CS 251: Scaling II
Sharding & Load Balancing

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Recap: Blockchain scalability

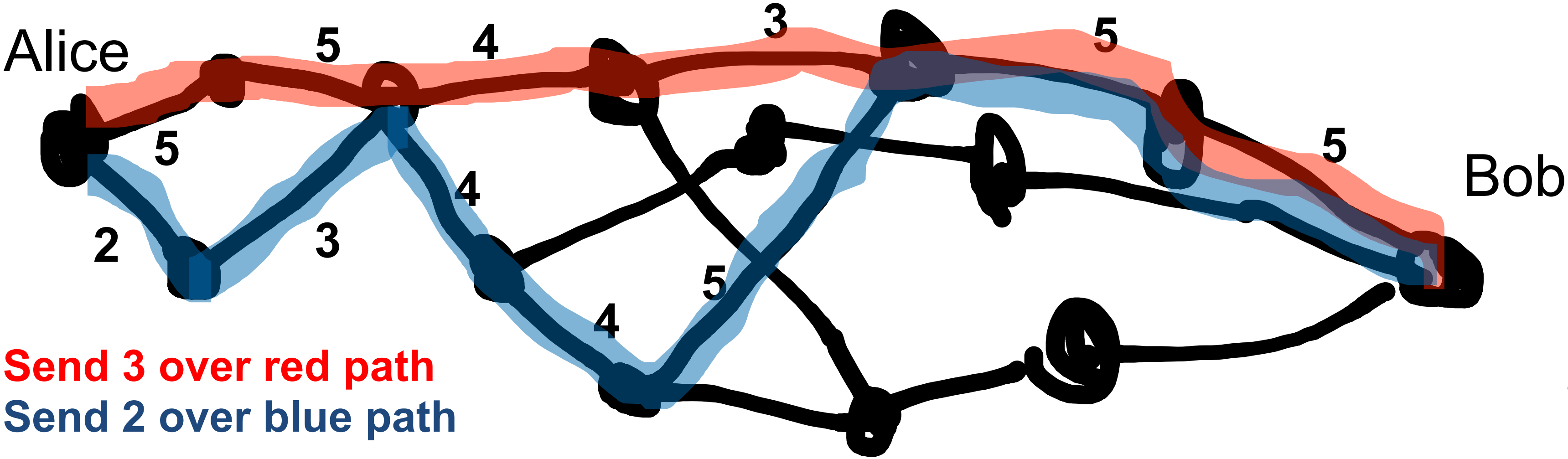
- Two types of scaling problems
    - ❖ Transaction throughput (txs/sec)
    - ❖ Blockchain size (state storage required to validate txs)
- Last lecture:
    - ❖ Off-chain transactions (“channels”)
- This lecture:
    - ❖ Sharding (distributing the verification work)
    - ❖ State commitments (load balancing storage)

Recap: Payment channels

- Bitcoin processes 3 txs / second. This would never be able to replace Visa for payments!
- Off-chain transactions (via channels) could make this a realistic possibility…
- In channels, transactions only hit the blockchain twice:
  - Once to open the channel and deposit collateral
  - Once to close the channel and net settle

Lightning network

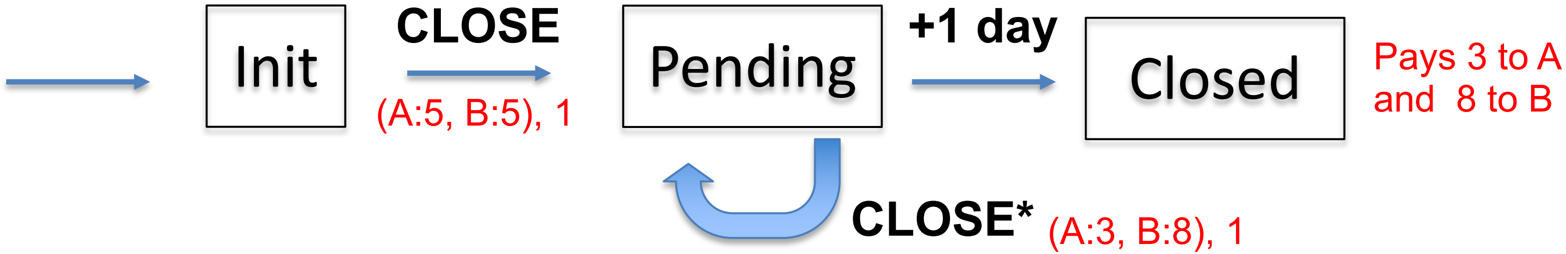
- Lightning is an overlay network of channels
- Payment from Alice to Bob can be routed over any multi-hop path of channels with sufficient collateral



