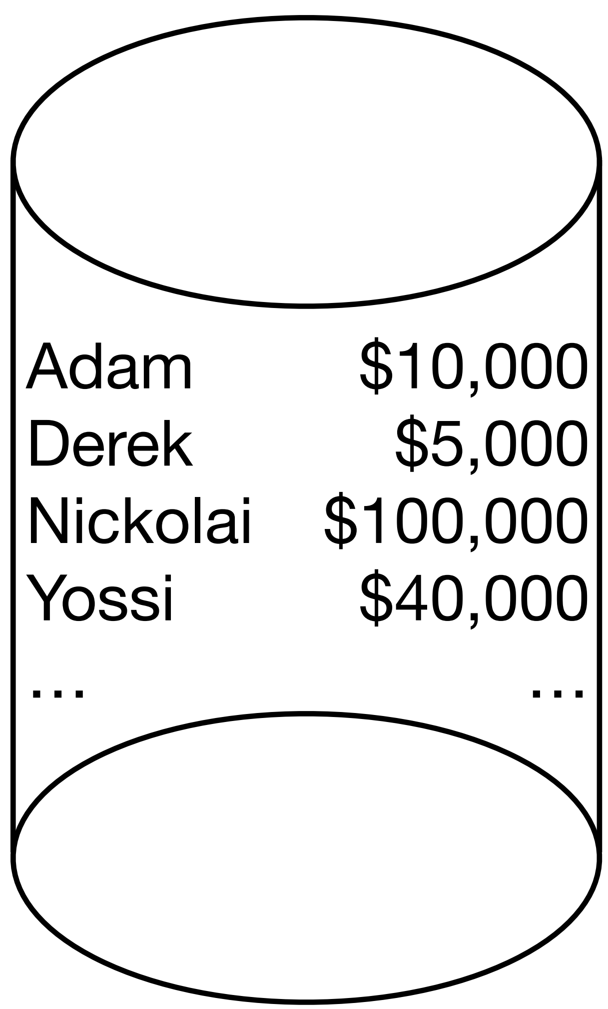
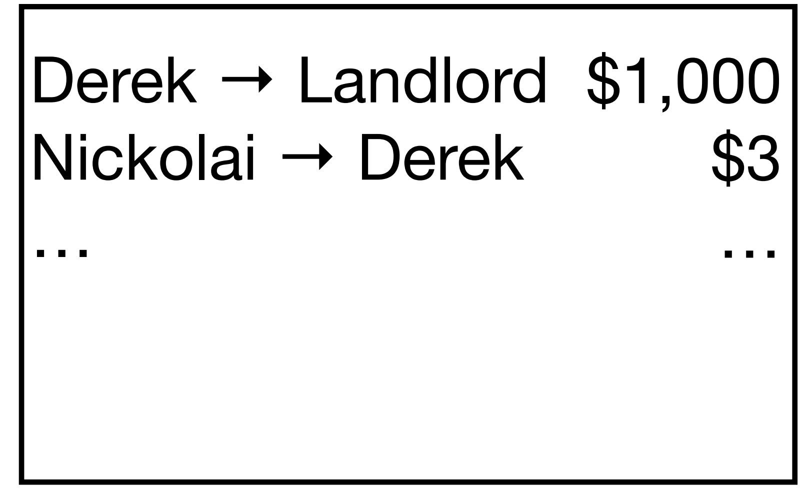
Vault: Fast Bootstrapping for the Algorand Cryptocurrency

Derek Leung, Adam Suhl, Yossi Gilad, Nickolai Zeldovich

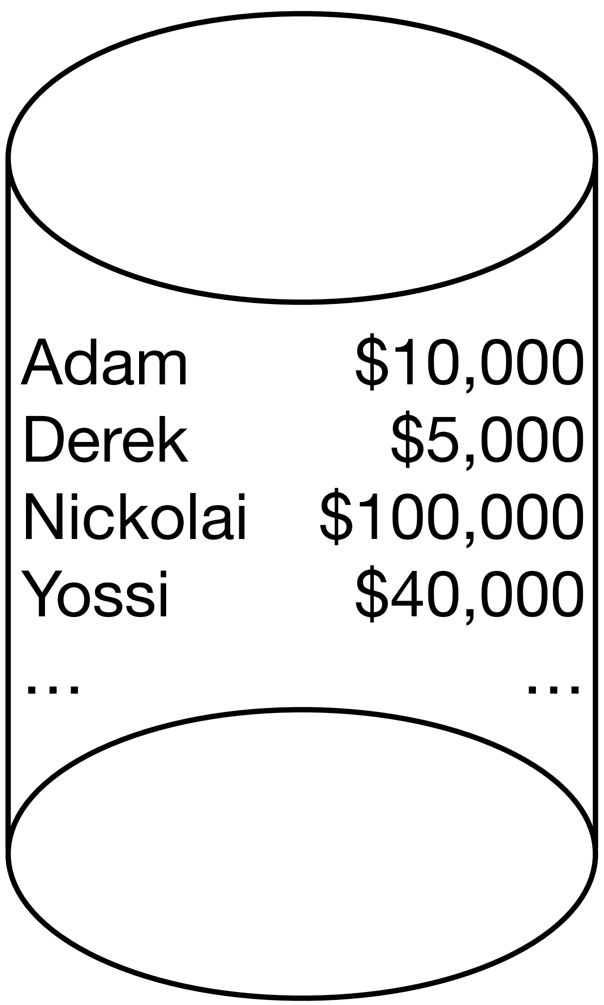
Algorand / MIT CSAIL



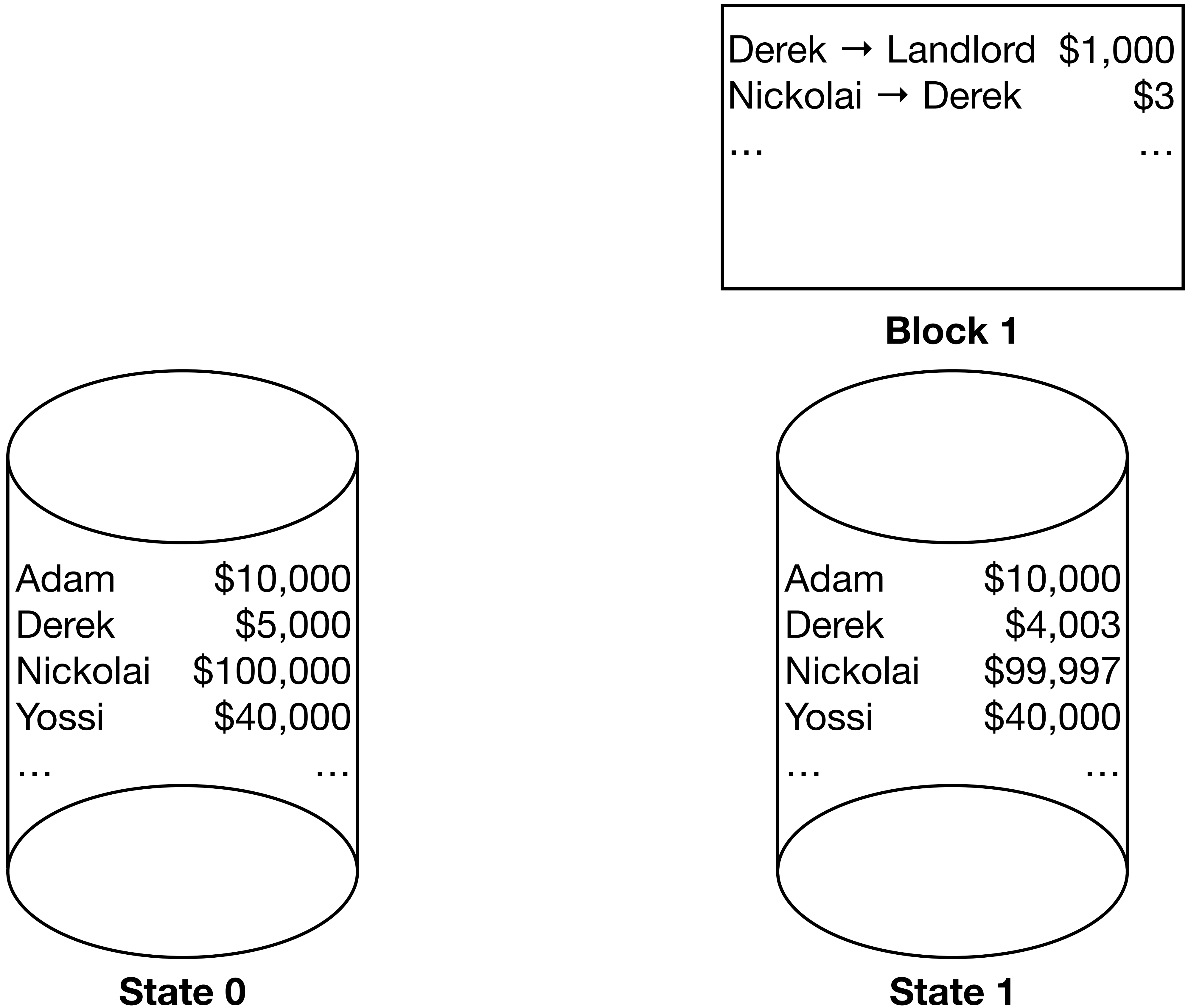
State 0

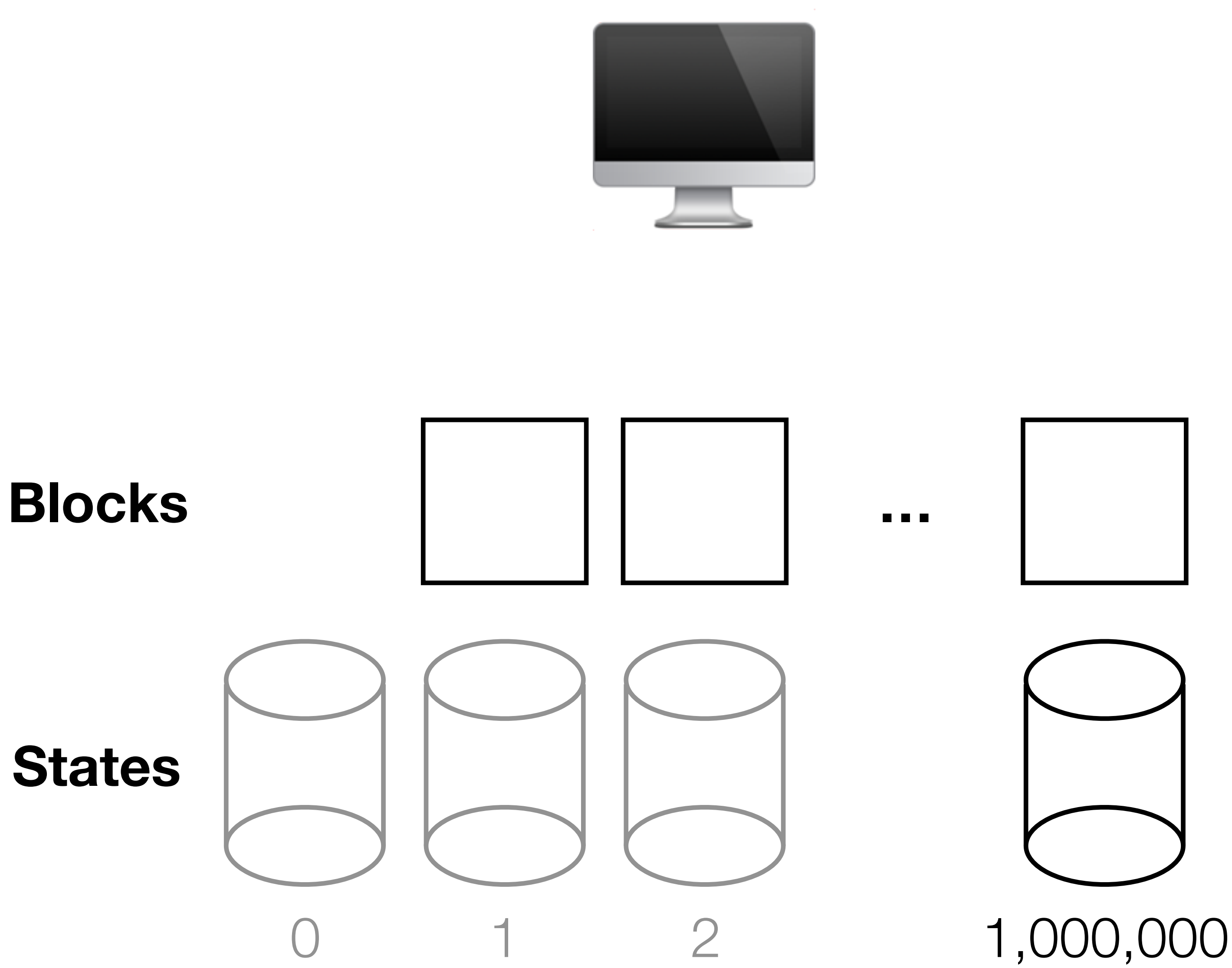


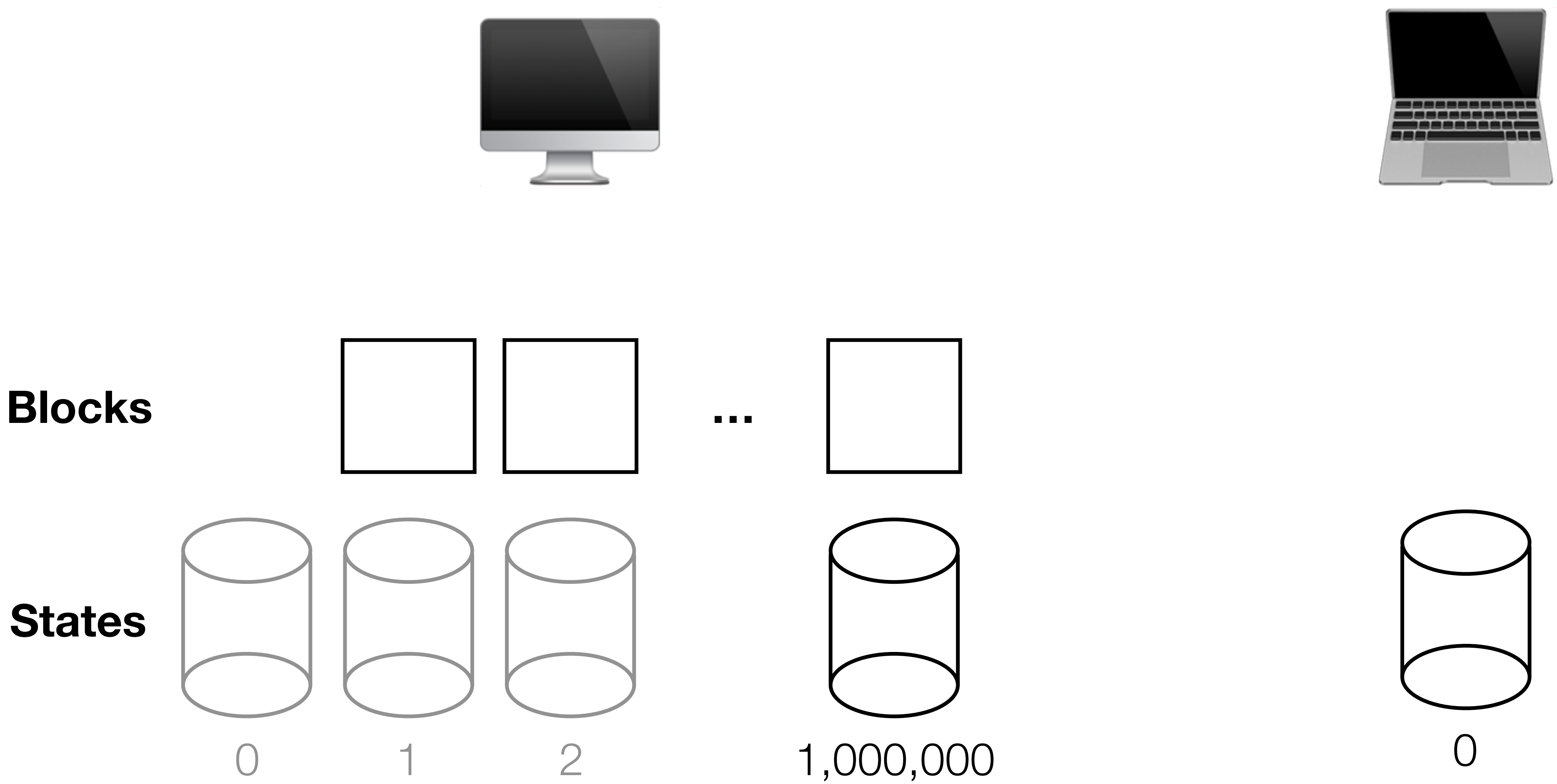
Block 1



State 0


Derek → Landlord $1,000
Nickolai → Derek $3
… …
Block 1
Adam $10,000
Derek $5,000
Nickolai $100,000
Yossi $40,000
… …
State 0
Adam $10,000
Derek $4,003
Nickolai $99,997
Yossi $40,000
… …
State 1


