Blockchain Tech

UNSW COMP9243 18s1

Michael Sproul

Warning

Blockchain is all the rage, but…

- It’s **very easy** to lose money (volatility, scams)
- The technology is still immature
- You may become obsessed ;)

Overview

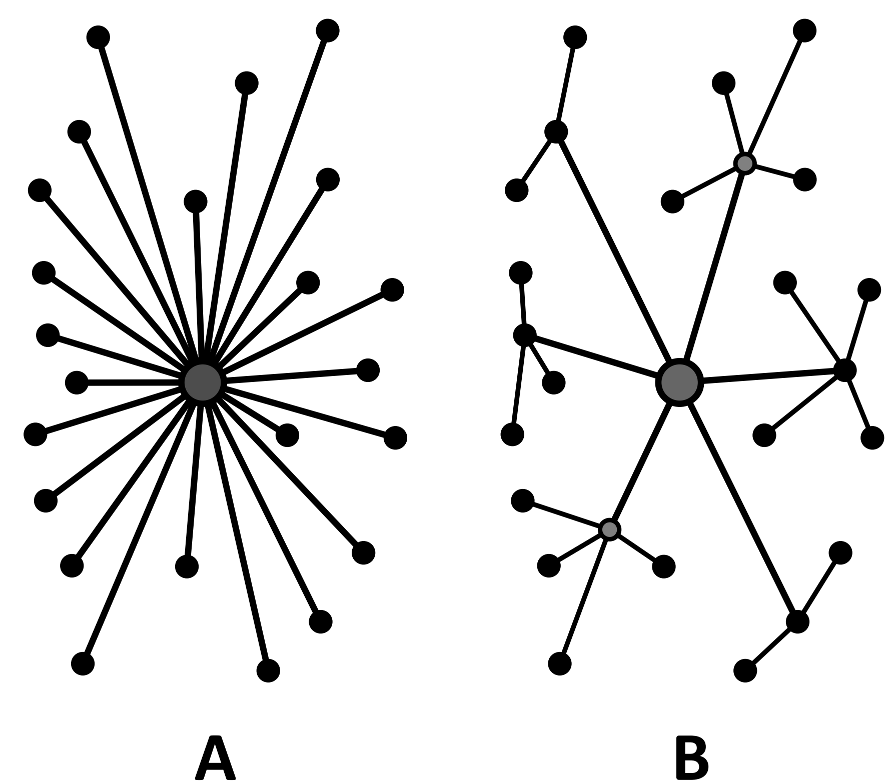
- Bitcoin
- Proof of Work
- Hard Forks vs Soft Forks
- Ethereum and Smart Contracts
- Proof of Stake

Bitcoin – Motivation

- Electronic cash
- Anonymous
- No middlemen or *centralised* control
- Deflationary monetary policy
- Satoshi Nakamoto 2008: *A Peer-to-Peer Electronic Cash System*

Bitcoin – Implementation

- Shared **ledger** storing account balances
- Accounts identified by **public keys**
- **Peer-to-peer** network (decentralised)
- Finite supply: 21 million BTC total
- Open source software

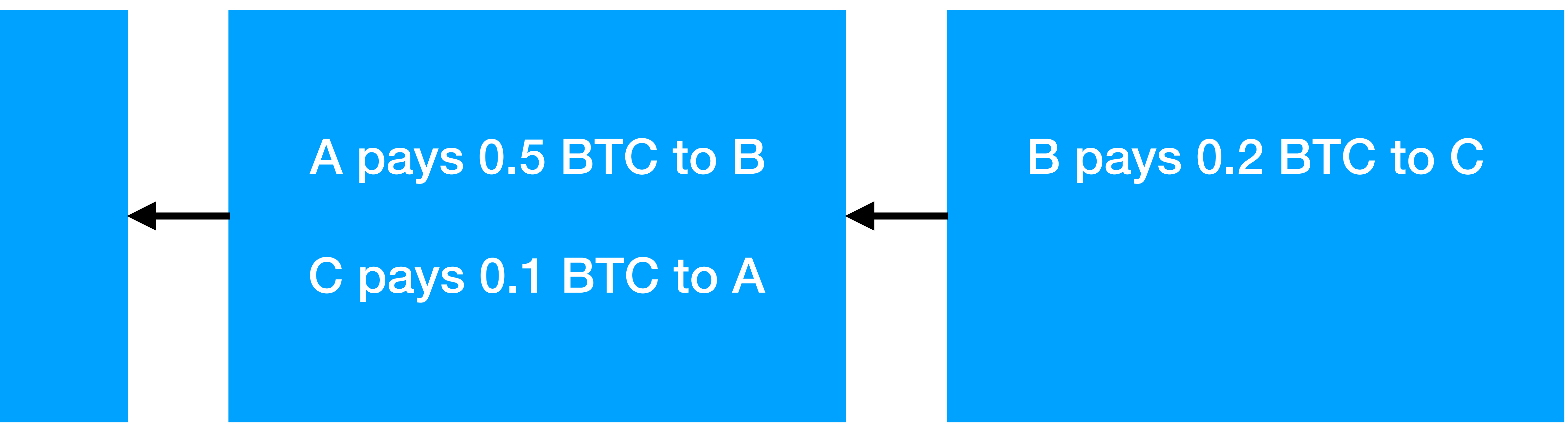


Blockchain Basics

Account Balances

A: 1.0 BTC	**A:** 0.6 BTC	**A:** 0.6 BTC
B: 0.0 BTC	**B:** 0.5 BTC	**B:** 0.3 BTC
C: 5.1 BTC	**C:** 5.0 BTC	**C:** 5.3 BTC

