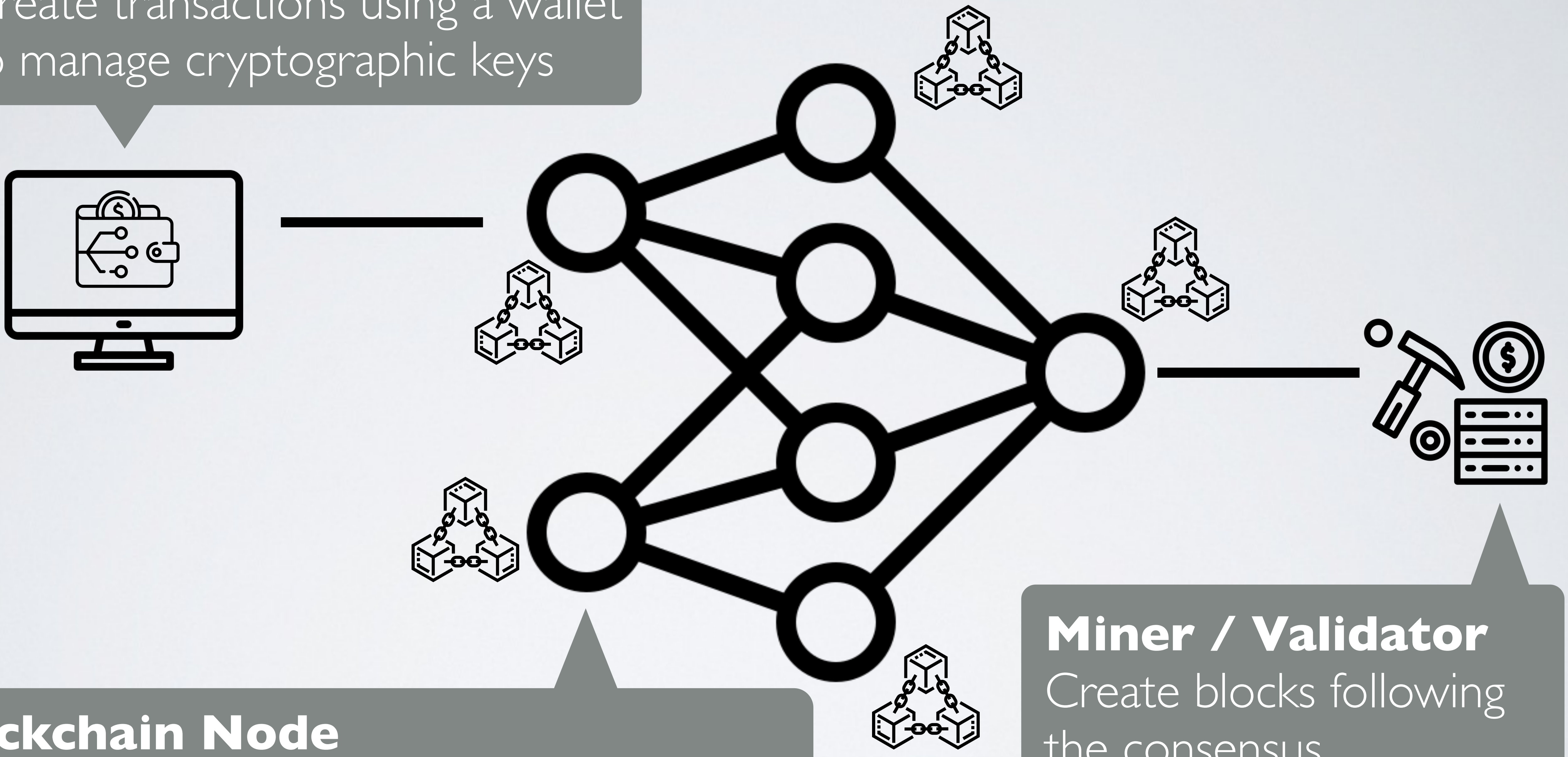
[Recap] Anatomy of a Blockchain Network

Client
Create transactions using a wallet to manage cryptographic keys



Blockchain Node
Ensures integrity of the blockchain (i.e preventing double spending) by validating and forwarding transactions and blocks

