Bitcoin

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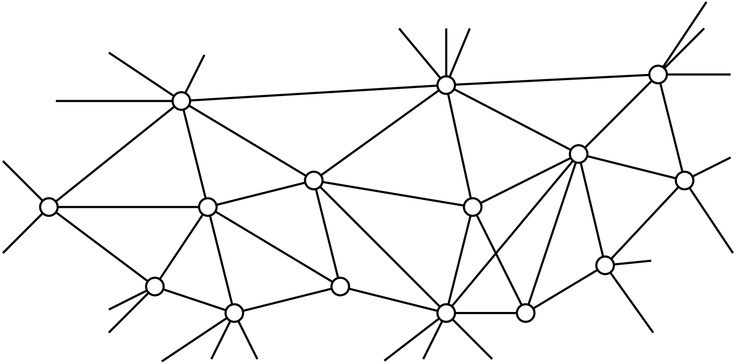
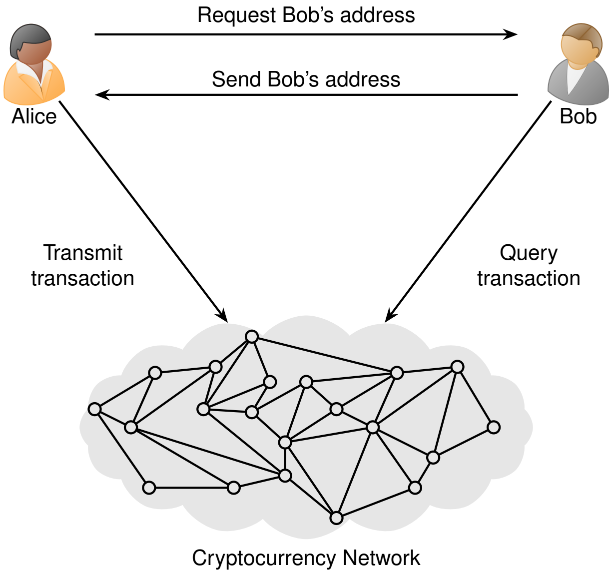
What is Bitcoin?

- Cryptocurrency
- Open source
- Decentralized network

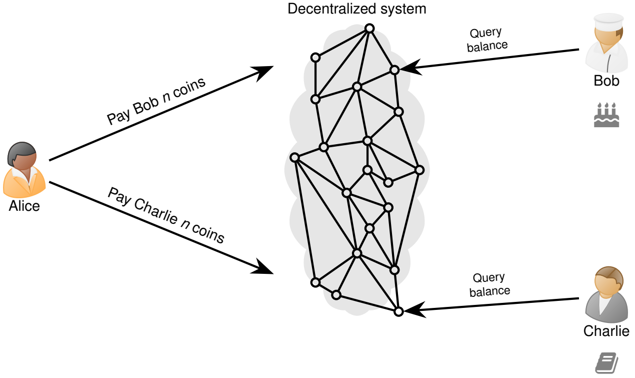


Cryptocurrency Transaction Workflow



Decentralization Challenges

- Counterfeiting
- Currency creation rules
- Double spending
  - Alice pays Bob *n* digicoins for a cake
  - Alice uses the **same** *n* digicoins to pay Charlie for a book



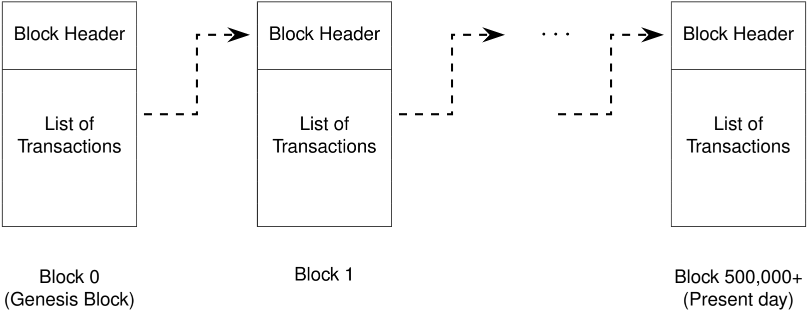
Solution without a central coordinator?