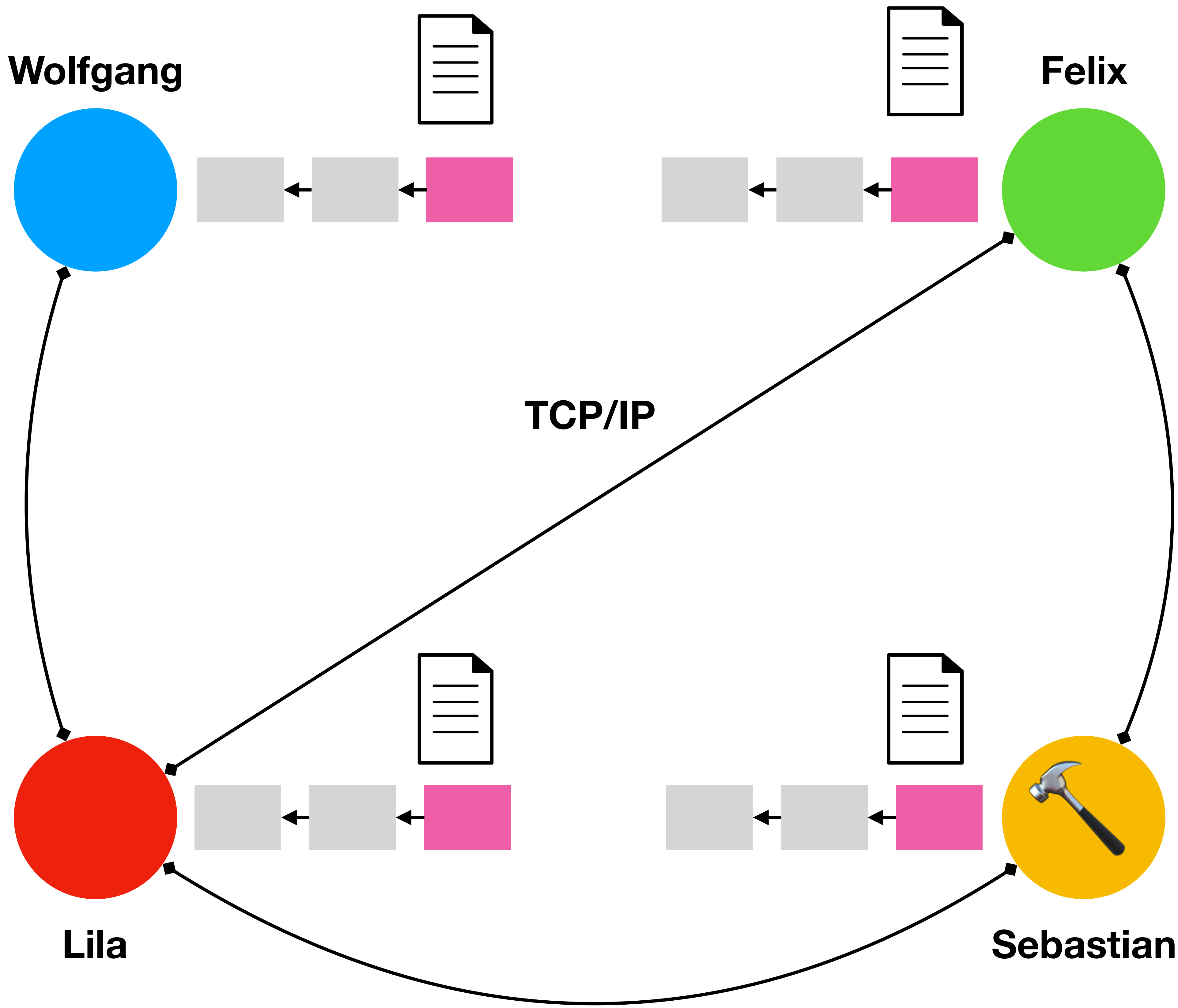
Blockchain State



Blockchain Basics

- Block = bundle of transactions + metadata
- Blockchain = list of blocks, chained together by hash pointers
- Each block includes the SHA256 hash of the previous block – impossible to change an earlier block without invalidating all subsequent blocks

The Bitcoin Network



The Bitcoin Network

- Obtain initial peers manually or via DNS
- Exchange knowledge of peers with other peers
- Maintain TCP/IP connections to reliable peers
- Broadcast transactions and blocks to all connected peers

Bitcoin Transactions

- New coins are created in special **coinbase** transactions that are paid to miners
- All other transactions refer to previous transactions as *inputs*, and specify recipients as *outputs*
- Transactions specify the conditions under which their outputs can be spent using a simple programming language: **Bitcoin Script**

Example Transaction

Wolfgang pays 0.5 BTC to Felix

Inputs

0:
Previous txn: <hash of previous txn where Wolfgang received 0.5 BTC>
Index: <which of the previous outputs Wolfgang wants to spend, e.g. #0>
scriptSig: <Wolfgang's signature> <Wolfgang's public key>

Outputs

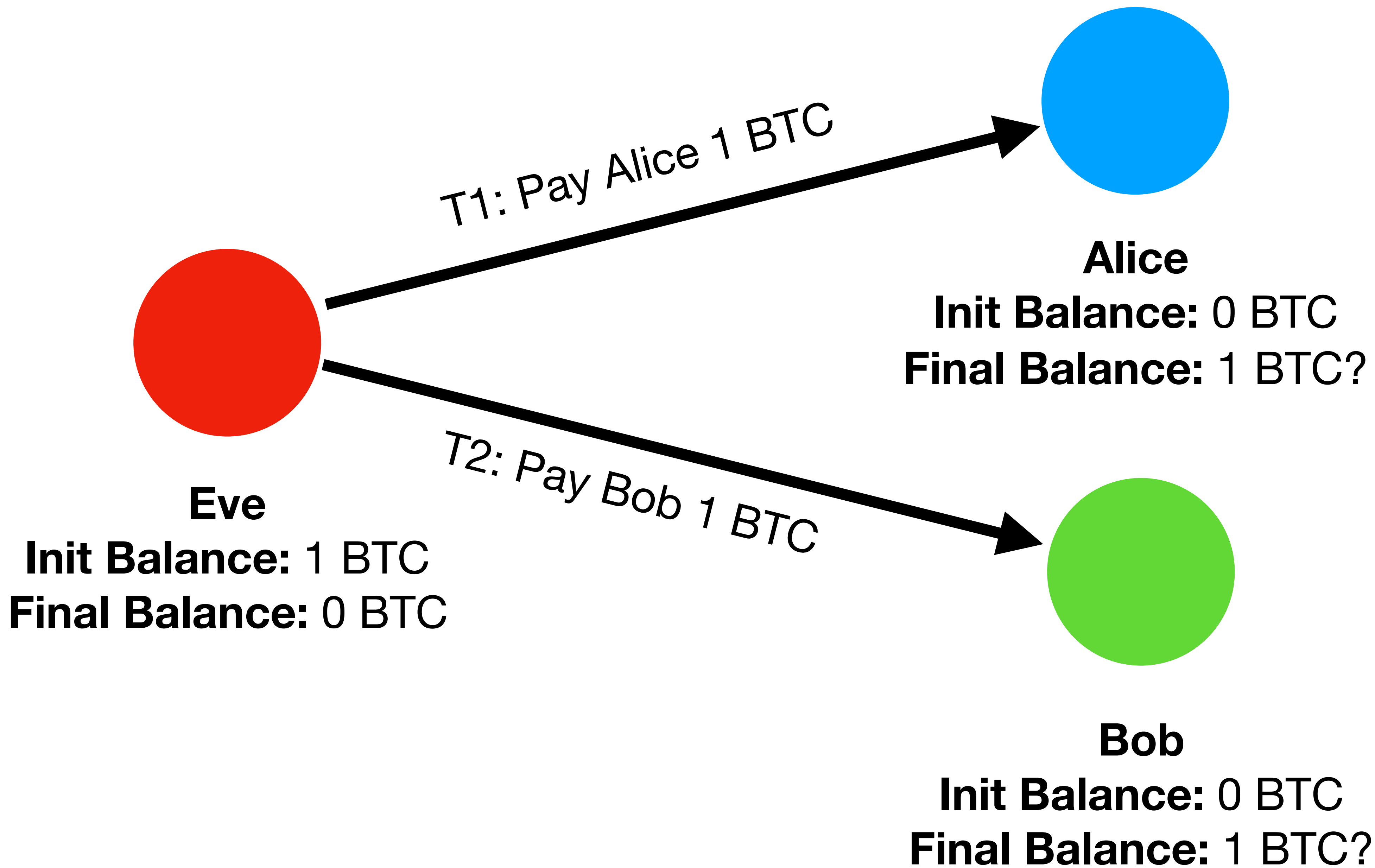
0:
Value: 50,000,000 (0.5 x 10^8 satoshis)
scriptPubKey: OP_DUP OP_HASH160 <Felix's Bitcoin address>
OP_EQUALVERIFY OP_CHECKSIG

Signatures prevent anyone except the owner of the coins from spending them

Consensus

- A blockchain is only secure so long as *everyone* agrees on the same chain (and thus transactions)
- Without consensus, malicious users could **double-spend** their coins by sending different transactions to different users

Double-spending



Both transactions cannot be accepted!