Miner / Validator
Create blocks following the consensus

[Recap] Blockchain Designs

Different blockchain models

- **UTXO-based**: Bitcoin, Monero, Cardano (and Dotcoin)
- **Account-based:** Ethereum, Solana

Different consensus (Today's lecture)

- **Proof-of-Work:** Bitcoin, Monero (and Dotcoin)
- **Proof-of-Stake**: Ethereum, Solana, Cardano

Dotcoin Assignment

Phase 1: Implementing the client

- Create transactions (wallet) and blocks (miner)
- **Challenge**: manage keys and utxos
- **Deadlines**: Fri Jan 23 (3 PM) and Sunday Jan 25 (11:59 PM)

Phase 2: Implementing the node server

- Store transactions and blocks (no P2P for simplicity)
- The starter code is technically working
- **Challenge**: only accept "valid" transactions and blocks to prevent double spending
- **Deadline**: Sunday Feb 1 (11:59 PM)

Consensus

Thierry Sans

The consensus problem

In lecture 2, we said

"*one node is selected to create the next block*"

But how nodes agree on something in which some nodes in the P2P network might fail or not be honest?

Outline

- Byzantine Agreement Problem and the Sybil attack
- Proof of Work (a.k.a Nakamoto Consensus)
- Proof of Stake
- Other consensus protocols

The Byzantine Agreement Problem
and
The Sybil Attack

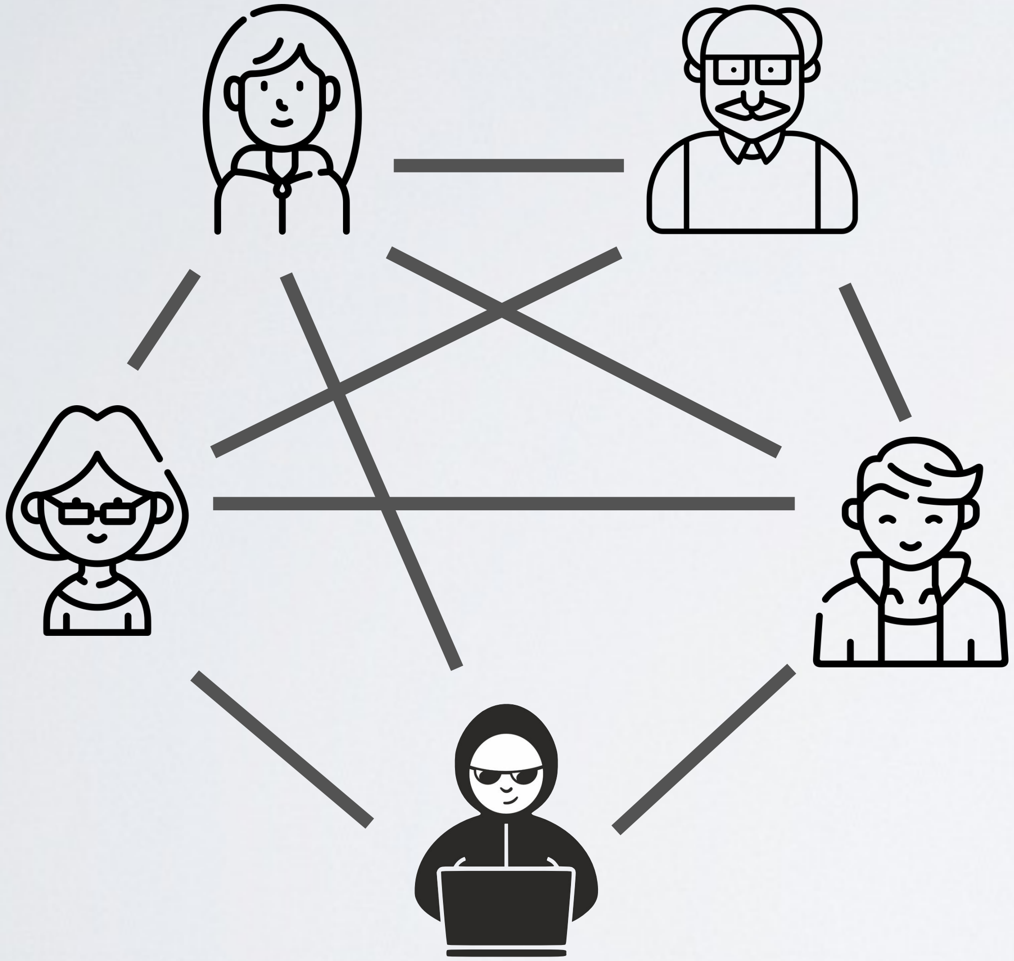
The byzantine agreement problem (introduce by Lamport in 1982)

