COMP6452 Lecture 3: Blockchain in Software Architecture 1

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Outline

- What is Taxonomy?

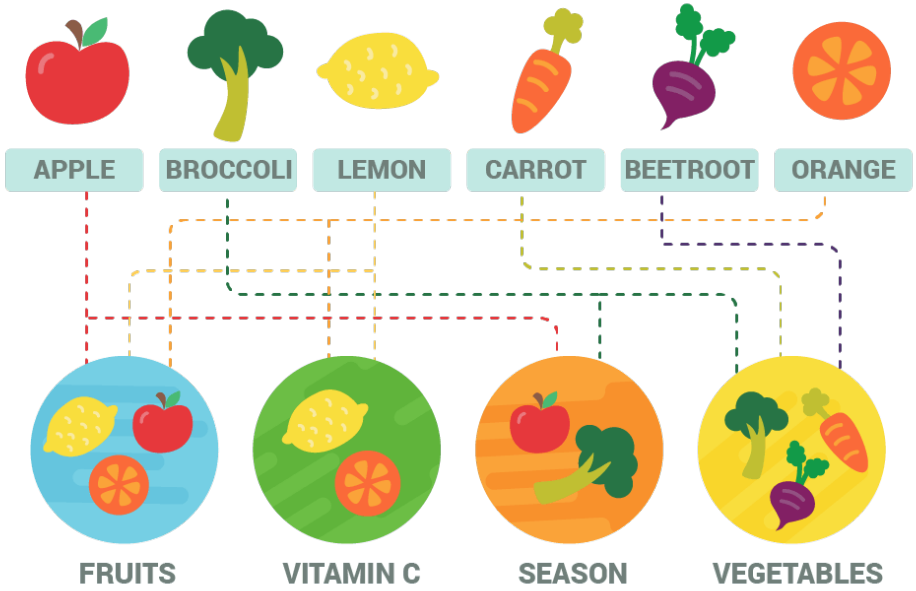
- Varieties of Blockchain − A Taxonomy
  - (De)centralization
  - Deployment
  - Ledger Structure
  - Consensus Protocol
  - Block Configuration and Data Structure
  - Auxiliary Blockchain
  - Anonymity
  - Incentive

- Summary

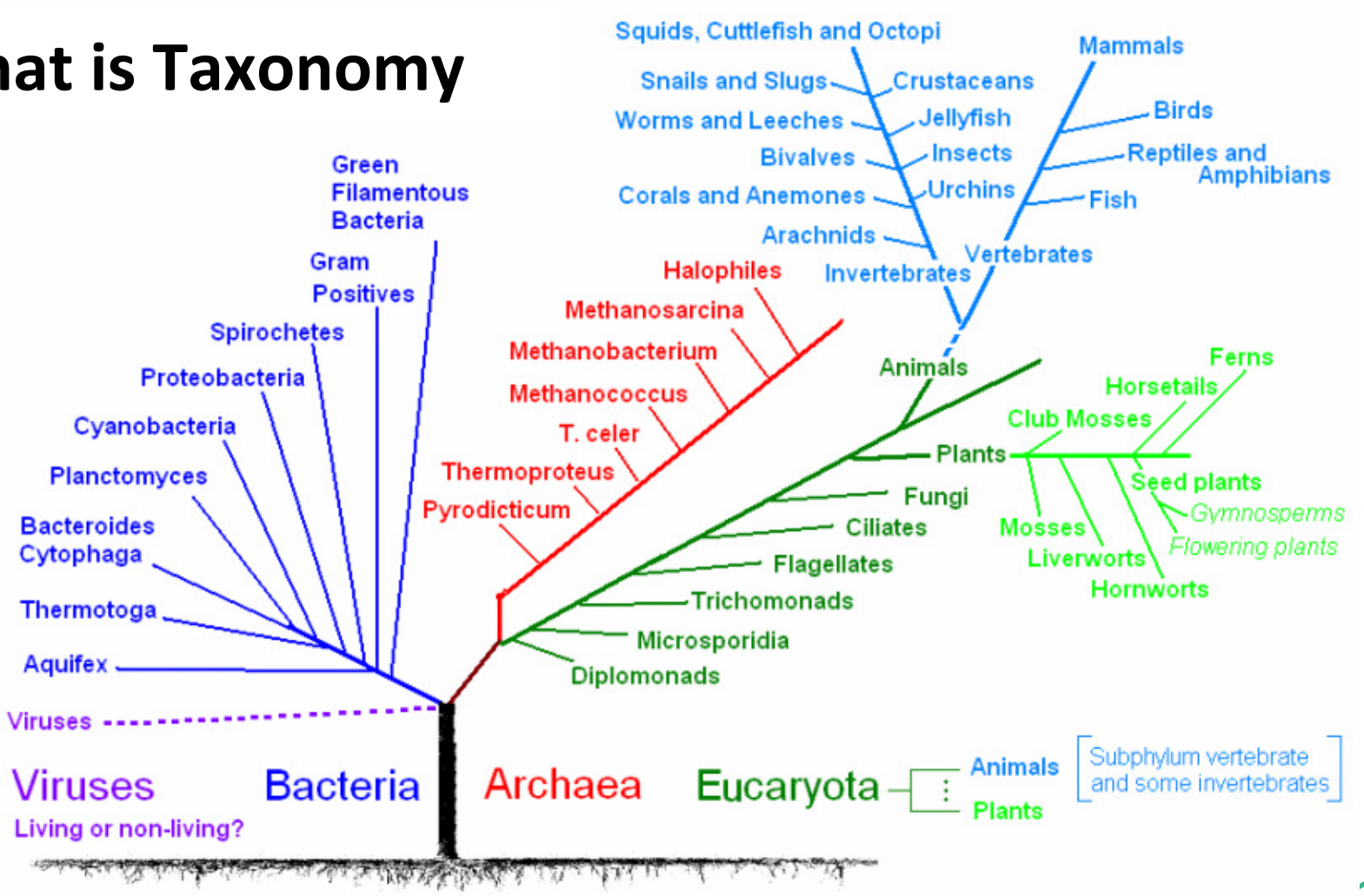
What is Taxonomy?

What is Taxonomy?

- *Taxonomy is the practice and science of classification of things or concepts, including the principles that underlie such classification*



What is Taxonomy



Why Taxonomy?

- Diverse range of blockchain has emerged since the advent of Bitcoin in 2008
  - Complex internal structure and many configurations and variants
- Comparison of different blockchain is difficult
  - Lack of product data and technology evaluation resources

- Blockchain Taxonomy
  - Dimensions and categories for classifying blockchains
  - Understanding blockchain technology

- Benefits
  - Systematically consider the features and configurations of blockchain
  - Explore the conceptual design space
  - Compare and evaluate design options
    - Assess their impact on **quality attributes**

Properties of Blockchain

- Blockchain cannot meet requirements for all usage scenarios
  - E.g. those that require real-time processing
- Fundamental Properties
  - Immutability *from committed transaction*
  - Integrity *from cryptographic tool*
  - Transparency *from public access*
  - Equal rights *from consensus*
    - Weighted by the compute power or stake owned by the miner
- Limitation
  - Data privacy
    - No privileged users
  - Scalability
    - Size of the data on blockchain
    - Transaction processing rate
    - Latency of data transmission

Taxonomy: A Glimpse 1/2

Classification

	Permission-less	Permissioned
Public	**Consensus**: Proof-of-X **Permission management** • Blockchain layer • Application layer (optional) **Incentive**: Blockchain layer	**Consensus** • Proof-of-X • PBFT, Federated consensus, Round Robin *etc.* **Permission management** • Blockchain layer • Application layer (optional) **Incentive**: • Blockchain layer • Governance around permissions
Private	**Consensus** • Proof-of-X • PBFT, Federated consensus, Round Robin *etc*. **Permission management:** • Blockchain layer • Network layer • Application layer (optional) **Incentive**: Governance around access	**Consensus** • Proof-of-X • PBFT , Federated consensus, Round Robin *etc.* **Permission management:** • Blockchain layer • Network layer • Application layer (optional) **Incentive**: Governance around access permissi

Taxonomy: A Glimpse 2/2

Quality Tradeoffs

		Permission-less		Permissioned	
Public	Immutability	+++ (#Nodes, Consensus, Topology)	Immutability	++
	Integrity	+++ (#Nodes, Consensus, Topology)	Integrity	++
	Transparency	++ (Access control)	Transparency	++
	Availability	+++ (#Nodes, Topology)	Availability	++
	Performance	+ (Consensus, latency)	Performance	++
	Cost Efficiency	+	Cost Efficiency	++
Private	Immutability	+	Immutability	+
	Integrity	+	Integrity	+
	Transparency	+	Transparency	+
	Availability	+	Availability	+
	Performance	+++	Performance	+++
	Cost Efficiency	+++	Cost Efficiency	+++

Taxonomy Dimensions

(De)centralization
Deployment
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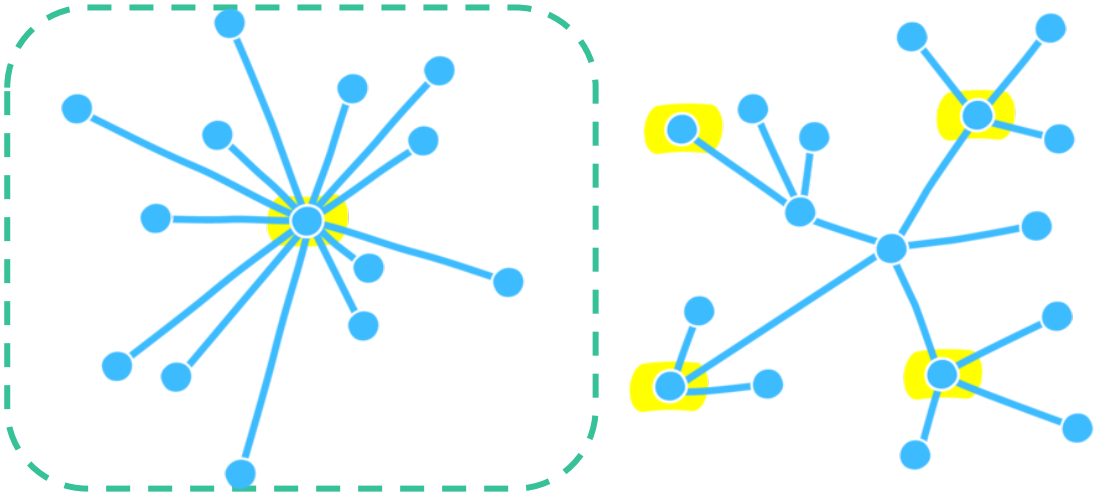
Centralization – Decentralization

