SoK: Cryptographic Authenticated Dictionaries

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Andrew Zitek-Estrada* — EPFL

Sarah Meiklejohn — UCL

Joseph Bonneau — NYU

Background

AuthDS Operations Part I

Like a dictionary but w/ proofs!

- 1) AuthDS.**Update** key / value pairs

Key	Value
Banana	Yellow
Peach	Orange

AuthDS Operations Part I

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- 2) AuthDS.**Lookup** the value of a key + get proof

Main difference

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AuthDS Operations Part I

Like a dictionary but w/ proofs!

- 1) AuthDS.**Update** key / value pairs
- 2) AuthDS.**Lookup** the value of a key + get proof (verify against commitment)

Main difference

- 3) **Commitment** (output by update)

State of the system

H

Key	Value
Banana	Yellow
Peach	Orange

Commitment is similar to a checksum!

Applications

Global Consistency + Auditing

Is my view of the world the same as everyone else?

💬 Key Transparency

Key	Value
+1 (805) 978 8790	EncryptionKey

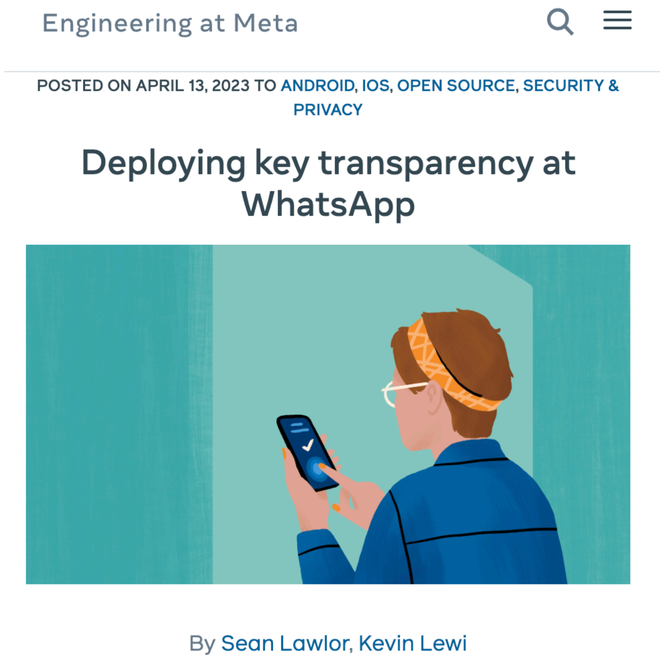

Photo Credit: https://engineering.fb.com/2023/04/13/security/whatsapp-key-transparency/

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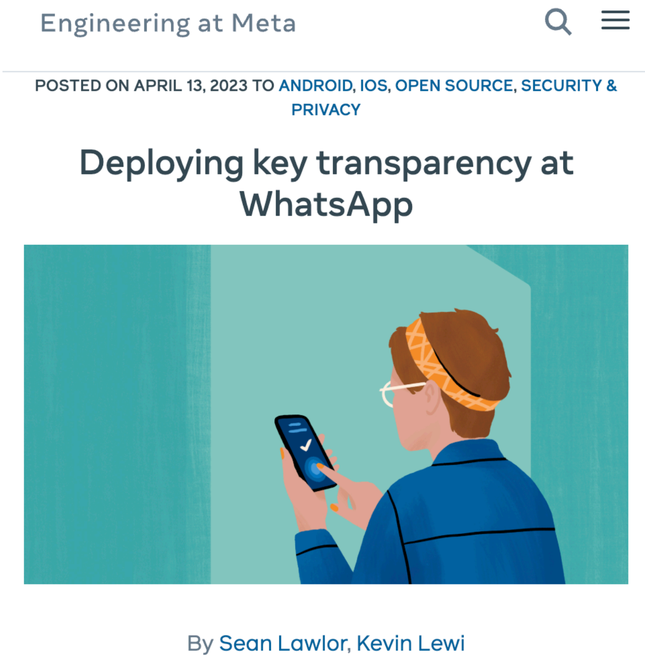

