Extending Existing Blockchains with Virtualchain

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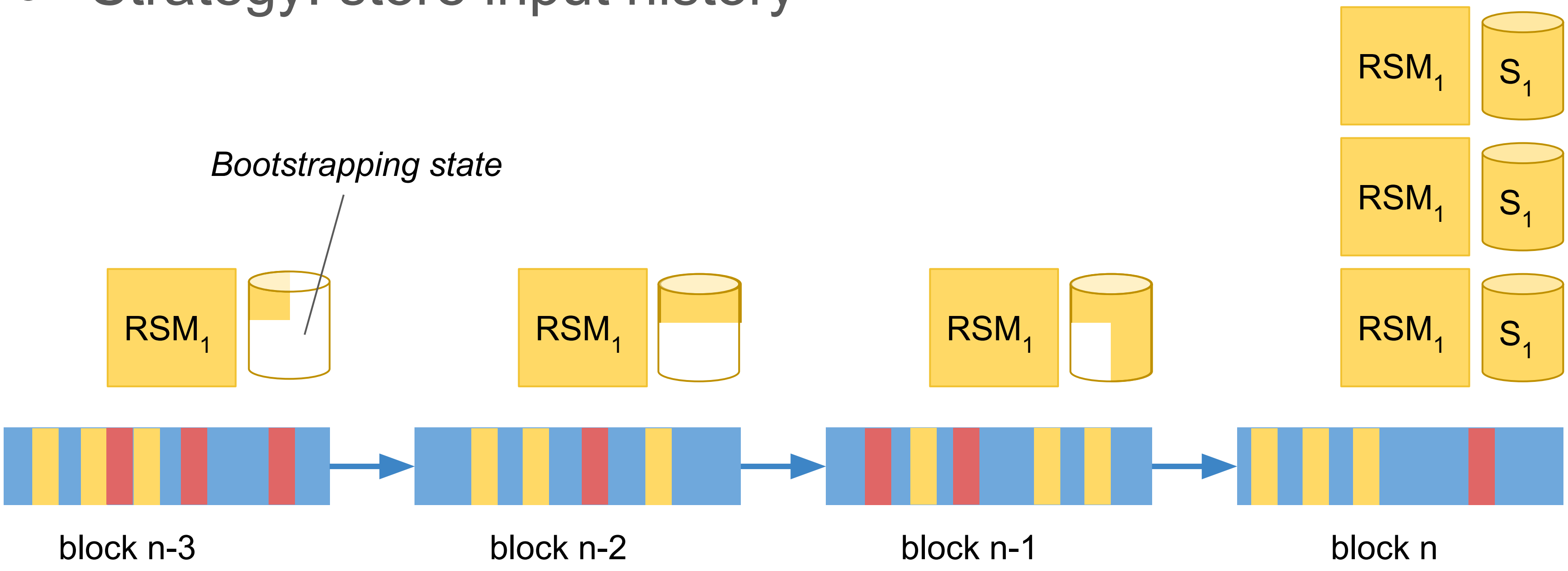
Pretend cryptocurrencies do not exist

What’s in a Proof-of-Work Blockchain?

- Total ordering of writes
- “Stable” view ordering (*)
- Append-only
- 100% replicated
- Tamper-resistant
- Anyone can write
- Fixed growth rate (pay-to-play)
- **Hard to upgrade once deployed**

Distributed Applications and Blockchains

- Replicated state machines (RSMs) on top?
- Strategy: store input history



Advantages

- Open app membership
- Survive total app failure
- Blockchain-agnostic
- App-agnostic

