How Bitcoin Works

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What is Bitcoin?

Bitcoin is a decentralized digital currency. It operates on a peer-to-peer network that enables instant and secure transactions between users, without the need for intermediaries like banks or governments.

The Software Side

- Bitcoin is Free Software (MIT license)
- `https://bitcoincore.org`
- `https://github.com/bitcoin/bitcoin`

Software Details

- Bitcoin Core latest release: 25.1
- About 682000 lines of code
- Mostly written in C++
- 926 contributors so far
- Many more contribute research, peer review, testing...
- About 40000 commits
- 343 open issues (7316 closed)
- 291 pull requests (19593 closed)

History of Bitcoin

- **2008**: Whitepaper Publication by Satoshi Nakamoto
- **2009**: Genesis Block and Launch
- **Early Years**...
- **2010**: First Known Commercial Bitcoin Transaction
- **2011-2013**: Growth and Volatility
- **2013**: Price Surges and Regulatory Interest
- **2014-2016**: Maturing and Development
- **2017**: Price Boom and Mainstream Attention
- **2018-2021**: Market Corrections and Development
- **2022-Today**: New Growth

Bitcoin Main Attributes

- Decentralized
- Immutable
- Transparent
- Open
- Secure

How is it used?

- Monetary transactions (cross-border too)
- Investment and Store of Value
- Bank Services for the Unbanked
- Fundraising, Crowdfunding, Donations
- ...

Basics: Hashing

Basics: Data

- What is data?
  - Numbers
  - Text
  - Some combination of the two
- Text can be encoded as numbers (e.g. A=65, B=66, C=67...)
- So ultimately, everything is a number!

Basics: Number Systems

Decimal	Binary	Octal	Hexadecimal
0	0000	0	0
1	0001	1	1
2	0010	2	2
3	0011	3	3
4	0100	4	4
5	0101	5	5
6	0110	6	6
7	0111	7	7
8	1000	10	8
9	1001	11	9
10	1010	12	A
11	1011	13	B
12	1100	14	C
13	1101	15	D
14	1110	16	E
15	1111	17	F

Basics: Numbers in Hex

Numbers in hex take less space... Examples:

Decimal	Hex
660475	A13FB
12965487	C5D66F

Basics: A Simple Hash Function

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  - U: 85
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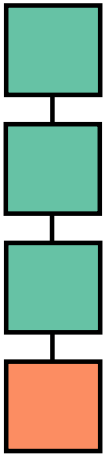
- Let's give it a maximum size of 256 (8 bits)
  - 726 % 256 = 214
- "214", or in hex "d6" can be considered a digital signature for "GreekLUG"

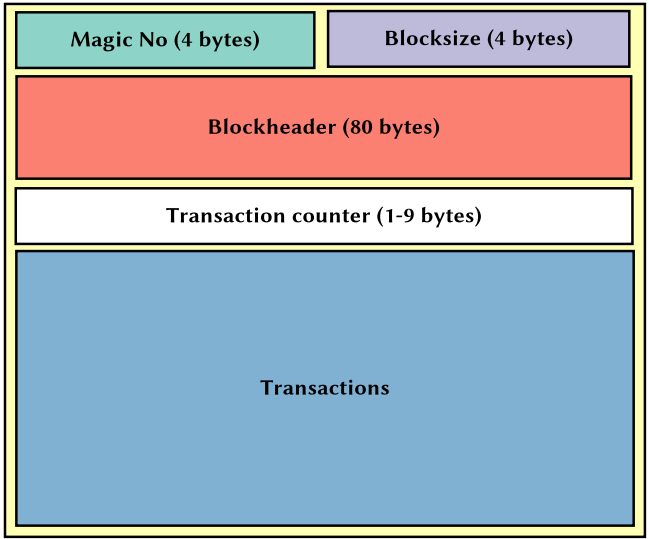
Basics: SHA256, A Much Better Hash Function

- Size: 256 bits (about 10^{77})
- Quick to calculate
- One way function
- Same input always results to same hash
- Any slight change in the input changes the output unpredictably
- Examples:
  - sha256("I have 2 apples") = `40a81c7a9d540081c7da5b5934c033a589a95657c13fd6eb99e286a3bfd0683c`
  - sha256("I have 3 apples") = `74d2c0de50110580f0e25fc22cf901d9ebda2006e1f0fd9c0216e79433c12c61`

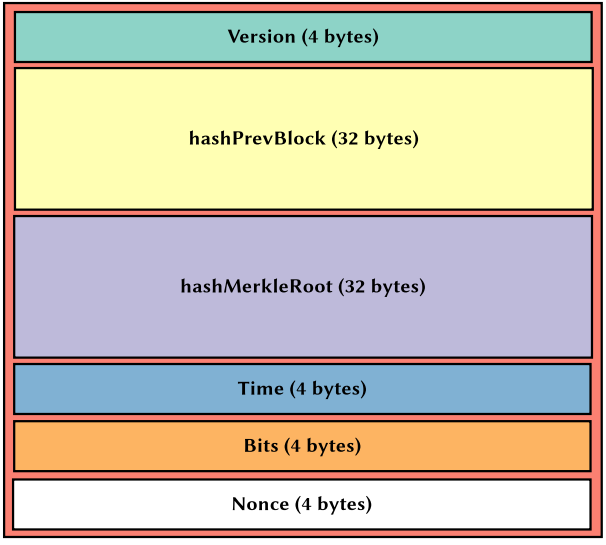
The Blockchain



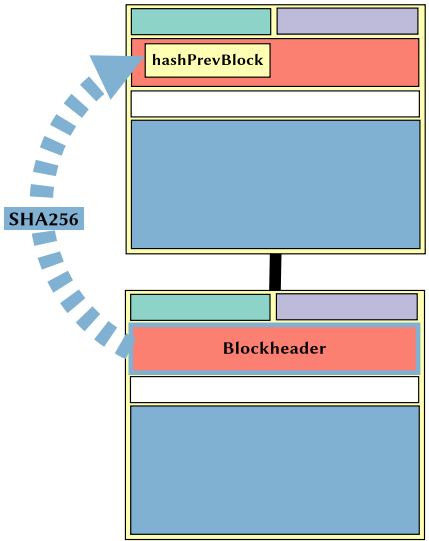
What's in a block?



What's in a block header?



Hashing the previous block



Transaction immutability

- The hash of the previous block is calculated only using the previous block's header
- But then how is it ensured that transactions in previous blocks won't be altered?

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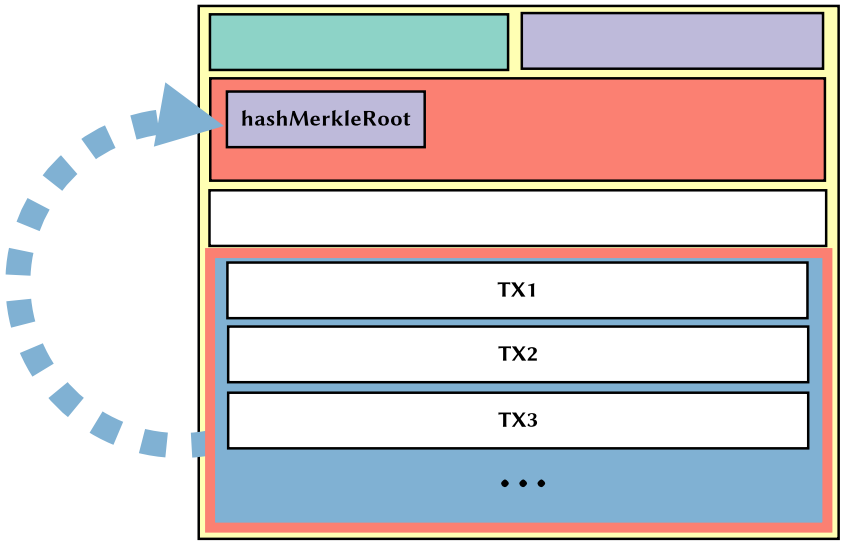
- But then how is it ensured that transactions in previous blocks won't be altered?
  - *The transactions themselves are hashed and their hash is stored in the current block's Merkle Root*