Send 3 over red path
Send 2 over blue path

State channels

- Much simpler to build a payment channel with stateful smart contract (e.g. in Ethereum)



- But stateful contracts require more *blockchain storage* and more complex *verification*

Channels lower user costs

- Micropayments (tx fees too high)
- High gas costs for Ethereum smart contracts

Today’s topic: load balancing

- Sharding (load balancing transaction verification)
- State-commitments and authenticated data-structures (load balancing state storage)

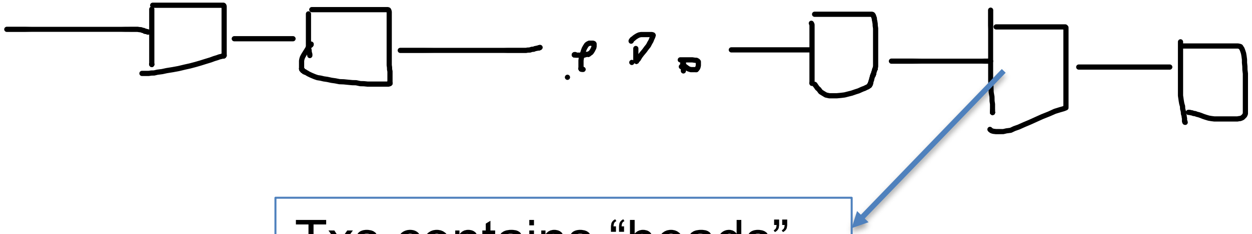
Sharding Strawman #1

- Split blockchain into N independent blockchains, call each a “blockchain shard”
  - Shards have independent states (e.g. different types of coins, independent smart contracts)
  - Shards have different sets of validators
  - Shards run consensus independently
- Problems:
  - Dividing validator set isn’t great for consensus security
  - Only handles state that can be truly partitioned

Sharding Strawman #2

- Attacker of Strawman #1 needs to compromise 1/N fewer validators to cause forks on one of the blockchains
- Idea: keep a root blockchain with all consensus validators that resolves forks, but doesn't verify transaction validity

Root ledger

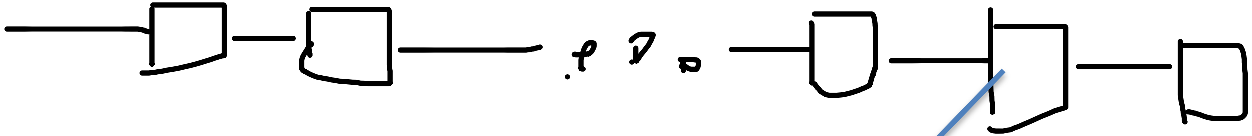


Txs contains “heads” of the N shard chains

Sharding Strawman #2

- Problem: adversary compromises validators on one shard, approves invalid transactions. **Can we leverage root ledger to resolve?**
- Solution: state commitments and fraud proofs