Challenges

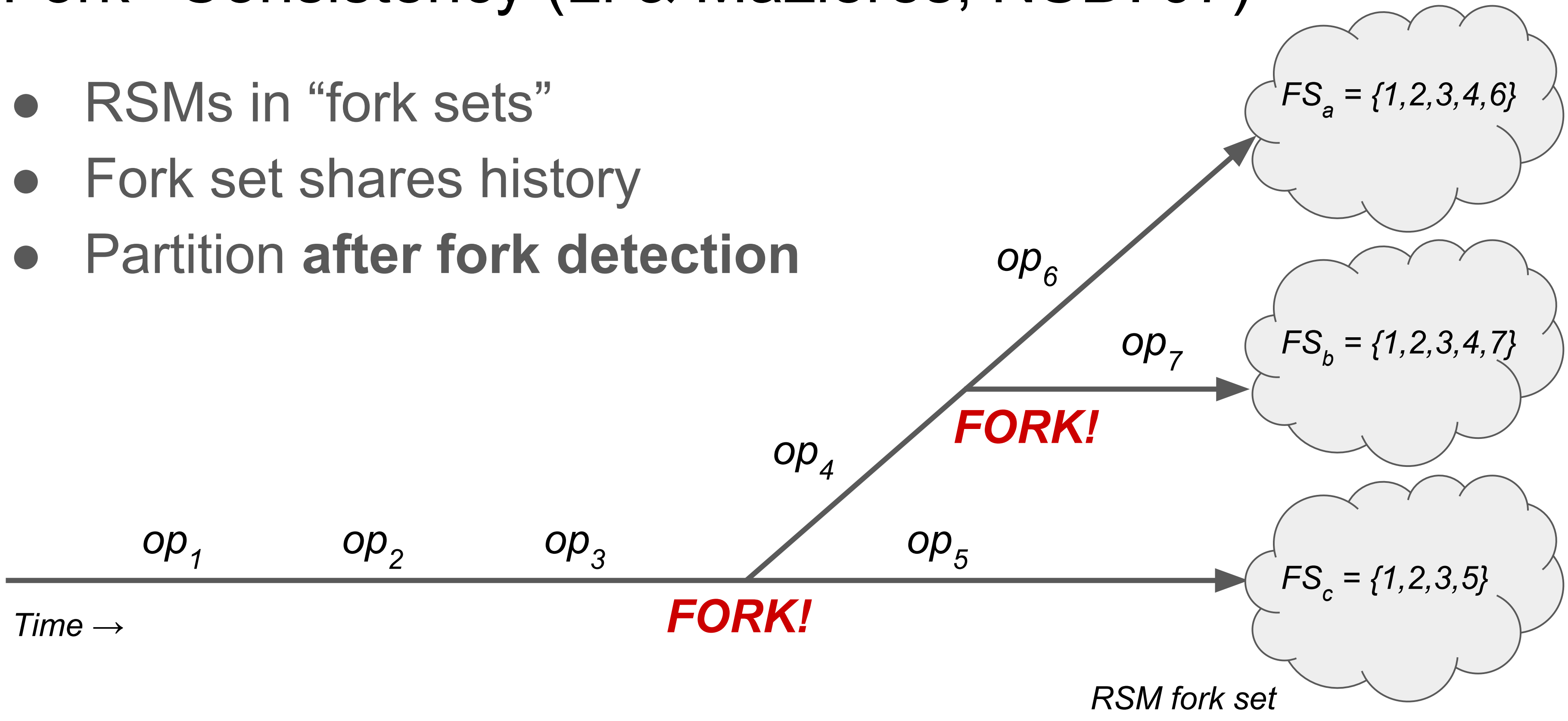
- Blockchain failure
  - Goes offline
  - “Centralization” attacks
- Blockchain forks
  - Data loss
  - Chain reorganization

Virtualchain

- Fork*-consistent RSMs on existing blockchains
- Fork detection & recovery
- Cross-chain migration

