Decentralizing Authorities into Scalable Strongest-Link Cothorities

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Stanford Univerisity – October 9, 2015

We depend on many authorities

Conceptually simple but **security-critical** services

- Logging, Time-stamping Services, Digital Notaries
- Naming Authorites (ICANN logo)
- Certificate Authorities
- Randomness Authorities (e.g., Lotteries)
- Software Update Services

But are authorities trustworthy?

WIRED Hack Obtains 9 Bogus Certificates for Prominent ...

HACK OBTAINS 9 BOGUS CERTIFICATES FOR PROMINENT WEBSITES; TRACED TO IRAN

But are authorities trustworthy?

CYBER CRIME SCAMS AND FRAUD

This Dude Hacked Lottery Computers To Win $14.3M Jackpot In U.S.

By *Waqas* on April 14, 2015 Email @hackread

But are authorities trustworthy?

threatpost | CATEGORIES | FEATURED | PODCASTS | VIDEOS

10/08/15 5:54 | Advanced notice: Security updates for Adobe Acrobat and Reader are due on Patch Tuesday: https://t.co/QLqnpulr0A

Welcome > Blog Home > Cryptography > D-Link Accidentally Leaks Private Code-Signing Keys

by Michael Mimoso Follow @mike_mimoso September 18, 2015 , 10:21 am

Talk Outline

- The Need to Decentralize Internet Authorities
- Witness Cothorities: Transparency via Collective Signing
- Timestamp Cothorities: Collectively Attesting Freshness
- Randomness Cothorities: Scalable Unbiased Randomness
- Conclusions and Future Work

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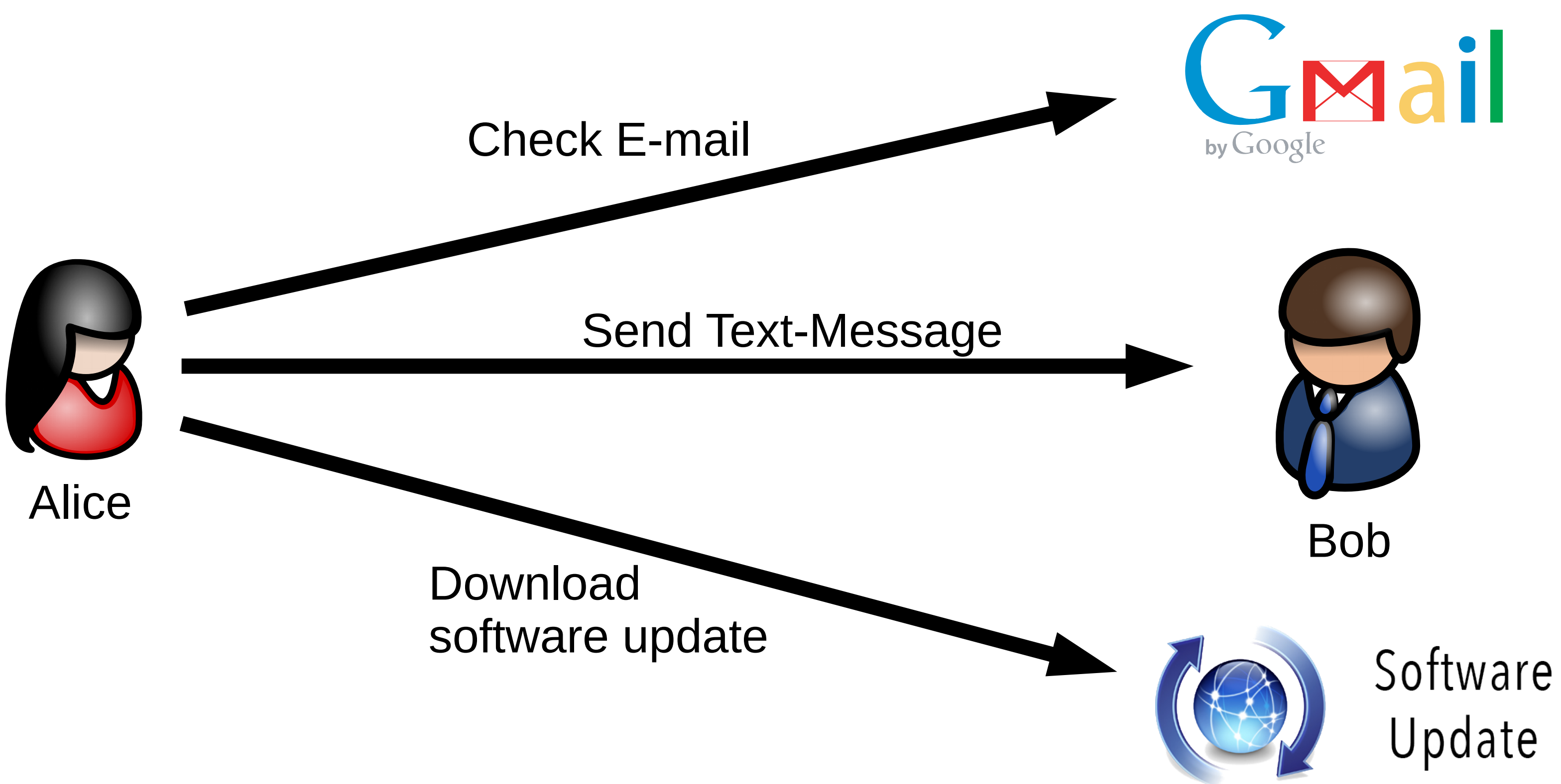
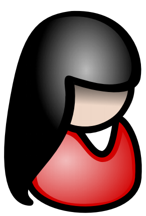
Why do we have authorities?



Why do we have authorities?

Respect my Authoritah!

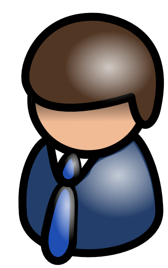
?



Alice

What is:
- Gmail's SSL public key?
- Bob's IM public key?
- Latest version of App?

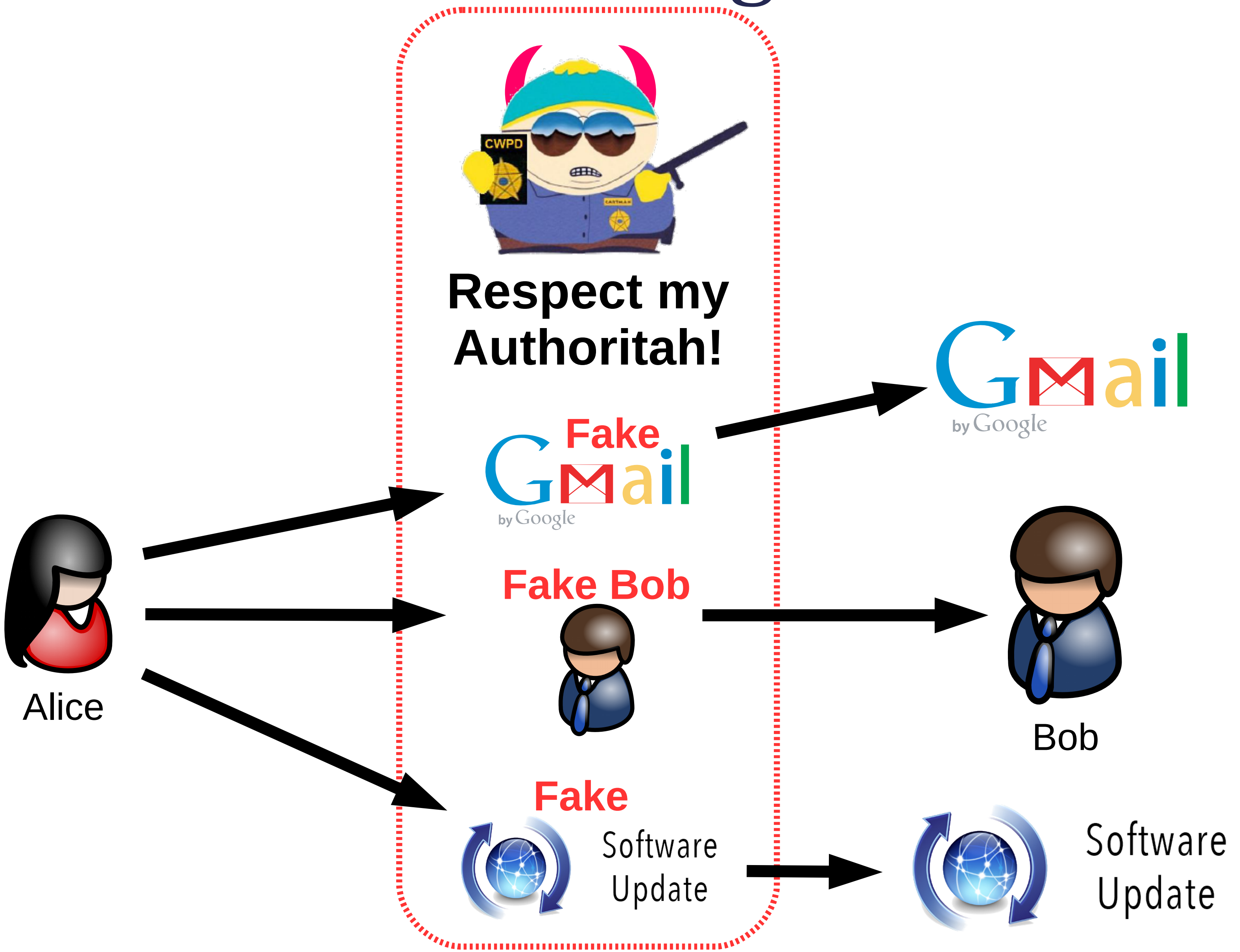
Gmail by Google



Bob

Software Update

When authorities go bad



Key Problem #1

Authorities (and their private keys) are **powerful**

- Bad CA → MITM any web site
- Bad keyserver → impersonate any user
- Bad update server → instant backdoor