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Engineering at Meta

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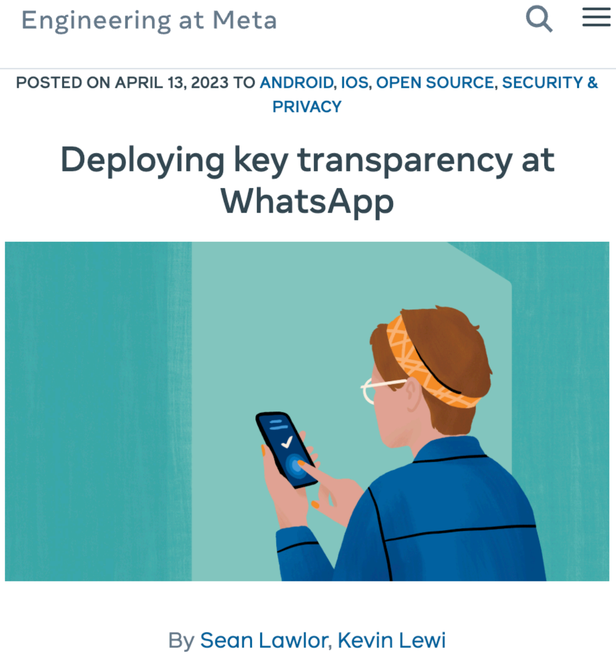

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Identifier	Balance

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📰 News Transparency

Article ID	SHA(Article)

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Construction

AuthDS Operations Part II

Must handle multiple versions

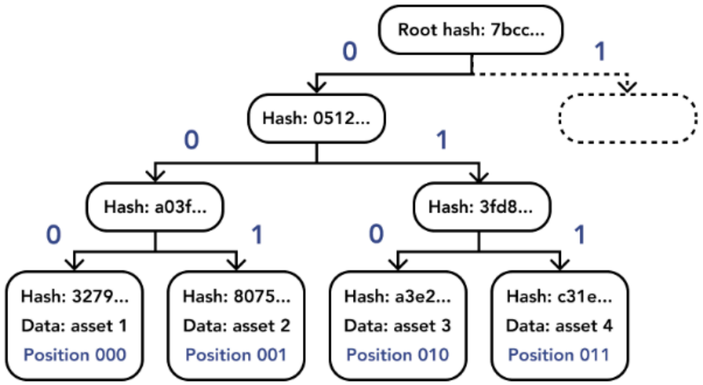

Photo Credit: https://river.com/learn/terms/s/sparse-merkle-tree/

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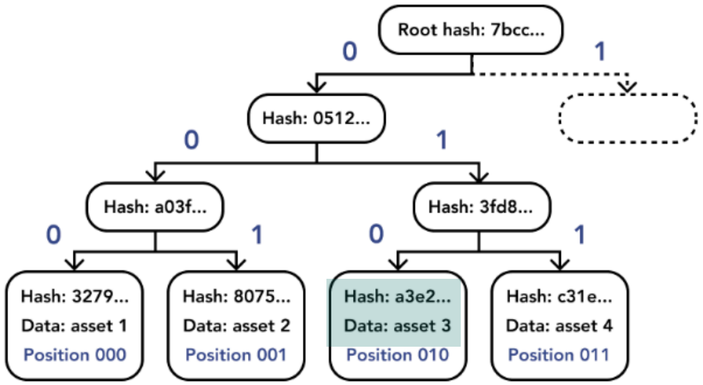

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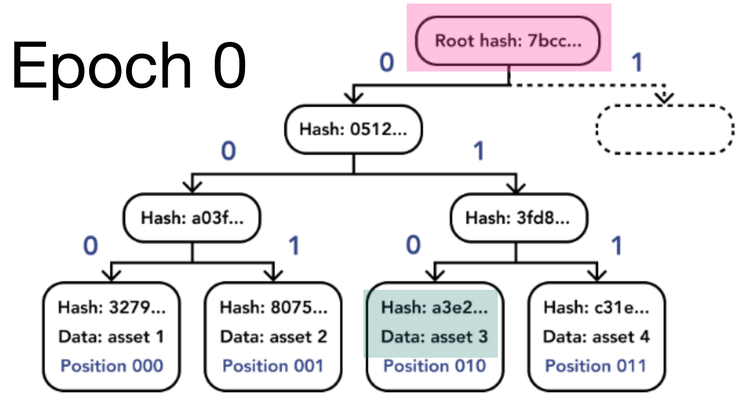

