Self-Auditable Key Transparency

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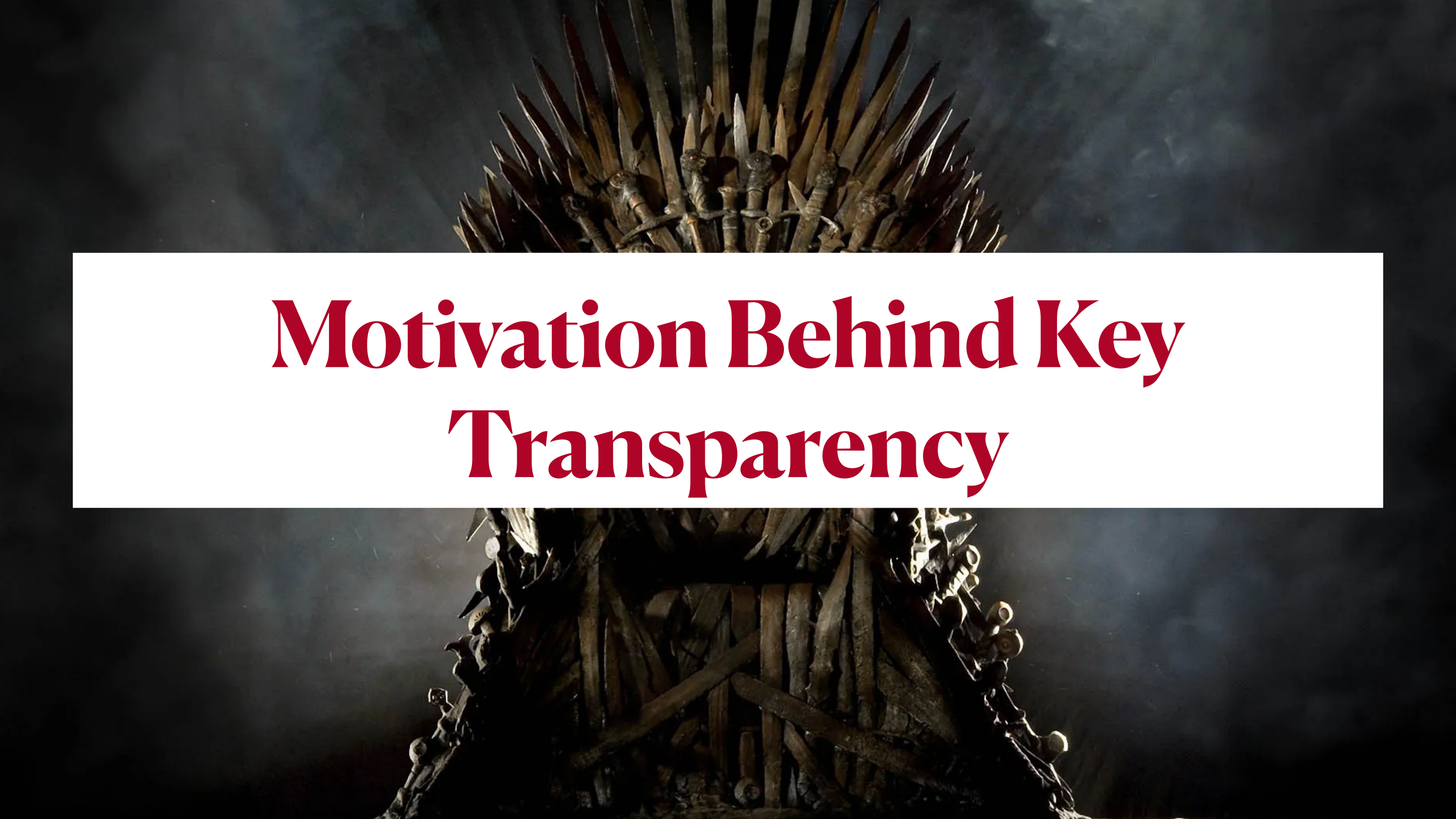

Motivation Behind Key Transparency

End-to-End Encrypted Messaging

$(pk_{\text{Jon}}, pk_{\text{Ygritte}})$

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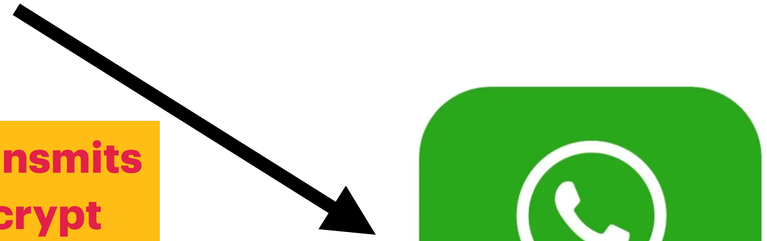

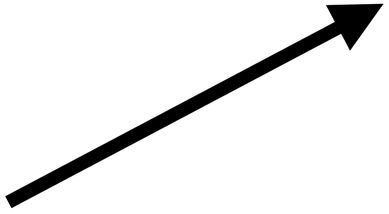

The service provider only transmits ciphertexts and cannot decrypt them

How do users get each other public keys from example from a phone number?

