COMP6452 Lecture 3: Blockchain in Software Architecture 1

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4th of March, 2019

Outline

- What is Taxonomy?

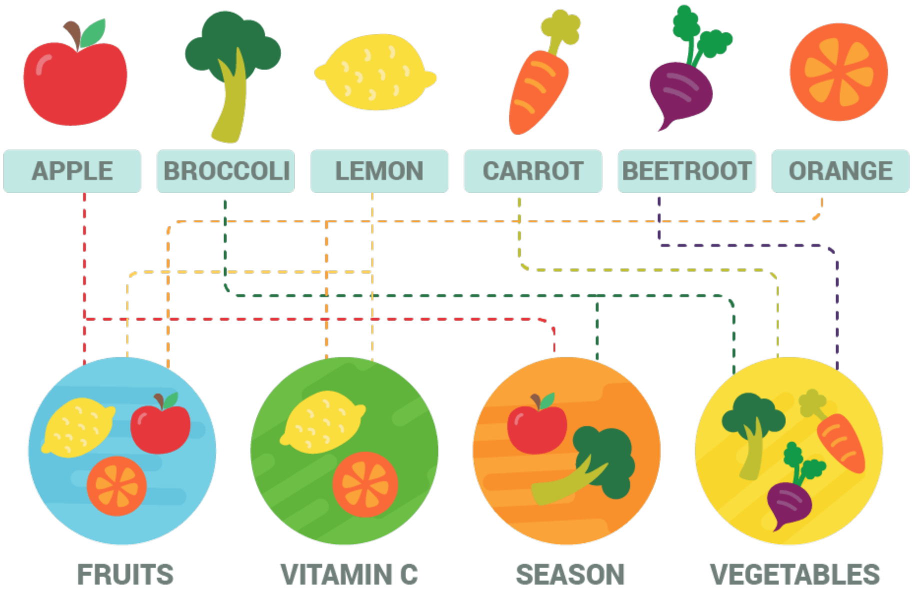
- Varieties of Blockchain – A Taxonomy
  - (De)centralization
  - Deployment
  - Ledger Structure
  - Consensus Protocol
  - Block Configuration and Data Structure
  - Auxiliary Blockchain
  - Anonymity
  - Incentive

- Summary

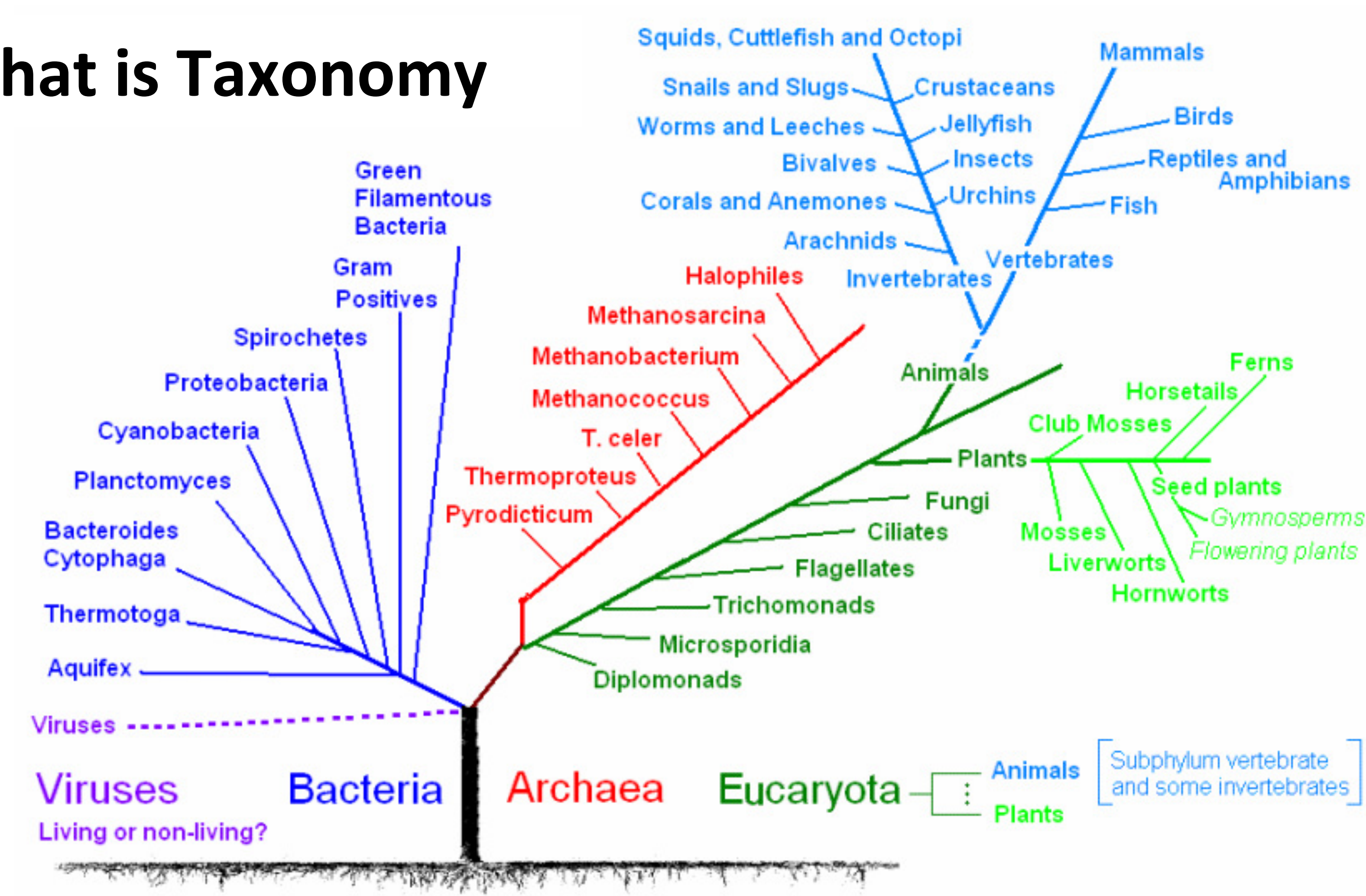
What is Taxonomy?

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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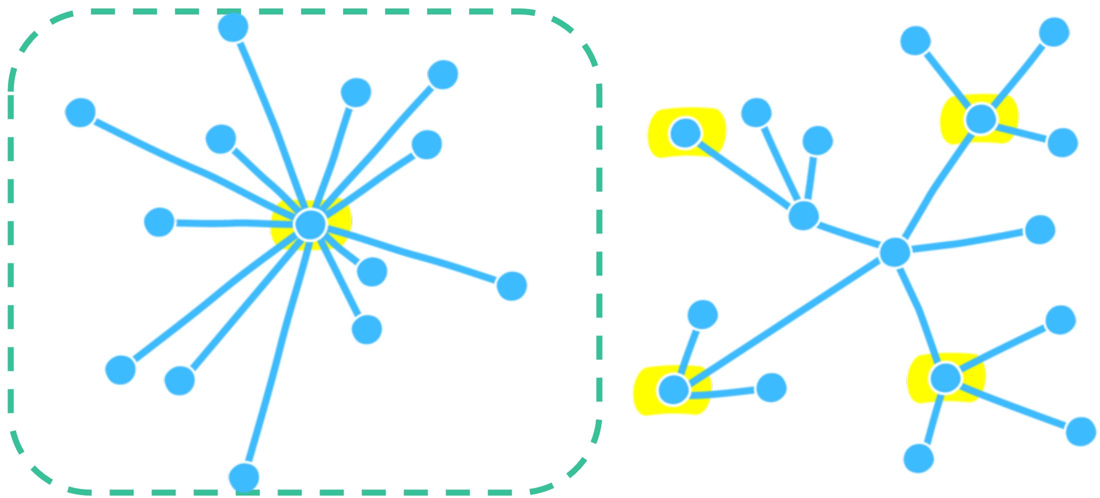
Centralization – Decentralization