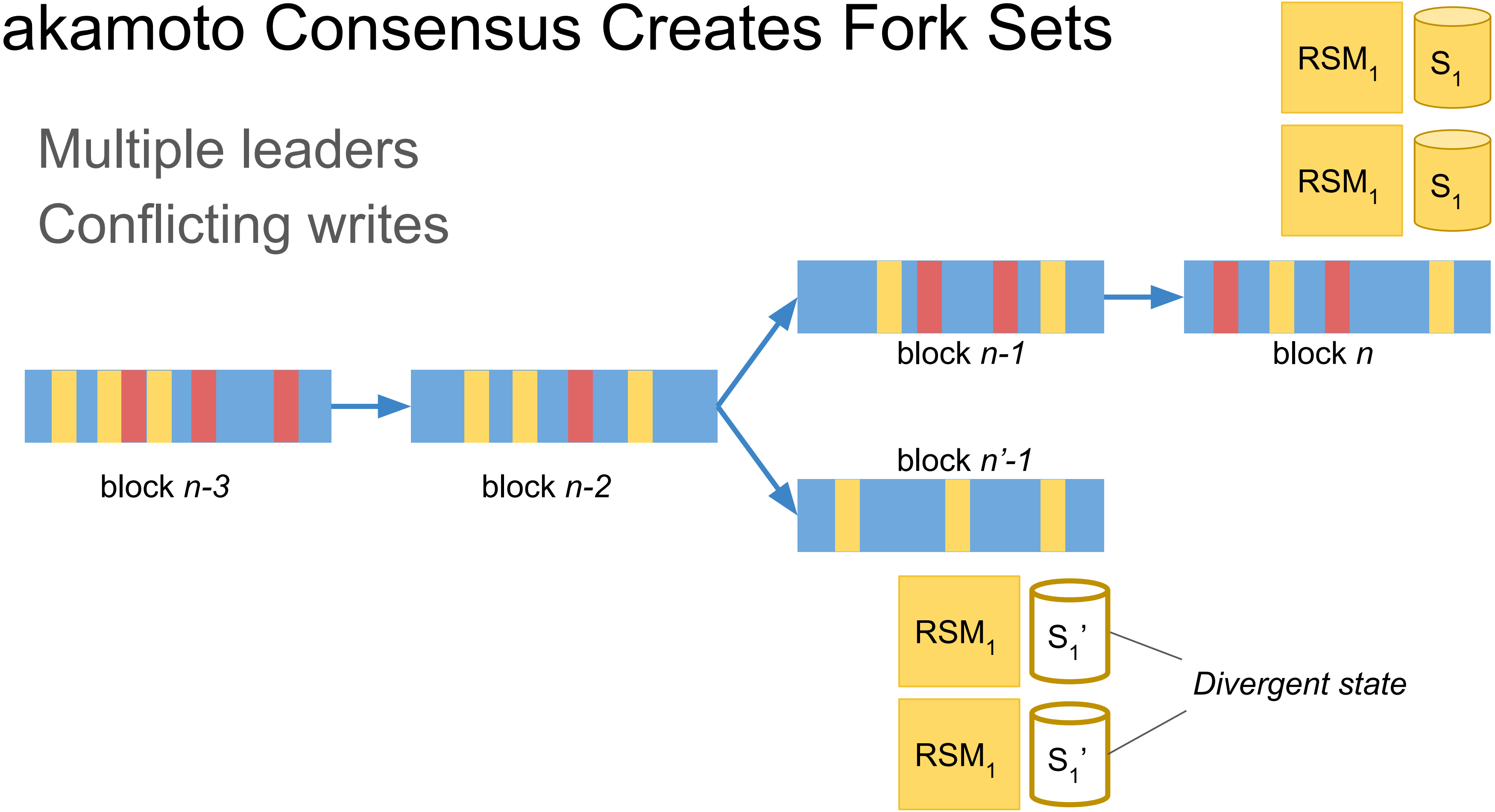
Fork*-Consistency (Li & Maziéres, NSDI’07)

- RSMs in “fork sets”
- Fork set shares history
- Partition **after fork detection**