Design Decision	Option	Impact			
		Fundamental properties	Cost efficiency	Performance	#Failure points
Fully Centralised	Services with a single provider (*e.g.*, governments, courts)	⊕	⊕⊕⊕	⊕⊕⊕	1
	Services with alternative providers (*e.g.*, banking, online payments, cloud services)				
Partially Centralised & Partially Decentralised	Permissioned blockchain with permissions for fine-grained operations on the transaction level (*e.g.*, permission to create assets)	⊕⊕	⊕⊕	⊕⊕	*
	Permissioned blockchain with permissioned miners (write), but permission-less normal nodes (read)				
Fully Decentralised	Permission-less blockchain bitcoin ethereum	⊕⊕⊕	⊕	⊕	Majority (nodes, power, stake)

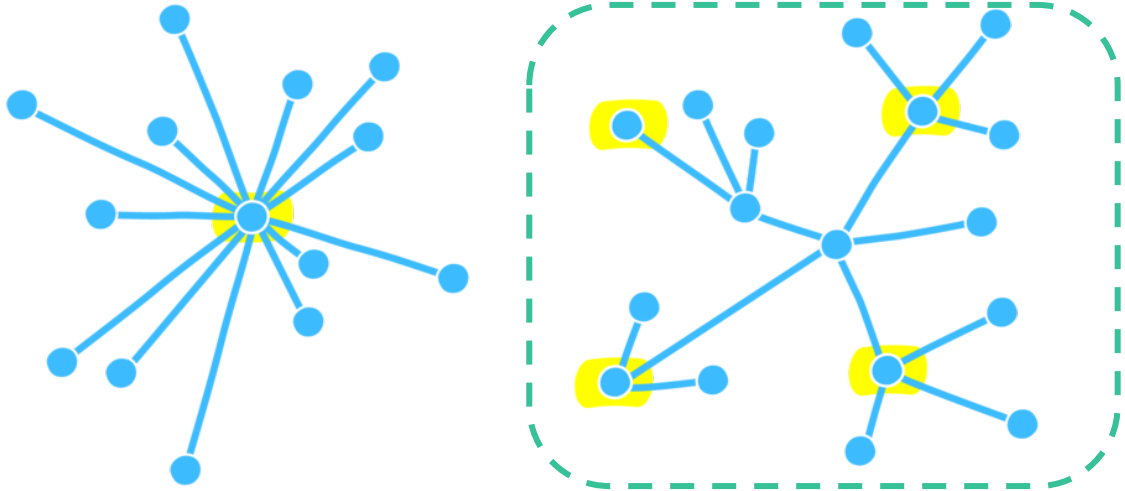
Full Centralization

- Services with a single provider
  - E.g., governments, courts, business monopolies
  - Single point of failure
- Services with alternative providers
  - E.g., banks, online payments, cloud services
  - Failure of a single service provider affects its users



Full Decentralization

- Permission-less public blockchains
- Completely open
  - New users can join, validate transaction or mine block at any time
- Protect against Sybil attack
  - Pseudonym: blockchain account represents a user
  - PoW: total amount of computational power rather than the number of nodes is important for integrity



Partial (De)centralization 1/2

- Permissioned blockchain requires authorities act as a gate for participation
  - Permission to join the network (read)
  - Permission to send transaction
  - Permission to mine (write)
- Permissioned blockchain with permissioned miners (write), and permission-less normal nodes (read)

- Permissioned blockchain with permissions for fine-grained operations
  - Permission to create assets

Partial (De)centralization 2/2

- More suitable in regulated industries
  - Banks establish the real-world identity of transacting parties
    - Know-Your-Customer (KYC) regulation
  - Transactions on permission-less blockchain
    - Across jurisdictional boundaries
    - Undermine regulatory controls

- Better control access to off-chain information about real-world assets

Tradeoffs between permissioned and permission-less blockchains

Transaction processing rate, cost, flexibility in changing the network rules, reversibility and finality

Taxonomy Dimensions

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Deployment Overview

Deployment Option	Impact			
	Fundamental properties	Cost efficiency	Performance	Flexibility
Public blockchain	⊕⊕⊕	⊕	⊕	⊕
Consortium/community blockchain	⊕⊕	⊕⊕	⊕⊕	⊕⊕
Private blockchain	⊕	⊕⊕⊕	⊕⊕⊕	⊕⊕⊕

- Public blockchain: Most cryptocurrencies
  - Anyone on the internet can access
  - Better information transparency and auditability
  - Sacrifice performance
  - Data privacy relies on encryption or cryptographic hashes
  - Different cost model (*Lecture 5*)

Deployment Overview

Deployment Option	Impact			
	Fundamental properties	Cost efficiency	Performance	Flexibility
Public blockchain	⊕⊕⊕	⊕	⊕	⊕
Consortium/community blockchain	⊕⊕	⊕⊕	⊕⊕	⊕⊕
Private blockchain	⊕	⊕⊕⊕	⊕⊕⊕	⊕⊕⊕

- Consortium/Community blockchain
  - Across multiple organizations
  - Consensus process controlled by pre-authorized nodes
  - Read permission can be public or restricted to specific participants
- Private blockchain
  - Write permission kept within one organization
  - Governed and hosted by a single organization - most flexible

Consortium/private instantiation of public blockchain
- Blockchain platform is open source
- Network layer access control – firewall

Taxonomy Dimensions

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List

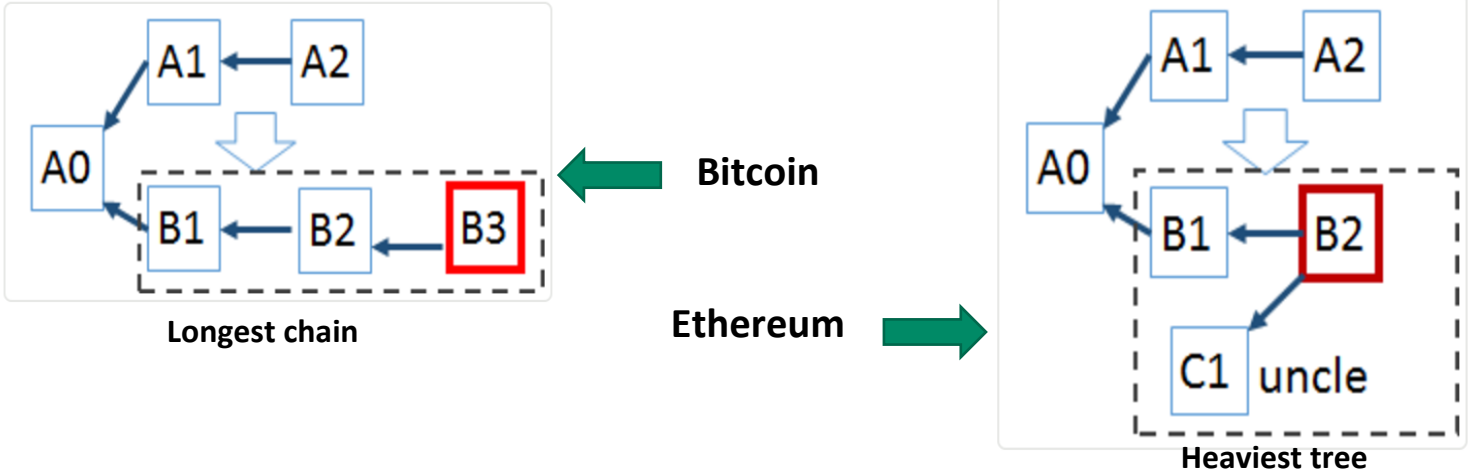
Option	Impact			
	Fundamental properties	Cost efficiency	Performance	Flexibility
Global list of blocks (Bitcoin)	⊕⊕⊕	⊕	⊕	⊕
Global DAG of blocks (Hashgraph)	⊕⊕	⊕⊕	⊕⊕	⊕⊕
Global DAG of transactions (IOTA)	⊕⊕	⊕⊕	⊕⊕	⊕⊕
Restricted shared ledgers (Corda)	⊕	⊕⊕⊕	⊕⊕⊕	⊕⊕⊕

- Global list of blocks
  - Bitcoin/Ethereum
  - Nodes record blockchain as tree of blocks
    - Shorter branches attached to the main chain represent alternative competing histories
    - Used for operating blockchain and determining consensus
  - Blockchain is a list of blocks under the logical view from a user's perspective

Tree

- Orphan/Stale
  - Two nodes find a block at same time
  - Propagated, verified, but eventually being cast off
  - Fast block time suffer from a high number of stale blocks
- Ghost (Greedy Heaviest-Observed Sub-Tree)
  - Add stale blocks (uncles) into calculation of cumulative difficulty

Bitcoin
- Block time interval: 10 minutes
- Block propagation (50% of the network): ~12 seconds



Directed Acyclic Graph (DAG)

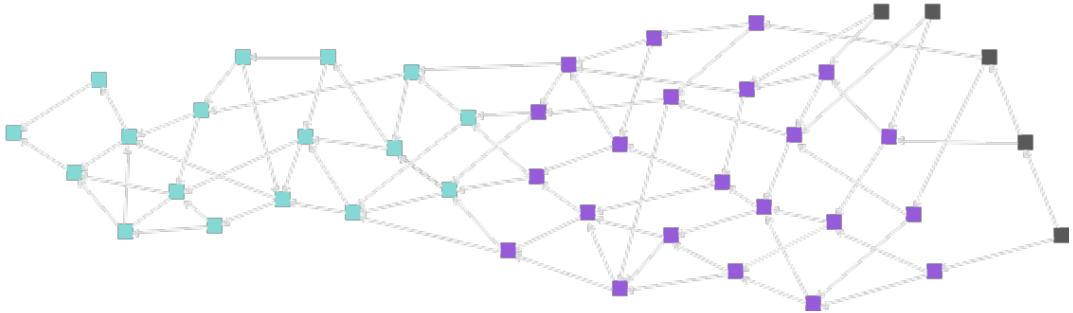
Option	Impact			
	Fundamental properties	Cost efficiency	Performance	Flexibility
Global list of blocks (Bitcoin)	⊕⊕⊕	⊕	⊕	⊕
Global DAG of blocks (Hashgraph)	⊕⊕	⊕⊕	⊕⊕	⊕⊕
Global DAG of transactions (IOTA)	⊕⊕	⊕⊕	⊕⊕	⊕⊕
Restricted shared ledgers (Corda)	⊕	⊕⊕⊕	⊕⊕⊕	⊕⊕⊕