Blocks
...
States
0
1
2
1,000,000


Blocks
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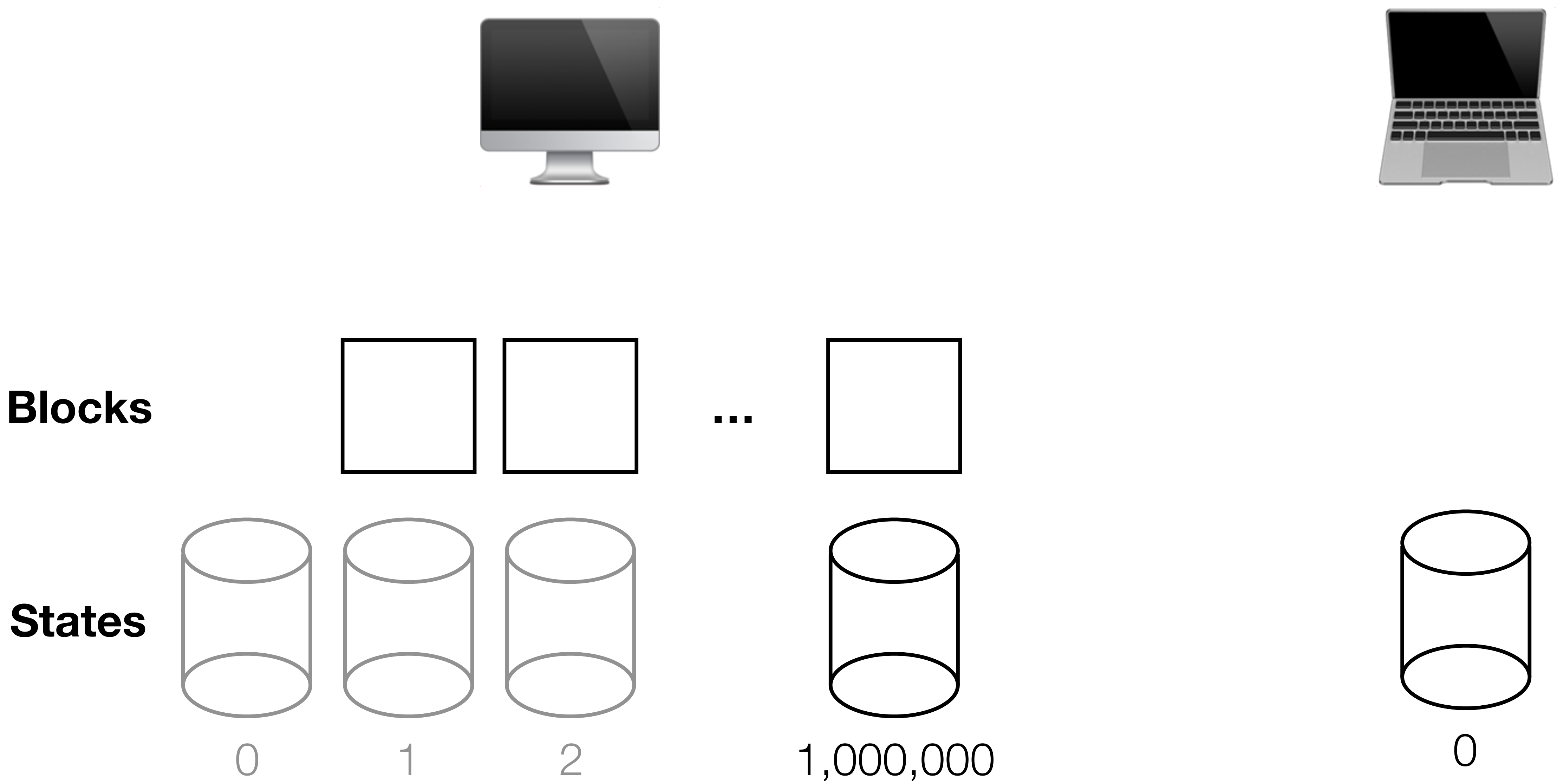
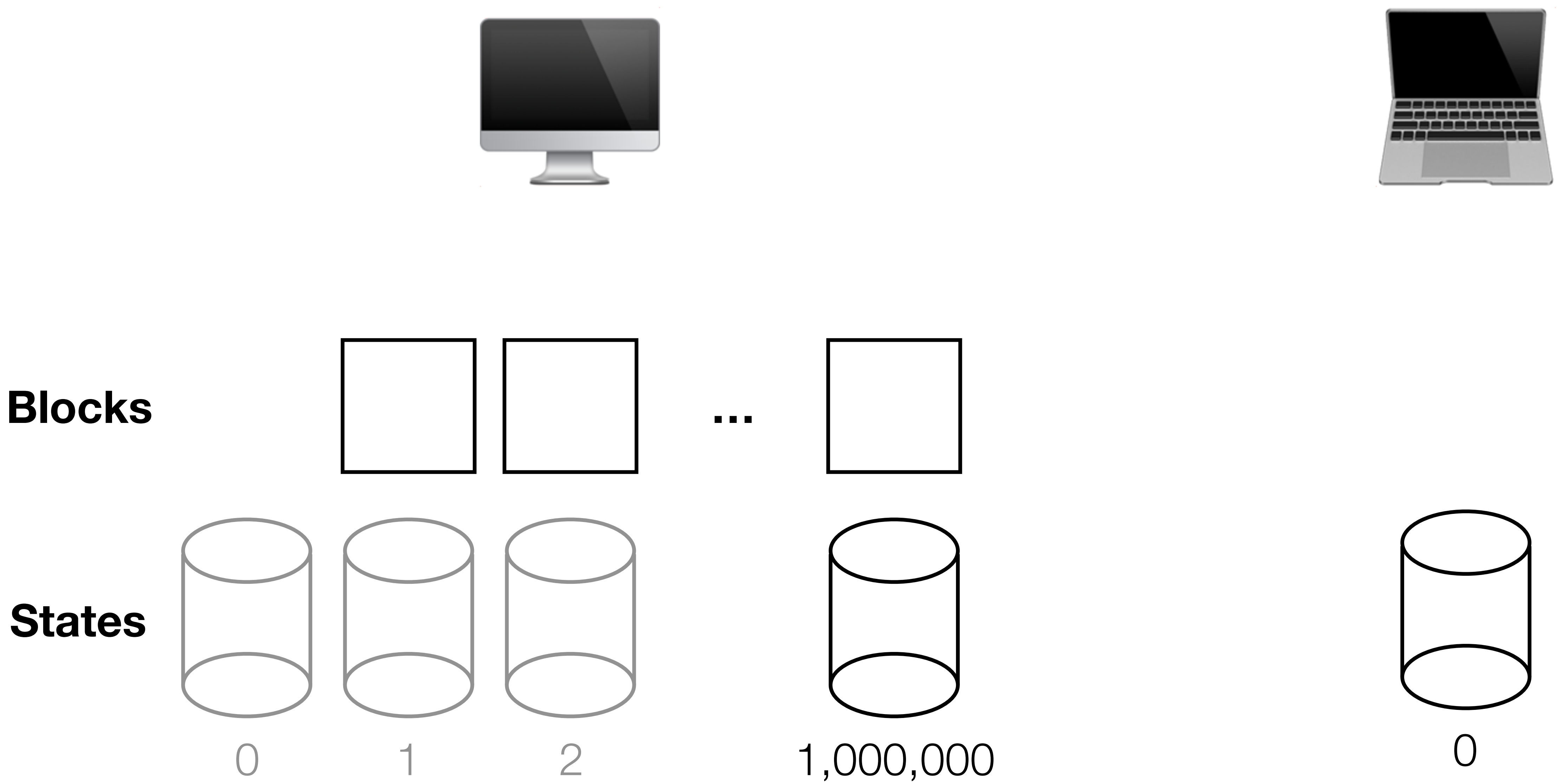
0



How does a new user join the system?

Bootstrapping



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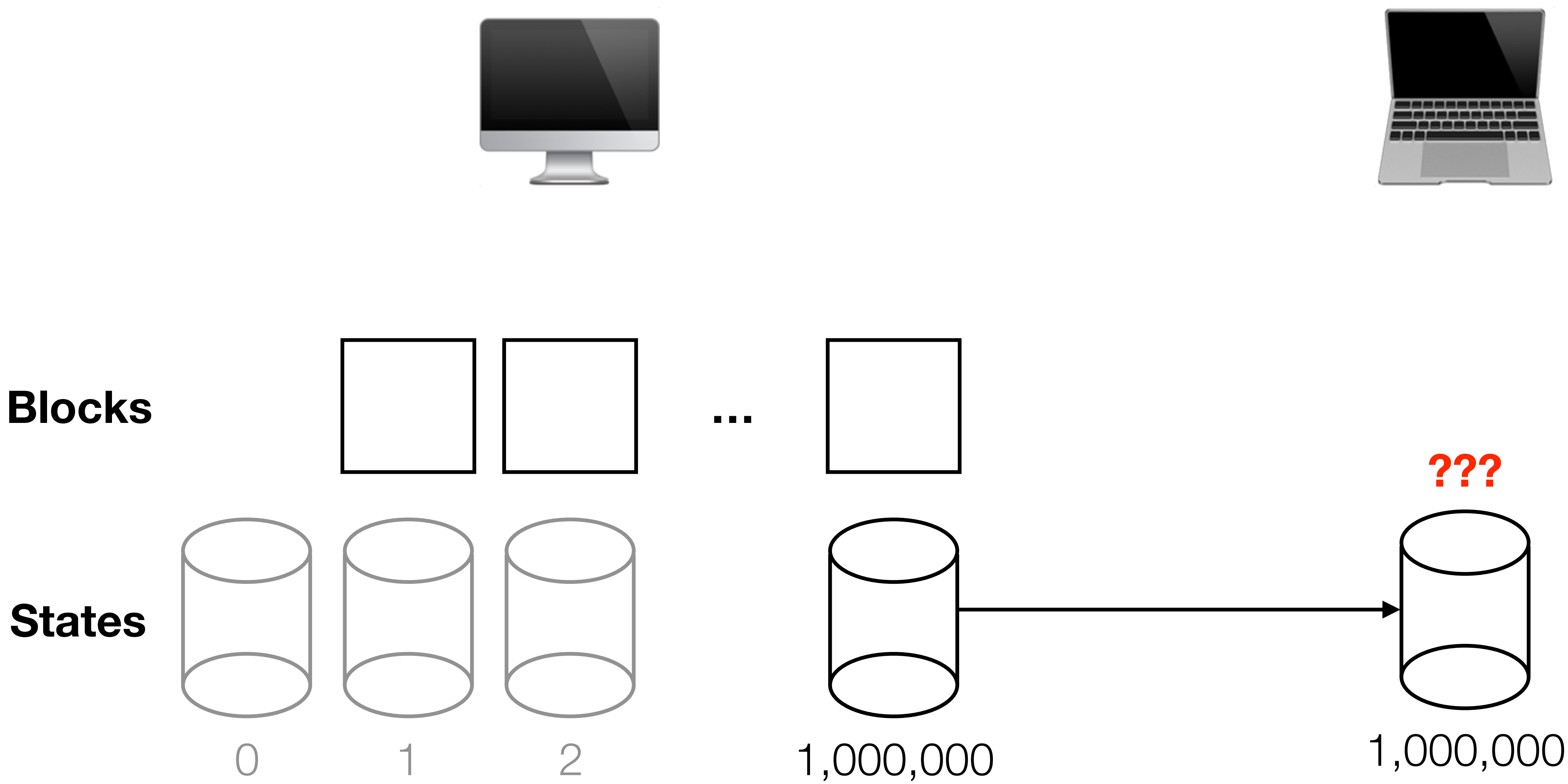

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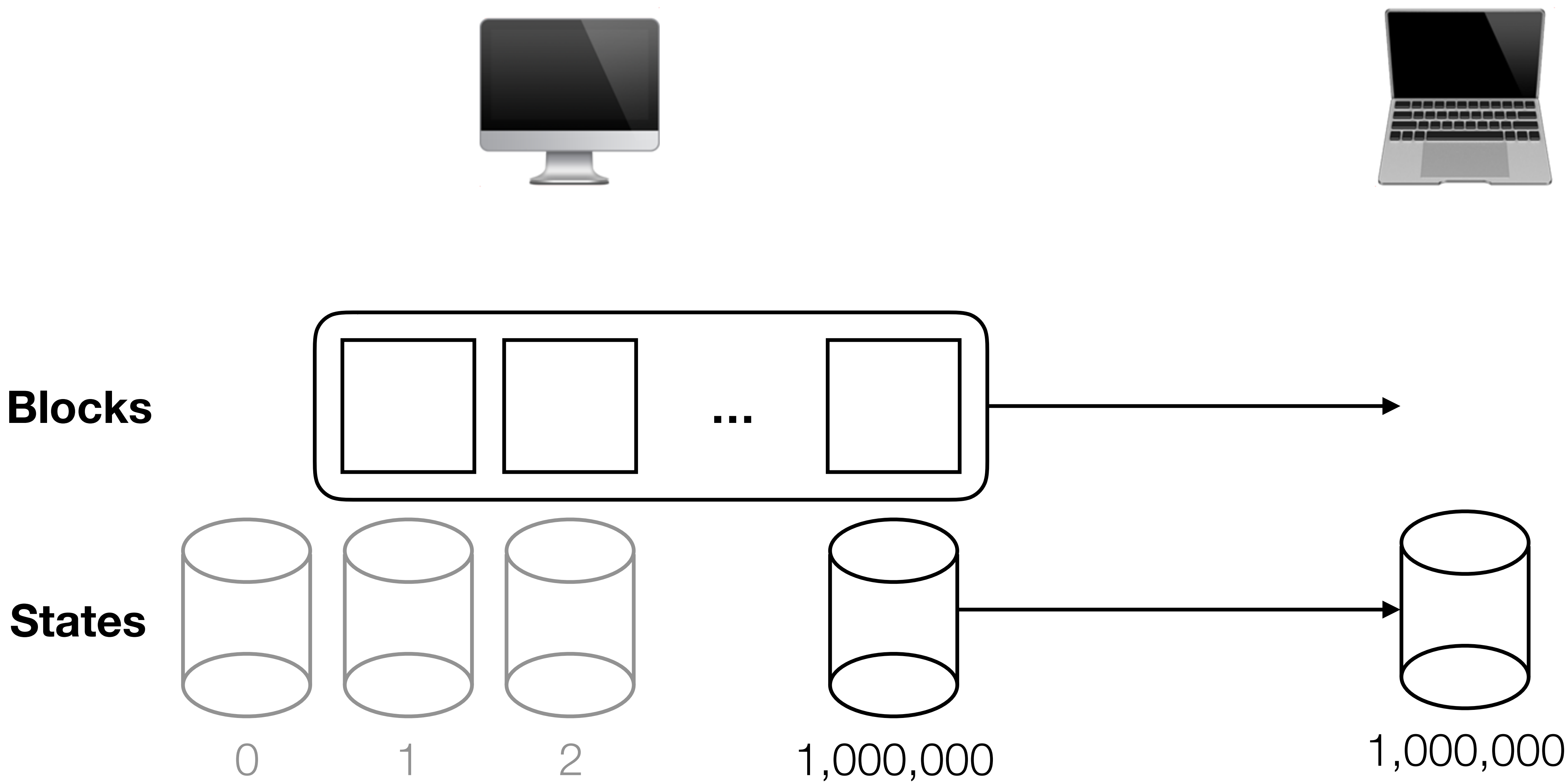

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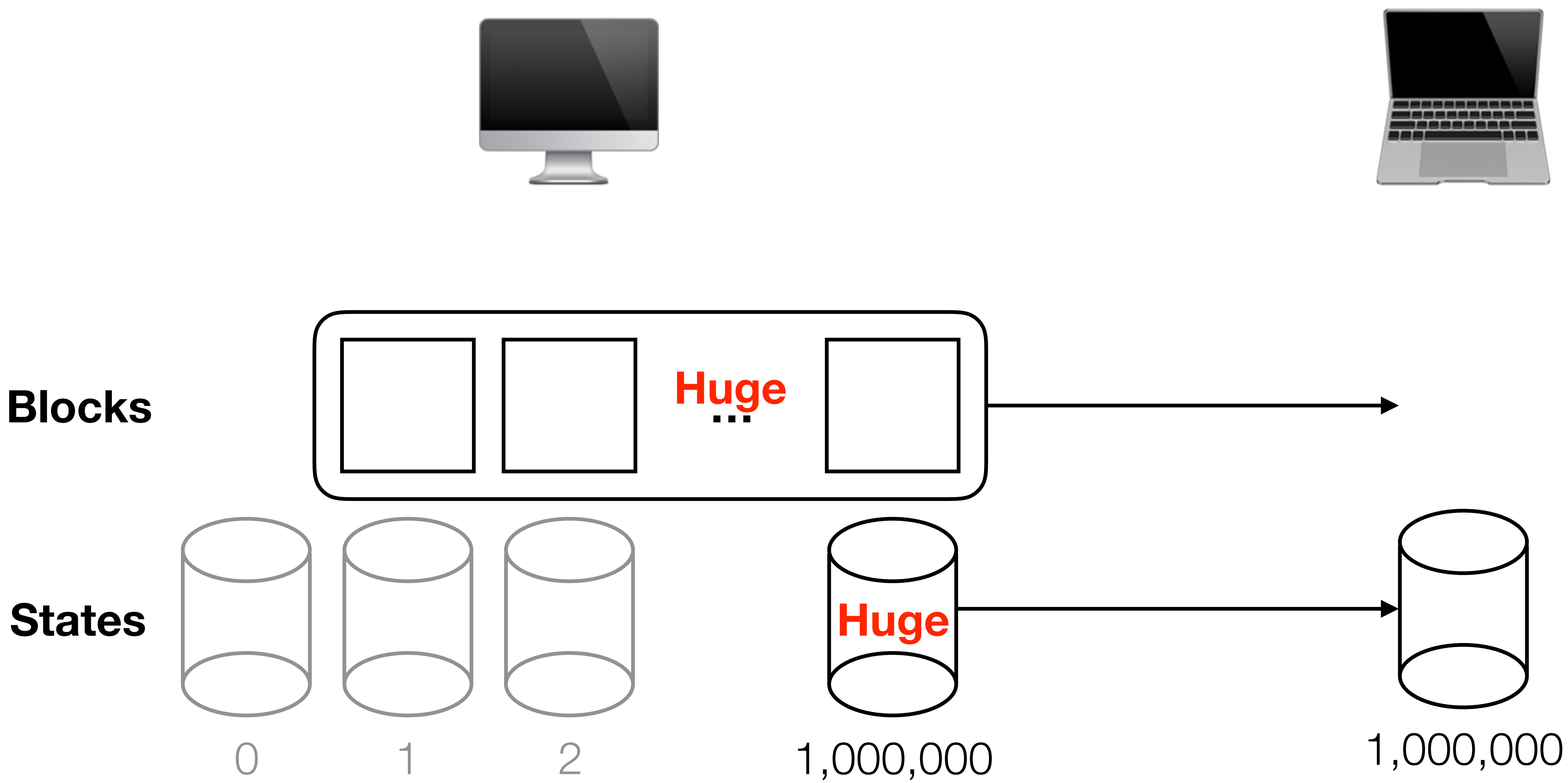

How does a new user join the system?

Bootstrapping

Goal: Securely and efficiently enable a new user to join, given initial state

- Minimize state transmitted
- Minimize proof that state is valid

Contribution

- Design of Vault, a system with secure and efficient bootstrapping
- 3 techniques for reducing sizes of state and proof of state
- 477MB data transfer cost for 500M transactions (Bitcoin: 143GB)

Vault Techniques

Approach	Challenge	Vault's Solution
Reduce state transmitted: Garbage collection	Transaction replay attacks	Force transactions to expire

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Reduce state transmitted: Shard state	Small shards lose security	Adaptive Merkle Tree sharding
Reduce size of state proof: Compress history	**Attacker tampers with history**	**Succinct certificates**

Background

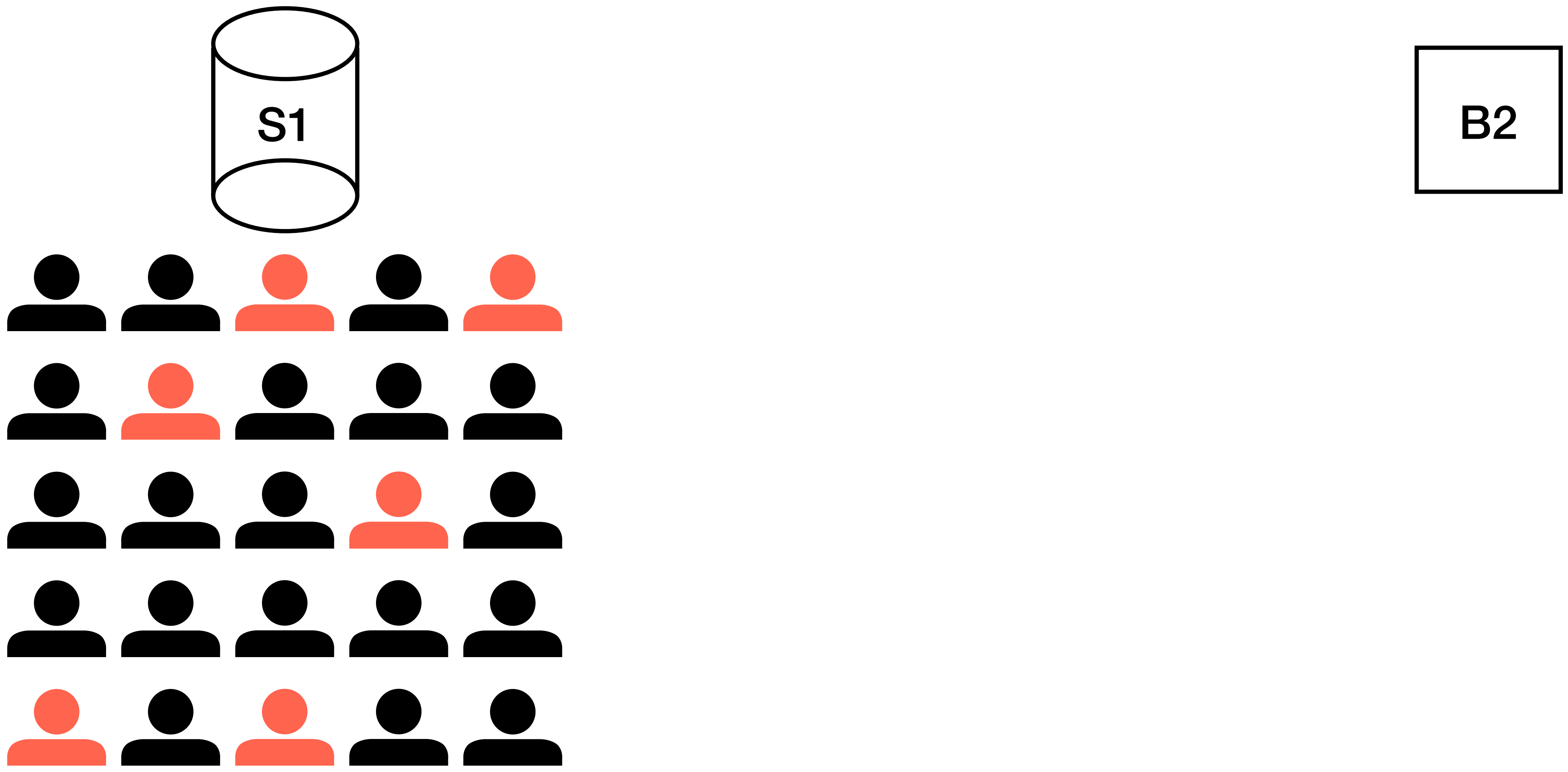
Algorand Background

- Permissionless
- Proof-of-stake
- Cryptographic proof that state is correct

Security Model

- Standard cryptographic assumptions
- New user knows state 0 (i.e., the “genesis”)
- $f \leq 20\%$ of stake is malicious