Double Spending

- Familiar to academics
- Submitting same paper to two conferences
- **Possible solution**
  Reviewers google paper contents to find duplicates
- Solution fails if
  - Conferences accepting papers at same time
  - Conference proceedings not published/indexed
- **Better solution**
  A single public database to store all submissions to all conferences

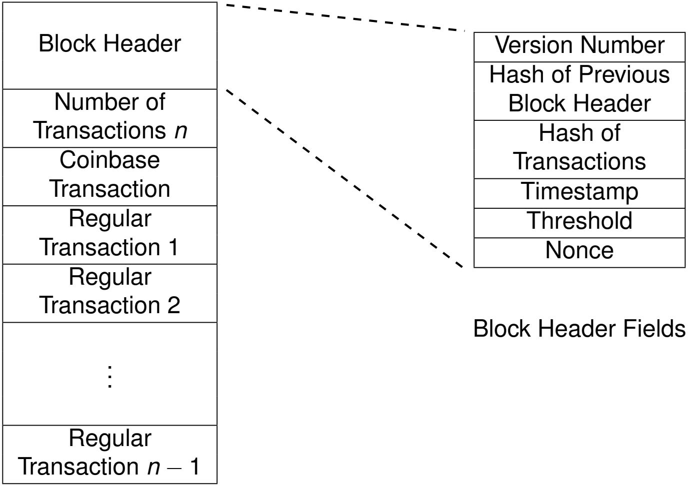
The Blockchain

Blockchain: A public database to store all transactions which is replicated by many network nodes



How are the blocks linked?

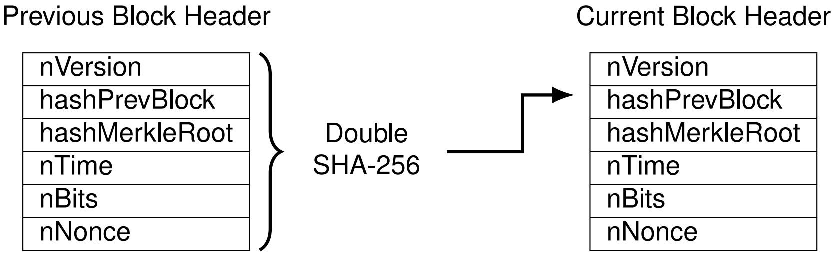
Bitcoin Block and Header Formats



- Hash = Output of cryptographic hash function

Block Header

nVersion	4 bytes
hashPrevBlock	32 bytes
hashMerkleRoot	32 bytes
nTime	4 bytes
nBits	4 bytes
nNonce	4 bytes



Cryptographic Hash Functions

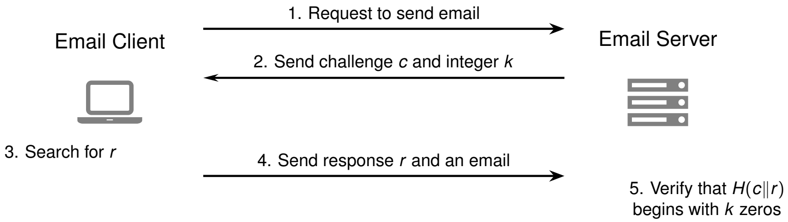
- Easy to compute but difficult to invert
- Collision-resistant
- Pseudorandom outputs
- SHA-256 = NIST approved CHF with 256-bit outputs

Input	SHA-256 Output
july0	**171c9f5053d5d675d1d1ed477c908e98498e6751ae392a78807c3cd6ad6975fa**
july1	**7d8033d140d8b8db8324753a25c5e32ee4faa9c4e306bddb317907be51cd8a24**
july2	**bda0b2ab2c7d654589b32f46a548cba27b7371f27b070ddd7d3b87122a078f06**
july3	**dfa3569a46b1a13c24c9f385da140f4763a3fbb70f8eebe0f29ba535145d32ca**
july4	**27d39d26edc54c11cc78d17bf0dd294413300dd004127fa6dcff368ea74bb87c**
july5	**a0ebd3e23823fc291b090abd2eb1403912be6b72398f3bf4e92c4ec555902d53**
july6	**dc7d6bcc266af402e53b9fb978b6579940bb97743f6e975a988cb20d903e0c5f**
july7	**984906fbbaa7dbad2ee01a81df7a237bfdb63aeb06b4cf97a89fc004542c1dab**
july8	**7be4d491b73a4797304980070d5b5fb5c7fd6921e70efc7ce38023c50664803d**
july9	**e8c4af8895bcddb9cea3e3e1e8a08e090690bb55fd6617da5aa0873f27e218ee**