- Global DAG of blocks
- Hashgraph
- Logical view of transactions is based on a directed acyclic graph of blocks
  - Rather than a list

Graph

Blockchain

Tangle (DAG/ Directed Acyclic Graph)



	Blockchain (Bitcoin)	IoTA
Byzantine Toleration	51%	34%
Confirmation Time	60 min (6-Confirmation)	Unstable

Tradeoff Overview

Option	Impact			
	Fundamental properties	Cost efficiency	Performance	Flexibility
Global list of blocks (Bitcoin)	⊕⊕⊕	⊕	⊕	⊕
Global DAG of blocks (Hashgraph)	⊕⊕	⊕⊕	⊕⊕	⊕⊕
Global DAG of transactions (IOTA)	⊕⊕	⊕⊕	⊕⊕	⊕⊕
Restricted shared ledgers (Corda)	⊕	⊕⊕⊕	⊕⊕⊕	⊕⊕⊕

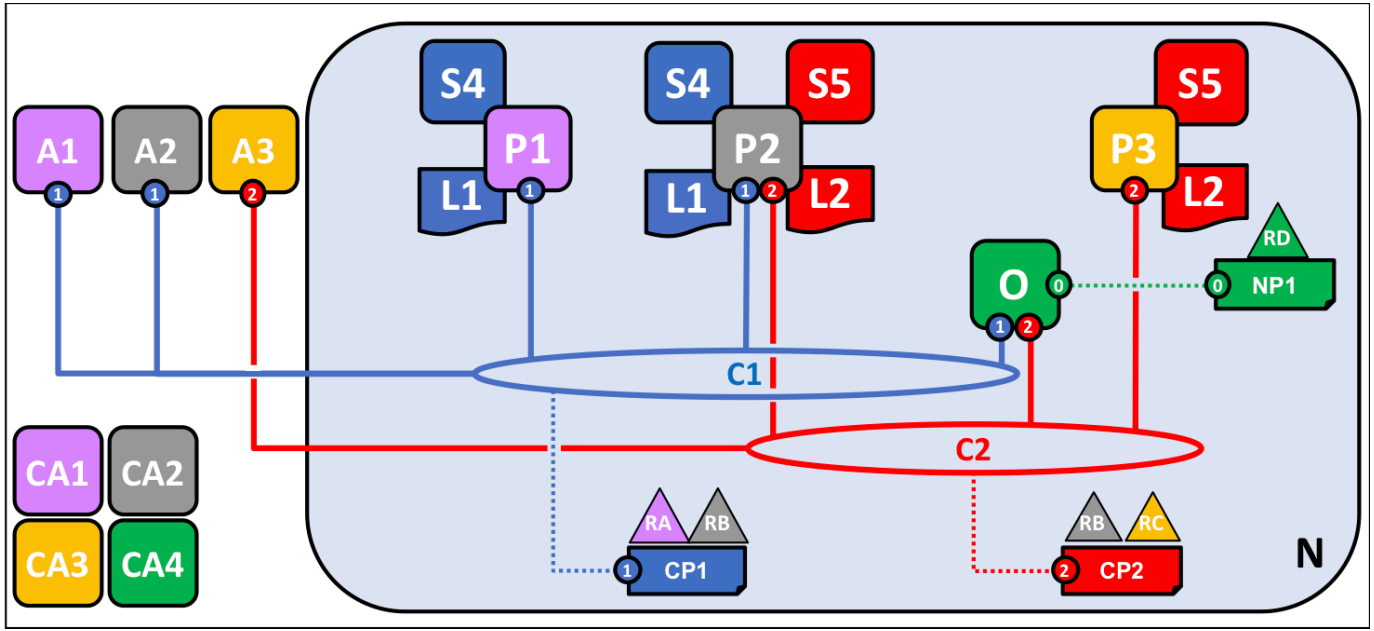
Single global transaction history

Multiple small ledgers

- Multiple small ledgers shared between parties of interest
  - Hyperledger Fabric, Corda
  - Parties of interest are authorized to view the transactions recorded in the ledgers

Peer-to-Peer Ledger

- Hyperledger Fabric
  - A collection of small ledgers
    - Channel
  - More rigid transaction distribution policy
    - Isolating transactions within the channels



- Corda
  - Abstract logic view is a global graph of transactions
    - View most parties see is a collection of small ledgers shared with other business contacts
  - Notaries are used to further limit transaction distribution
    - Special agents
    - Attest to the integrity of unseen parts of the global transaction graph

Taxonomy Dimensions

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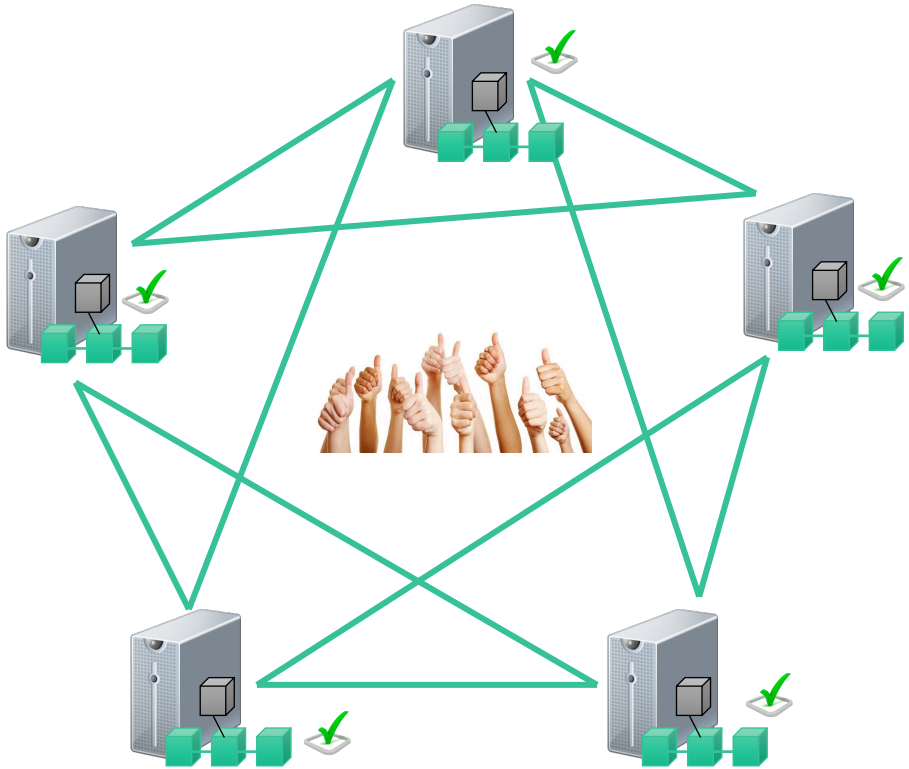
Consensus Protocol

- Miners generate new blocks
- Miners propagate the blocks to the peers in the blockchain network
- Miners encounter different competing new blocks
- Miners resolve this using consensus mechanism



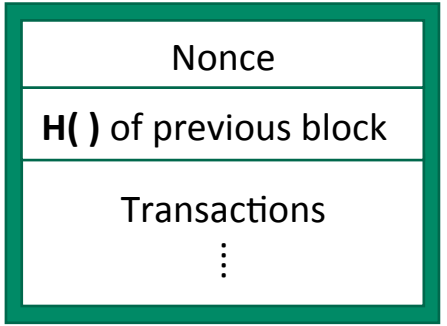
Consensus Overview

	Option	Impact			
		Fundamental properties	Cost efficiency	Performance	Flexibility
Security-wise	Proof-of-work	⊕⊕⊕	⊕	⊕	⊕
	Proof-of-retrievability	⊕⊕⊕	⊕	⊕	⊕
	Proof-of-stake	⊕⊕	⊕⊕	⊕⊕	⊕⊕⊕
	Practical Byzantine Fault Tolerance (PBFT)	⊕	⊕⊕⊕	⊕⊕⊕	⊕
Scalability-wise	Bitcoin-NG	⊕⊕⊕	⊕	⊕	⊕
	RBBC	⊕⊕	⊕⊕⊕	⊕⊕⊕	⊕