Generals attacking a fortress must decide whether to attack or retreat

✓ They must reach a common decision and make a coordinated action (consensus)

◉ Some participants might default or sabotage the consensus process
(a.k.a Byzantine failure)

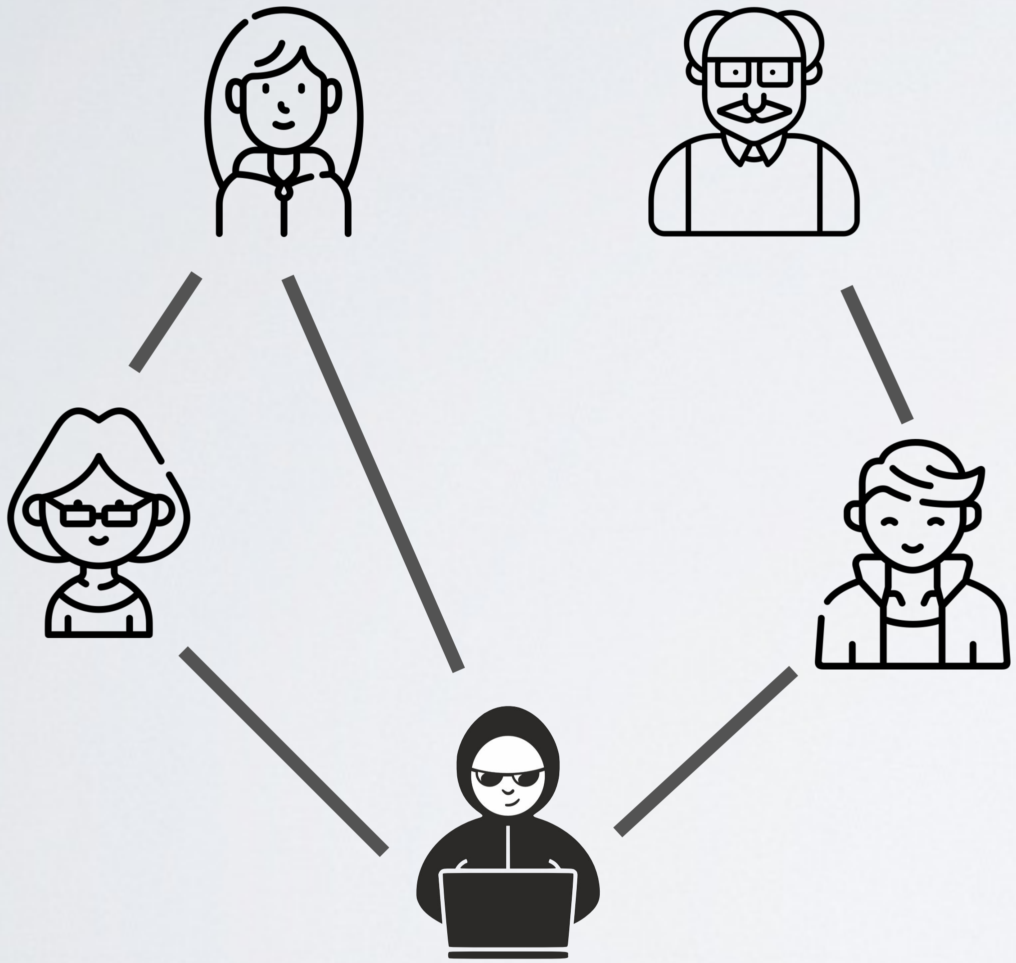
A fully connected network



Each generals send their vote to all others individually

- (failure) some votes might not reach their destination
- (sabotage) a general might send different vote to different people