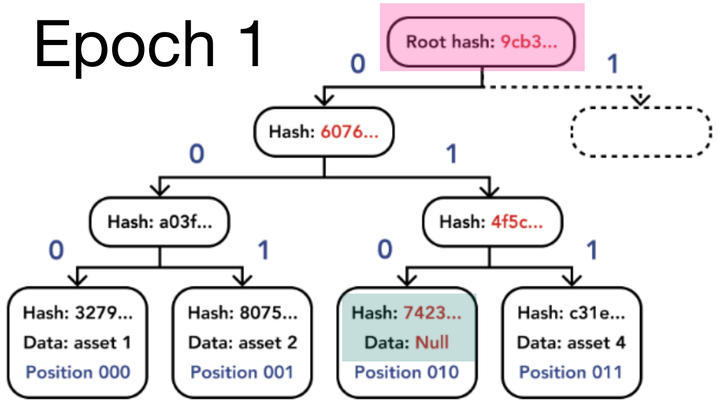

Handling mutations over time is technically challenging

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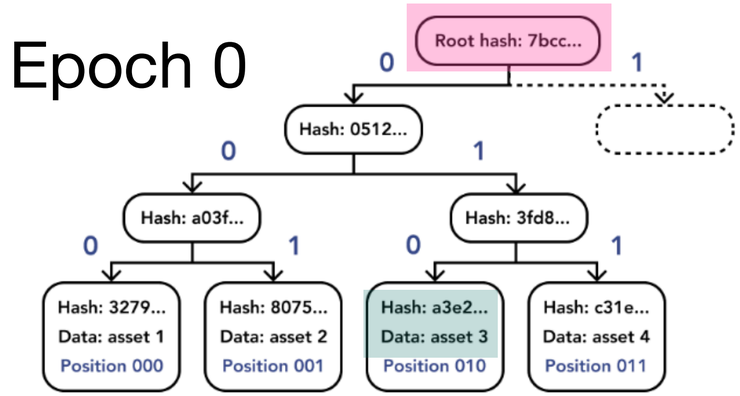
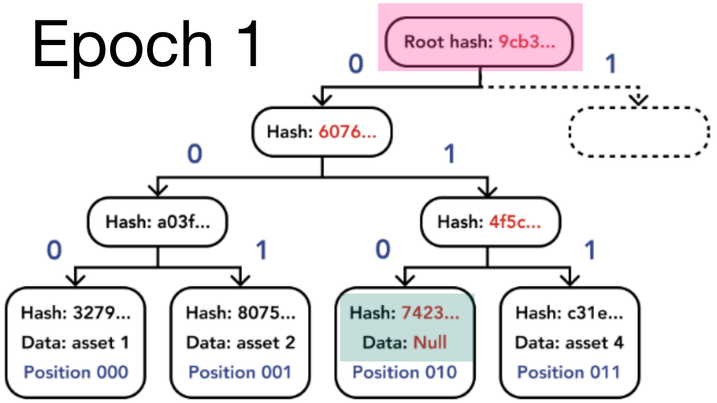
- 4) AuthDS.**VerifyHistory** <— concerns one key

