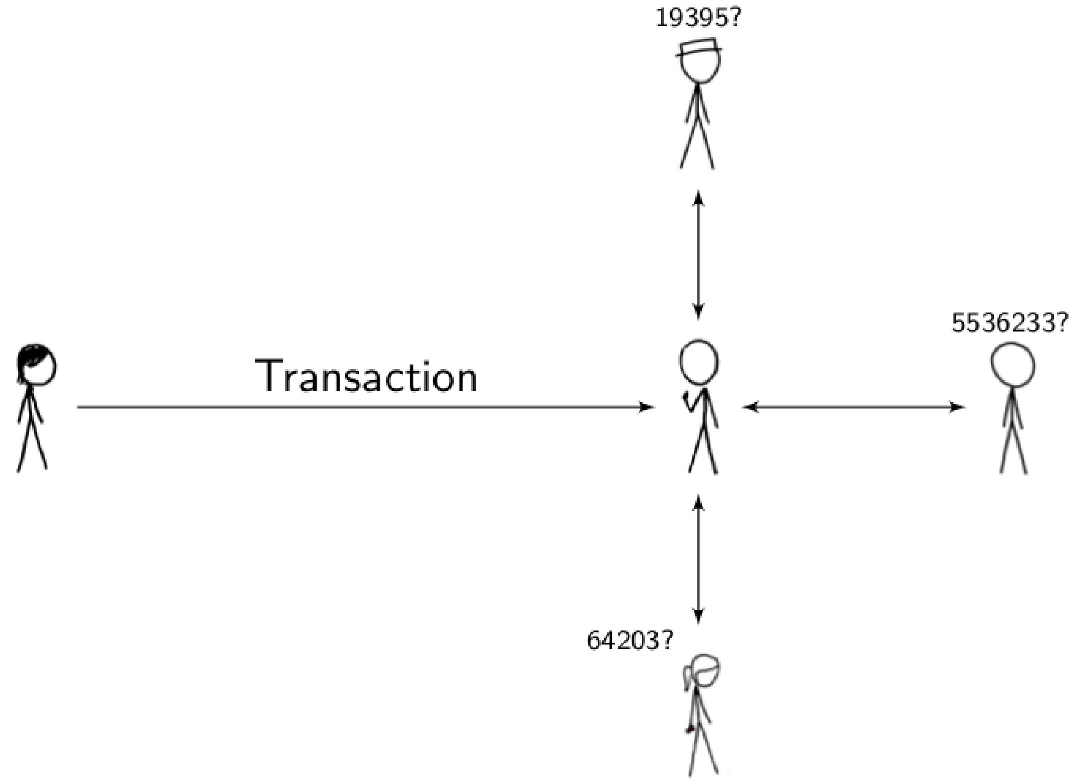
$m+k$	$h(k+m)$
AAA0	802dbe2e69...
AAA1	bbfce0d522...
AAA2	7bb4db476f...
...	...
AAA770239	00000921ac...

$k = 770239$ is a valid solution

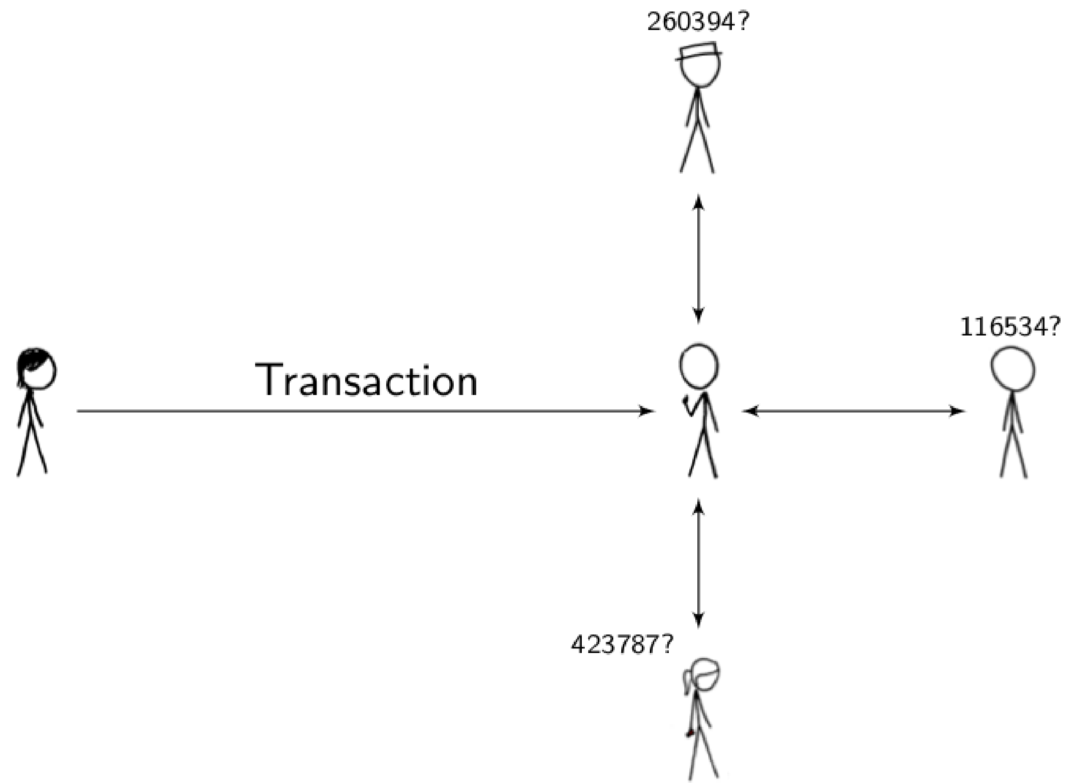
- Note that in the normal case, k is chosen randomly.
- There are several solutions k to the problem $h(m+k) < T$.