Proof-of-Work 1/2

bitcoin ETHEREUM

- Miners compete for right to write block
- Solve a hash puzzle
  - Easy to verify, difficult to solve
  - Takes effectively random time




```
H(nonce || H() of previous block || Tx || … || Tx) is very small
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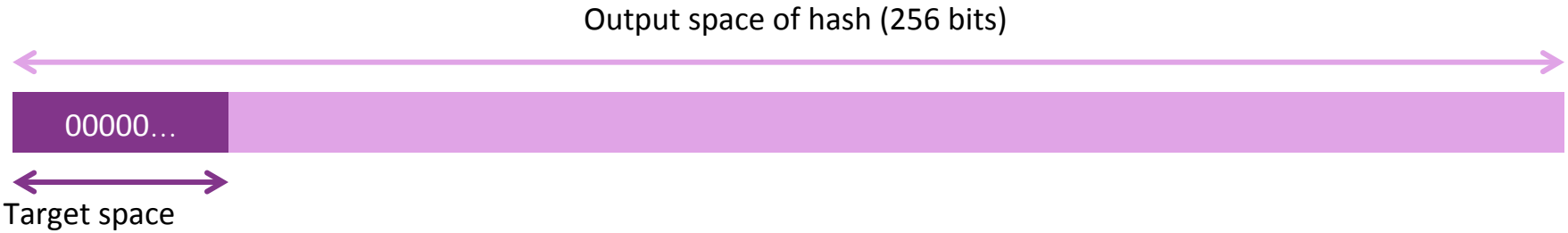

- *If the Hash function is secure: The only way to succeed is to try enough number of values*
- *Prob (wining next block) = Fraction of global hash power the miner controls*

Proof-of-Work 2/2

- Not energy-efficient
  - Electricity consumption of Bitcoin is close to Turkmenistan

- Proof-of-work for good use
  - Primecoin
    - Generates prime number chains which are of interest to mathematical research

Proof-of-Stake

- Select the next mining node based on the control of the native digital currency
  - Align the incentive of digital currency holders with the good operation
  - Does not necessarily select the next miner with the largest stakeholding
  - More Cost-efficient, shorter latency

Peercoin
- Prove the ownership of a certain amount of peercoin
- Combines randomization and coin age

peercoin NXT Cryptocurrency Tendermint casper

- Delegated Proof-of-Stake
  - Account delegate their stake to other accounts rather than participating in the transaction validation
  - Bitshares
    - Representative take turns in a round-robin manner

bitshares

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Practical Byzantine Fault Tolerance (PBFT)

- Ensure consensus despite arbitrary behaviors from fraction of participants
- More conventional approach within distributed systems
- Stronger consistency and lower latency
- Smaller number of participants
- Used in permissioned blockchains
  - All participants agree on the list of participants in the network

Other Alternatives

- Proof-of-Retrievability (Permacoin)
  - In proportion to distributed storage of archival data

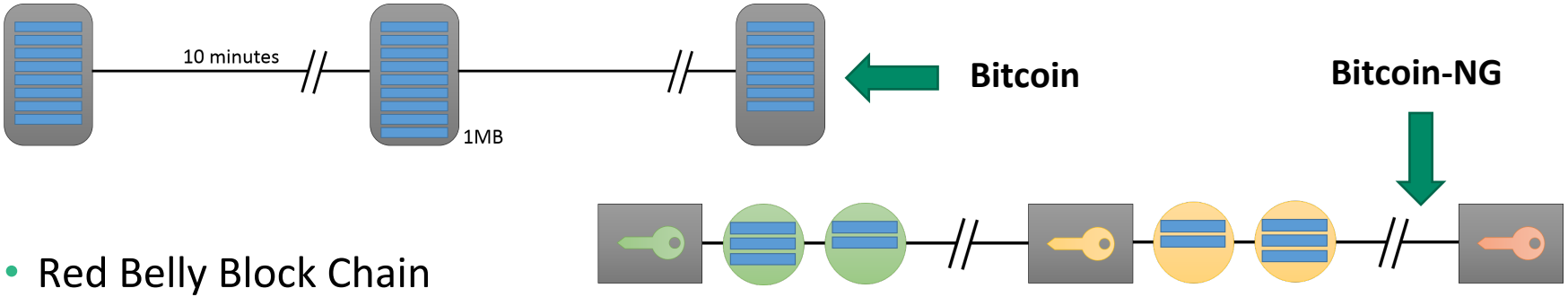
- Proof-of-Elapsed Time
  - Miner waiting a random time to write the next block
  - Using Intel SGX (Software Guard Extension)
    - Run trusted code in trusted environment
    - Ensure the wait times are created fairly

Consensus Overview

	Option	Impact			
		Fundamental properties	Cost efficiency	Performance	Flexibility
Security-wise	Proof-of-work	⊕⊕⊕	⊕	⊕	⊕
	Proof-of-retrievability	⊕⊕⊕	⊕	⊕	⊕
	Proof-of-stake	⊕⊕	⊕⊕	⊕⊕	⊕⊕⊕
	Practical Byzantine Fault Tolerance (PBFT)	⊕	⊕⊕⊕	⊕⊕⊕	⊕
Scalability-wise	Bitcoin-NG	⊕⊕⊕	⊕	⊕	⊕
	RBBC	⊕⊕	⊕⊕⊕	⊕⊕⊕	⊕

Scalability-wise

- Bitcoin-NG
  - Decouple Bitcoin's operation into two planes: Leader election and transaction serialisation
  - Selected leader is entitled to serialize transactions until the next leader is selected



- Red Belly Block Chain
  - Democratic Byzantine consensus without leader nodes
  - Transactions being collected by a set of proposers
  - Proposers collectively decide on a proposed set of transaction to send to a verifier
