Erasure Coded Sharding

Bribery-resistant sharding for scalable blockchains

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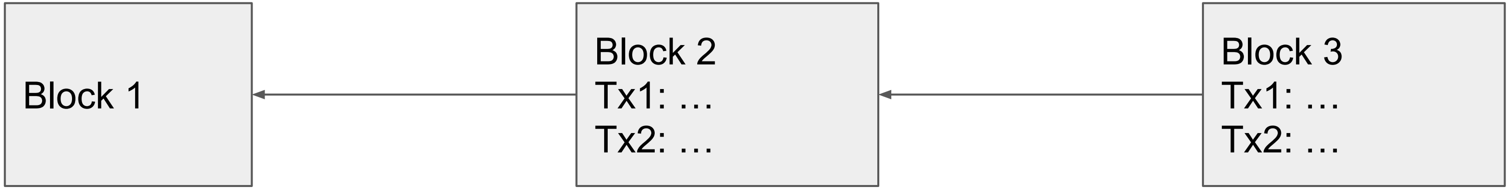
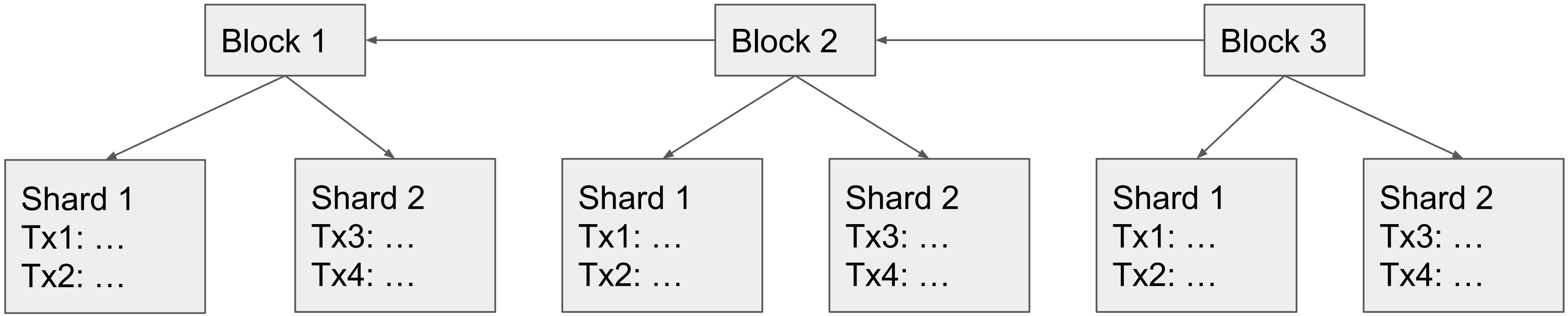
Regular blockchains (Bitcoin, Ethereum)



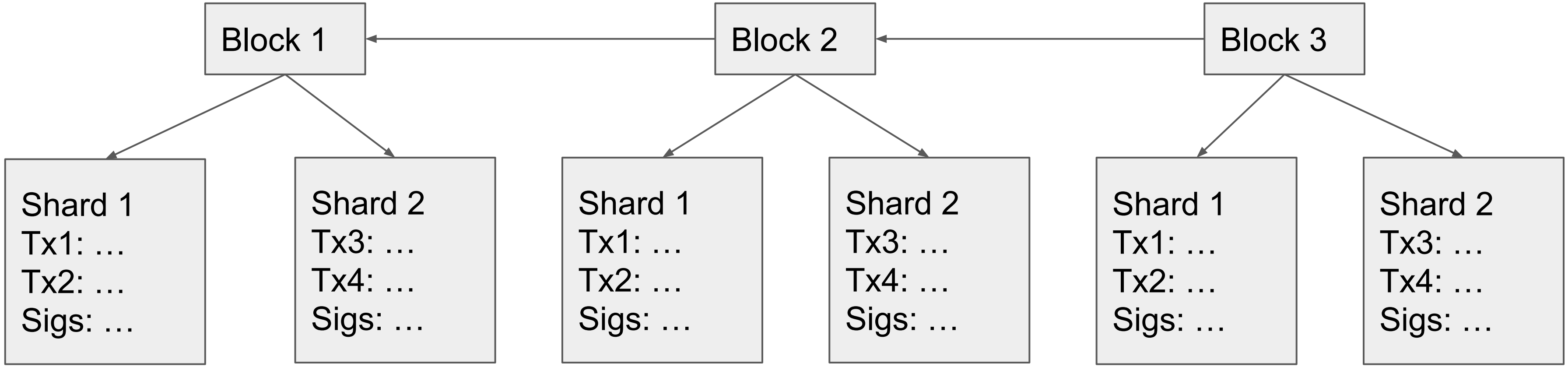
- “A → B” means “A includes hash code of B”
- Proof-of-work or proof-of-stake (details omitted)
- All full nodes download and verify every transaction
- Problem: this limits how many transactions per second there can be

Sharded blockchain



- Regular full nodes only download top chain
- Shard-level verifiers download data for a given shard
- Each shard is responsible for a subset of accounts
- Split transactions into “send” and “receive” (like actor model)
- Problem: how do regular full nodes know shard-level data is valid?