Root ledger



Txs contains “heads” of the N shard chains

State commitment

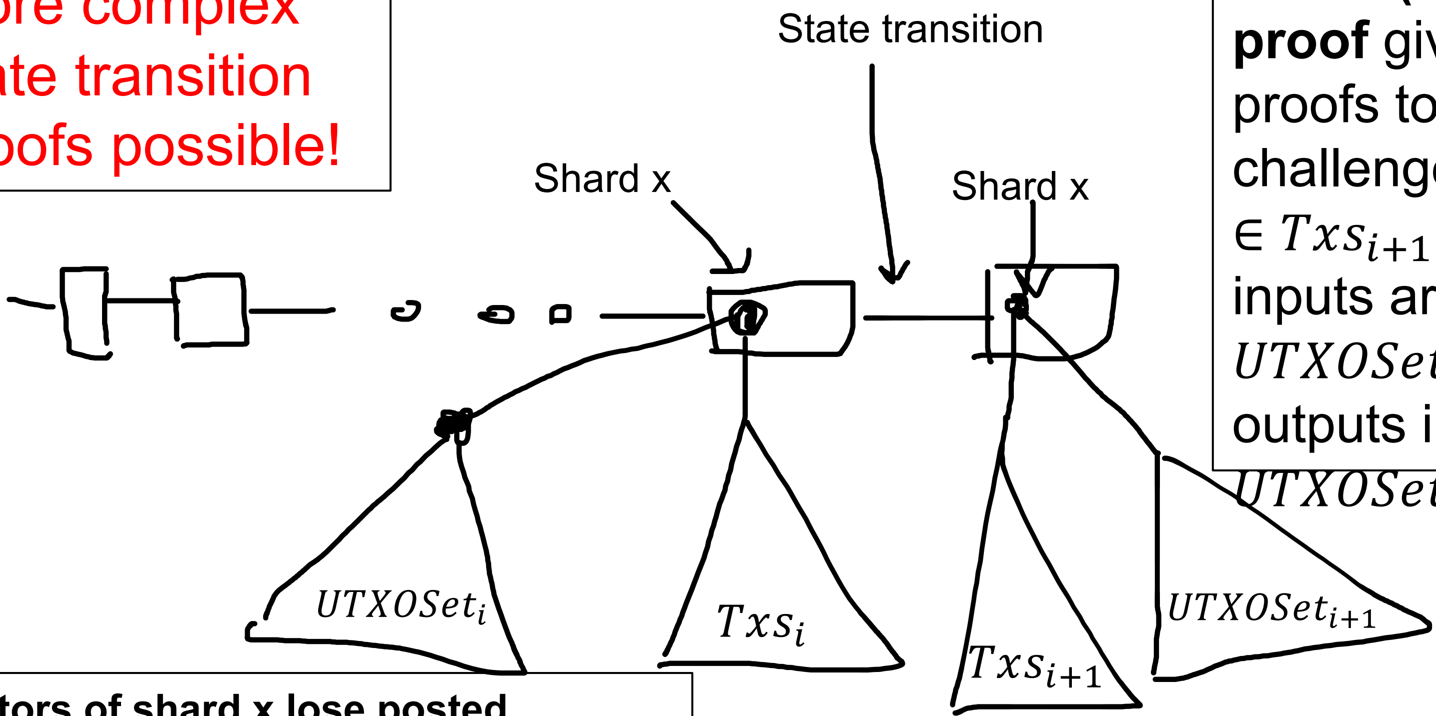
- Bitcoin state is the UTXO set (the set of currently *spendable* coins) --- i.e. valid records of ownership
- Verifying a transaction consists of:
  - Checking inputs are *valid*, i.e. in the current UTXO set
  - Checking local information (running script on transaction data), e.g. sum inputs > sum outputs
- Idea: Blockchain stores Merkle tree root of UTXO set
  - Root commits to the state, updatable
  - Validity of coin/txo proved with Merkle path

Plasma (simplified)

- Root blockchain logs state commitments for N shards, and commitment to txs in each update
- Shard state commitment could be a UTXO set (Merkle tree), or more complex (Sparse Merkle tree, Patricia tree)
- If shard *x* sends state update that included bogus tx, then users may challenge the update:
  - Whistleblower posts txid, claims fraud
  - Validator(s) of shard *x* produce tx payload, validity proofs (e.g. Merkle) for the tx and all its inputs
  - Whistleblower may perhaps collect collateral reward

Plasma (simplified)

More complex state transition proofs possible!



Fraud (defensive) proof gives Merkle proofs to show challenged $tx \in Txs_{i+1}$ and all inputs are in $UTXOSet_i$, all outputs in $UTXOSet_{i+1}$

Validators of shard x lose posted collateral for failed fraud proof

Cross-shard transaction

- Can we pay from account on shard x to account on shard y?
- With state commitments, validators on shard y can verify existence of transaction processed on shard x given validity proofs
- **Receipt tx:**
    - Tx1 removes z coins from account A on x, creates special receipt output *rct1*
    - Tx2 adds z coins to account B on y, pre-conditioned on validity proof for *rct1*

Random committee shards

- Rather than fraud proofs, can we guarantee that w.h.p. enough honest validators are in charge of each shard?
- **Recall beacons/VRF sortition:** Elect random committees of validators (e.g. from set of weighted public-keys) to govern each shard
- Can re-elect committees periodically
    - Requires reshuffling shard data storage

“Stateless” validator

- Validator only stores sequence of state commitments
- Attached to each tx are validity proofs (e.g., Merkle proofs) for all inputs
- Validators update state commitments after each new block of txs (**how? Think how this could be done with Merkle trees…**)
- With Merkle trees a bit impractical…attaching proofs to every tx makes this large (would increase Bitcoin tx size from 250bytes to >1KB)
- Merkle tree replacements based on classic RSA accumulators can batch/aggregate proofs (new result from last year!)

“Stateless” validator

“Stateless” validators enable:

- Validator separation from data/storage providers (*availability providers*)
- Frequent random shuffling of validators among shards without moving data
- In extreme case, users store their own UTXOs/account data (nobody stores the whole blockchain)

Utreexo – by T. Dryja
Batching Techniques for Accumulators w/ Applications to Stateless Blockchains by D. Boneh, B. Bünz, B. Fisch
https://ethresear.ch/t/the-stateless-client-concept/172 – V. Buterin

Summary

- **Payment/state channels** drastically reduce txs that need to hit the blockchain
- **Sharding methods** load balance both validation of txs and state storage
- **State commitments** are a key sharding tool:
    - Enable flexible roles (nodes contributing to data *availability, consensus, validation)*
    - Extreme case: data spread over users