Proving a Block Correct



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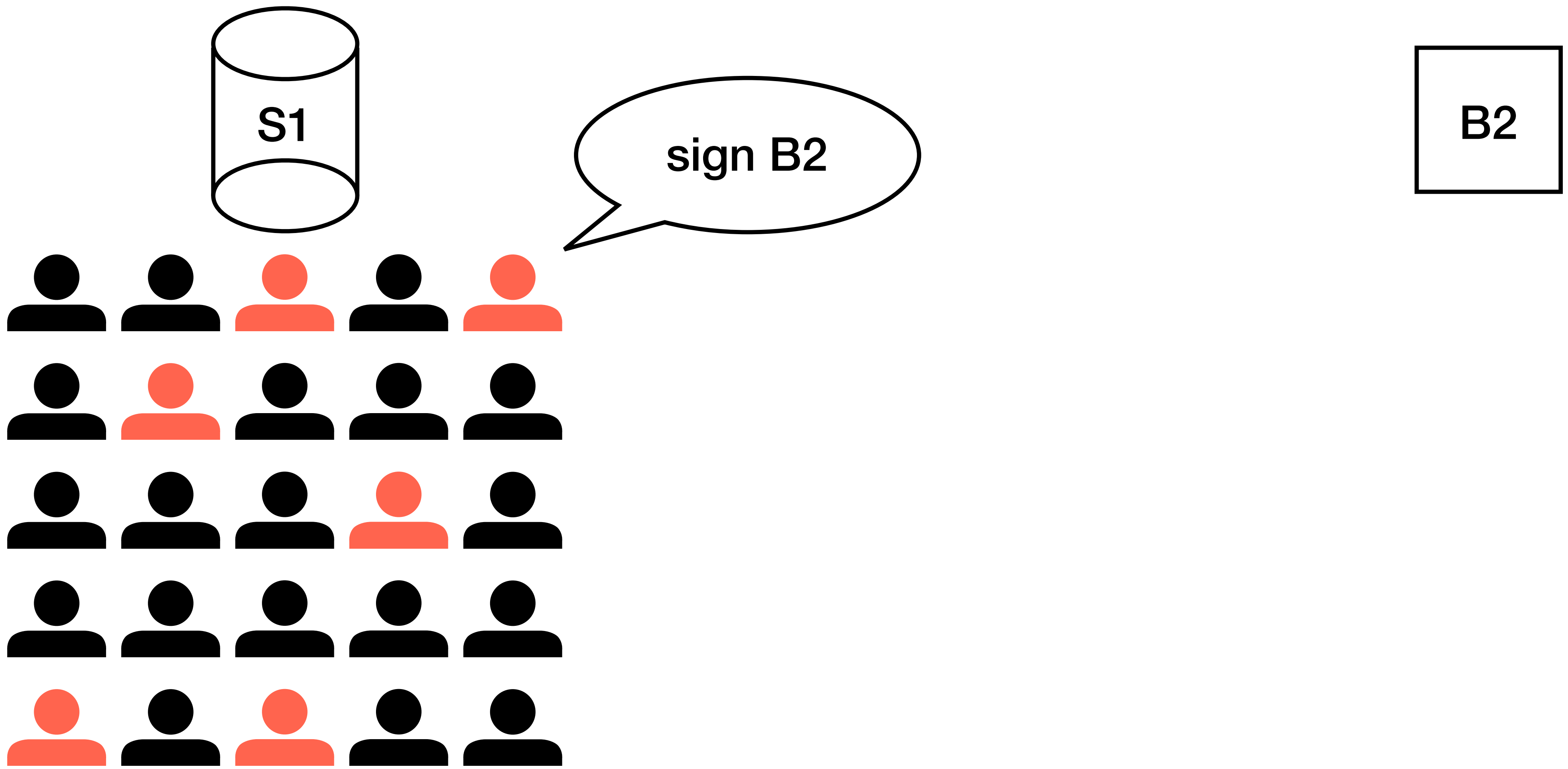

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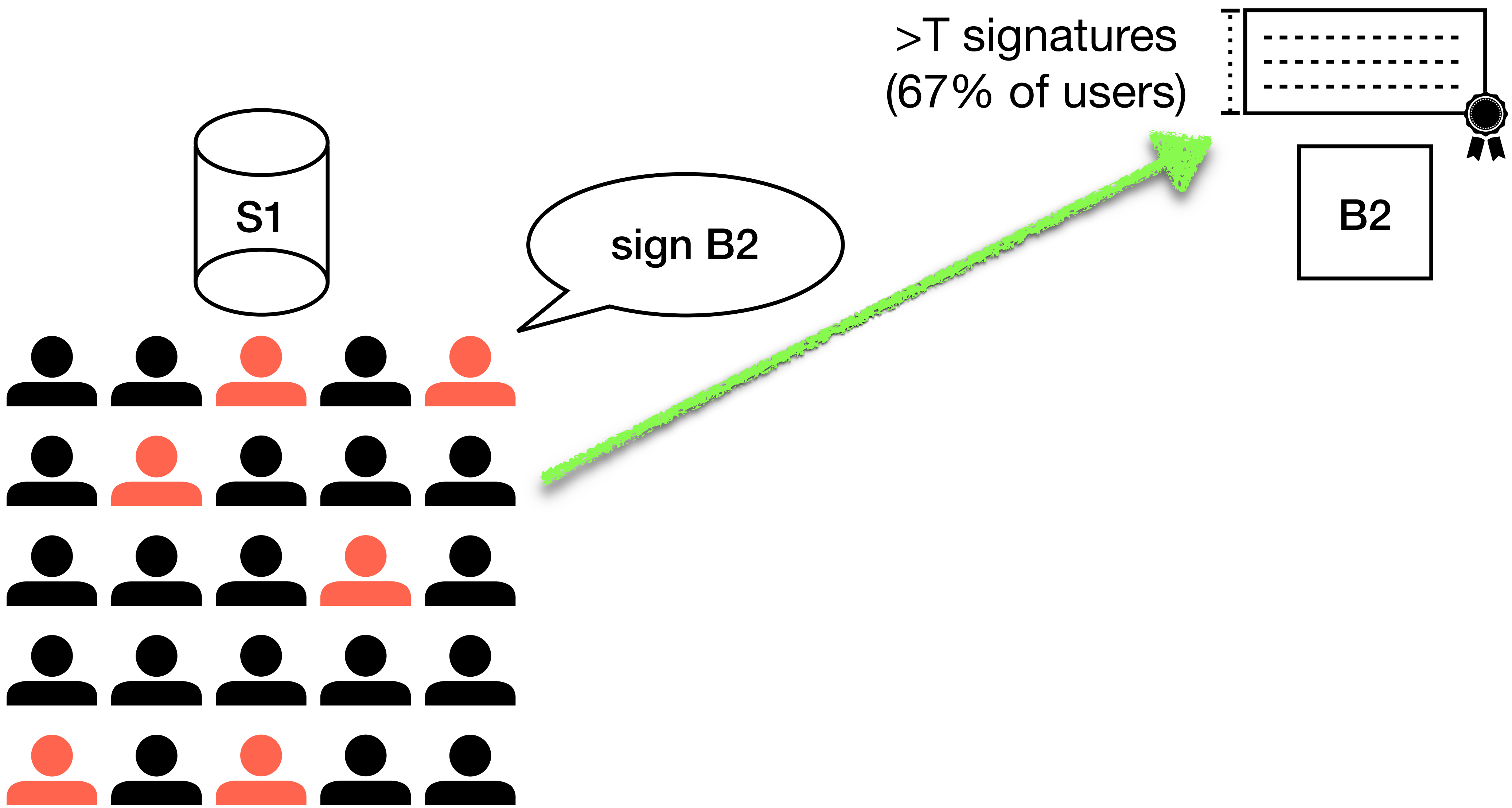

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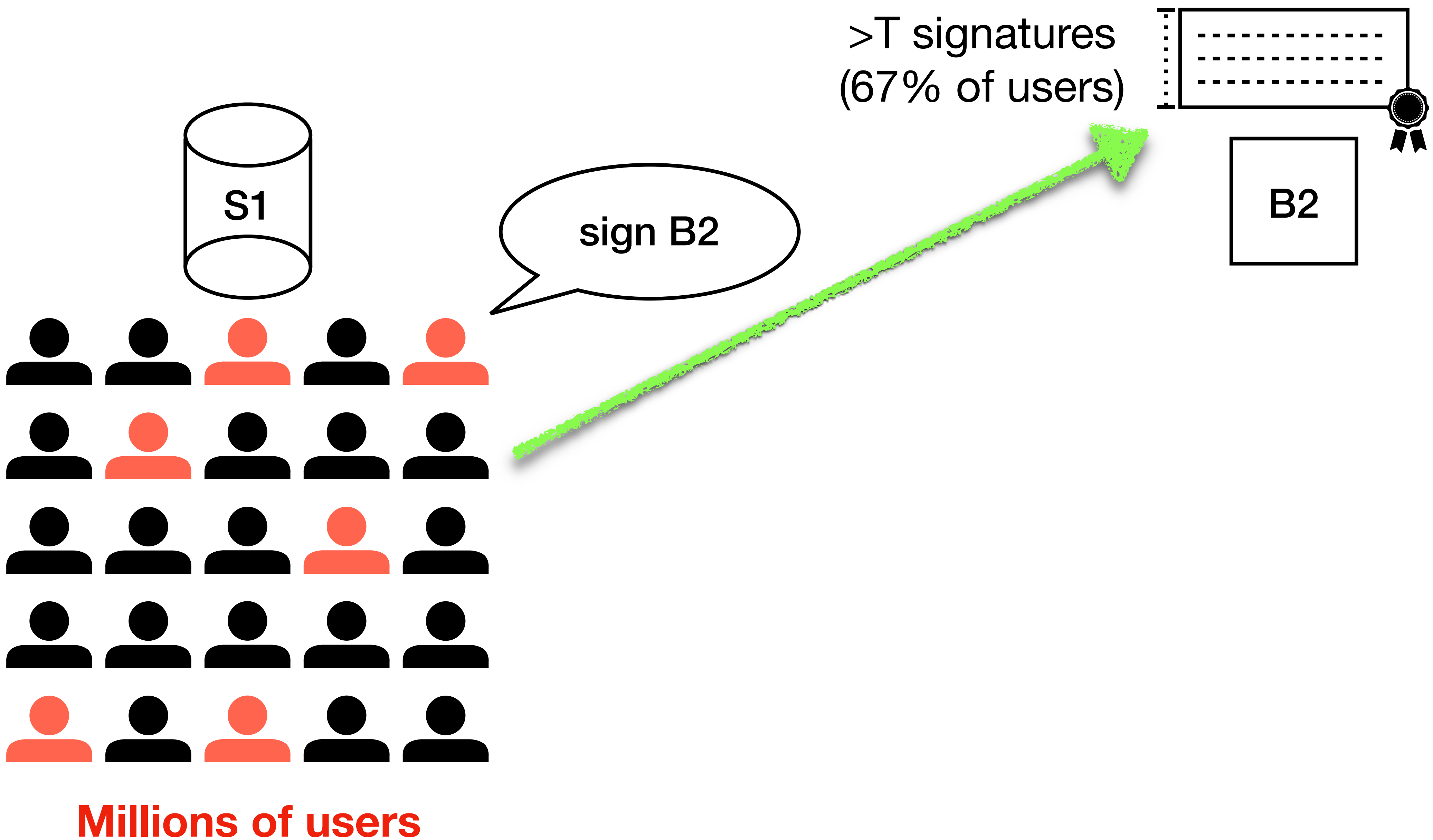

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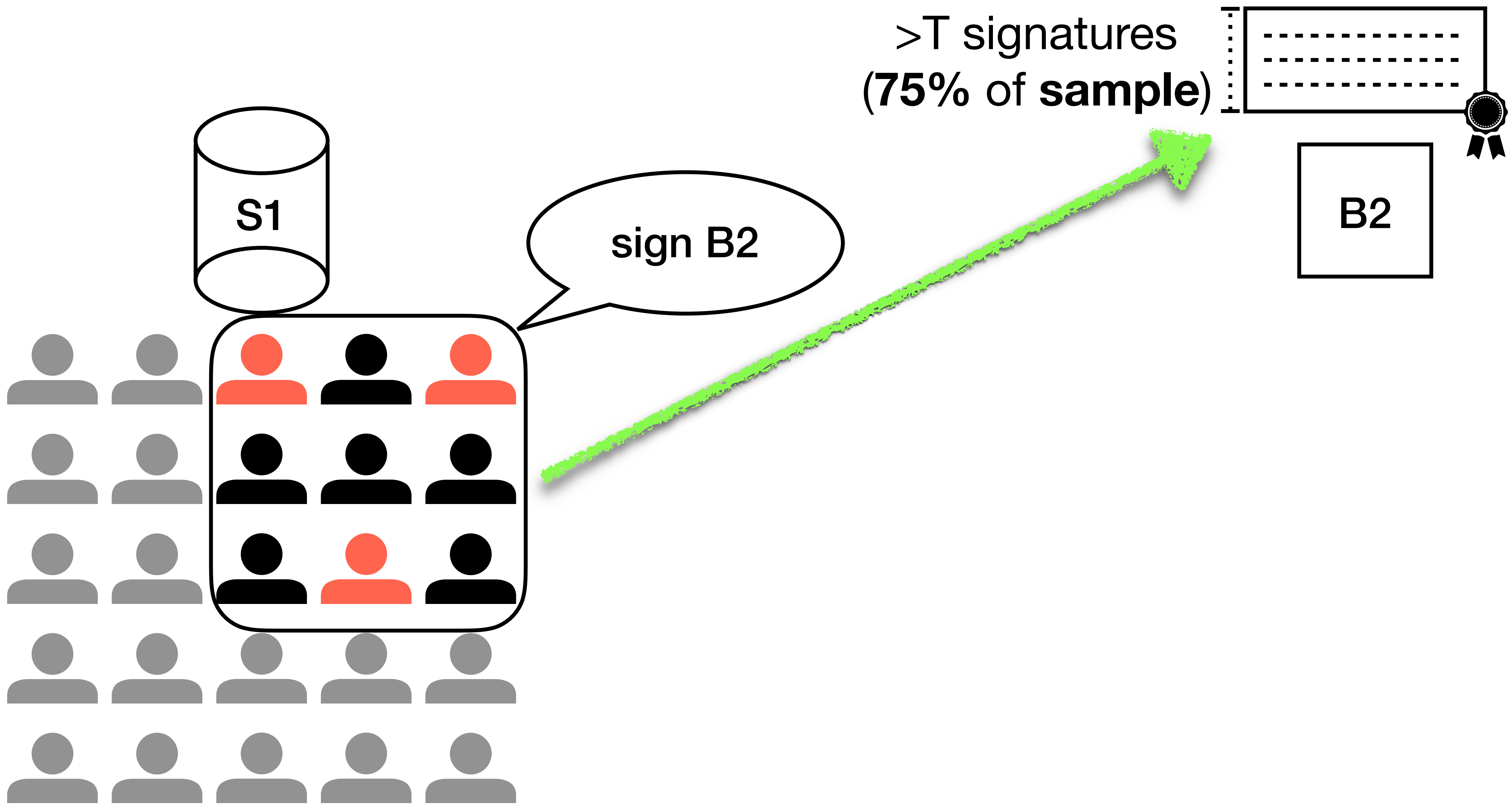
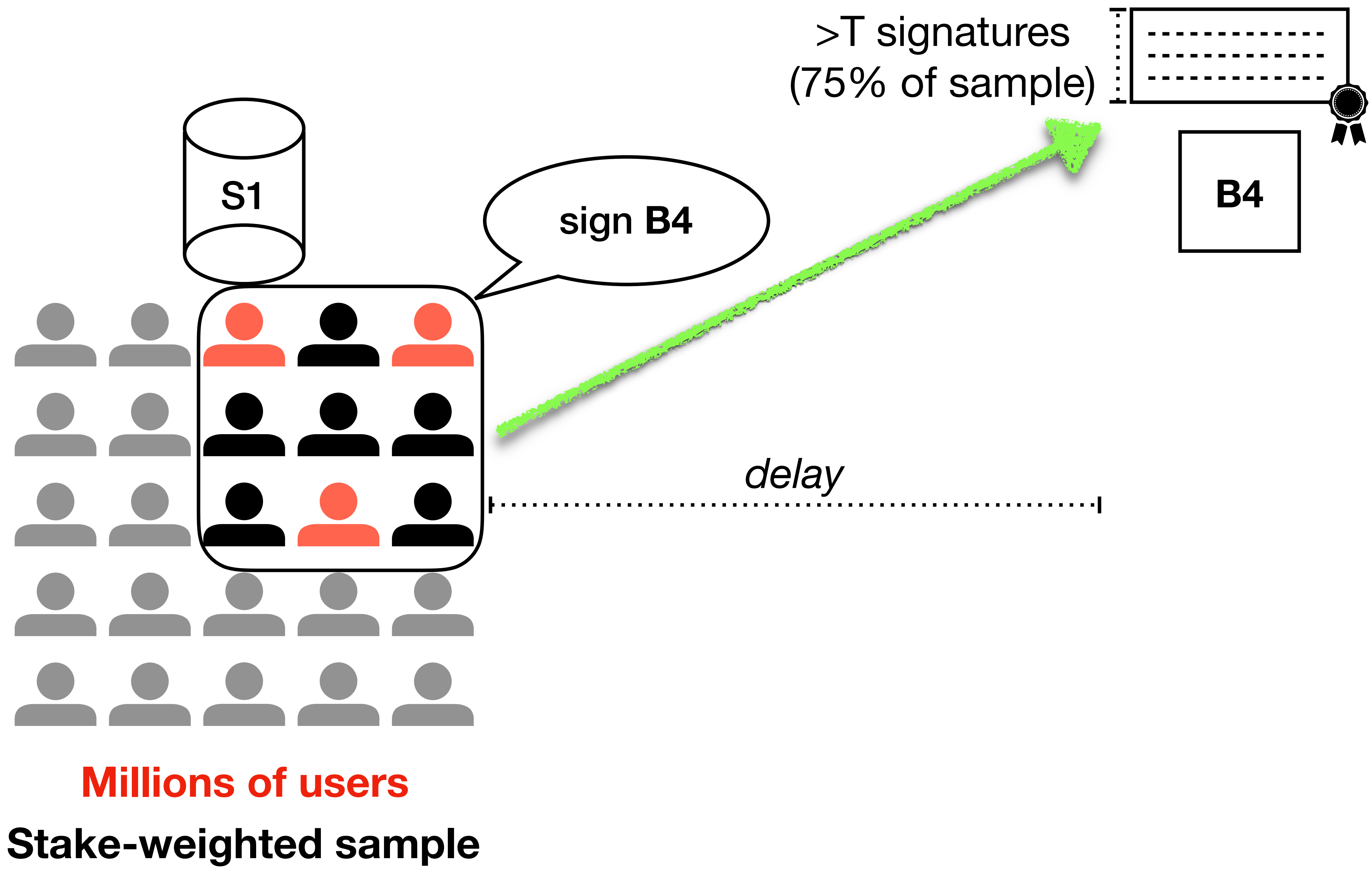