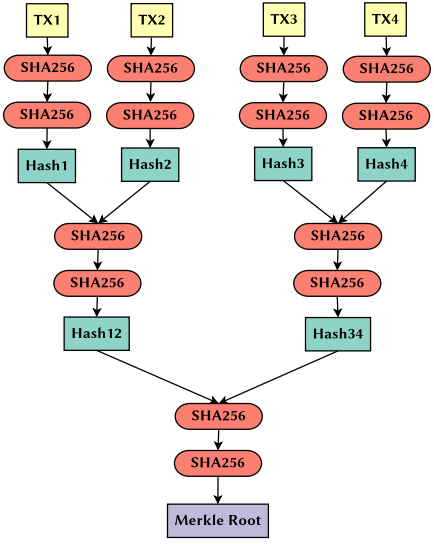
Transaction immutability

- So, if a transaction is altered, the Merkle Root would be changed.
- Since the Merkle Root is included in the block header, if the Merkle Root is changed, the block header contents would be changed.
- If the block header contents are changed the block header hash would be changed.

Calculating the Merkle Root

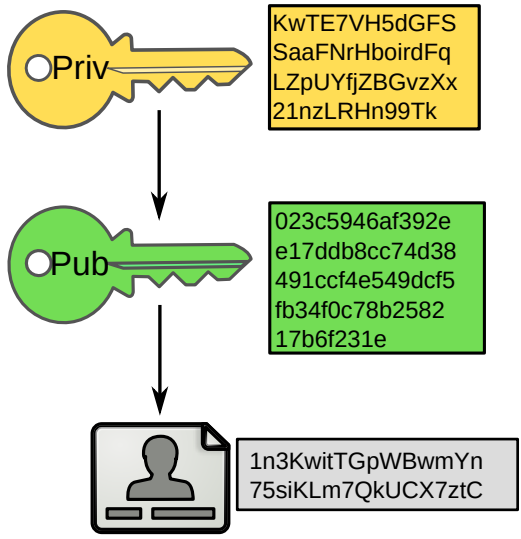


The Merkle Tree



Addresses: Overview

- Each user owns a pair of private/public keys
- A private key is just a very large random number (256 bits), base58 encoded
- The public key (also just a number) is calculated from the private key using Elliptic Curve Cryptography
  - One way function
  - Size 65 bytes (uncompressed), 33 bytes (compressed)
- An address (also just a number) is calculated from a public key (SHA256 and RIPEMD160 algorithms)


Priv
KwTE7VH5dGFS
SaaFNrHboirdFq
LZpUYfjZBGvzXx
21nzLRHn99Tk
Pub
023c5946af392e
e17ddb8cc74d38
491ccf4e549dcf5
fb34f0c78b2582
17b6f231e
1n3KwitTGpWBwmYn
75siKLm7QkUCX7ztC

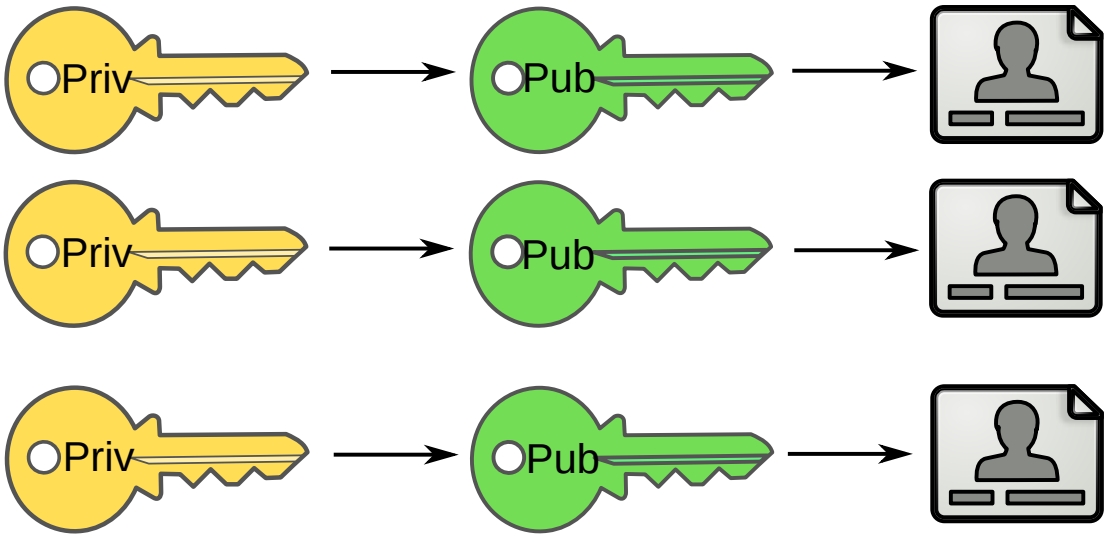
Keys and Addresses

- A private key should never be shared
- A public key may be shared but it's better to use an address for that
- An address represents the owner of a private/public pair
- An address is shared to receive bitcoins
- Ownership of the private key gives access to the respective address
- An address may represent complex scripts (P2SH)

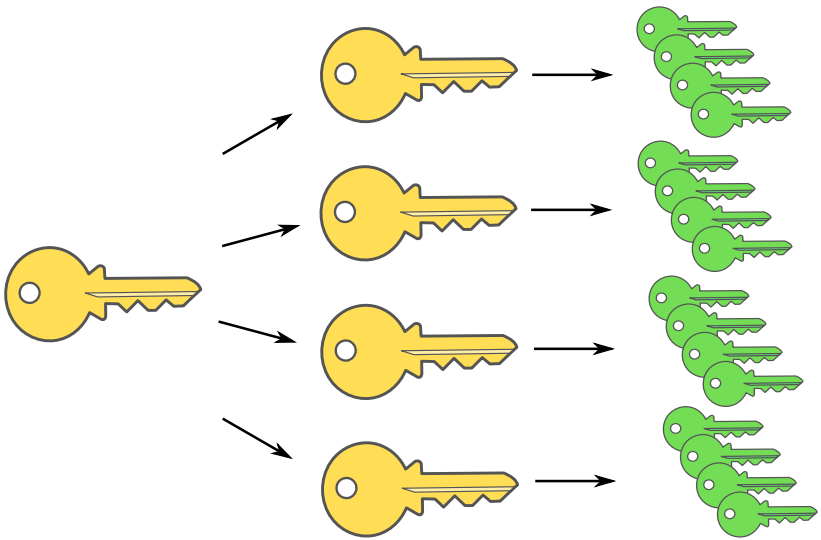
Bitcoin Wallets

- Bitcoin wallets do not hold Bitcoins. They hold private keys
- Allow management of keys and addresses
- Multiple keys can be managed by a single wallet
- A key is usually only used once
- Types of wallets:
  - Non-deterministic: Multiple private keys are pregenerated
  - Deterministic: One master key. All other keys are derived from that
- Can be used to send bitcoins, check balances (receive bitcoins?)