Attractive targets for hackers, criminals, spy agencies

Key Problem #2

There are **many** authorities:
e.g., hundreds of CAs trusted by web browsers

- Any CA can issue cert for any domain name

Hacker (or spy agency) needs **only one CA key**

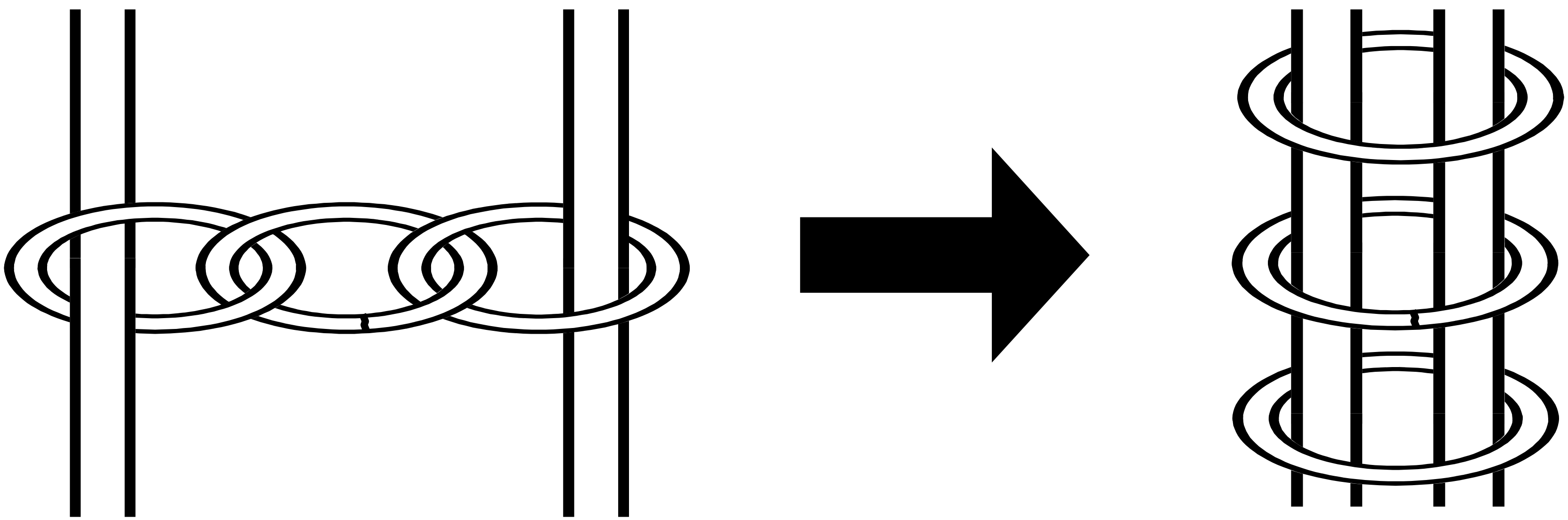
- **Weakest-link** security
- @#$% happens
  - DigiNotar, Comodo, CNNIC/MCS

Challenge: Decentralize Authorities

Split important authority functions across multiple participants (preferably independent)

- So authority isn't compromised unless multiple participants compromised

From **weakest-link** to **strongest-link** security



Decentralizing Trust

We have many technical tools already

- "Anytrust": 1-of-k servers honest, all k live
- Byzantine replication: 2/3 honest, 2/3 live
- Threshold cryptography, multisignatures

Example: **Tor** directory authority (8 servers)

Limitations of Trust-Splitting

Trust-splitting is rare, challenging to implement, usually scales only to small groups.

- Is splitting across 5-10 servers **enough**?
- Are they **truly independent** and **diverse**?
- Who **chooses** the composition and how?

Are we convinced there is no adversary powerful enough to hack 5 of 8 directory servers?

Grand Challenge: Trust Scaling

Large-scale collective authorities: “**Cothorities”**

- Split trust over hundreds, thousands of parties
- Correct unless *large fraction* compromised

E.g.: replace **hundreds of CAs** with **one CA** with authority split across **hundreds of parties**

- *Diversity* of servers, operators, organizations, countries, interests, software, hardware, …
- Make adding participants *cheap, efficient*
- Ensure *security* scales with *size* and *sensitivity*

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A First-Step Goal

Generically improve security of any authority, independent of authority **type** or **semantics**

Introducing **Witness Cothorities**...

Witness Cothorities

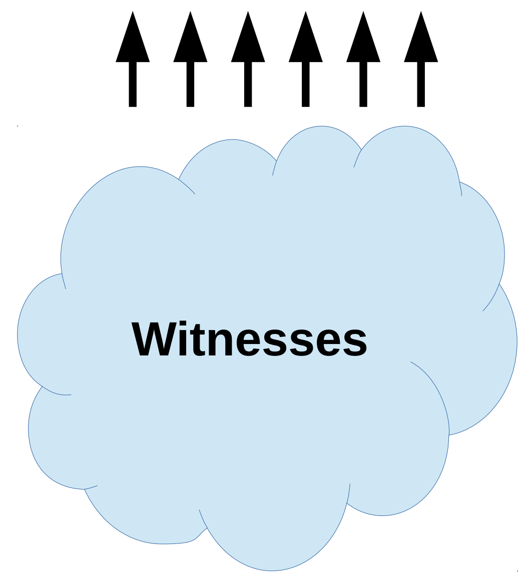
“Who watches the watchers?”

Public witnesses!

Enforce two security properties:

- Any signed authoritative statement has been **widely witnessed**
- Any signed authoritative statement conforms to checkable **standards**

Respect my Authoritah!



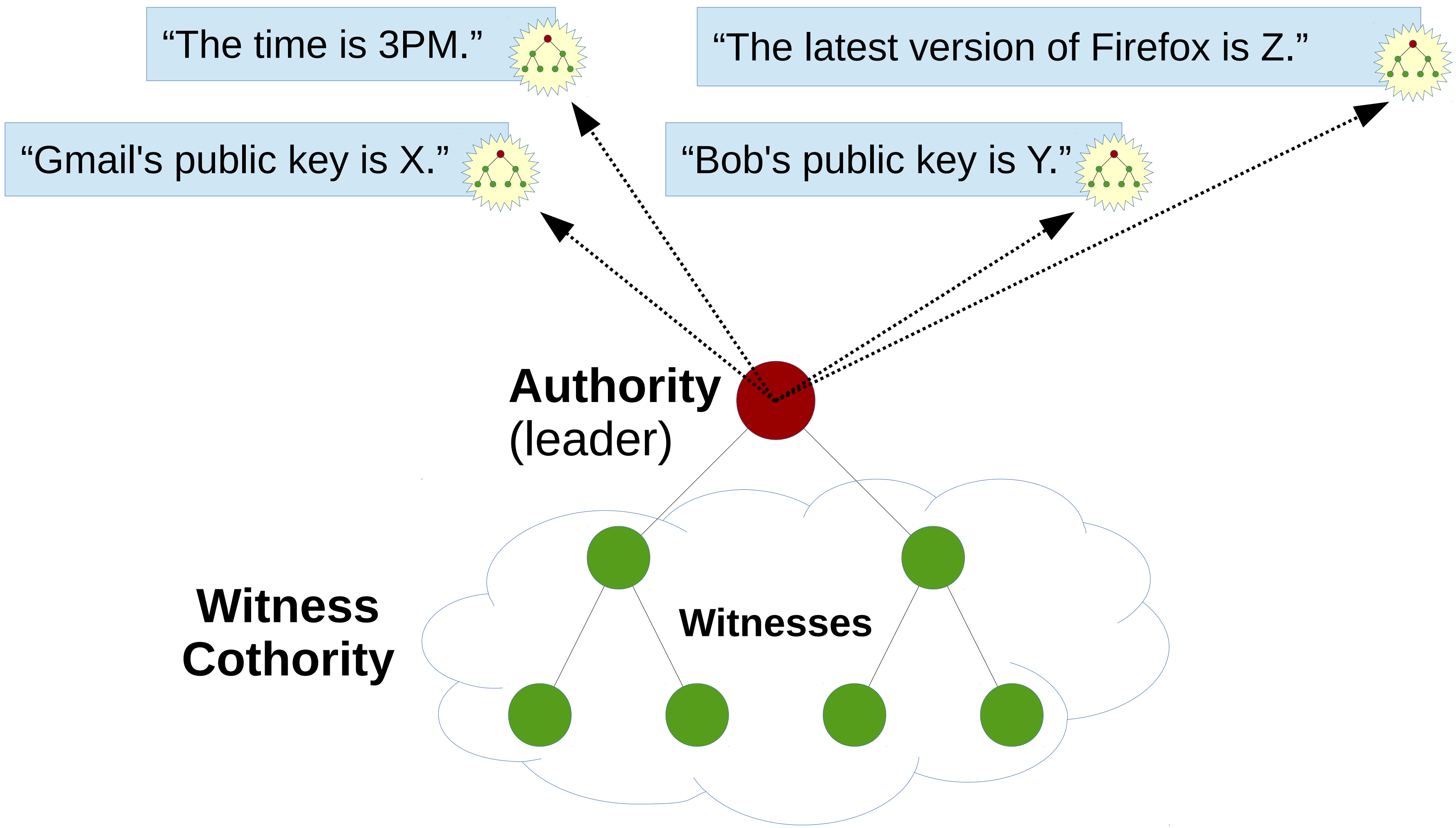
CoSi: Collective Signing

Operation:

- **Authority** server generates statements
- **Witness** servers collectively sanity-check and *contribute* to authority's signature
- Each statement gets a **collective signature**: small, quick and easy for anyone to verify

→ Authority (or key thief) can't sign anything in secret without *many* colluding followers

CoSi: Collective Signing



CoSi Crypto Primitives

Builds on well-known primitives:

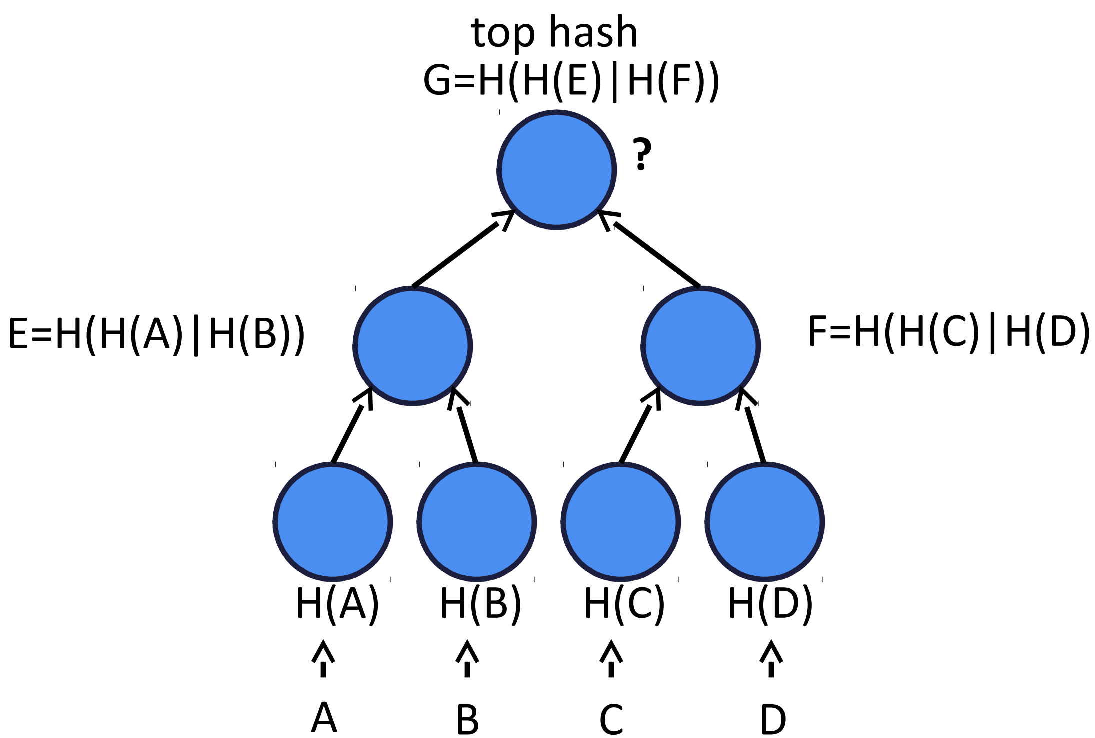
- Merkle Trees
- Schnorr Signature and Multisignatures