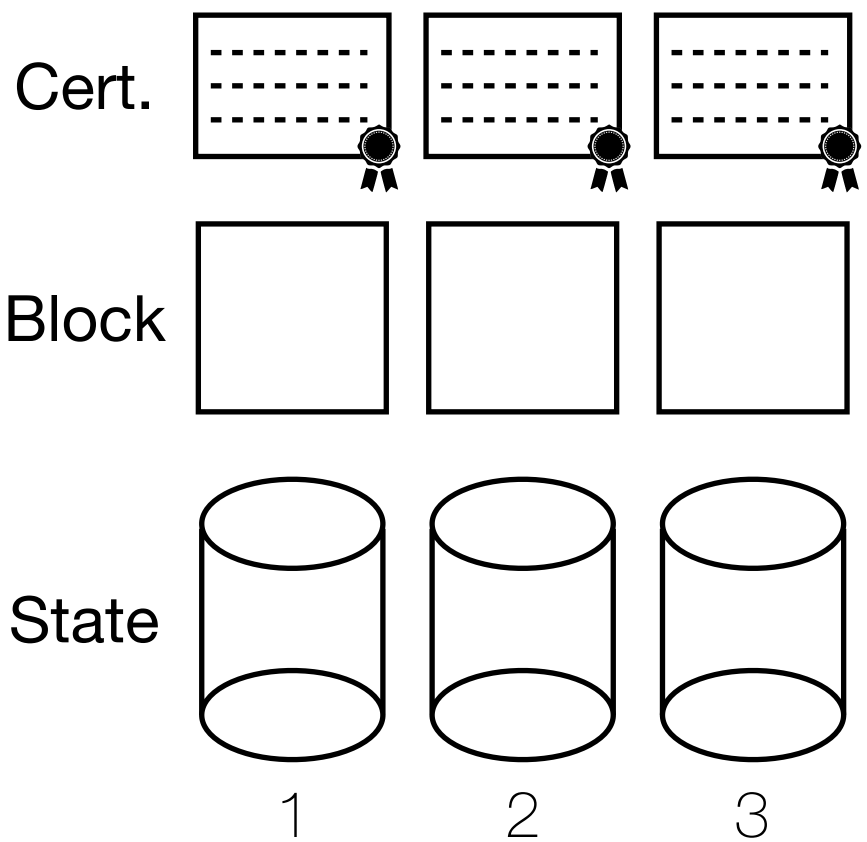
Millions of users

Stake-weighted sample

Proving a Block Correct



Base Bootstrapping



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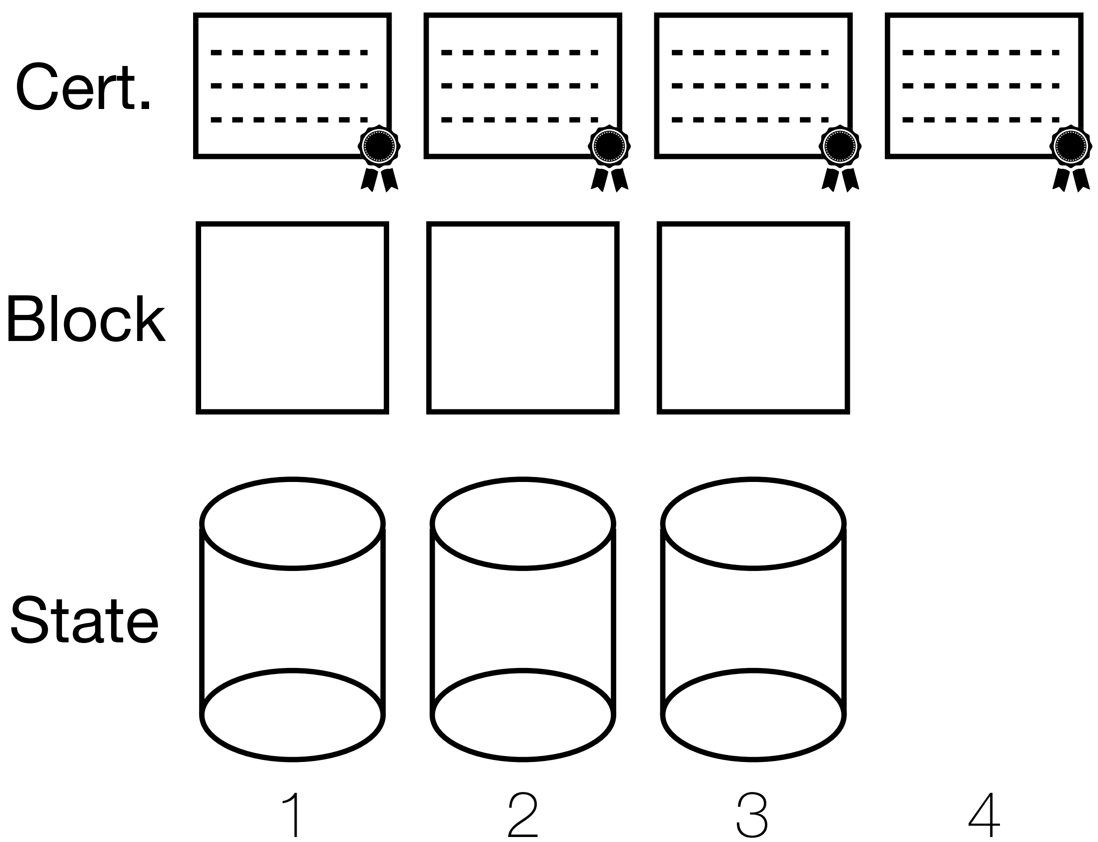

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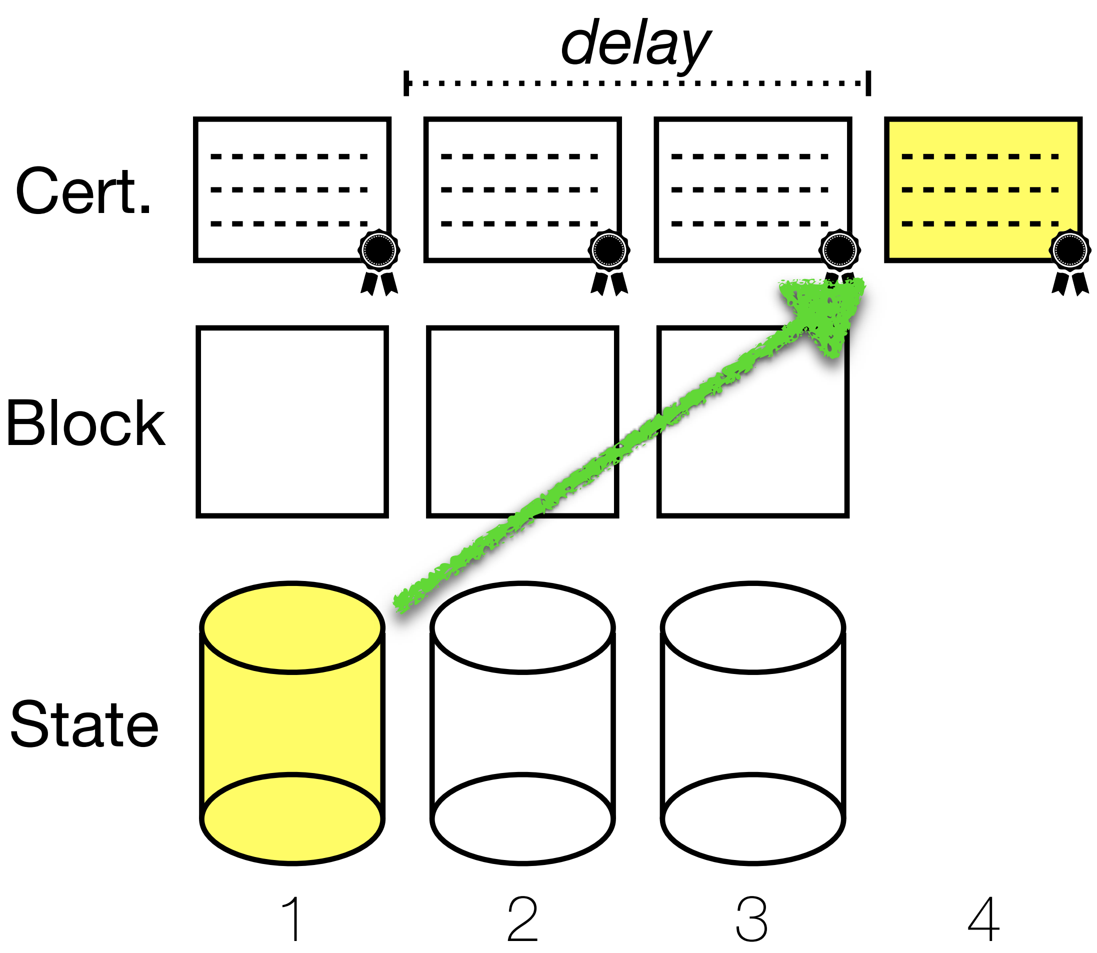

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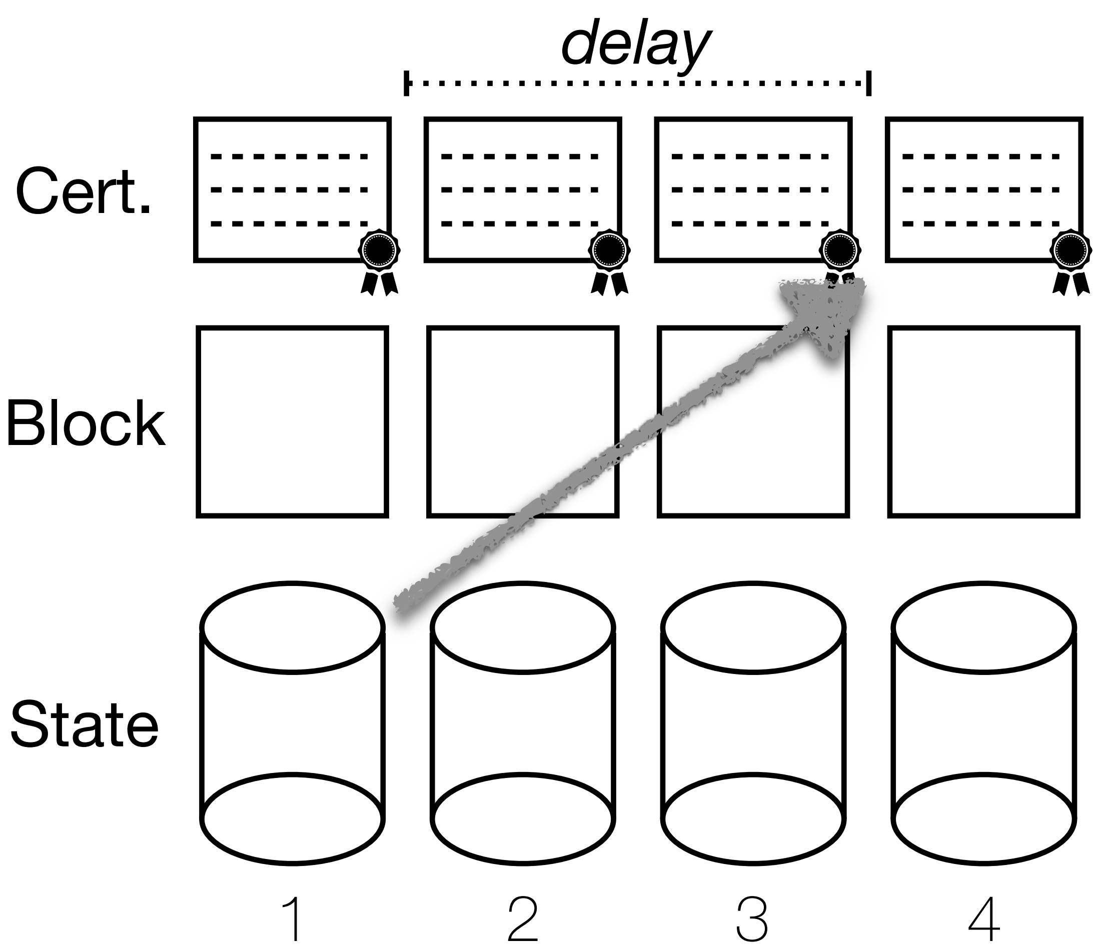

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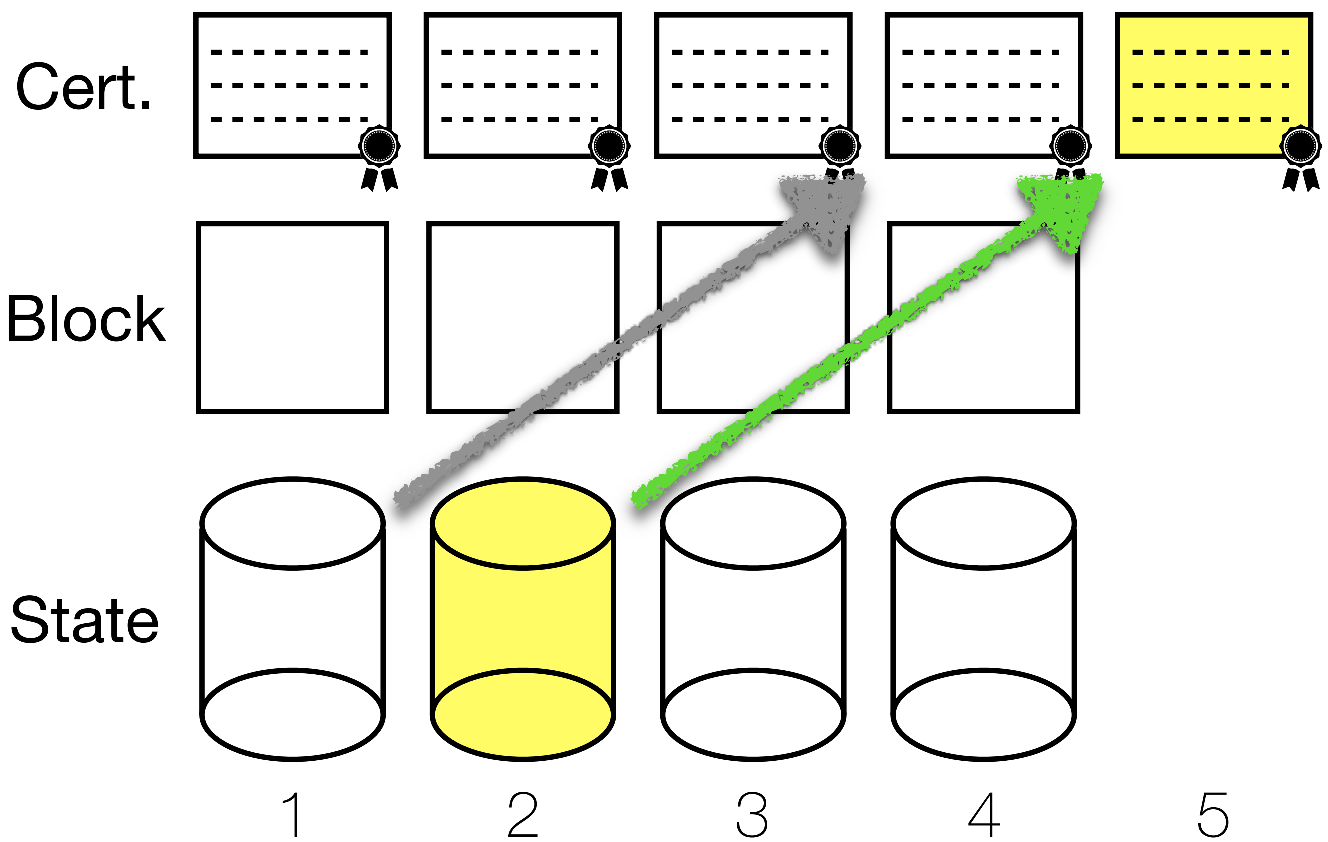
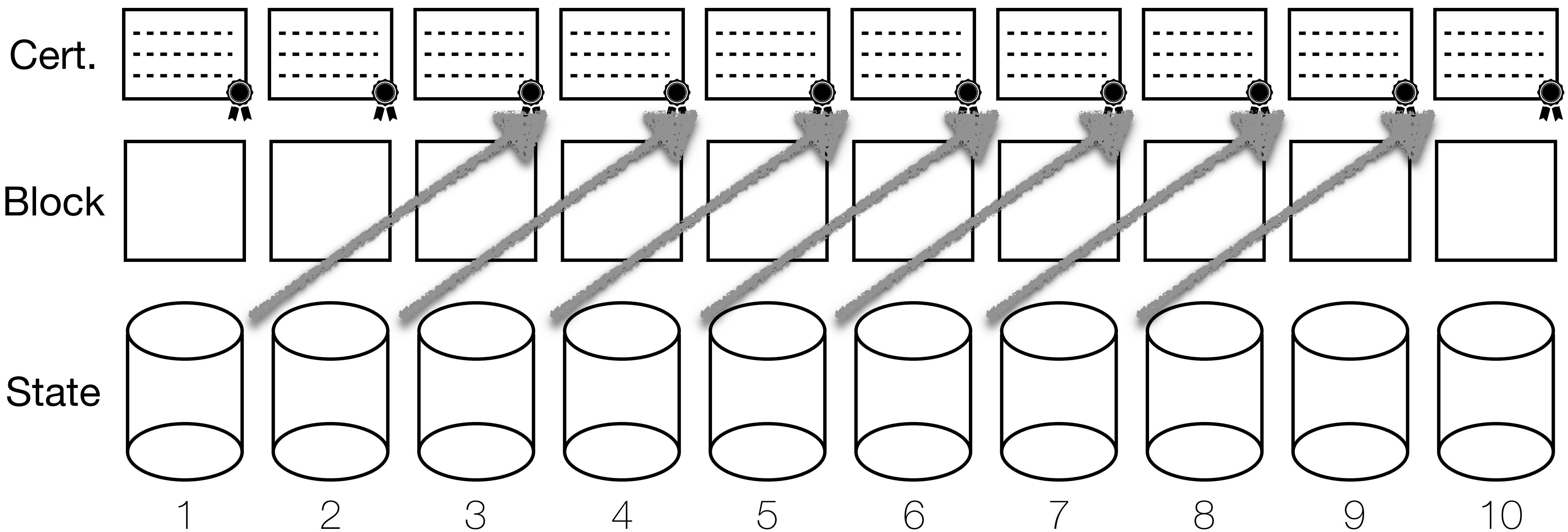
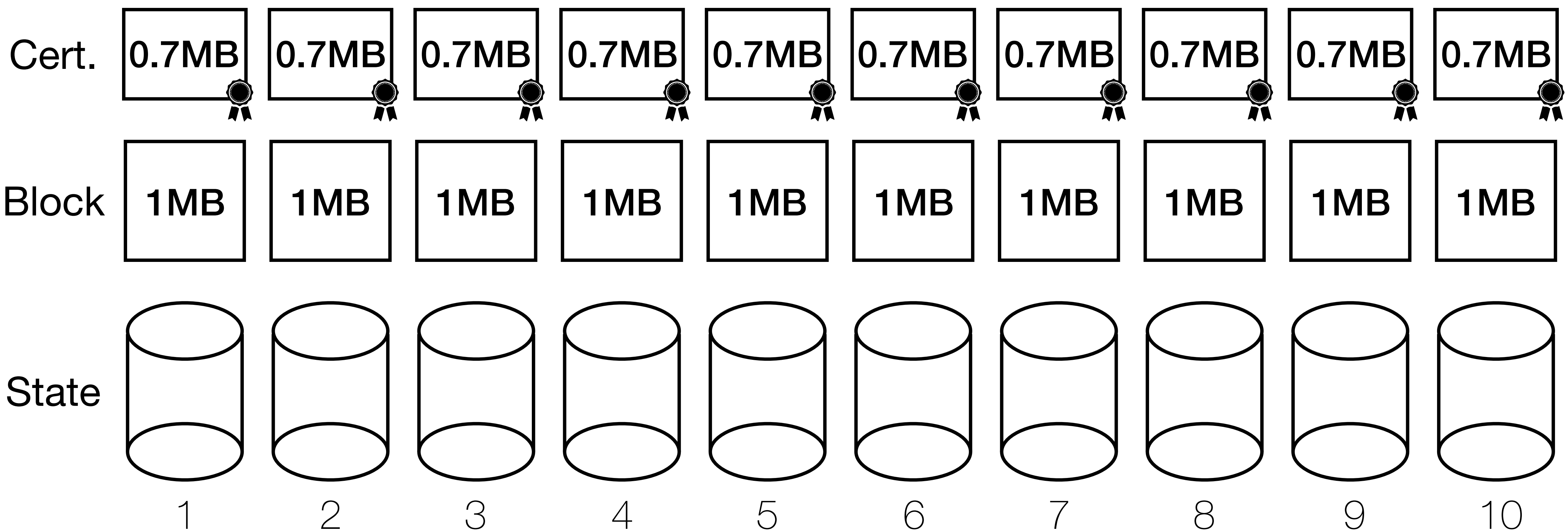