Design Decision	Option	Impact: Fundamental properties	Impact: Cost efficiency	Impact: Performance	Impact: #Failure points
Fully Centralised	Services with a single provider (*e.g.*, governments, courts) Services with alternative providers (*e.g.*, banking, online payments, cloud services)	⊕	⊕⊕⊕	⊕⊕⊕	1
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)

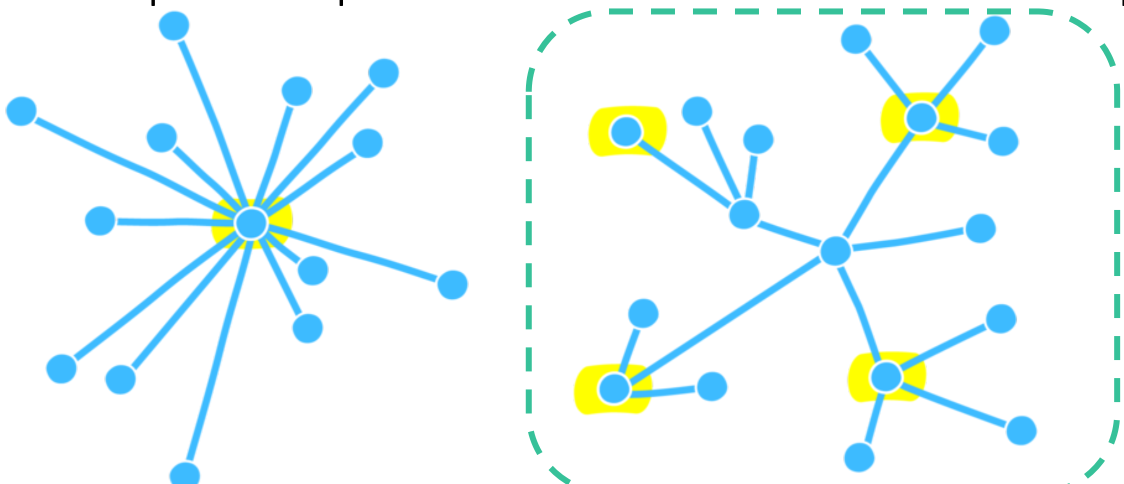
Full Centralization

- 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

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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

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

- Private blockchain
  - Write permission kept within one organization
  - Governed and hosted by a single organization - most flexible

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List

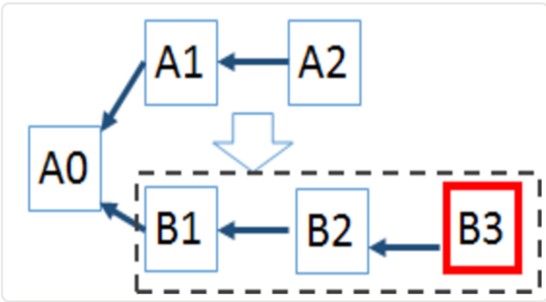
Option	Impact: Fundamental properties	Cost efficiency	Performance	Flexibility
Global list of blocks (Bitcoin)	⊕⊕⊕	⊕	⊕	⊕
Global DAG of blocks (Hashgraph)	⊕⊕	⊕⊕	⊕⊕	⊕⊕
Global DAG of transactions (IOTA)	⊕⊕	⊕⊕	⊕⊕	⊕⊕
Restricted shared ledgers (Corda)	⊕	⊕⊕⊕	⊕⊕⊕	⊕⊕⊕

- 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

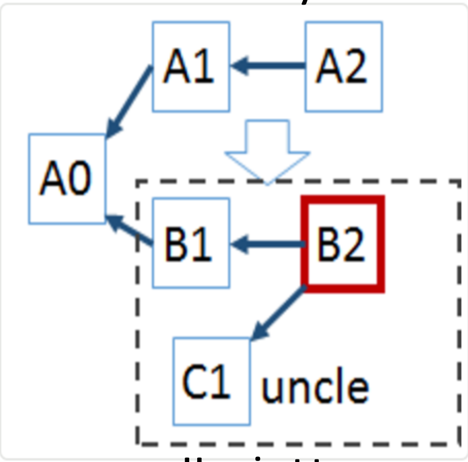
Bitcoin
- Block time interval: 10 minutes
- Block propagation (50% of the network): ~12 seconds



Longest chain

Bitcoin

Ethereum



Heaviest tree

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)	⊕	⊕⊕⊕	⊕⊕⊕	⊕⊕⊕

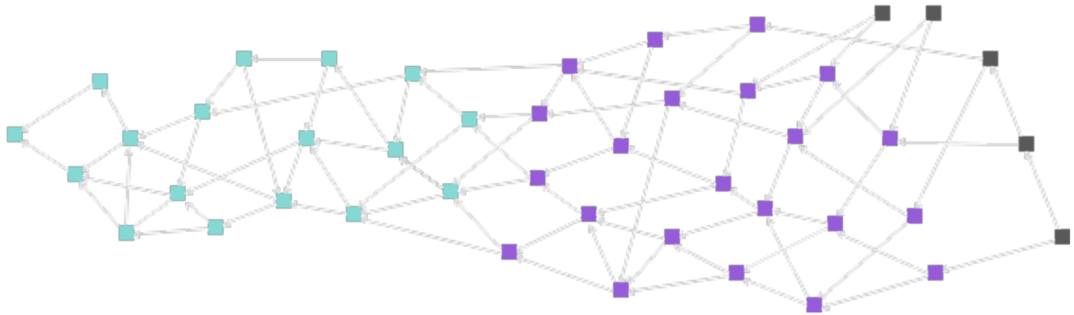
- Global DAG of blocks
  - Hashgraph
  - Logical view of transactions is based on a directed acyclic graph of blocks
    - Rather than a list

Graph

IOTA

Blockchain

Tangle (DAG/ Directed Acyclic Graph)