Consensus

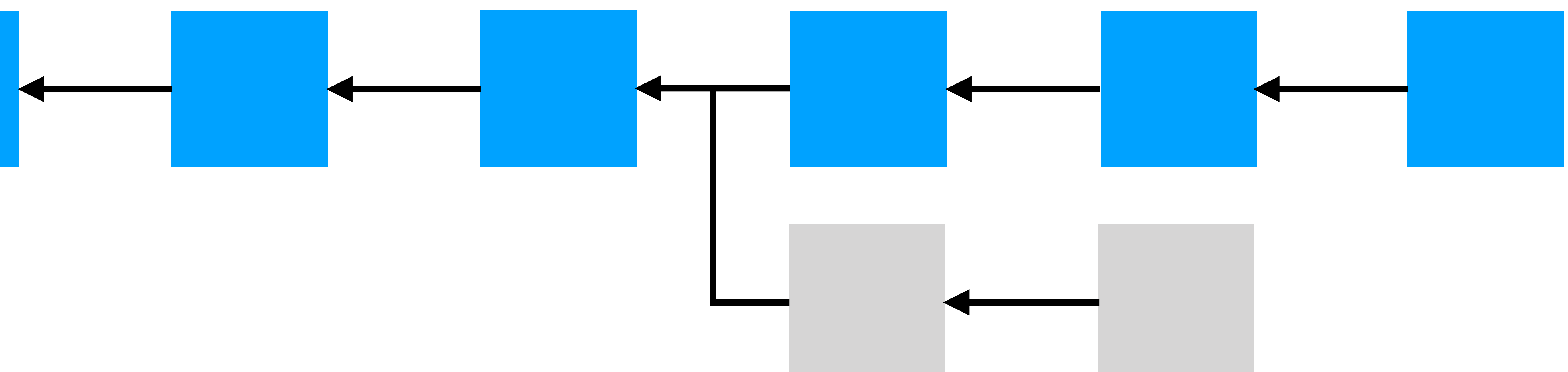
- Consensus is achieved by all nodes in the network running the same **consensus algorithm** to decide on the state of the blockchain

Proof of Work Consensus

- **Miners** solve computational puzzles
- Solving a puzzle grants a miner the right to add a new block to the head of the chain (and claim a **block reward**)
- The **difficulty** of the puzzles automatically adjusts to the rate at which puzzles are solved by the miners, so that the **average time between puzzle solutions remains constant**

Proof of Work Consensus

- Miners must **compete** with each other to solve the puzzles, and this competition prevents any single entity from controlling the chain
- In any case where two chains conflict, the **longest chain** is taken to be valid



Bitcoin's PoW

- Puzzle: find an arbitrary **nonce** to include in your block so that the double SHA256 hash of the block is *less than* a **target** value

  SHA256(SHA256(block)) = 0000e12a… < 0000fffff…

- Difficulty: adjust the **target** every 2016 blocks so that the average block time moves closer to 10 minutes

Economic Security

- Once a transaction is buried several blocks deep, it becomes **very expensive** to revert. An attacker would have to mine a new chain starting from before the transaction occurred, and **outrun** the main chain ("51% attack")
- Miners spend (and are paid) **millions of dollars** per day to secure the network ($10-50M USD/day)
- 6 confirmations ≈ $825,000 (6 * 12.5 * $11000)