A P2P network



Each generals sign and forward their vote to peers that we relay it (flooding algorithm)

- (failure) some votes might not reach their destination
- (sabotage) a general might send different vote to different people
- (sabotage) a general might not forward certain vote

Requirements for Byzantine Fault Tolerance (BFT)

Given a system of n nodes, t of which are dishonest. When a node A broadcasts the value x, the other nodes are allowed to discuss with each other and verify the consistency of A's broadcast, and eventually settle on a common value y.

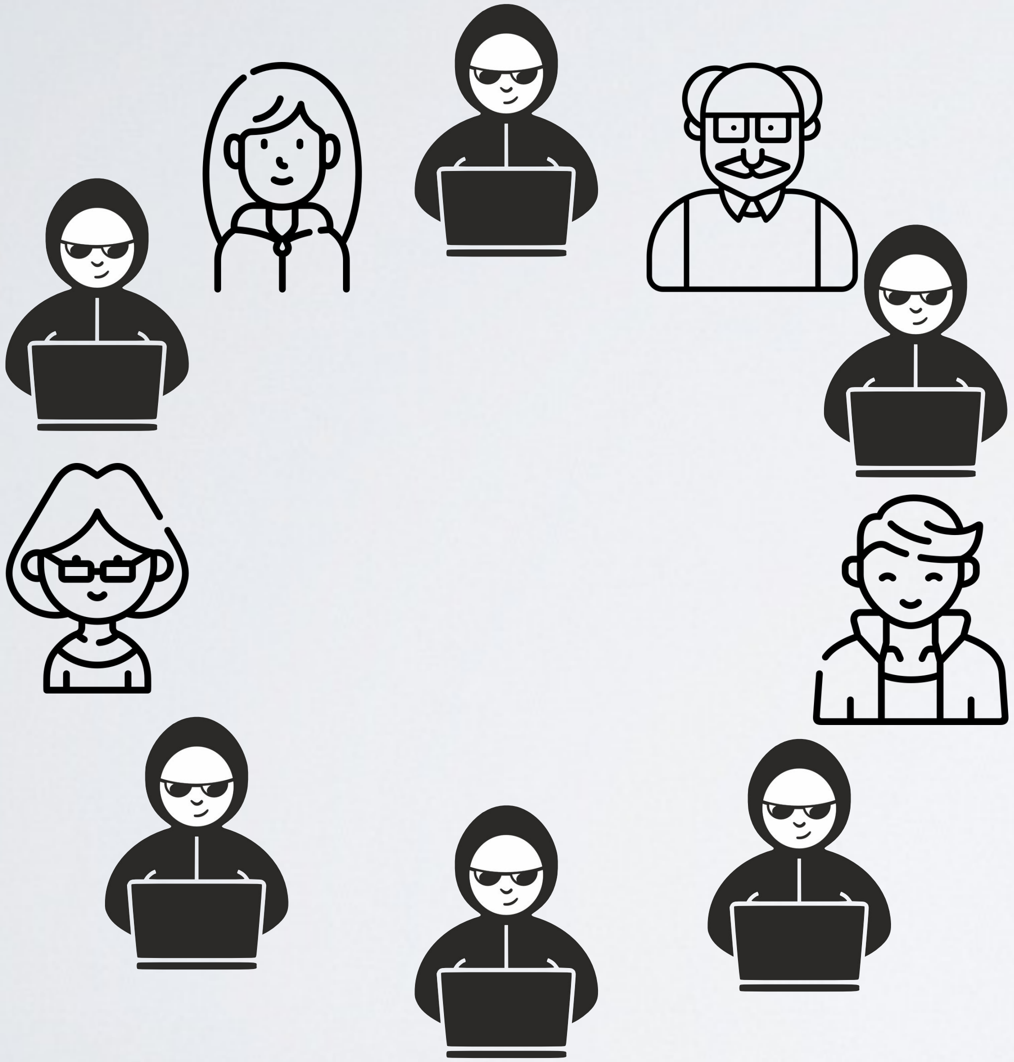
The system is said to resist Byzantine faults if either