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

Tradeoff Overview

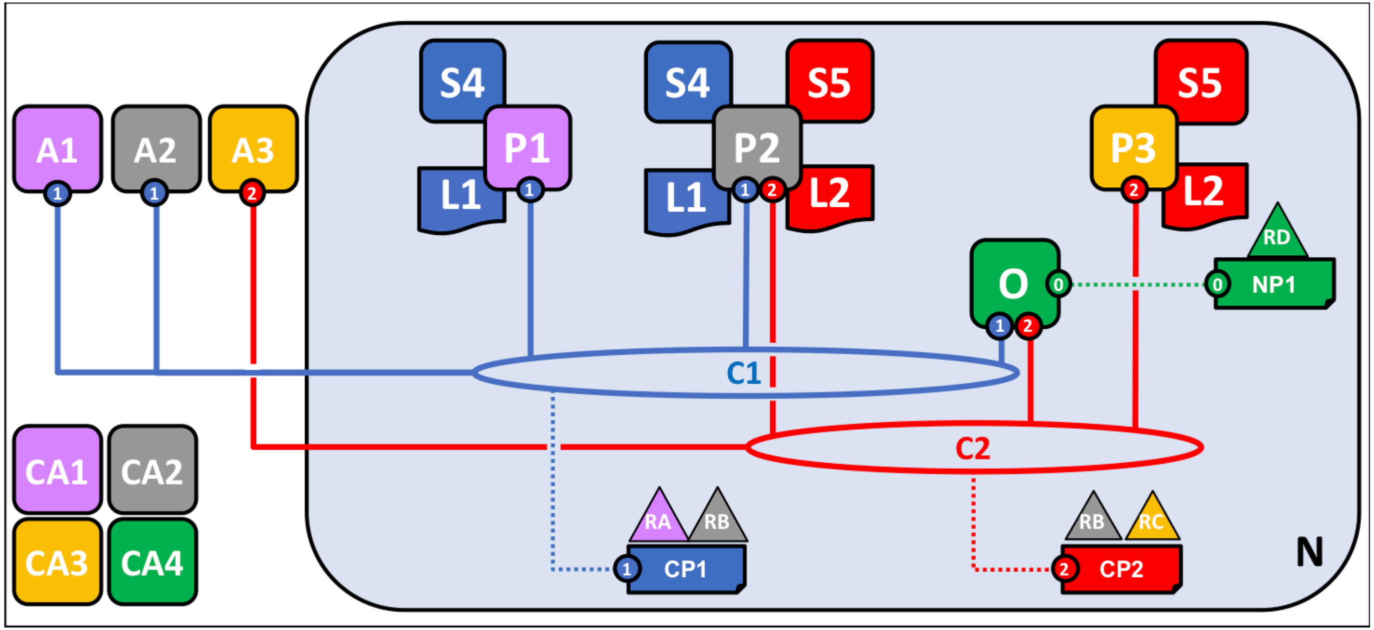
Option	Impact: Fundamental properties	Impact: Cost efficiency	Impact: Performance	Impact: Flexibility
Global list of blocks (Bitcoin)	⊕⊕⊕	⊕	⊕	⊕
Global DAG of blocks (Hashgraph)	⊕⊕	⊕⊕	⊕⊕	⊕⊕
Global DAG of transactions (IOTA)	⊕⊕	⊕⊕	⊕⊕	⊕⊕
Restricted shared ledgers (Corda)	⊕	⊕⊕⊕	⊕⊕⊕	⊕⊕⊕

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

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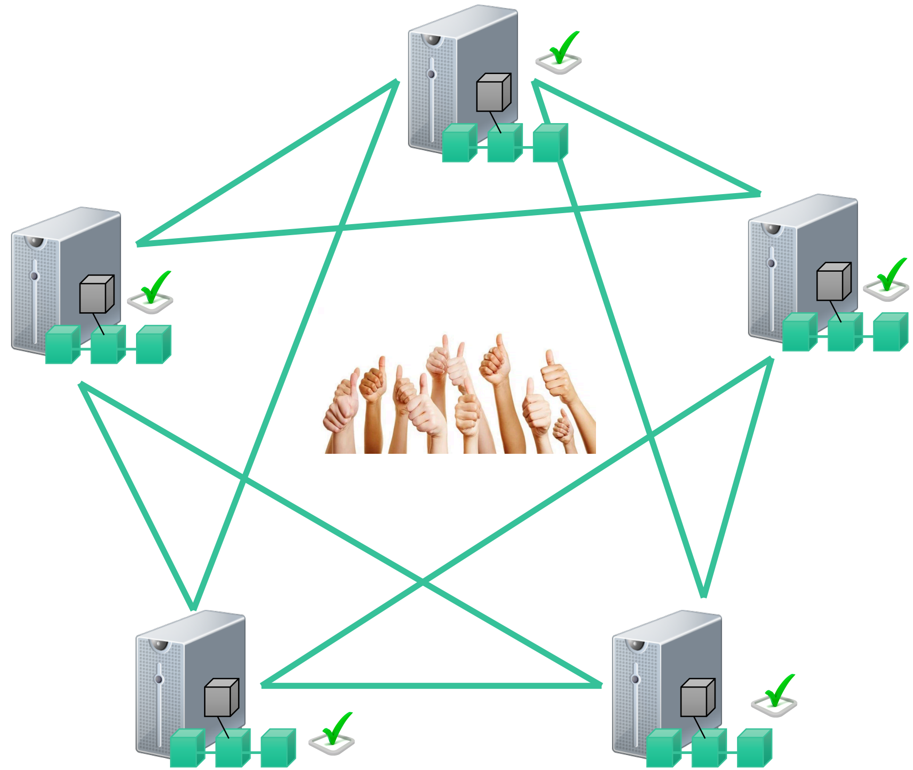
Consensus Protocol

- 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

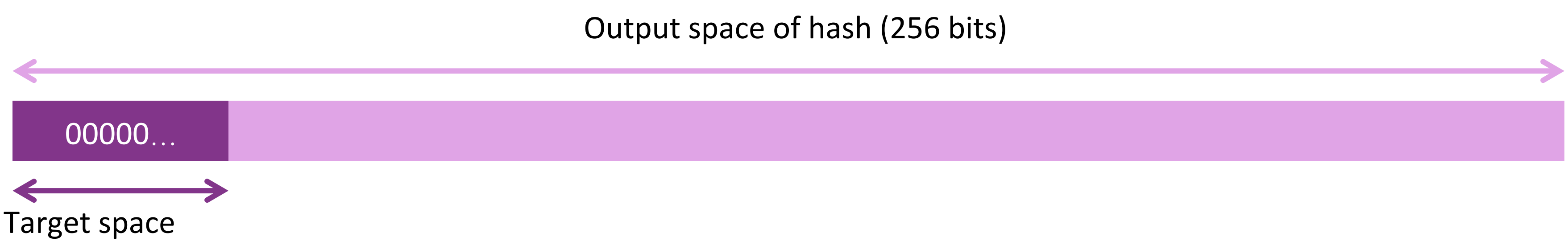
	Option	Impact: Fundamental properties	Cost efficiency	Performance	Flexibility
Security-wise	Proof-of-work	⊕⊕⊕	⊕	⊕	⊕
	Proof-of-retrievability	⊕⊕⊕	⊕	⊕	⊕
	Proof-of-stake	⊕⊕	⊕⊕	⊕⊕	⊕⊕⊕
	Practical Byzantine Fault Tolerance (PBFT)	⊕	⊕⊕⊕	⊕⊕⊕	⊕
Scalability-wise	Bitcoin-NG	⊕⊕⊕	⊕	⊕	⊕
	RBBC	⊕⊕	⊕⊕⊕	⊕⊕⊕	⊕

Proof-of-Work 1/2

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

Nonce
H( ) of previous block
Transactions ⋮

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



- *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

Primecoin

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

- 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

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

STELLAR Tendermint HYPERLEDGER FABRIC corda

Other Alternatives

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

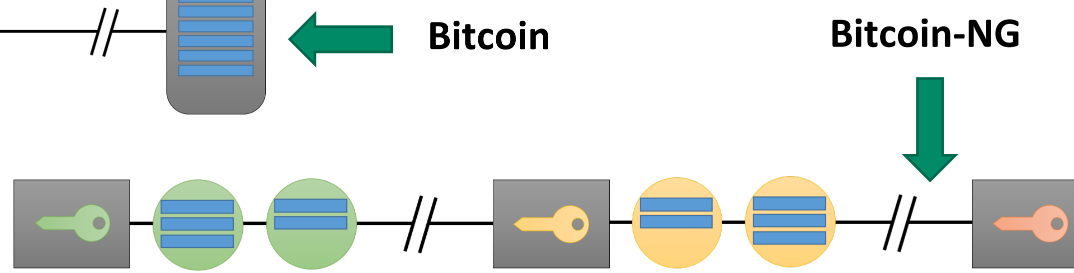
- Proof-of-Elapsed Time
- Miner waiting a random time to write the next block
- Using Intel SGX (Software Guard Extension)
    - Run trusted code in trusted environment
    - Ensure the wait times are created fairly

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	Impact: Cost efficiency	Impact: Performance	Impact: 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