Mining is a competition (1)

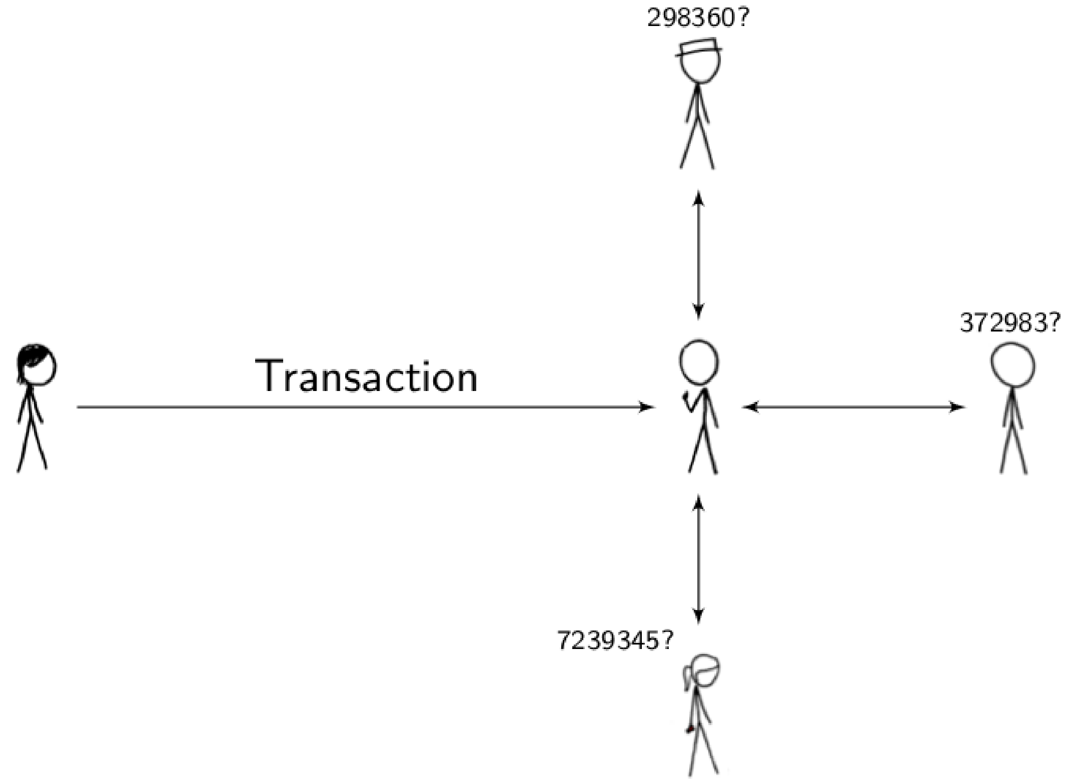
Mining is a competition (2)