- Hex digits: **0 = 0000, 1 = 0001, 2 = 0010,..., a = 1010, b = 1011, c = 1100,..., e = 1110, f = 1111**
- At a billion outputs per second, 78 billion years required to calculate 2^{100} outputs

Hashcash

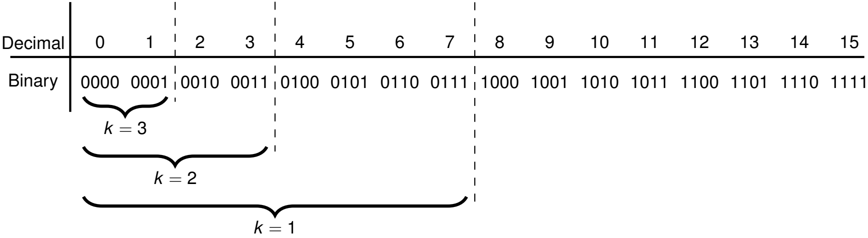
- A database you own where anyone in the world can add entries? Your email inbox
- Hashcash was proposed in 1997 to prevent spam
- Protocol
  - Suppose an email client wants to send email to an email server
  - Client and server agree upon a cryptographic hash function H
  - Email server sends the client a challenge string c
  - Client needs to find a string r such that $H(c \| r)$ begins with k zeros



- The r is considered **proof-of-work (PoW)**; difficult to generate but easy to verify
- Demo

Difficulty Increases with k

- Let hash function output length n be 4 bits

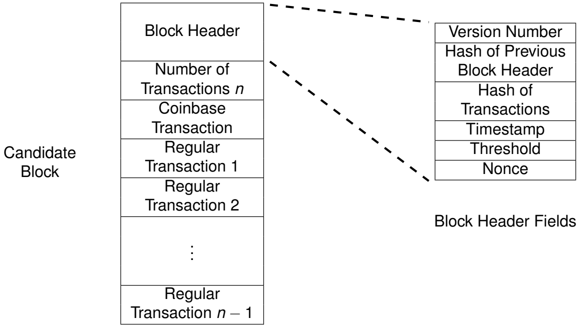


- Since H has pseudorandom outputs, probability of success in a single trial is

$$\frac{2^{n-k}}{2^n} = \frac{1}{2^k}$$

Bitcoin Mining

- Mining = Process of adding new blocks to the blockchain
- Nodes which want to perform transactions broadcast them
- Miners collect some of these transactions into a candidate block



- Threshold encodes a 256-bit value like $0x\underbrace{00\cdots00}_{\text{16 times}}\underbrace{FFFFF\cdots FFFFF}_{\text{48 times}}$
- Miner who can find Nonce such that

$$\text{SHA256}(\text{SHA256}(\underbrace{\text{Version Number} \,\|\, \cdots \,\|\, \text{Nonce}}_{\text{Candidate Block Header}})) \leq \text{Threshold}.$$

can add a new block

Mining is Hard

Target value T	Fraction of SHA256d outputs $\leq T$
$0x7\underbrace{FFFF\ FFFF \cdots FFFF}_{63 \text{ times}}$	$\frac{1}{2}$
$0x0\underbrace{FFFF\ FFFF \cdots FFFF}_{63 \text{ times}}$	$\frac{1}{16}$
$0x\underbrace{00 \cdots 00}_{16 \text{ times}}\underbrace{FFFFF \cdots FFFFF}_{48 \text{ times}}$	$\frac{1}{2^{64}}$

$$\Pr\left[\text{SHA256d output} \leq T\right] \approx \frac{T+1}{2^{256}}$$

Why should anyone mine blocks?

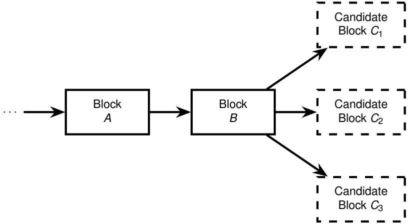
- Successful miner gets rewarded in bitcoins
- Every block contains a **coinbase transaction** which creates 12.5 bitcoins
- Each miner specifies his own address as the destination of the new coins
- Every miner is competing to solve their own PoW puzzle
- Miners also collect the transaction fees in the block

Mining Farms

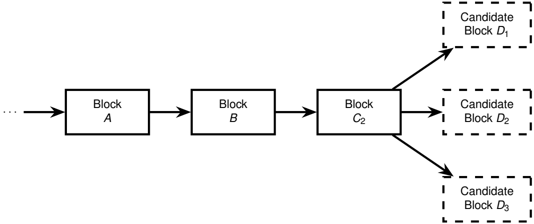
- Mining farms have thousands of mining rigs
- Each mining rig has dozens of mining chips
- Each chip has dozens of SHA256 mining cores
- Farms are located in places with cheap power and cooling