  - Verifier enforces consensus using hashes exchanged for the proposed sets of transactions

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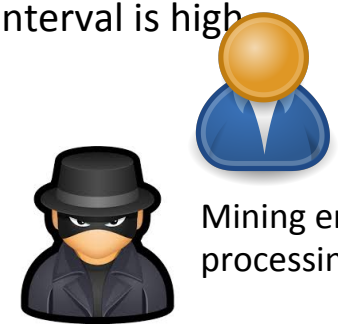
Block Configuration 1/2

Option	Impact			
	Fundamental properties	Cost efficiency	Performance	Flexibility
Original block size and frequency	⊕⊕	n/a	⊕	n/a
Increase block size / Decrease mining time	⊕	n/a	⊕⊕	n/a

- Adjust mining difficulty to shorten the block time interval
- Reducing latency
- Increasing throughput
- Increased frequency of forks
  - Ethereum has shorter block time interval (10-20 seconds) than Bitcoin (10 minutes)
  - Ethereum needs more confirmation blocks than Bitcoin

Block Configuration 2/2

- Block size limit
  - Data size in MB (Bitcoin): Proposal for Bitcoin to increase block size from 1MB to 8 MB
  - Gas limit (Ethereum): Limit the complexity of the contained transactions
- Decision on block size is subject to tradeoffs
  - Speed of replication, block time interval and throughput
  - Mining new block can not start before observing the latest block
    - State changes as a result of the new block
- Unlimited block size causes DoS
  - Flooding system with transactions such that the block time interval is high
- High block size increase the risk of empty blocks
  - It is economical to mine as many empty blocks as possible
    - If block limit and block mining reward is high
  - Deteriorates the value of the network
    - Not processing new transaction anymore



Processing transactions

Mining empty blocks without processing transactions

Block Data Structure 1/3

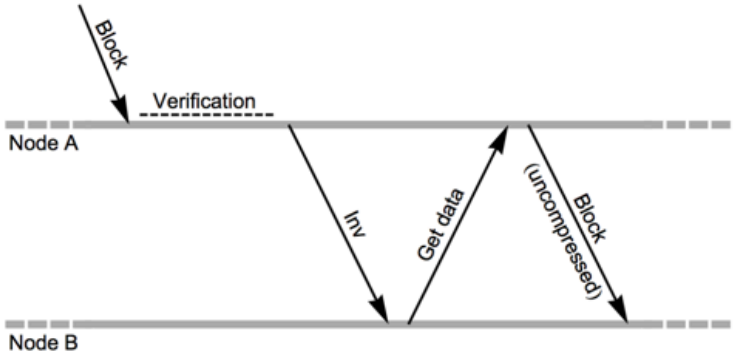
- Block size limit might not be a consensus rule in the first place
  - A hard limit on the block size chokes the growth of Transaction
  - Changing the limit requires a change of the consensus rules
    - Developers decide a new block size limit
    - Merge code and hope the ecosystem follows (can be rejected by miners)

- Bitcoin unlimited
  - Removed block size from the consensus rules
  - The maximum size of a block is freely adjustable by the miners
  - New Bitcoin client that helps the system to scale

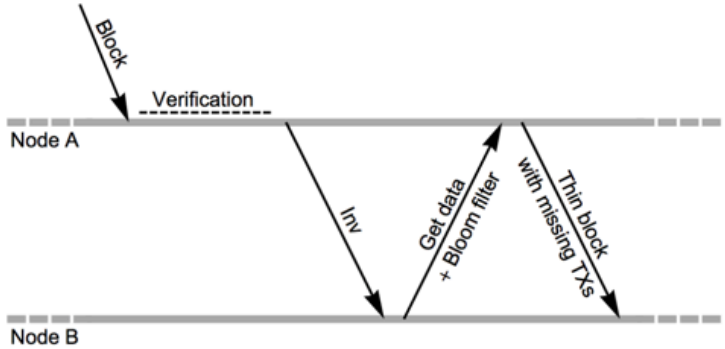
Block Data Structure 2/3

bitcoinunlimited

- Bitcoin Nodes
  - Keeping a list of unconfirmed transaction in memory (*mempool*)
  - When a new block is minded, its transactions must be relayed between nodes
- Bitcoin unlimited Nodes with Xtreme Thinblock
  - Avoid sending transactions again
  - Using a Bloom filter to reduce transmission sizes
    - Images the *mempool* onto a Bloom filter



Standard block propagation

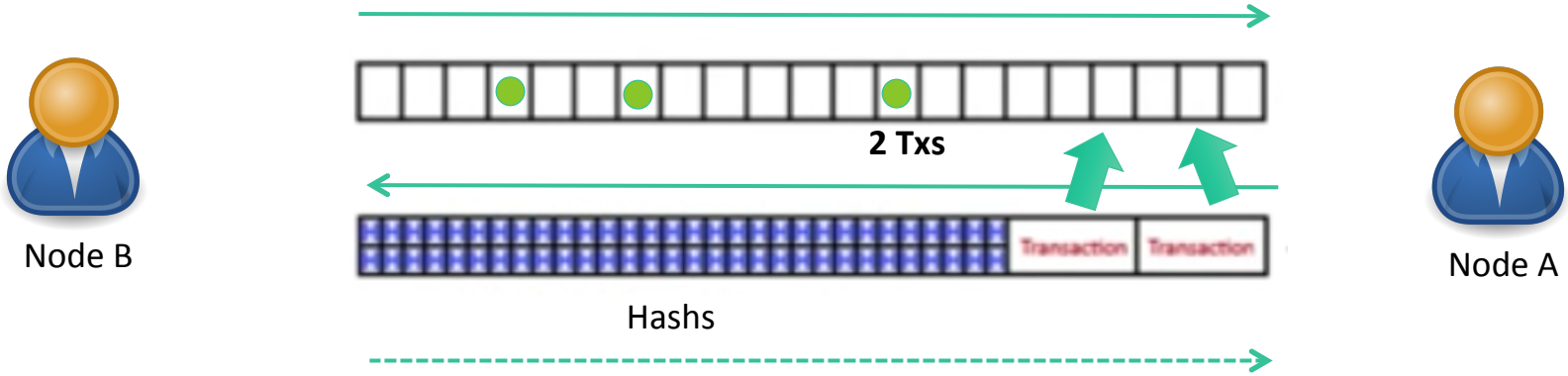


Extreme Thinblock propagation

Block Data Structure 3/3

bitcoinunlimited

- Bloom filter
  - An array of Boolean
  - Designed to indicate whether an element is present in a set
  - Probabilistic data structure
    - Either definitely is not in the set or may be in the set



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Tradeoff Overview