Non-deterministic Wallets



Deterministic Wallets



Addresses (mainnet)

- P2PKH Addresses: 34 characters in Base58 encoding. Start with 1.
- P2SH Addresses: 34 characters in Base58 encoding. Start with 3.
- SegWit Addresses: 42 characters in Bech32 encoding. Start with bc1.

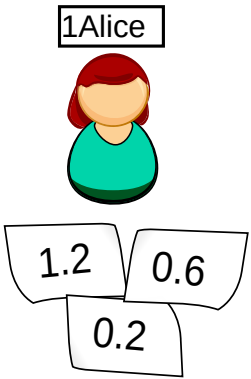
Transactions

- Transactions specify how bitcoins are transferred
  - 1Alice sends 1.3 BTC to 1Bob
- Alice has to prove that she owns that 1.3 BTC
- Bob doesn't need to do anything

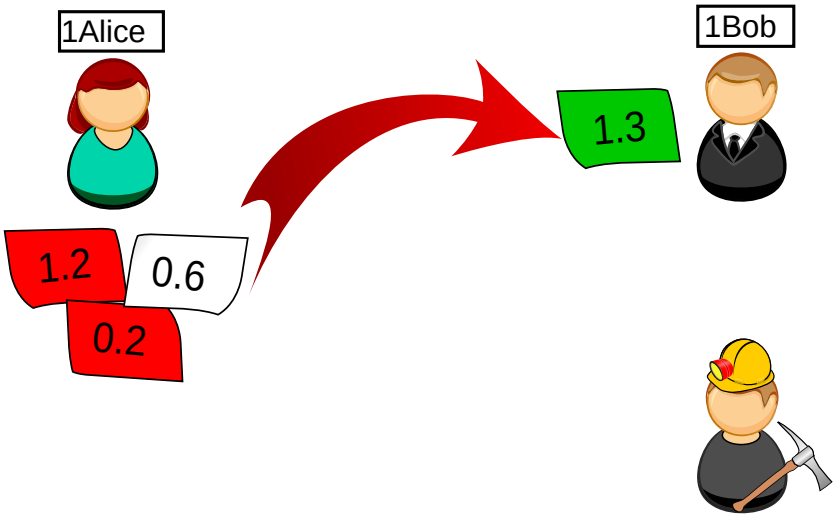
UTXOs

- Unspent Transaction Outputs
- Consider them as the Bitcoin notes
- Can hold any value of BTC
- They are created when received
- They are destroyed when they are spent

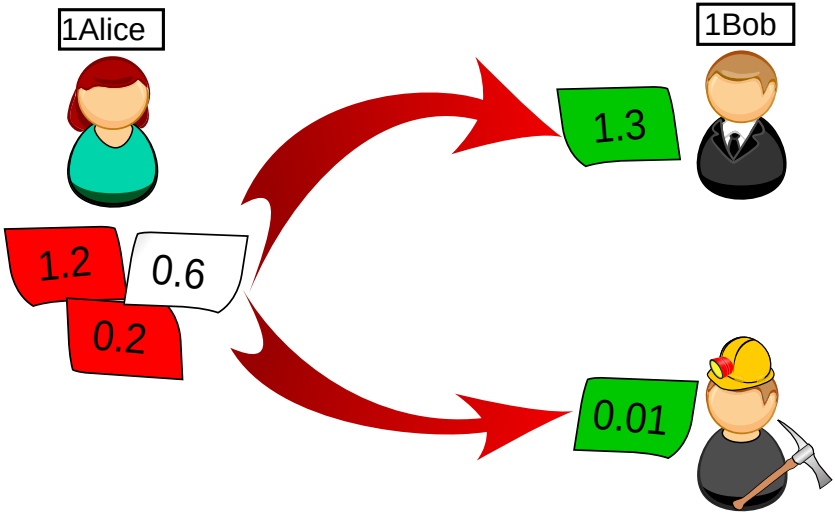
Transaction Example (1)



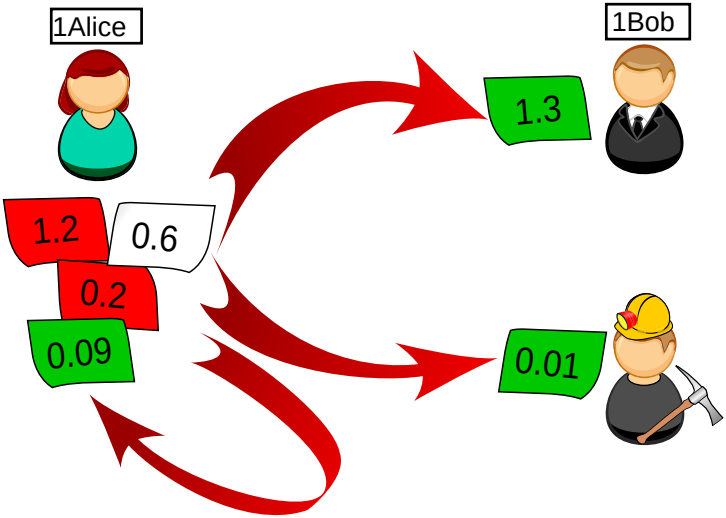
Transaction Example (2)



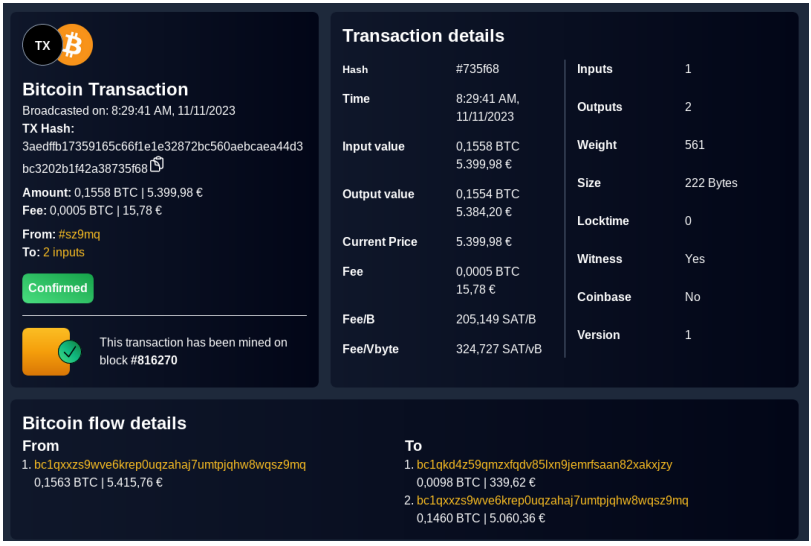
Transaction Example (3)



Transaction Example (4)



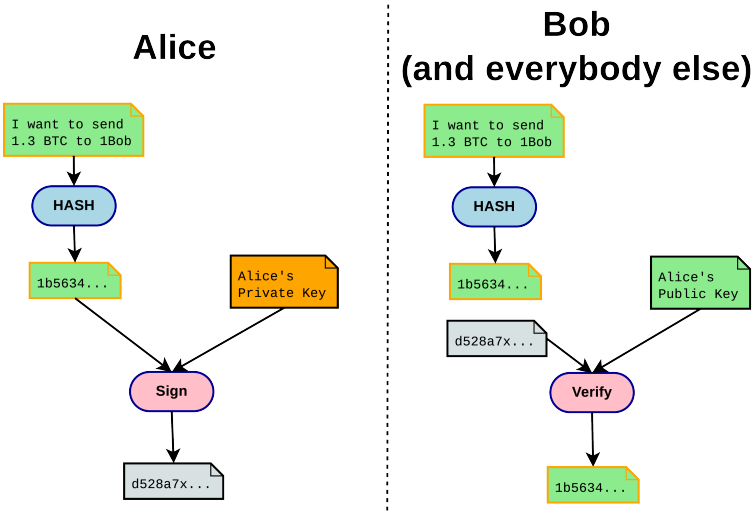
A Real Transaction



Proving Ownership

- You prove that you actually own the BTC you want to transfer using digital signatures