- A is honest and all honest nodes agree that A says x, or
- A fails or is dishonest and all honest node agree that A says Y

Security properties:

- **Consistency** - Honest nodes do not contradict
- **Liveness** - Progress is made

Another problem - Sybil Attack

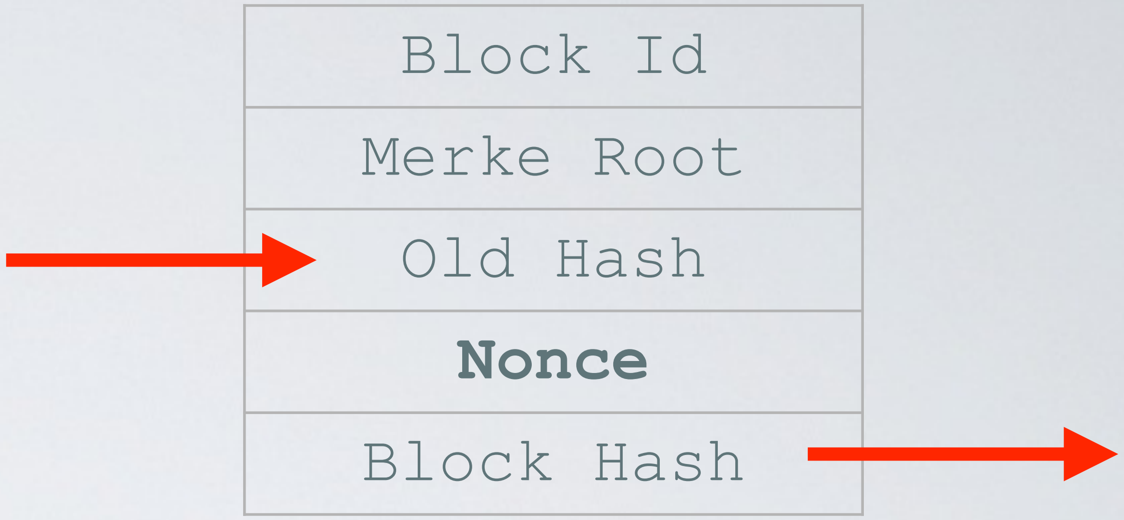


If a reputation system, an attacker can creates and operates multiple nodes/identities to

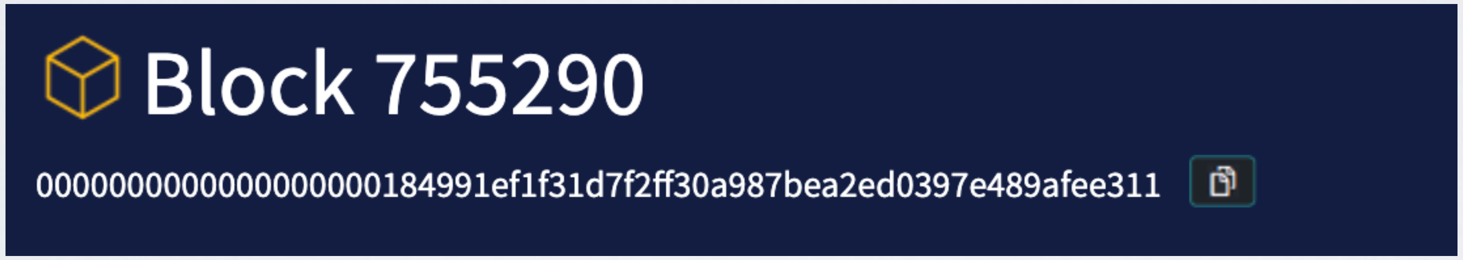
- Carry out a 51% attack to control the consensus outcome
- Block messages from honest nodes (P2P network)

Proof of Work
(a.k.a Nakamoto Consensus)

The Mining Challenge



- ➡ Find a nonce such that H(block) has a certain number of leading 0s



Block 755290

0000000000000000000184991ef1f31d7f2ff30a987bea2ed0397e489afee311

The number of zeros is determined from the target
https://en.bitcoinwiki.org/wiki/Difficulty_in_Mining#Bitcoin_mining_difficulty