Block Addition Workflow

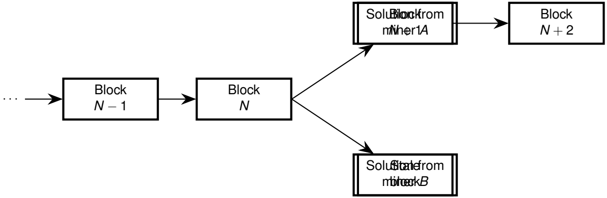
- Nodes broadcast transactions
- Miners accept valid transactions and reject invalid ones (solves double spending)
- Miners try extending the latest block



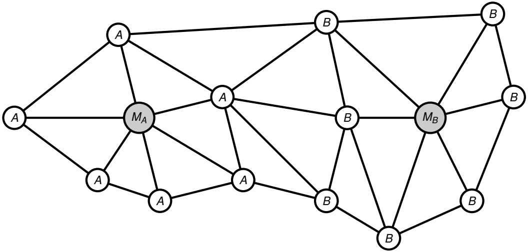
- Miners compete to solve the search puzzle and broadcast solutions
- Unsuccessful miners abandon their current candidate blocks and start work on new ones



What if two miners solve the puzzle at the same time?



- Both miners will broadcast their solution on the network
- Nodes will accept the first solution they hear and reject others



- Nodes always switch to the chain which was more difficult to produce
- Eventually the network will converge and achieve consensus
- This is called proof-of-work (PoW) consensus

How often are new blocks created?

- Once every 10 minutes

nVersion
hashPrevBlock
hashMerkleRoot
nTime
nBits
nNonce

- Every 2016 blocks, the target T is recalculated
- Let t_{sum} = Number of seconds taken to mine last 2016 blocks

$$T_{\text{new}} = \frac{t_{\text{sum}}}{2016 \times 10 \times 60} \times T$$

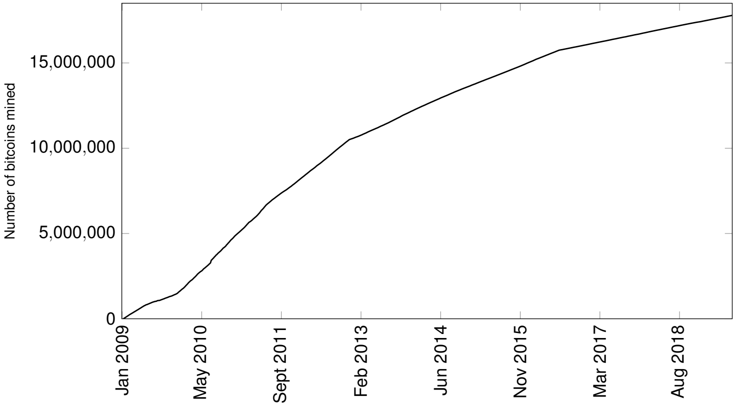
- Recall that probability of success in single trial is $\frac{T+1}{2^{256}}$
- If $t_{\text{sum}} = 2016 \times 8 \times 60$, then $T_{\text{new}} = \frac{4}{5} T$
- If $t_{\text{sum}} = 2016 \times 12 \times 60$, then $T_{\text{new}} = \frac{6}{5} T$

Bitcoin Blockchain Explorers

- Web interfaces to view current blockchain state
  - `https://www.blockstream.info`
  - `https://www.blockchain.com/explorer`
- Demo checklist
  - List of transactions (coinbase, regular)
  - Address generation in `https://www.bitaddress.org`
  - Brainwallet generation at `https://brainwalletx.github.io`

Bitcoin Supply

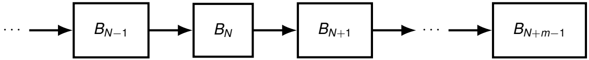
- The block subsidy was initially 50 BTC per block
- Halves every 210,000 blocks $\approx$ 4 years
- Became 25 BTC in Nov 2012 and 12.5 BTC in July 2016
- Total Bitcoin supply is 21 million



