Resolving Concurrency in Group Ratcheting Protocols

Secure Messaging Summit 2020

2020-09-03

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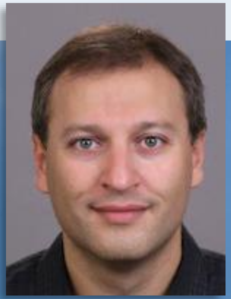
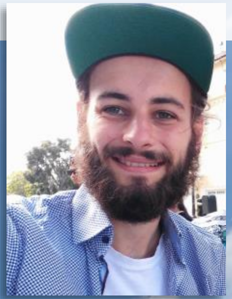
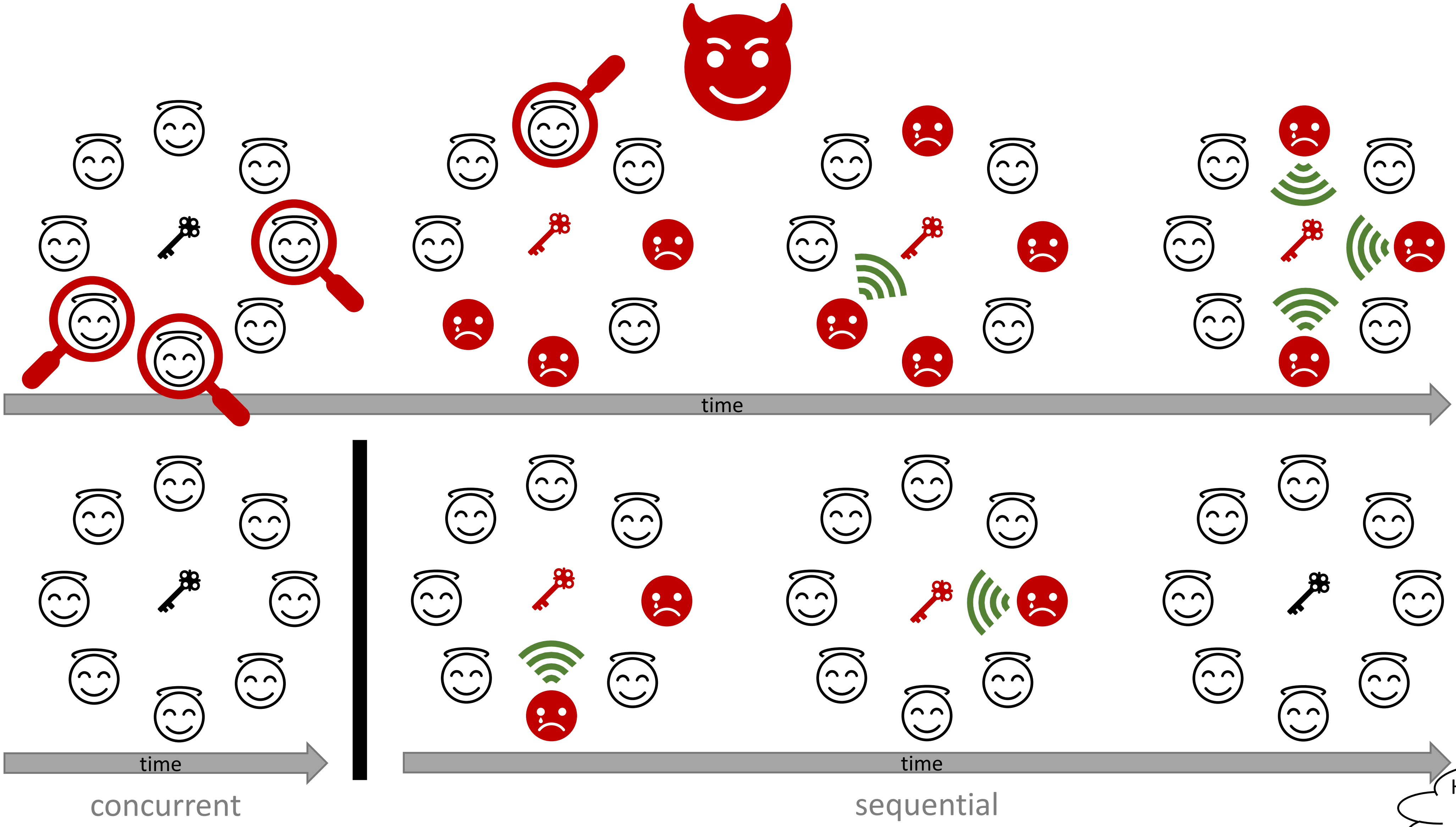
Paul Rösler