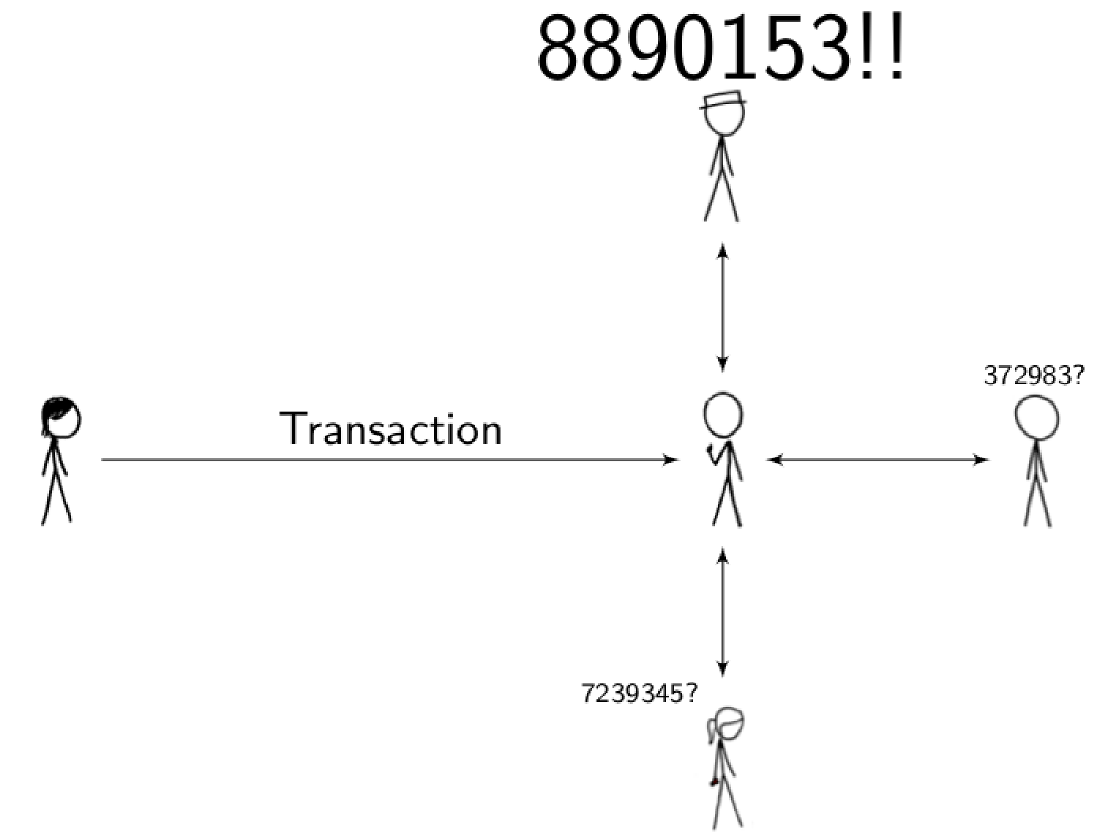
Mining is a competition (3)



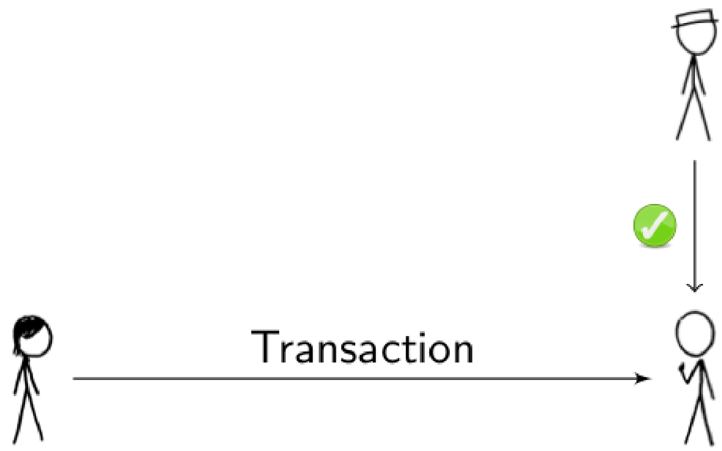
Mining is a competition (4)