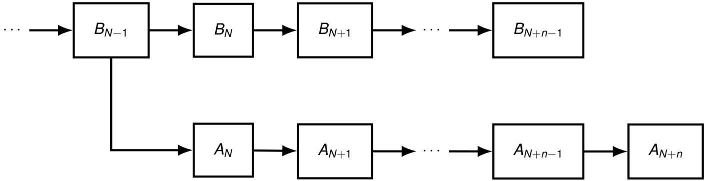
- The last bitcoin will be mined in 2140

Tamper Resistance

- Suppose Alice wants to modify block B_N

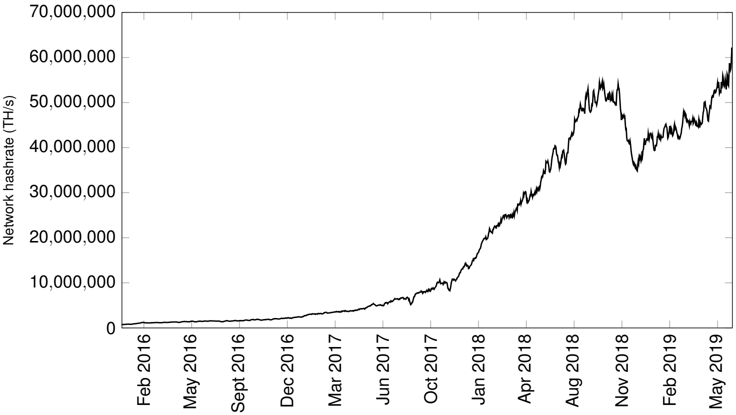


- Alice works on A_N branch; other miners work on B_N branch



- She needs to mine blocks faster than the rest of the miners
- Possible if she controls 50% or more of network hashrate
- Current Bitcoin network hashrate $\approx$ 78 EH/s = 78×10^{18} H/s
- One mining unit costing $350 gives 16 TH/s
- Controlling 50% of hashrate = Controlling 853 million USD worth of hardware

Bitcoin Hashrate



Data source: `https://www.blockchain.com/charts/hash-rate`

Key Takeaways

- Bitcoin's blockchain prevents double spending and tampering
- Secure only if nobody controls 50% or more of network hashrate
- Mining difficulty adjusted to regulate coin supply
- Miners incentivized by block reward
- Block subsidy halves every four years to cap total coin supply

Blockstream Satellite

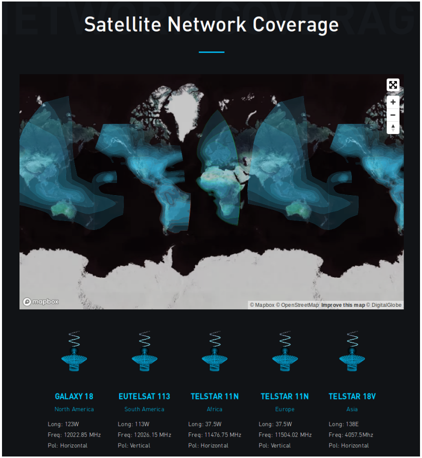


Image credit: `https://blockstream.com/satellite/`

- Blockstream Satellite network broadcasts the Bitcoin blockchain for free
- No Internet required to receive blocks (verify payments in Bitcoin)

How Blockstream Satellite Works?

Image credit: `https://blockstream.com/satellite/`

- Ground stations (teleports) participate in the Bitcoin network and transmit blocks to geosynchronous satellites
- Satellites receive the blocks and broadcast them across the Earth
- Anyone in the coverage area with a small satellite antenna and an inexpensive USB receiver can receive these blocks
- Anyone can verify large payments in remote areas

Bitcoin Testnet Transactions

- Each cryptocurrency has a mainnet and one or more testnets
- Bitcoin Testnet
  `https://live.blockcypher.com/btc-testnet/`
- Testnet Address Generator `https://bitcoinpaperwallet.com/bitcoinpaperwallet/generate-wallet.html?design=alt-testnet`
- Testnet faucet 1
  `https://coinfaucet.eu/en/btc-testnet/`
- Testnet faucet 2 `https://bitcoinfaucet.uo1.net`
- Mycelium Testnet Wallet Mobile App

References

- Chapter 4 of *An Introduction to Bitcoin*, S. Vijayakumaran, `www.ee.iitb.ac.in/~sarva/bitcoin.html`
- Bitcoin Charts `https://www.blockchain.com/charts`
- Bitmain Mining Rigs `https://shop.bitmain.com`
- Blockstream Satellite `https://blockstream.com/satellite/`