End-to-End Encrypted Messaging

$(pk_{\text{Jon}}, pk_{\text{NK}})$

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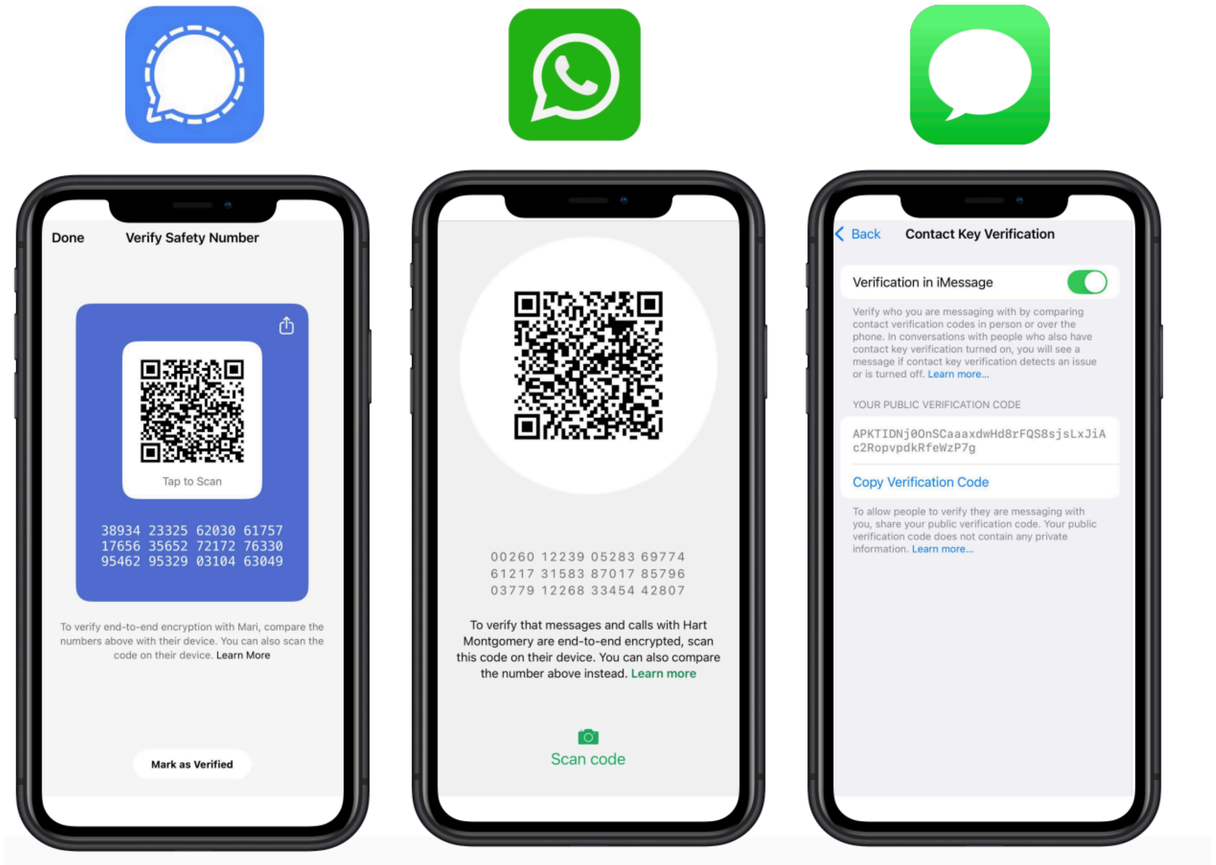
Give Jon a malicious public key


“You know nothing, Jon Snow.”

Traditional Solution: Out-of-Band Verification



Traditional Solution: Out-of-Band Verification

Key Transparency: CONIKS [MBBFF15]

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Periodically post

Signed commitments

to directory

WhatsApp

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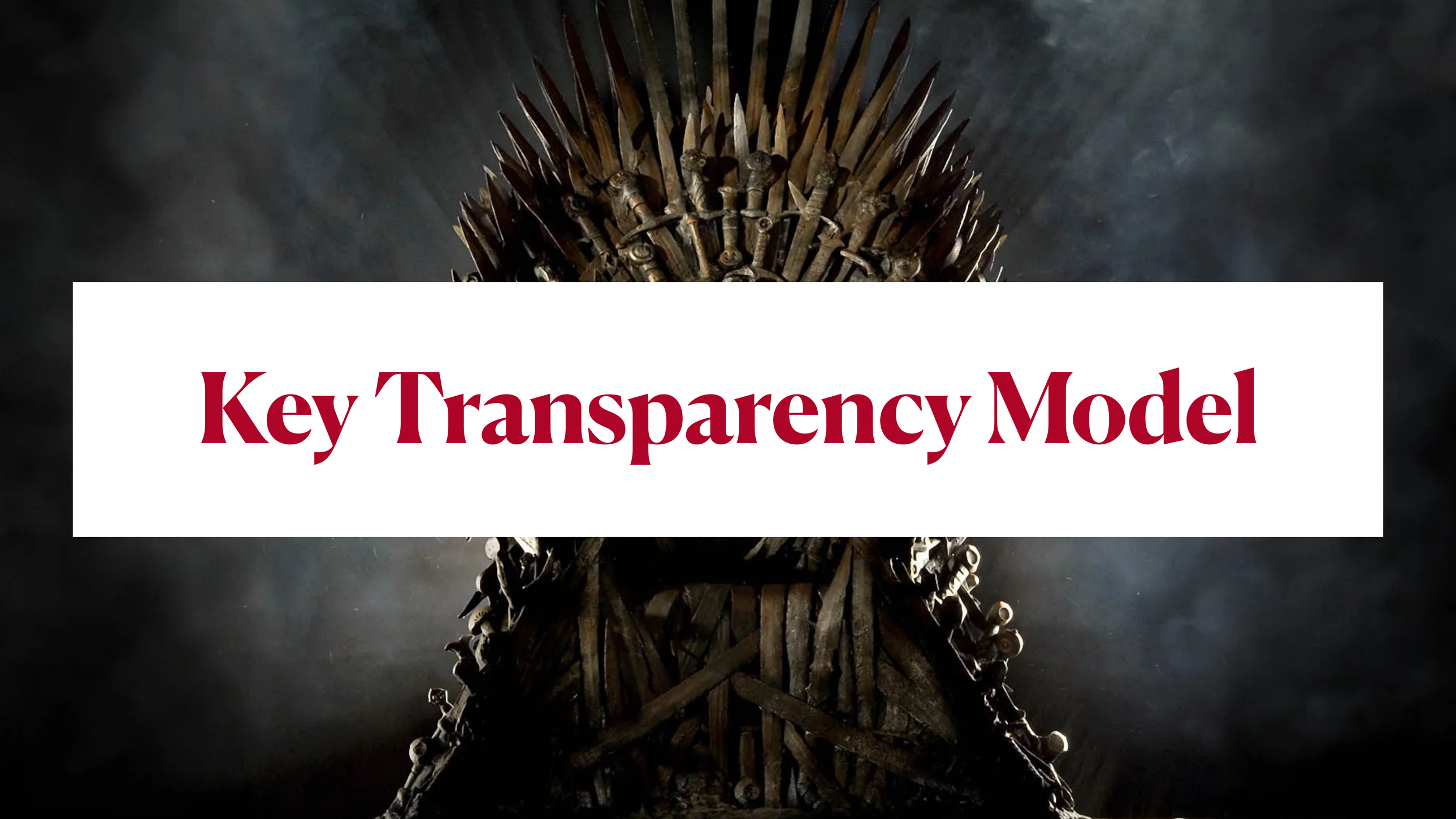
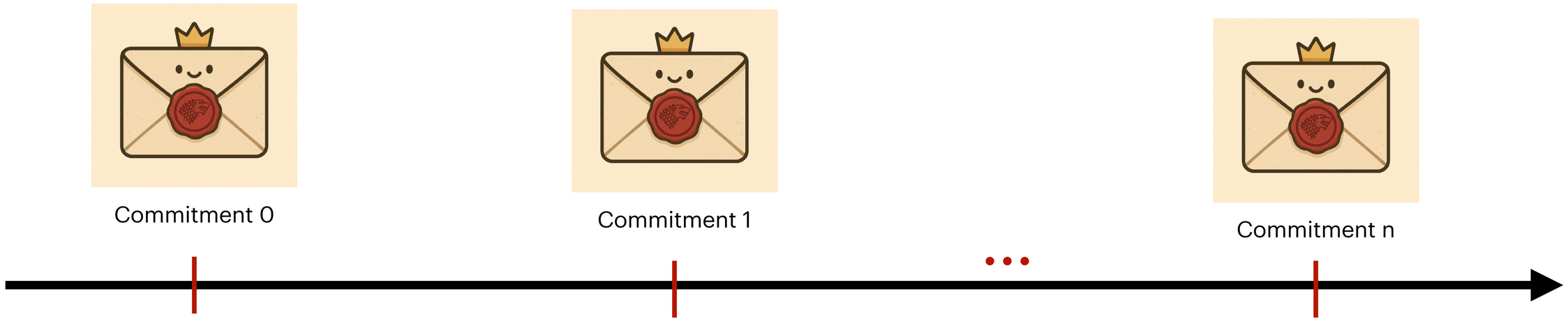
AUTOMATED SOLUTION: no manual effort for Jon and Ygrittee