Value generated from a unique sequence of changes





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AuthDS Operations Part II

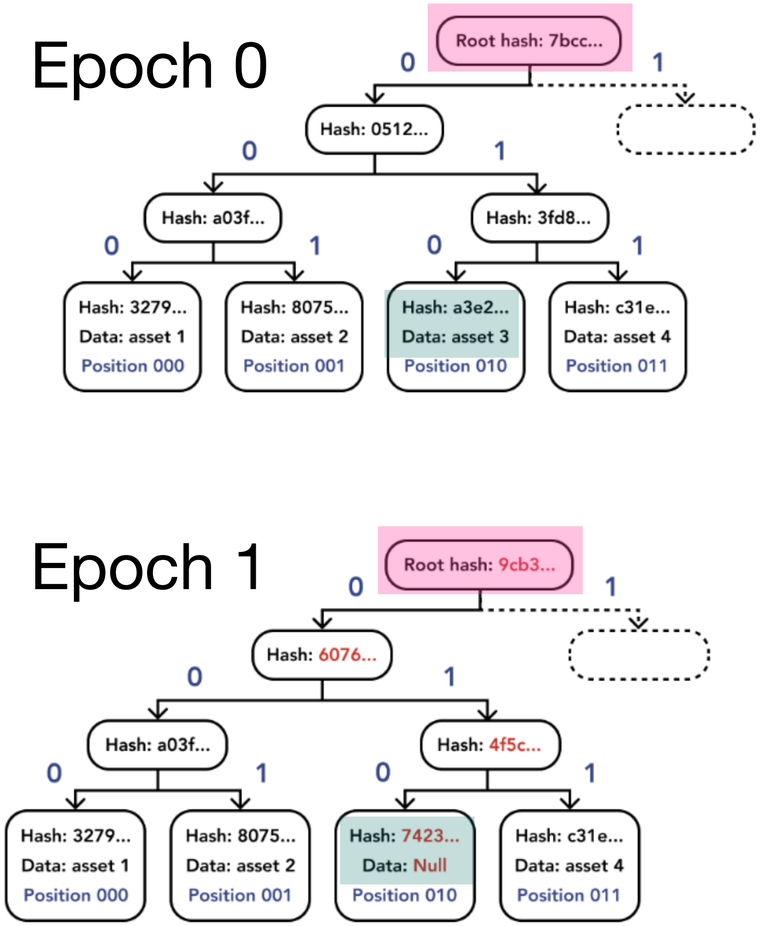
Must handle multiple versions

- 4) AuthDS.**VerifyHistory** <— concerns one key

Value generated from a unique sequence of changes

- 5) AuthDS.**VerifyUpdate** <— concerns all keys

Current state is last state + sequence of all updates



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Contributions

Contributions at a Glance

Four main contributions

(C1) Unified Framework for Trust Models

- 🤝🏾 Five models with five core roles each

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🏗️ More than 30 schemes spanning 30 years

(C4) Asymptotic Performance Survey

📈 Tradeoff between lookup and update revealed

Trust Models

Five Trust Models

1) Private Outsourced Storage 📱
   ☁️ Cloud backup, encrypted filesystems

Private Outsourced Storage Model

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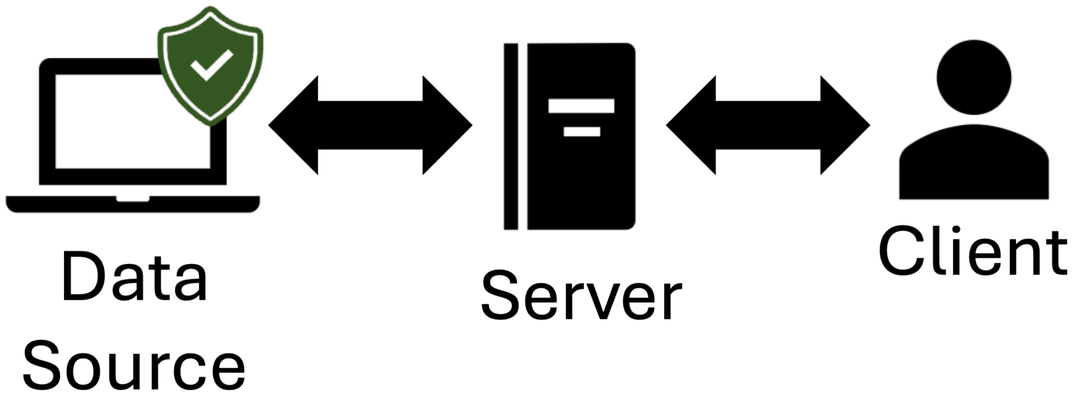
2) Public Outsourced Storage
   💾 immudb, Amazon QLDB 🚗