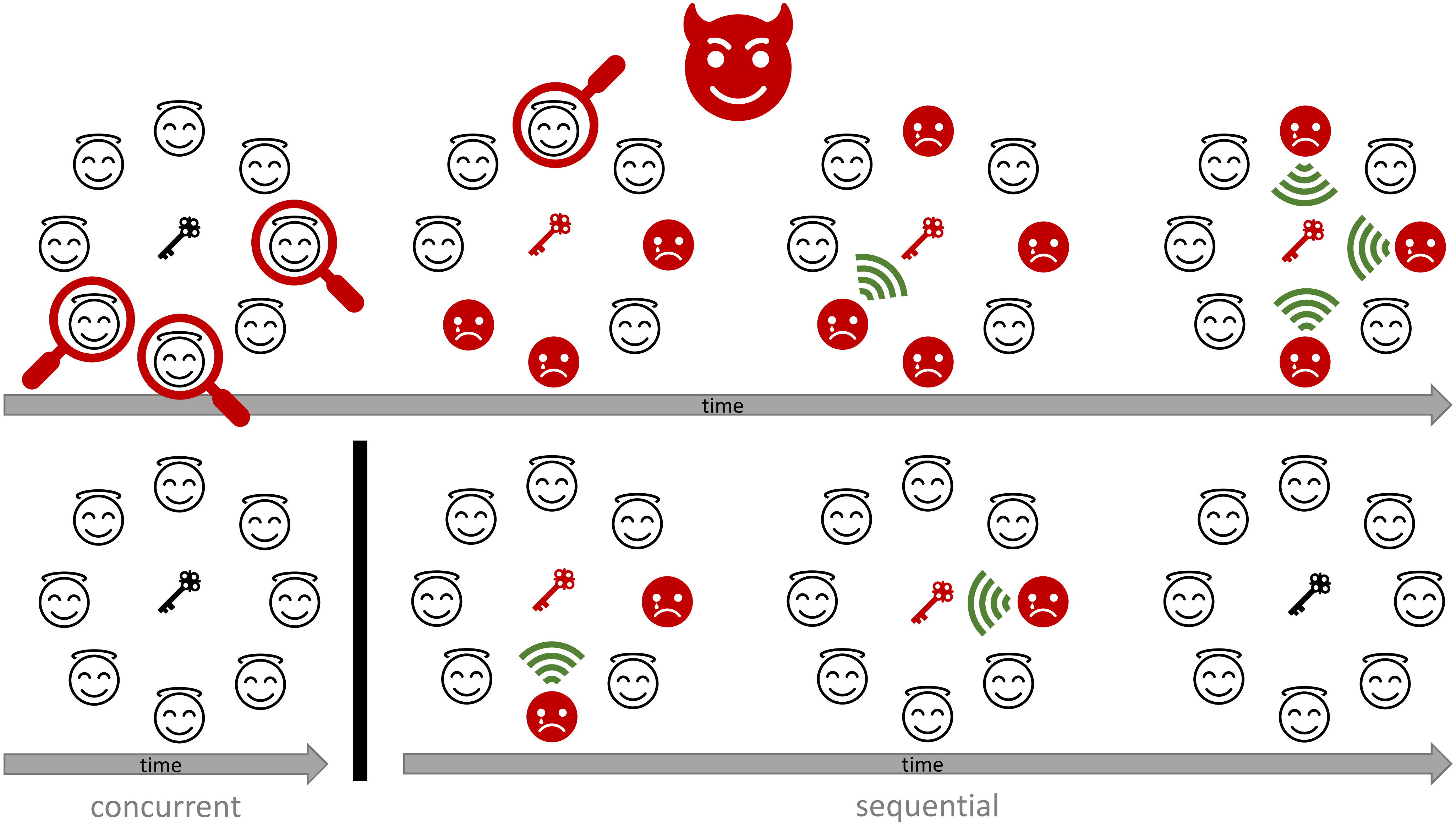
(Concurrent) Group Ratcheting



- Group computes joint keys
- Exposure of local state temporarily
  - Long-term sessions, mobile devices etc.
  - Leaks group key until all states recovered
- Recovery:
  - Generate new secrets
  - Share public values
- Concurrent recovery
  - Speedup
  - Merge recoveries

Here: one group, concurrent users.
[CHK'19]: Many groups, sequential users.