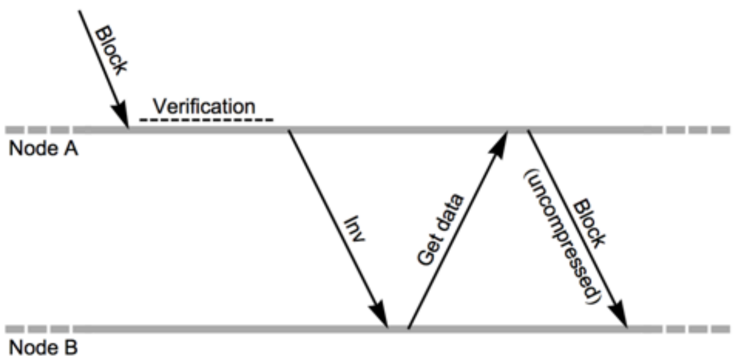
Block Data Structure 1/3

- 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)

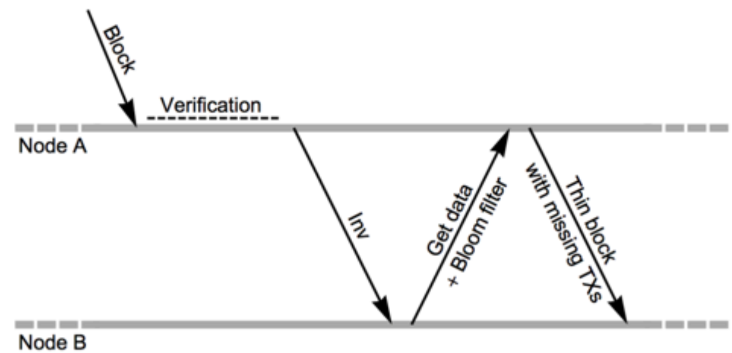
- Bitcoin unlimited
  - Removed block size from the consensus rules
  - The maximum size of a block is freely adjustable by the miners
  - New Bitcoin client that helps the system to scale

Block Data Structure 2/3

- 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



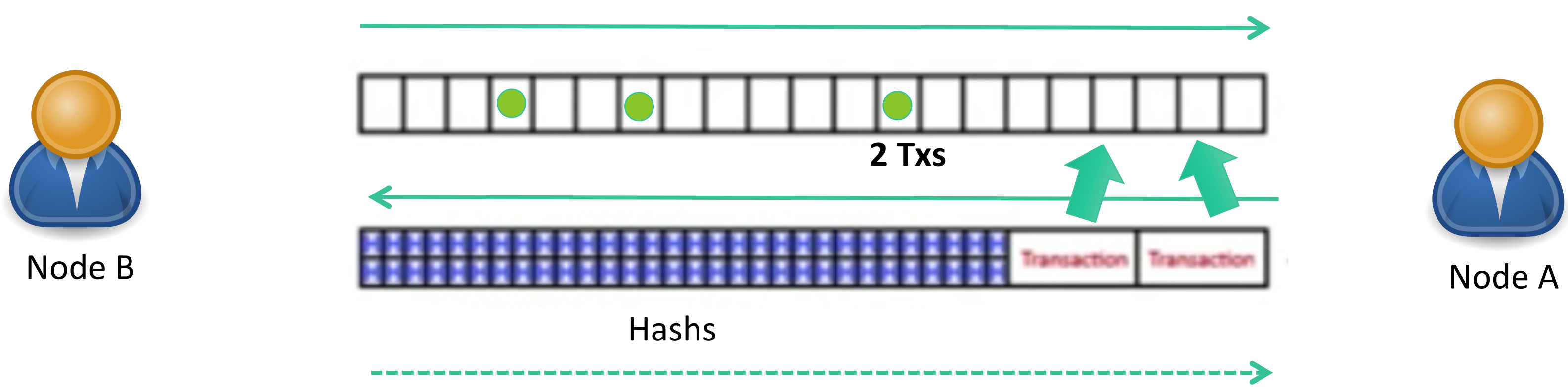
Standard block propagation



Extreme Thinblock propagation

Block Data Structure 3/3

- 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	Impact: Cost efficiency	Impact: Performance	Impact: 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)

New chain

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

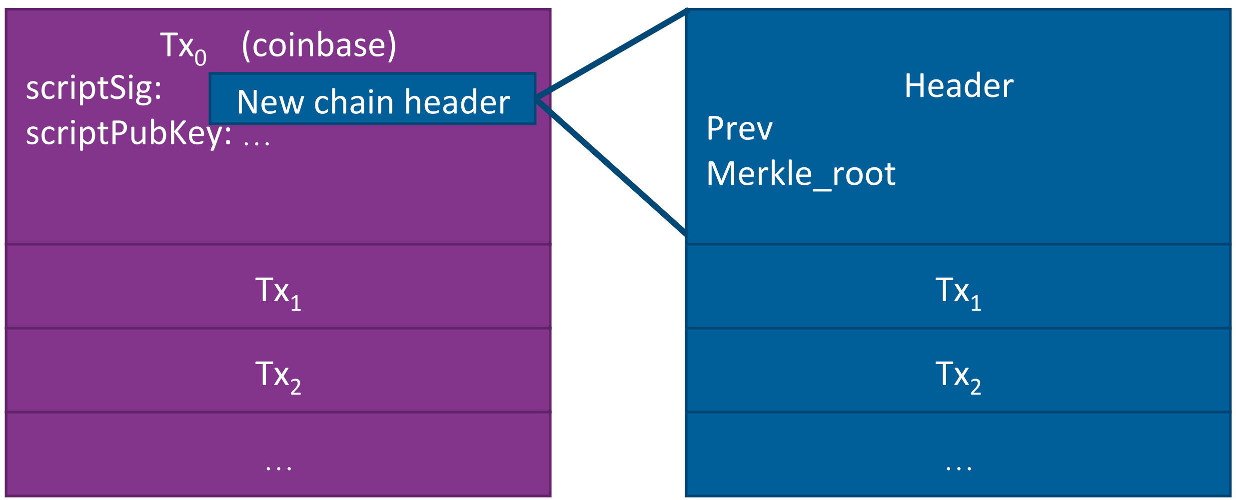
Merged Mining 2/5

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

Parent chain (bitcoin)

New chain

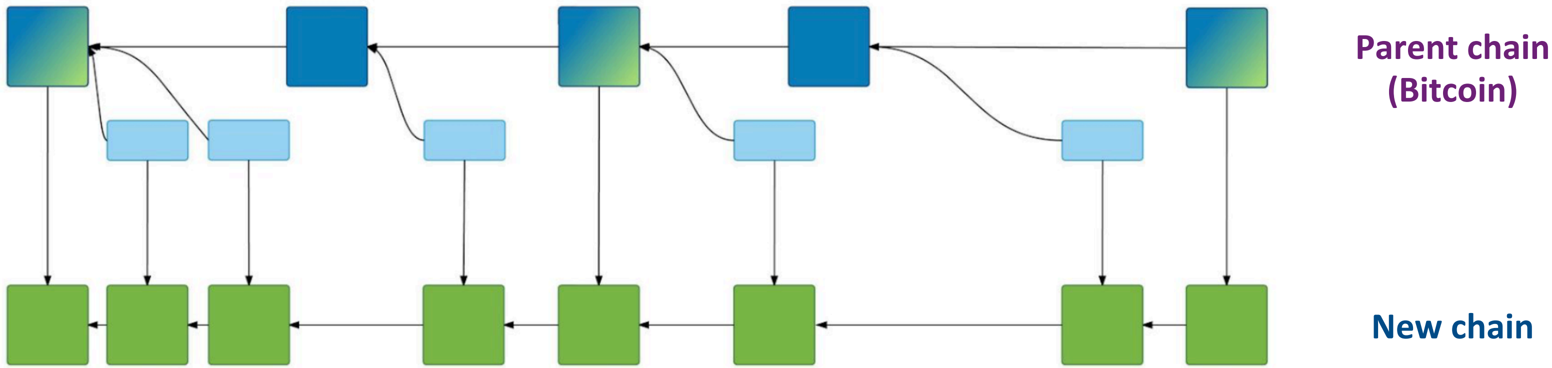
Hash(prev || merkle_root || nonce) < TARGET



