Lecture 8:
SCALING BLOCKCHAIN

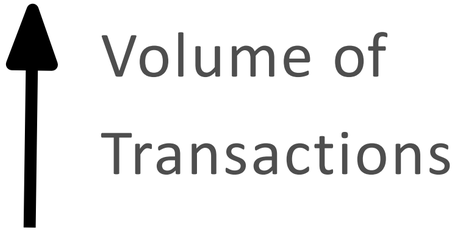
LECTURE OVERVIEW

1. BACKGROUND
2. VERTICAL SCALING ON-CHAIN
3. VERTICAL SCALING OFF-CHAIN
4. HORIZONTAL SCALING

1 BACKGROUND

WHAT IS THE SCALABILITY PROBLEM?

SCALABILITY DEFINITION



WHAT IS THE SCALABILITY PROBLEM?

SCALABILITY DEFINITION

Volume of Transactions

Block Time

WHAT IS THE SCALABILITY PROBLEM?

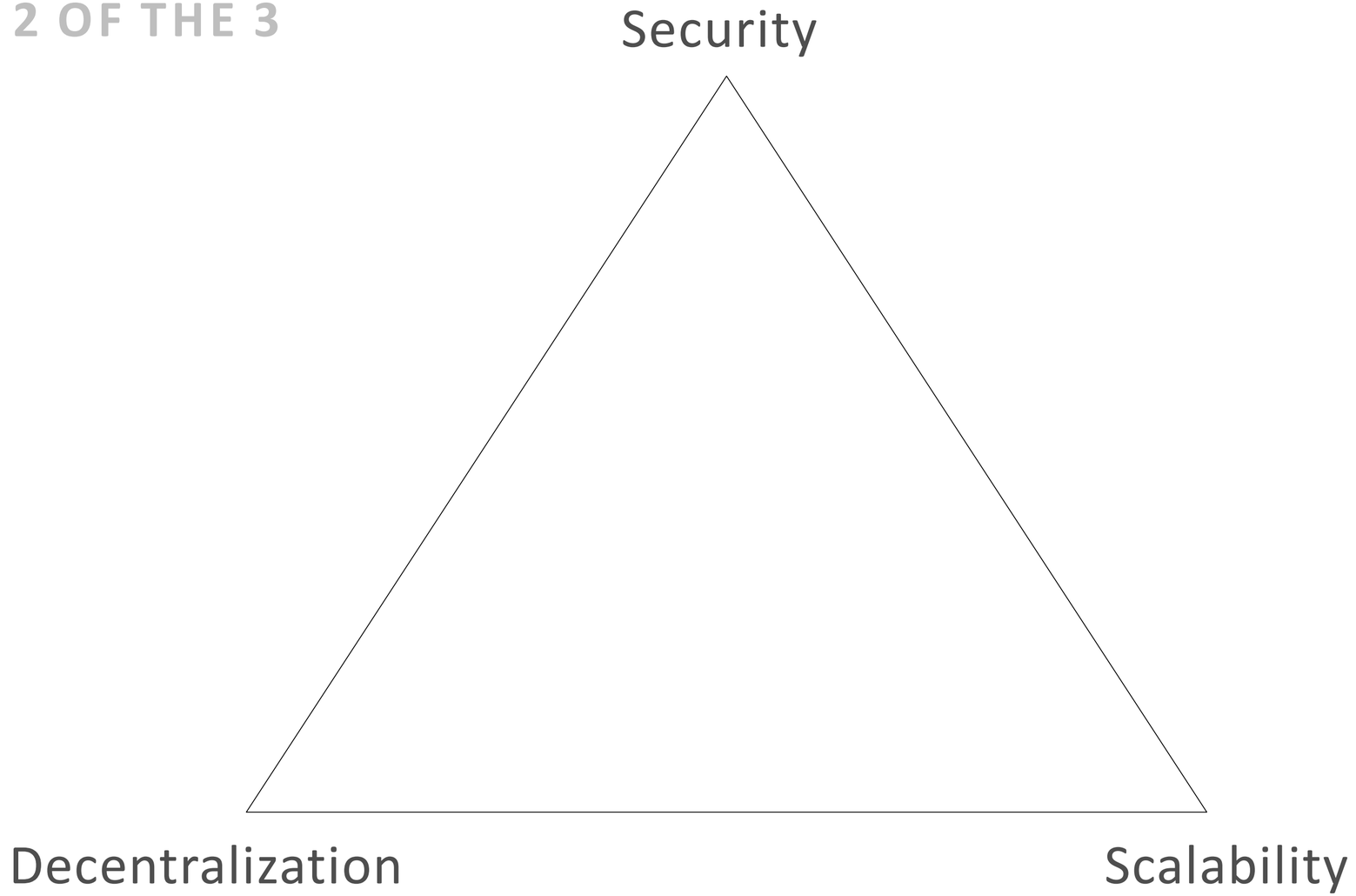
ANOTHER CONSIDERATION

- Size of the blockchain
  - Make it easier for nodes to store in the future
  - Easier to join the network (casually)
  - Currently ~180GB (Late August 2018)

Source: https://www.youtube.com/watch?v=arG9WD0Lsu4

SCALABILITY TRILEMMA

PICK 2 OF THE 3



TRANSACTION SIZE

BLOCKCHAIN FUNDAMENTALS

Statistics

	Transaction Size
Observations	500
Mean	546.38
Median	530.94
Mode	391.77
Std. Dev.	69.58

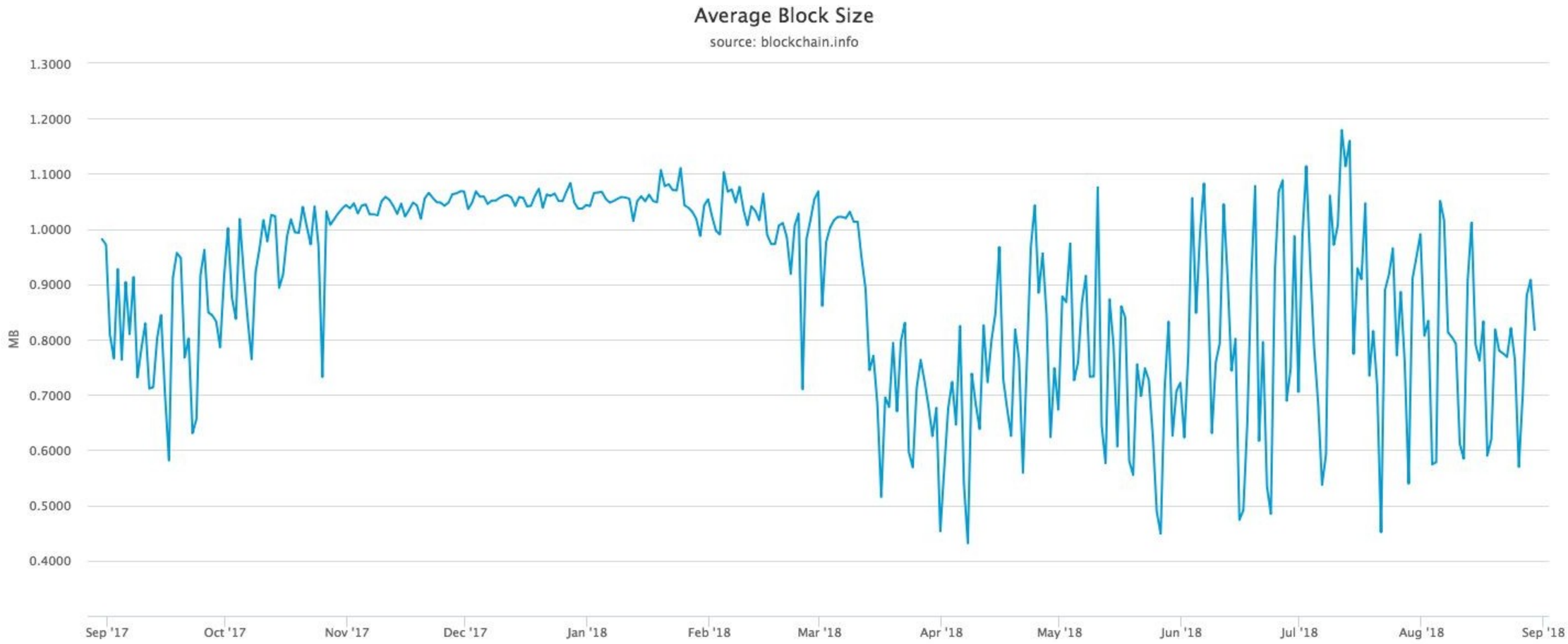
500

546.38

530.94

MAX TRANSACTIONS PERSECOND

BLOCKCHAIN FUNDAMENTALS



MAX TRANSACTIONS PERSECOND

BLOCKCHAIN FUNDAMENTALS

From previous slide:

- Average of 546 bytes per transaction.
- Current blocksize is 1MiB.
- Expected time to next block is 10 min.

Therefore we can compute the sustained maximum transaction volume in tps:

$$\frac{1\ MiB}{1\ block} \times \frac{1\ txn}{546\ bytes} \times \frac{1\ block}{10\ min} \approx 3.2\ tps$$

TPS COMPARISONS

BITCOIN VS MODERN PAYMENTS

How does Bitcoin compare with other traditional payment systems?

	Average	High Load / Maximum
Bitcoin	3 tps	3.2 tps
PayPal*,**	150 tps	450 tps
VISA***	2,000 tps	56,000 tps

*https://investor.paypal-corp.com/secfiling.cfm?filingID=1206774-16-5430&CIK=1633917
**http://www.fool.com/investing/general/2016/02/04/5-things-paypal-holdings-inc-wants-you-to-know.aspx
***https://usa.visa.com/dam/VCOM/download/corporate/media/visa-fact-sheet-Jun2015.pdf

CURRENT SCALABILITY

BLOCKCHAIN FUNDAMENTALS

Variables we can play with to increase $\frac{\text{Transactions}}{\text{Second}}$

- Size of transactions
- Size of blocks

↑ Volume of Transactions

- Block creation rate

↓ Block Time

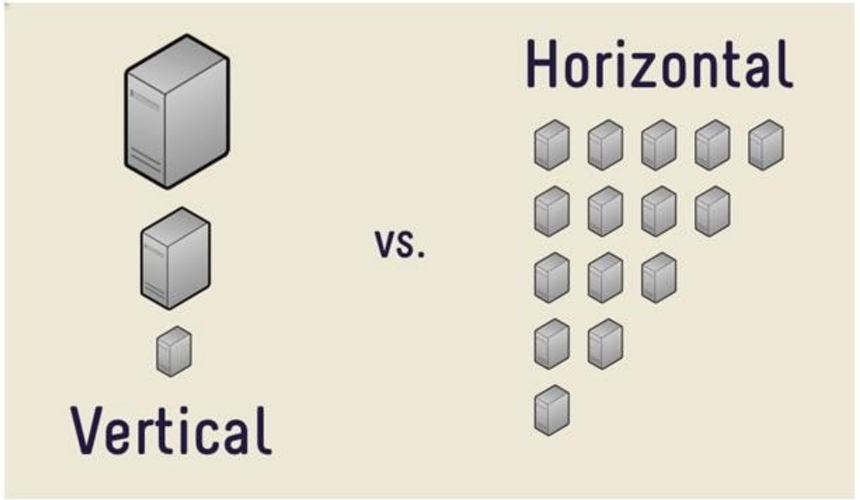
SCALING TECHNIQUES

HOW DO WE SCALE?