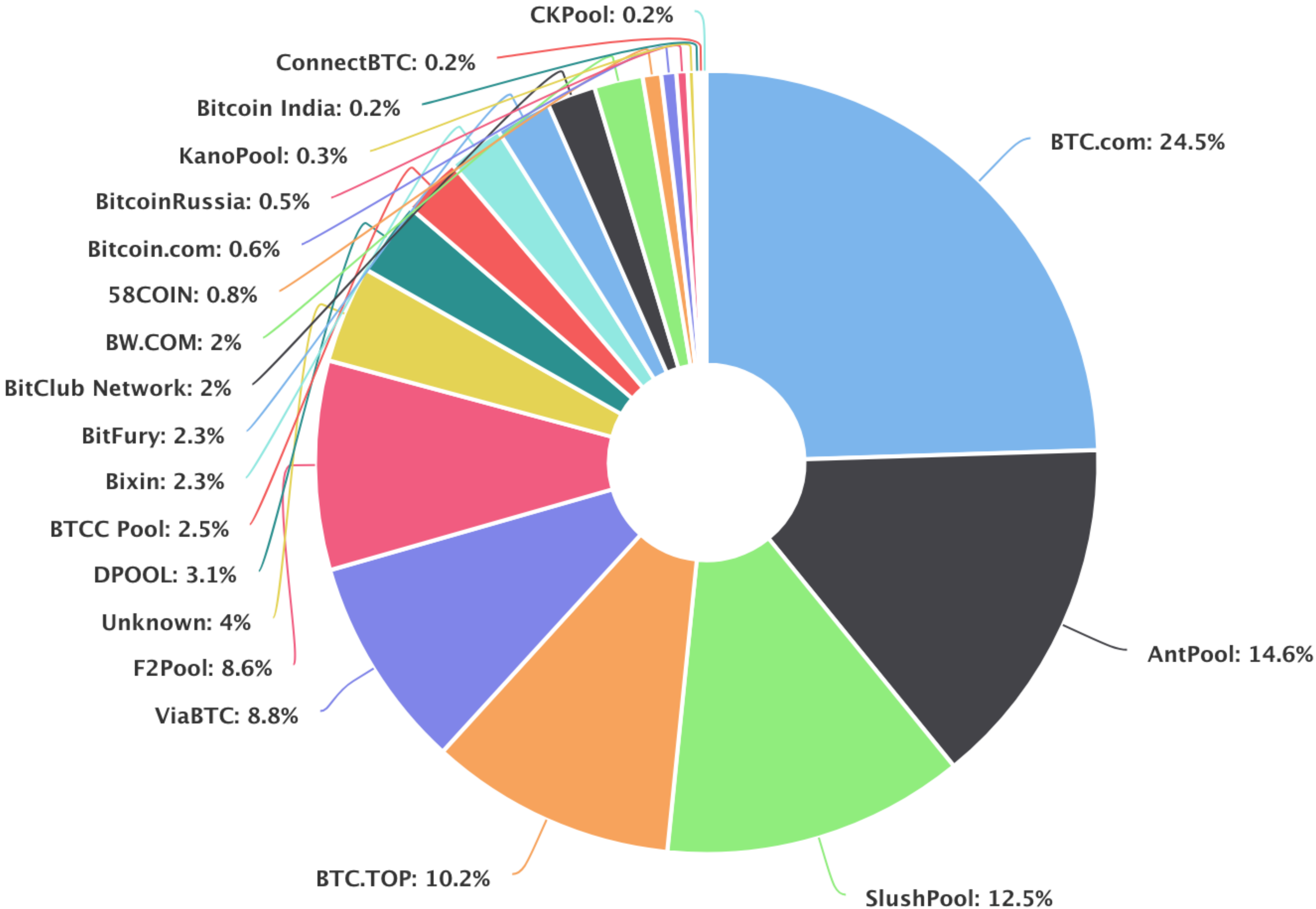
Attacks on PoW

Several (difficult) ways to **double-spend**:

- 51% attack: mine an alternative history.
  - Requires a huge **budget**, but **cost** is minimal if the attack is successful (paid via block rewards)
- Network attack: **partition** your target from the rest of the network and present them with an alternative history, or censor their transactions

Mining

- Economies of scale make **large-scale** mining enterprises much more profitable than small ones
- Lifecycle for a PoW coin: CPUs -> GPUs -> ASICs
- Result is mining **centralisation** (!) around a handful of companies



Percentage of Bitcoin blocks mined by different pools around 28/05/2018, source: blockchain.info

Energy Efficiency

- Miners can (must) spend a large portion of their **mining revenue** on electricity to run their ASICs
- Therefore, energy usage follows USD price (!!)
- Bitcoin uses **6-60 TWh** of electricity per year, which is somewhere between **Ethiopia** (6.7 TWh) and **Switzerland** (58 TWh)
- Energy use mitigated by time and money required to manufacture and deploy new ASICs

What About Upgrades?

- Recall: all nodes in the network run the same validation and consensus logic
- Botched upgrades can cause failures, so use a **flag day** – release a new version of the software that runs the upgraded code once an agreed upon block number is reached 🏴
- What if some node operators refuse to upgrade?

Hard Forks vs Soft Forks

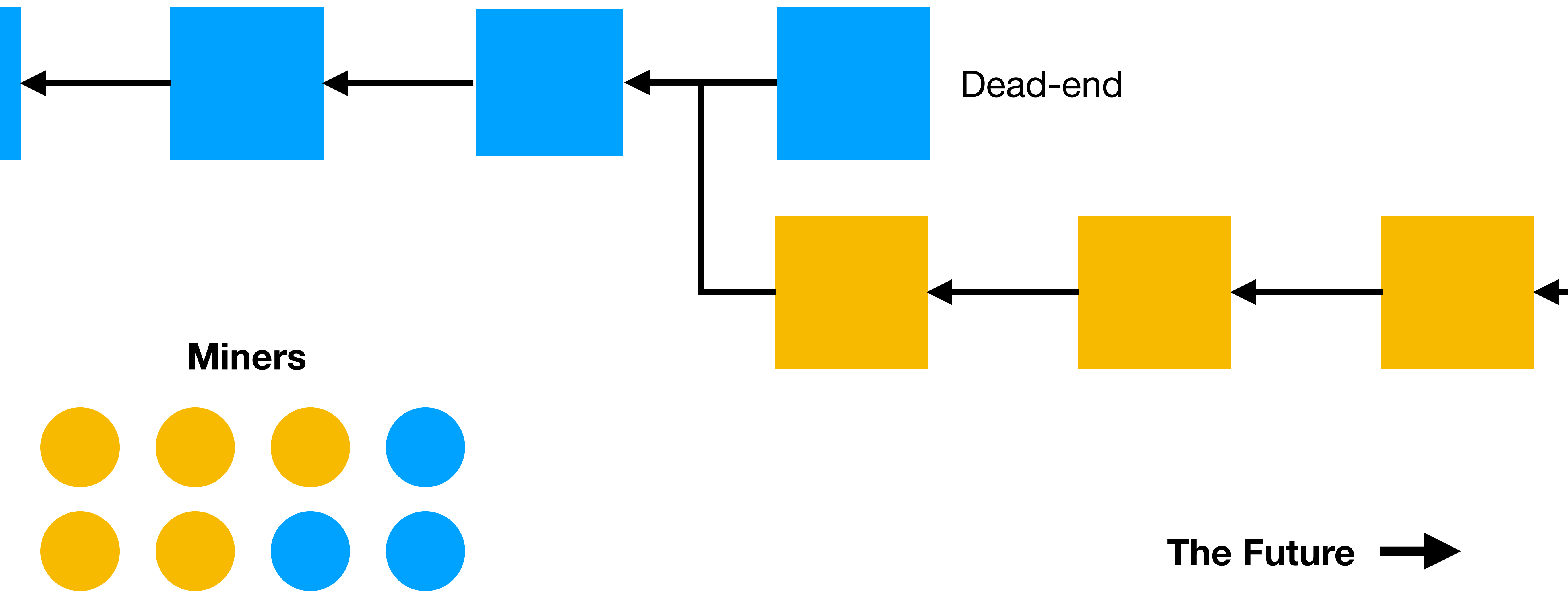
- **Soft fork:** *Restricts* the set of valid blocks. Backwards-compatible with old nodes that don't upgrade. Example: *decreasing* max block size

- **Hard fork:** *Expands* the set of valid blocks. *Not* backwards-compatible with old nodes. Example: *increasing* max block size

- **Chain split:** When the chain splits permanently, which can happen with either a minority (<50%) soft fork, or non-unanimous (<100%) hard fork