Public Outsourced Storage Model



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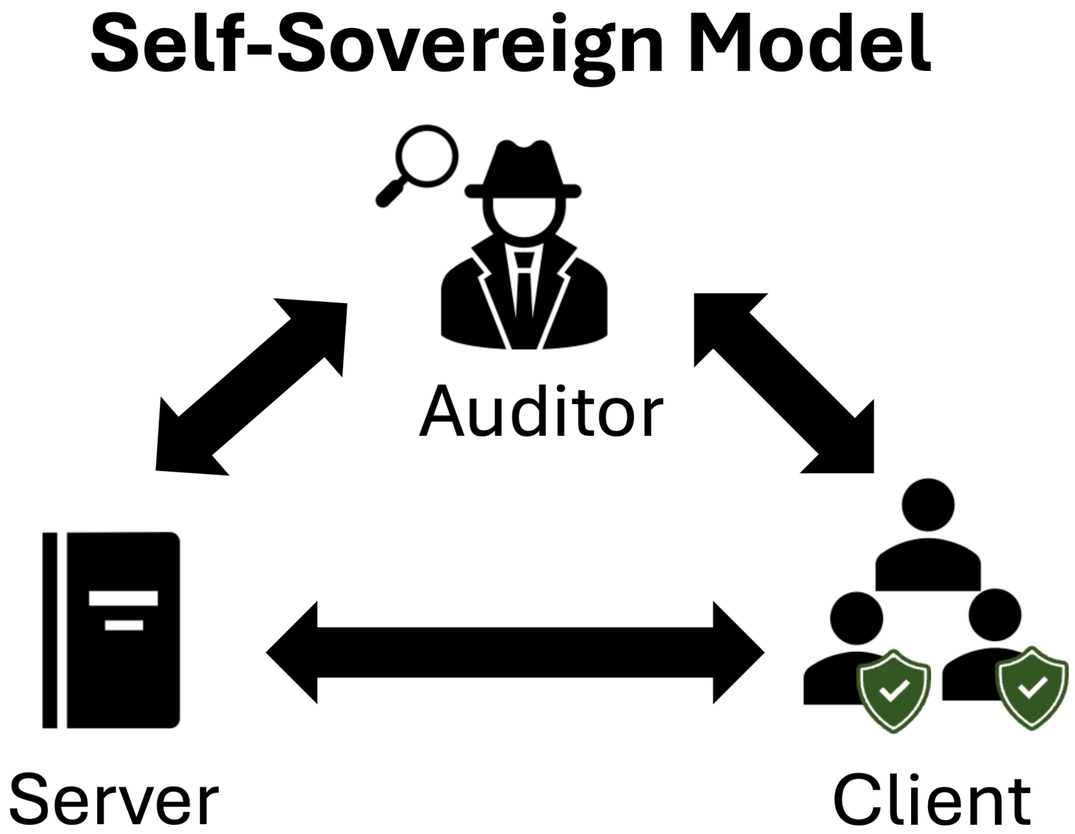
Multiple clients sign 🔑 their own entries in the log



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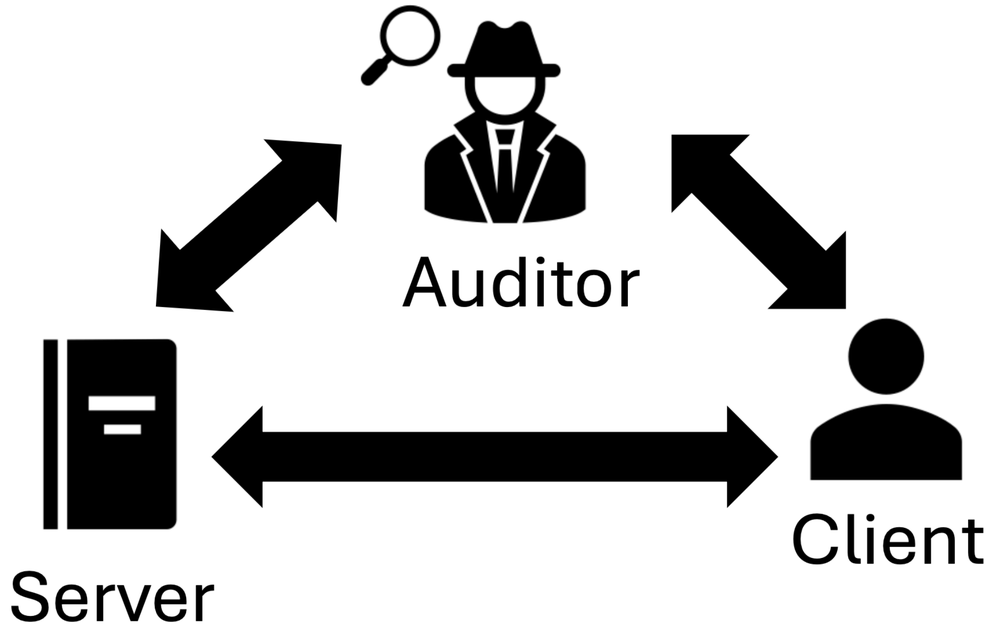
   💬 WhatsApp KT, iMessage, Apple CT