Digital Signatures



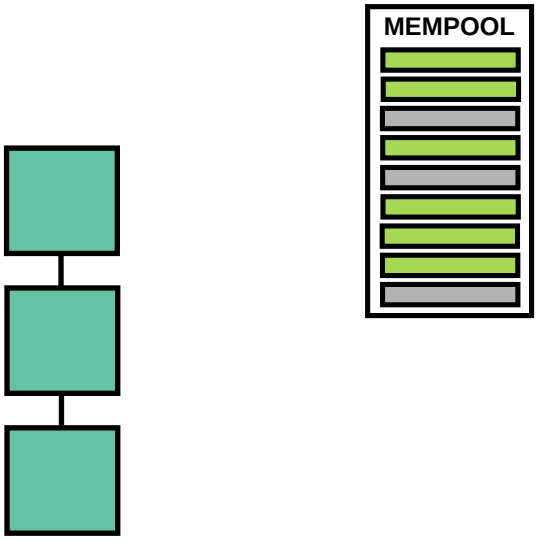
Sending a Transaction

- Every time someone wants to make a transaction, they sign it and broadcast it to all the other users in the network
- The transaction is stored in a data structure called the **Mempool**
- Miners pick transactions from the mempool to create a new block

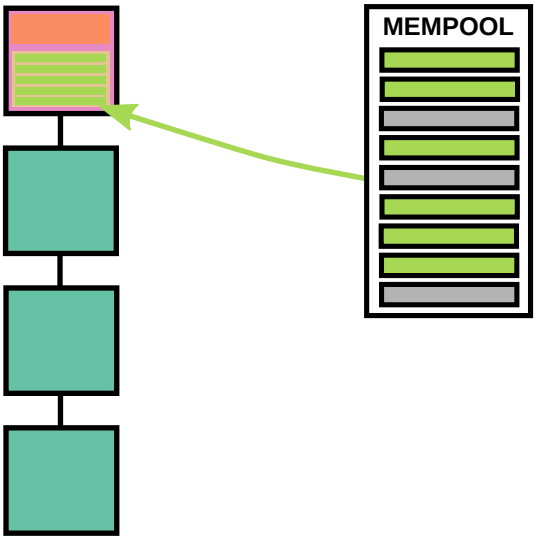
Mining

- The process of creating new blocks and adding new transactions
- Needs a lot of computing power, energy intensive process
- The only way new Bitcoins are created

Including Transactions in a New Block (1)



Including Transactions in a New Block (2)



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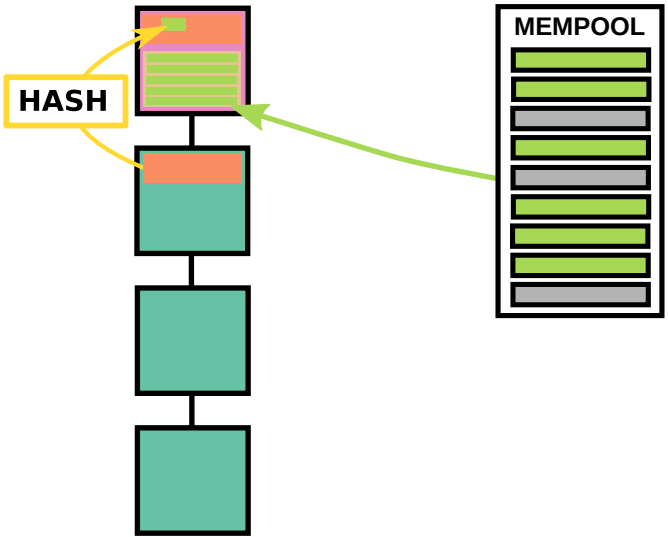

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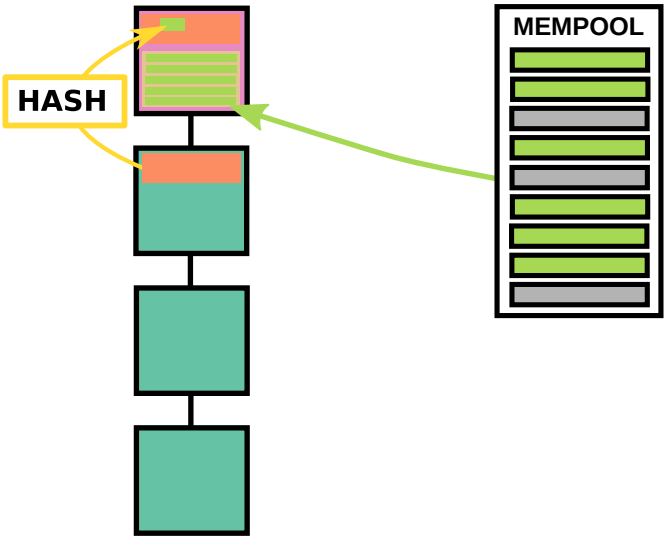
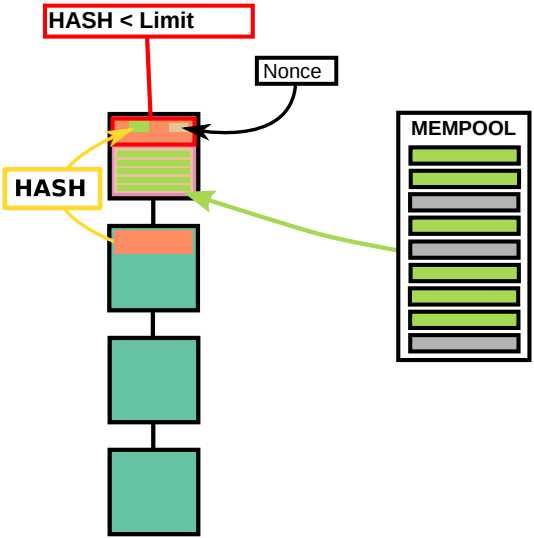


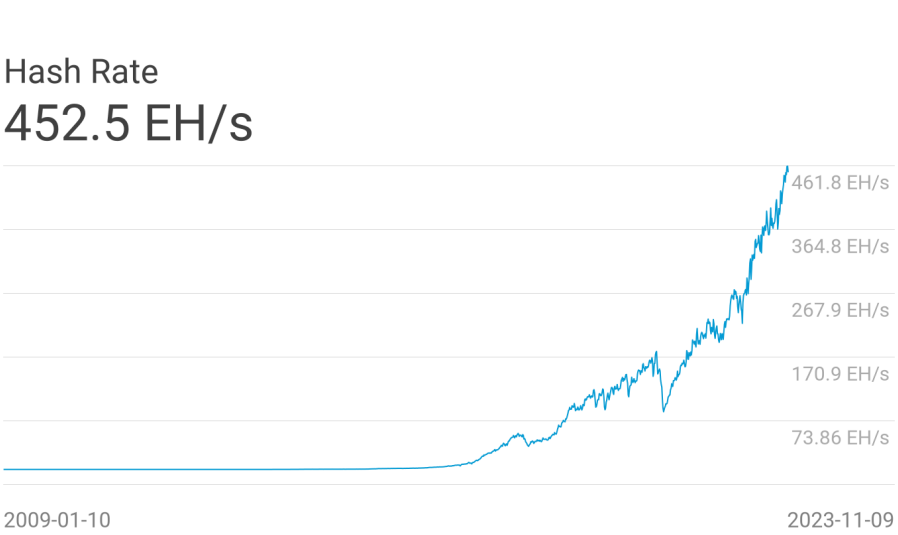
Including Transactions in a New Block (5)