- **Vertical Scaling** - add more RAM/ CPU power to each existing machine

- **Horizontal Scaling** - add more machines of the same computational power

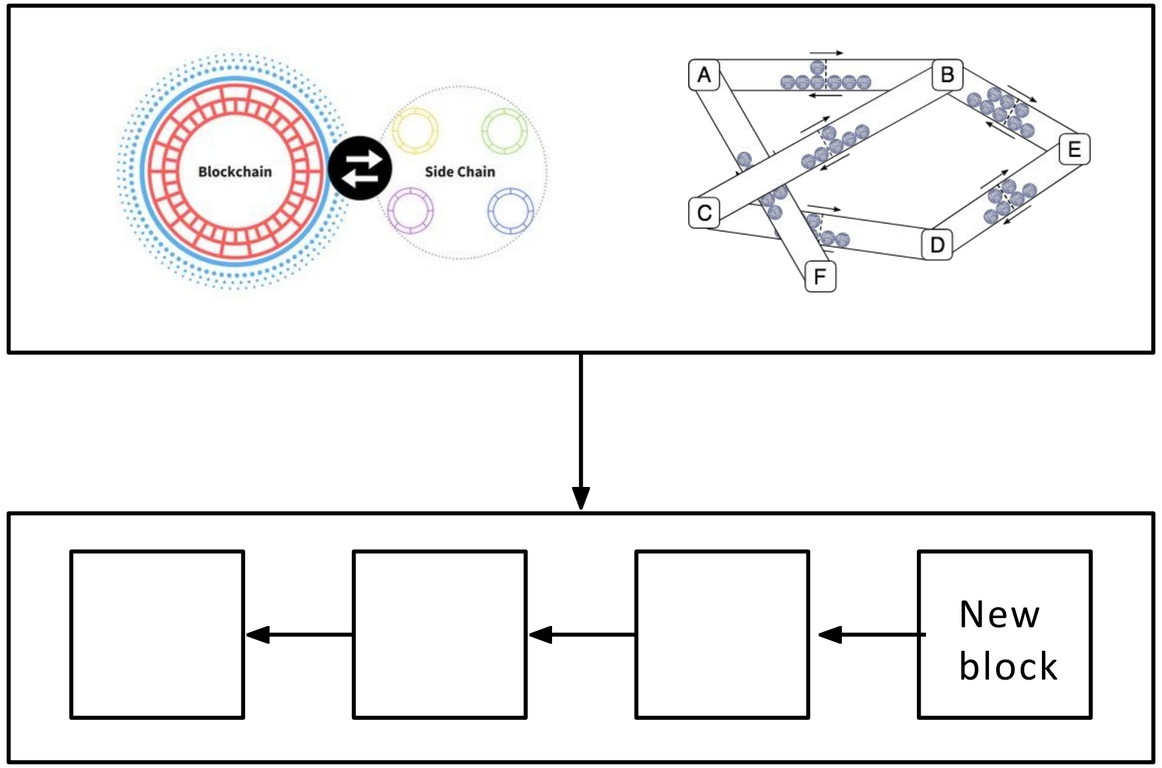
- **Diagonal Scaling** - add more powerful machines



LAYERS OF SCALING

BLOCKCHAINS HAVE LAYERS

- Layer 2 scaling refers to pushing computation off the blockchain
  - Off-chain scaling
- Layer 1 scaling refers to changing the blockchain itself
  - On-chain scaling



Sources:
https://raiden.network/101.html
https://en.bitcoinwiki.org/wiki/Sidechain

2

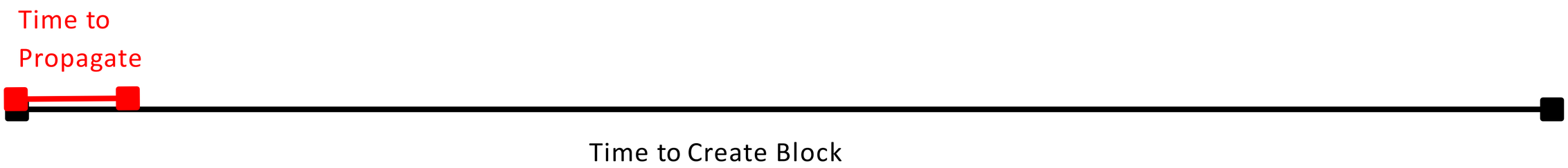
VERTICAL SCALING ON-CHAIN

2.1 NAIVE SOLUTION

NAIVE SOLUTION

IDEA

Why not increase the speed of blocks by decreasing difficulty of the PoW problem?

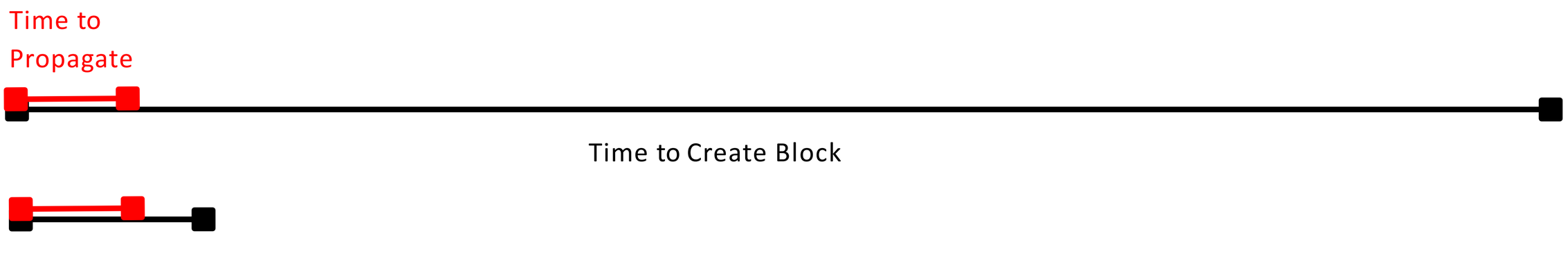


NAIVE SOLUTION

IDEA

Why not increase the speed of blocks by decreasing difficulty of the PoW problem?

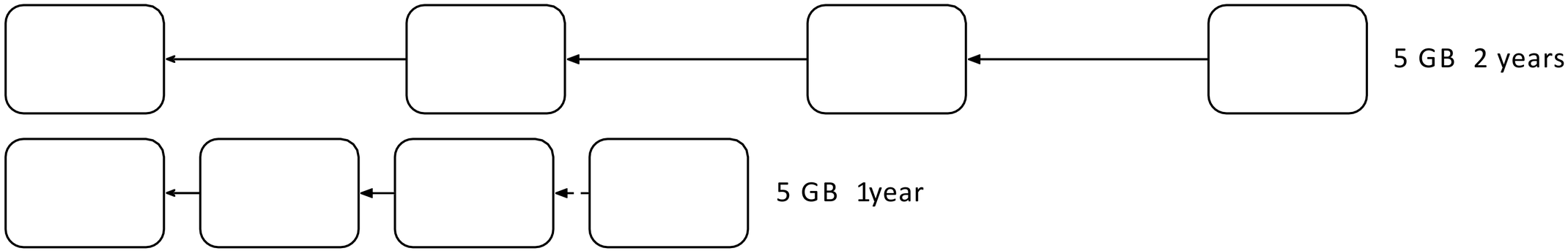
Time to broadcast block fixed while Block creation time decreases



NAIVE SOLUTION

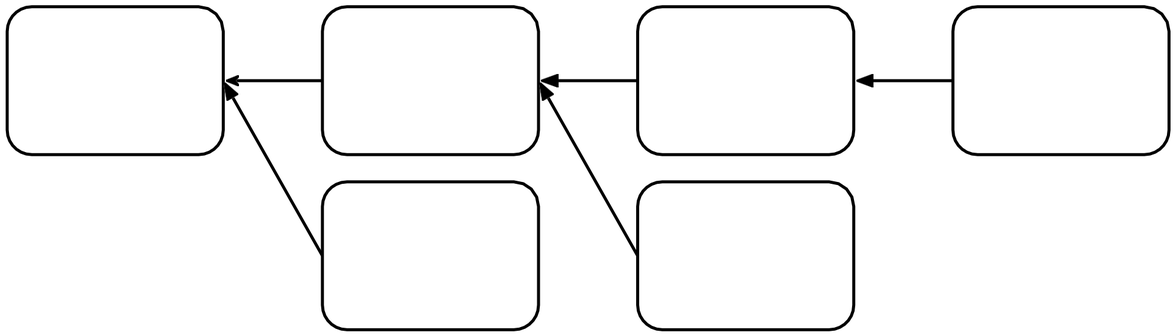
CONS: SIZE

Size matters!