CoSi builds upon existing primitives but makes it possible to scale to thousands of nodes

- Using communication trees and aggregation, as in scalable multicast protocols

Merkle Trees

- Every non-leaf node labeled with the hash of the labels of its children.
- Efficient verification of items added into the tree
- Authentication path - top hash and siblings hashes



Schnorr Signature

- Generator *g* of prime order *q* group
- Public/private key pair: $(K=g^k, k)$

	Signer		Verifier
Commitment	$V=g^v$	$\longrightarrow$	V
Challenge	c	$\longleftarrow$	$c = H(M\|V)$
Response	$r = (v - kc)$	$\longrightarrow$	r

Signature on M: (c, r)

Commitment recovery	$V' = g^r K^c \quad = g^{v-kc} g^{kc} \ = g^v = V$
Challenge recovery	$c' = H(M\|V')$
Decision	$c' = c$? ✓

Collective Signing

- Goal: collective signing with *N* signers
  - Strawman: everyone produces a signature
  - *N* signers-> *N* signatures -> *N* verifications
  - Bad if we have thousands of signers
- Better choice: multisignatures

Schnorr Multisignature

- Key pairs: $(K_1=g^{k_1}, k_1)$ and $(K_2=g^{k_2}, k_2)$

	Signer 1	Signer 2	Verifier		
Commitment	$V_1=g^{v_1}$	$V_2=g^{v_2}$	V_1	V_2	$V=V_1*V_2$
Challenge	c	c	$c = H(M\|V_1)$		$c = H(M\|V)$
Response	$r_1 = (v_1 - k_1c)$	$r_2 = (v_2 - k_2c)$	r_1	r_2	$r=r_1+r_2$

Signature on M: (c, r) Same signature!

Commitment recovery	Same verification!	$V' = g^rK^c$	$K=K_1*K_2$
Challenge recovery	Done once!	$c' = H(M\|V')$	
Decision		$c' = c$?	

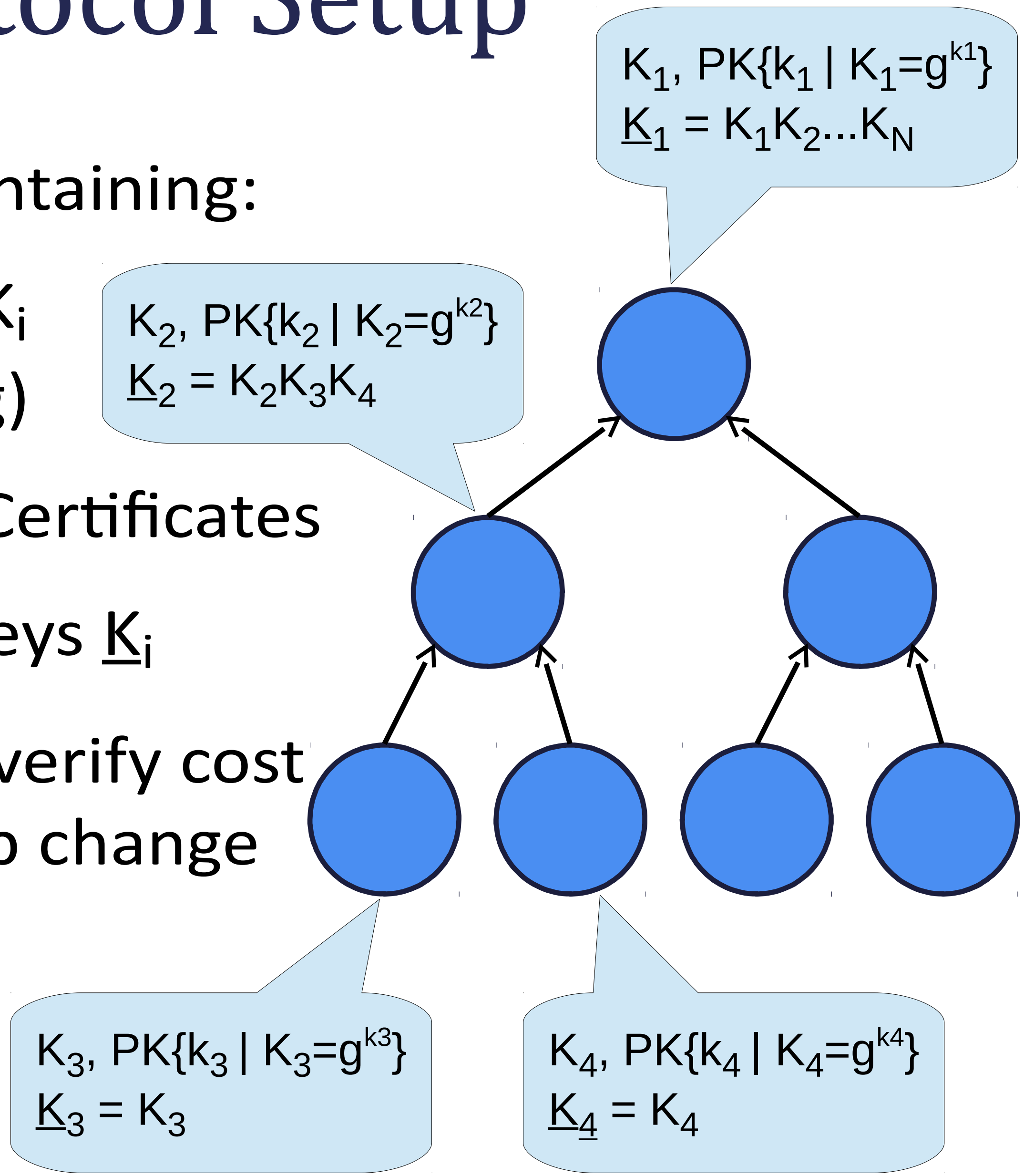
CoSi Protocol Setup

Merkle tree containing:

- Public keys K_i (discrete-log)
- Self-signed Certificates
- Aggregate keys $\underline{K}_i$

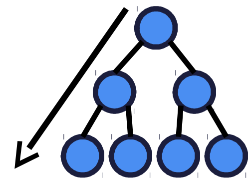
O(n) one-time verify cost

O(|n'-n|) group change

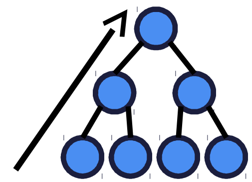


CoSi Protocol Rounds

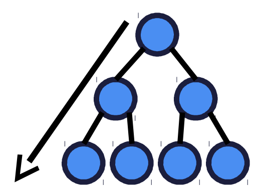
1. Announcement Phase



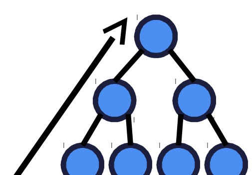
2. Commitment Phase



3. Challenge Phase



4. Response Phase

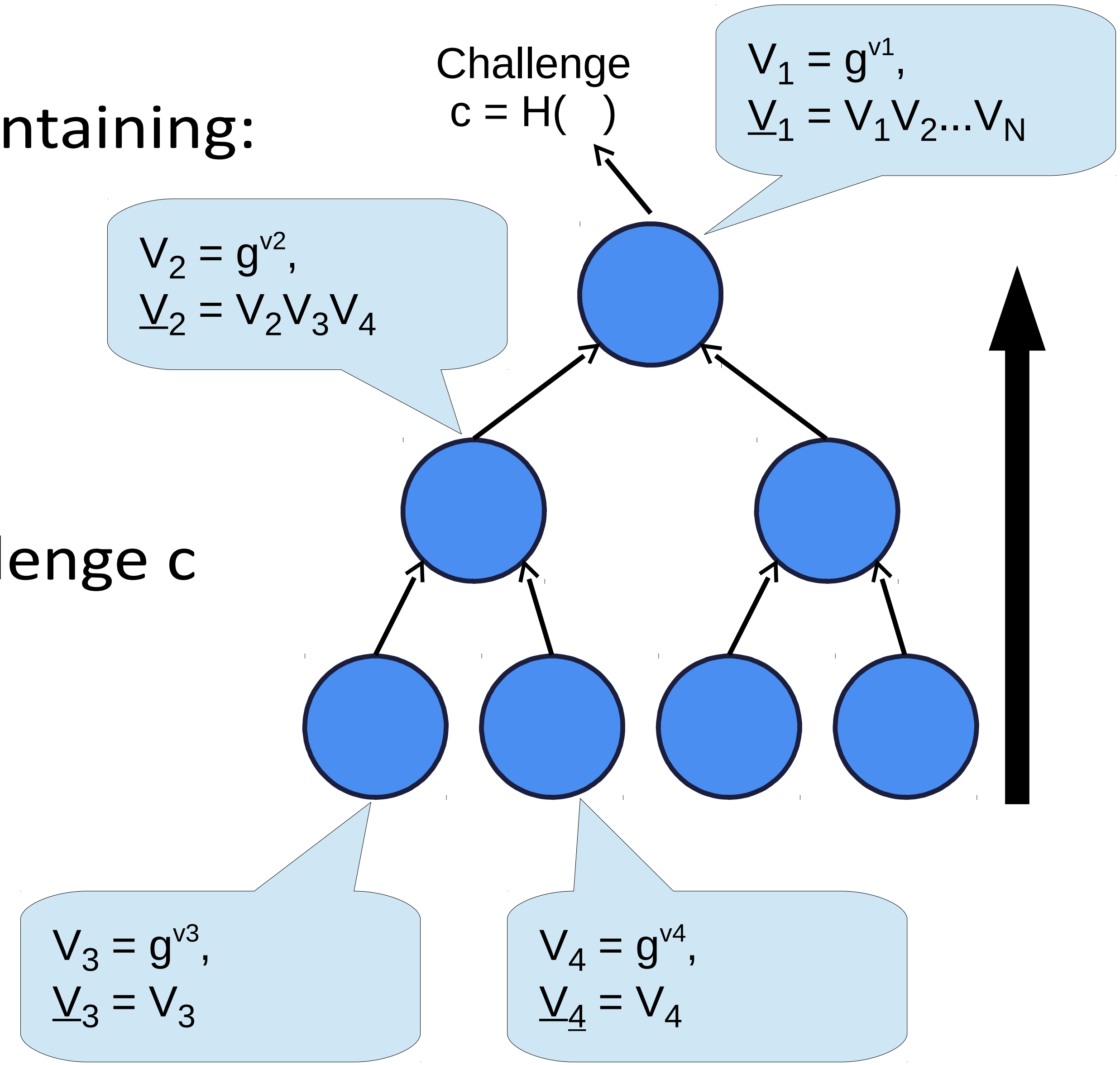


CoSi Commit Phase

Merkle tree containing:

- Commits V_i
- Aggregate commits $\underline{V}_i$

Collective challenge c is **root hash** of per-round Merkle tree



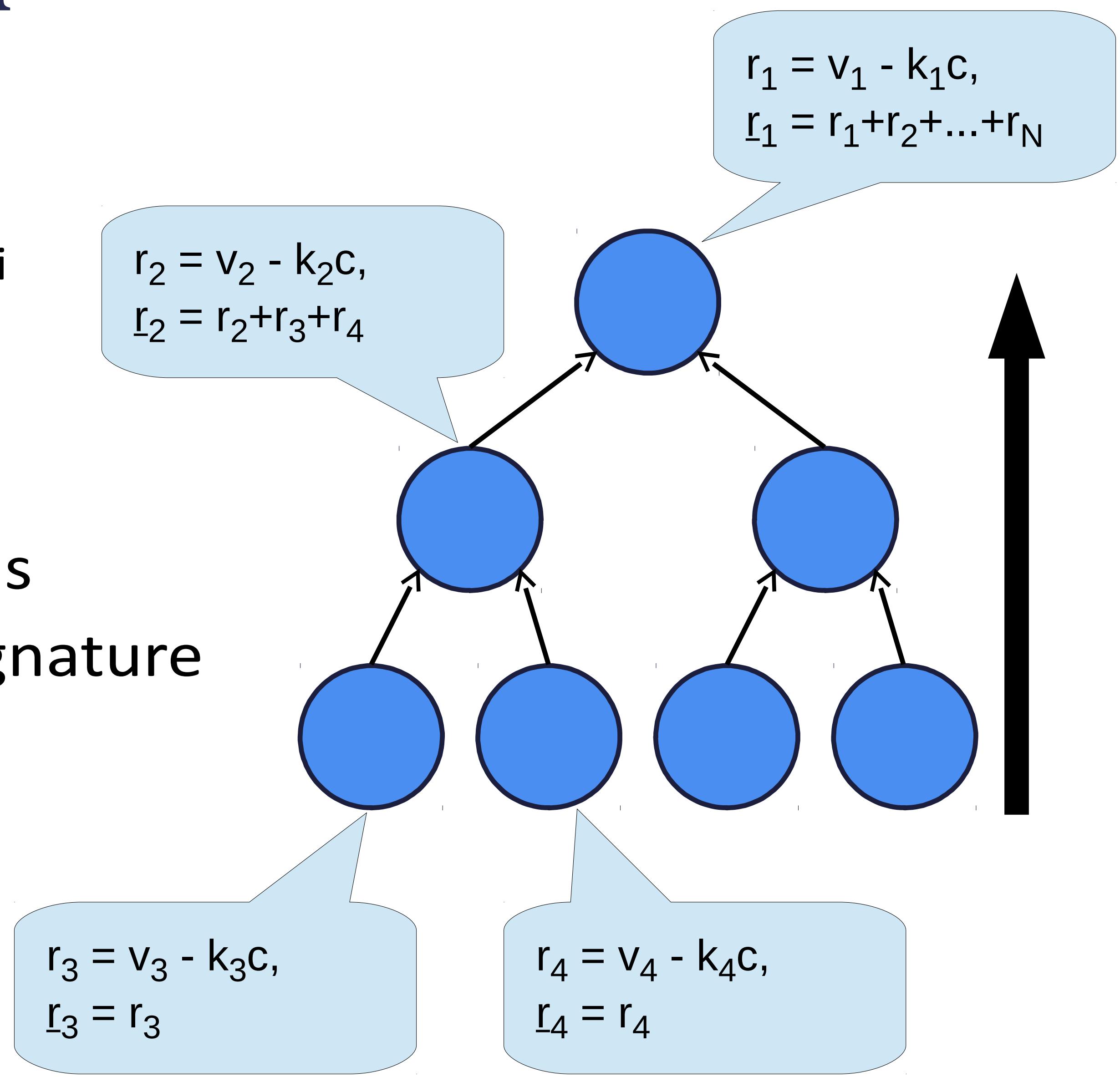
CoSi Response Phase

Compute

- Responses r_i
- Aggregate responses $\underline{r}_i$

Each $(c,\underline{r}_i)$ forms valid **partial** signature

$(c,\underline{r}_1)$ forms **complete** signature



The Availability Problem

Assume server failures are **rare** but **non-negligible**

- Availability loss, DoS vulnerability if not addressed
- But *persistently bad* servers administratively booted

Two approaches:

- Exceptions – currently implemented, working
- Life Insurance – partially implemented, in-progress

Simple Solution: Exceptions

- If node A fails, remaining nodes create signature
  - For a modified collective key: $K' = K * K^{-1}_A$
  - Using a modified commitment: $V' = V * V^{-1}_A$
  - And modified response: $r' = r - r_A$

- Client gets a signature under K' along with exception metadata e_A
  - e_A also lists conditions under which it was issued

- Client accepts **only** if a quorum of nodes maintained

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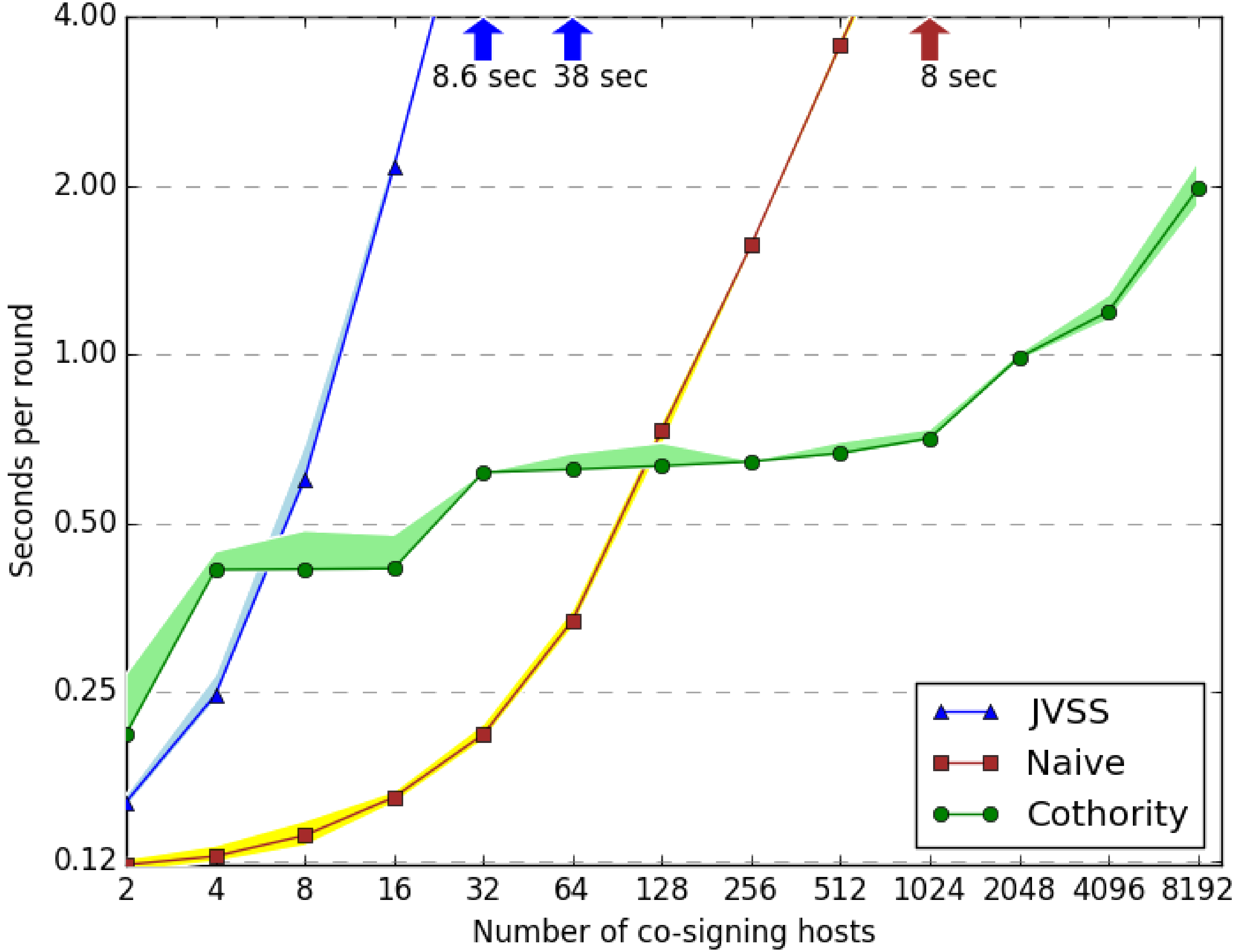
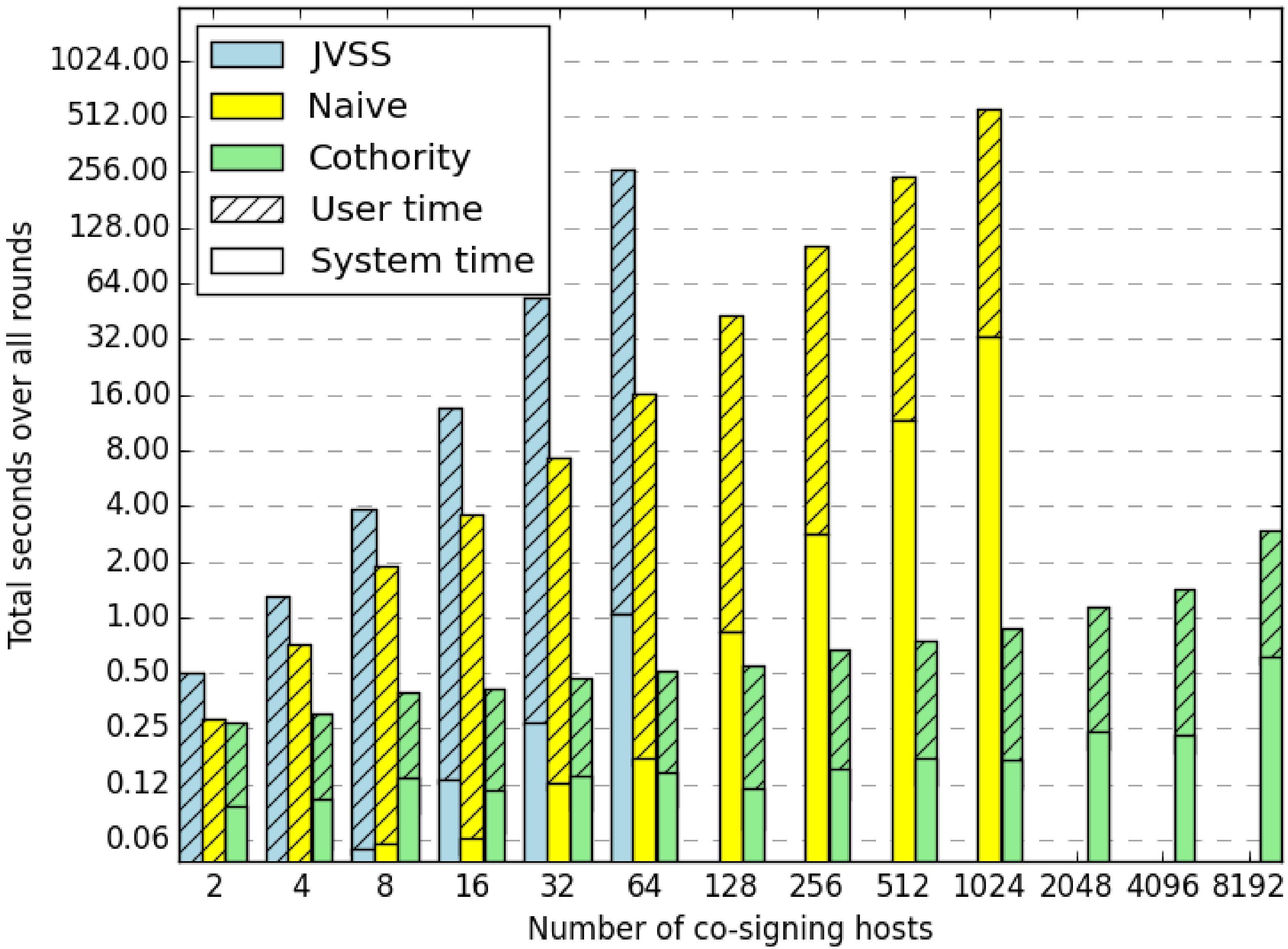
Implementation