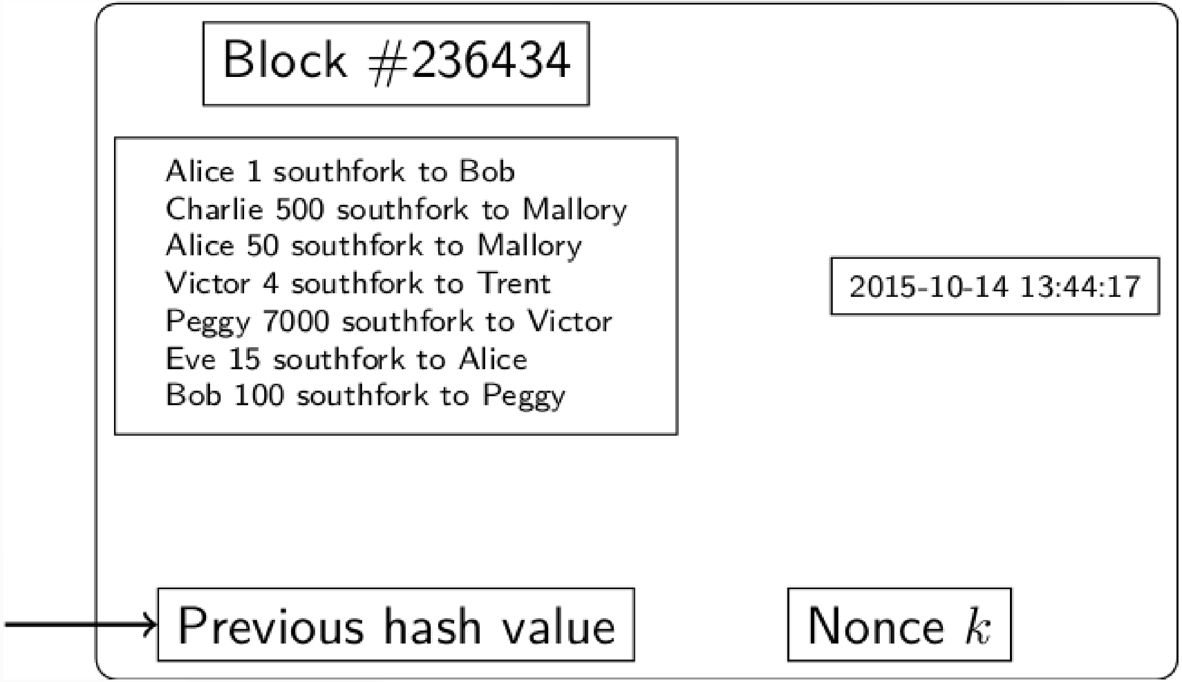
Mining is a competition (5)



Mining is a competition (6)



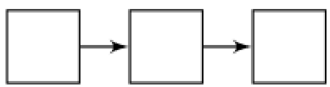
Blocks



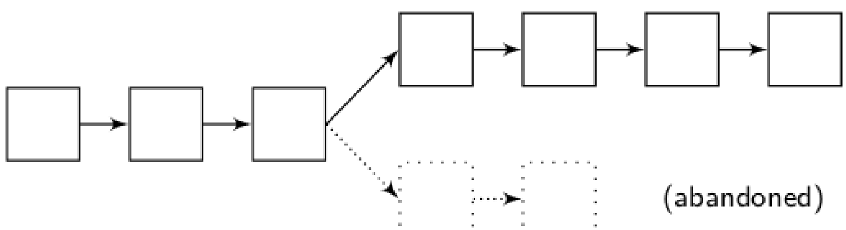
- A block is a large number of transactions.
- A block is only valid if its hash value is less than T.

The blockchain

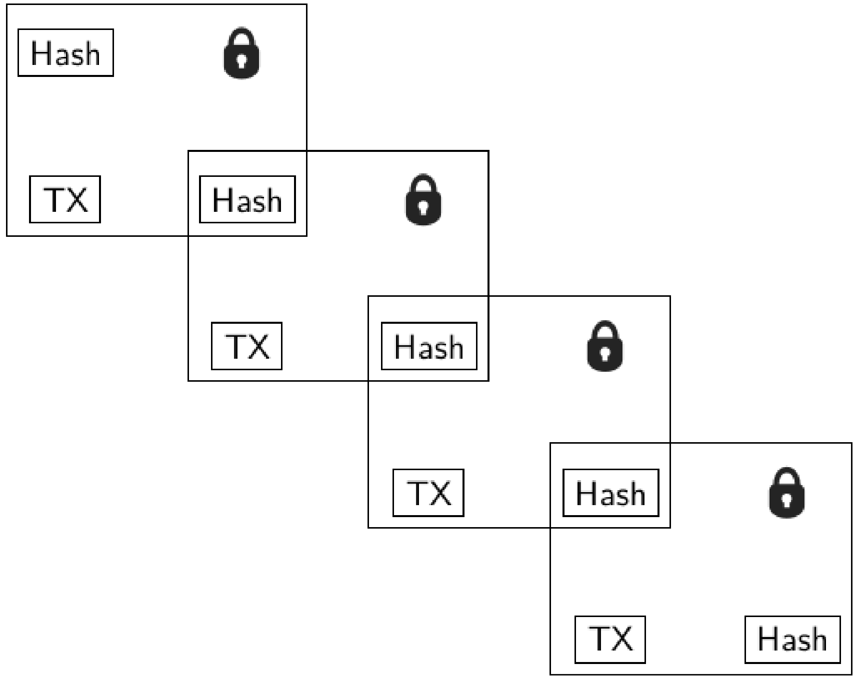
- The process of adding transactions into the distributed ledger is called mining.
- Transactions are grouped in blocks, that are numbered and form a long chain, called the blockchain.



- If two miners find a valid block simultaneously, the resolution strategy is to switch to the branch with the largest cumulated work.



Security



- Each block gives security to the previous ones in the branch.
  - The hash of a block is computed partly based on the hash of the previous hash.
- Bob waits for 6 blocks before accepting Alice's transaction.
- Forging transactions requires finding collisions for all blocks in the suffix, which requires a large amount of work.