NAIVE SOLUTION

CONS: NATURAL FORKS

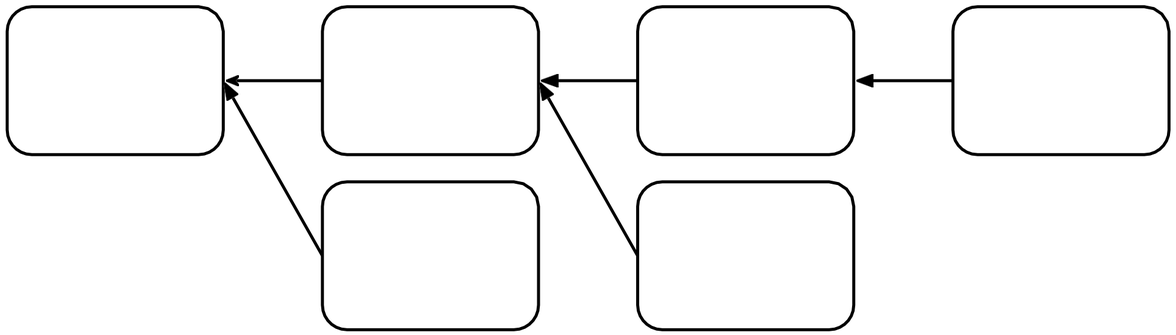


2.2

DECREASE BLOCK CREATION TIME

NAIVE SOLUTION REVISITED

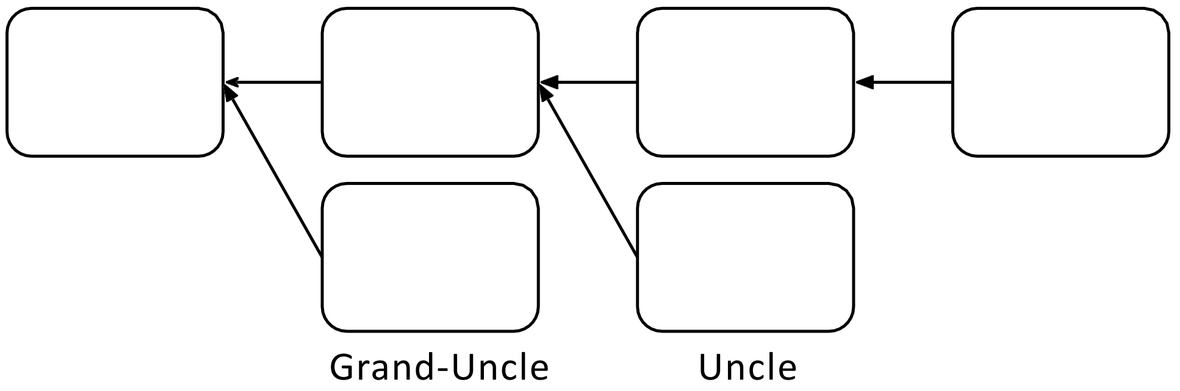
CONS: NATURAL FORKS



GHOST

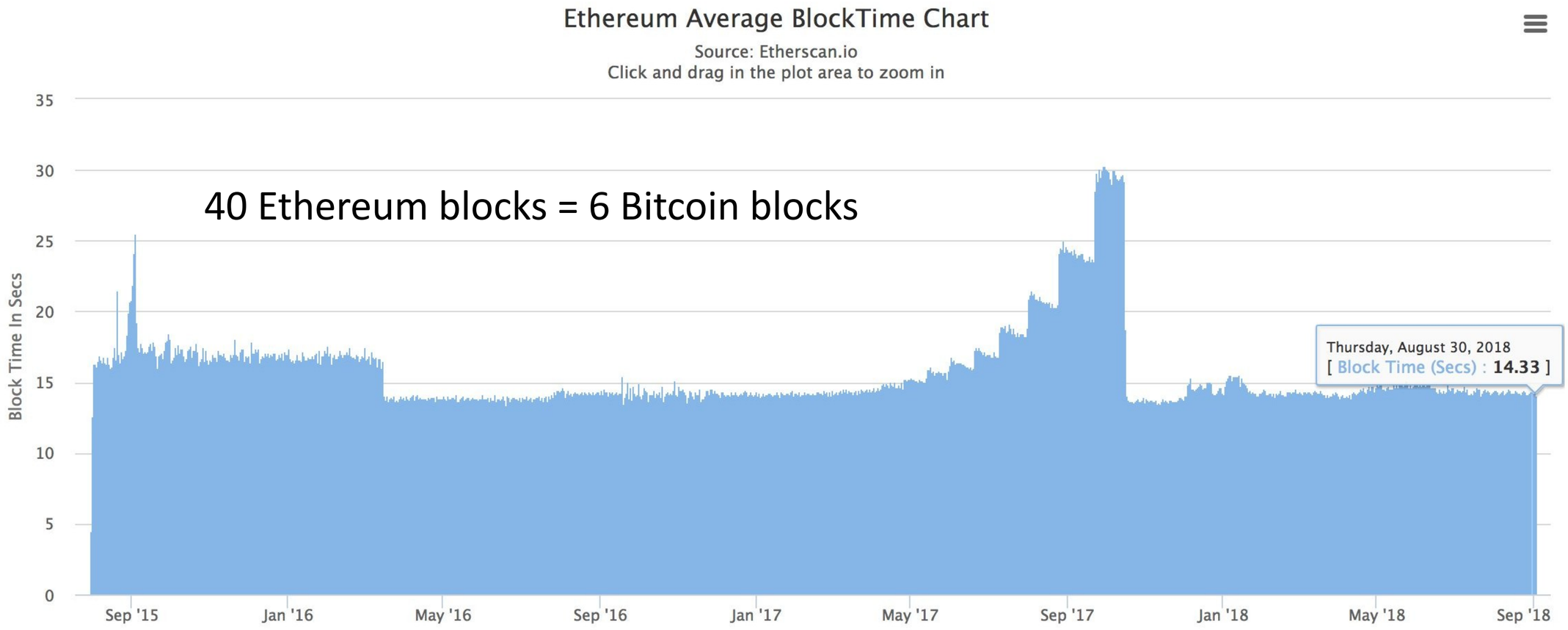
IDEA

- Increase the speed of blocks by **decreasing difficulty of the POW + weighted POW blockchain** (instead of longest)
- + Decrease Incentive for Pooled Mining!



GHOST

ETHEREUM AVERAGE BLOCK TIME



Source: https://etherscan.io/chart/blocktime

2.3

INCREASE BLOCKSIZE

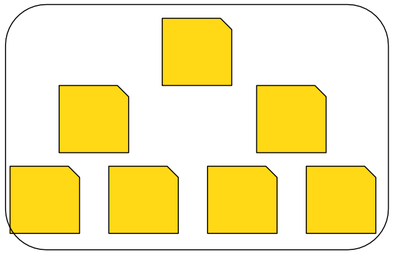
BLOCKSIZE INCREASE

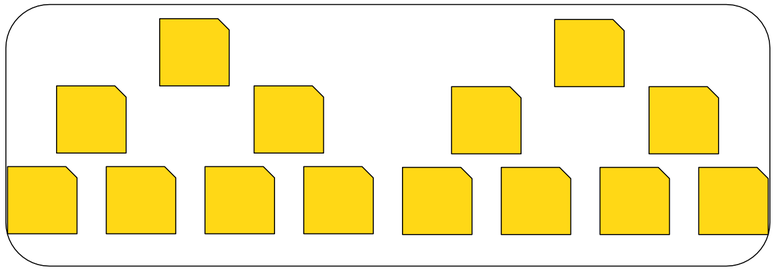
IDEA

If we just increase the blocksize, we can fit more transactions in a single block!

Pros:

- It’s an “easy” implementation. Just get miners to agree.
- Lower transaction fees for users
  - Verification of transactions on the same block



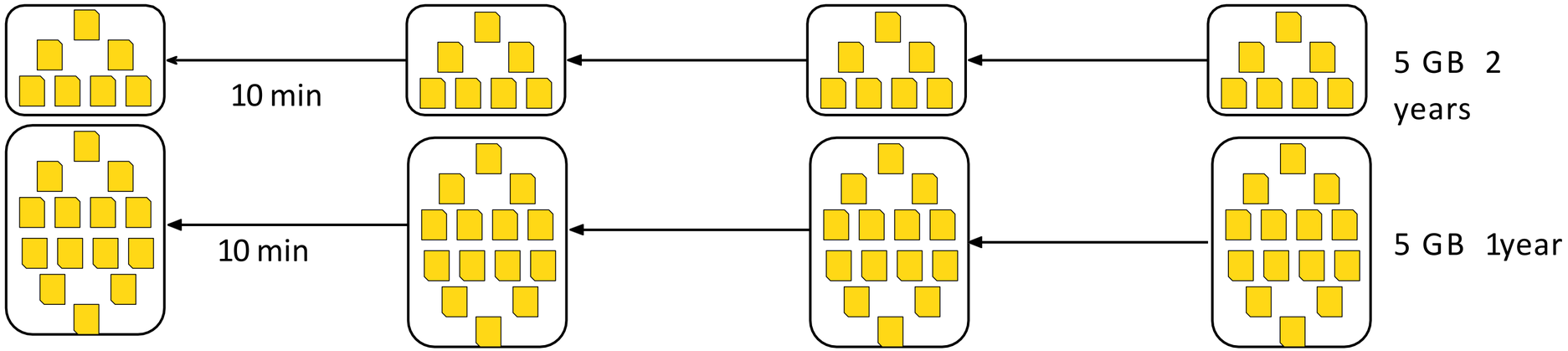


BLOCKSIZE INCREASE

CONS

- Hard fork
- Lessen transaction fees
- Size increases very fast

- One time linear capacity increase
  - Temporary Fix
- Longer Propagation Times
  - Authoring miner has better shot at next block