Key Transparency Model

Key Transparency Scheme

- Key transparency scheme consists of a server that at every epoch publishes the new commitment to the directory along with auxiliary data (invariance proof)



Key Transparency Scheme

Jon

(I) what is Ygritte's latest public key?

Lookup

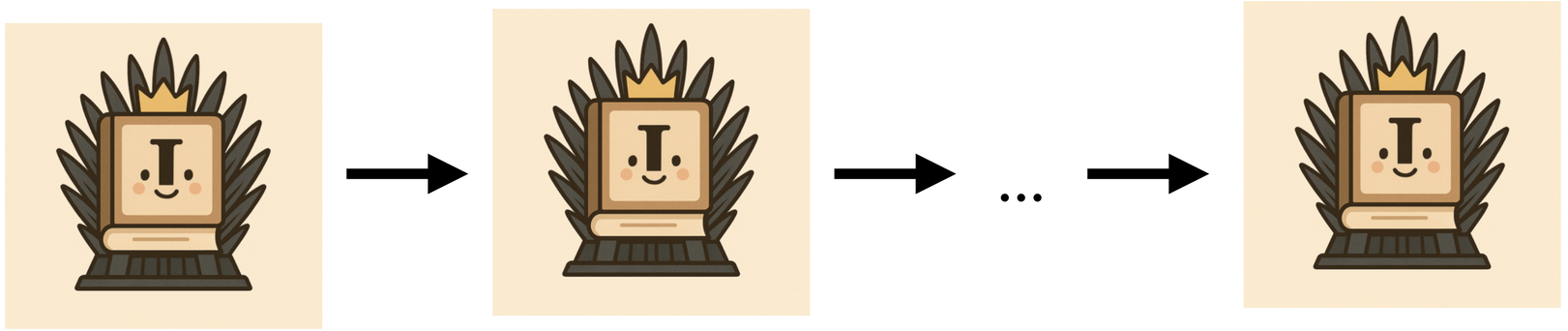
(II) Prove my key hasn't changed since last year?