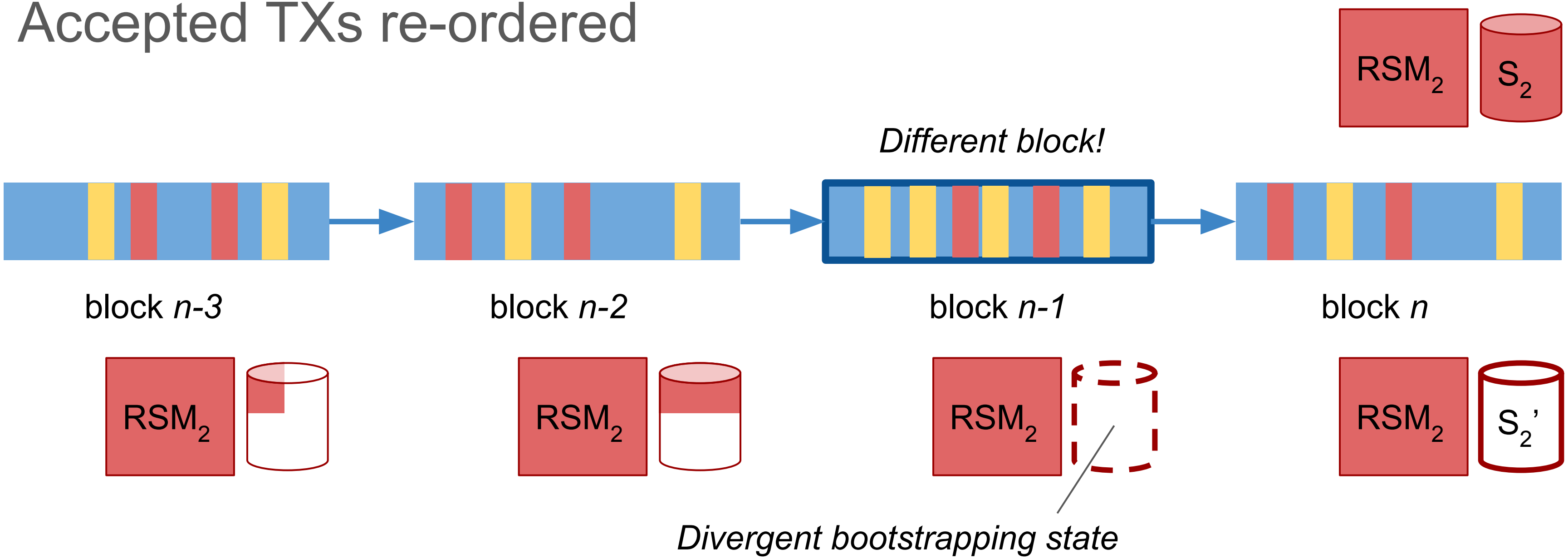
Nakamoto Consensus Creates Fork Sets

- Multiple leaders
- Conflicting writes



Reorganizations Create Fork Sets

- Conflicting TXs discarded
- Accepted TXs re-ordered

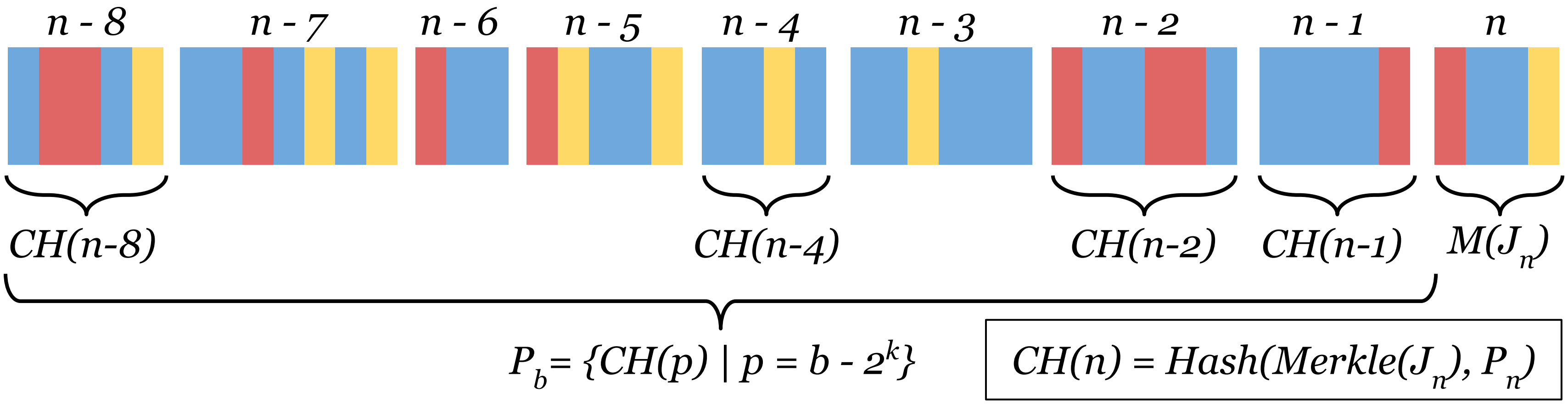


Solution: Consensus Hashes

- In-band app-level consensus
- Used for:
    - Identifying fork sets (multiplexing)
    - Fork detection and recovery
    - Blockchain migration
    - Lightweight fork set selection

Consensus Hash Construction

- *CH(n)*: cryptographic hash
- Covers ***state transition history*** (“journal”)