Base Bootstrapping



Base Bootstrapping



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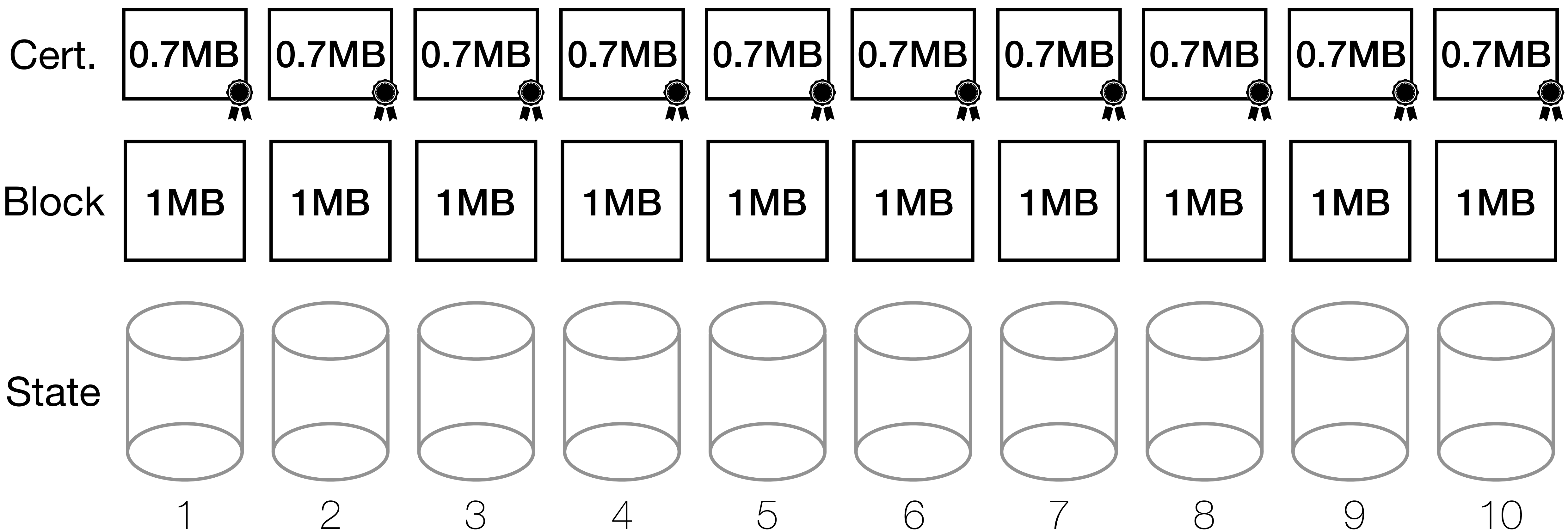


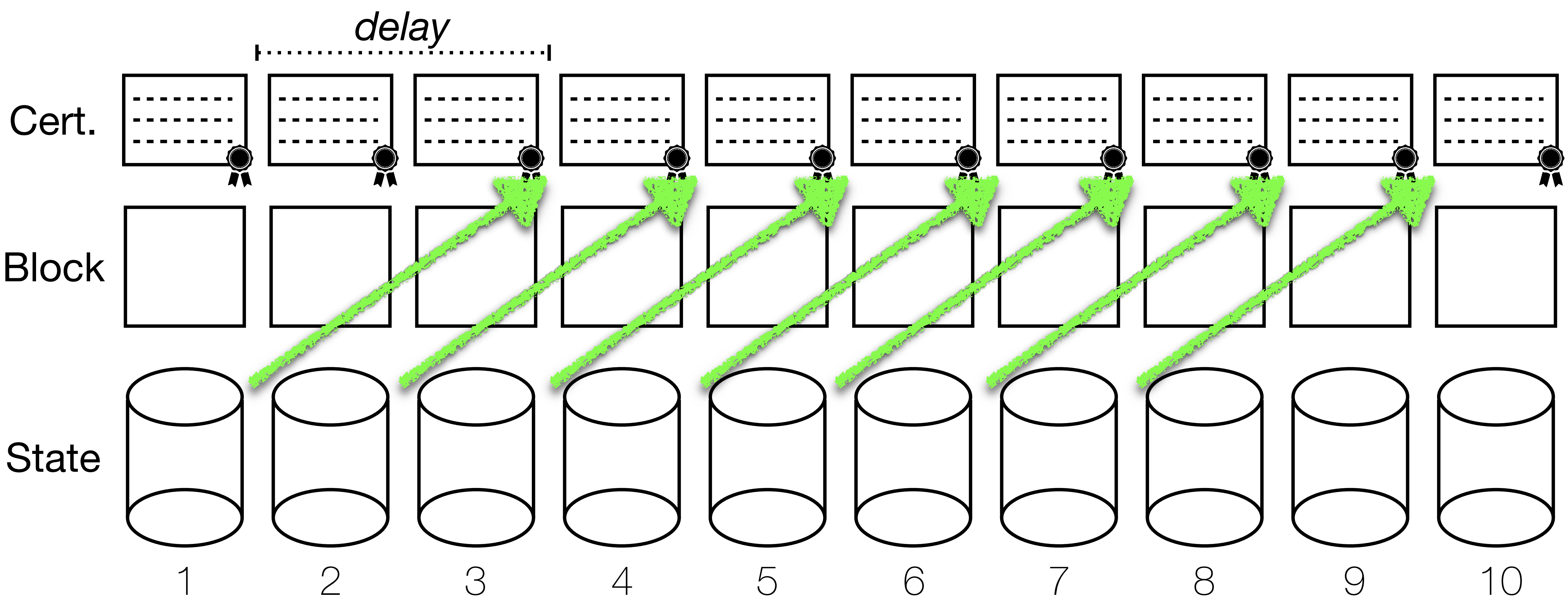
Must download every block and certificate

Vault: Compress History

1. Vault skips blocks
2. Vault shrinks certificates

1. Skipping Blocks

Base Bootstrapping



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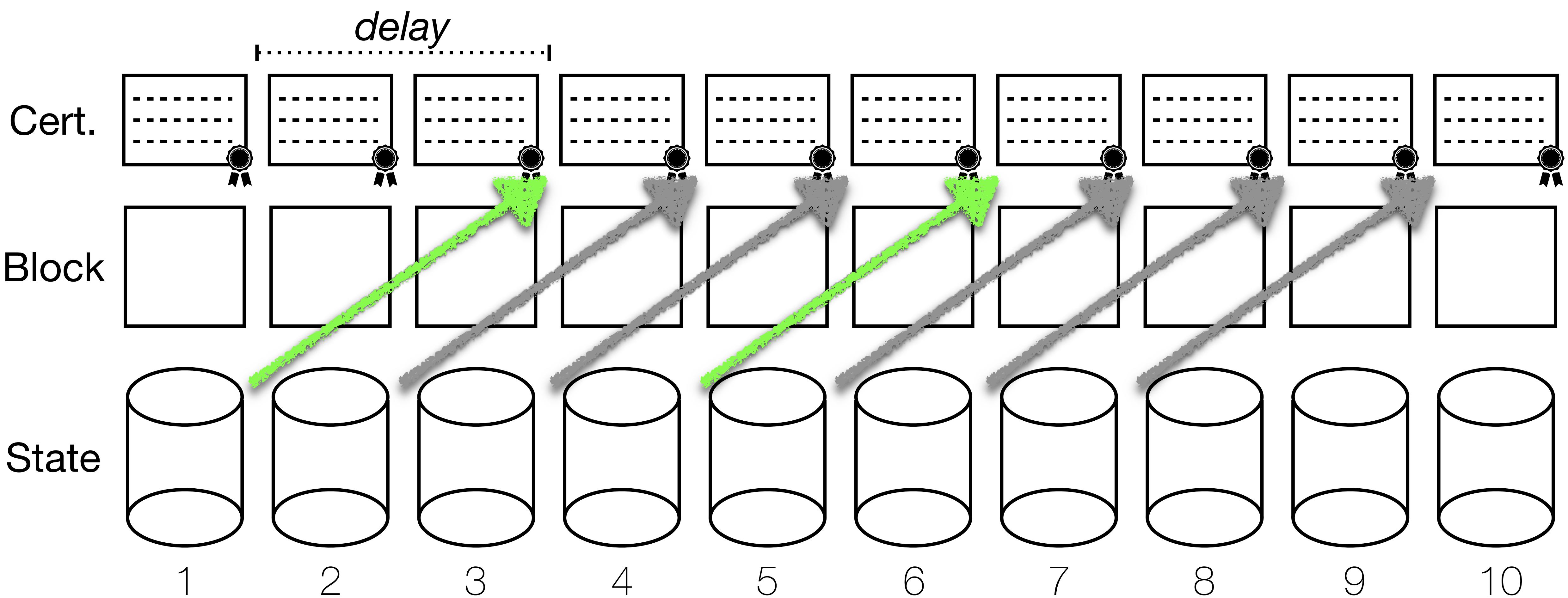
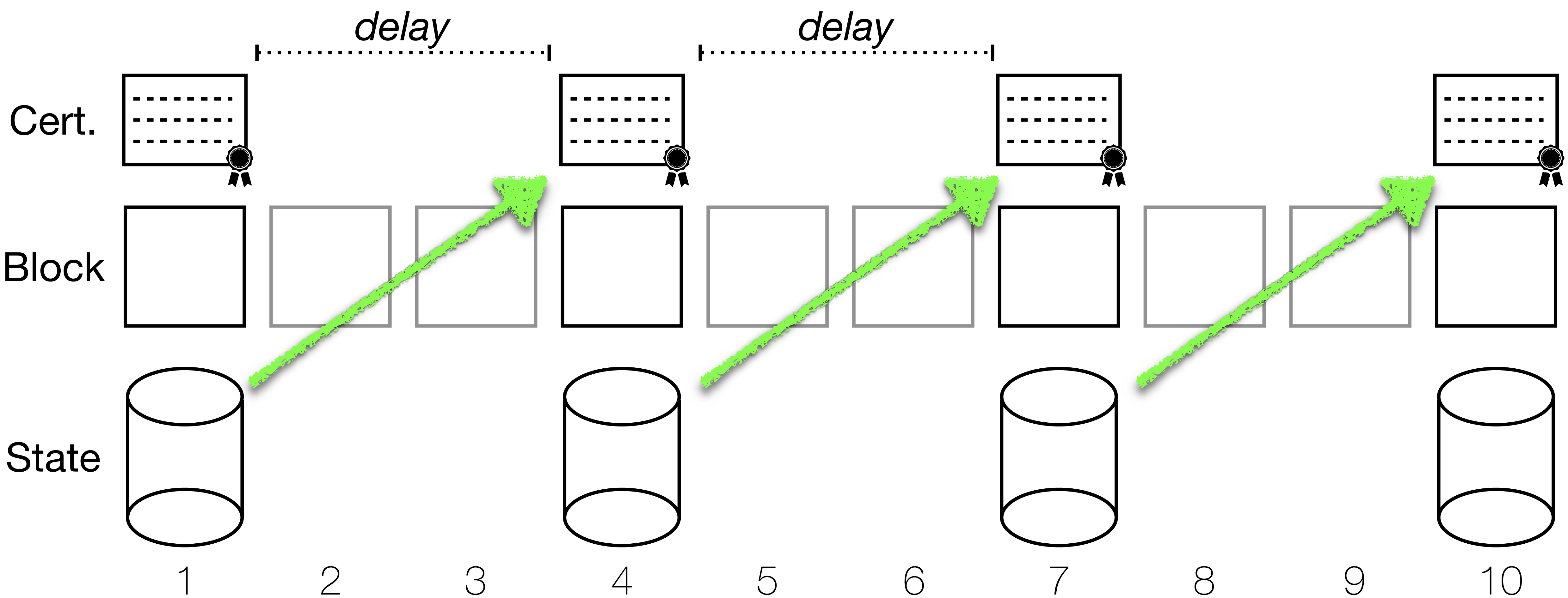
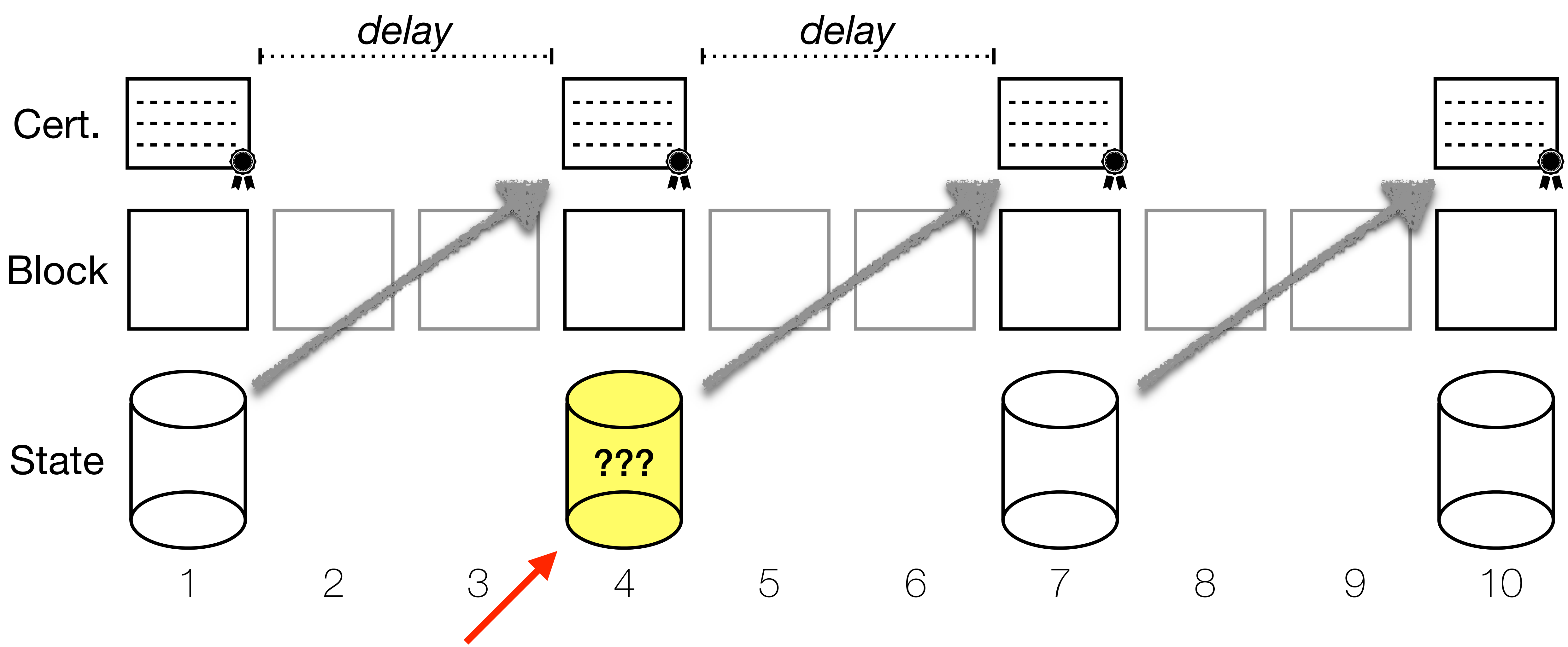