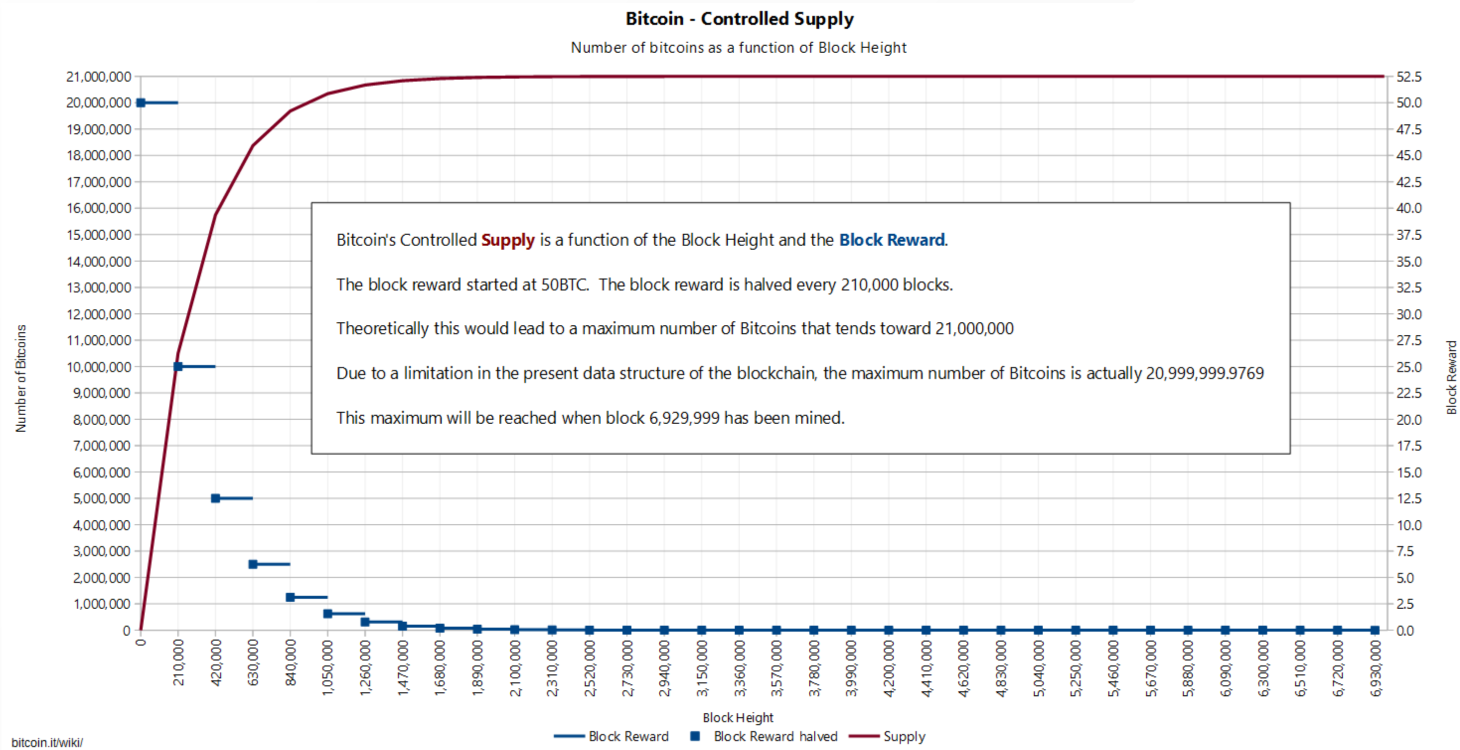
Consensus by proof-of-work

- Consensus is guaranteed probabilistically, provided that the majority of the hashing power is detained by loyal nodes.
- The only way for Alice to cheat the system would be to:
  - Buy a supercomputer;
  - Save up money for the electricity bill;
  - Broadcast an invalid transaction m to Bob;
  - Let the supercomputer search for a block containing m.
  - The computer must be faster than everybody else's, combined.
- Alice has a hard time cheating Bob:
  - With 1% of the total hashing power, the chance of mining six blocks in a row is $0.01^6 = 10^{-12}$.
- Therefore, with high probability, transactions confirmed in the ledger are legit.

New coins

- The number of transactions in a block is automatically adjusted to aim for an average block rate of 1 block / 10 minutes.
- When a new block is discovered, the miner may award itself a certain number of coins.
    - Currently:
        - The bounty is 12.5BTC.
        - T is set to hash values beginning with $\geq$ 20 zeros.
            - `00000000000000000af0d5752187e109c477ea70bb96c5c5aa8f92c6a6c8b02`
- The block reward decreases every 210 000 blocks.
- The total number of coins is limited to 21 000 000.
- The last Bitcoin should be mined in 2140.