Parent chain block

New chain block

Merged Mining 3/5



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”

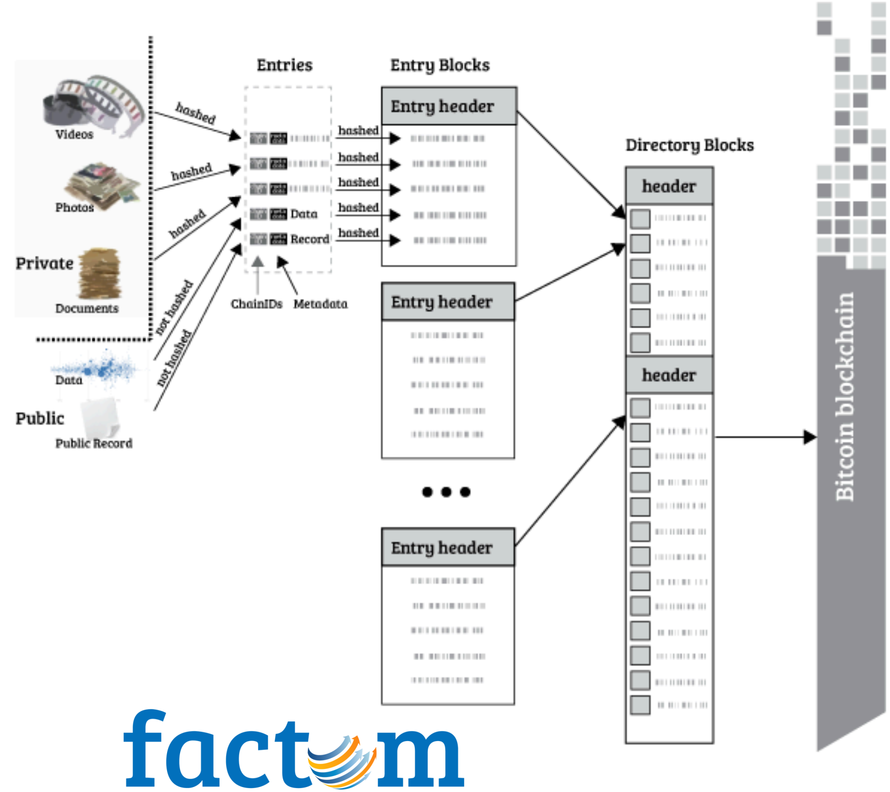
Merged Mining 5/5

- 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

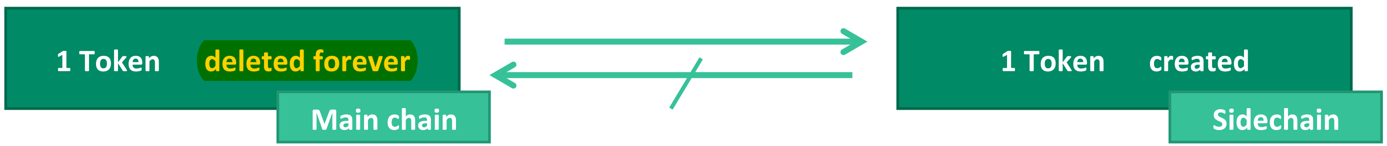
Hooking into Public Blockchain at Transaction Level