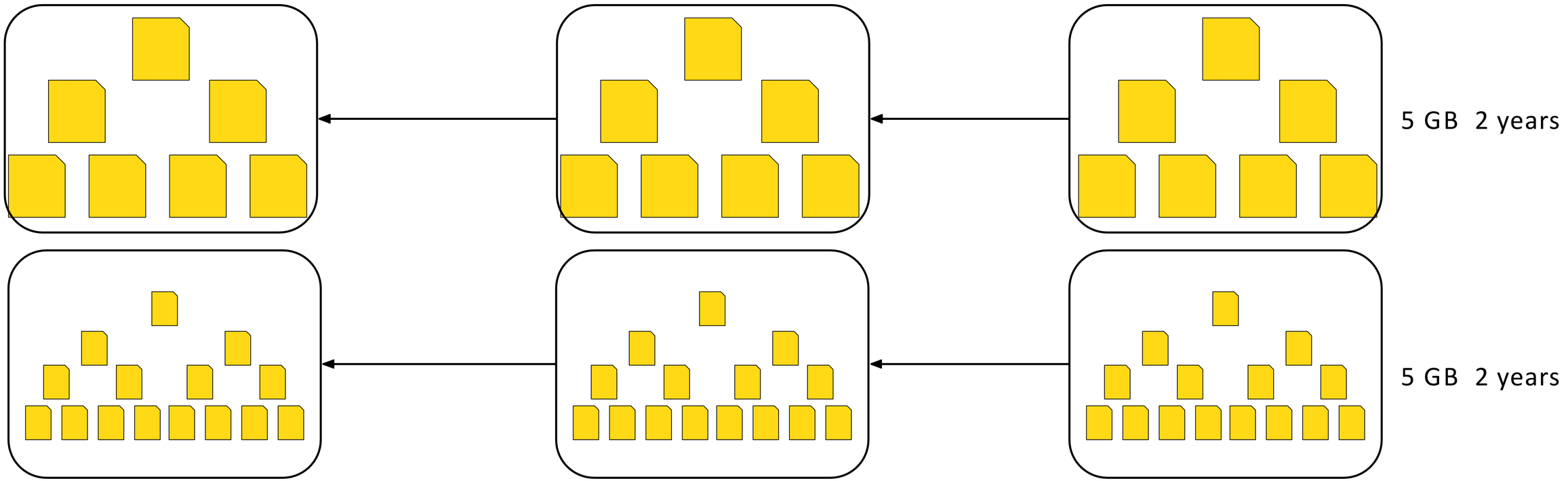
2.4

DECREASE SIZE OF TRANSACTIONS

DECREASE TRANSACTION SIZE

IDEA

- Segwit



SEGREGATED WITNESS

IDEA

Signature field takes around %50 of the space. It is used to

- Verify the transaction is valid
- Owner is legit

SEGREGATED WITNESS

AVOID HARD FORK

Segwit P2W*

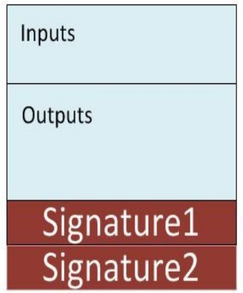
For New Nodes:

ScriptPubKey: 0 e4873ef43eac347471dd94bc899c51b395a509a5

ScriptSig: Empty

WitScript: Signature1

Result: **Valid**



Source: https://programmingblockchain.gitbooks.io/

SEGREGATED WITNESS

AVOID HARD FORK

Segwit P2W*

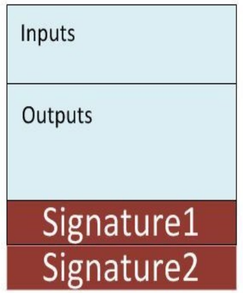
For New Nodes:

ScriptPubKey: 0 e4873ef43eac347471dd94bc899c51b395a509a5

ScriptSig: Empty

WitScript: Signature1

Result: **Valid**



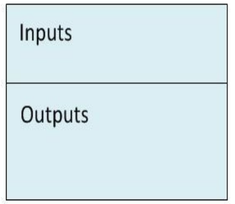
Segwit P2W*

For Old Nodes:

ScriptPubKey: 0 e4873ef43eac347471dd94bc899c51b395a509a5

ScriptSig: Empty

Result: **Valid**

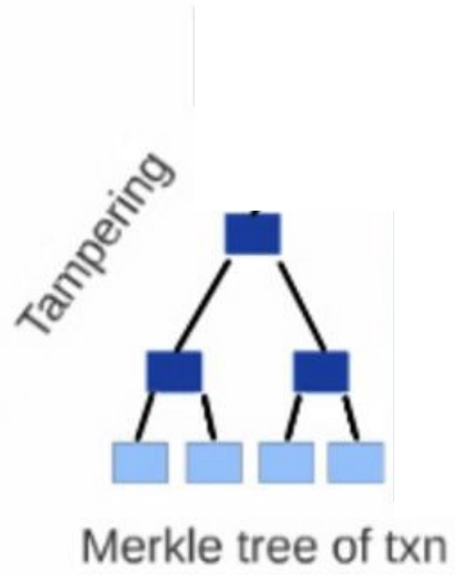


Source: https://programmingblockchain.gitbooks.io/

SEGREGATED WITNESS

MIRROR SIGNATURE TREE

But now, the blockchain doesn’t have any evidence that correct signatures were included in transactions?

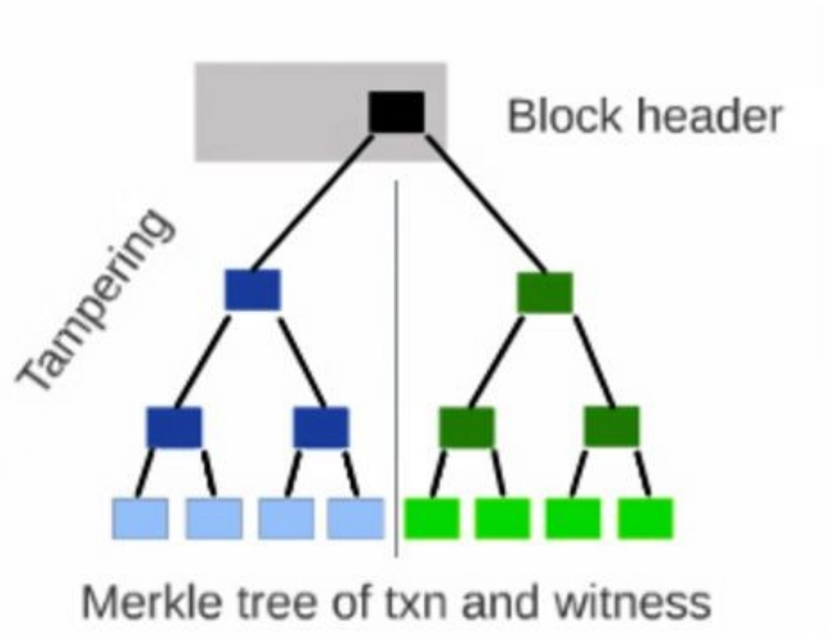


SEGREGATED WITNESS

MIRROR SIGNATURE TREE

But now, the blockchain doesn't have any evidence that correct signatures were included in transactions.

- A SegWit miner creates a Merkle tree out of segregated witnesses that mirrors the transaction tree
- This tree's merkel root is included in the input field of the coinbase transaction.
- This changes the transaction ID of the coinbase transaction
- Therefore signatures influence the block header and, ultimately, the makeup of the blockchain.



SEGREGATED WITNESS

PROS AND CONS

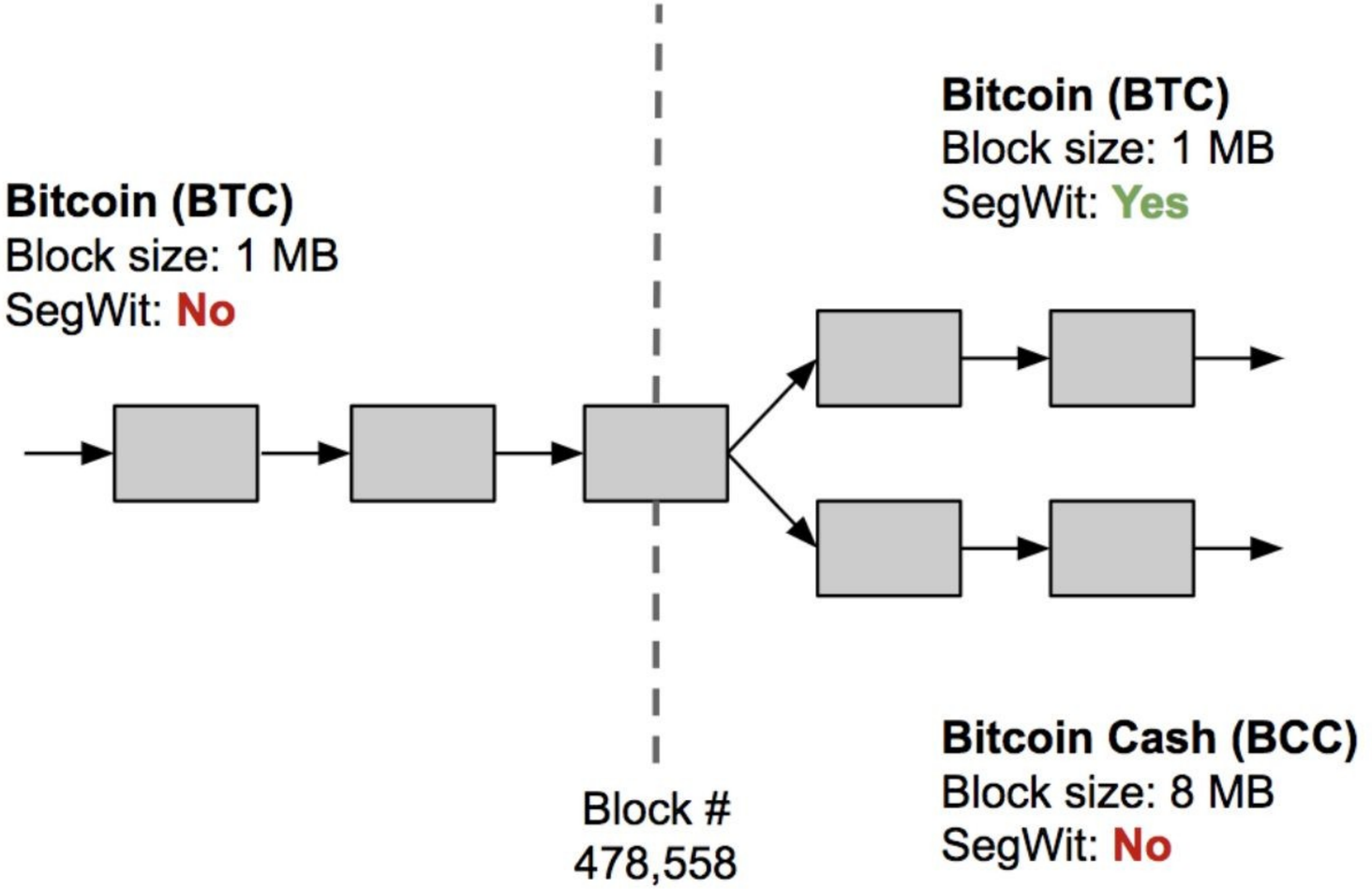
Pros:

- Fixes Transaction Malleability
  - Allows Lightning Network and sidechains to work
- Only soft fork
- No slippery slope
- Efficiency Gains
- Smaller Size of Blockchain

Cons:

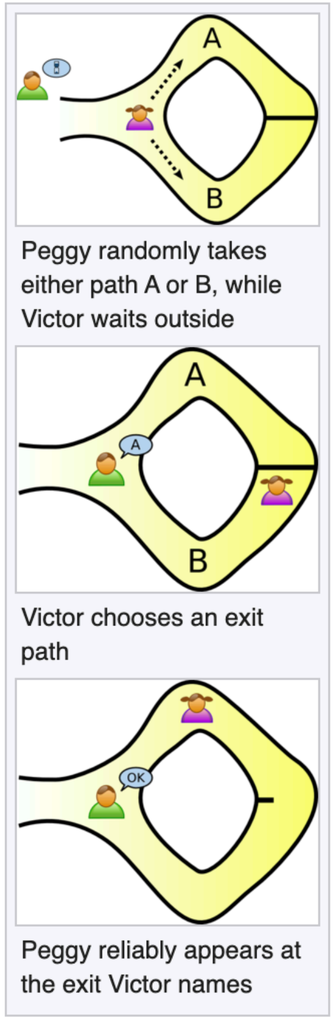
- One time linear capacity increase
- Very complicated and ugly (Over 500 lines of code)
- Wallets have to incorporate it
- Other ways to solve malleability

Source: https://bitco.in/forum/threads/segregated-witness-sotf-fork-segwit-pros-and-cons.986/


Bitcoin (BTC)
Block size: 1 MB
SegWit: No
Bitcoin (BTC)
Block size: 1 MB
SegWit: Yes
Block #
478,558
Bitcoin Cash (BCC)
Block size: 8 MB
SegWit: No

Zero Knowledge Proofs

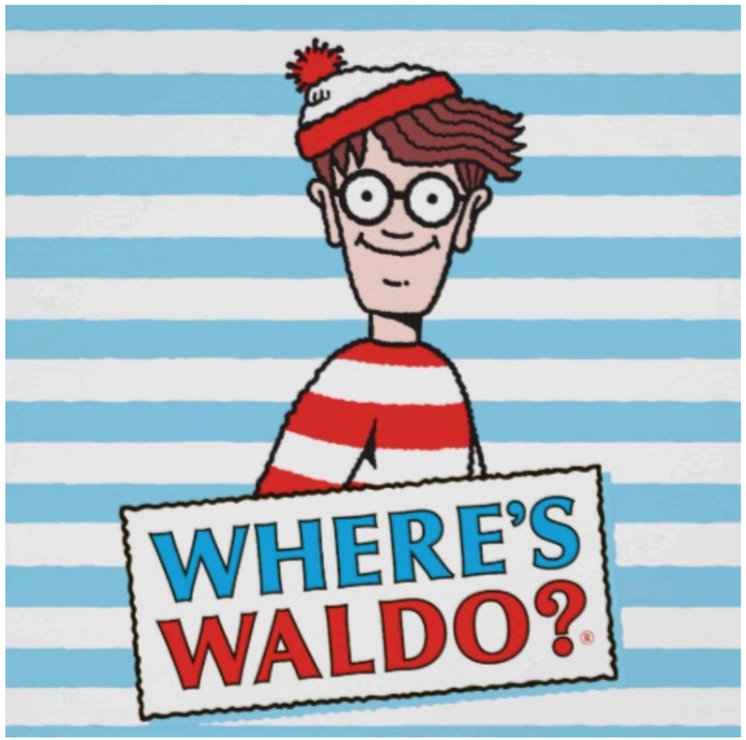
A **zero-knowledge proof** is a method by which one party (the prover) can prove to another party (the verifier) that they know a value *x*, without conveying any information apart from the fact that they know the value *x*. The essence of zero-knowledge proofs is that it is trivial to prove that one possesses knowledge of certain information by simply revealing it; the challenge is to prove such possession without revealing the information itself or any additional information.

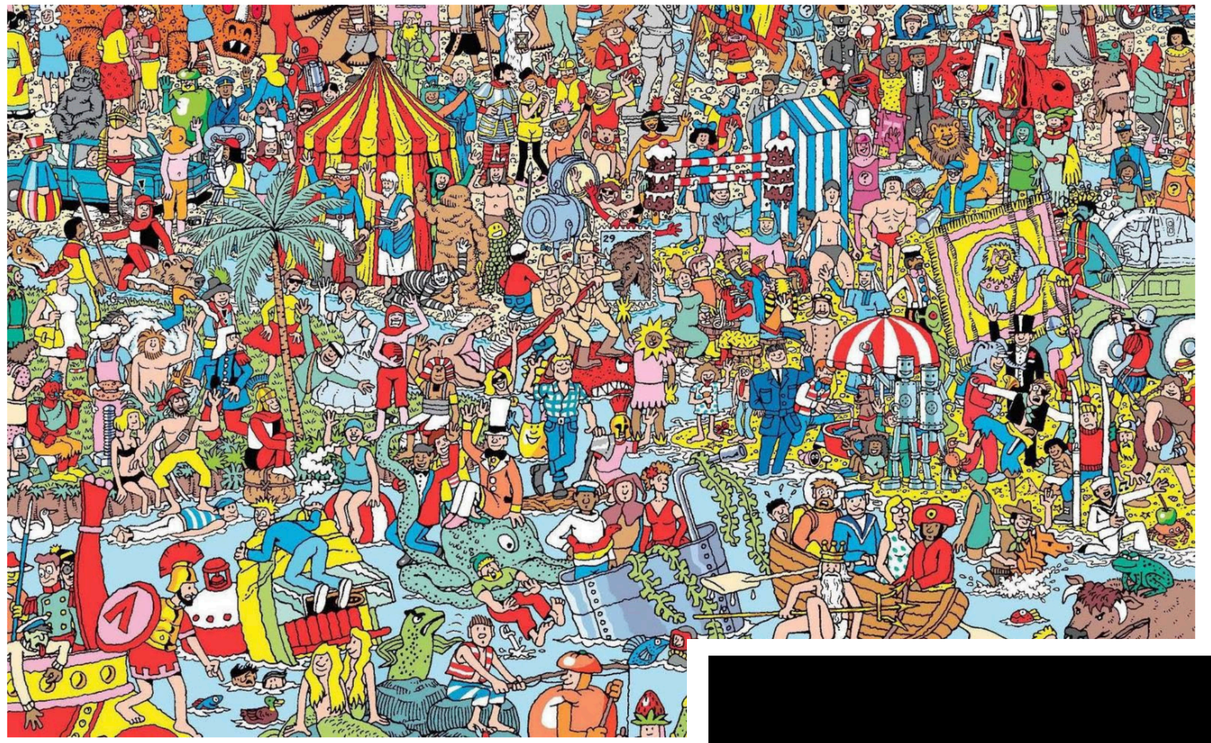


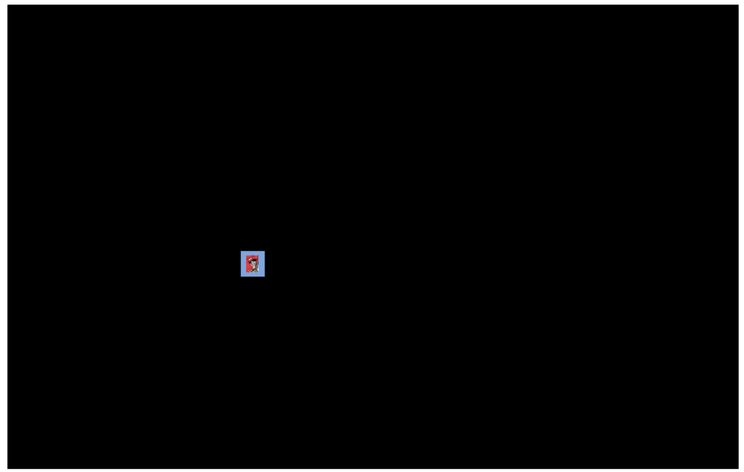
https://en.wikipedia.org/wiki/Zero-knowledge_proof

Decrease transaction size by utilizing Zero knowledge Proofs and not including the whole signature

Zero Knowledge Proofs







Here's Waldo!

3

VERTICAL SCALING OFF-CHAIN

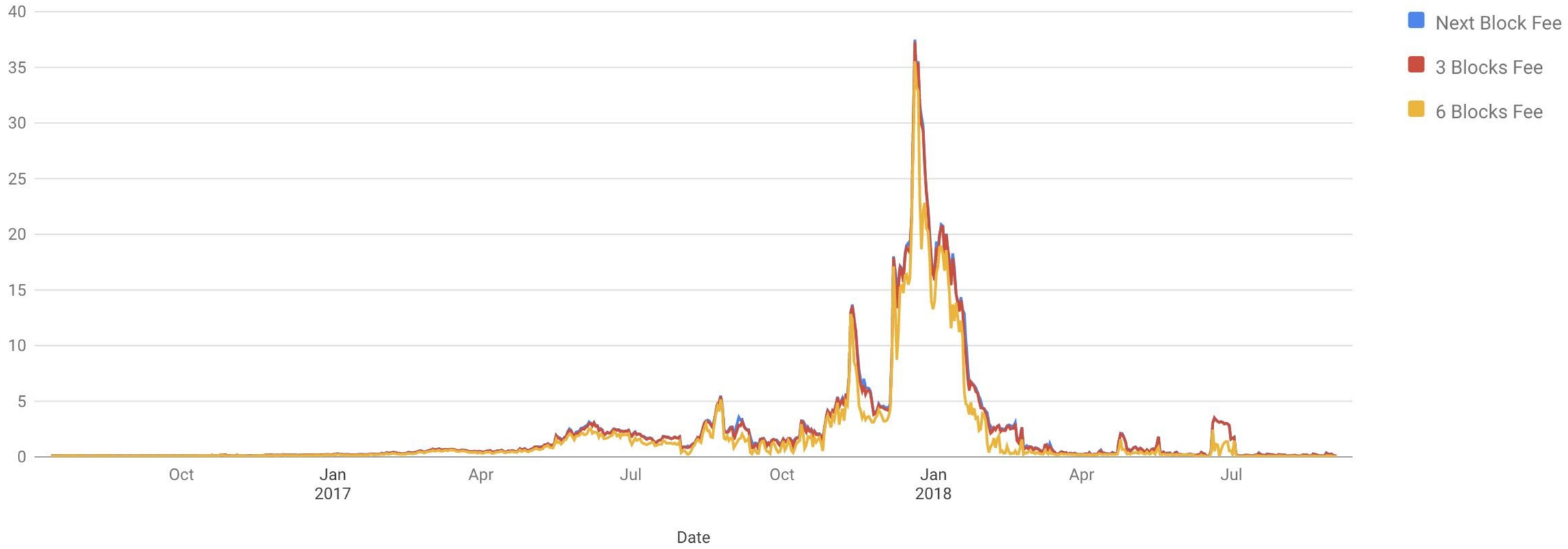
RECALL: BITCOIN TRANSACTIONS

ISSUE WITH BITCOIN PAYMENTS

- **Long delays**
  - 6 confs = about 1hour wait
- **High Fees**
  - Inconsistencies (11-2017, $6.75 avg tx fee)
  - Not economical for low-value items

RECALL: BITCOIN TRANSACTIONS

ISSUE WITH BITCOIN PAYMENTS



Source: https://bitcoinfees.info/

PAYMENT CHANNEL BUILDUP

PRIVATE CHANNELS

Idea:

- Can Alice and Bob make payments between themselves without always needing to consult the blockchain?