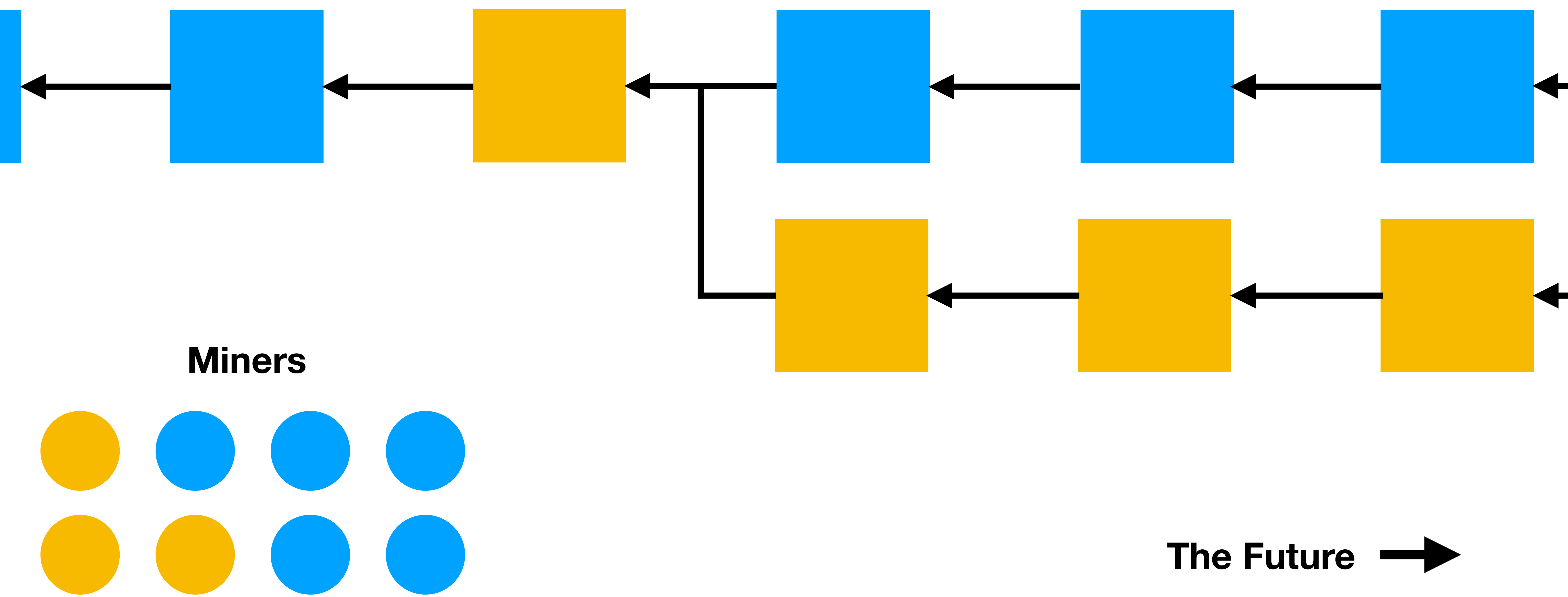
Soft Fork, No Split

Majority of miners follow the new rules, so the new chain wins



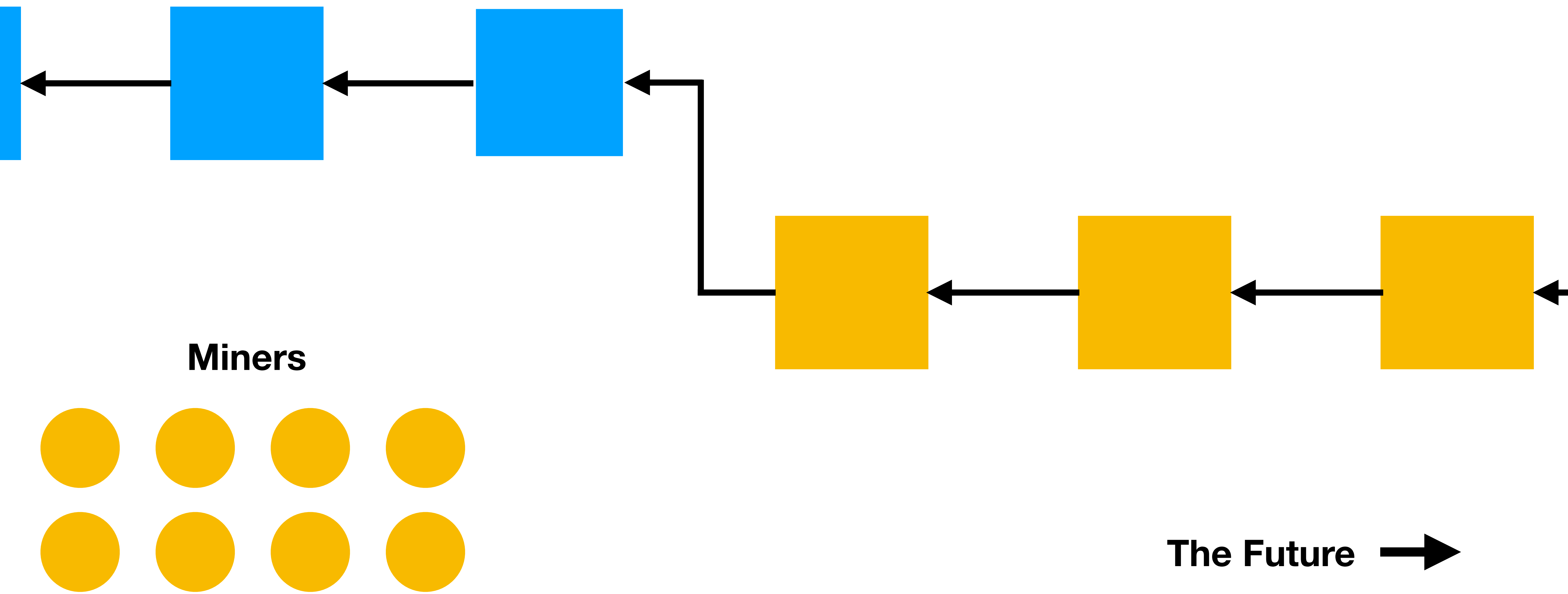
Soft Fork, Split

Majority of miners don’t upgrade, upgraded nodes split onto a weaker chain



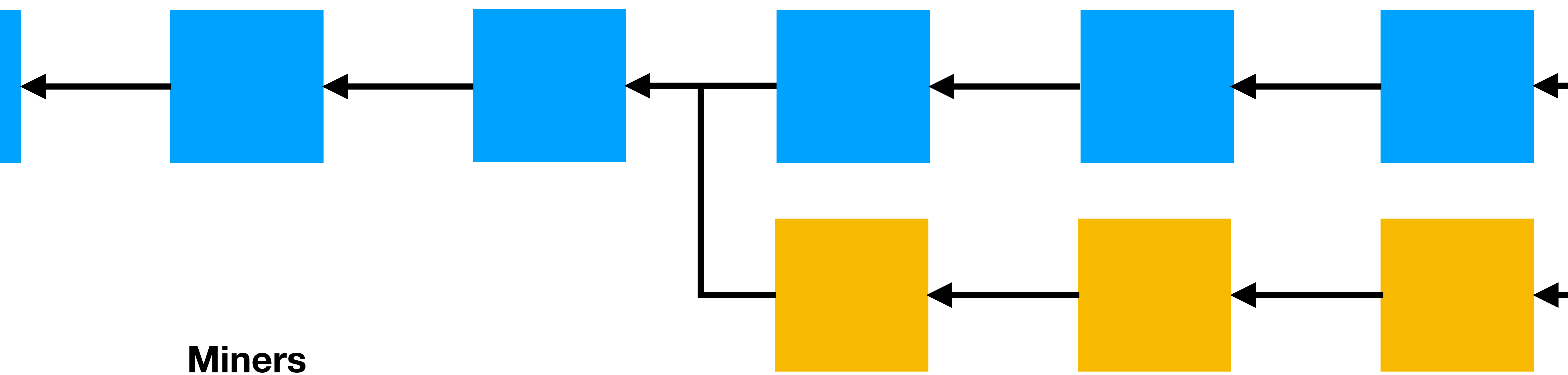
Hard Fork, No Split

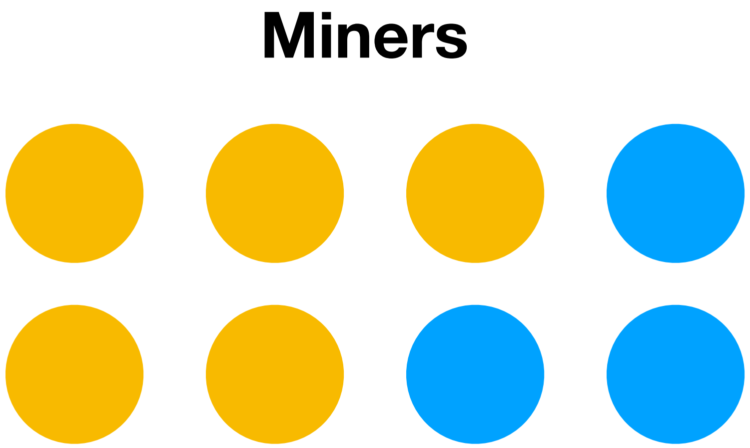
All nodes and miners upgrade



Hard Fork, Split

Some nodes don't upgrade
and continue the original chain





Health of each chain depends
on its % support

The Future →

Fork Politics

- Bitcoin is quite “fork-conservative”. Bitcoin has only ever upgraded via soft forks (e.g. SegWit)

- Bitcoin hard forks have happened, but mostly for the creation of new derivative coins, e.g. Bitcoin Cash, Bitcoin Gold

- Ethereum has experienced hard forks that split the chain (Ethereum Classic), and hard forks that don’t (Byzantium)

- Forks are POLITICAL. Different people have different ideas about how blockchain networks should operate

Bitcoin's Strengths

- Fault-Tolerant (no single point of failure)
- Censorship Resistant (infeasible to stop a txn)
- Simple and Stable (compared to competition)

Bitcoin's Weaknesses

- Generality (blockchains can do more than money)
- Energy Inefficiency (PoW is wasteful)
- Privacy (all data public)