Mining Difficulty

- The miner needs to create a block with a hash value smaller than a *Limit* value
- That is what is called the *Proof-of-Work (PoW)* algorithm
  - Extremely difficult to calculate
  - Extremely easy to validate
- The *Limit* value is determined in the previous block in the *Bits* section
- The miner can try to find a right hash by changing the nonce, rearranging the transactions, picking other transaction, changing the timestamp...
- Current hash rate is about 450000000 TH/s (1TH = 10^{12} hashes)
- Mining difficulty is adjusted every 2016 blocks (about two weeks)
- Mining difficulty is adjusted so that, on average, a new block is mined in about 10 minutes

Hash Rate Evolution



Why Miners Mine

- Miners earn a block reward with every block they mine
- They also receive fees from every transaction they include
- The block reward was originally 50 BTC
- Algorithmically set to halve every 210000 blocks (about four years)
- Currently set to 6.25 BTC (about 225000€)

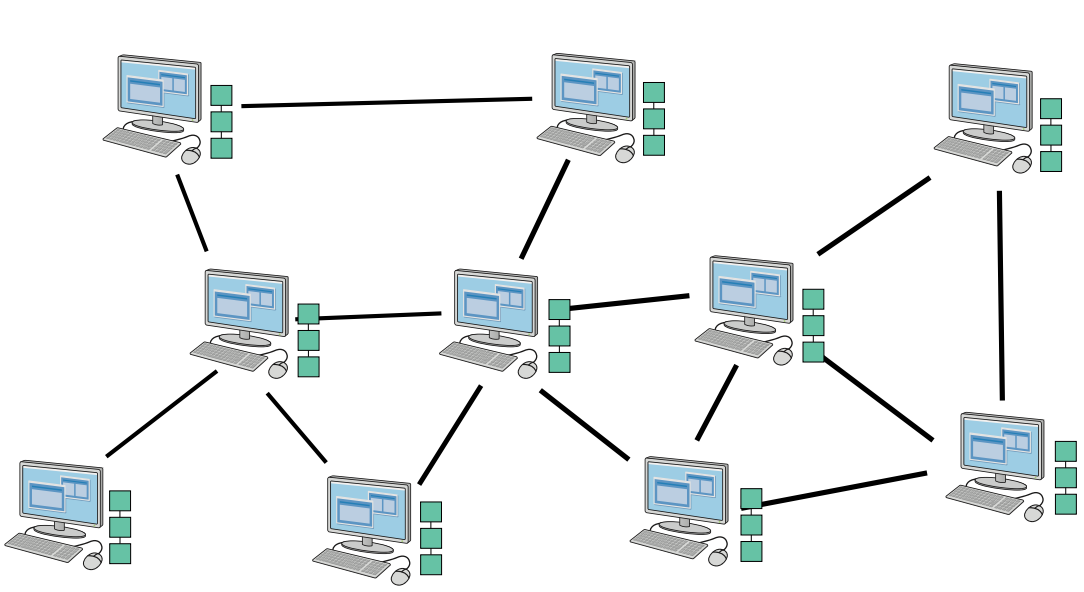
What Do Miners Use for Mining?

- These days mining is only possible with ASICs (Application Specific Integrated Circuits)
- Cost thousands of euros
- Capable of up to 230 TH/s
- Not cost effective to run on a home setup (unless you have free electricity?)

What do we get from PoW?

- Consensus mechanism
- Security against attacks
- Decentralization
- Trustlessness

How Blocks Propagate (1)



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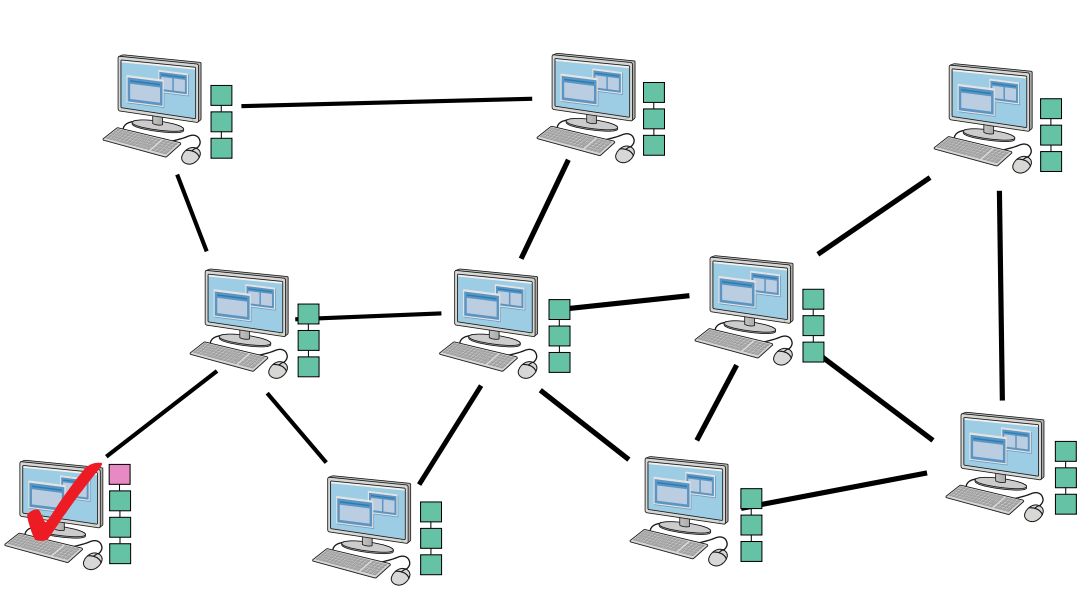

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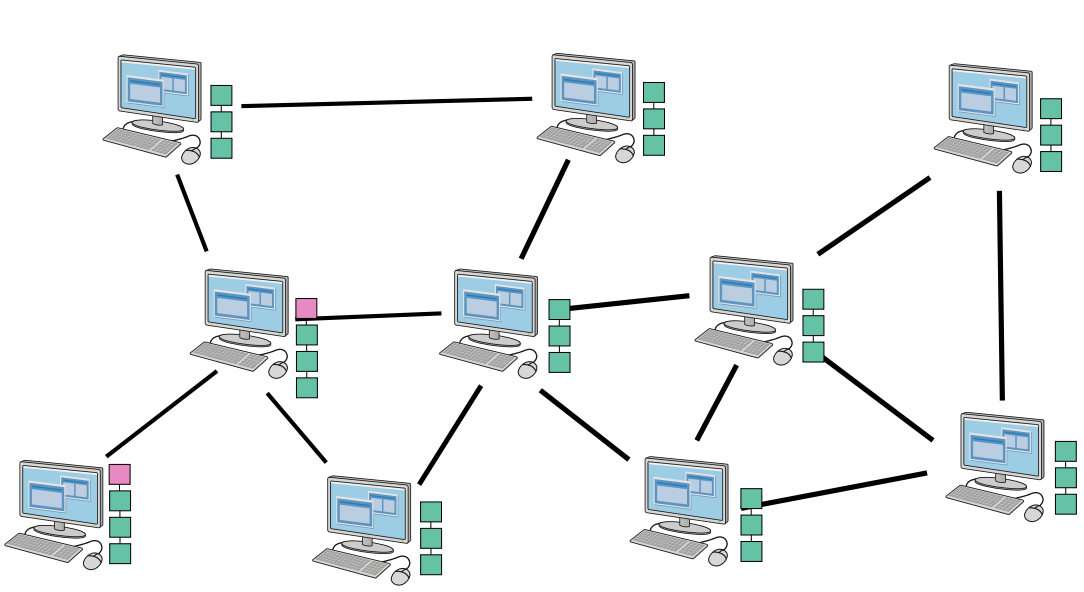