- Implemented in Go with dedis crypto library
  - https://github.com/DeDiS/crypto
- Schnorr multisignatures on Ed25519 curve
  - AGL's Go port of DJB's optimized code
- Run experiments on DeterLab
  - Up to 8192 virtual CoSi nodes
  - Multiplexed atop up 64 physical machines
  - Latency: 100ms roundtrip between two servers

Results: Collective Signing Time



Results: Computation Cost



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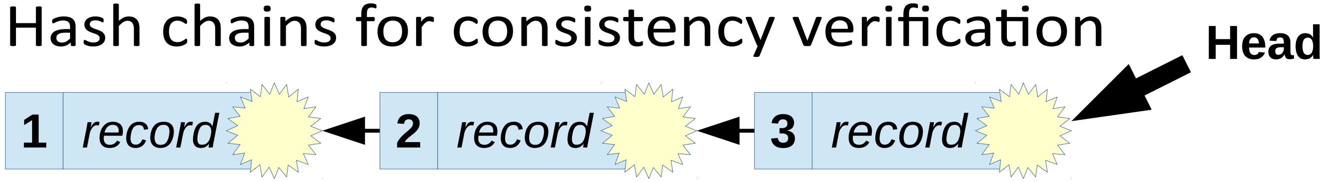
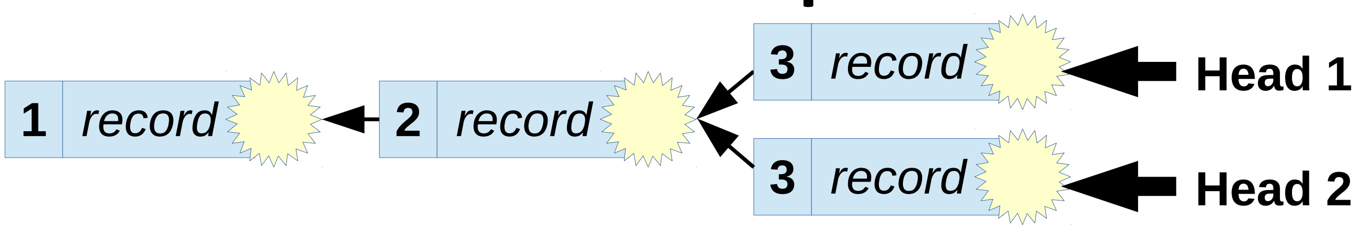
Application: Secure Logging

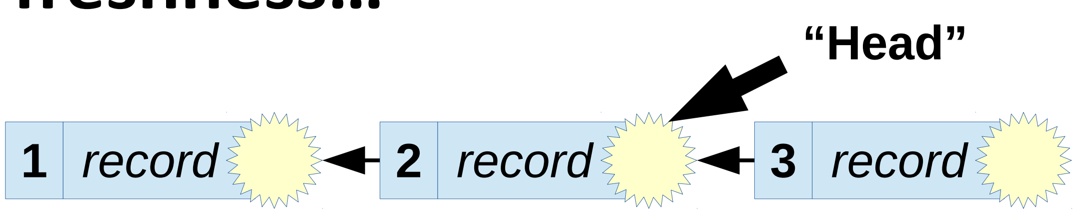
- Many authorities make “public statements”
- Often recorded in **tamper-evident public log**
  - Hash chains for consistency verification