	Option	Impact			
		Fundamental properties	Cost efficiency	Performance	Flexibility
Security-wise	Merged mining	⊕⊕⊕	⊕⊕	⊕	⊕
	Hook into popular blockchain at transaction level	⊕⊕	⊕	⊕⊕	⊕⊕⊕
	Proof-of-burn	⊕	⊕	⊕⊕⊕	⊕⊕
Scalability-wise	Sidechains	⊕⊕⊕	⊕	⊕	⊕
	Multiple private blockchains	⊕	⊕⊕⊕	⊕⊕⊕	⊕⊕⊕

Merged Mining 1/5

- Mining is ordinarily exclusive
  - Each attempt either has a chance to be a parent chain block or has a chance to be a new chain block
- Obstacle to bootstrapping
  - Miner splits mining resource to mine a new blockchain
  - Miner switch between parent chain and new chain

Hash(prev || merkle_root || nonce) < TARGET

Parent chain (Bitcoin)

Hash(prev || merkle_root || nonce) < TARGET

New chain

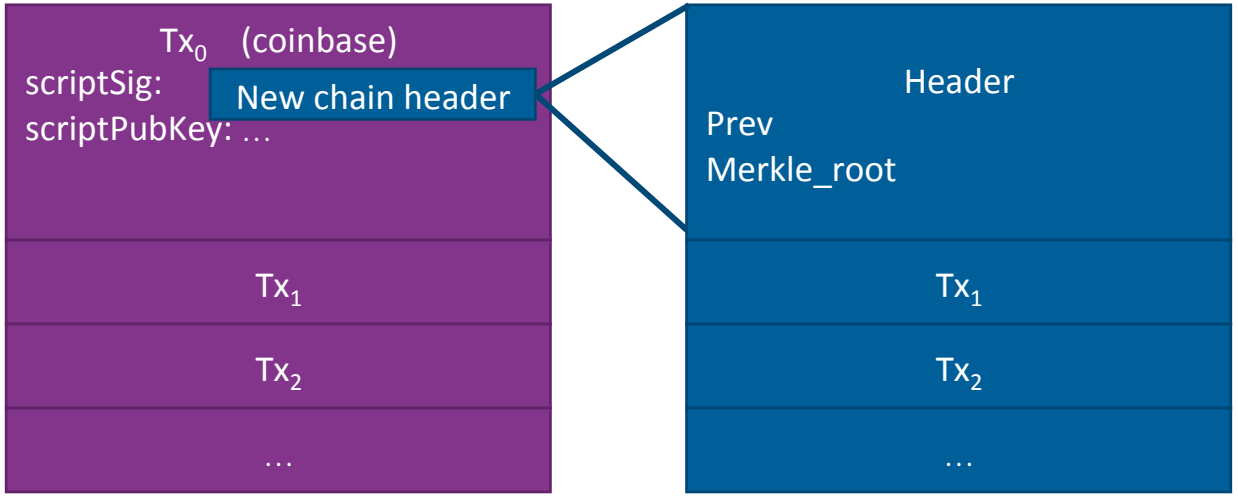
Merged Mining 2/5

Hash(prev || merkle_root || nonce) < TARGET

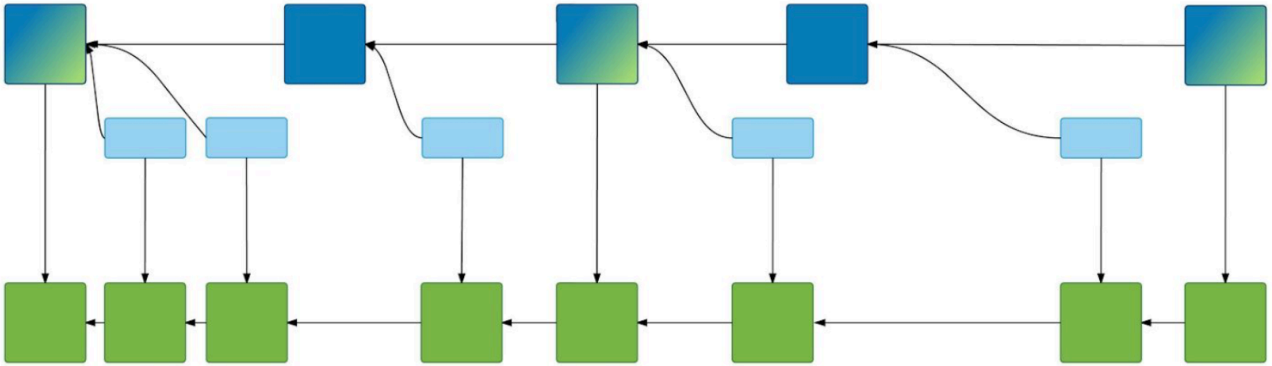
Parent chain (bitcoin)

New chain

Hash(prev || merkle_root || nonce) < TARGET



Merged Mining 3/5



Parent chain (Bitcoin)

New chain

New chain block

Parent chain block mined by new chain merge-miners

Parent chain block mined by parent chain miners

Attempted parent chain block found by new chain merge-miners that met the new chain's difficulty target but not the parent chain's target

Merged Mining 4/5

- Parent chain client
  - Block with encoded new chain block looks like any other Bitcoin block
  - Hash in *scriptSig* is ignored
  - No change

- New chain client
  - Interpret new chain block
    - Ignore parent chain transactions
  - Understand parent chain block
    - Be able to verify the “work”

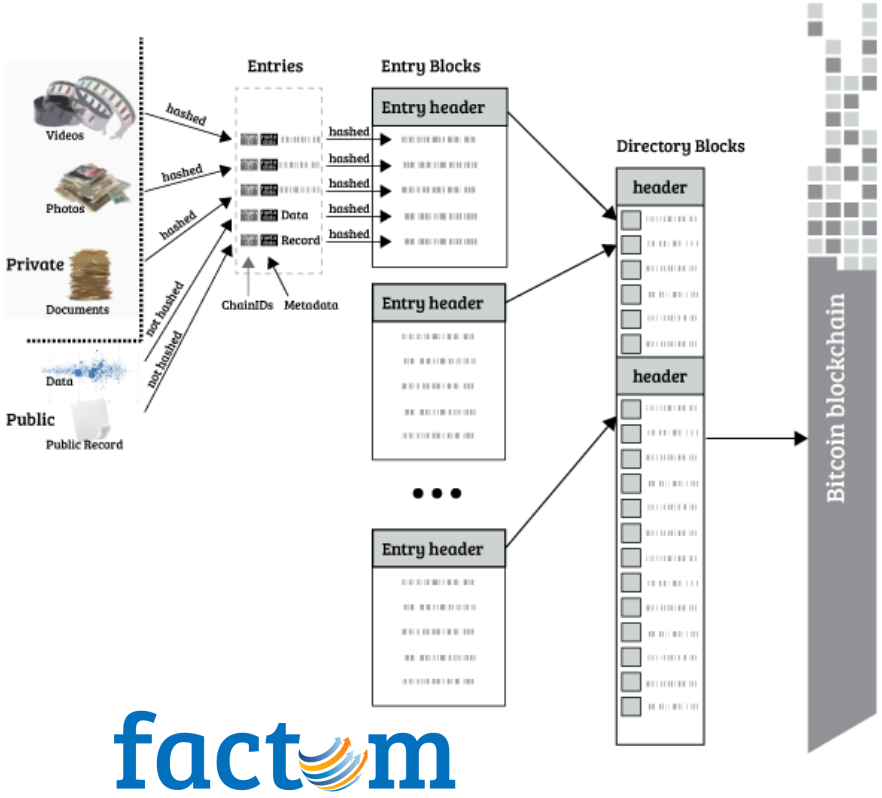
Merged Mining 5/5

- Namecoin is the first blockchain uses merged mining with Bitcoin

- A small miner (or mining pool) on a large network can demolish a merged mining blockchain
  - Jan 2012: CoiledCoin − Eligius pool (large mining pool)
    - Eligius decided that CoiledCoin is a scam
    - Launch an attack to mine a lot of blocks that reversed days of transaction history of CoiledCoin
    - A long chain with empty blocks containing no transaction to make DoS
    - Cheaper for attackers
  - Jul 2013: TerraCoin − unknown
  - Nov 2013: WorldCoin − unknown
- Many mining pools merge-mine several sidechains
  - Ghash.IO: Bitcoin, Namecoin, IXCoin, Devcoin

Hooking into Public Blockchain at Transaction Level

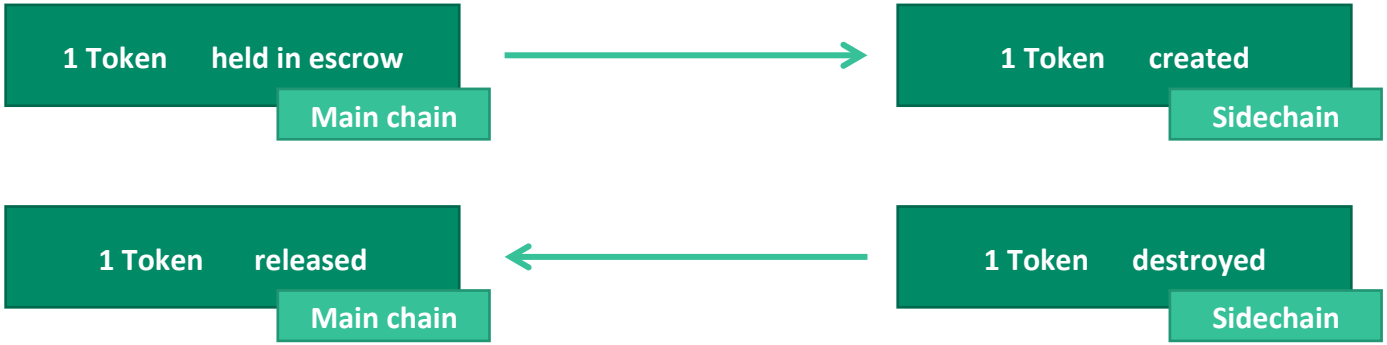
- Hash of new chain is embedded in transaction of parent blockchain (*OP_RETURN*)



Sidechain 1/5

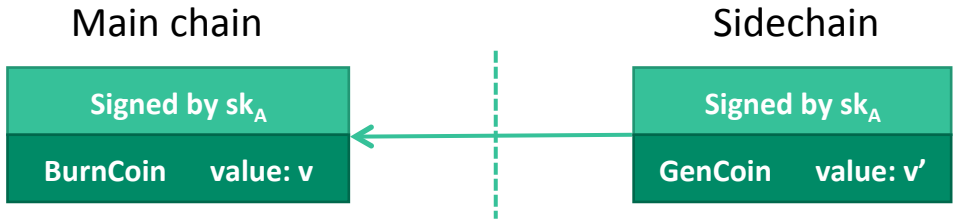
- Unilateral peg

- Bilateral peg



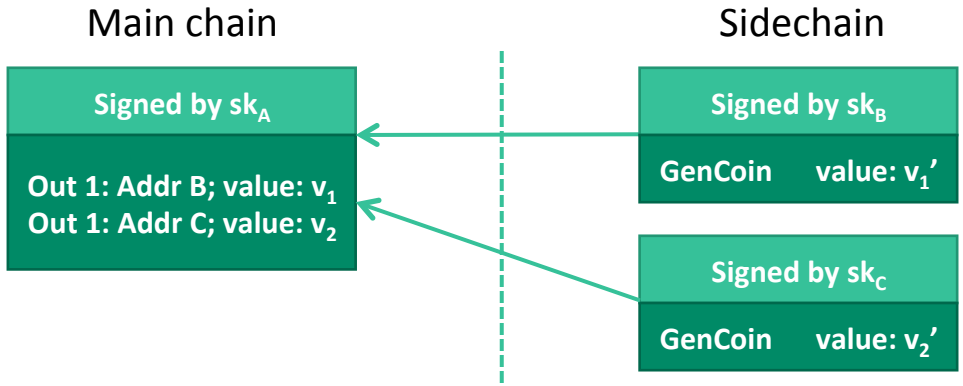
Sidechain 2/5

- Proof-of-Burn



- Signed by the same private key
- Same signature scheme

- Snapshot

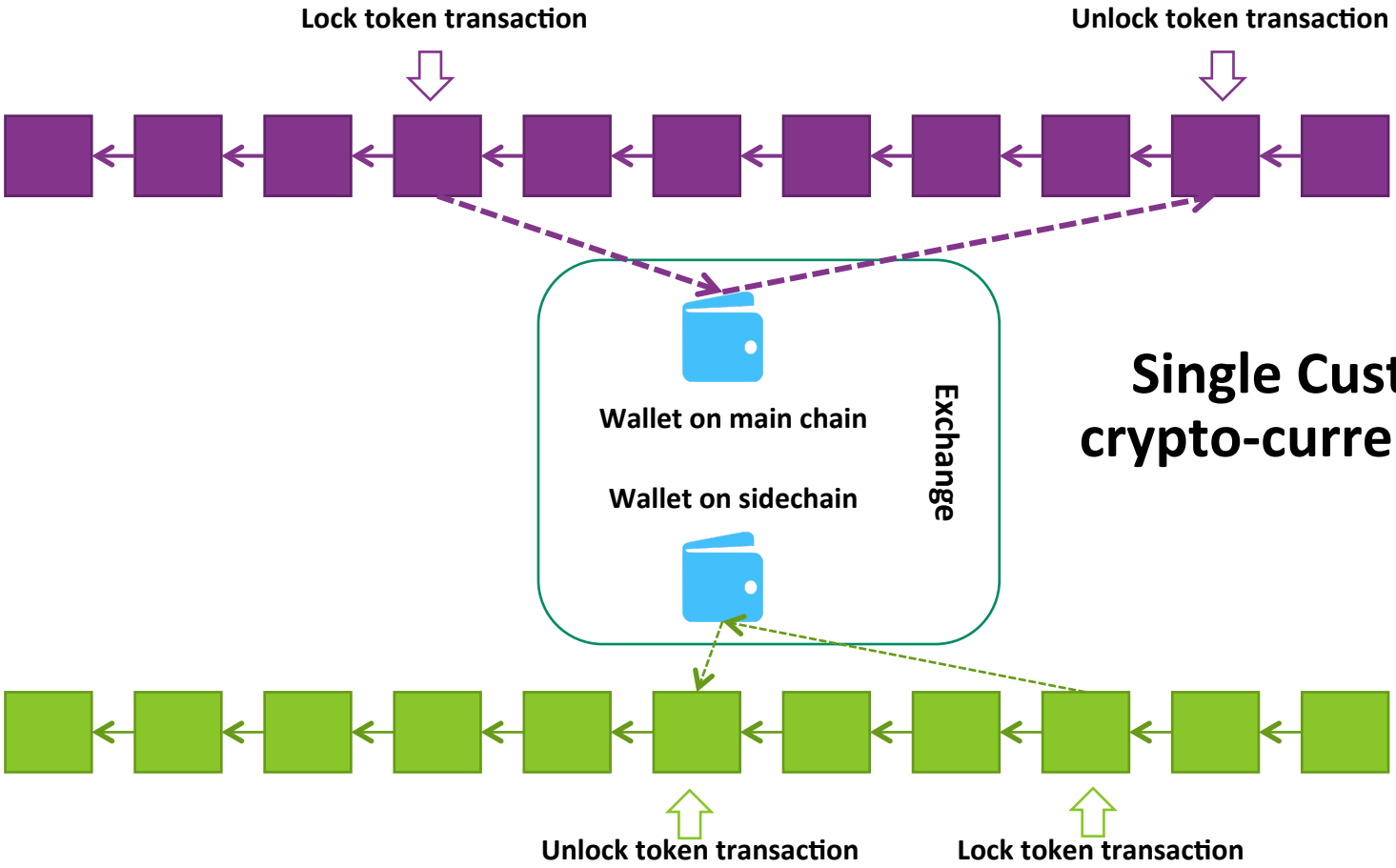


Sidechain 3/5

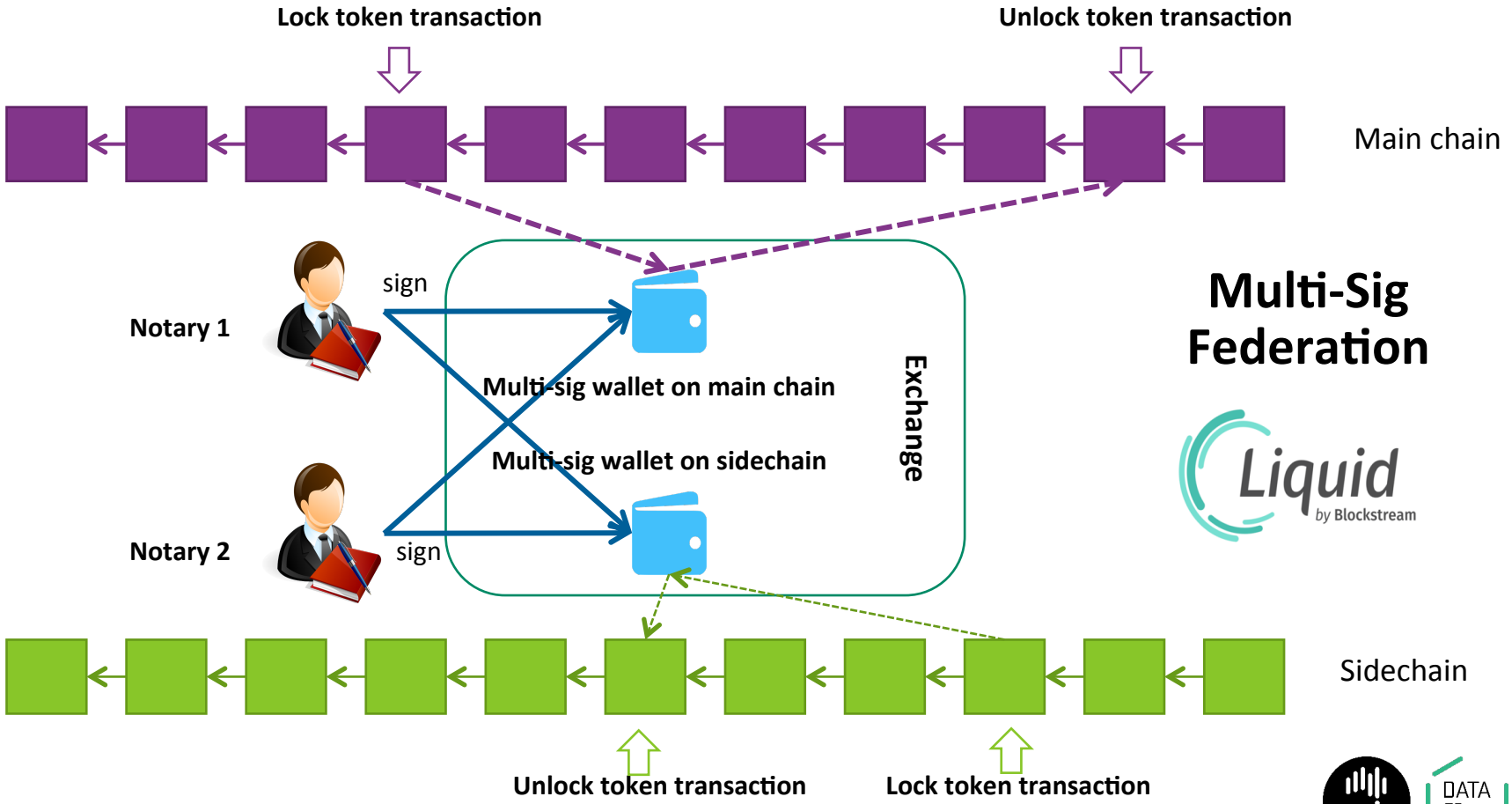
- *Bilateral pegged sidechain is a voting system*
- A group of custodians cast vote on
  - When to unlock tokens
  - Where to send the unlocked tokens to