Proof of consistency

WhatsApp

Necessity of Proof of Consistency

Assume Jon is offline from state i+1 to state j-1



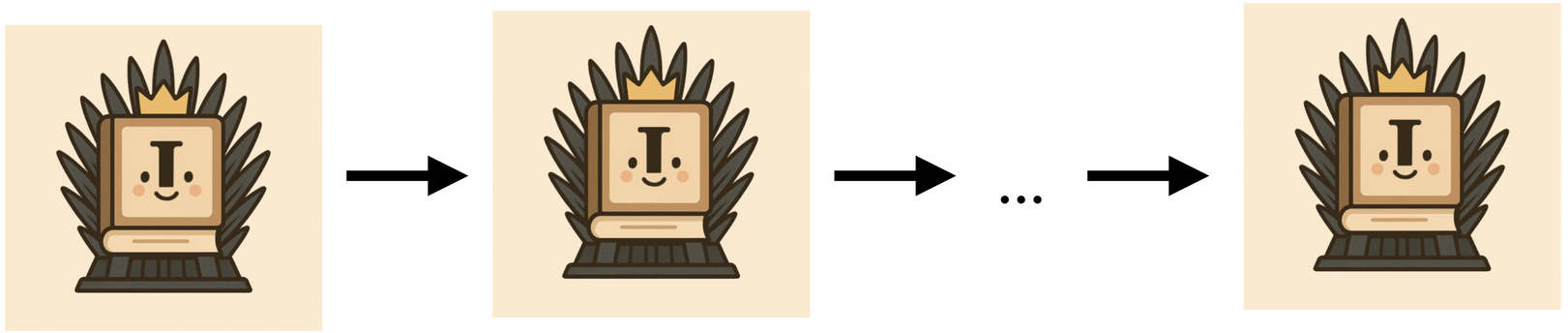
State i

State i+1

State j

Necessity of Proof of Consistency

Assume Jon is offline from state i+1 to state j-1



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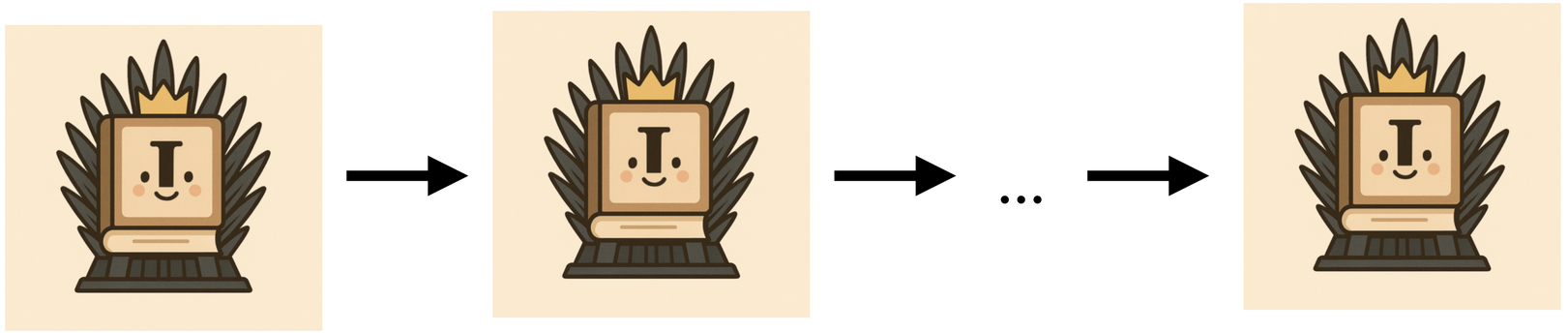