- But hashes don't address **equivocation…**

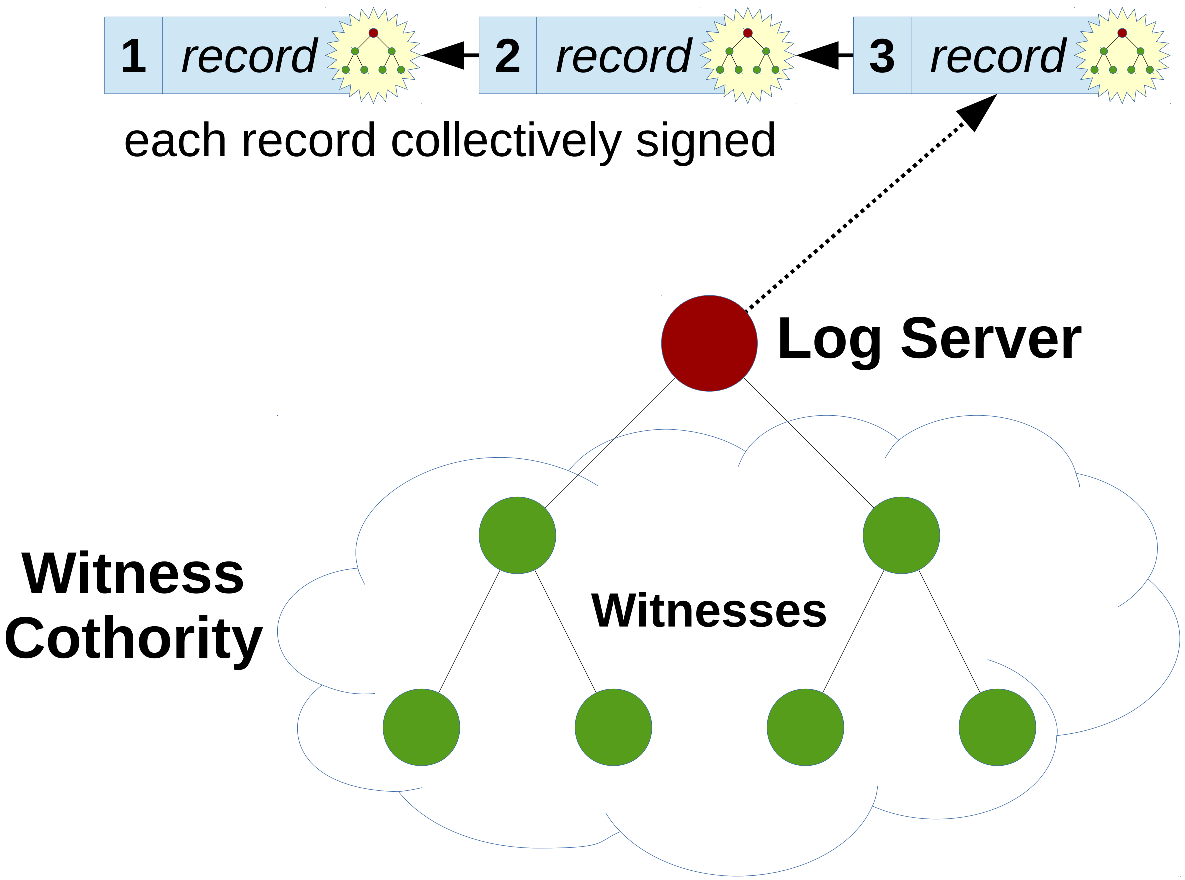


- Or **freshness…**

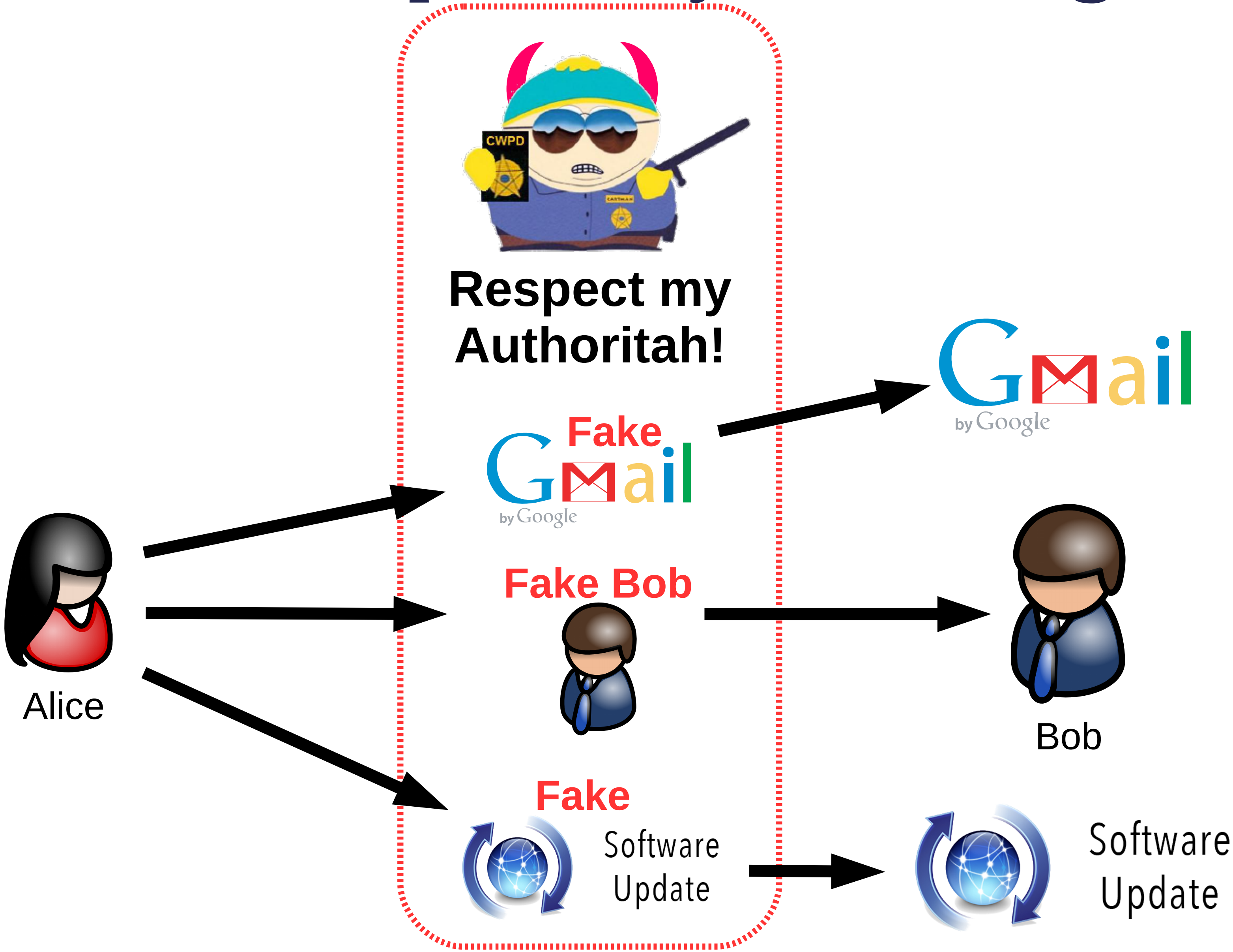


Witnessing Public Log Servers

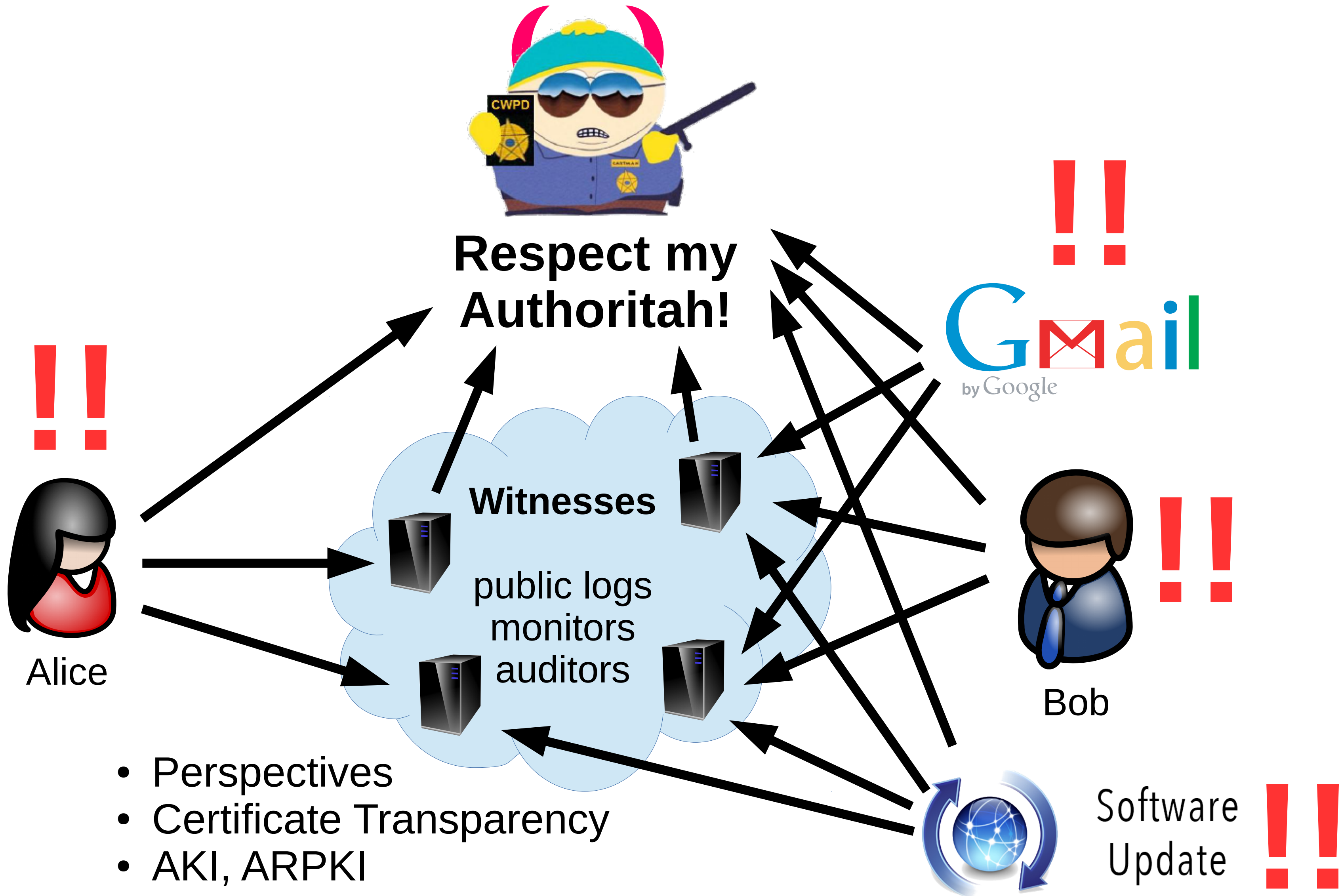
- Witnesses collectively verify log structure, Leader can't equivocate without being busted