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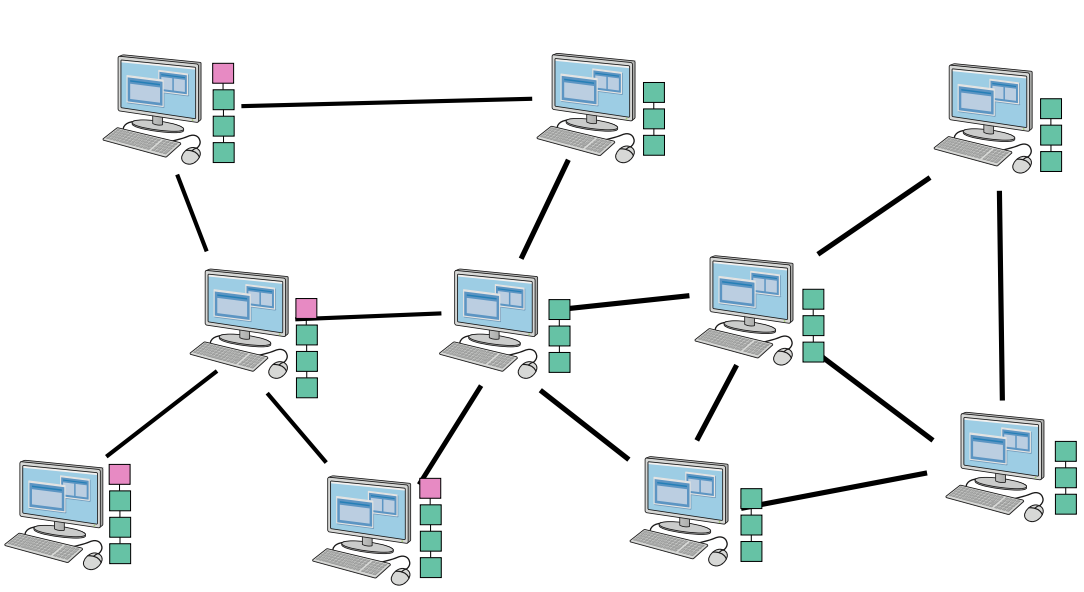

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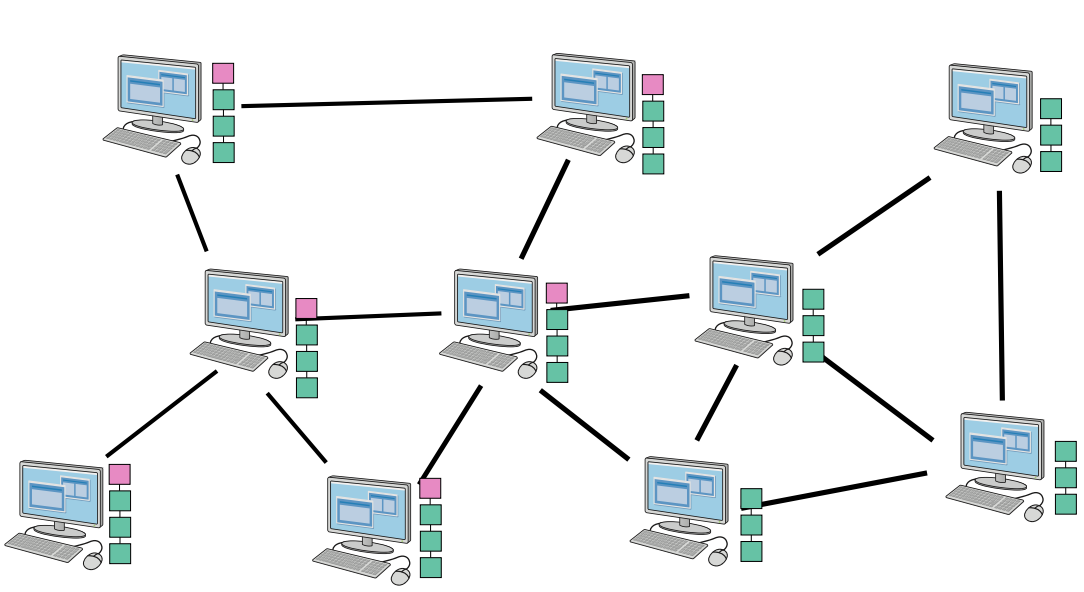
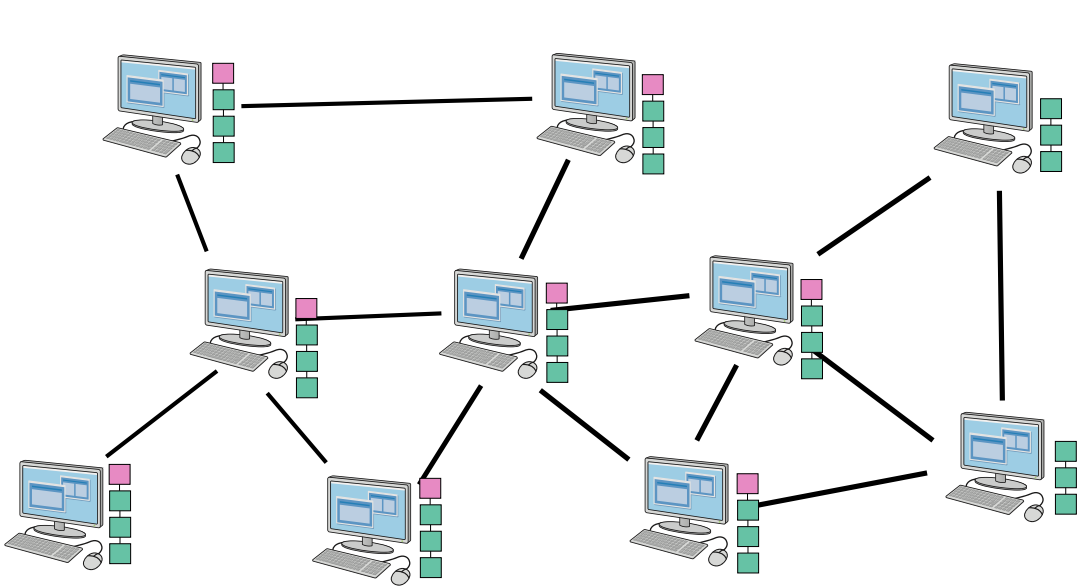
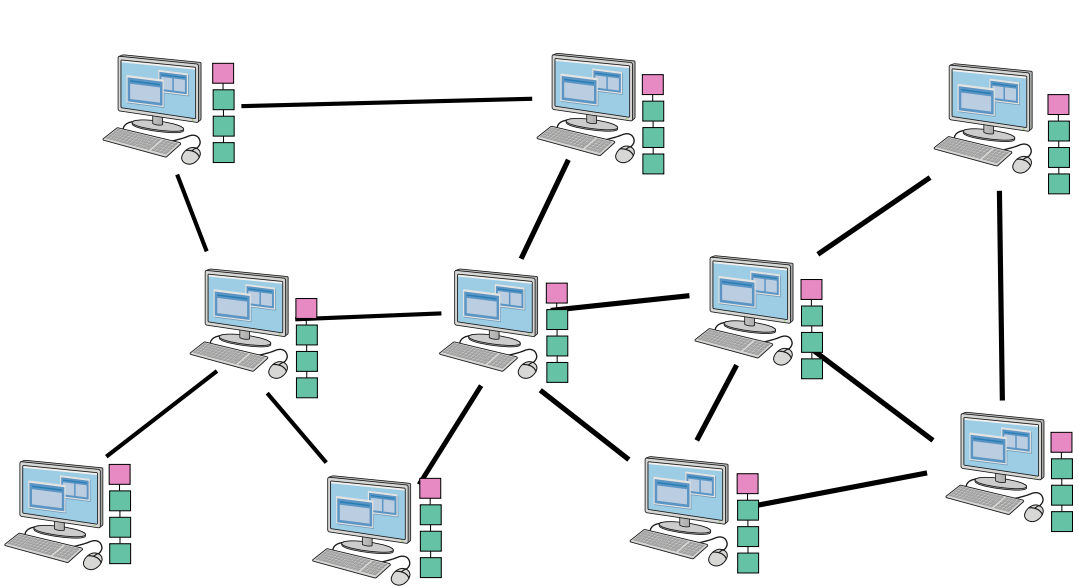