State i

State i+1

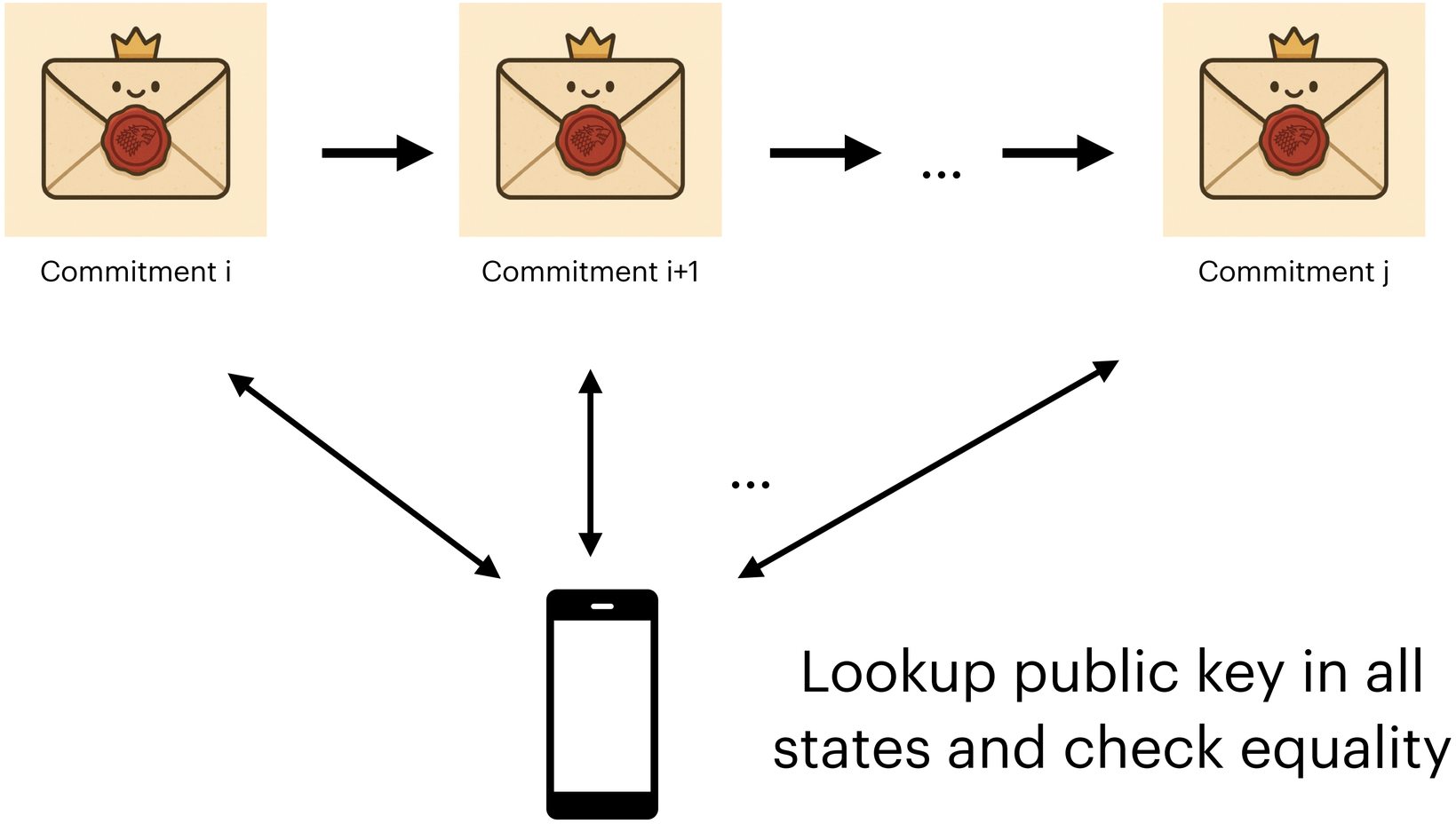
State j

Request a proof of consistency from epoch i to epoch j

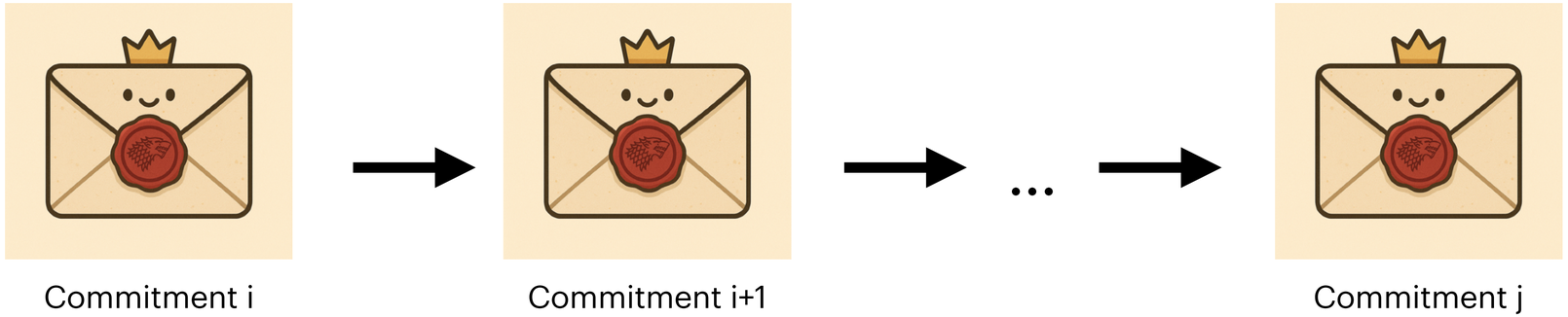
Different Solutions to Proof of Consistency

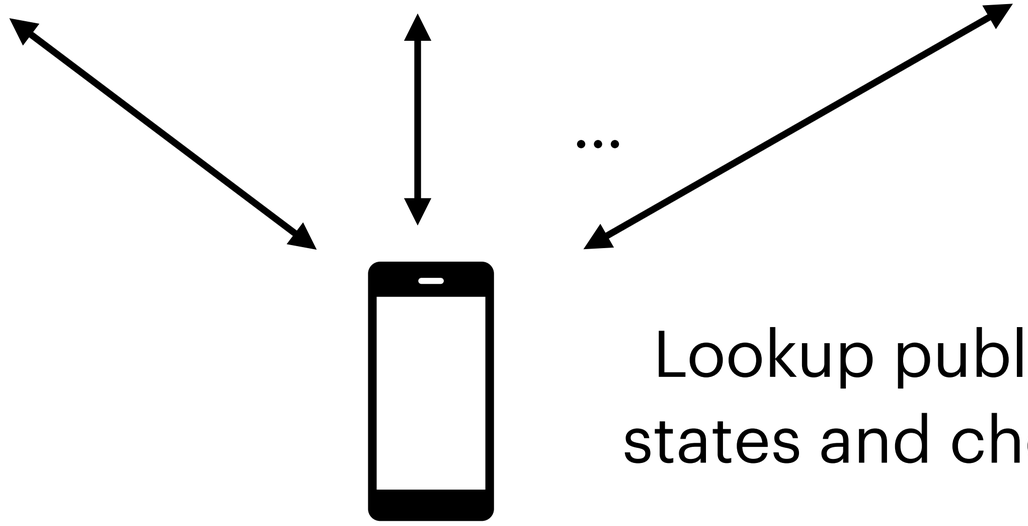
- Naively performing lookup for every epoch, e.g. CONIKS [Mel+15]
- Version Invariant, e.g. SEEMless [Cha+19], Parakeet [Mal+23], Optiks [Len+24]
- Random Version Invariant, e.g. IronDict [Haf+26] and Aegon [Haf+26]

Proof of Consistency: Naive Solution [Mal+15]



Proof of Consistency: Naive Solution [Mal+15]

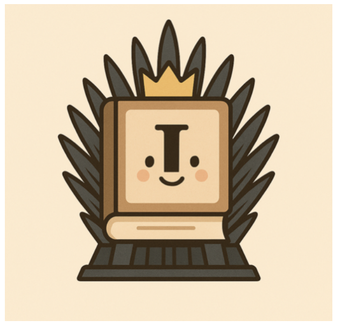




Lookup public key in all states and check equality

Version Invariant [Cha+19, Mal+23, Len+24]

i



state i

$(pk_{\mathsf{Jon},i}, v_i)$

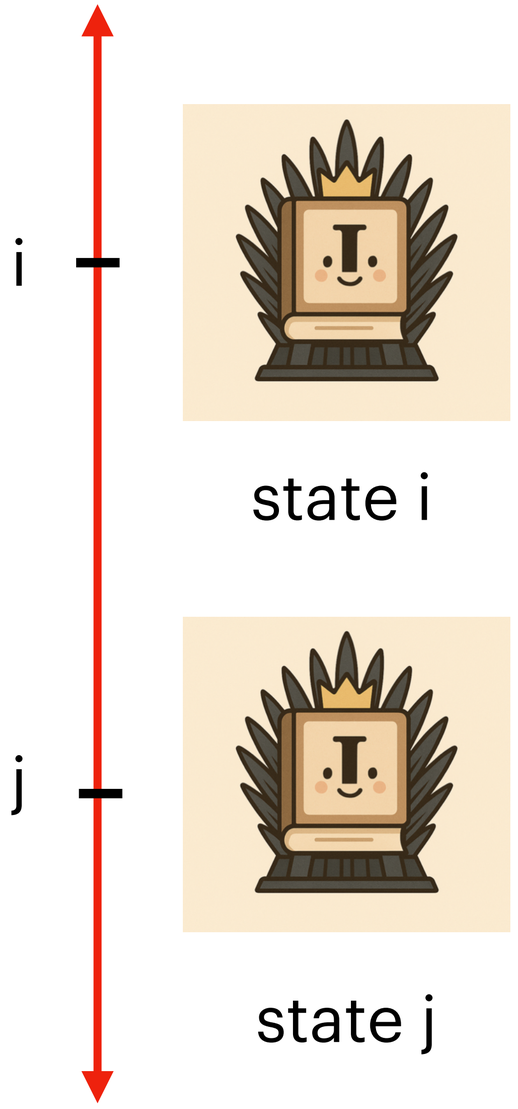
j

state j

$(pk_{\mathsf{Jon},j}, v_j)$

time

Version Invariant [Cha+19, Mal+23, Len+24]