PAYMENT CHANNEL BUILDUP

PRIVATE CHANNELS

Idea:

- What if Alice and Bob maintain a **private balance sheet**
  - update the private balance sheet with every payment
  - only consult the blockchain when they want to settle the balance

Alice and Bob's Balance Sheet	
Alice	Bob
10 BTC	5 BTC

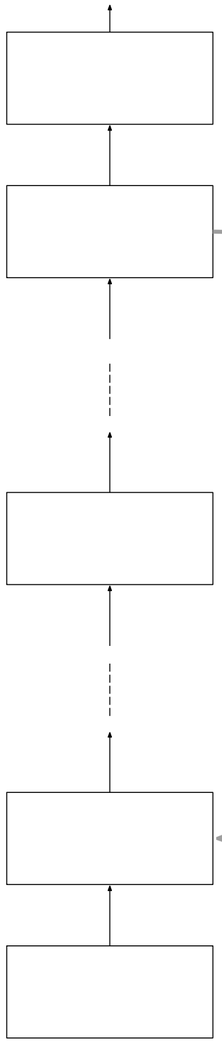
Alice pays Bob 2 BTC

Alice and Bob's Balance Sheet	
Alice	Bob
8 BTC	7 BTC

PAYMENT CHANNEL BUILDUP

PRIVATE CHANNELS

Alice and Bob only make a transaction on the blockchain when they want to settle their private balances.



Alice and Bob open a private balance sheet

Alice and Bob's Balance Sheet	
Alice	Bob
10 BTC	0 BTC

Alice and Bob make several private txns.

Alice and Bob's Balance Sheet	
Alice	Bob
3 BTC	7 BTC

Alice and Bob later close the balance sheet

PAYMENT CHANNEL BUILDUP

IDEA

- Use Bitcoin script to create blockchain-enforceable contracts between Alice and Bob so that neither party can cheat the other, while maintaining the private balance sheet functionality!
- In blockchain land, we call these **payment channels**.
- Payment channel's full name: *Payment Channel with Hash TimeLock Contract (HTLC)*

PAYMENT CHANNEL PAYMENTS

BLOCKCHAIN FUNDAMENTALS

State 0: Total 10 BTC	What Bob needs to claim 1st (on chain)	What Alice needs to claim 1st (on chain)
Alice: 10 BTC	Alice Sig	Bob Sig + Alice Secret 1 or Alice Sig + 1000 blocks
Bob: 0 BTC	Alice Sig + Bob Secret 1 or Bob Sig + 1000 blocks	Bob Sig

PAYMENT CHANNEL PAYMENTS

BLOCKCHAIN FUNDAMENTALS

State 0: Total 10 BTC	What Bob needs to claim 1st (on chain)	What Alice needs to claim 1st (on chain)
Alice: 10 BTC	Alice Sig	Bob Sig + 32874494 **or** Alice Sig + 1000 blocks
Bob: 0 BTC	Alice Sig + 1273394 **or** Bob Sig + 1000 blocks	Bob Sig

State 1: Total 10 BTC	What Bob needs to claim 1st (on chain)	What Alice needs to claim 1st (on chain)
Alice: 7 BTC	Alice Sig	Bob Sig + Alice Secret 2 **or** Alice Sig + 1000 blocks
Bob: 3 BTC	Alice Sig + Bob Secret 2 **or** Bob Sig + 1000 blocks	Bob Sig

Alice sends 3 BTC to Bob!

PAYMENT CHANNEL CONCLUSIONS

GOALS REACHED

Observation:

- If either Alice or Bob cheat
  - can always override and take all the money in the deposit.
- If Alice and Bob always cooperate
  - never have to touch the blockchain, except when creating the payment channel and settling the balance.
- Only two transactions on the blockchain
  - Supports arbitrary number of local transactions between Alice and Bob.

PAYMENT CHANNEL CONCLUSIONS

ISSUES

Issue:

- Alice and Bob need to have capital locked up in this HTLC (Hash Time-Lock Contract) before they can send money between each other.

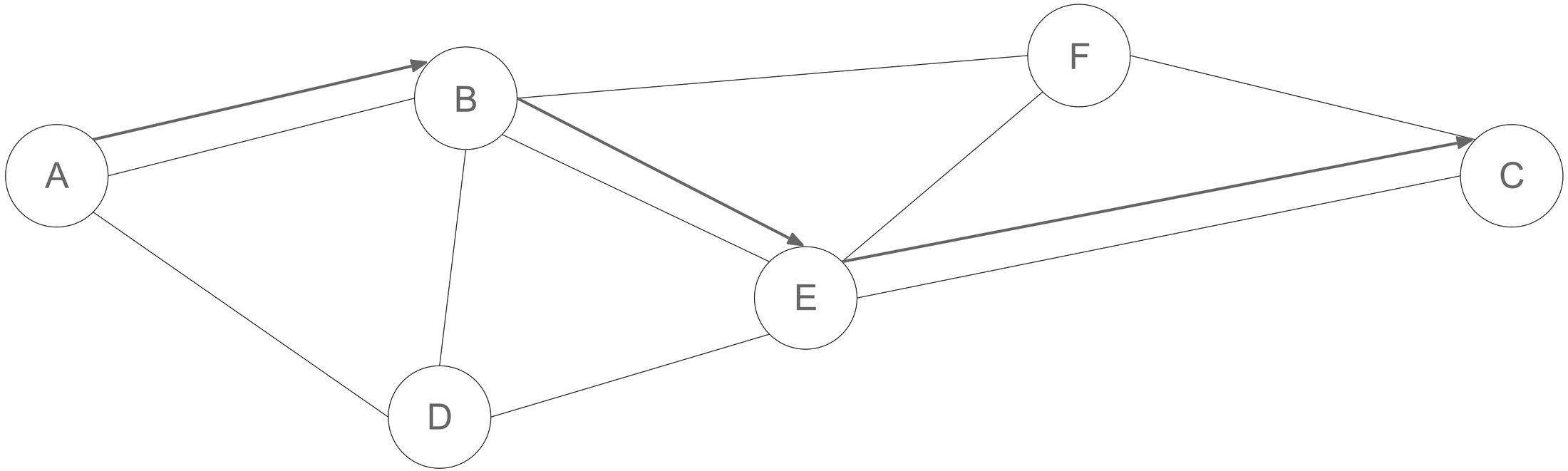
Issue:

- With this payment channel, Alice and Bob can only easily and scalably send money between themselves.

LIGHTNING NETWORK

BLOCKCHAIN FUNDAMENTALS

- Alice sends money to Charlie through this hypothetical payment channel network



LIGHTNING NETWORK

BLOCKCHAIN FUNDAMENTALS

Can we do this securely?

- With some small additions on top of our HTLC construction, we can trustlessly send money across a network of HTLCs!

The Bitcoin Lightning Network: Scalable Off-Chain Instant Payments

- By Joseph Poon & Thaddeus Dryja

https://lightning.network/lightning-network-paper.pdf

LIGHTNING NETWORK SCALABILITY

BLOCKCHAIN FUNDAMENTALS

What does the Lightning Network mean for scalability?

1. If we assume that there is enough capital in this payment channel network, *people can make payments instantly*.
   a. don't need to wait for confirmation times
   b. transactions as fast as communication delay across network.
2. Only use the Bitcoin blockchain as an arbiter to settle disputes and close out payment channels
   a. far fewer (expensive) transactions on the Blockchain.

LIGHTNING NETWORK SCALABILITY

What does the Lightning Network mean for scalability?

3. Instead of 3 tps, the Bitcoin network can support 10,000's+ of tps
   a. delegate payments to simple bookkeeping in each payment channel
   b. kept off-chain 99% of the time!
4. Sending packets across the internet is very cheap and fast.
   a. Lightning Network transaction fees will be several orders of magnitude cheaper.
   b. Only pay expensive fees on channel open /close.

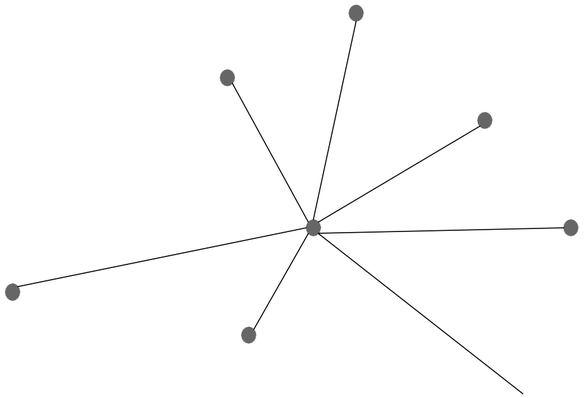
LIGHTNING NETWORK SCALABILITY

BLOCKCHAIN FUNDAMENTALS

Issues with Lightning Network:

1. Nodes need to keep very large amounts of capital locked up in payment channels.
    a. problematic if most payments in only one direction
2. **Strong centralization force**, since only nodes with significant capital can afford to hold payment channels for long.
    a. Larger payment channels get settled less often, less fees
3. **Less capital is required with less nodes** on the network
    a. ⇒ tendency towards *hub-and-spoke network topology*.