Random validator pools

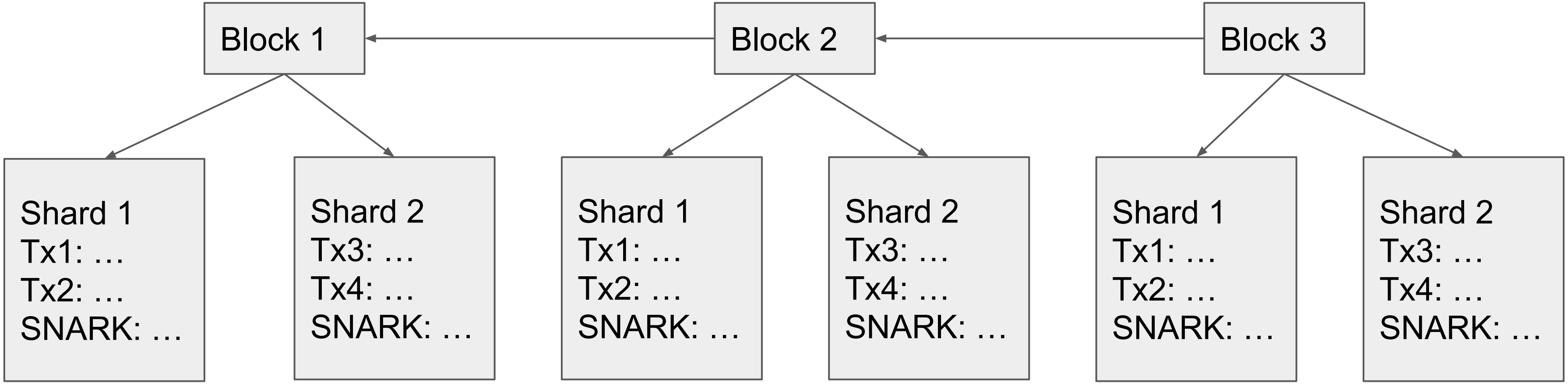


- Call together a validator committee by selecting ~1000 random stakers
- If >⅔ of stakers are honest, with high probability >½ of the committee is honest
- Regular full nodes only download signatures, not transactions
- Can be iterated multiple levels (Inductive Consensus Tree Protocol, ictp.io)
- Problem: bribery

3 types of validators

- 😇 Altruistic: Always honest
- 😈 Malicious: Trying to sabotage the system, even at cost to self
- 🤑 Greedy: Honest unless bribed sufficiently
- If >⅓ of stakers are malicious or greedy, committees are likely to be bribable.
- Only one committee must be bribed to mint fake currency; bribery is cheap.

zk-SNARK verification



- Each valid shard contains a zero-knowledge proof of its validity
- Full nodes download and check SNARKs, not transactions
- Can be iterated multiple levels (and compressed) with recursive SNARKs
- Problem: data availability attacks (reveal SNARK, withhold data)

Data availability attacks

- Shard-level validators may provide a SNARK showing the shard is valid, but withhold the shard data (incl. transactions) from others
- This prevents individual accounts from proving account states or unspent transactions, which prevents the account's funds from being accessible
- Can we use random validator committees to mitigate this? They can be bribed, knocking out lots of account data
- Solution concept: Can we force a large *percentage* of committees to be knocked out to make *any* shard's data unavailable?
- (inspired by PolyShard, algorithm details differ; PolyShard requires all validators to download all new blocks)

Erasure code

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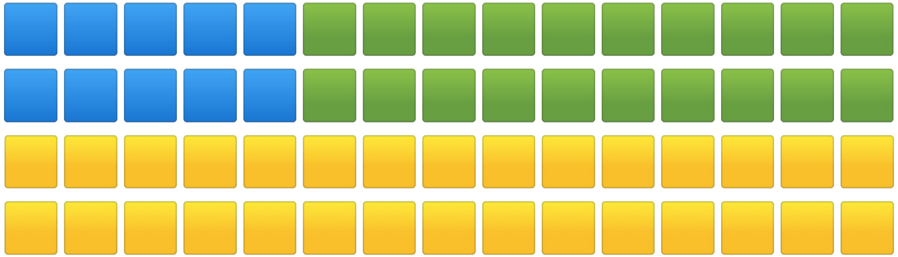
- k blue squares = original data chunks (each the same # bytes), 5 in this case
- Redundancy factor α, 3 in this case
- $k(\alpha - 1)$ green squares = data augmentation
- Can recover k blue squares given *any* k blue or green squares!
- Reed-Solomon code works by polynomial interpolation: interpret blue squares as polynomial coefficients in a finite field, get green squares by evaluating polynomial at more points, recover blue squares by fitting a polynomial
- Encoding is $\sim O(\alpha k)$, decoding is $\sim O(\alpha^2 k^2)$ for Reed Solomon codes
- Encoding is $\sim O(\alpha k)$, decoding is $\sim O(\alpha k)$ for Raptor codes (need ~10 extra chunks)
- Reed-Solomon parallelizes well, tractable to do in a SNARK