Clients can detect but not prove changes that were unauthorized

Audited Transparency Model



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5) Transparency
   👀

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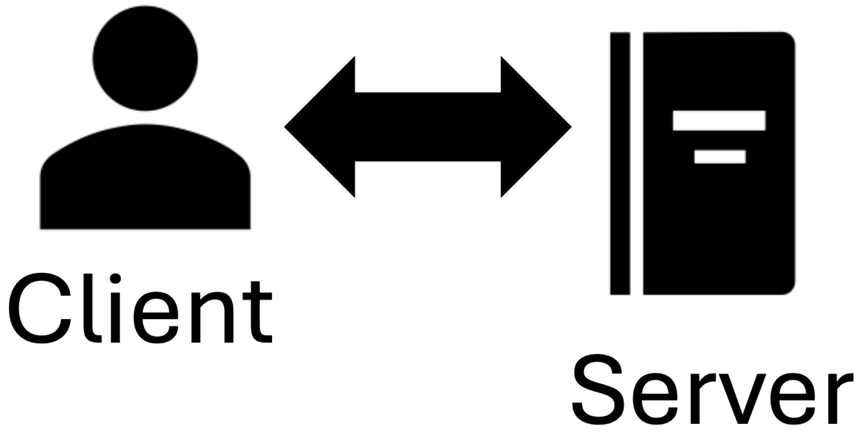
Clients do auditing themselves

Transparency Model



Performance

Performance Barrier

Option A: Balanced

Lookup = O(log n)
Update = O(log n)

Option B: Tradeoff

Lookup = O(1)
Update = O(n)

No known construction achieves: O(1) lookup AND O(log n) update

Trust Does Not Buy Efficiency

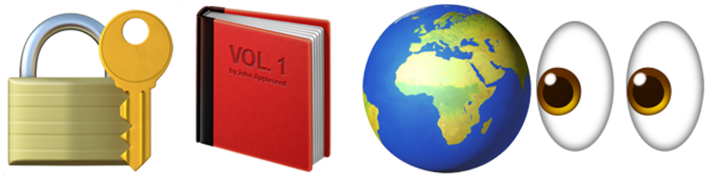
Trusted Source	No Trusted Party
Lookup = O(log n) Update = O(log n)	Lookup = O(log n) Update = O(log n)

Stronger trust != Better Asymptotics

Discussion

Open Questions

And discussion



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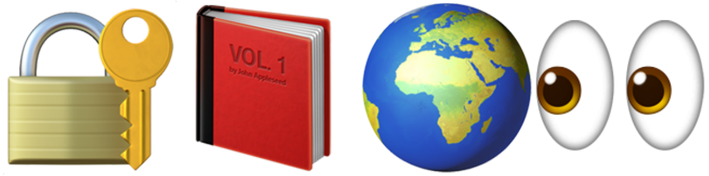

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- Can we achieve sufficient performance for client auditing?

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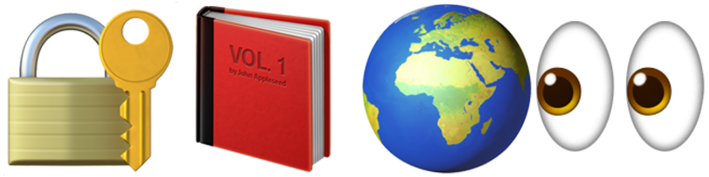

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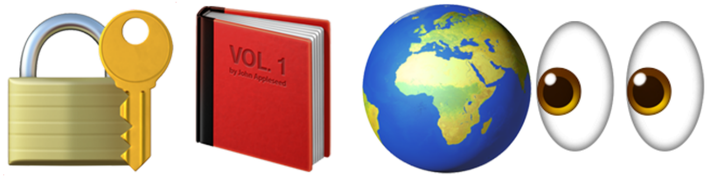

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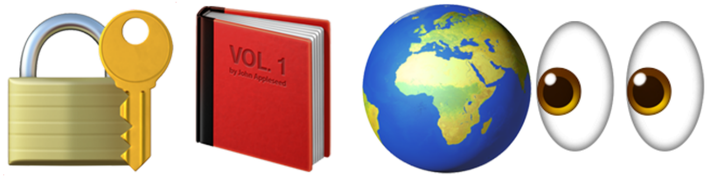

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Lots more discussion in the paper!