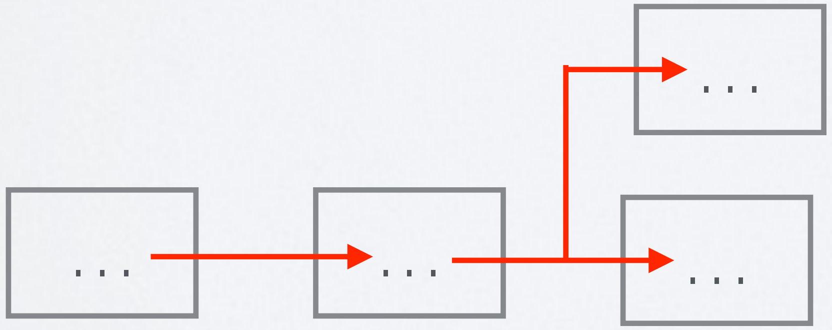
Target is adjusted every 2016 blocks (every 2 weeks) to mine a block every 10 minutes in average

- ✓ Finding the right nonce that outputs the right hash is hard (but not impossible) to compute
- ✓ Verifying the nonce and the block hash is easy to verify by other nodes

Good but ...

- ✓ Prevents the sybil attack
  Probability of winning is relative to the computation power

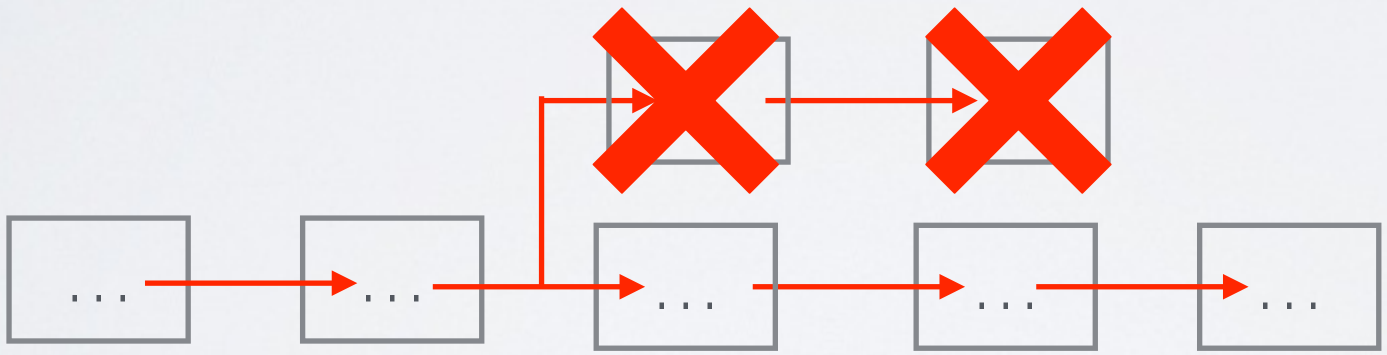
- ◉ Does not fully solve the Byzantine Agreement Problem (yet)
  The mining challenge does not prevent **two valid** blocks be found and broadcasted at relatively same time



The Longest-chain Wins Protocol

Simple rule

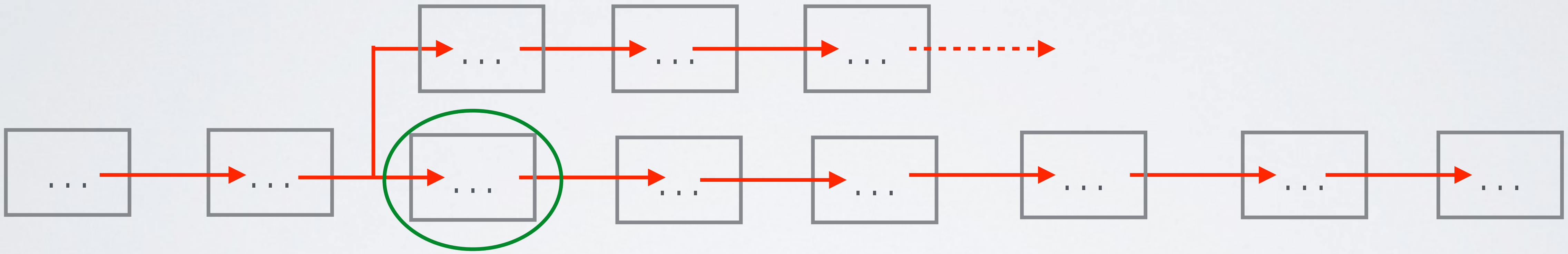
A miner must mine a block on the longest chain known