- Scalability (not many transactions/second)

Other Cryptocurrencies

- **Ethereum**: improves generality by adding *smart contracts* which can express more complex applications than Bitcoin Script

- **Proof of Stake coins**: improve energy efficiency by replacing mining with in-protocol rewards and punishments

- **Zcash/Monero**: improve privacy by hiding the details of transactions using sophisticated cryptography

Ethereum

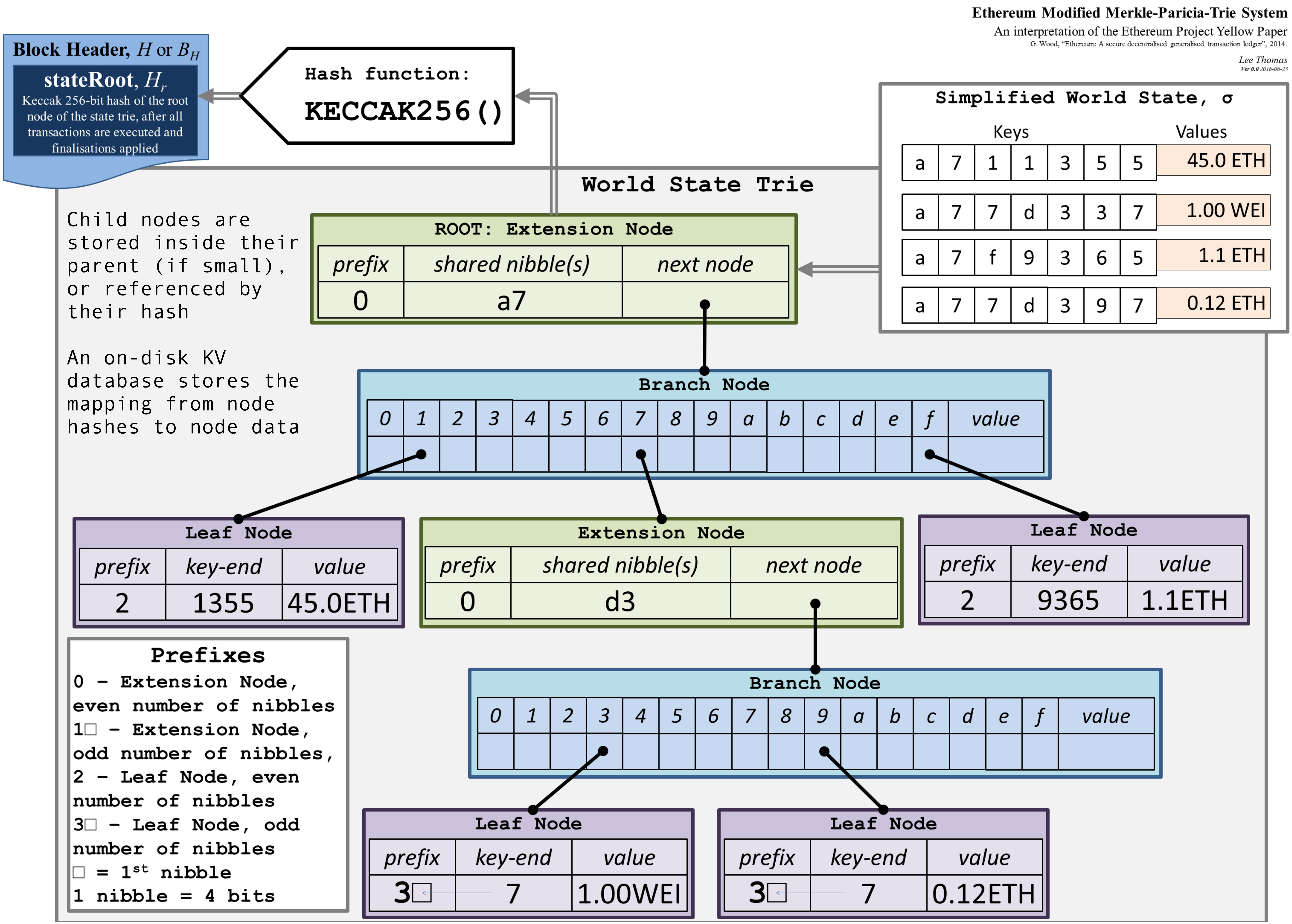
- Uses a blockchain to agree on the state of programmable “world computer”, the **Ethereum Virtual Machine (EVM)**

- **Smart Contracts** are programs written in EVM bytecode that are stored on the blockchain and executed by all the nodes on the network

- Users can send transactions that create new smart contracts, execute existing ones, or transfer funds

Ethereum World State

- World state: 160 bit Ethereum address => Account
- Account (or Contract)
  - **balance:** number of Wei owned by this account (1 Ether = 10^{18} Wei)
  - **storageRoot:** hash of the root of a *Merkle Patricia Trie* for this contract's storage. Storage is itself a map from 256-bit VM addresses to 256-bit values
  - **codeHash:** hash of the VM bytecode for this contract
- World state is also stored in a *Merkle Patricia Trie*