Thank you!

See paper:

https://shorturl.at/YQQTw

Three Types of ADs

Mutating Indexed ADs	Append-only Indexed ADs	In-place append-only Indexed ADs
CONIKS, Verkle, VeRSA	SEEMless, Parakeet, AAD	Keybase, Verdict, Chainiac

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Only last value

Mutating Indexed ADs

CONIKS,
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Append-only Indexed ADs

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All Values in separate structure

All Values

In-place append-only Indexed ADs

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Security Definitions

Three Core Security Definitions

1) Value Binding (weakest)

✅ Two key lookups from same commitment get same answer

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Best for No Trusted Source

implies

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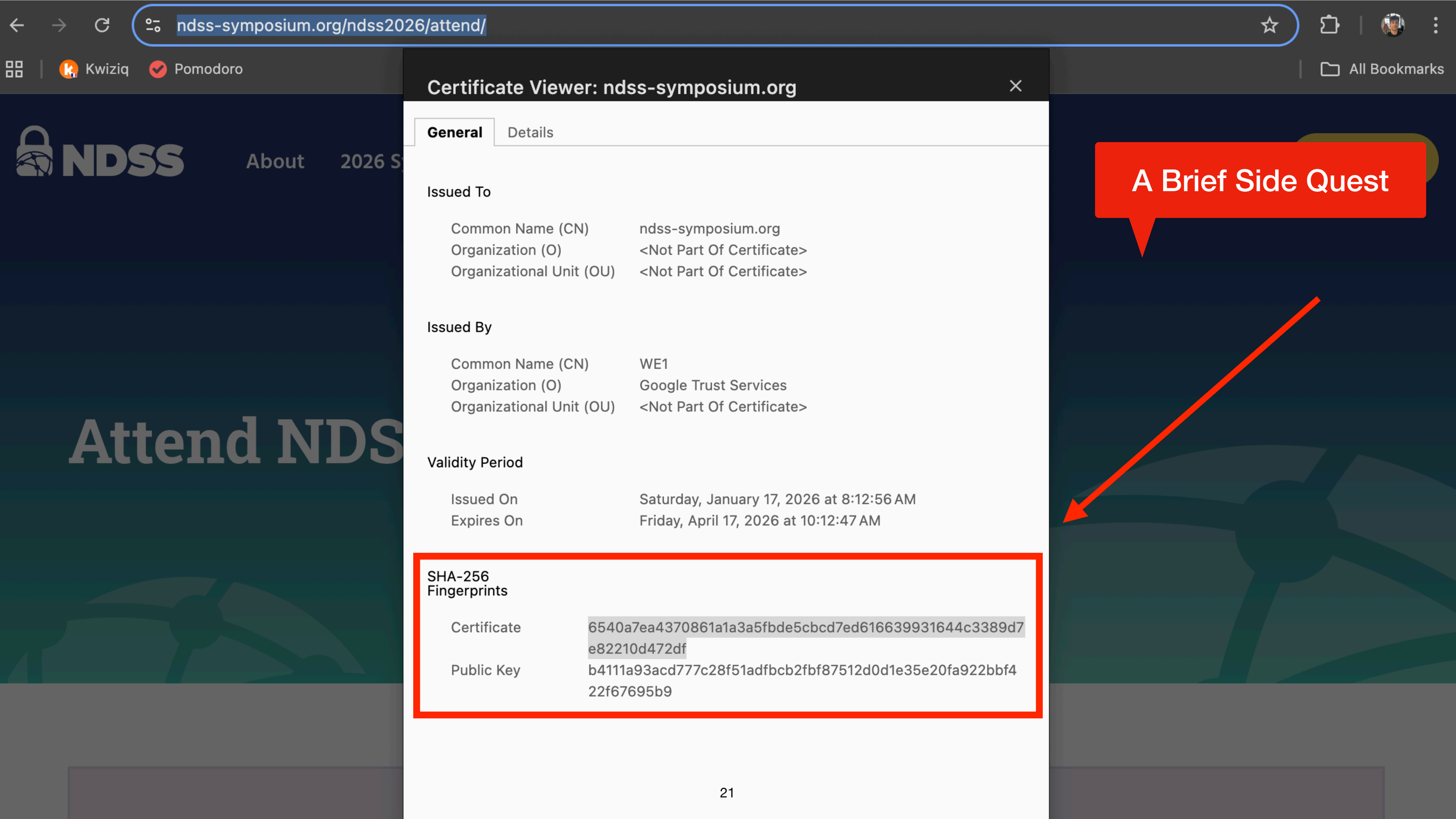
3) Read-Write Consistency (strongest)