$P_b = \{CH(p) \mid p = b - 2^k\}$

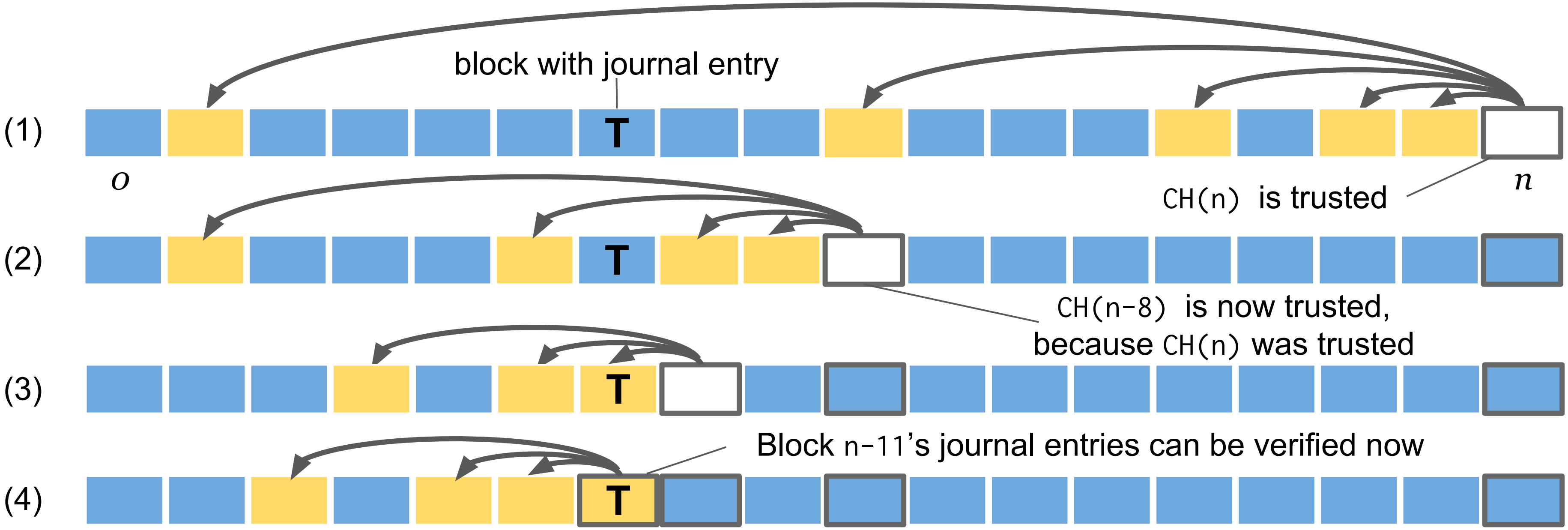
$$\boxed{CH(n) = Hash(Merkle(J_n), P_n)}$$

In-band Consensus

- Fork sets: agree on *CH(n)* **for all *n***
- Client: embed latest *CH* in input TX
  - Obtained from preferred fork set
- Server: consider TX only if *CH* is “recent”
  - “Send/ACK” with *K*-block timeout