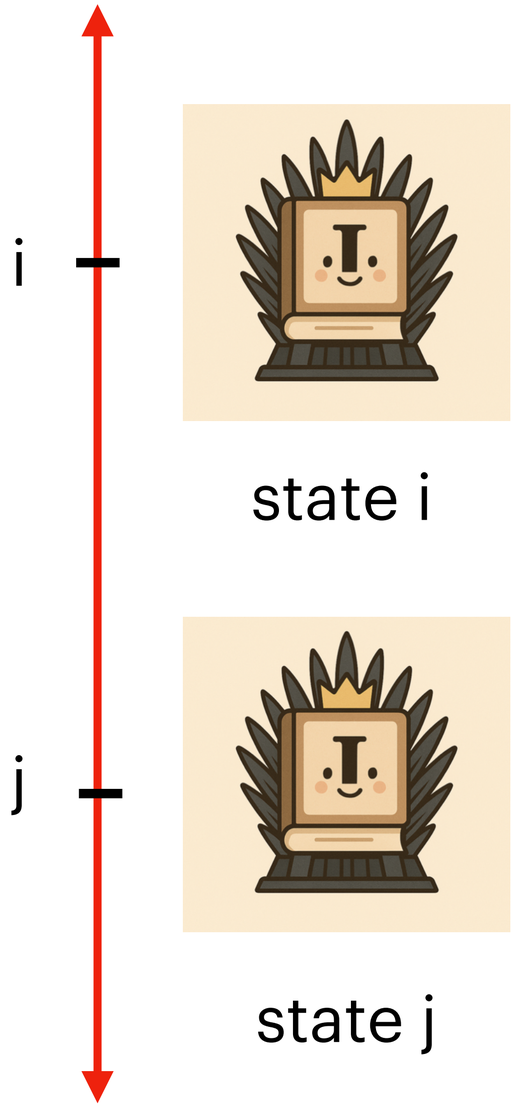
$(pk_{\mathsf{Jon},i}, v_i)$

$(pk_{\mathsf{Jon},j}, v_j)$

proof of consistency from epoch i to j

$$\iff v_i = v_j$$

Version Invariant [Cha+19, Mal+23, Len+24]



state i

$(pk_{\mathsf{Jon},i}, v_i)$

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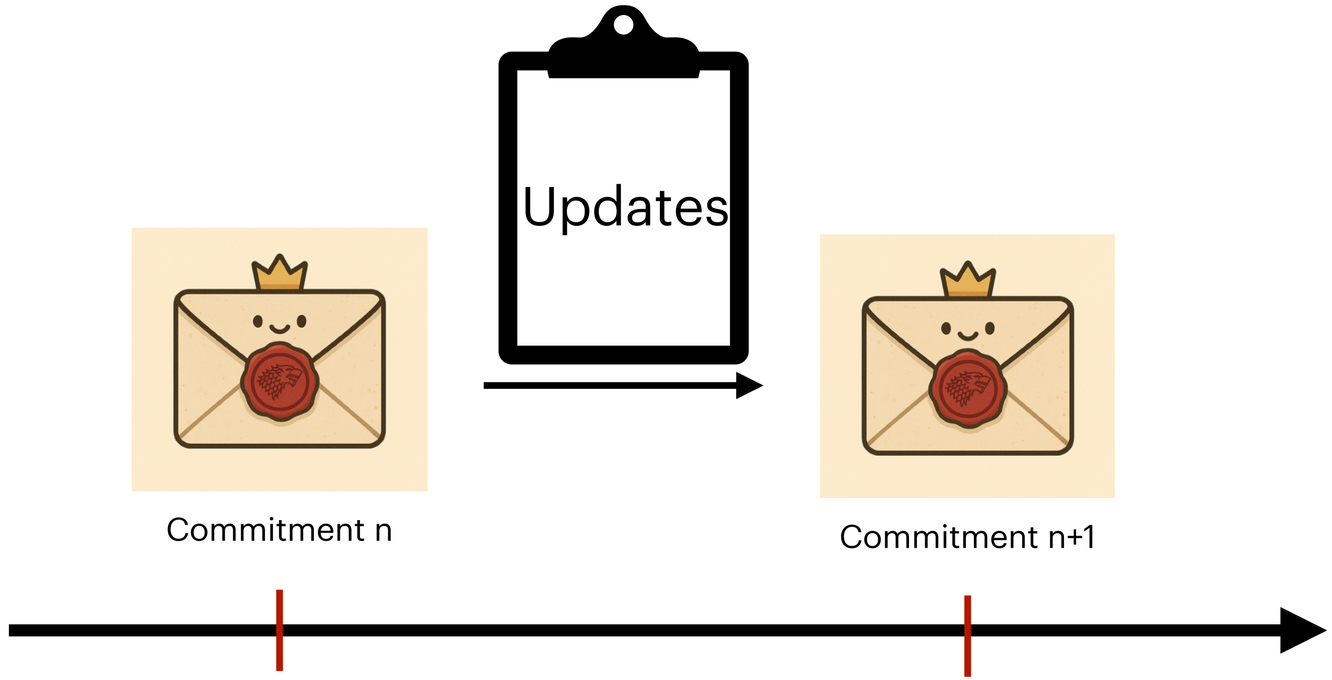
How to audit the version invariant?