Hub-and-Spoke Topology



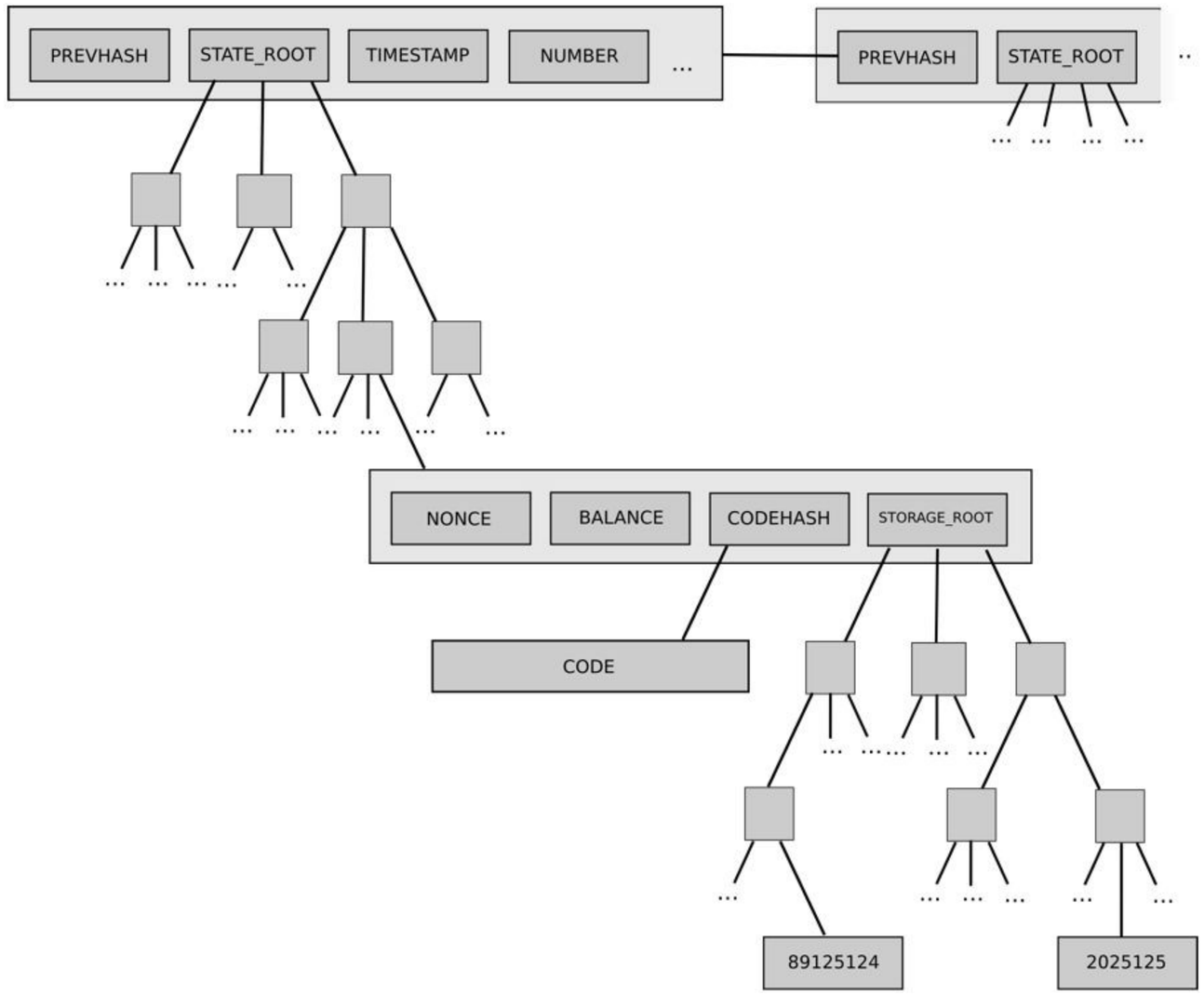
4

HORIZONTAL SCALING

SHARDING

IDEA

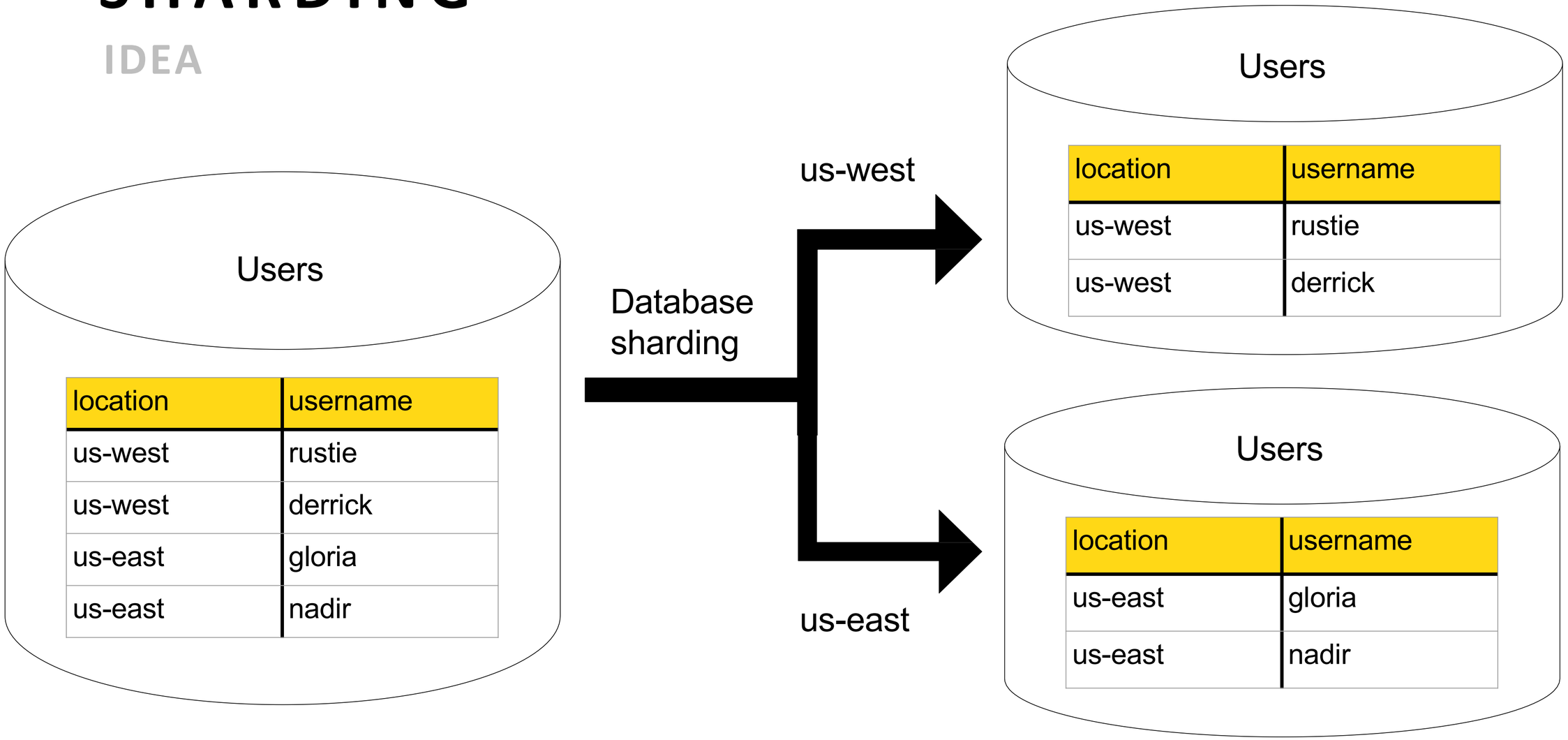
Sharding is the idea of not requiring every miner to be working on every single block, essentially creating parallel but connected blockchains.