(Concurrent) Group Ratcheting



Target:

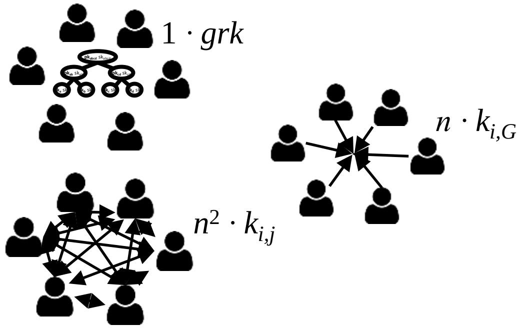
1. Post-Compromise Security
2. Small shares
3. Concurrency

Otherwise:

- Slow recovery from exposures
- Consensus required

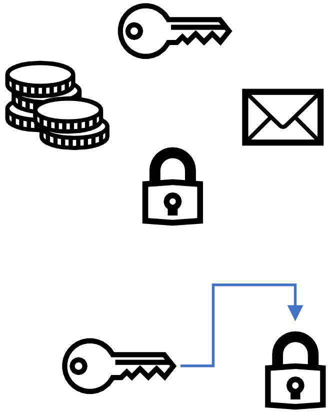
→ Inapplicable to decentralized networks

Agenda



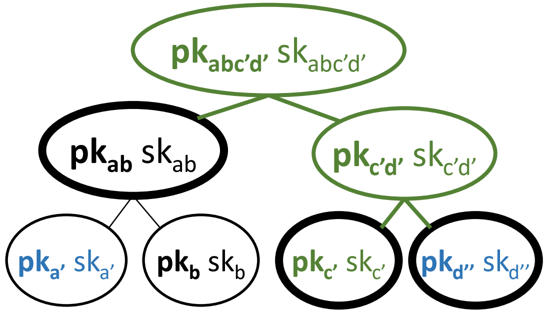
Previous Work: What's the Problem?

Lower Bound: What's the minimal overhead?