Lightweight Fork Set Selection

- Given *CH(n)*, search for *characteristic state transitions*

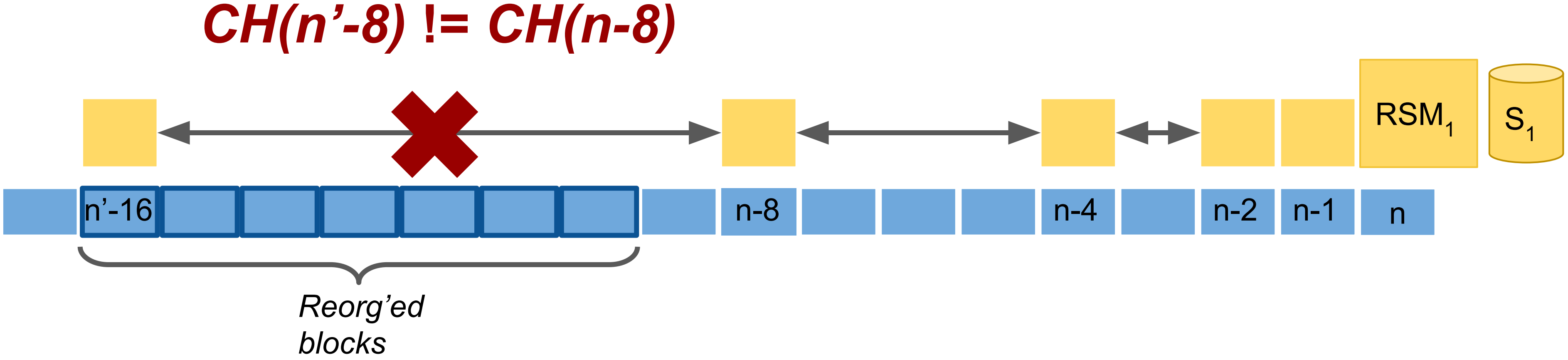


Dealing with Blockchain Forks

- Most forks are short-lived
  - Avoid with “confirmations”
- Long-lasting forks are rare
  - But widely noticed!
  - Due to bugs or attacks