How Blocks Propagate (6)



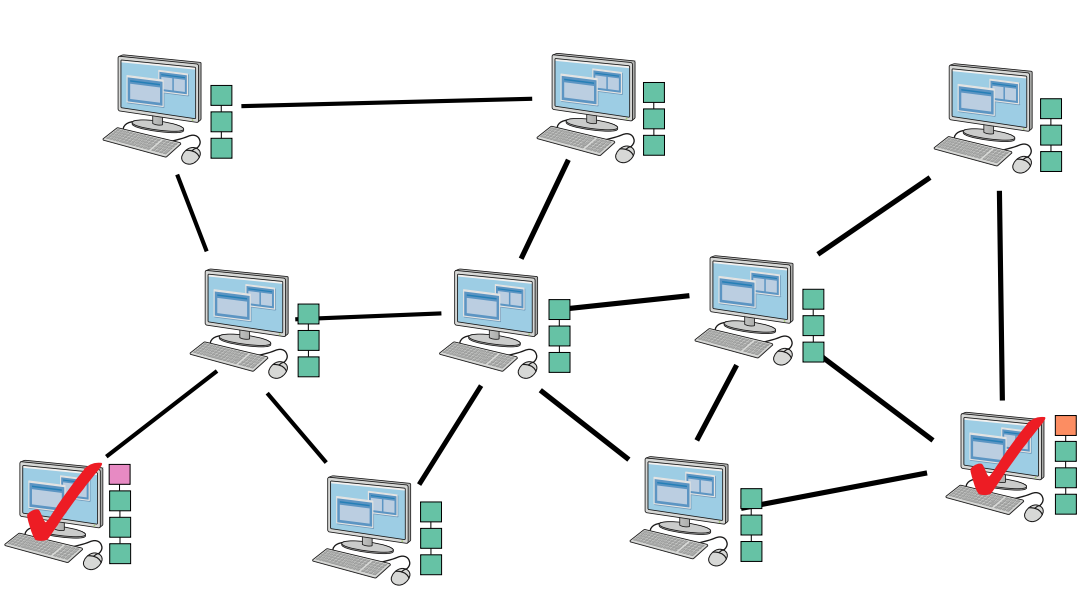
How Blocks Propagate (7)



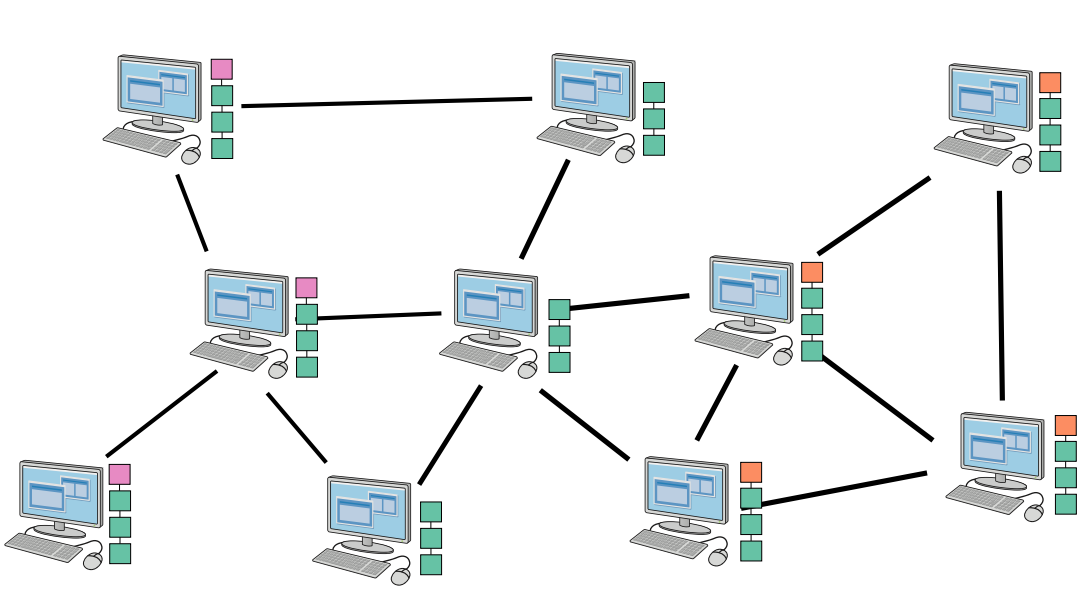
Multiple Miners

- There is not only a single solution to the mining problem
- More than one miners may mine new block at the same time
- The network is divided
- But eventually will get back into balance, probably by the next block
  - The longer chain wins (actually the one with the more work in it)

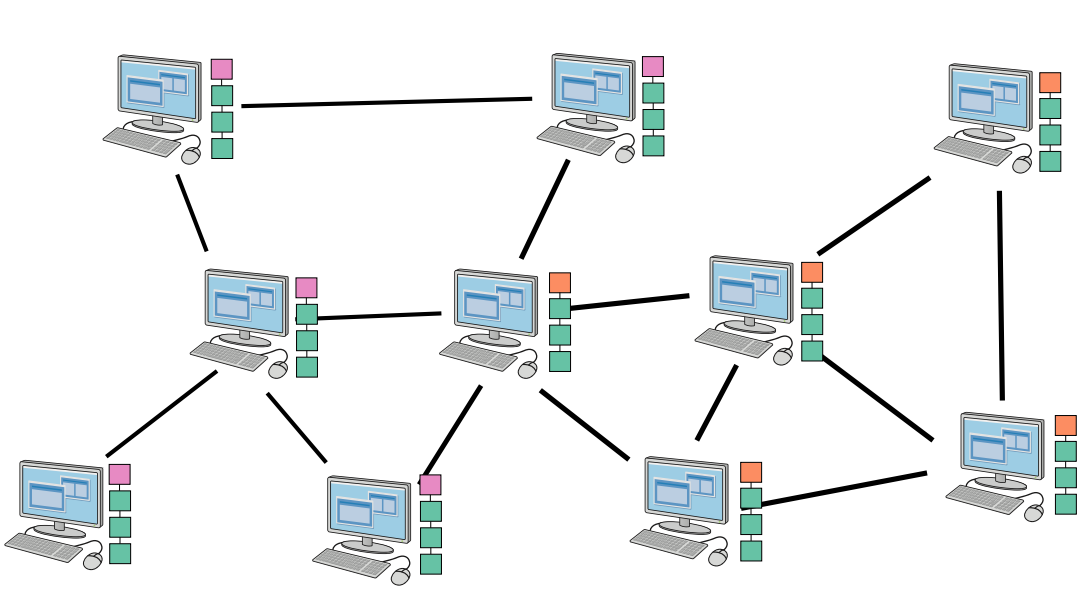
How Blocks Propagate (8)