✅ Lookups are consistent with history verification and changes were authorized

❌ Doesn’t apply to untrusted source models bc no authorization mechanism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Kwiziq
Pomodoro
All Bookmarks
NDSS
About
2026 S
Attend NDS
A Brief Side Quest
Certificate Viewer: ndss-symposium.org
General
Details
Issued To
Common Name (CN) ndss-symposium.org
Organization (O) <Not Part Of Certificate>
Organizational Unit (OU) <Not Part Of Certificate>
Issued By
Common Name (CN) WE1
Organization (O) Google Trust Services
Organizational Unit (OU) <Not Part Of Certificate>
Validity Period
Issued On Saturday, January 17, 2026 at 8:12:56 AM
Expires On Friday, April 17, 2026 at 10:12:47 AM
SHA-256 Fingerprints
Certificate 6540a7ea4370861a1a3a5fbde5cbcd7ed616639931644c3389d7e82210d472df
Public Key b4111a93acd777c28f51adfbcb2fbf87512d0d1e35e20fa922bbf422f67695b9

crt.sh Certificate Search

Criteria	SHA-256(Certificate) = '6540a7ea4370861a1a3a5fbde5cbcd7ed616639931644c3389d7e82210d472df'

crt.sh ID	23817853543
Summary	Leaf certificate

Certificate Transparency

Log entries for this certificate:

Timestamp	Entry #	Log Operator	Log URL
2026-01-17 08:15:31 UTC	1661073509	Google	https://ct.googleapis.com/logs/eu1/xenon2026h1
2026-01-17 08:15:31 UTC	1239888643	Sectigo	https://elephant2026h1.ct.sectigo.com
2026-01-17 08:15:31 UTC	885460556	IPng Networks	https://halloumi2026h1.mon.ct.ipng.ch
2026-01-17 08:15:31 UTC	1771769056	Google	https://ct.googleapis.com/logs/us1/argon2026h1

A Brief Side Quest

Revocation

Report a problem with this certificate to the CA

Mechanism	Provider	Status	Revocation Date	Last Observed in CRL	Last Checked (Error)
OCSP	The CA	Check	?	n/a	?
CRL	The CA	Not Revoked	n/a	n/a	2026-02-09 13:09:10 UTC
CRLSet/Blocklist	Google	Not Revoked	n/a	n/a	n/a
disallowedcert.stl	Microsoft	Not Revoked	n/a	n/a	n/a
OneCRL	Mozilla	Not Revoked	n/a	n/a	n/a

Certificate Fingerprints

SHA-256 6540A7EA4370861A1A3A5FBDE5CBCD7ED616639931644C3389D7E82210D472DF

SHA-1 AE F00AF6EC8F4EF92CB406D87D876082C67859BF

| ASN.1 | Certificate | Graph | Hierarchy | pv |

Hide metadata

Run linters using pkimetal

Download Certificate: PEM

```
Certificate:
    Data:
        Version: 3 (0x2)
        Serial Number:
            cb:63:cb:10:9a:9b:ea:74:13:c8:80:04:1e:ca:c9:df
        Signature Algorithm: ecdsa-with-SHA256
        Issuer:  (CA ID: 286236)
            commonName                = WE1
            organizationName          = Google Trust Services
            countryName               = US
        Validity
            Not Before: Jan 17 07:12:56 2026 GMT
            Not After : Apr 17 08:12:47 2026 GMT
        Subject:
            commonName                = ndss-symposium.org
        Subject Public Key Info:
            Public Key Algorithm: id-ecPublicKey
                Public-Key: (256 bit)
```

11 logs: Sectigo, TrustAsia, Cloudflare…