- Single Custodian
- Multi-sig Federation

Sidechain 4/5



Sidechain 5/5



Problems of Sidechain

- Public blockchains do not have settlement finality
  - Main chain can never be 100% sure if a sidechain transaction has been accepted by the network
  - Neither does sidechain
- Bitcoin-backed sidechains require a soft-fork or hard-fork for Bitcoin to add new complex *opcode*

Entangled Blockchains

- Entangle both chains to overcome the lack of transaction finality
- Reversal of the lock transaction in main chain → Reversal of the unlock transaction in side chain
  - Sidechain transaction is embedded in transaction of parent blockchain (*OP_RETURN*)
  - Sidechain block has extra parent in the parent blockchain
    - Sidechain nodes verify that parents
  - Sidechain block is anchored by cryptographic commitments in parent blockchain transaction
- Sidechain client maintains a copy of parent blockchain

Tradeoff Overview

	Option	Impact			
		Fundamental properties	Cost efficiency	Performance	Flexibility
Security-wise	Merged mining	⊕⊕⊕	⊕⊕	⊕	⊕
	Hook into popular blockchain at transaction level	⊕⊕	⊕	⊕⊕	⊕⊕⊕
	Proof-of-burn	⊕	⊕	⊕⊕⊕	⊕⊕
Scalability-wise	Sidechains	⊕⊕⊕	⊕	⊕	⊕
	Multiple private blockchains	⊕	⊕⊕⊕	⊕⊕⊕	⊕⊕⊕

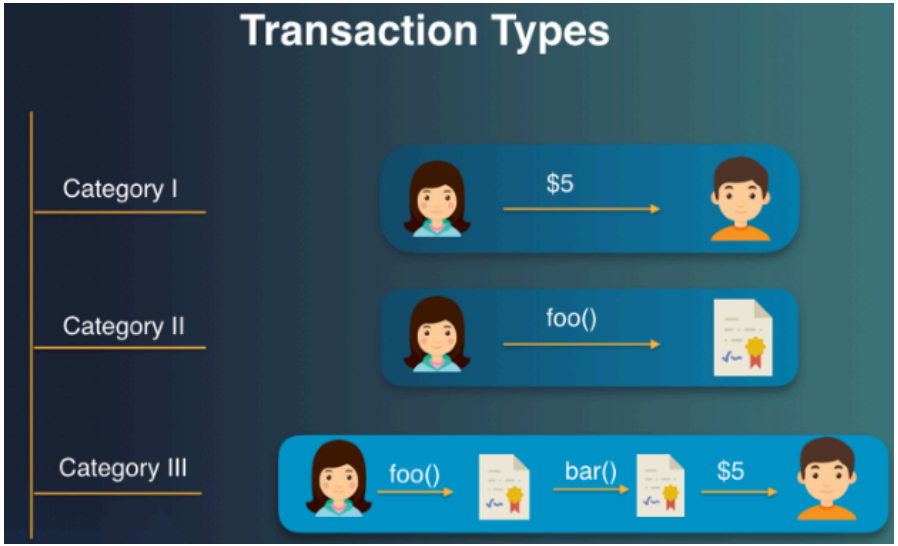
Sharding 1/5

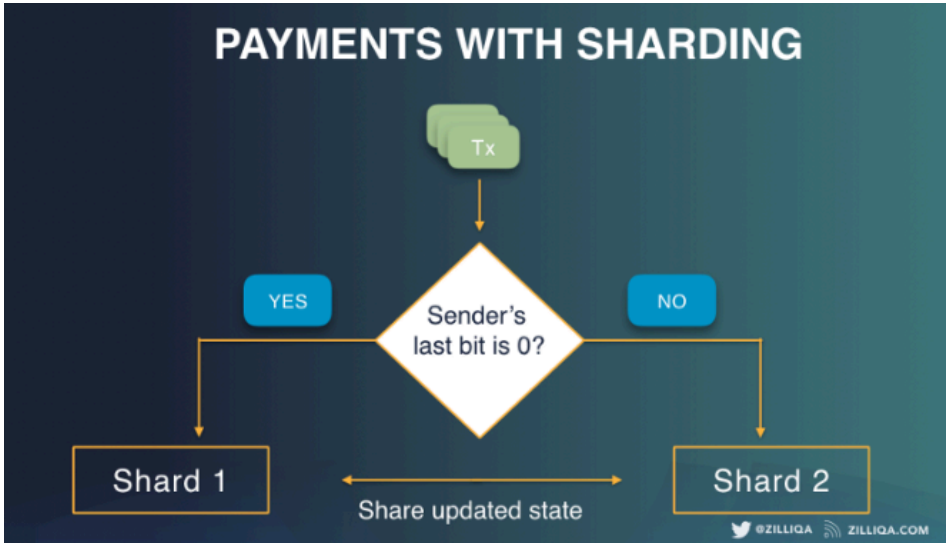
- Full nodes require sizeable storage space
  - Bitcoin > 200GB
  - Ethereum > 600GB
  - Keep growing

- Sharding
  - Divide the blockchain state into pieces
  - Blockchain nodes only hold some shards
  - Transaction sharding vs. State sharding

Sharding 2/5

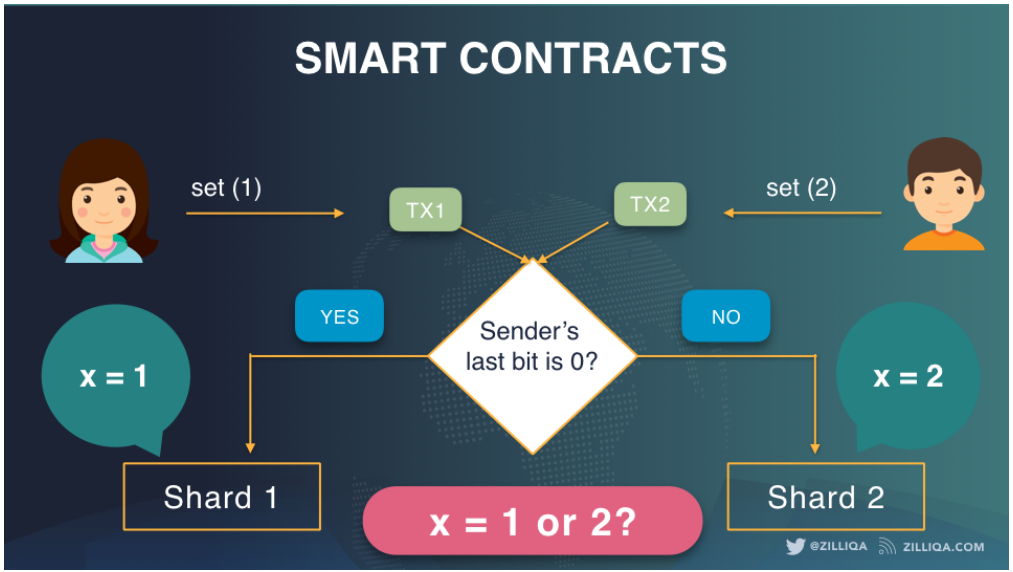
- Transaction Sharding





Sharding 3/5

- Conflicting state
- Using the recipient address instead
  - Smart contract address



Sharding 4/5

- After sharding is activated
  - State sharding
  - Each unique account is in one shard
  - Accounts can only transact with other accounts within the same shard
- Two levels of interaction

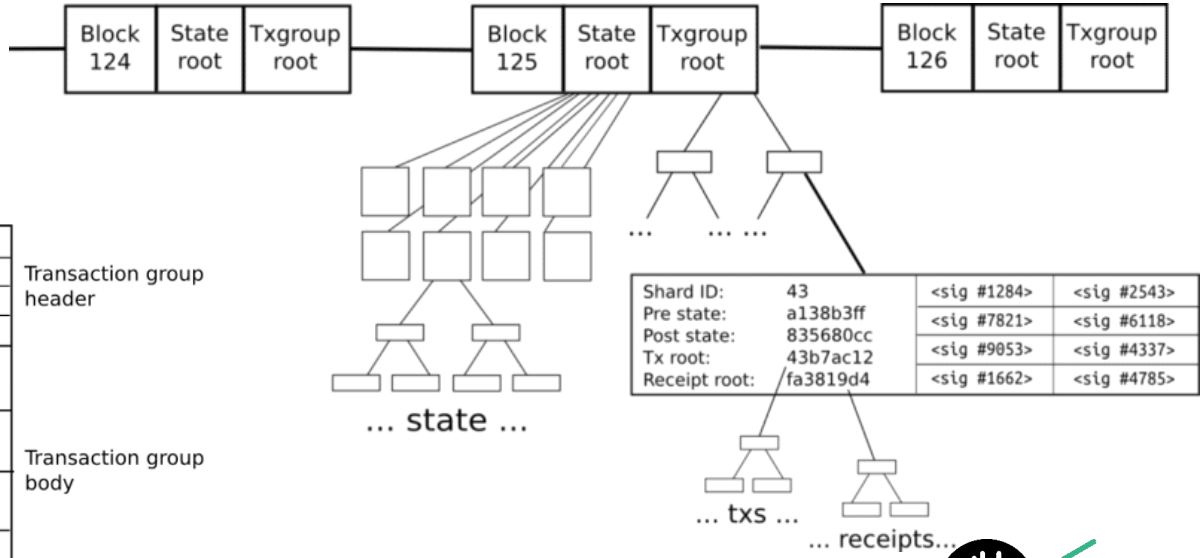
Random validator who need to verify the transactions in the shard

Shard ID: 43 Pre state: a138b3ff Post state: 835680cc Receipt root: fa3819d4	<sig #1284>	<sig #2543>
	<sig #7821>	<sig #6118>
	<sig #9053>	<sig #4337>
	<sig #1662>	<sig #4785>

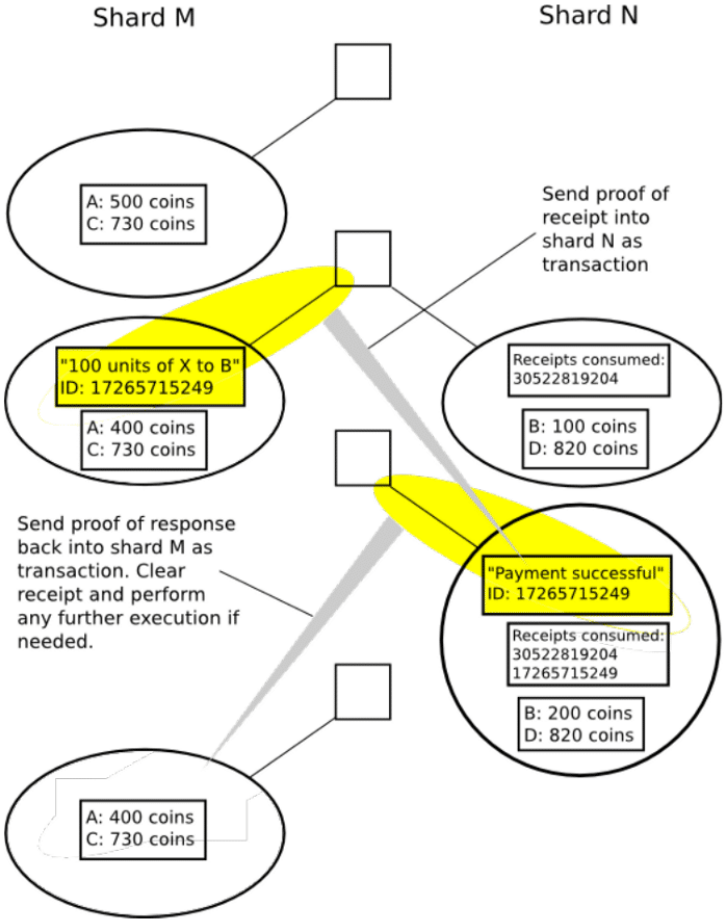
Transaction group header

Tx a142	Tx a558	Tx eca6
Tx a35f	Tx e25a	Tx 34ac
Tx 2308	Tx 6987	Tx f260
Tx 9f14	Tx ec30	Tx 5fc3

Transaction group body



Sharding 5/5



ethereum

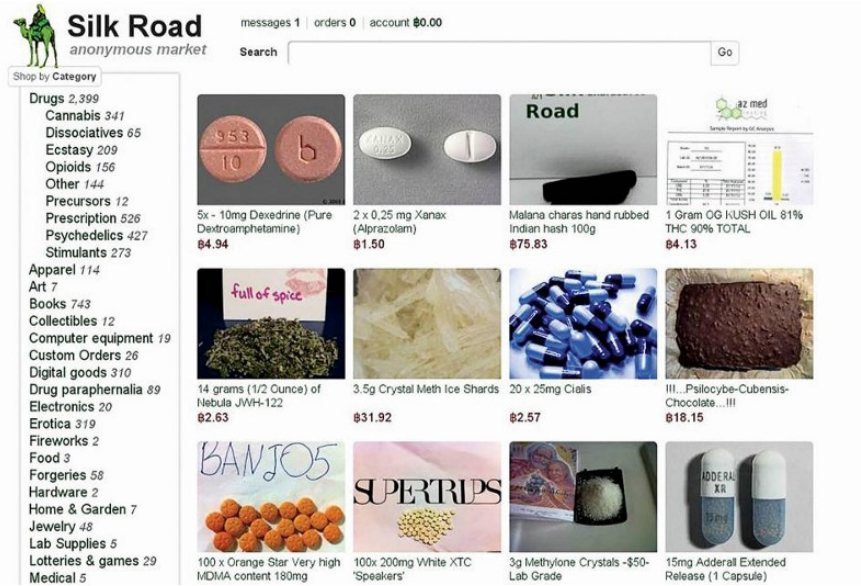
- Transaction
  - Change the state of shard
  - Generate a receipt
- Receipts
  - Stored in a distributed shared memory
  - Seen by other shards
  - Not modified
- Receipts enable cross-shard communication
  - Accessed via multiple Merkle trees from the the transaction group Merkle root

Taxonomy Dimensions

(De)centralization
Deployment
Ledger Structure
Consensus Protocol
Block Configuration and Data Structure
Auxiliary Blockchain
Anonymity
Incentive

Pseudonymity