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

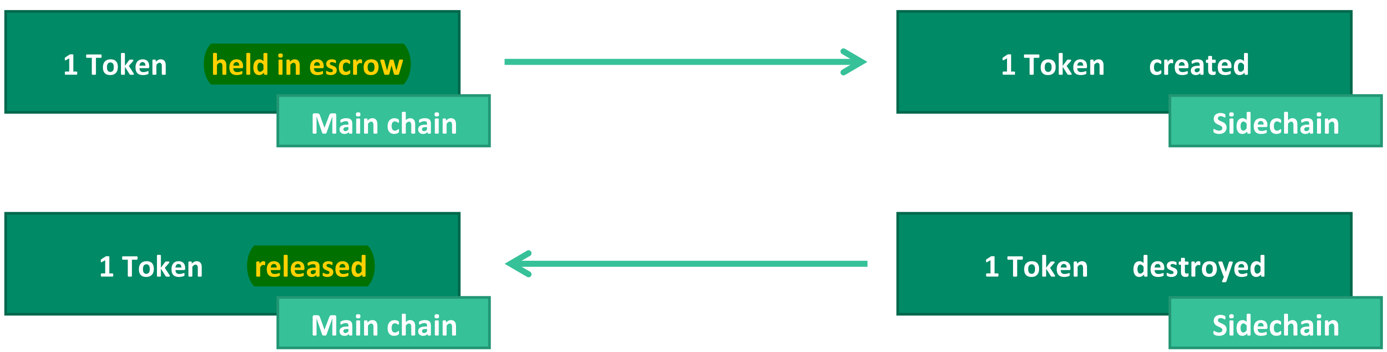


Sidechain 1/5

- Unilateral peg

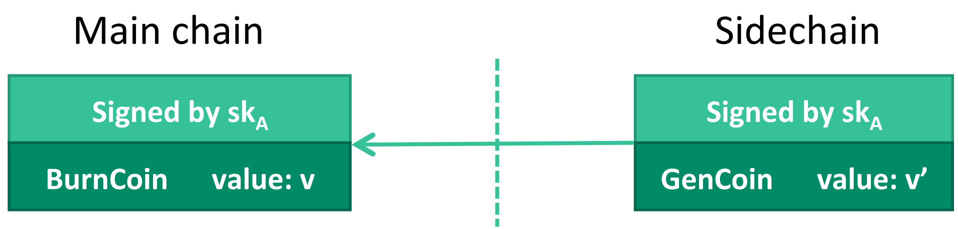


- Bilateral peg



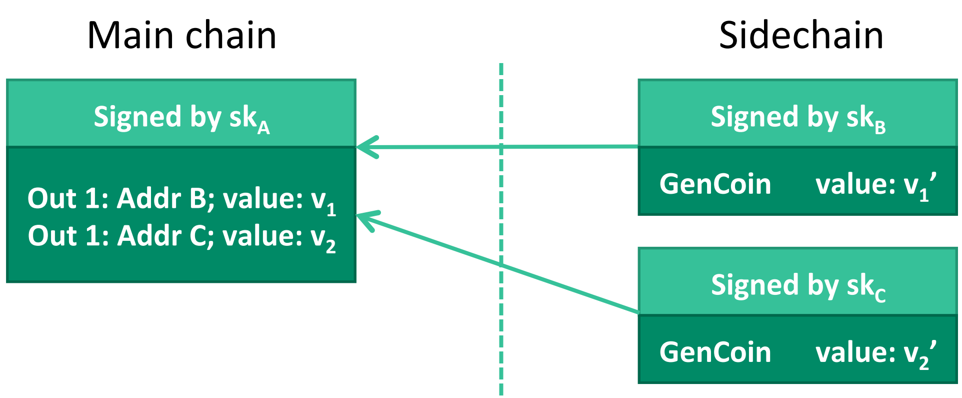
Sidechain 2/5

- Proof-of-Burn



- Signed by the same private key
- Same signature scheme

- Snapshot

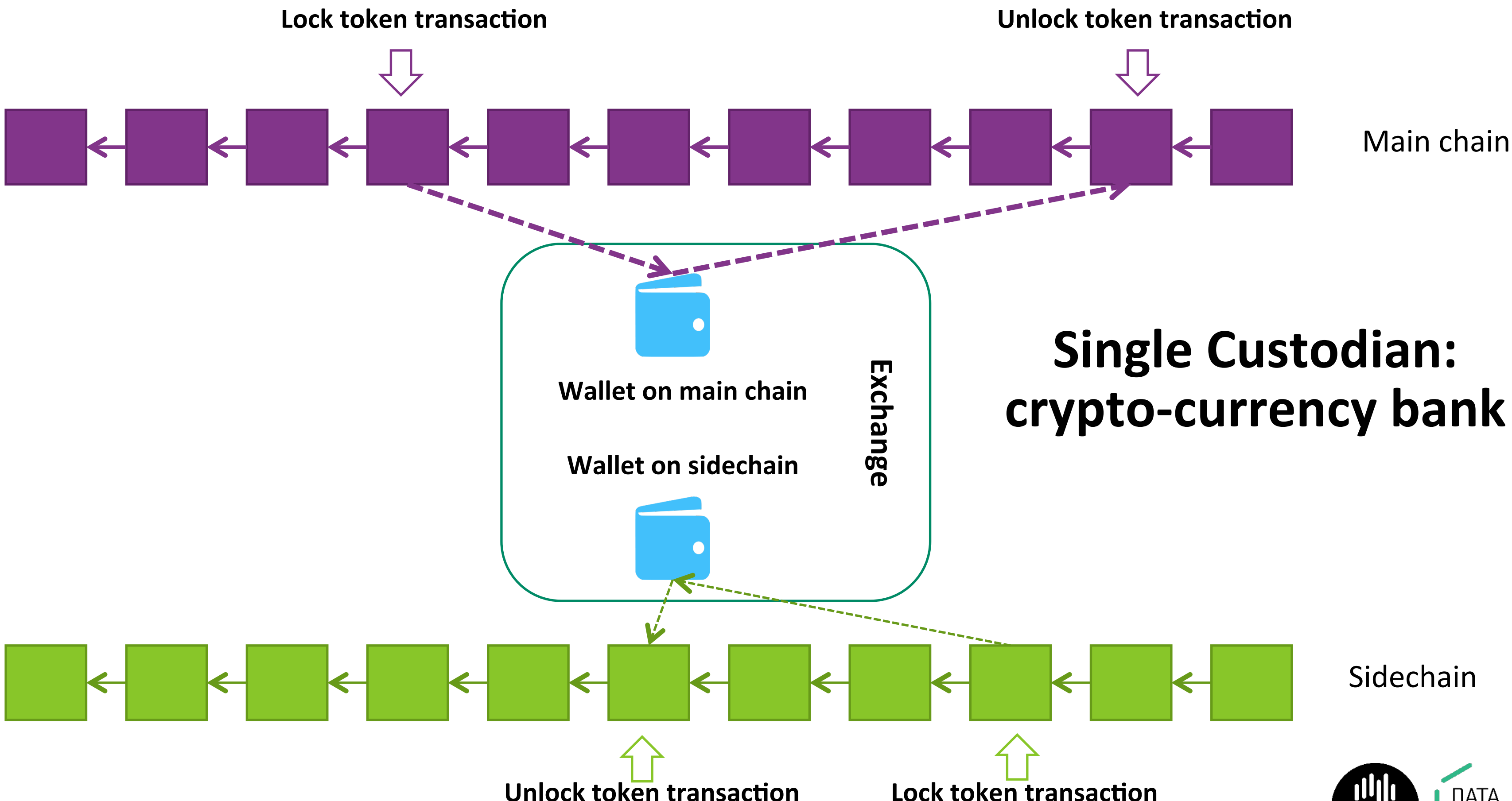


Sidechain 3/5

- *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

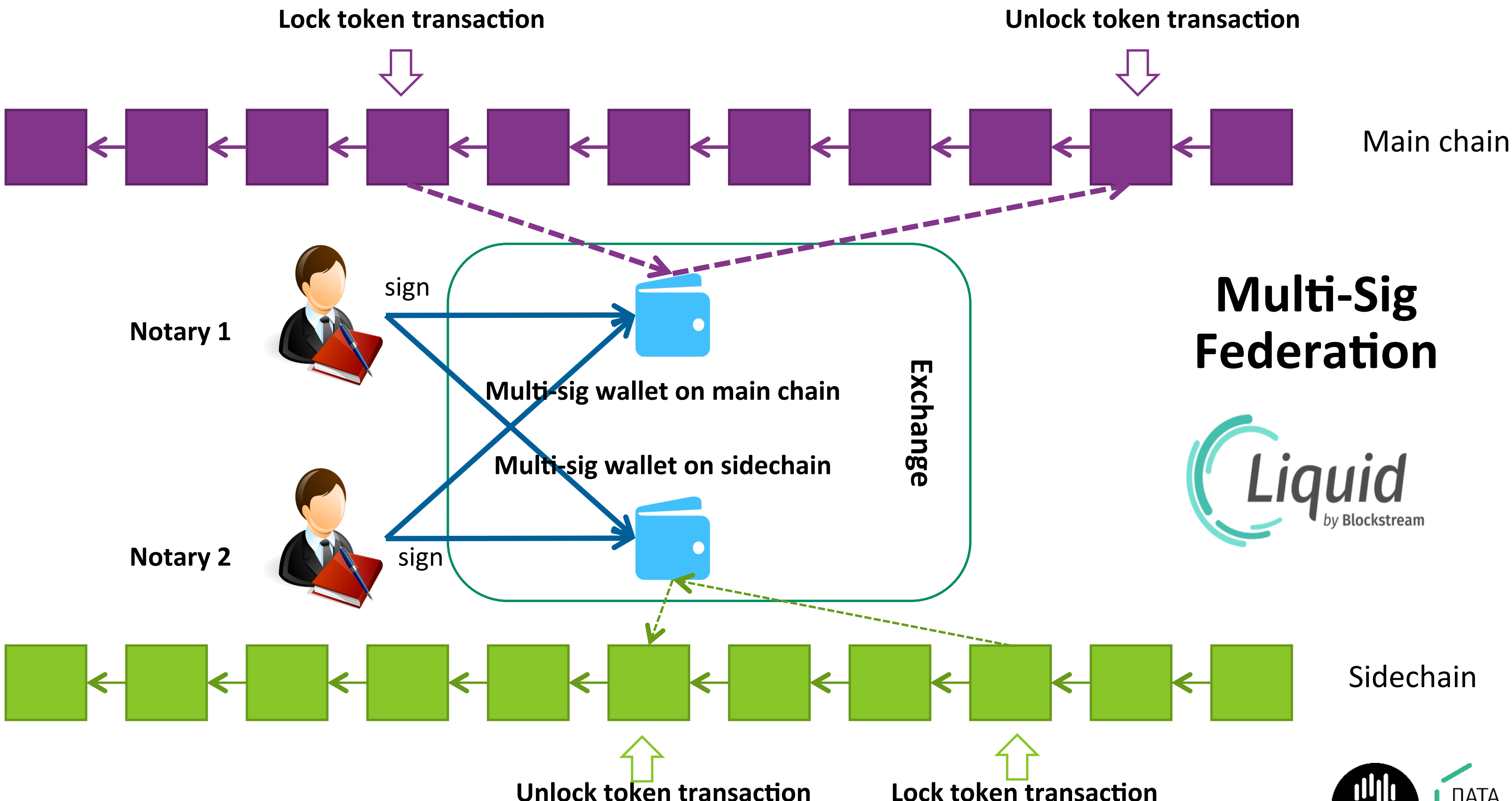
- Single Custodian
- Multi-sig Federation