Erasure coding shard data

- Shard 1 data: 
- Shard 2 data: 
- Etc, for x shards
- The data consists of $k\alpha$ chunks for each shard ($xk\alpha$ total chunks)
- Split into $k\alpha$ columns; we can recover all data from k full columns
- Split stakers into $k\alpha$ equal-sized pools, each responsible for storing 1 column
- If enough honest stakers store all their data, we can recover everything!
- Storage per staker = x chunks (1/k of original data), it scales decently
- Use SNARKs to prove that enough signatures exist that a significant fraction of stakers would have to lie about their storage for data to be unrecoverable
- In case some chunks are dropped, use a different SNARK for each shard

Reducing storage by erasure coding each column

- Shard 1 data:
- Shard 2 data:
- Redundant 1:
- Redundant 2:



- Secondary redundancy factor β (2 in this case)
- We can recover a column with x of βx chunks
- We can recover everything with (α + β - 1)xk of αβxk chunks
- Split stakers into αβxk equal-sized pools, each responsible for storing 1 chunk
- If enough honest stakers store their chunk, we can recover everything!
- Storage per staker = 1 chunk (1/(xk) of original data), it scales very well

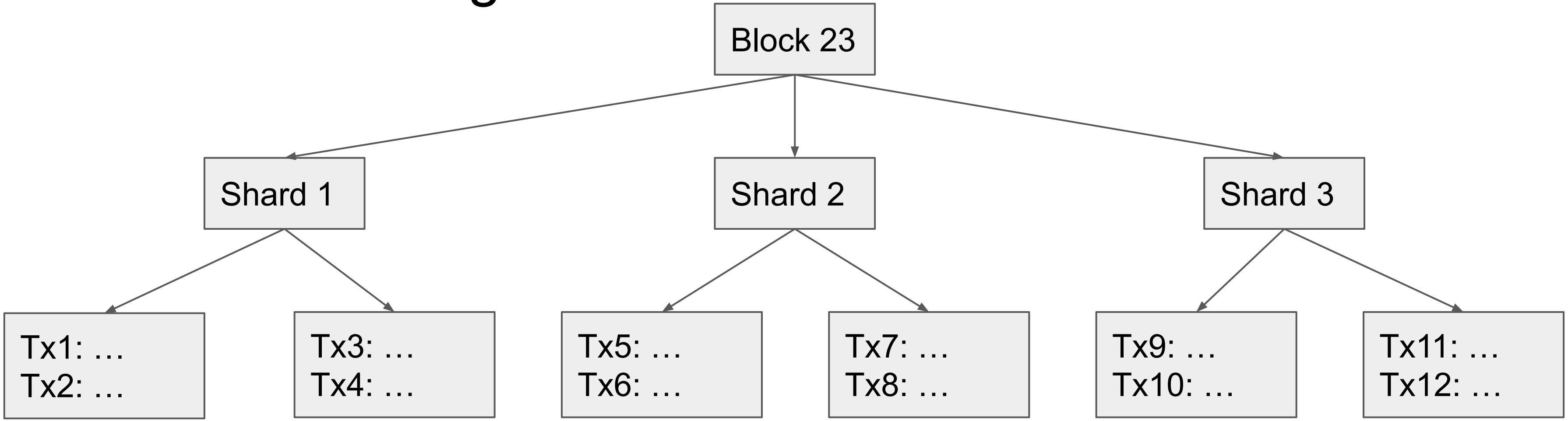
Security analysis

- Set threshold γ, proportion of chunks that must be *asserted* to be stored
- Proportion that must *actually* be stored is $(\alpha + \beta - 1)/(\alpha\beta)$
- Secure if less than $\gamma-(\alpha + \beta - 1)/(\alpha\beta)$ proportion of stakers act maliciously
- Malicious includes 😈 and bribed 🤑
- Cost of bribery ≈ stake amount (easy to prove chunk unavailability & punish)
- Functional if more than γ proportion of stakers are honest most rounds
- Acting honestly includes 😇 and 🤑 (bribery won't happen most rounds)
- E.g. $\gamma=⅔$, $\alpha=\beta=6$ → secure if less than 36.1% of stakers act maliciously

Privacy and smart contracts

- Privacy is easy since we're already using SNARKs
- Transaction data for a private transaction consists of account ID and hash code of new private state (64 bytes total)
- SNARK for a shard proves SNARKs exist for each account state transaction
- 2 types of smart contracts: per-account and independent
- Per-account smart contracts modify account data, including private data
- A single account can partake in multiple per-account smart contracts
- E.g. tokens which are similarly private to the base currency
- Independent contracts are like their own account, data is public

Multi-level sharding



- 3 instead of 2 levels, reduced branching factor
- Reduces work per node
- Use 2d erasure code for each shard, 3d overall (decreases data efficiency, increases compute efficiency of Reed Solomon encoding/decoding)