Auditing Version Invariant [Cha+19, Mal+23, Len+24]

- Server publishes invariance proof == the list of updates.
- “Auditors” verify the updates have been appended correctly.



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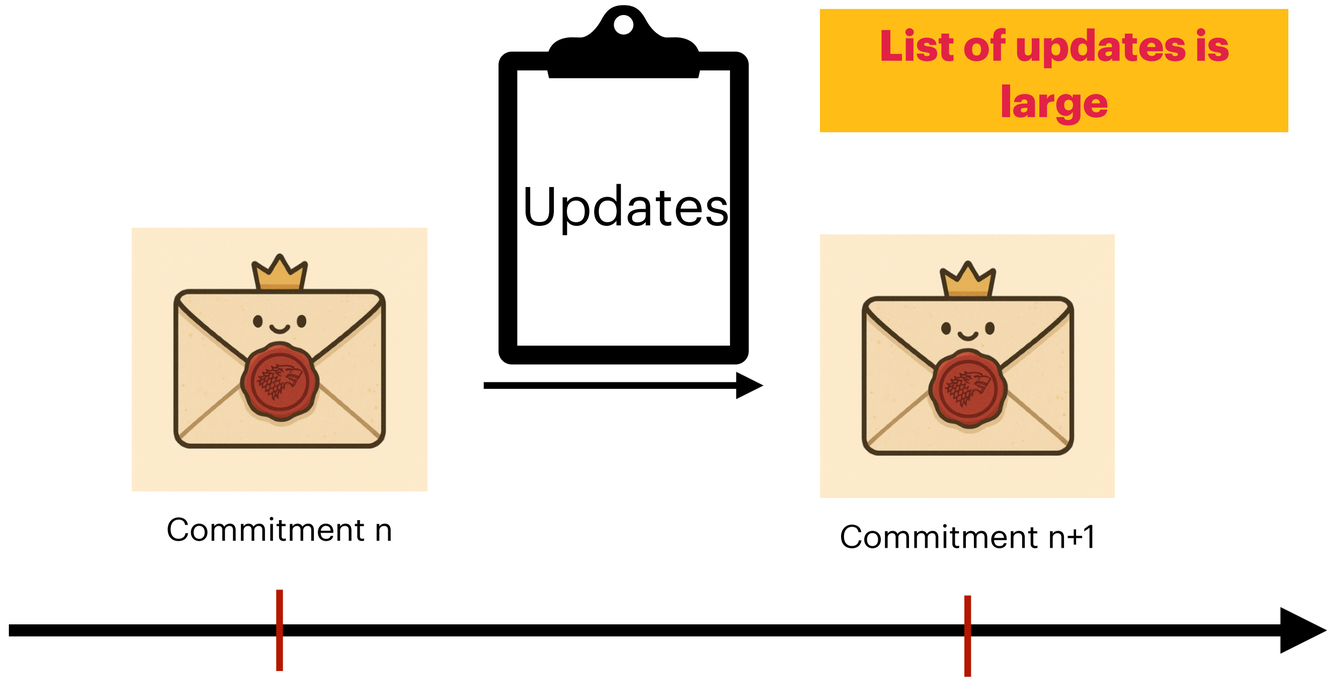

Drawbacks of Existing Schemes:

What Are Our Main Challenges?
SEEMless [Cha+19], Parakeet [Mal+23], Optiks [Len+24]

- Self-Auditablity
- Perfect Privacy
- History Pruning

Challenge I: Self-Auditablity

- Auditor’s proof is large ==> linear in the number of updates in the epoch.

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Attempts to make the proof succinct using SNARKs (e.g., Verdict [Tzi+22] and Hekaton [Ros+24]) ==> high hash-function costs in circuits limit scalability.

Challenge II: Perfect Privacy

- Privacy is crucial in the context of key transparency:
  - E.g. lookups shouldn't reveal pattern of changing keys of users.
  - Otherwise an adversary observing a user doesn't change their key regularly, makes it a potential target for them.

Challenge II: Perfect Privacy

- Privacy is crucial in the context of key transparency:
  - E.g. lookups shouldn't reveal pattern of changing keys of users.
  - Otherwise an adversary observing a user doesn't change their key regularly, makes it a potential target for them.
- Tree-based solutions do not offer perfect privacy.
  - e.g., SEEMless reveal the last time a key was updated during a lookup.