Skipping Blocks

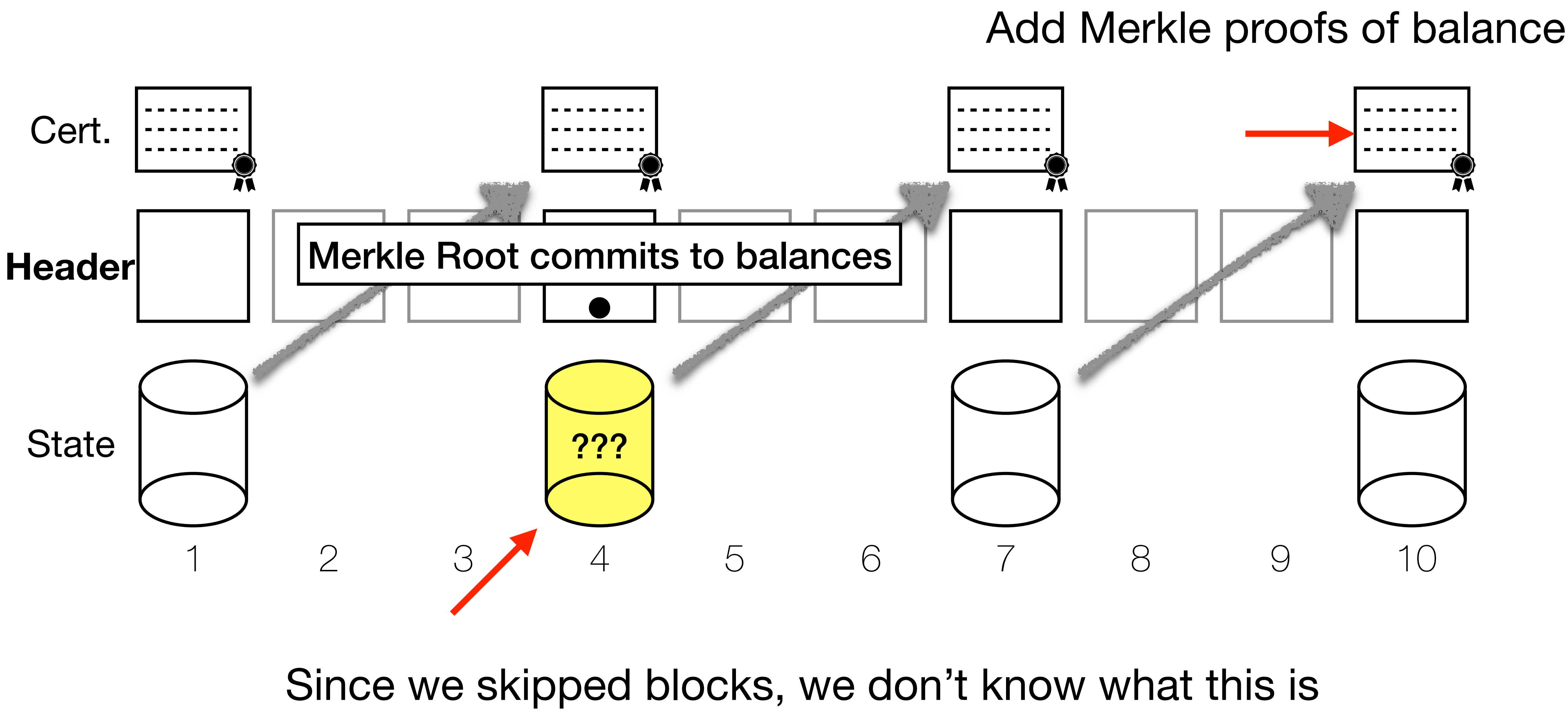


Skipping Blocks



Since we skipped blocks, we don’t know what this is

Skipping Blocks



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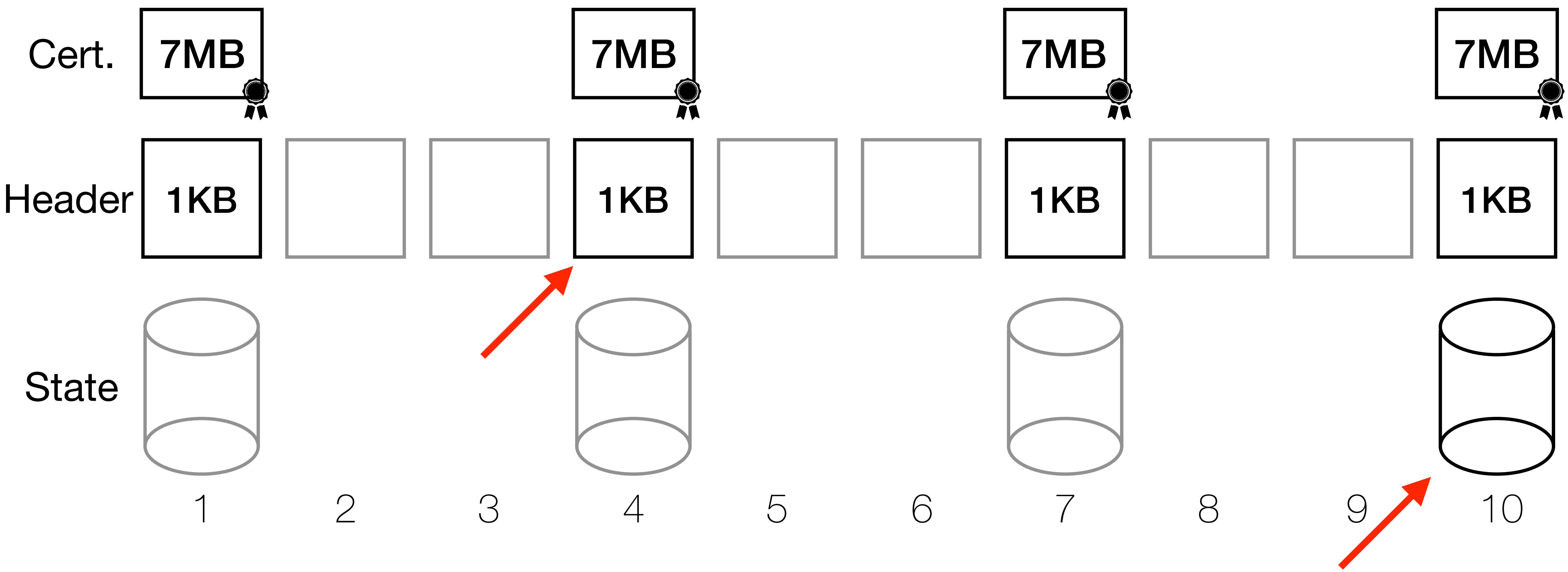
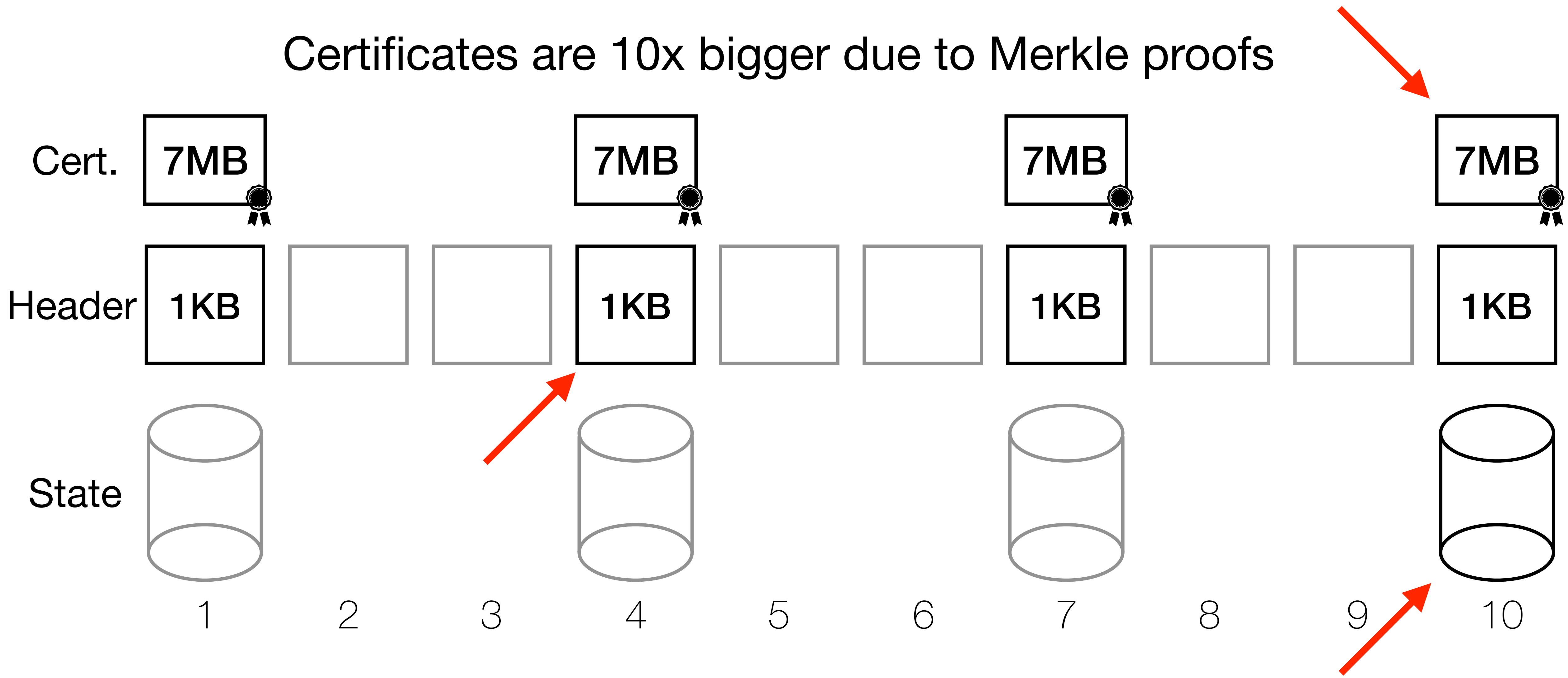


Only need headers, certificates, and final state

Skipping Blocks

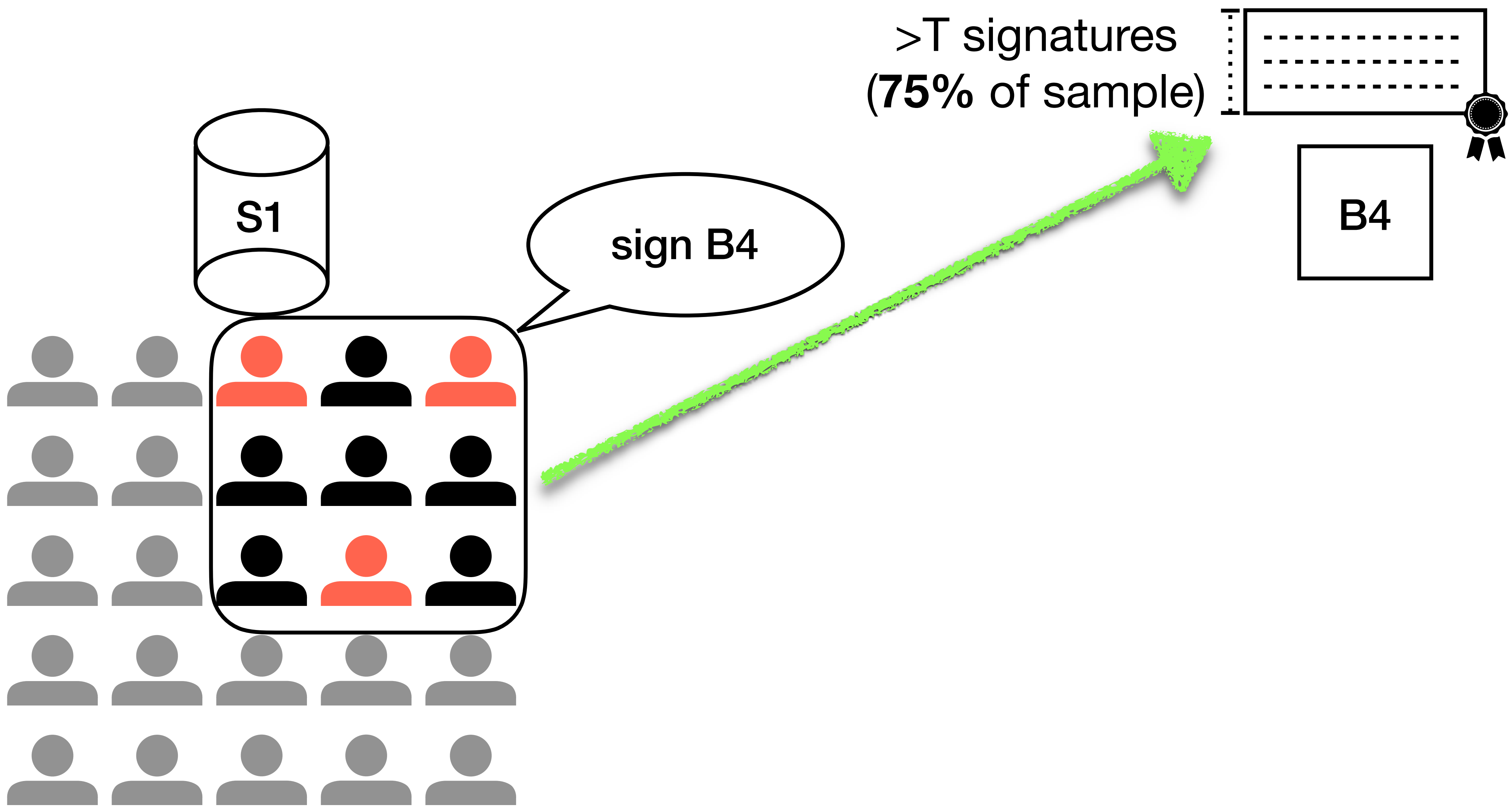
Certificates are 10x bigger due to Merkle proofs



Only need headers, certificates, and final state

2. Shrinking Certificates

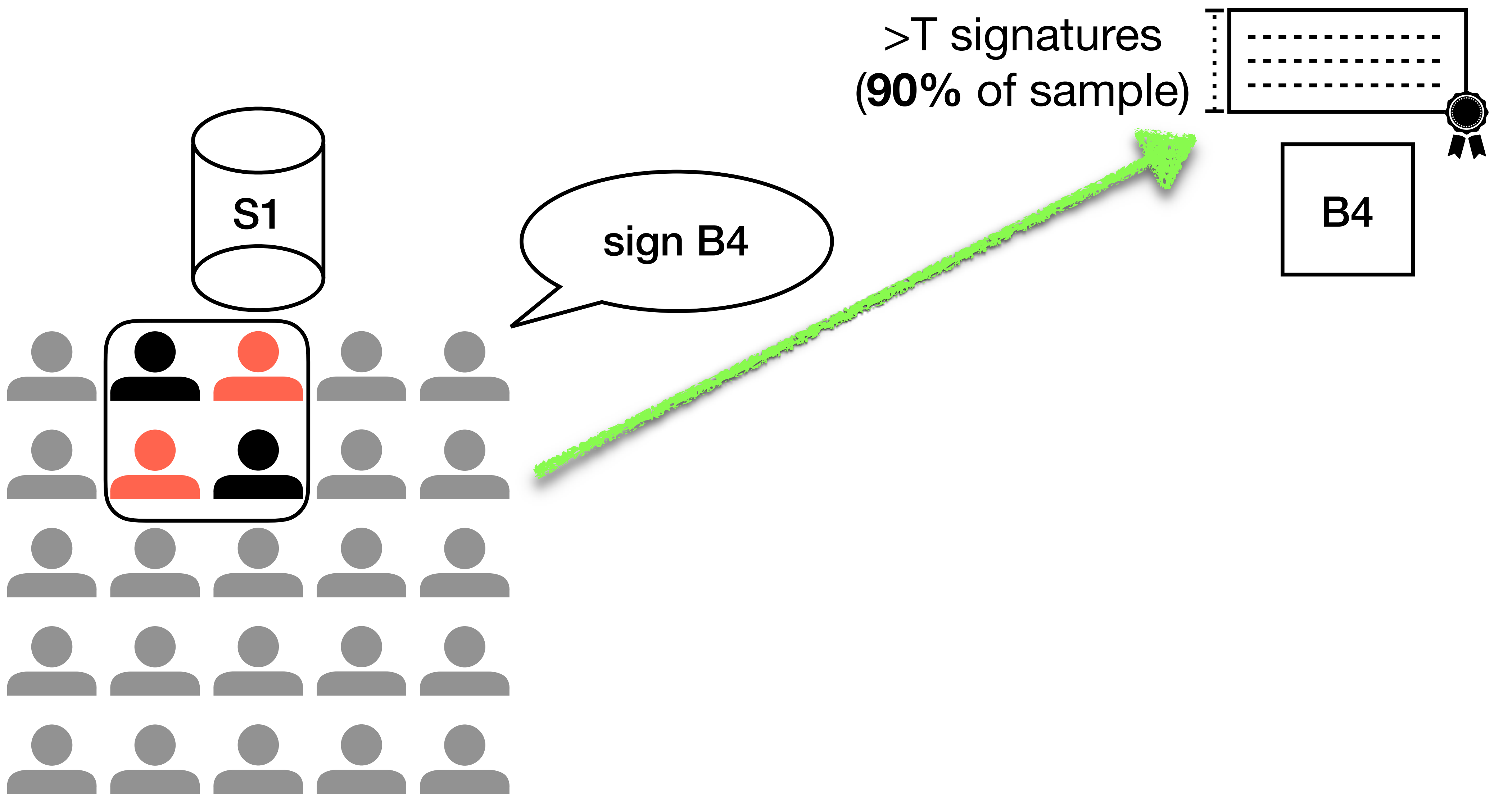
Proving a Block Correct



Millions of users

Stake-weighted sample

Smaller Proofs



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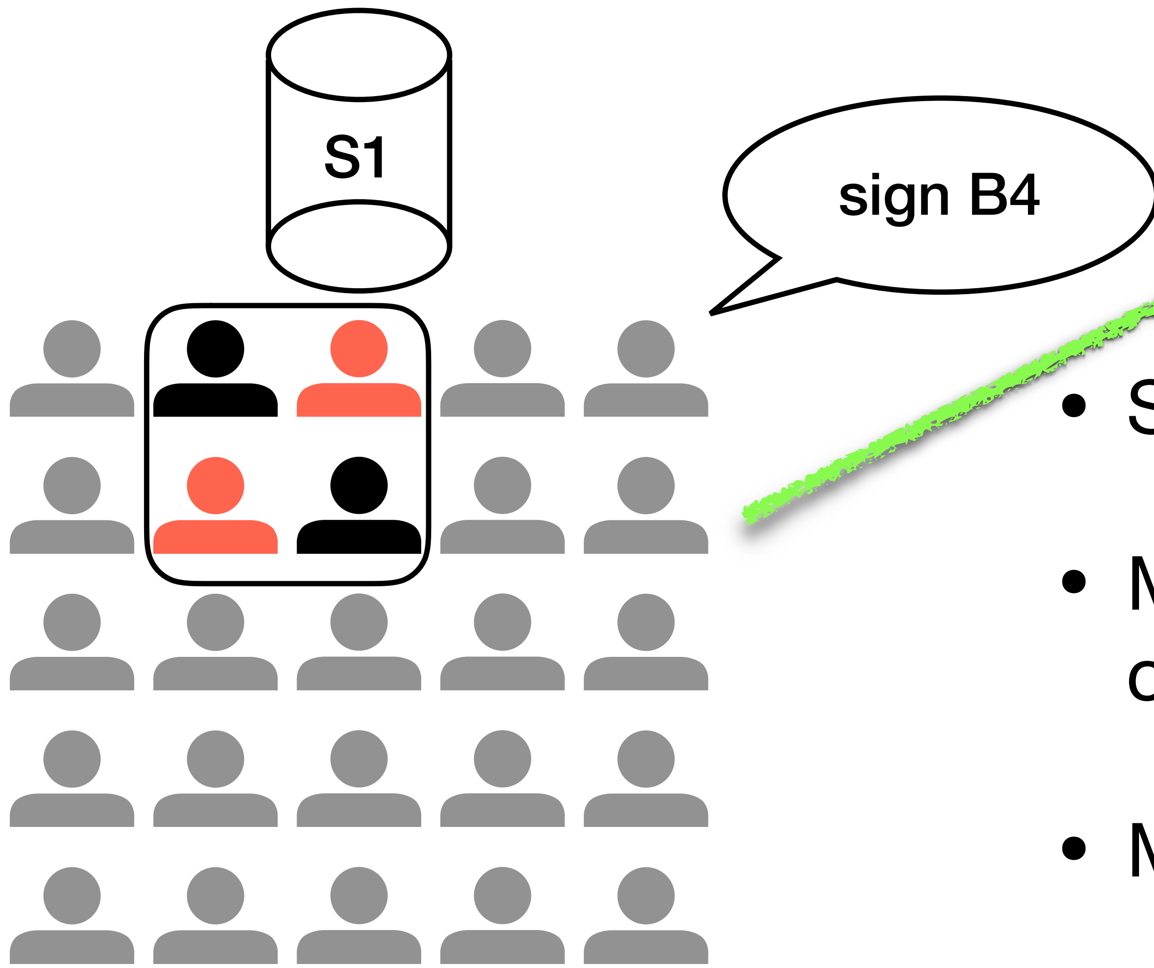

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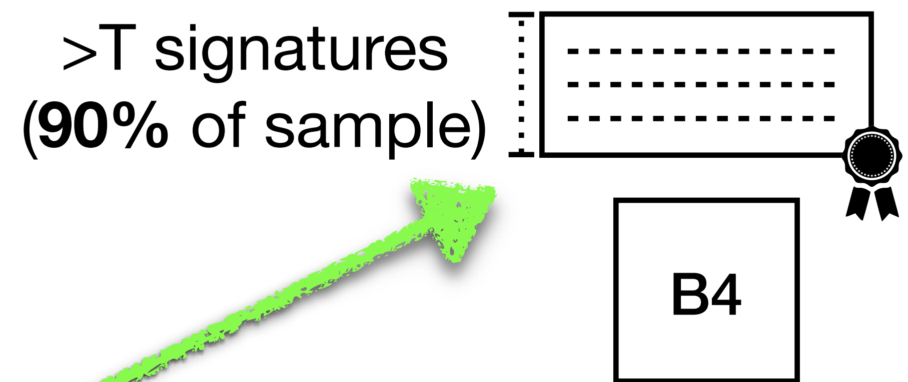
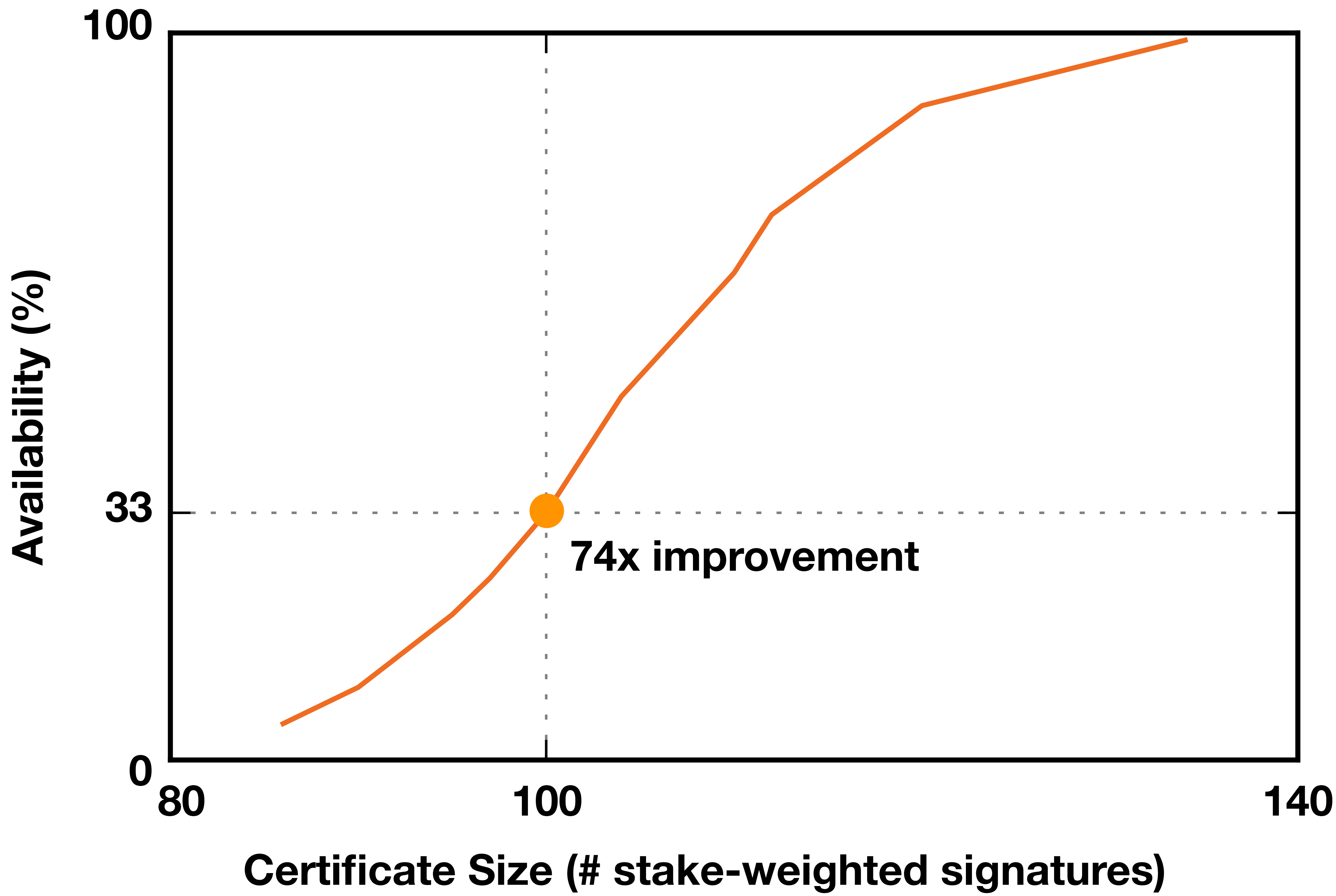
Stake-weighted sample



- Smaller sample: higher variance
- Must raise certificate threshold to compensate (e.g., 75% to 90%)
- May fail to meet threshold!