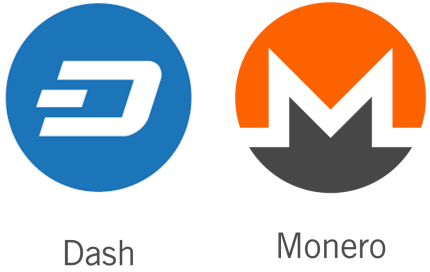
- Bitcoin is pseudonymous (pseudo-anonymous)
  - Physical world evidence can be connected to compromise the anonymity of Bitcoin users
- Silk Road
  - "eBay for drugs"
  - Cash flow of at least USD213 million
  - Combination Tor and Bitcoin
  - Exposed physical IP address of the Silk Road server
    - Iceland
  - Customer service manager was arrested
  - Linked Ross Ulbricht with "Dread Pirate Roberts"
  - FBI became the second largest owner of Bitcoins
    - 144, 000 Bitcoins

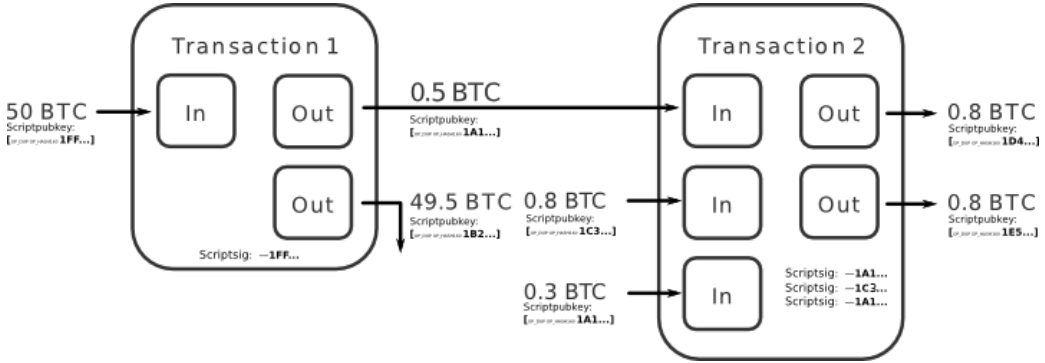


Tor is a intermediary server
- Hidden IP address
- Hidden users surfing on it

Mixing Services

- Mixing service
  - Group transactions together with multiple *input* addresses and *output* addresses
  - Hard to track which output address is paid by which input address
  - A series of mixing services can be linked sequentially
  - Mixed transactions are uniformed in value
- Dash: Pre-anonymize founds through mixing rounds
- Monero: Ring signature

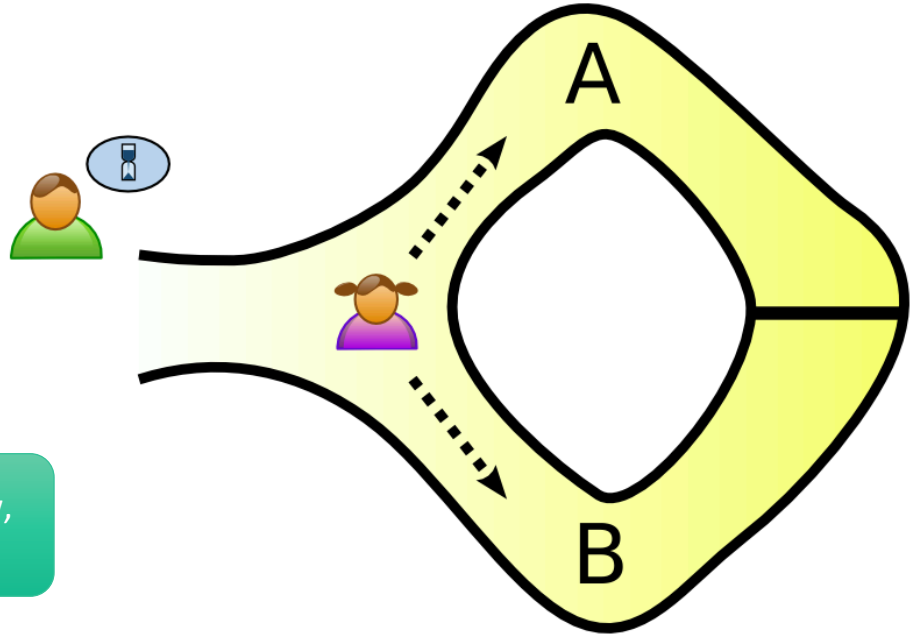




Advanced Cryptographic Technology

- Zcash
  - Encrypted payment information in transaction
  - Crytographical method to verify the validity of the encrypted transaction
    - Zero-knowledge proof

- Zero-knowledge proof
  - Allow the blockchain network to maintain a secure ledger
  - Enable private payment without disclosing the parties or amounts involved



You have a secret that you don't want others to know, but you want to proof you have the secret

Taxonomy Dimensions

(De)centralization
Deployment
Ledger Structure
Consensus Protocol
Block Configuration and Data Structure
Auxiliary Blockchain
Anonymity
Incentive

Incentive

- Financial incentive in the cryptocurrencies
  - Join the network
  - Validate transactions
  - Generate blocks
  - Execute smart contract

- Bitcoin
  - Reward for generating new blocks and fees associated with transactions
- Ethereum
  - Fee to execute smart contract
- Enigma
  - Fixed price for storage, data retrieval and computation within the network
  - Security deposit
    - Deposit of dishonest node will be split among the honest nodes

Summary

- Blockchain Taxonomy
  - (De)centralization
  - Deployment
  - Ledger Structure
  - Consensus Protocol
  - Block Configuration and Data Structure
  - Auxiliary Blockchain
  - Anonymity
  - Incentive

Course Outline – next two weeks

Week	Date	Lecturer	Lecture Topic	Relevant Book Chapters	Notes
3rd	4 Mar	Sherry Xu	Blockchain in Software Architecture 1	3. Varieties of blockchain 5. Blockchain in Software Architecture (including software architecture basics) 1/2	
4th	11 Mar	Mark Staples	Blockchain in Software Architecture 2	5. Blockchain in Software Architecture (Non-functional properties and trade-offs) 2/2	Pitching session Assignment 1 due (Wednesday)
5th	18 Mar	Sherry Xu	NPFs 1	6. Design Process for Applications on Blockchain 9. Cost	

Consultation Time

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