The Transparency Challenge

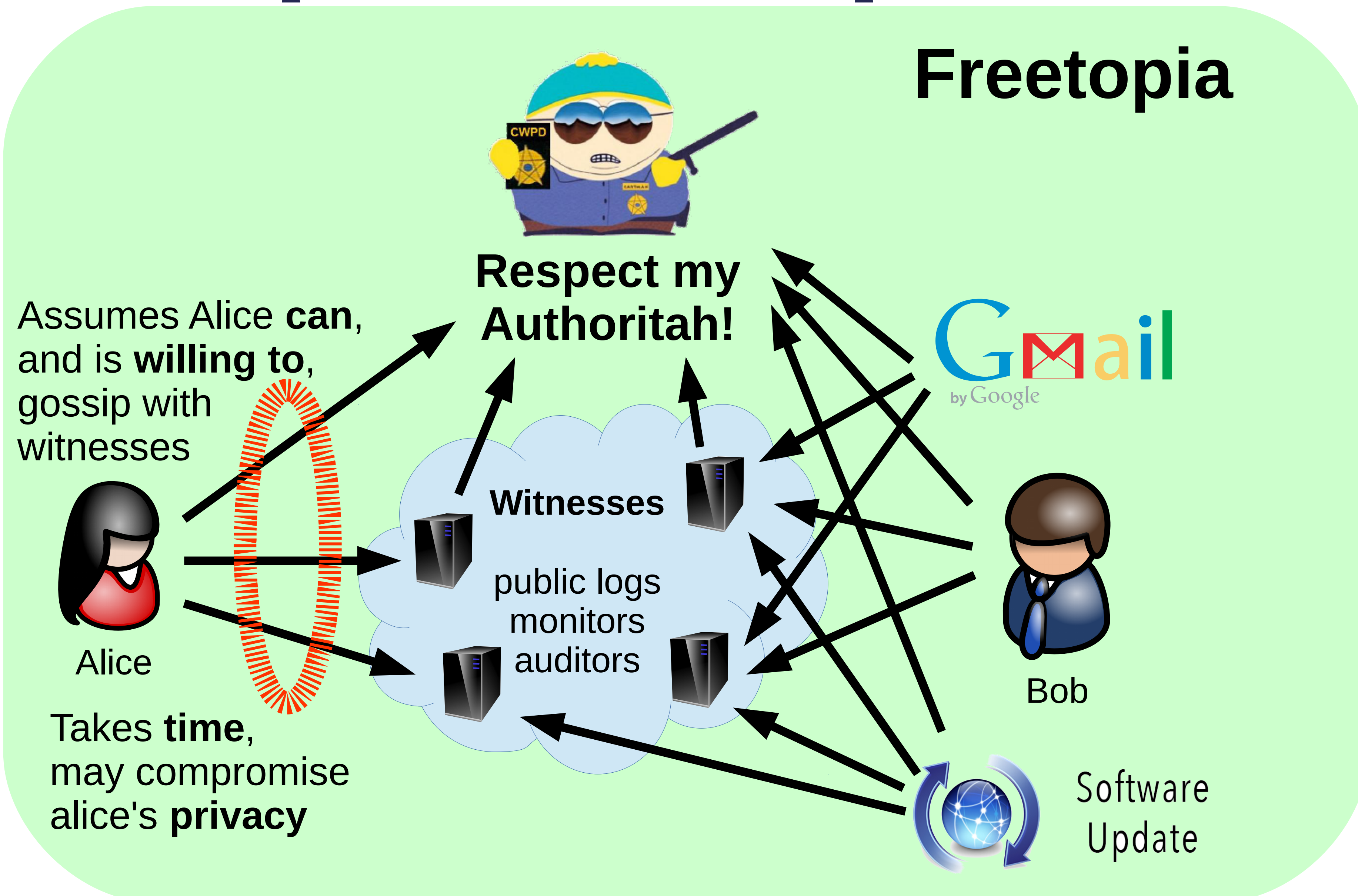


Current Transparency Solutions

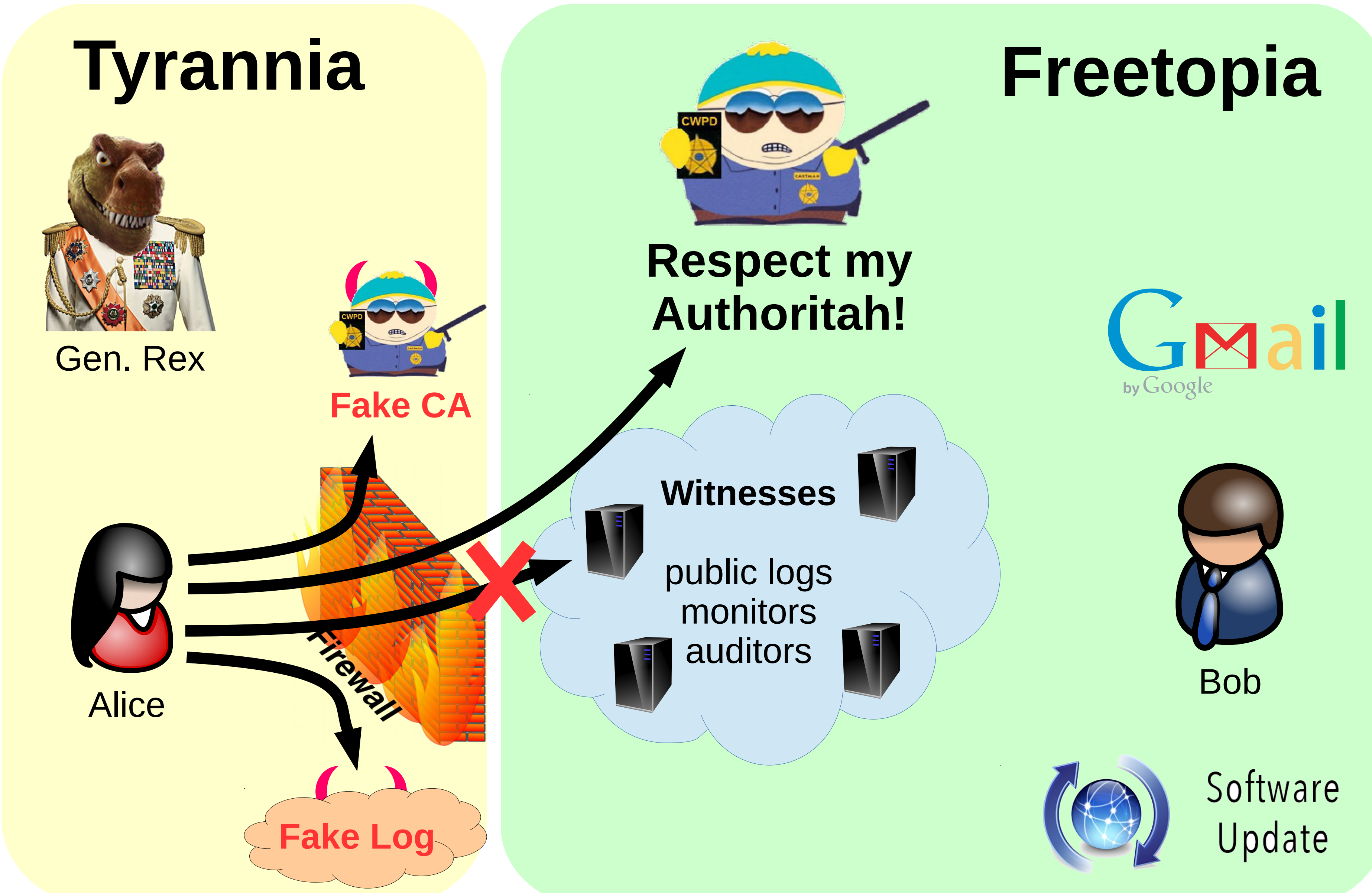


- Perspectives
- Certificate Transparency
- AKI, ARPKI
- CONIKS

An Important Assumption



A Different Scenario



Gossip versus Collective Signing

Gossip can't protect Alice if she...

- **Can't** (because she's in Tyrannia)
- **Doesn't want to** (for privacy), or
- **Doesn't have time to**

cross-check each authoritative statements.

Collective signing **proactively** protects her from secret attacks even via her access network.

- Attacker can't secretly produce valid signature

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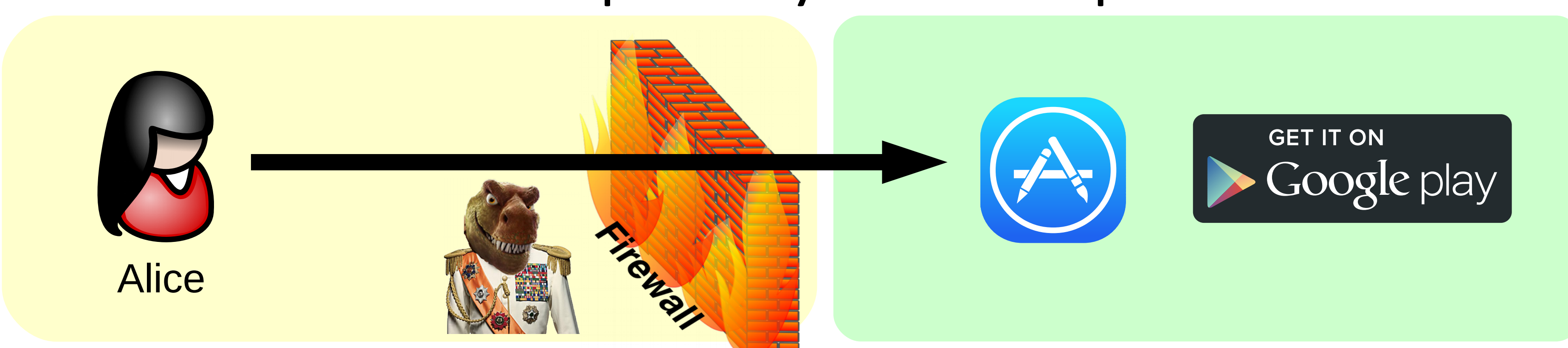
Software Update Scenario

Alice, traveling in Tyrannia, is offered a **software update** for her favorite app

- Claims to be "latest version" - but is it?
- Rex's firewall might inject **authentic** but **outdated, now exploitable** version
- If Alice accepts, she is **instantly Pwned;** retroactive transparency won't help!



Timestamping Cothority

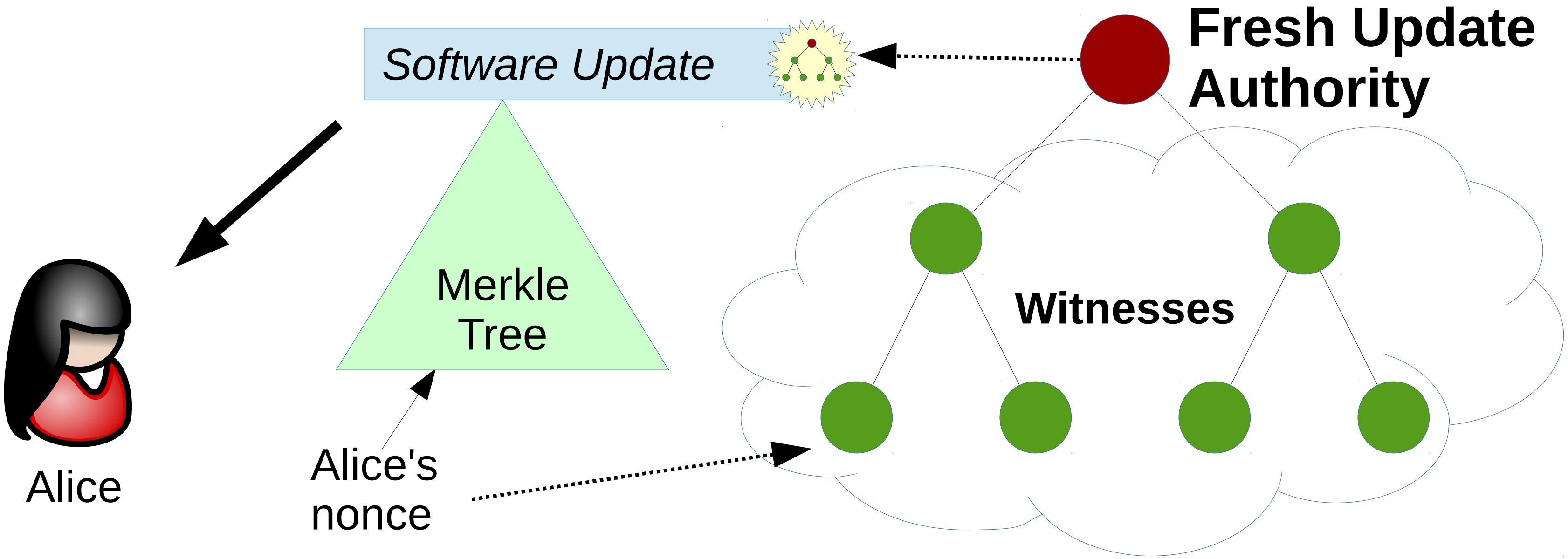
Like classic **digital timestamp** services, only decentralized.

- Each round (e.g., 10 secs):
  1) Each server collects hashes, nonces to timestamp
  2) Each server aggregates hashes into Merkle tree
  3) Servers aggregate local trees into one global tree
  4) Servers collectively sign root of global tree
  5) Server give signed root + inclusion proof to clients
- Clients verify signature + Merkle inclusion proof

Verifiably Fresh Software Updates

Alice accepts only updates with fresh timestamp:

- Knows update can't be an outdated version: tree contains inclusion proof of *her* nonce
- Knows update can't have targeted backdoor: witness cothority ensures *many* parties saw it



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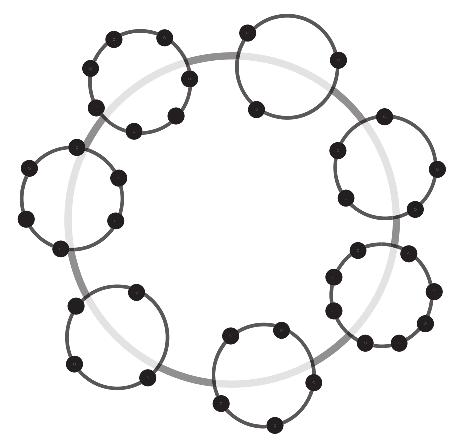
Unbiased Public Randomness

Need authority that can "flip coins" in public, convince everyone result is **fair** and **unbiased**.