Source: https://github.com/ethereum/wiki/wiki/Sharding-FAQs

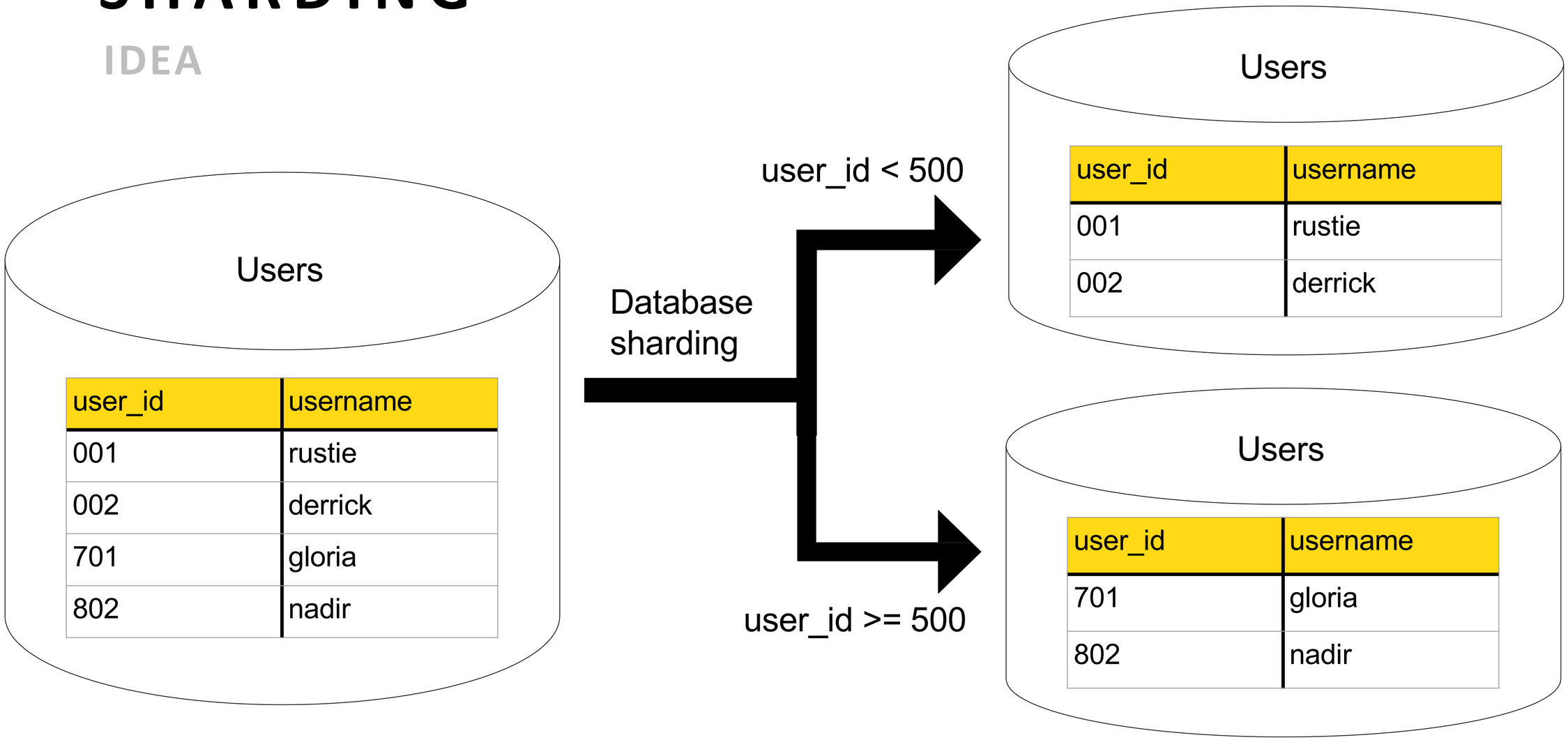
SHARDING

IDEA



SHARDING

IDEA



SHARDING

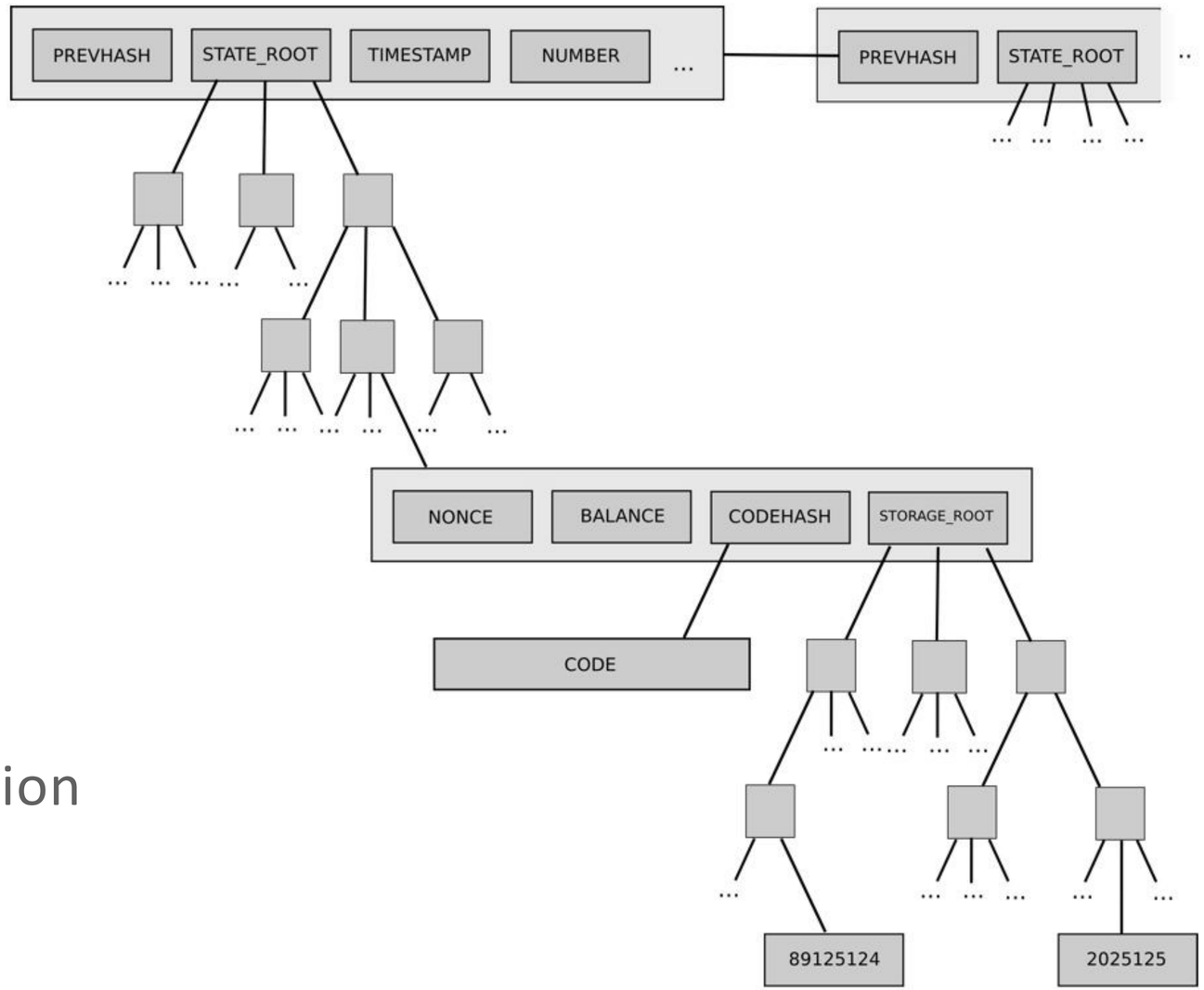
IDEA

Node categories:

- super-full node
- top-level node
- single-shard node
- light node

Some challenges:

- Cross-shard communication
- Single-shard takeover



Source: https://github.com/ethereum/wiki/wiki/Sharding-FAQs

SIDECHAINS

BITCOIN SIDECHAINS

Idea: If you can't speed up the bitcoin blockchain, why not create multiple blockchains with approx. 10 minute block times?

One could move their bitcoin over to a faster, less-secure blockchain for purchasing their morning coffee.

Pros:

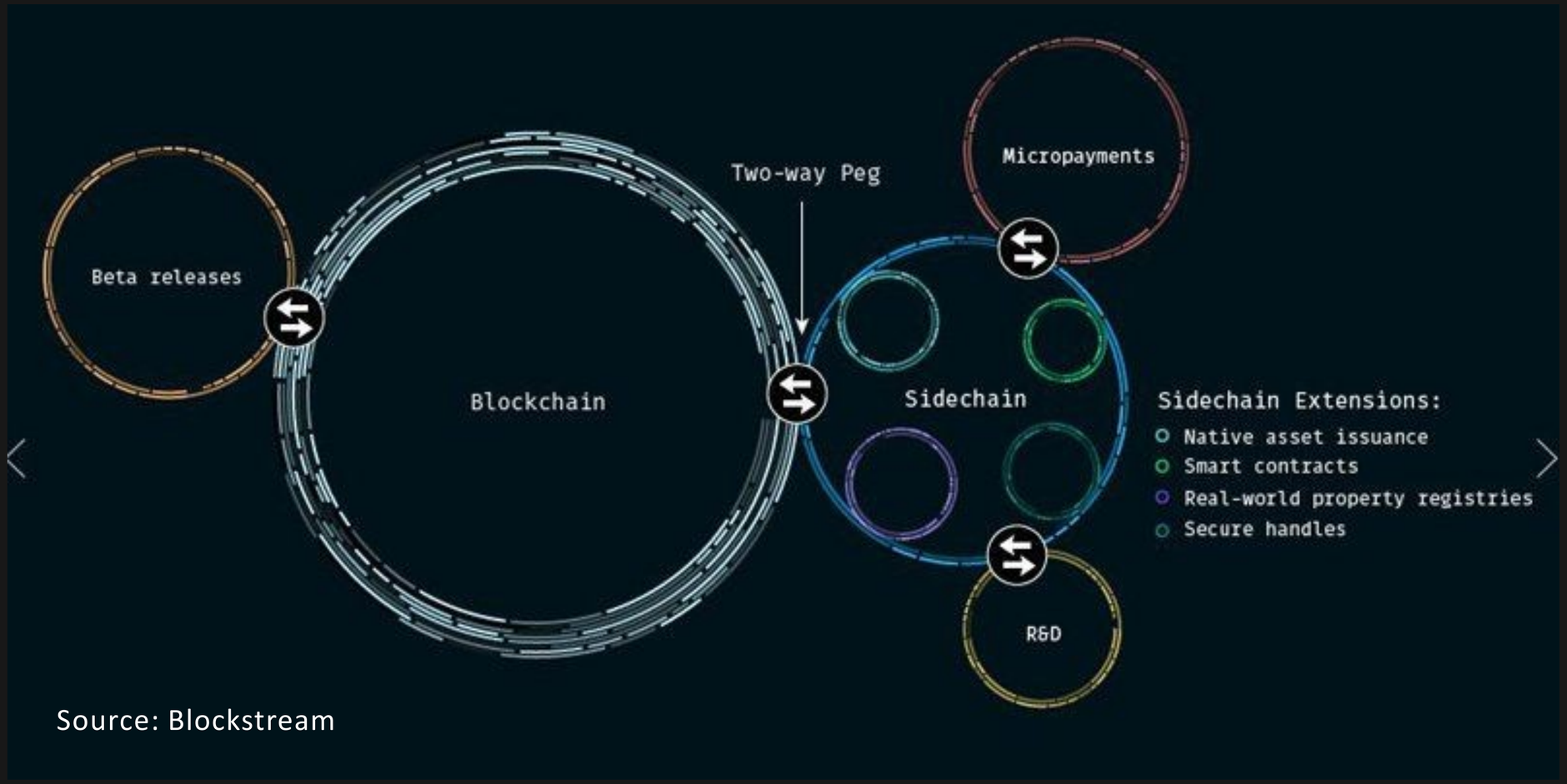
Less things on bitcoin blockchain, but can still be pegged to it.

Cons:

Loses security as hashing power is spread over multiple chains.

SIDECHAINS

BLOCKCHAIN FUNDAMENTALS



Source: Blockstream

SCALABILITY SUMMARY

BLOCKCHAIN FUNDAMENTALS

Bitcoin and other similar Blockchains have an inherent scalability issue:

- If they want to be used on a global scale, they need to support global transaction volumes.
- Can we solve this issue without compromising Bitcoin’s original vision of secure, decentralized, trustless payments?

SCALABILITY SUMMARY

BLOCKCHAIN FUNDAMENTALS

1. **Blocksize Capacity Increase**
   a. Small scalability boost with larger blocks.
   b. Centralization risk as minimum server requirements for nodes increases.
2. **Segregated Witness (SegWit)**
   a. Small scalability boost since blocks don’t need to store signatures.
3. **Sidechains**
   a. Potential for large scalability boost
   b. Potential novel sidechains with better scalability (yet to be seen in practice)
4. **Lightning Network**
   a. Large potential for orders-of-magnitude scalability boost.
   b. Significant restructuring of payment process.
   c. Centralization risk due to capital prereqs.

READINGS

What is transaction malleability?

- https://www.coindesk.com/bitcoin-bug-guide-transaction-malleability

What is the Lightning Network?

- https://www.coindesk.com/information/what-is-the-lightning-network

Zero Knowledge Proofs

- https://blog.cryptographyengineering.com/2014/11/27/zero-knowledge-proofs-illustrated-primer/

References

Slides mainly adopted from

- Blockchain @ Berkeley : https://blockchain.berkeley.edu/
- Blockchain @ Princeton : http://bitcoinbook.cs.princeton.edu/