Ethereum Modified Merkle-Paricia-Trie System
An interpretation of the Ethereum Project Yellow Paper
G. Wood, "Ethereum: A secure decentralised generalised transaction ledger", 2014.
Lee Thomas
Ver 0.0 2016-06-23
Block Header, H or B_H
stateRoot, H_r
Keccak 256-bit hash of the root node of the state trie, after all transactions are executed and finalisations applied
Hash function:
KECCAK256()
Simplified World State, σ
Keys
Values
a 7 1 1 3 5 5
45.0 ETH
a 7 7 d 3 3 7
1.00 WEI
a 7 f 9 3 6 5
1.1 ETH
a 7 7 d 3 9 7
0.12 ETH
World State Trie
Child nodes are stored inside their parent (if small), or referenced by their hash
An on-disk KV database stores the mapping from node hashes to node data
ROOT: Extension Node
prefix
shared nibble(s)
next node
0
a7
Branch Node
0 1 2 3 4 5 6 7 8 9 a b c d e f value
Leaf Node
prefix
key-end
value
2
1355
45.0ETH
Extension Node
prefix
shared nibble(s)
next node
0
d3
Leaf Node
prefix
key-end
value
2
9365
1.1ETH
Prefixes
0 – Extension Node, even number of nibbles
1□ – Extension Node, odd number of nibbles,
2 – Leaf Node, even number of nibbles
3□ – Leaf Node, odd number of nibbles
□ = 1st nibble
1 nibble = 4 bits
Branch Node
0 1 2 3 4 5 6 7 8 9 a b c d e f value
Leaf Node
prefix
key-end
value
3□
7
1.00WEI
Leaf Node
prefix
key-end
value
3□
7
0.12ETH

Ethereum Blocks

- Hash of previous block (just like Bitcoin)
- Root hash of the Merkle trie for all transactions in the block
- Root hash of the Merkle trie for the world state after all transactions have been applied to it

Ethereum Smart Contracts

- Each contract has access to its own address space mapping 256-bit addresses to 256-bit values
- EVM assembly is a low-level stack-based language. Instructions include: PUSH, POP, JUMP, MLOAD, MSTORE, ADD, SSTORE, SLOAD
- Each instruction has a **gas cost** that must be paid to execute it. This compensates miners, and ensures that every transaction terminates
- Most contracts are written in high-level languages that compile down to EVM assembly, e.g. **Solidity**, **Vyper**

```
contract MyToken {
    // Map data-structure to store balances
    mapping (address => uint256) public balanceOf;

    // Constructor that gives all the tokens to the contract creator
    constructor(uint256 initialSupply) public {
        balanceOf[msg.sender] = initialSupply;
    }

    // User-invocable function to transfer tokens
    function transfer(address _to, uint256 _value) public {
        // Check that the sender has sufficient balance
        require(balanceOf[msg.sender] >= _value);
        // Check that the receiver's balance won't overflow
        require(balanceOf[_to] + _value >= balanceOf[_to]);
        // Update the balanceOf data structure
        balanceOf[msg.sender] -= _value;
        balanceOf[_to] += _value;
    }
}
```

Ethereum DApps

- **Ethereum Name Service**: decentralised DNS replacement. I registered `comp9243.eth`
- Lots of **Initial Coin Offerings** (ICOs/tokens)
- Decentralised Exchanges (e.g. EtherDelta)
- Identity Management (e.g. uPort)
- Games (e.g. CryptoKitties)

Proof of Stake

- Recall: proof of work mining consumes massive amounts of electricity
- What if we could achieve similar security by using some game theory instead?
- Ethereum is planning to switch to Proof of Stake as soon as possible

Proof of Stake Basics

- Miners replaced by **stakers**
- Instead of buying ASICs, stakers lock funds in **security deposits**
- Stakers **vote** on blocks to be added to the chain, as in a traditional Byzantine Fault Tolerant consensus algorithm
- Stakers are rewarded with new coins for casting valid votes
- Stakers **have their deposit seized** if they misbehave

Slashing Conditions

- We only want one block at a given height, so we **slash a staker's deposit** if they vote on two conflicting blocks at the same height
- We require >2/3 of stakers by weight to vote for a block for it to be considered valid
- Therefore, if two conflicting blocks become valid we know that at least 1/3 of the stakers misbehaved and will lose their deposits