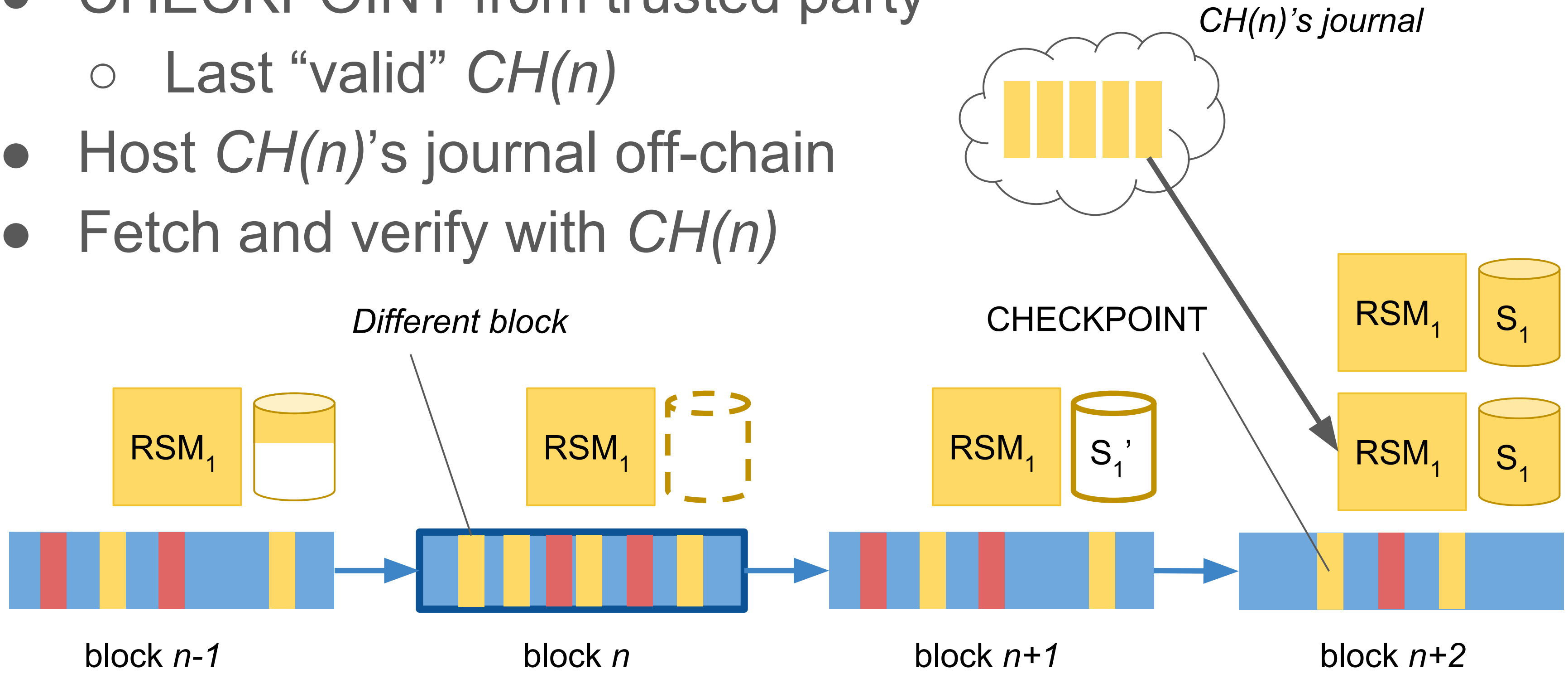
Fork/Reorganization Detection

- Continuously audit CH history
- Alert on disagreement



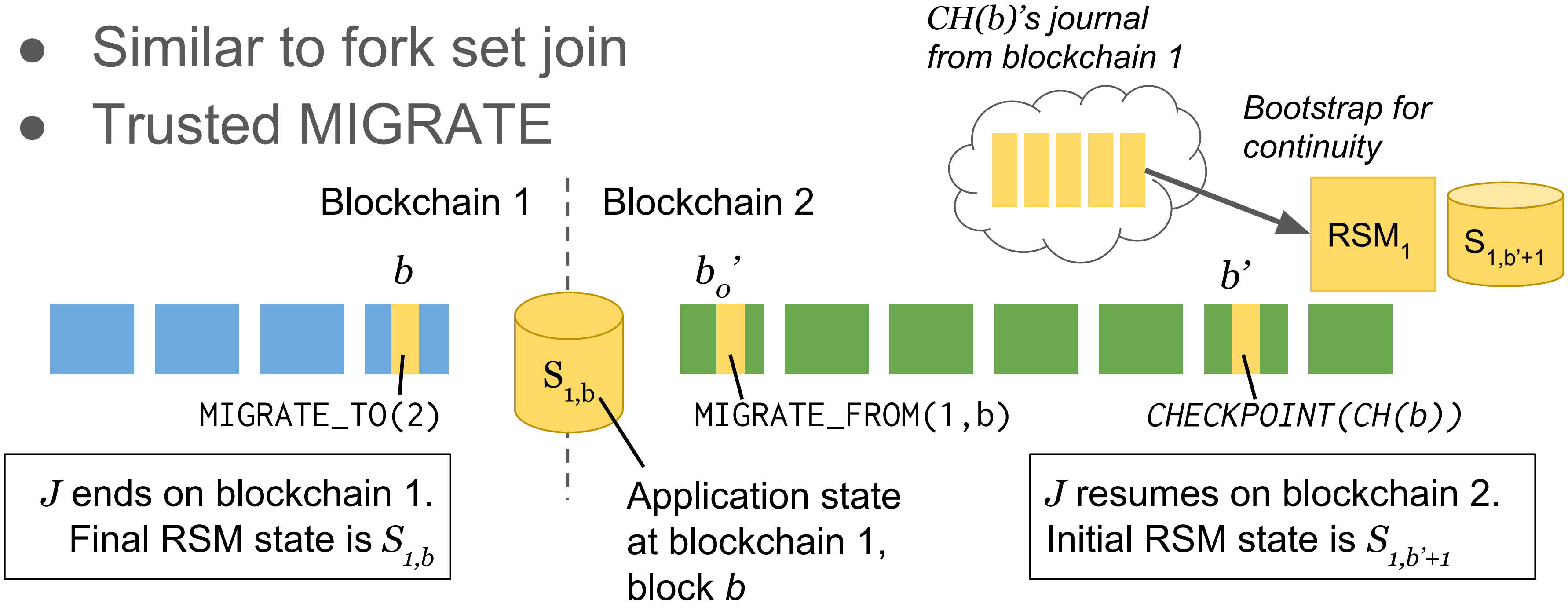
Joining Fork Sets

- CHECKPOINT from trusted party
    - Last “valid” *CH(n)*
- Host *CH(n)*’s journal off-chain
- Fetch and verify with *CH(n)*