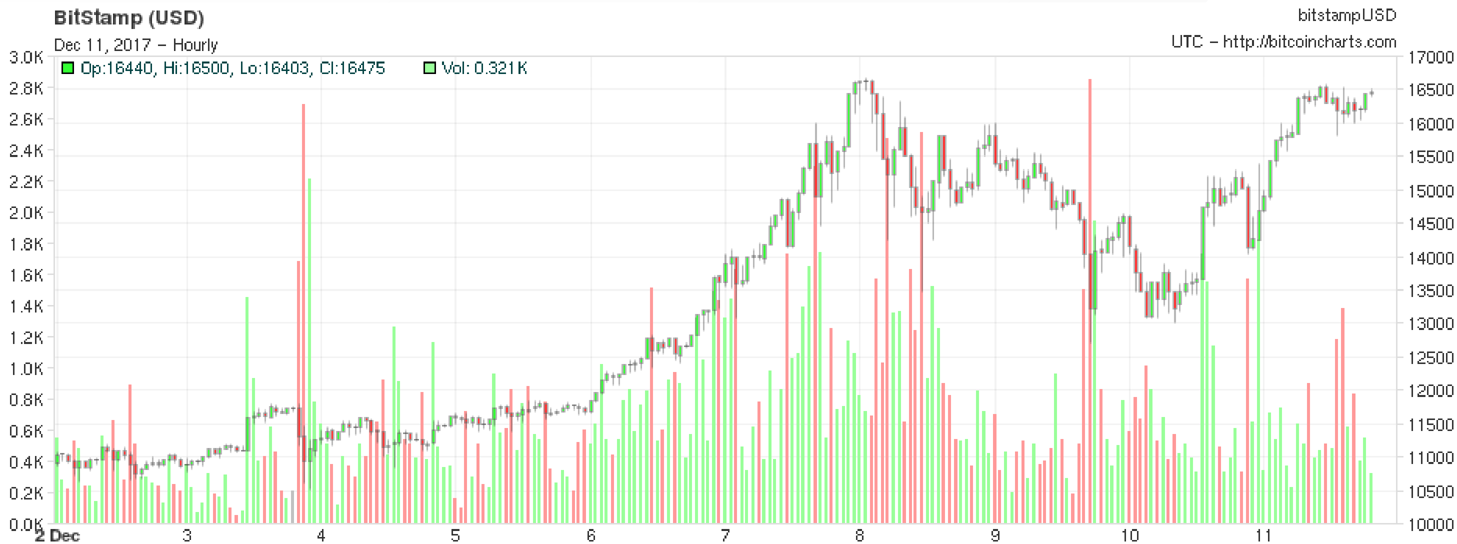
[Q] How long does it take confirm a transaction? (on average)


Bitcoin - Controlled Supply
Number of bitcoins as a function of Block Height
Bitcoin's Controlled Supply is a function of the Block Height and the Block Reward.
The block reward started at 50BTC. The block reward is halved every 210,000 blocks.
Theoretically this would lead to a maximum number of Bitcoins that tends toward 21,000,000
Due to a limitation in the present data structure of the blockchain, the maximum number of Bitcoins is actually 20,999,999.9769
This maximum will be reached when block 6,929,999 has been mined.
Number of Bitcoins
Block Reward
Block Height
Block Reward
Block Reward halved
Supply
bitcoin.it/wiki/

Bitcoin trading

- Today: 1 BTC $\approx$ 16500 USD (Dec 11, 2017)
- Bitcoin can be bought and sold like any other currency.
- Bitcoin ATMs even exist in some countries!