Upper Bound: Almost optimal construction

Open Questions …

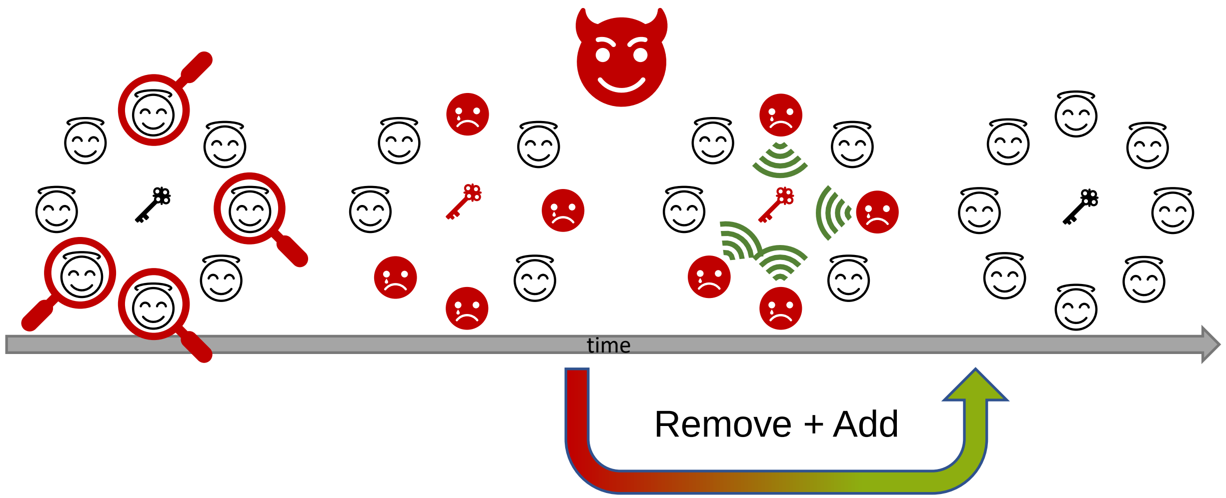


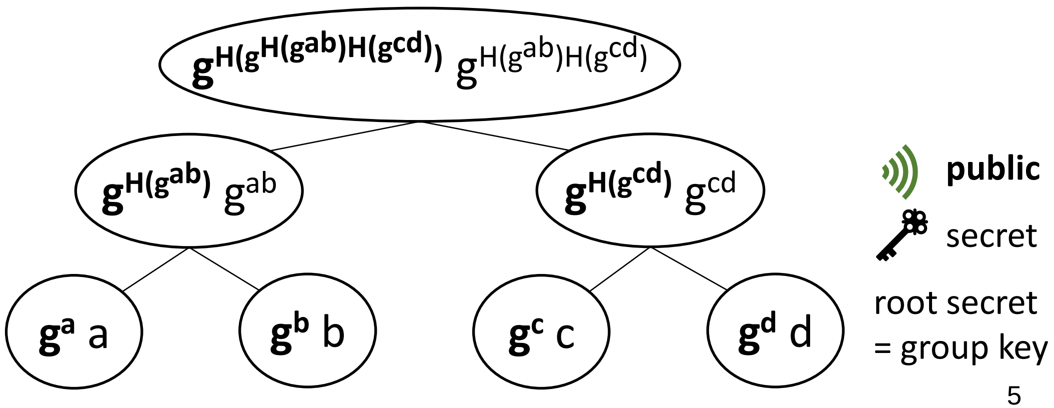
Ω(t) vs. O(t·(1+log(n/t))?
NIKE?
PCS-Delay?
Forward-secrecy?
Application to MLS

Previous Work: What's the Problem?

- Essentially: Dynamic group key exchange (DGKE)
  - Expose = Unwanted member
  - Recovery = Remove + Add (R&A)

  - Many protocols from '80s – '00ers
  - Tree-based DGKE best suited for asynchronous settings:
    - Little communication for R&A: O(log n)
    - (Almost) non-interactive for R&A
    - → First known DH-tree-based protocol [KPT'04]





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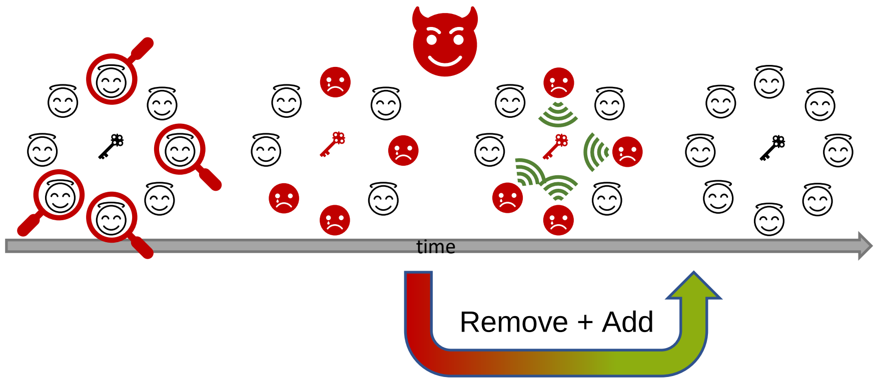