During bootstrapping, trade off availability for size

Trading Away Availability



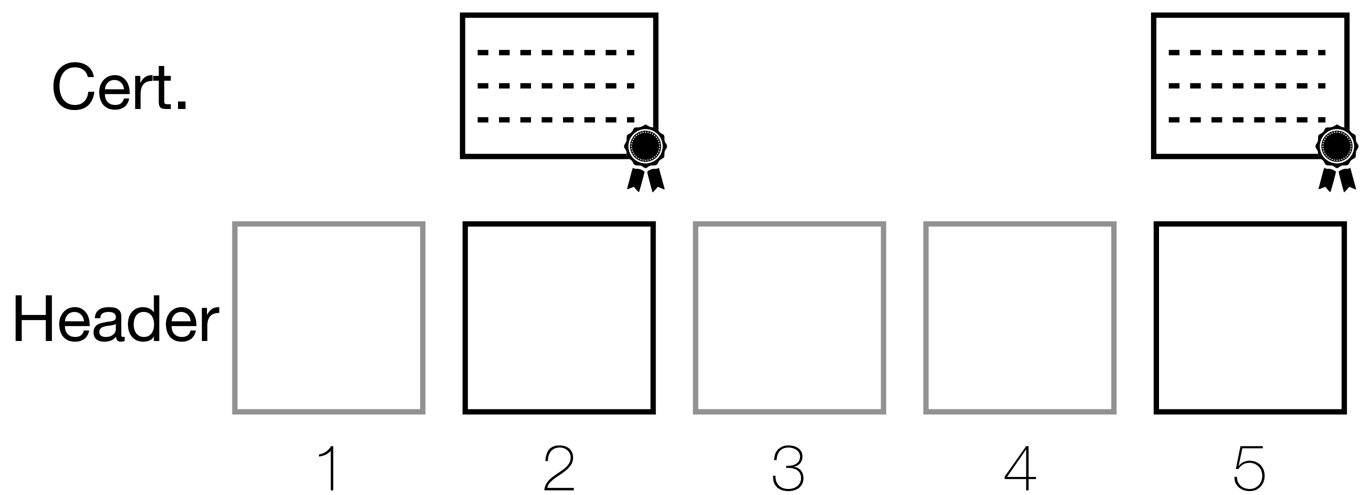
Trading Away Availability

Shrink certificates by 74x (tunable)

On failure, use block header hashes to bypass failure

(0.1MB to skip < *delay* blocks)

Block Hash Vaulting



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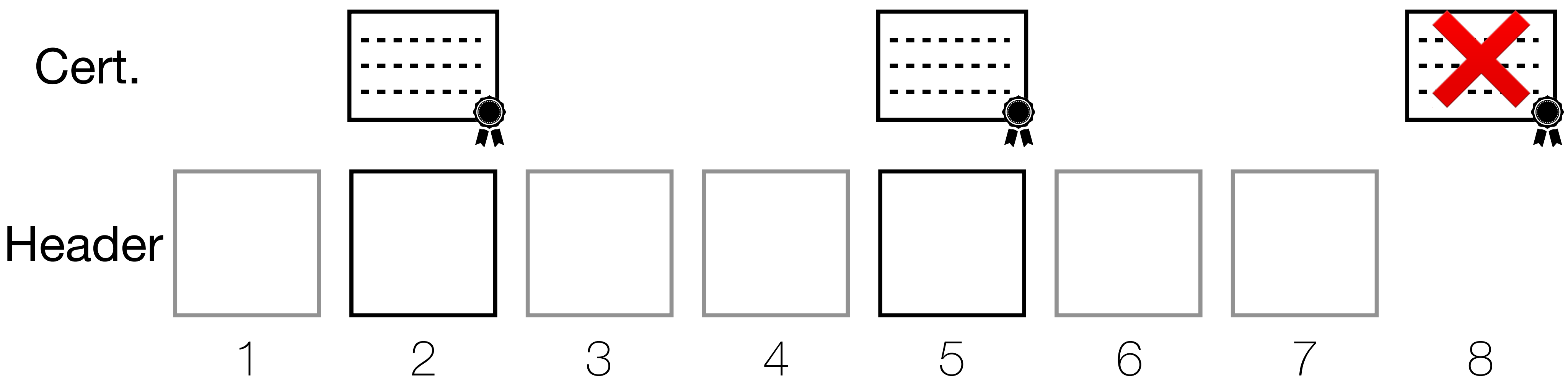

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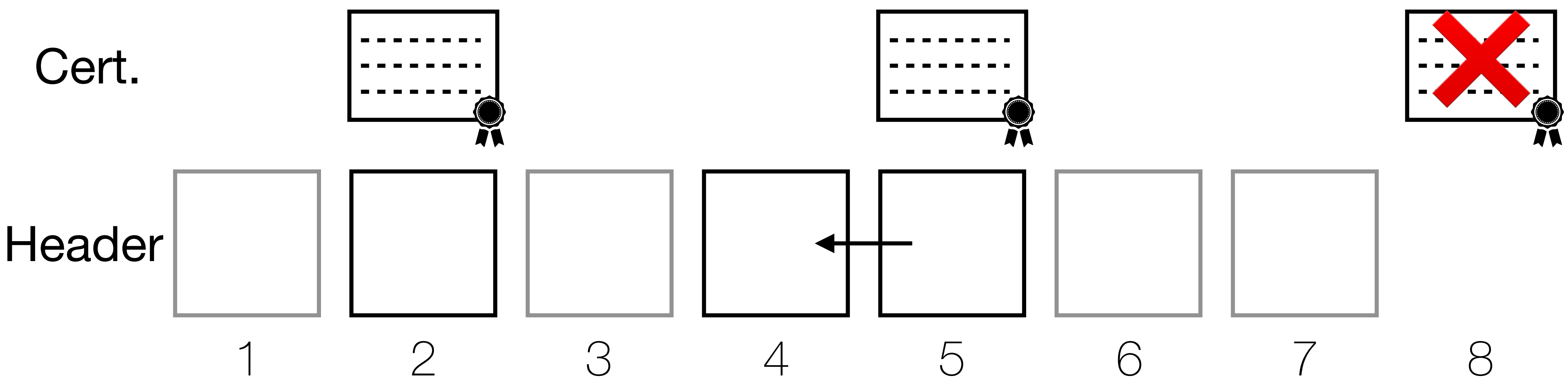

Block headers contains hash of previous block headers

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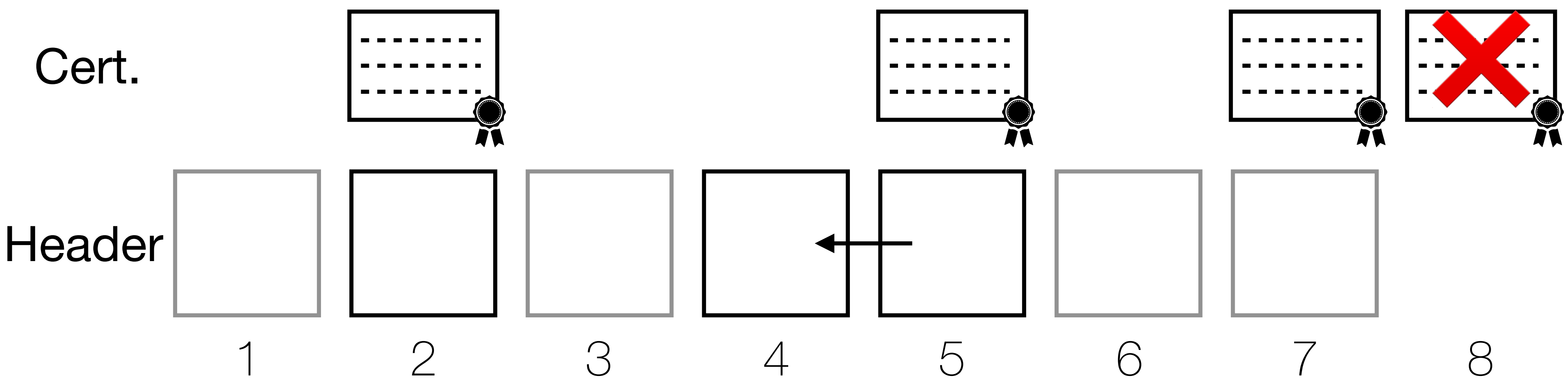

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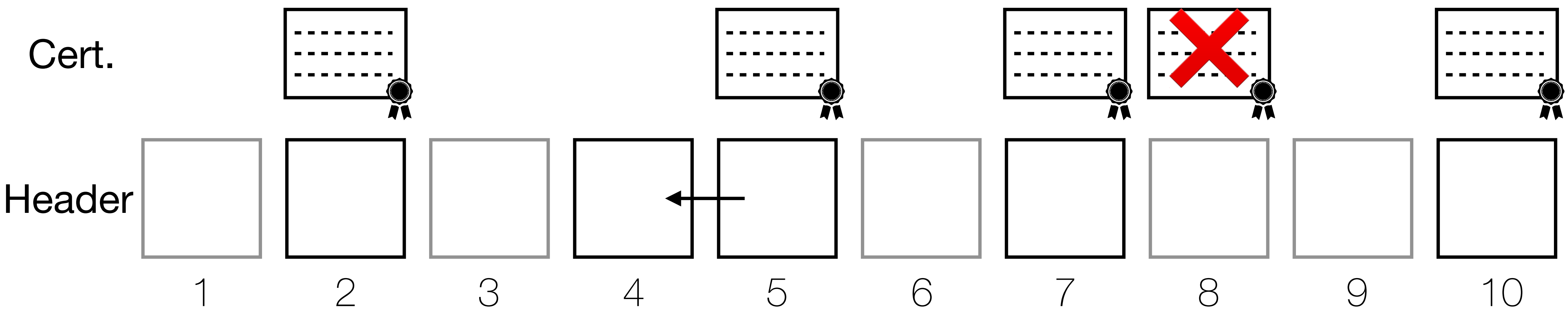

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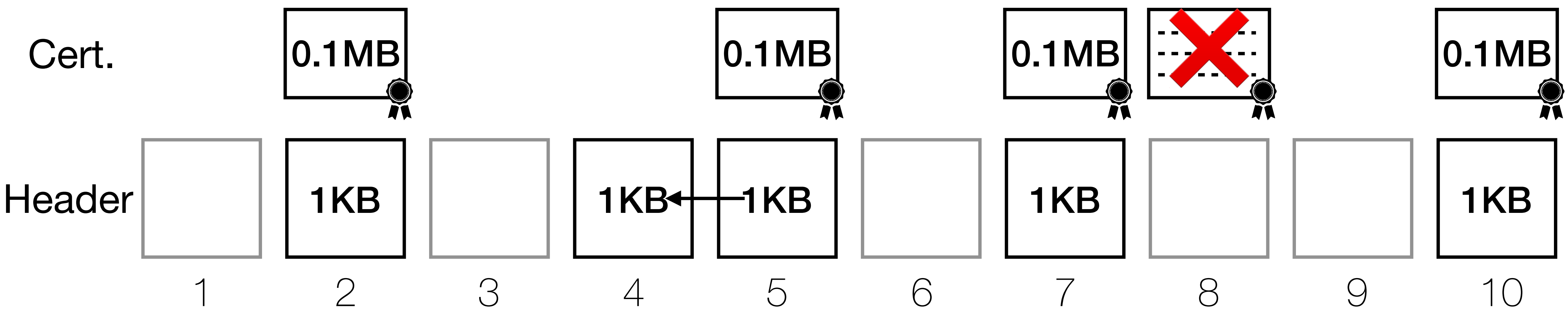

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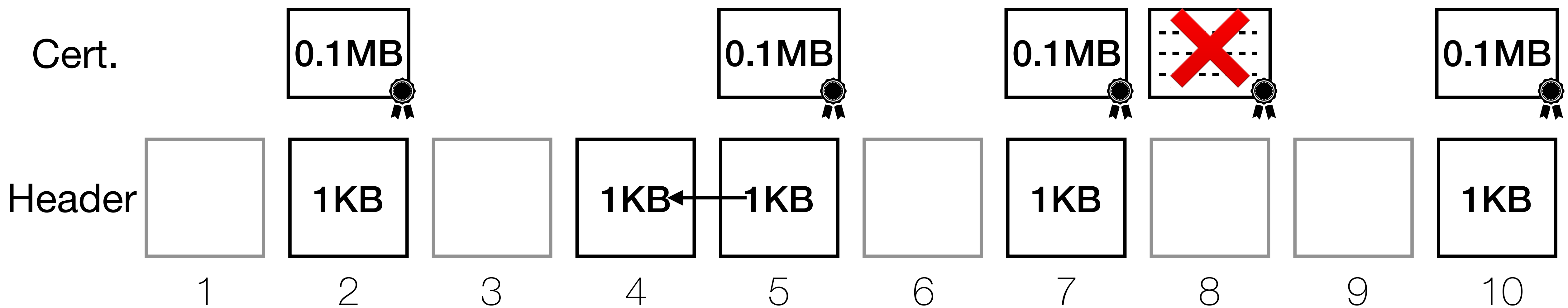


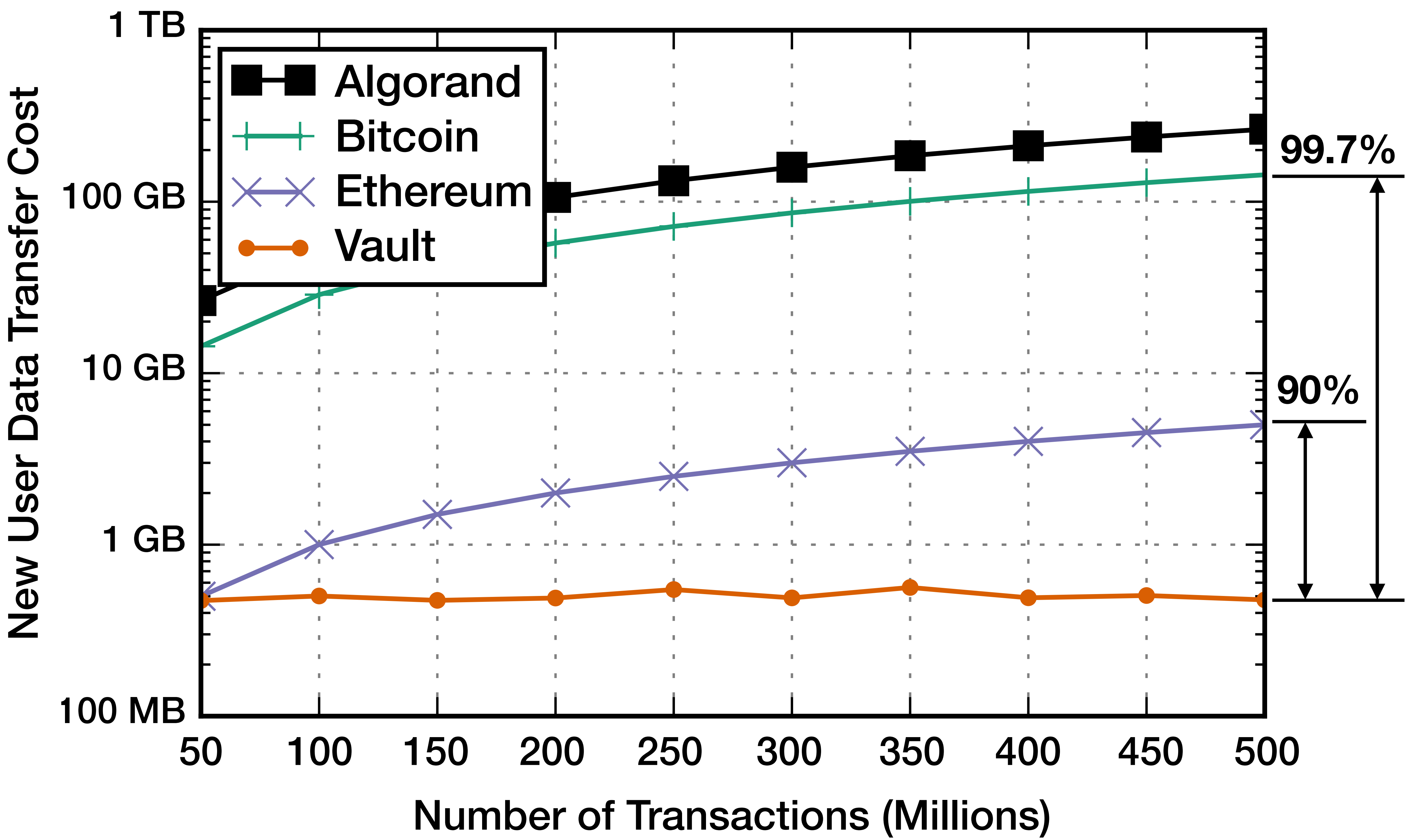
Block headers contains hash of previous block headers

Fall back to large certificates (7MB to skip *delay* blocks)

Evaluation

- Simulate trace of 500 million simple transactions
- Prototype data structures in Bitcoin, Ethereum, Algorand, and Vault
  - All 3 Vault techniques: transaction expiration, adaptive sharding, and succinct certificates
  - *delay* = 1000, #*shards* = 1000
- Measure bootstrapping data transfer cost

Data Transfer Cost



Related Work

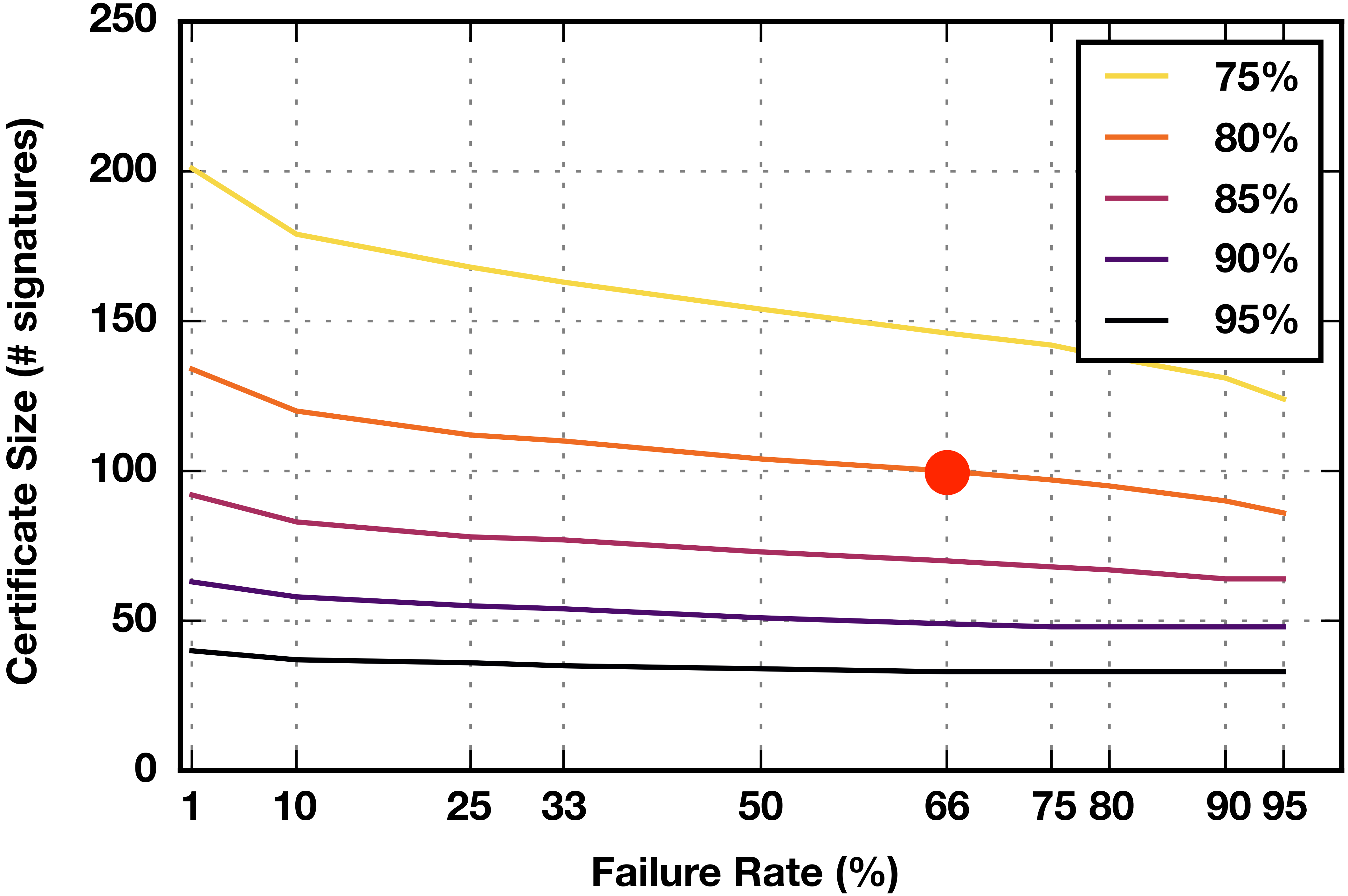
- Minimize State:
  - Lightning Network (Poon and Dryja)
  - Edrax (Chepurnoy *et al*.)
  - OmniLedger (Kokoris-Kogias *et al*.)
- Minimize Proof of State:
  - MimbleWimble (Poelstra)
  - Chainiac (Nikitin *et al*.)