Challenge III: History Pruning

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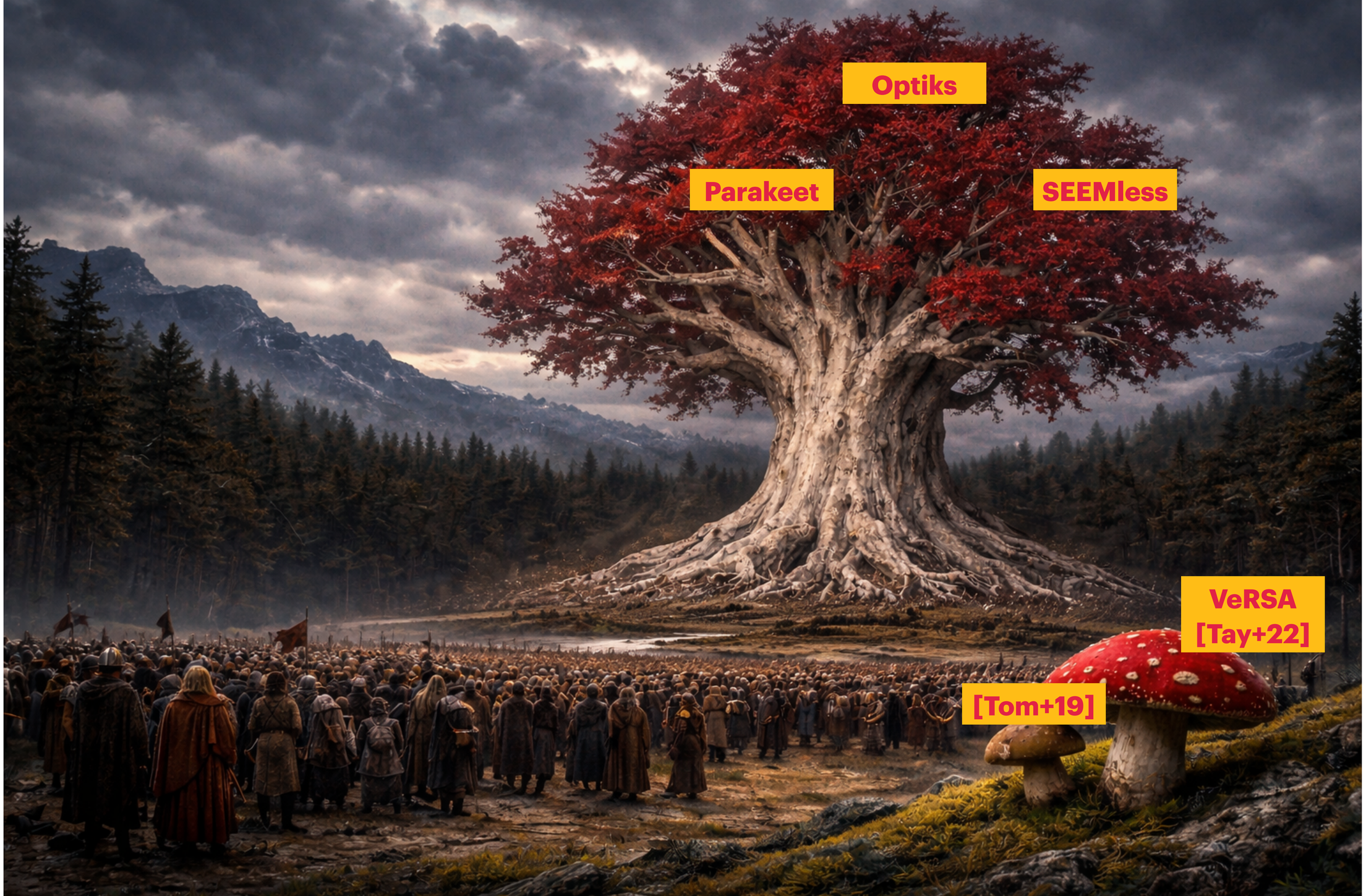
- All unnecessary historical data are kept in the tree and its size grows indefinitely.
- WhatsApp has a user base of 3-4 billion, but its tree size is more than 100 billion.

Our Proposed Schemes: IronDict and Aegon


Optiks
Parakeet
SEEMless


Optiks
Parakeet
SEEMless
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[Tay+22]
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IronDict / Aegon
based on polynomials
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IronDict:
Transparent Dictionaries from Polynomial Commitments

Hossein Hafezi[†1], Alireza Shirzad[†2], Benedikt Bünz[3], and Joseph Bonneau[4]

[1,3,4]New York University
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USENIX Security 2026

IronDict: Transparent Dictionaries from Polynomial Commitments

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[1,3,4]New York University
[2]University of Pennsylvania

USENIX Security 2026

Aegon: Scalable and Self-Auditable Key Transparency

Hossein Hafezi*
University of Cambridge

Alireza Shirzad*
University of Pennsylvania

Benedikt Buñz
NYU

Kevin Lewi
Meta

Dillon George
Meta

Joseph Bonneau
NYU

IronDict

- **Self-auditability:** constant proof size, 8 kB for dictionary of size 1 billion.

IronDict

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IronDict

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  - **fast-forwarding:** Check a single audit proof and verify the whole history
  - Self-auditablity without fast-forwarding is pointless.
- **Perfect-privacy**


AEGON
IRONDICT
Requirement of a Linear-Sized Setup
High Epoch Latency
Storage Inefficiency
Not Horizontally Scalable

Random Version Invariant of IronDict and Aegon

$$\mathrm{Dict}_i = (pk_1^{(i)}, pk_2^{(i)}, \ldots, pk_N^{(i)}),$$

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Ghost key attack : $\sum_{i<k\leq j} \Delta_k[t] = 0$ and $\exists\, i < i_0 \leq j : \Delta_{i_0}[t] \neq 0$

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Use randomness so the differences do not cancel out each other

Random Version Invariant of IronDict and Aegon

$$\text{Rand vector} : \text{Rand}_n = \text{Dict}_0 + \sum_{i \leq n} r_i \cdot \Delta_i \equiv \text{Rand}_{n+1} = \text{Rand}_n + r_{n+1} \cdot \Delta_{n+1}$$

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$$\text{proof of consistency from epoch i to epoch j} \iff \text{Rand}_i[t] = \text{Rand}_j[t]$$

$$\text{auditor's task} \implies \text{ensure Rand}_n \text{ is computed correctly}$$

See Numbers!

	Aegon	WhatsApp KT (SEEMLESS + Parakeet)
Epoch Latency	**60 s**	**60 s**
Throughput	**~1000 update/s**	**~1000 update/s**
Lookup proof / verification	**20KB / 29ms**	**2-4 KB / 0.1 ms**
Lookup latency (server)	**33ms (more computation)**	**0.5 s < (no computation)**
Audit proof / verification	**256B / 2ms**	**80 MB / 0.7s**

Concrete Instantiation?

- Aegon = generic over any polynomial commitment schemes. We initiate it with KZH [Kad+25] that requires a powers-of-tau setup ==> MPC ceremony setup

KZH-Fold:
Accountable Voting from Sublinear Accumulation

George Kadianakis[1], Arantxa Zapico[2], Hossein Hafezi[3], and Benedikt Bünz[4]

[1,2]Ethereum Foundation
[3,4]New York University

- Future Work: Design alternative polynomial commitments without a trusted setup.

Details of IronDict and Aegon?

- Check out the eprint
    - IronDict: https://ia.cr/2025/1580
    - Aegon: Would be online in less than a month!
- Talk on Details of IronDict and Aegon:
    - Check out talk we gave at Microsoft Research (thanks to **Melissa Chase**!)