Cross-chain Migration

- Similar to fork set join
- Trusted MIGRATE



CH(b)'s journal from blockchain 1

Bootstrap for continuity

J ends on blockchain 1. Final RSM state is $S_{1,b}$

Application state at blockchain 1, block *b*

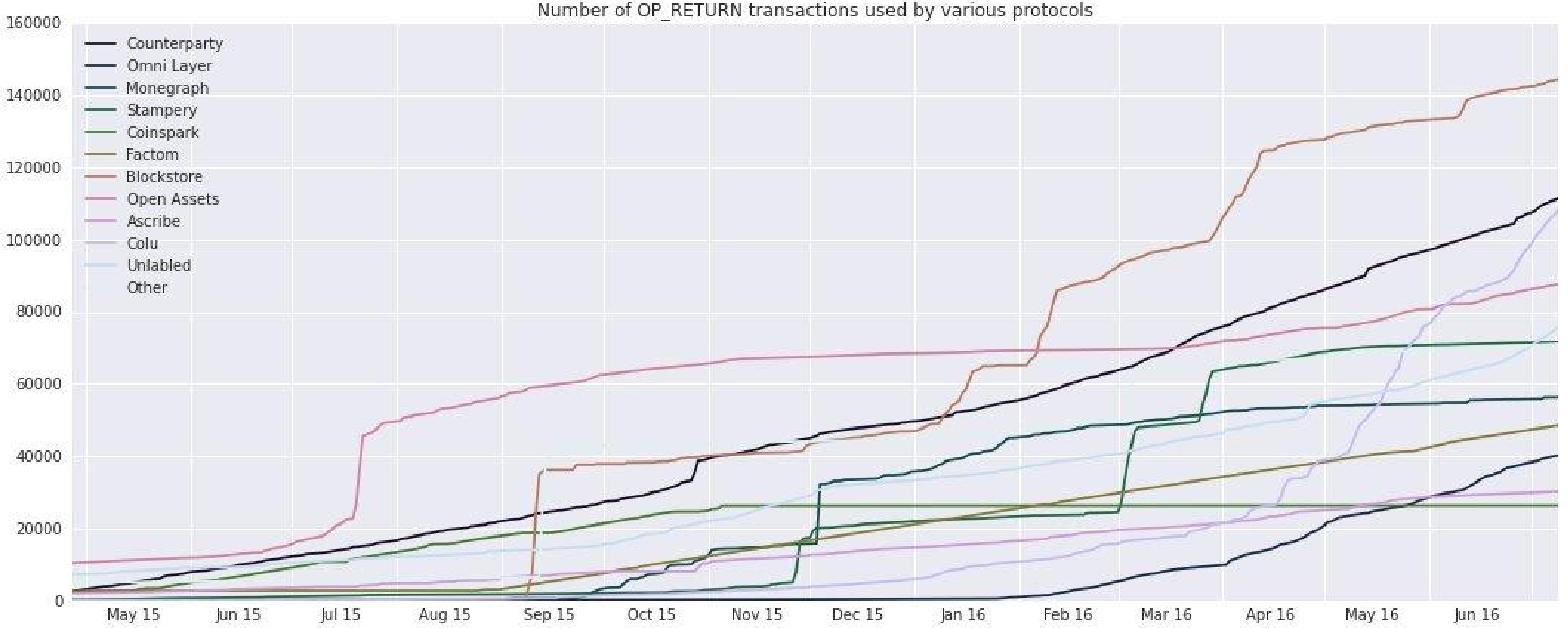
J resumes on blockchain 2. Initial RSM state is $S_{1,b'+1}$

On Centralization, Trust, and Cryptocurrencies

- Already trust RSM author
- Use CHECKPOINT, MIGRATE **judiciously**
  - Ignore with **no loss of security**
- Cryptocurrency: RSM input rate-limiter
  - RSMs becoming key use-case
  - Cloud market is >10x more valuable

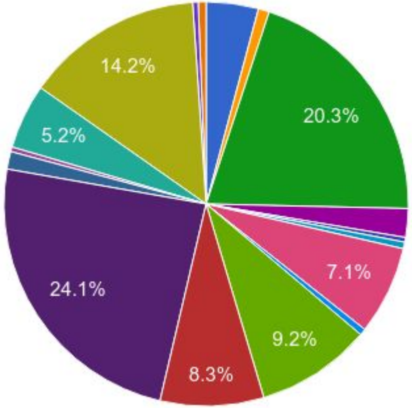
Example: Bitcoin OP_RETURN Usage

Source: Harry Kalodner

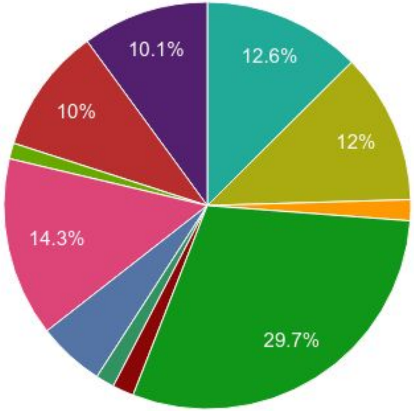


Concluding Remarks

- In production for >1 year in Blockstack
- https://github.com/blockstack/blockstack-virtualchain
- Ali, Nelson, Shea, Freedman (ATC'16)
- Migrated from Namecoin to Bitcoin



Source:
opreturn.org



Thank you!
Questions?