Conclusion

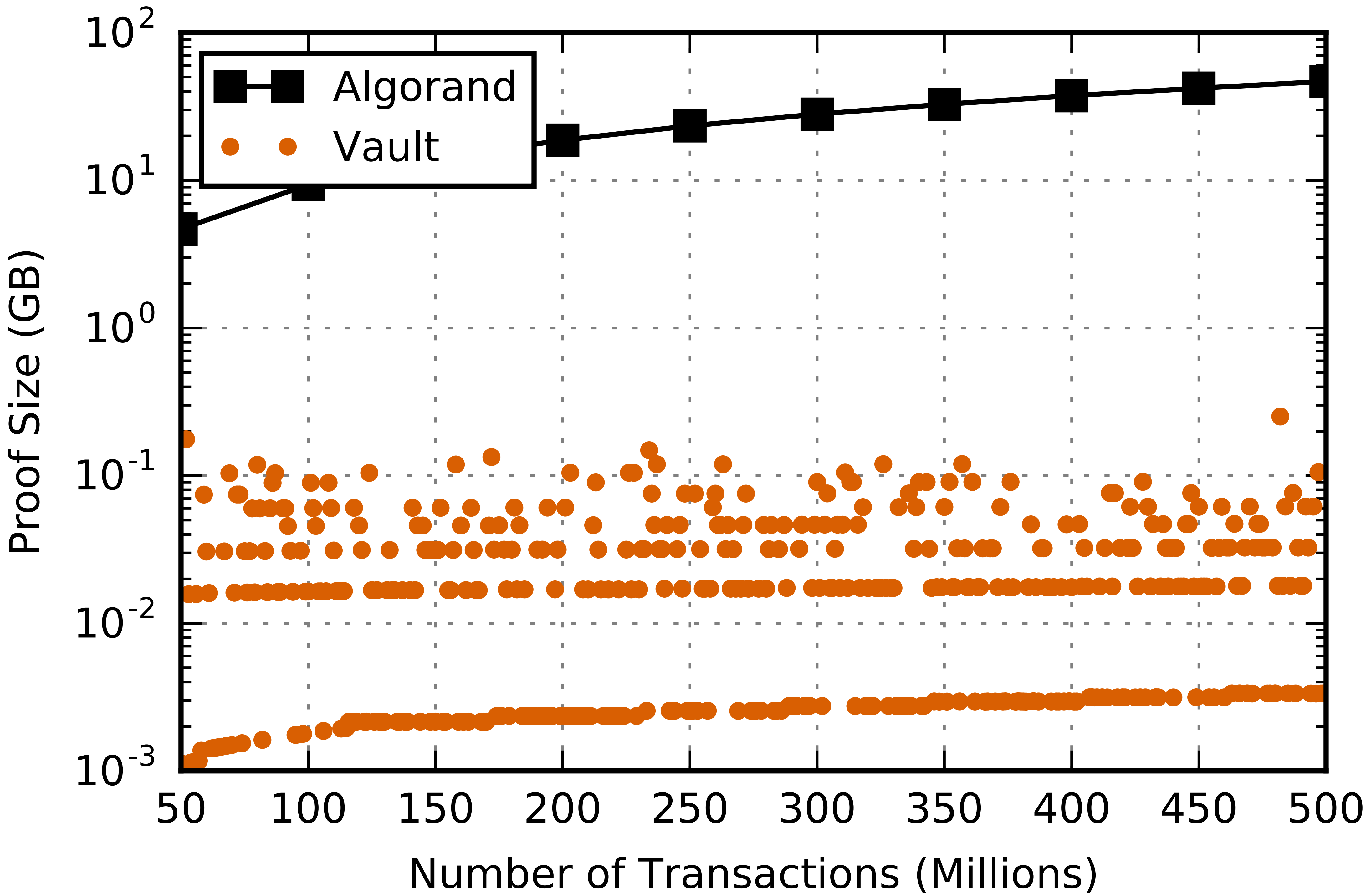
- Bootstrapping costs prevent scaling
- Vault techniques address these costs
  - Succinct certificates securely compress history, trading off availability
- Reduction in bootstrapping costs to 477MB:
  lower by 90.5% (Ethereum) or 99.7% (Bitcoin)

Backup slides

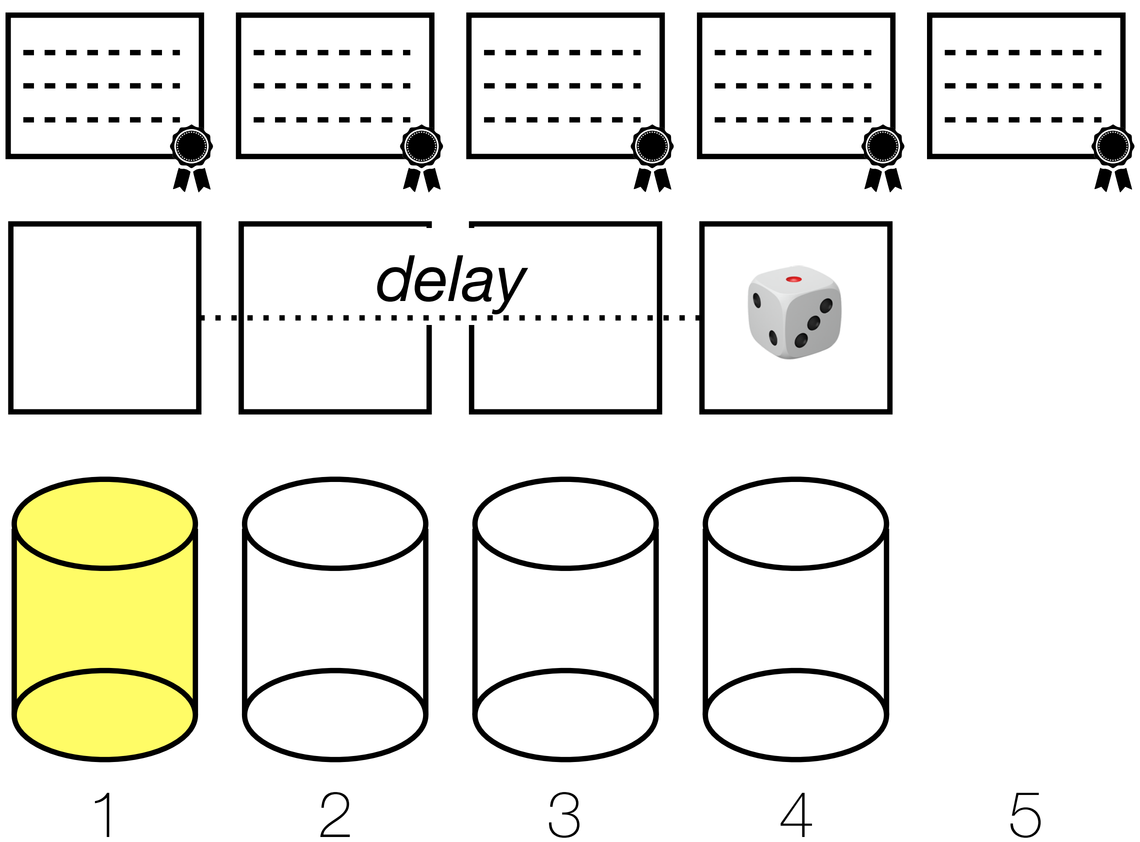
Different settings of *f*



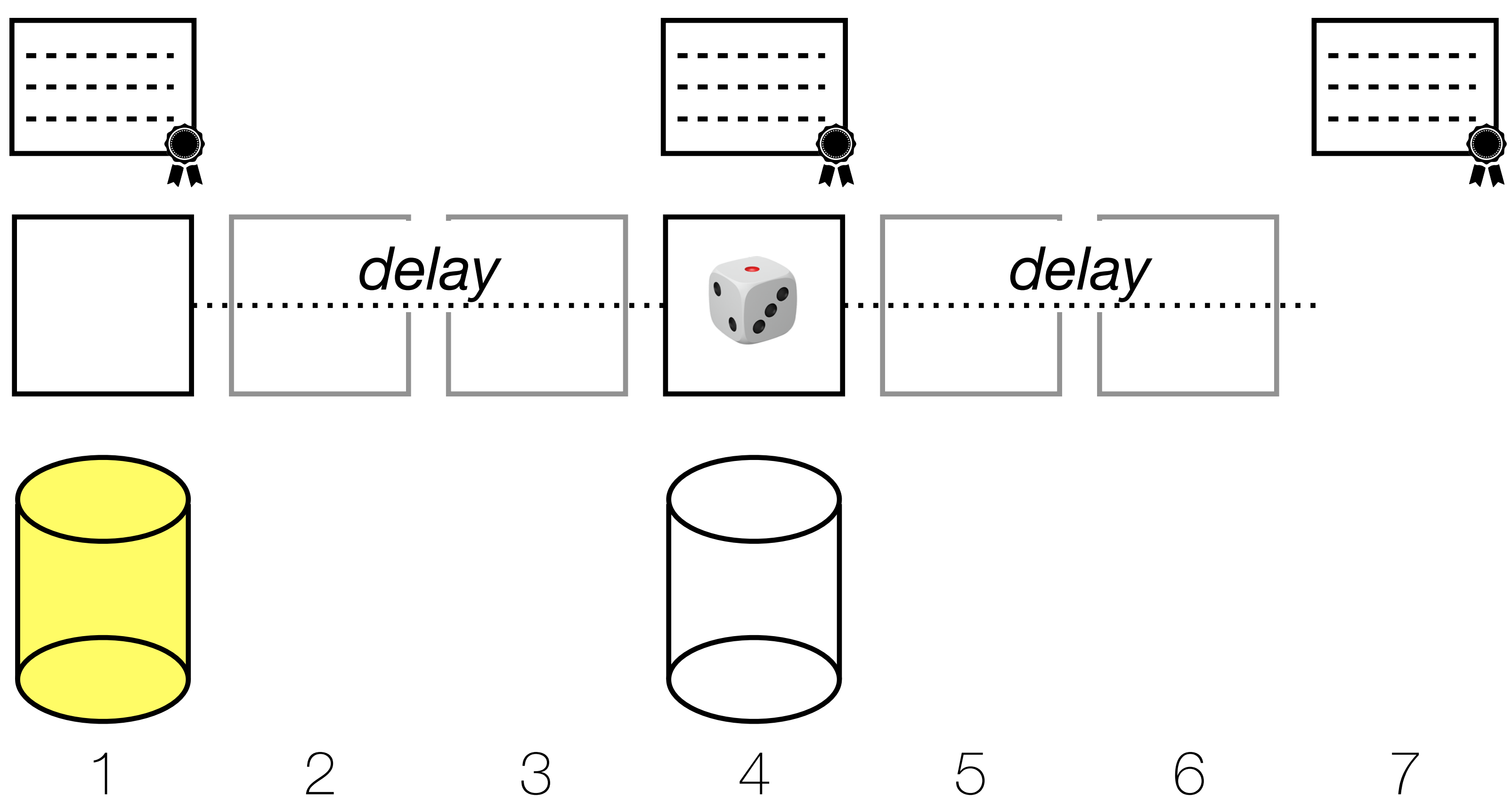
Bootstrapping Proof Size



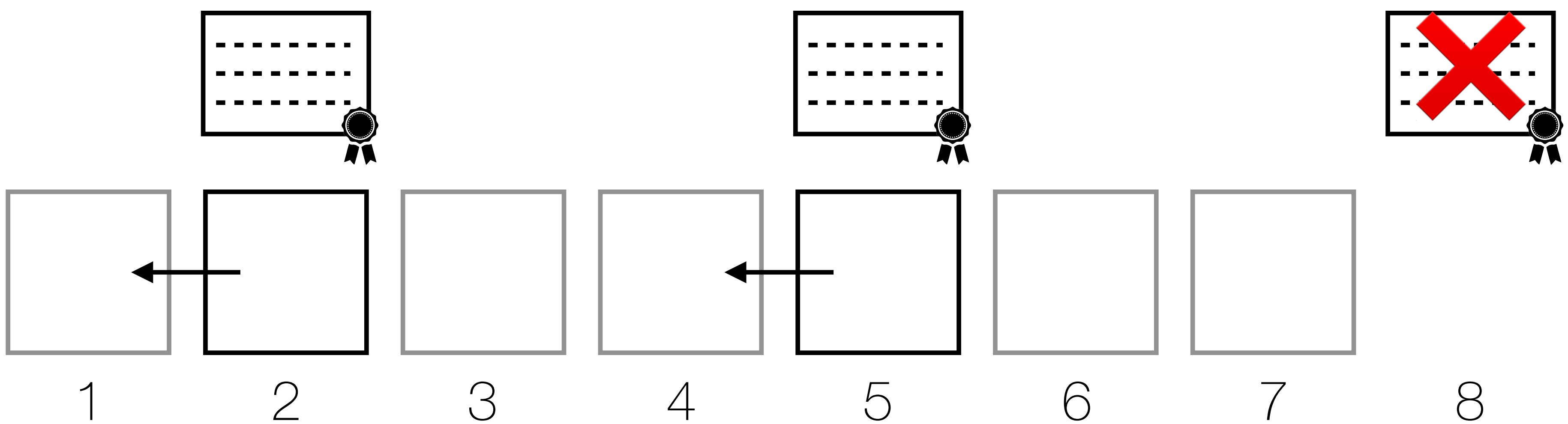
Bootstrapping with Randomization



Skipping Blocks with Randomization



Vaulting with Randomization



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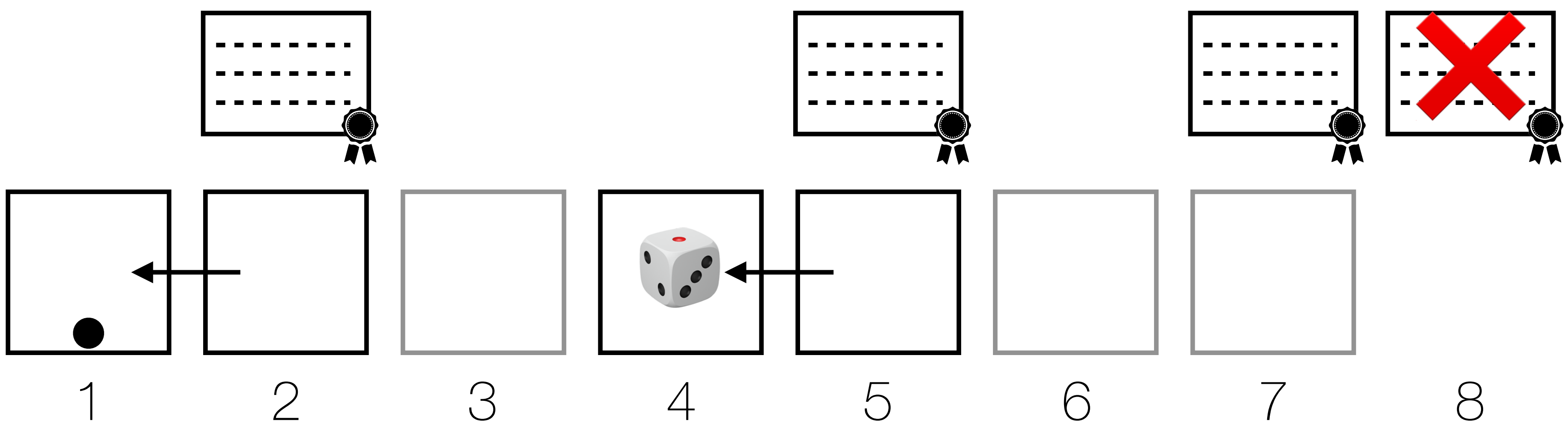

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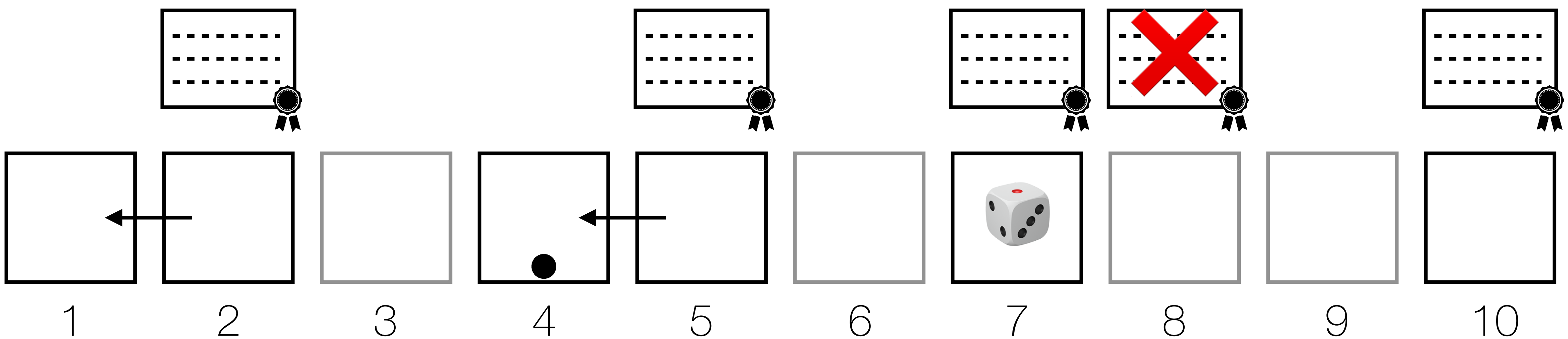

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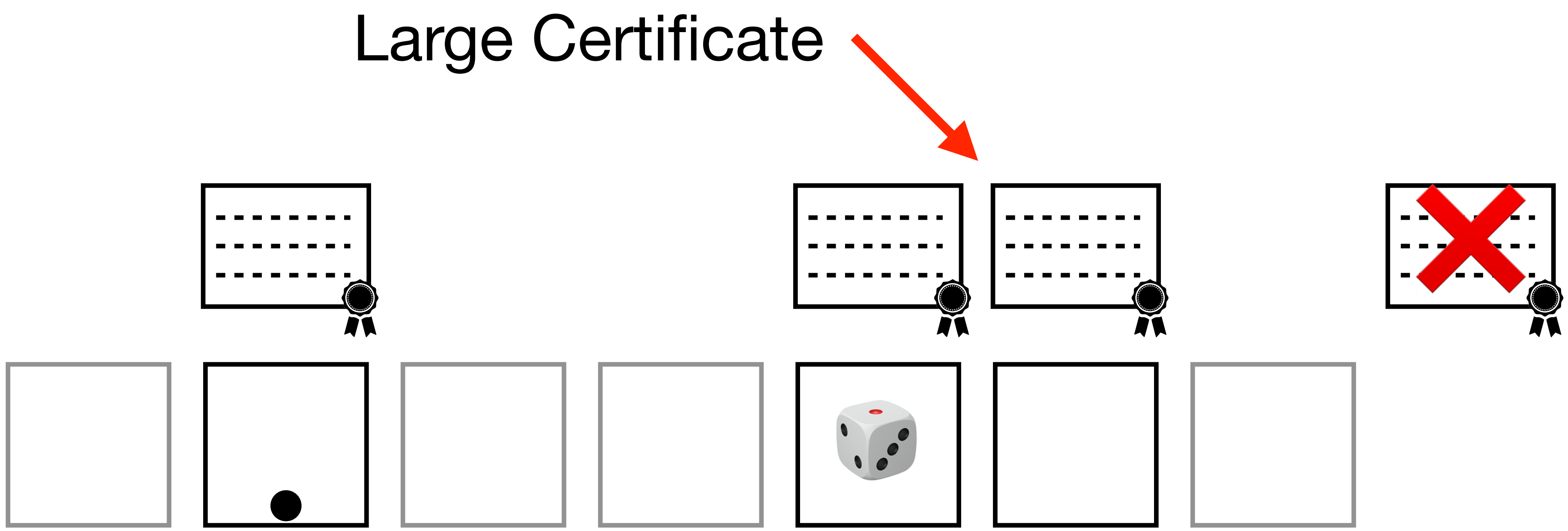
Fallback with Algorand



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