- Choose lottery winner
- Sampling ballots in election auditing
- Pick BFT clusters from large pool of servers
- Divide large user network into smaller random anonymity sets
  - e.g., Herbivore [Goel/Sirir '04]



Related: Existing Approaches

Algorithmic work on quorum-building

- e.g., King et al, ICDCN 2011
- Unclear how to implement, apply

Randomness via "slow hashes"

- e.g., Lenstra/Wesolowski, 2015
- New, nonstandard crypto assumptions

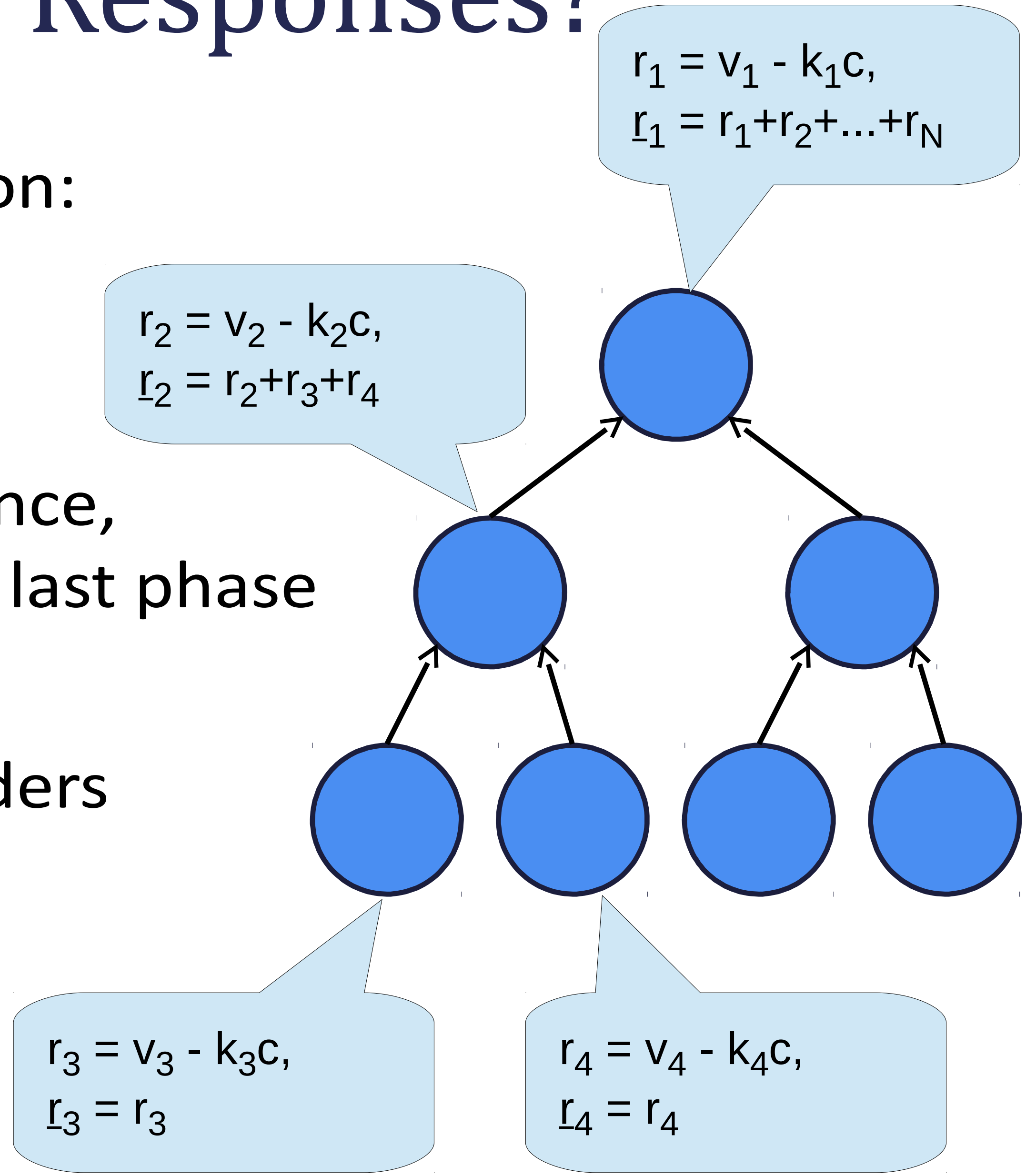
CoSi Protocol Responses?

Appealing near-solution:

- Contributions from all participants
- Committed in advance, unpredictable until last phase

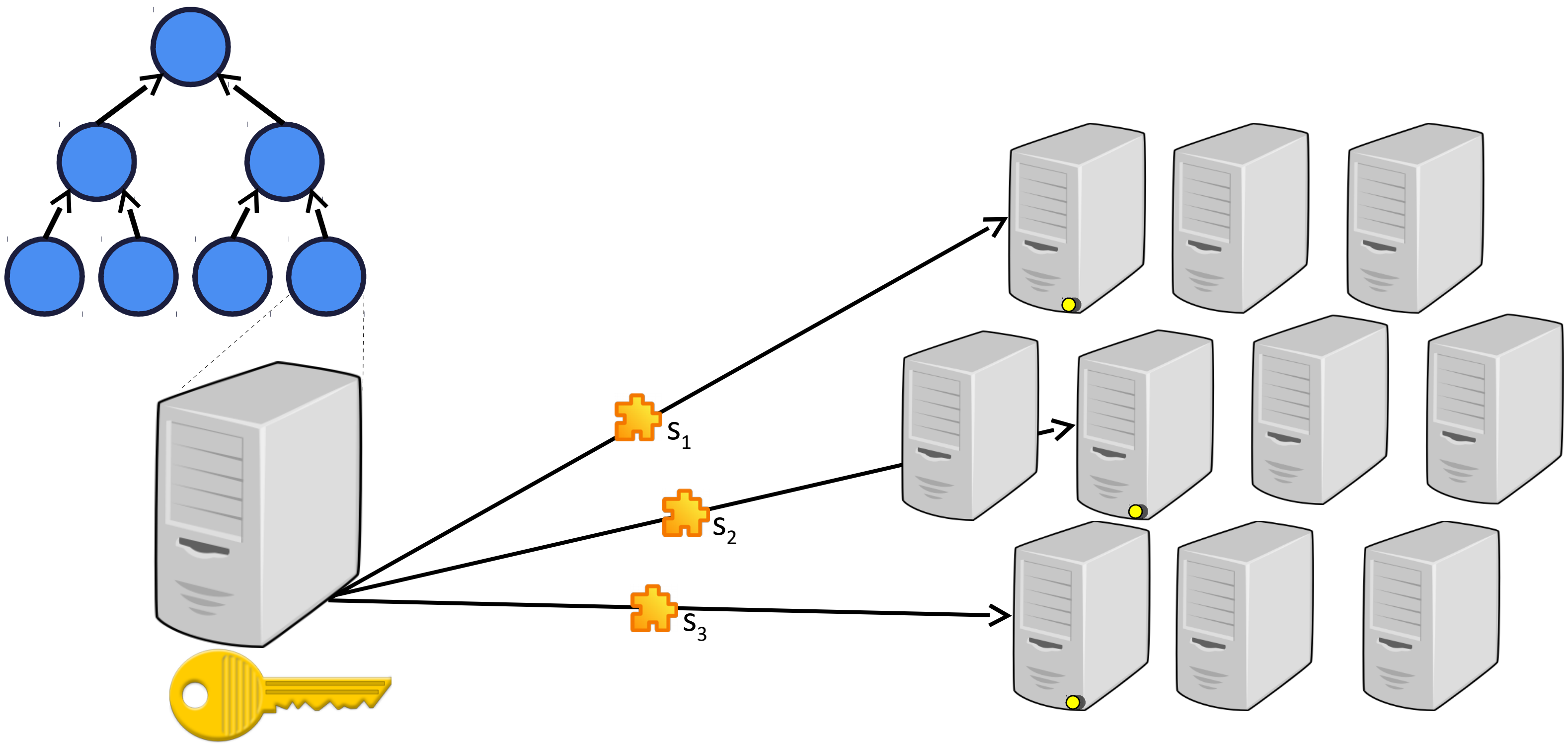
But can still be *biased* by leader with *k* colluders

- Use exceptions to pick “best of” 2^k outcomes



Availability via "life insurance"

- Node "insures" its private key by depositing the key shares with threshold group of "trustee" servers
  - Shamir verifiable secret sharing (VSS)
- Trustees can sign on behalf of failed node

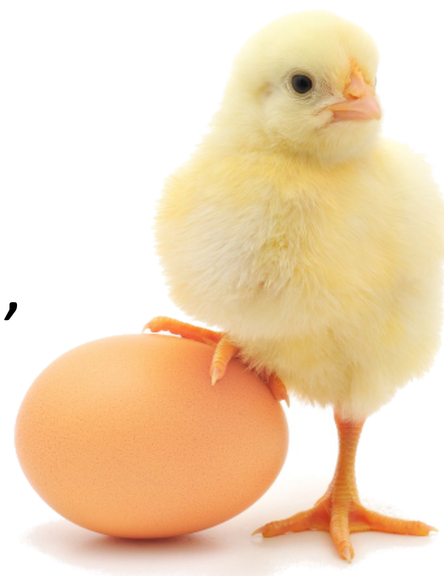


The Challenge

How to pick set of trustees for given witness?

- All nodes trustees (JVSS): doesn't scale, $O(N^2)$
- Witness-chosen: can pick bad group → DoS
- Leader-chosen: pick cronies, get secret early

We need **unbiased public randomness**
to pick these random trustee subgroups,
to get **unbiased public randomness!**



RandHound: Protocol Sketch

Intuition: bootstrap from
pairwise unbiased randomness

1) Leader commits to random value R_L,
   each follower i commits to random R_i

2) Reveal; follower i picks trustees via $H(R_L,R_i)$,
   deals secret S_i to picked trustees

3) Leader commits to threshold set of secrets
   s.t. must include *at least one* honest follower

4) Followers reveal dealt secret shares

RandHound: Security Properties

Assuming a fraction of participants are honest:

Unpredictability: no one can recover the (one) honest follower's secret before final reveal phase

Unbiasability: only one possible outcome after leader's threshold-set commit in phase 3

Availability: protocol runs to completion w.h.p. unless leader dishonestly colludes to DoS itself

Scalability: O(NT), where
trustees T depends only on security parameter

Status

Still preliminary:

- Initial implementation working
  (code available on DeDiS github)
- Experimentation in-progress
- Cothority integration in-progress

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Ongoing/Future Work

Backward-compatible integration into authorities

- Web PKI: Certificate Authorities, CT, AKI
- Personal PKI: PGP keyservers, CONIKS
- Practical software release, update services

Build more general collective authorities...

Towards Better Blockchains?

Decentralized consensus, secure ledgers

- Without proof-of-work and massive power waste
- Without risk of temporary forks
- Without 51% attack vulnerability
- Stronger protection for clients, "light" nodes
  - Just check *one* log-head signature for correctness
- Efficient: with FawkesCoin hash-based ledger, just *one* public-key crypto operation per round
- Scalable: every server need not store, verify every record throughout blockchain history

Conclusion

Cothorities build on old ideas

- Distributed/Byzantine consensus protocols
- Threshold cryptography, multisignatures

But demonstrate how to *scale* trust-splitting

- Strongest-link security among many witnesses
- Practical: demonstrated for 8000+ participants
- Efficient: 1.5-second signing latency at scale

More details: http://arxiv.org/abs/1503.08768