Sidechain 4/5



Single Custodian: crypto-currency bank

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

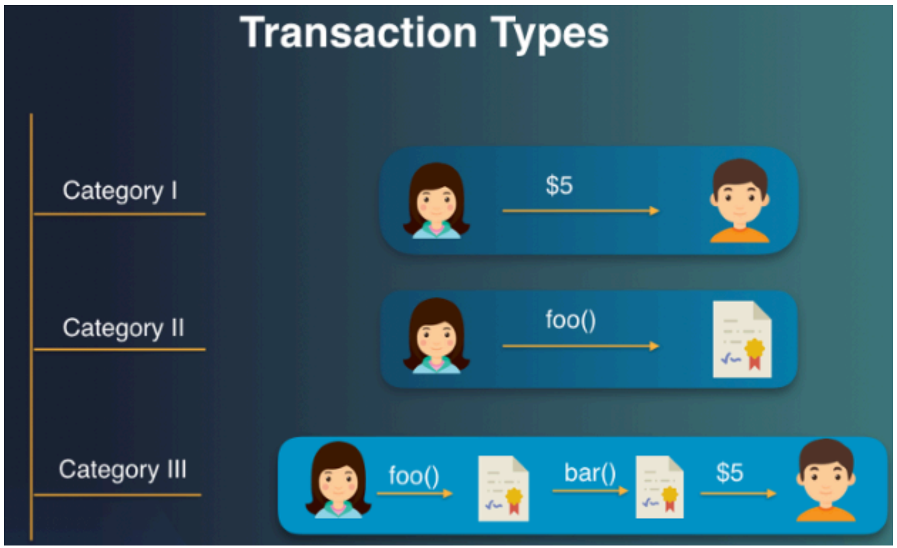
Sharding 1/5

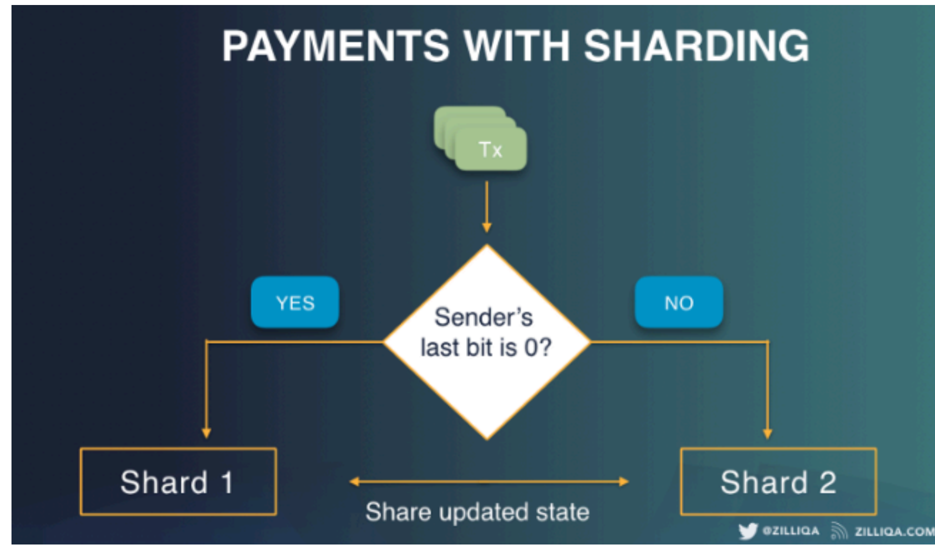
- Full nodes require sizeable storage space
  - Bitcoin > 200GB
  - Ethereum > 600GB
  - Keep growing

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

Sharding 2/5

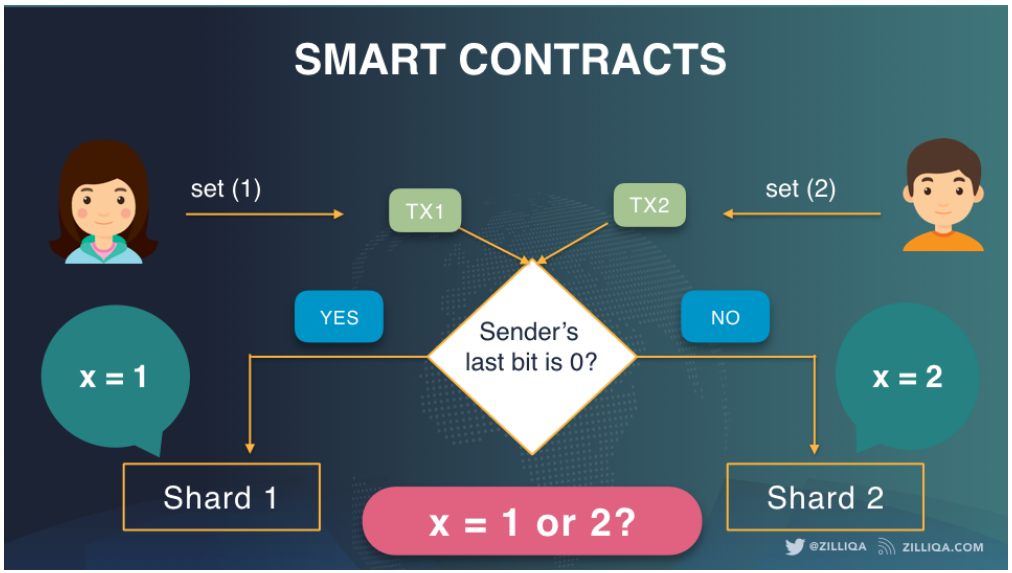
- Transaction Sharding





Sharding 3/5

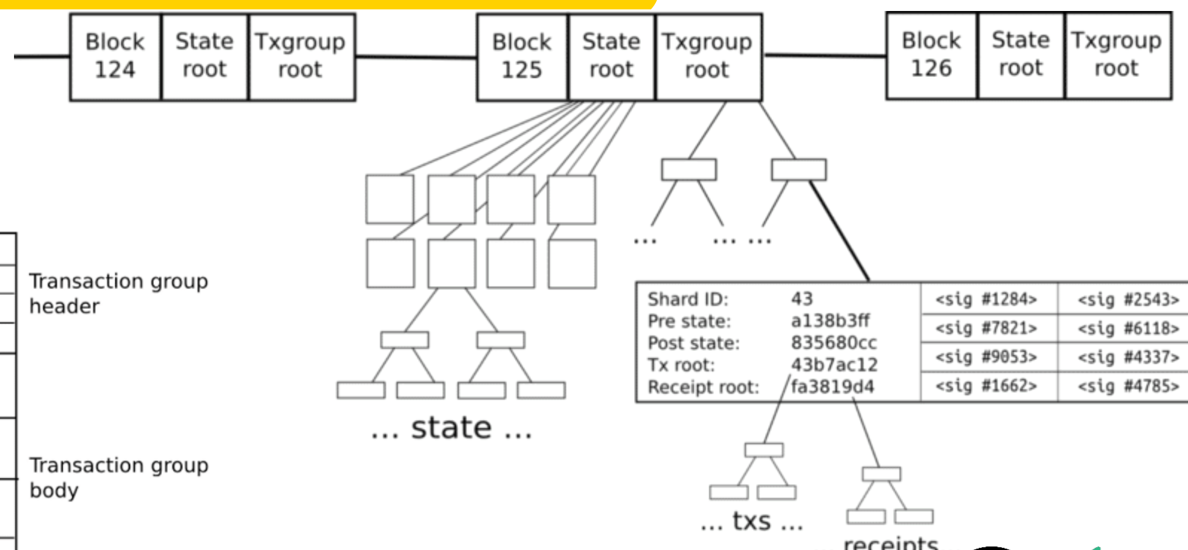
- Conflicting state
- Using the recipient address instead
  - Smart contract address