Volatility

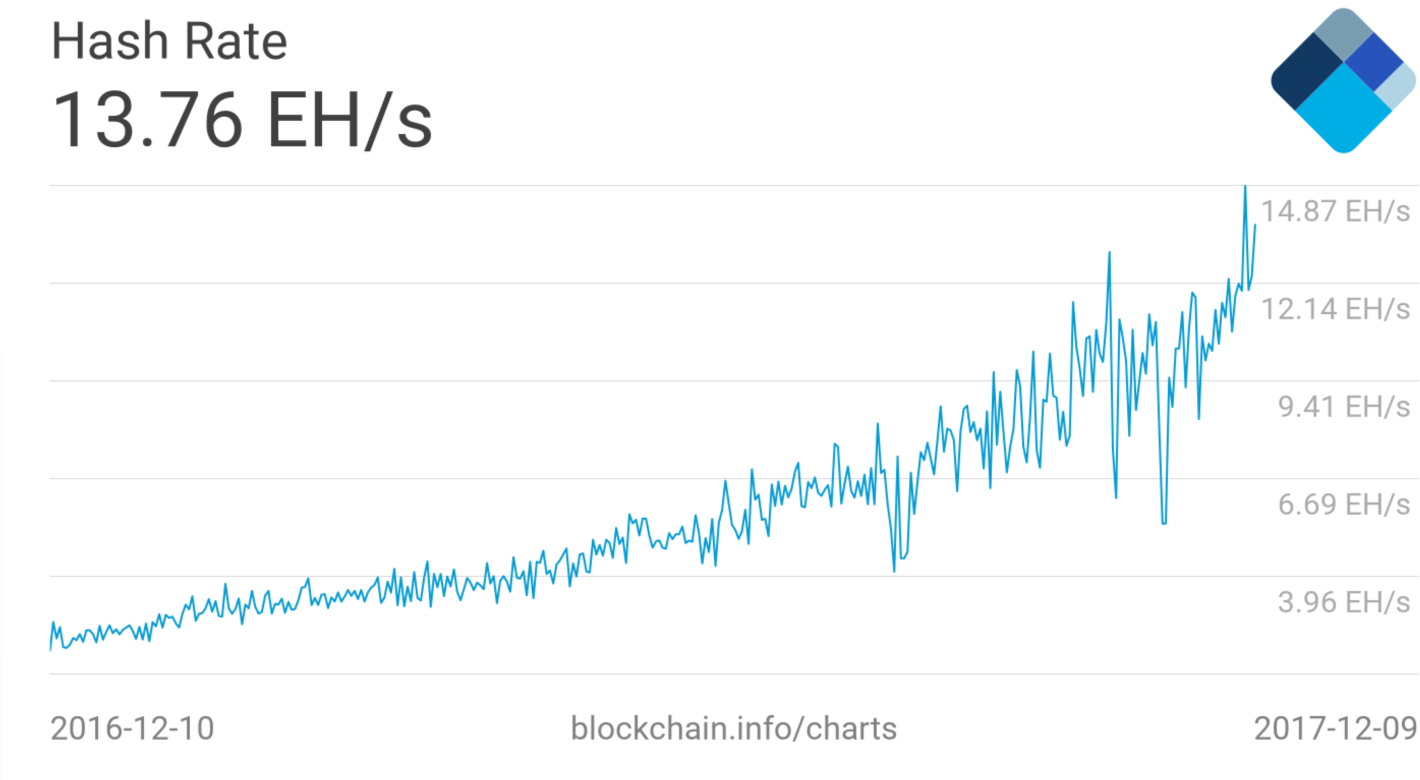


- Bitcoins remain highly volatile.
- A volatile asset is risky to hold:
  - On any given day, its value may go up or down substantially.

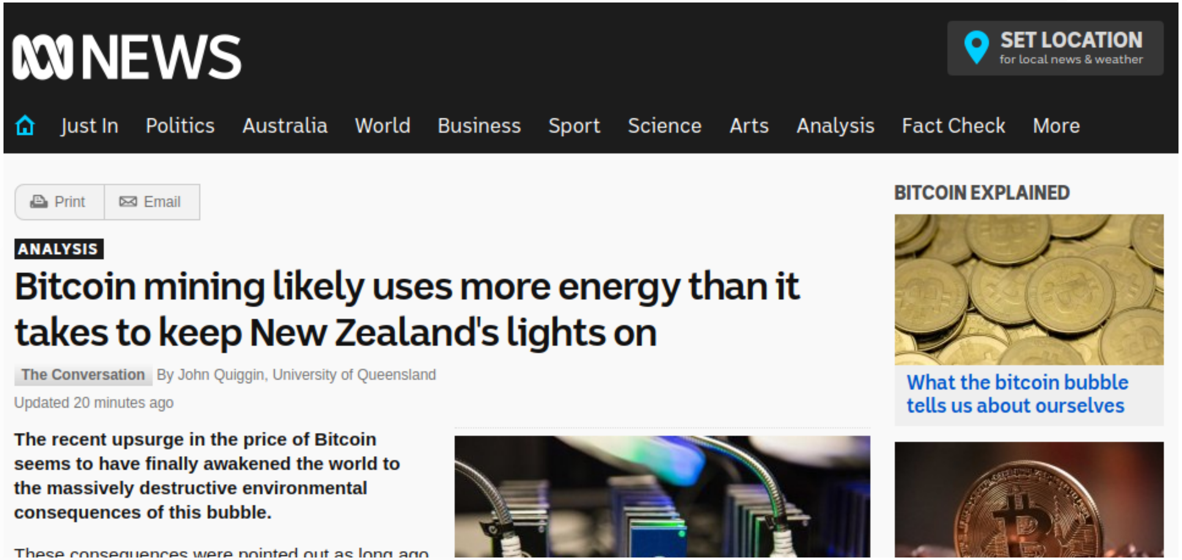
Bitcoin mining is a big business

A bitcoin mining farm.