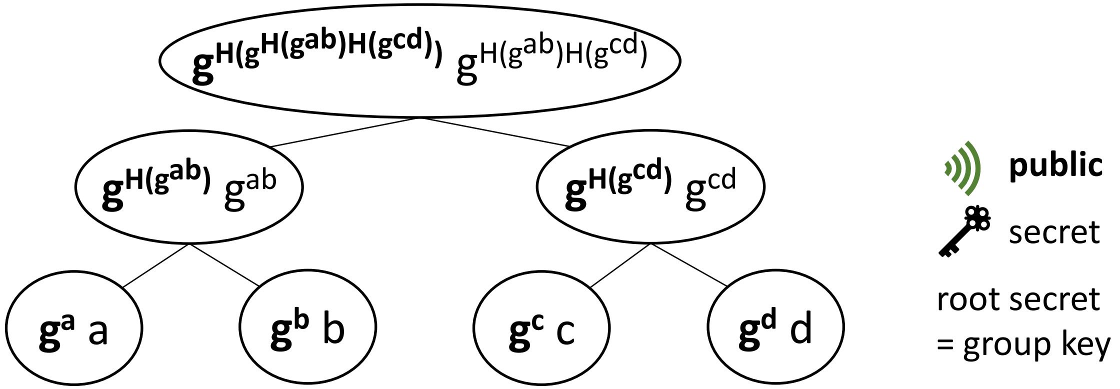

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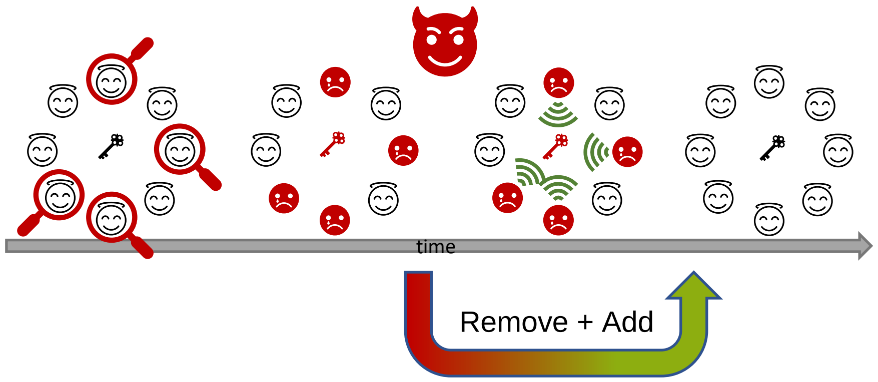

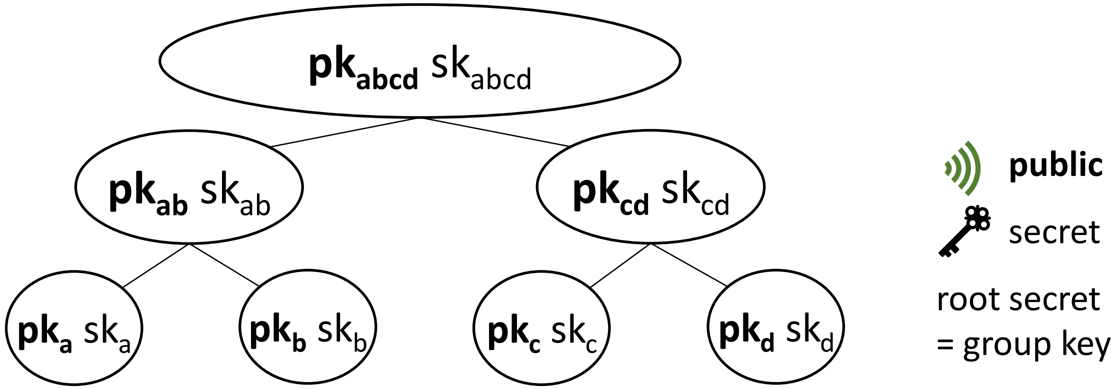

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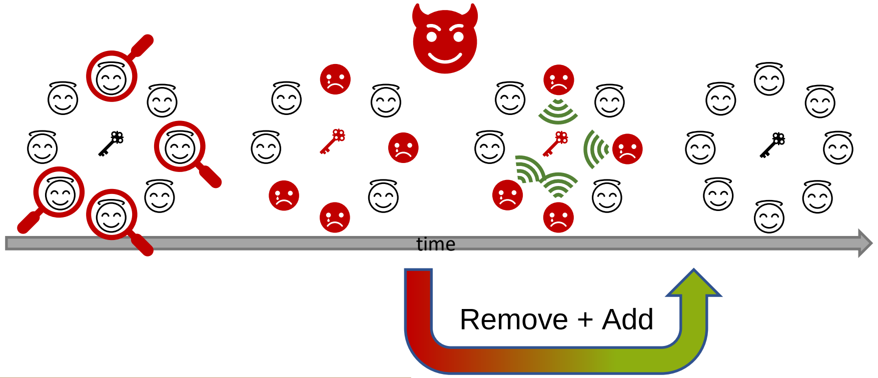

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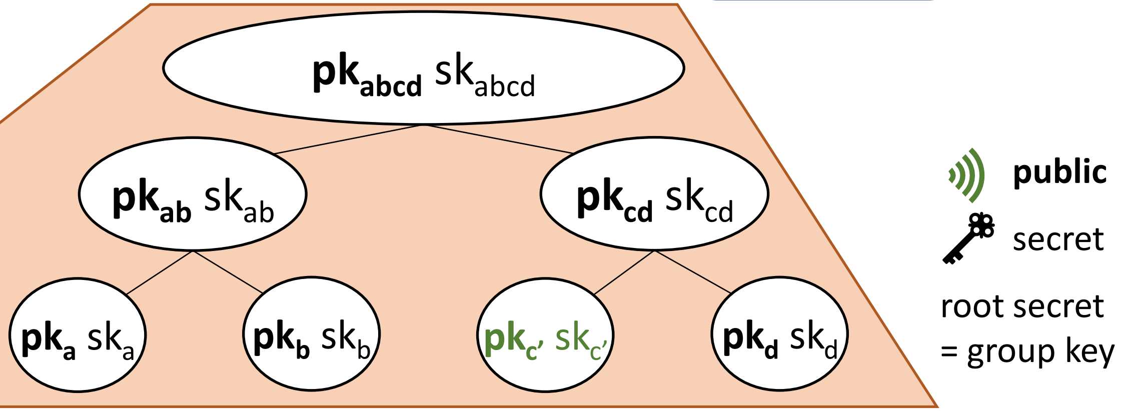