How Blocks Propagate (9)



How Blocks Propagate (10)



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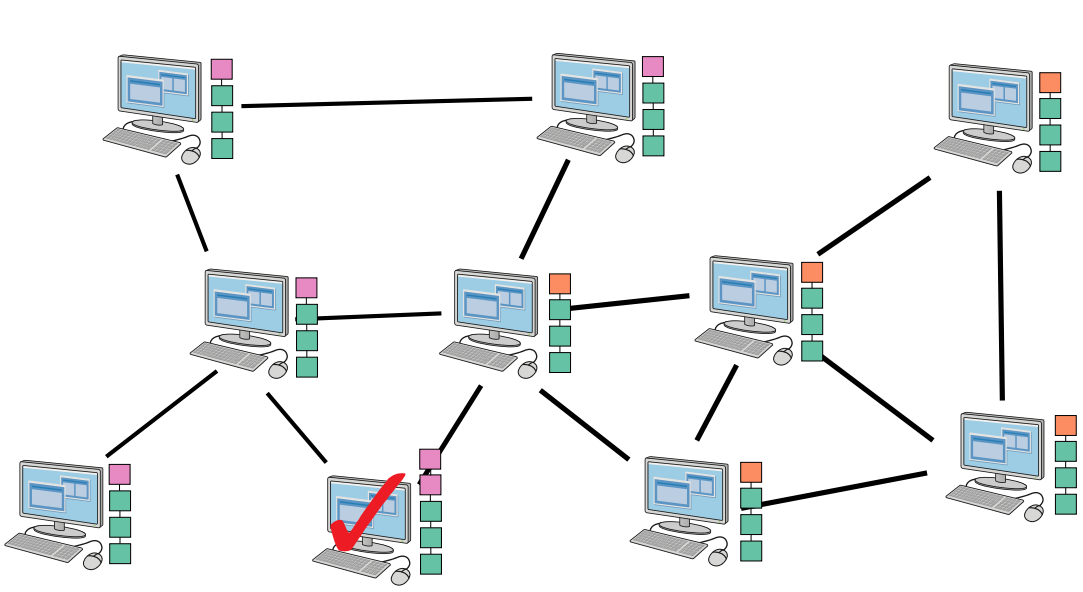

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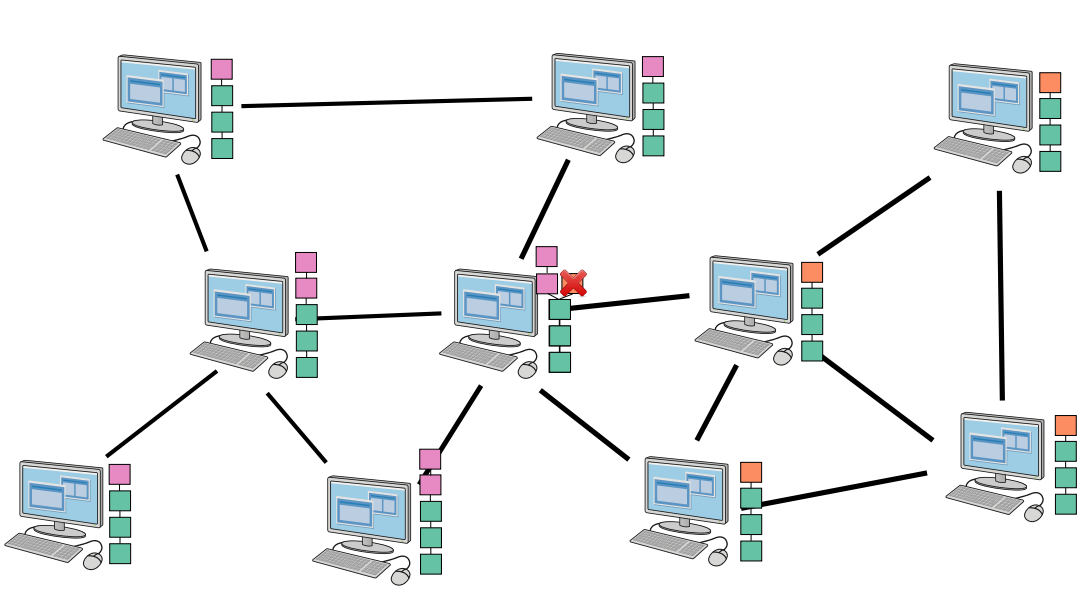

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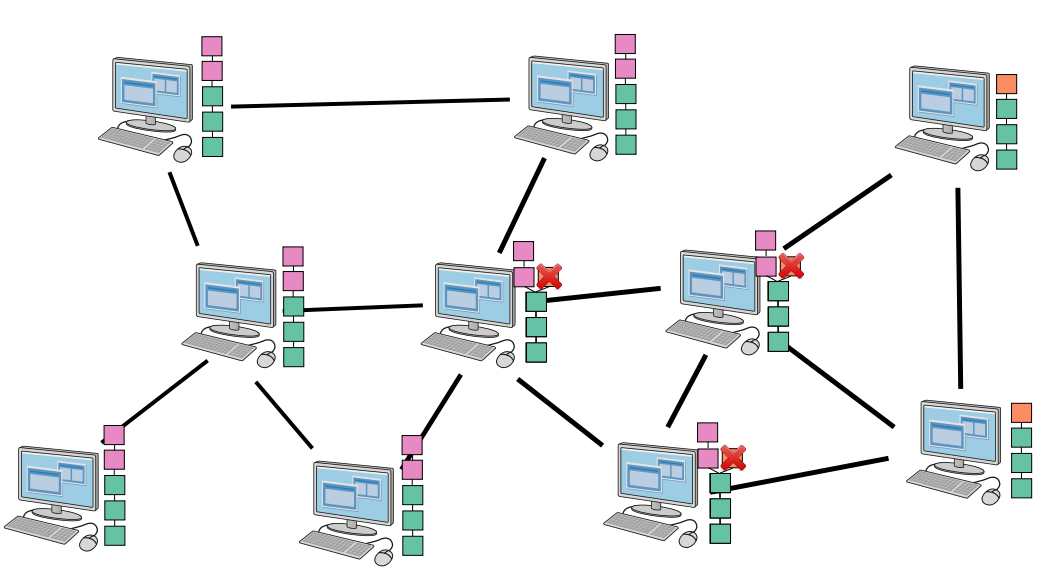

How Do I Connect to the Bitcoin Network

- Pick a client (wallet): `https://bitcoin.org`
- Official client is BitcoinCore, only for Linux, Mac, Windows: `https://bitcoincore.org`
  - Supports full nodes, pruned nodes
  - Syncs the entire blockchain (currently about 560 GB)
  - Works from CLI, Qt GUI
- Lots of other clients for mobile devices
  - Lightweight nodes
  - Better pick an open source client
- Web clients. Rely on 3rd parties. Avoid.
- You may create new transactions, view balances and manage keys with any type of client

Other Kinds of Wallets

- Paper wallets: e.g. `https://www.bitaddress.org`
- Hardware wallets (Trezor, Ledger...)

Thank you!

Questions?