Extreme competition



Energy sinkhole



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ANALYSIS

Bitcoin mining likely uses more energy than it takes to keep New Zealand's lights on

The Conversation By John Quiggin, University of Queensland

Updated 20 minutes ago

The recent upsurge in the price of Bitcoin seems to have finally awakened the world to the massively destructive environmental consequences of this bubble.

These consequences were pointed out as long ago

BITCOIN EXPLAINED

What the bitcoin bubble tells us about ourselves

HOME > Business > Technology

Bitcoin miners' power needs could soar higher than global energy production by 2020

The electricity required to mine the cryptocurrency is now higher than Serbia's annual power consumption

EDITOR'S PICKS

UAE

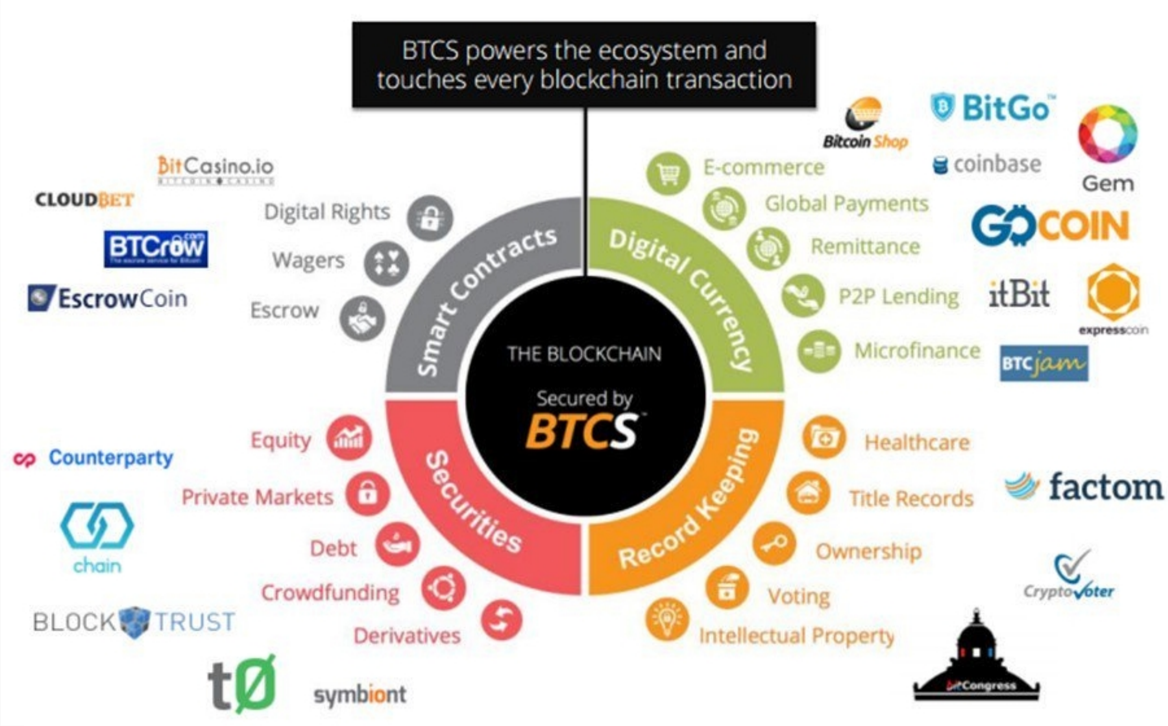
Yemen

Bitcoin and trust

- In Bitcoin, users only need to trust the algorithm, nothing else.
- In contrast, with traditional currency trust is in a central bank.
- You don't even need to trust the initial creator.

Other applications

- A blockchain can be viewed as a continuously growing list of records.
- Blockchains are secure by design, with high Byzantine fault tolerance.
- In addition to storing transactions, blockchains can therefore be used to store sensitive information that should not be altered.



Summary and challenges

- Bitcoin is a peer-to-peer fully decentralized currency based on the blockchain.
- The core principles of the blockchain rely on consensus by proof-of-work.
- As a currency:
    - Bitcoin is very young,
    - Transactions are safe, storage is not.
    - If Alice loses her key, she loses her money.
    - If Eve finds Alice's key, she can get her money.
    - Taxation? Volatility? Illicit trade?

References

- Nakamoto, Satoshi. "Bitcoin: A peer-to-peer electronic cash system." (2008): 28.
- Jonathan Jogenfors, "Cryptography Lecture 12: Bitcoin and friends".