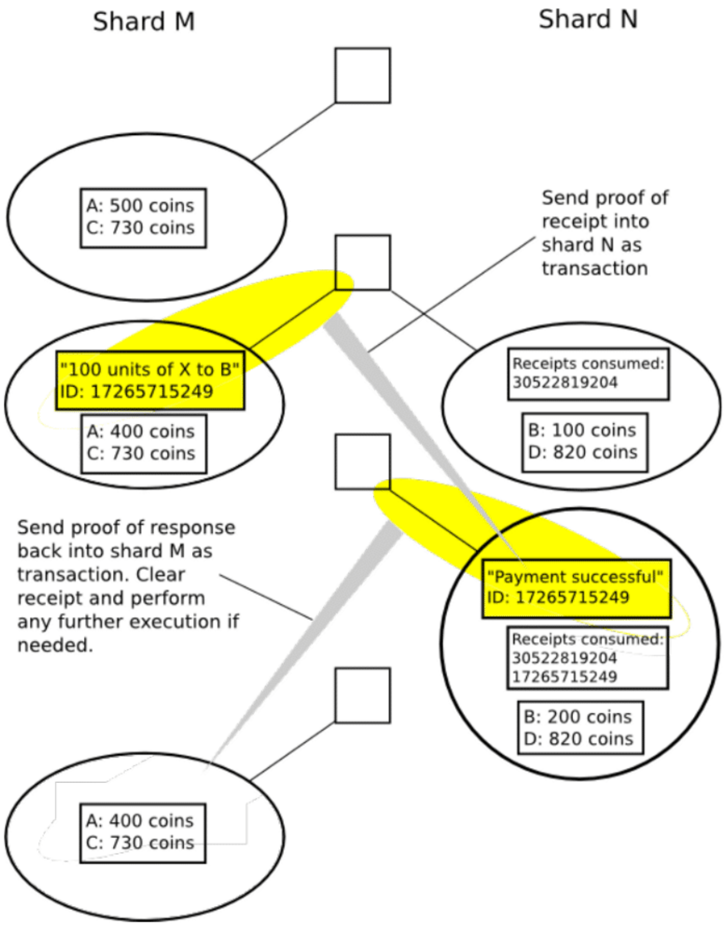
Sharding 4/5

- 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



Sharding 5/5



ethereum

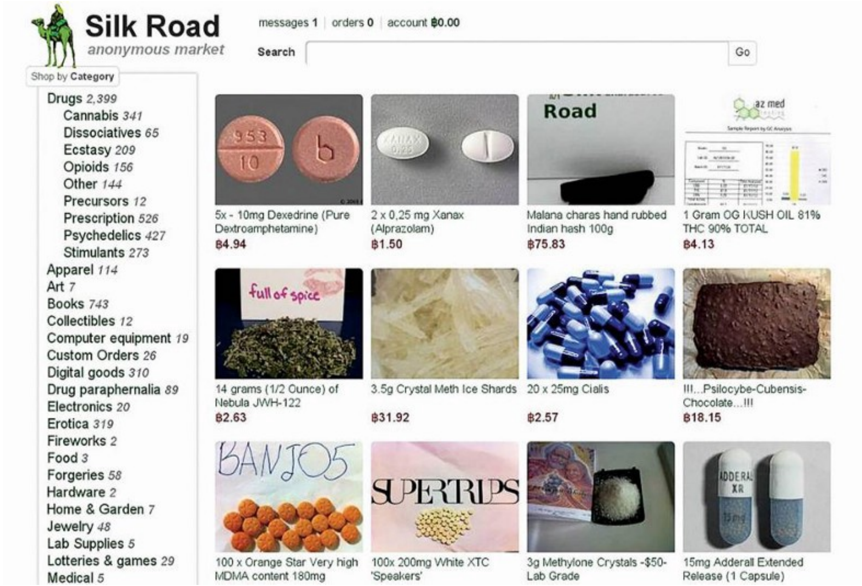
- Transaction
  - Change the state of shard
  - Generate a receipt
- Receipts
  - Stored in a distributed shared memory
  - Seen by other shards
  - Not modified
- Receipts enable cross-shard communication
  - Accessed via multiple Merkle trees from the the transaction group Merkle root

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



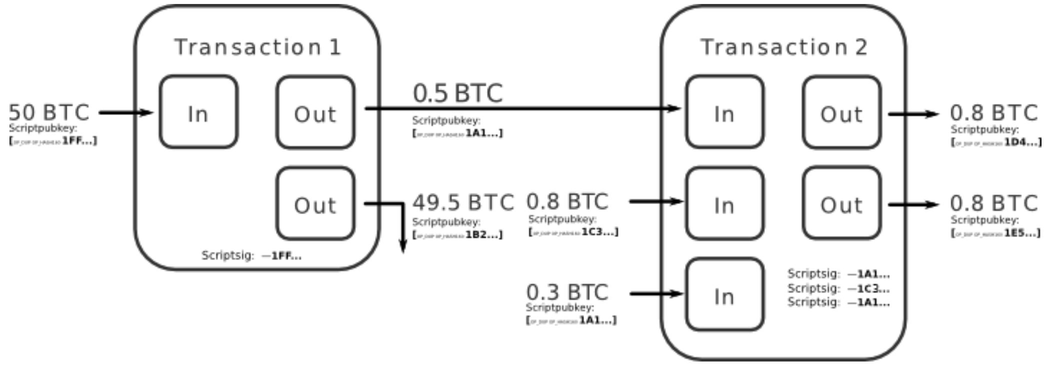
Tor is a intermediary server
- Hidden IP address
- Hidden users surfing on it

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

Dash

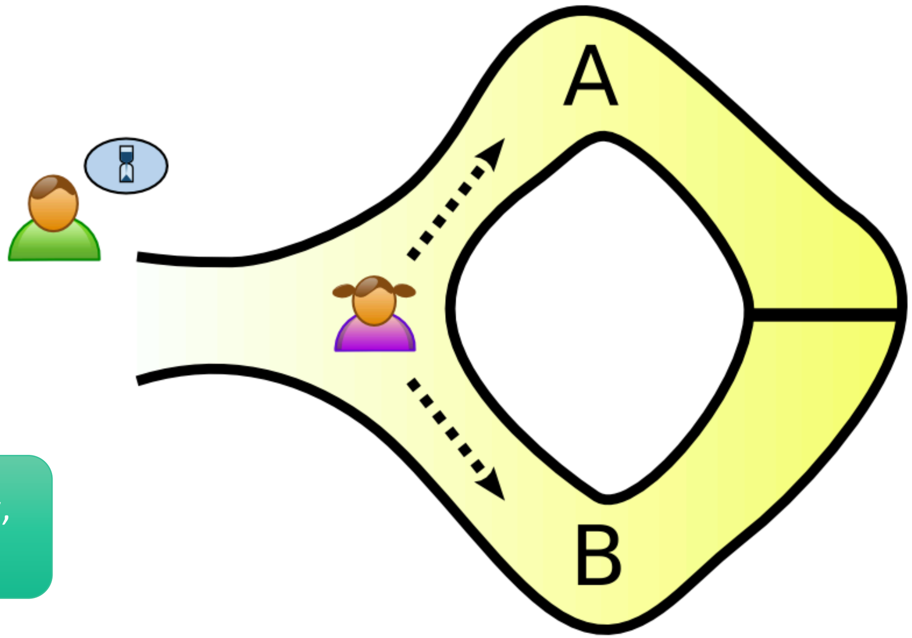
Monero



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
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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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