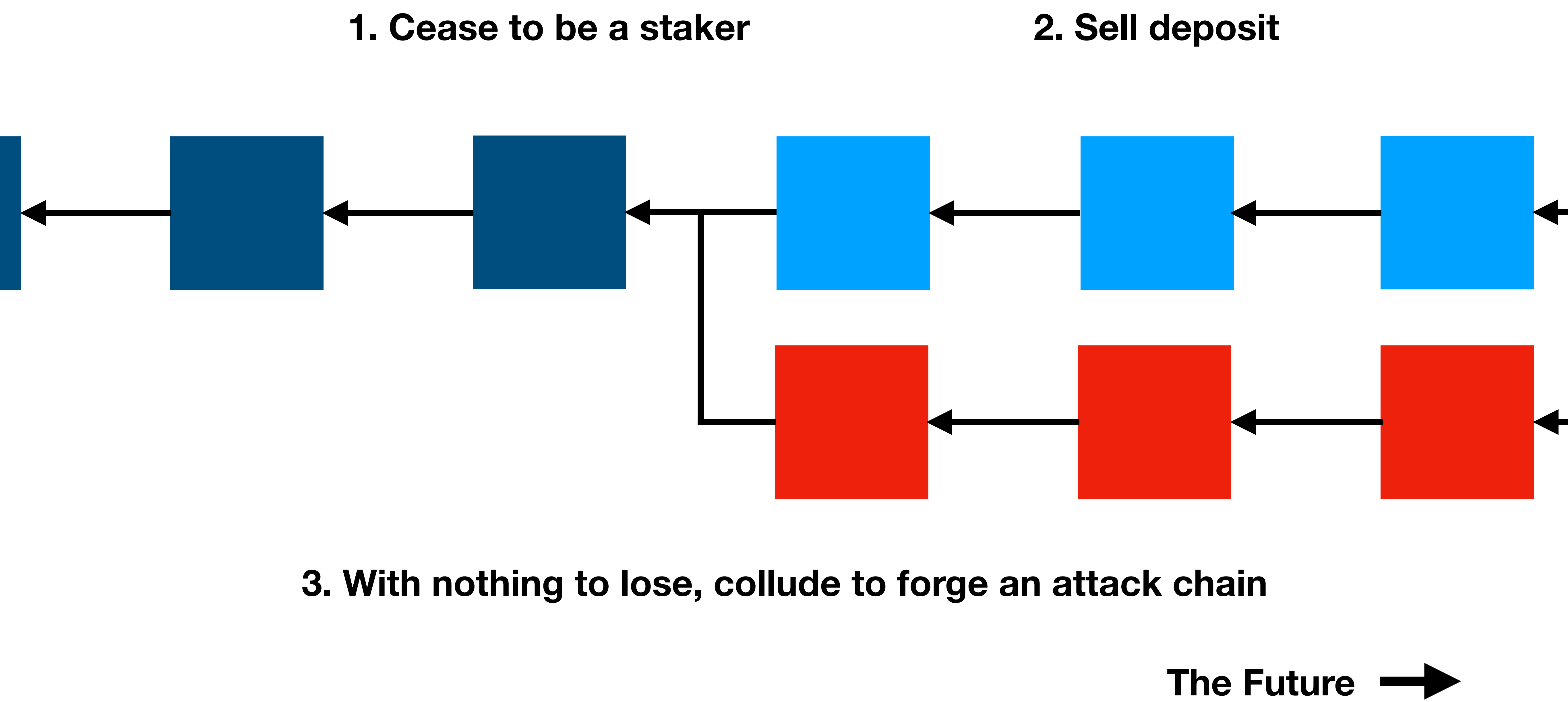
Liveness

- What happens if there are two blocks at the same height with 50% of the vote weight each?
- Most protocols use some kind of **timeout** and allow the stakers to retry
    - Vitalik's Casper uses an **epoch** number and allows the validators to retry in the next epoch if no block is finalised
    - Still an area of <u>open research</u>! Join the fun!

Economic Finality

- Achieve similar security guarantee to a PoW blockchain by requiring 1/3 of total deposits to be some large amount (e.g. **$50M USD**)
- Recall that the *cost* of a 51% attack on PoW is quite low: PoS security can be **stronger** than PoW because malicious actors are **actually punished**

Short-range Attacks



Short-range Attacks

- Once a staker stops staking, their security deposit is still **locked** and can't be withdrawn for a reasonably long time, e.g. a month
- Prevents **short-range attacks** where an attacker sells all their coins and then creates an alternative history in the recent past that they can't be punished for

Long-range Attacks

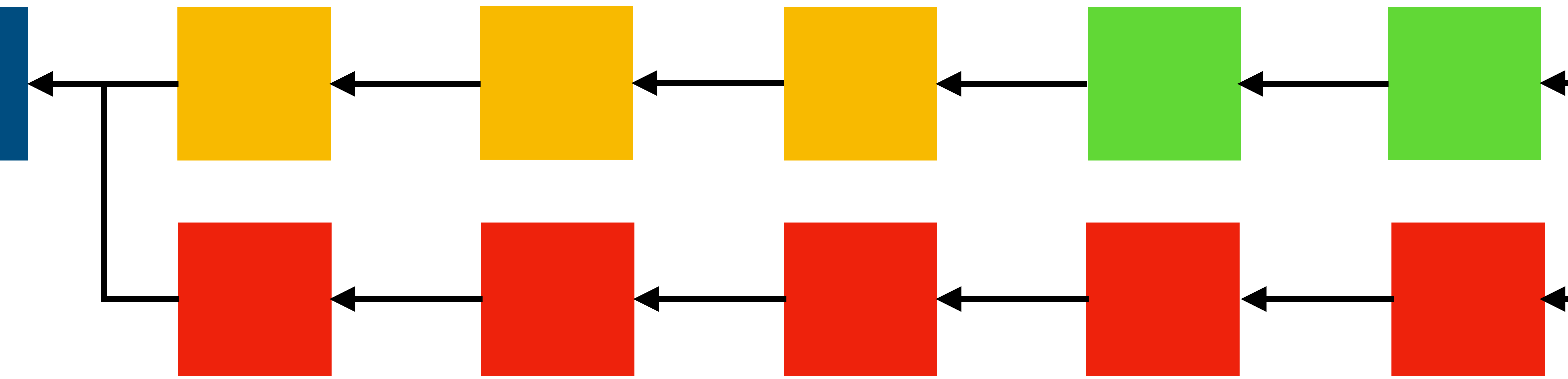
- What if an attacker just attacks as soon as their deposit is unlocked?

Long-range Attacks

1. Cease to be a staker

2. Wait a month for your deposit to unlock

3. Sell your deposit



4. Forge attack chain from >1 month ago, with nothing to lose

Long-range Attacks

- What if an attacker just attacks as soon as their deposit is unlocked?
- Idea: **never** revert blocks older than some large duration of time (e.g. 1 week)
- Intuition: the network should have plenty of time to propagate messages and come to consensus over a week – any changes after that are likely to be malicious long-range attacks

Weak Subjectivity

- Objectivity: PoW chain contains intrinsic proof of the work required to create it

- Weak Subjectivity: PoS chains are trivial to fabricate with the right keys, need to rely on external knowledge to choose a canonical version

- In practice: PoS clients that log on infrequently need to get a checkpoint from a trusted source

Summary

- Blockchains solve the decentralised consensus problem, allowing parties who don't trust each other to agree on a single transaction history (no **double-spends**)
- Proof of work is a blockchain consensus mechanism that relies on the difficulty of obtaining more computational power than the rest of the network
- Proof of stake attempts to improve the energy-efficiency of PoW by replacing mining with **in-protocol rewards and penalties**

Summary

- Upgrading a blockchain network is hard! Soft forks are slightly easier to pull off than hard forks, both can cause permanent chain splits

- **Smart contracts** are programs that run on blockchain networks, and use the blockchain to store their state

- There's lots of work to do! What could you build?

Questions?

Learn More

- Bitcoin: https://bitcoin.org/bitcoin.pdf
- Bitcoin Block Explorer: https://blockchain.info
- Bitcoin Wiki: https://en.bitcoin.it/wiki/Main_Page
- Bitcoin Source: https://github.com/bitcoin/bitcoin
- BIPs: https://github.com/bitcoin/bips
- Bitcoin Energy Consumption: https://digiconomist.net/bitcoin-energy-consumption
- Ethereum: https://ethereum.github.io/yellowpaper/paper.pdf
- Ethereum Block Explorer: https://etherscan.io/

Learn More

- Ethereum Research Forum: https://ethresear.ch/
- Go Ethereum Client: https://github.com/ethereum/go-ethereum
- Solidity Contracts: https://solidity.readthedocs.io/
- Solidity Gas Golfing Competition: https://g.solidity.cc/
- Crypto Twitter: https://twitter.com/search?q=cryptocurrency
- Vitalik's Casper PoS: https://arxiv.org/abs/1710.09437
- Correct-by-construction Casper PoS: https://github.com/ethereum/research/blob/master/papers/CasperTFG/CasperTFG.pdf
- Ouroboros PoS: https://eprint.iacr.org/2016/889

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- Txn icon: https://commons.wikimedia.org/wiki/File:Document_icon_(the_Noun_Project_27904).svg
- Mining distribution: https://blockchain.info/pools
- Merkle trie: https://ethereum.stackexchange.com/questions/6415/eli5-how-does-a-merkle-patricia-trie-tree-work