➡ **Consequence** : one should wait at least 6 confirmation blocks to consider a transaction as fully confirmed

Double-spending attack

Can Mallory perform a double-spending attack by crafting a chain that exceeds 6 blocks previously confirmed?



✓ Binomial Random Walk (see Bitcoin paper)
Impossible to catch up with the longest chain unless Mallory controls more than 51% of the blockchain computing power

Criticism of Proof of Work

- All miners spend considerable amount of energy to eventually have only one of them being rewarded

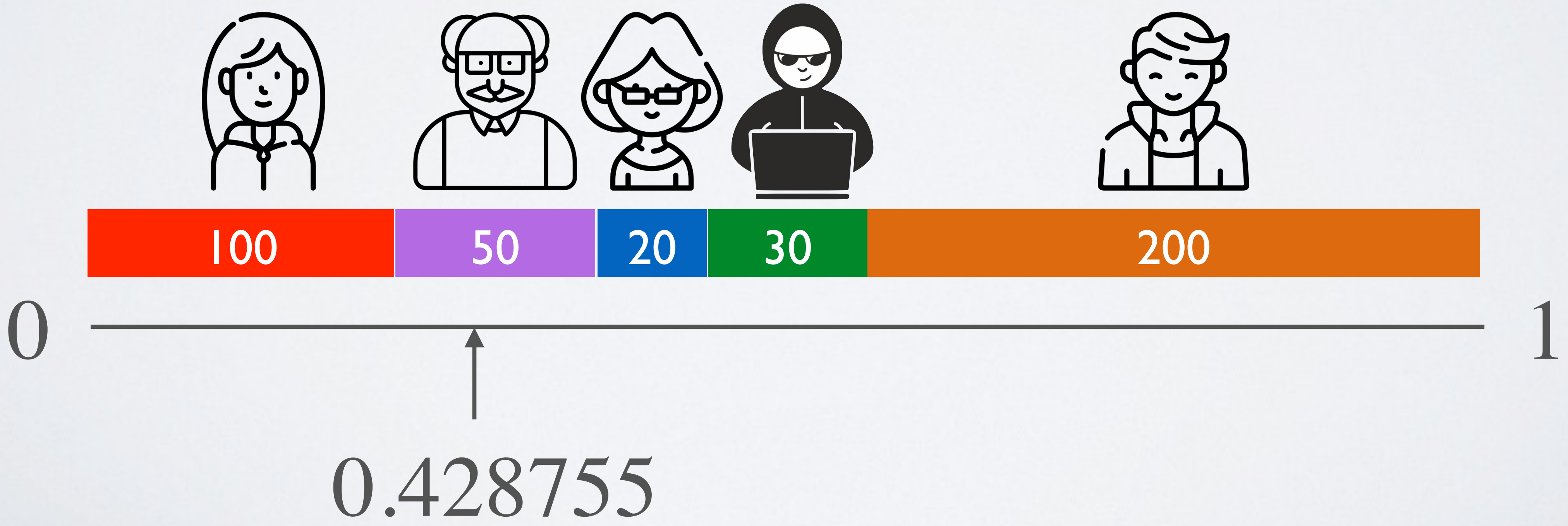
Proof of Stake

A more energy efficient approach

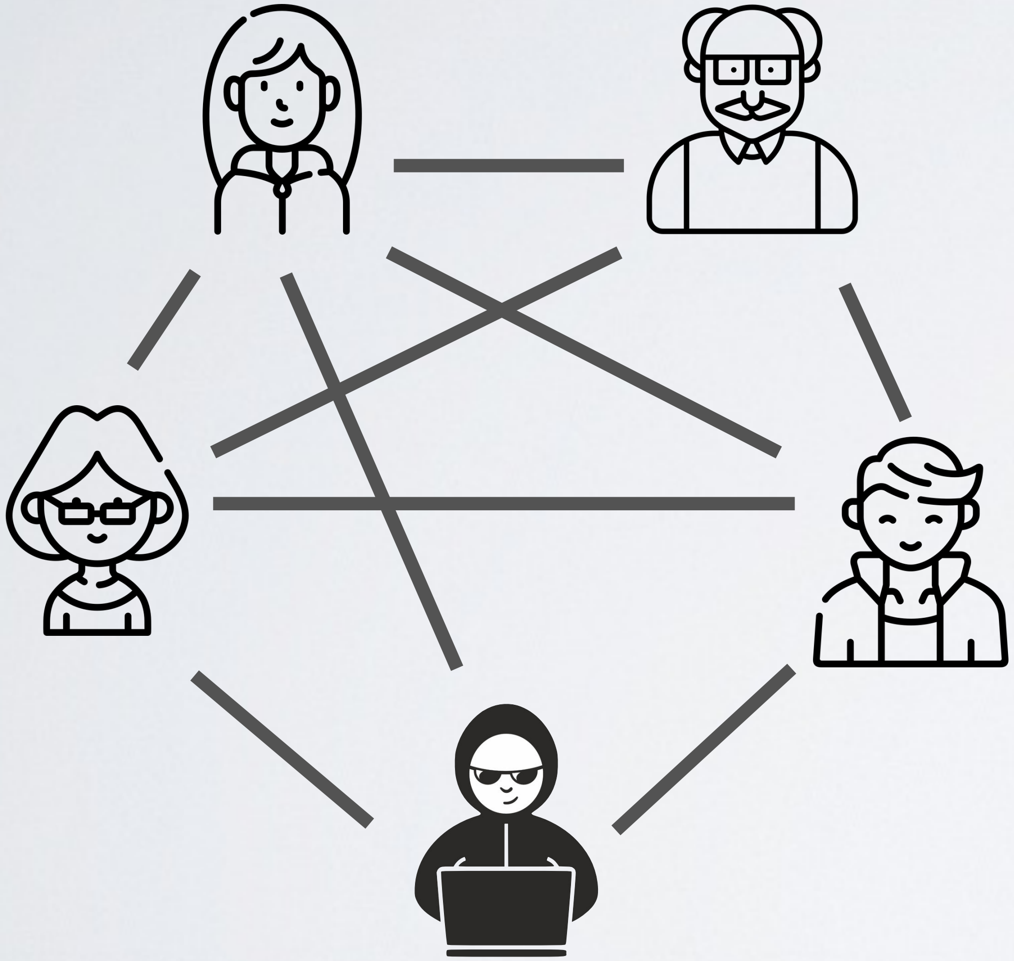
- ✓ Solving the Byzantine Agreement Problem by electing the node that will mine the next block
- ✓ Preventing a sybil attack by making the probability of being elected relative to the monetary power (staking)

Election process

Electing one of the node to mine the next block requires **a beacon** : an ideal service that regularly publishes random value which no party can predict or manipulate



Collect Random Approach



Step 0 - Each node $\mathbf{i}$ generate a random number $\mathbf{r_i}$

Step 1 - Each node commits its random number by broadcasting $\mathbf{H(r_i)}$

Step 2 - Each node broadcasts its random $\mathbf{r_i}$ and verifies all committed hashes others

Step 3 - Each node calculate the beacon value

$$\text{beacon} = H(r_1 \,||\, r_2 \; .... \,||\, r_n)$$

Step 4 - The elected node mine the next block and broadcast it to the network

Step 5 - The other nodes check the block
If the block is invalid, the elected node lose its stake (slashing)

Beyond Pow and Pos

Other consensus

- Proof of Stake variant based on pBFT - Practical Byzantine Fault Tolerant (Cosmos Tendermint)
- Proof of Authority ~ private network (Facebook Libra)