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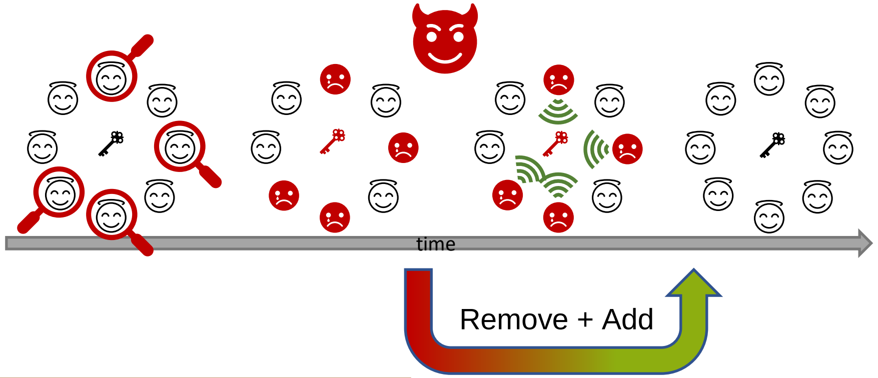

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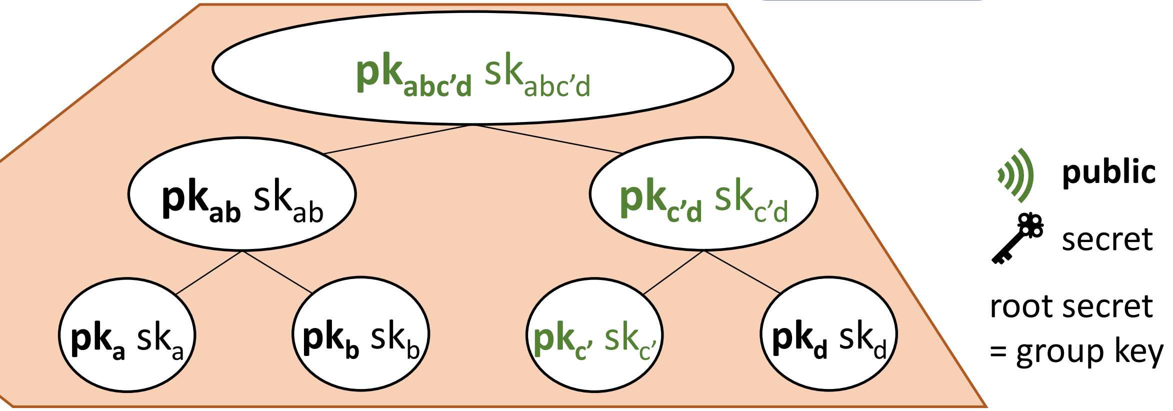

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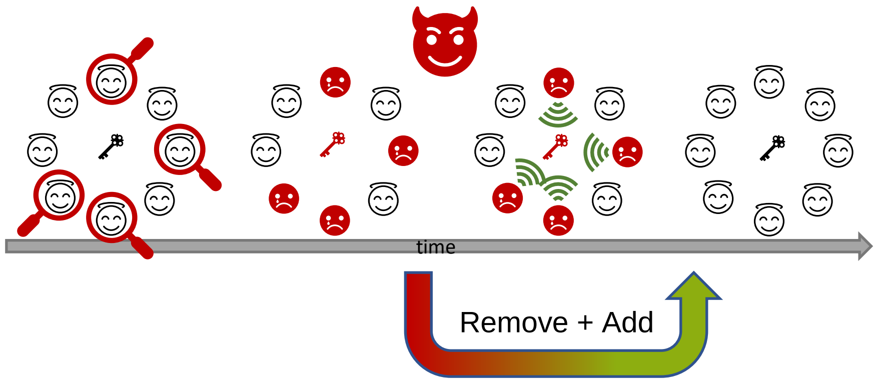

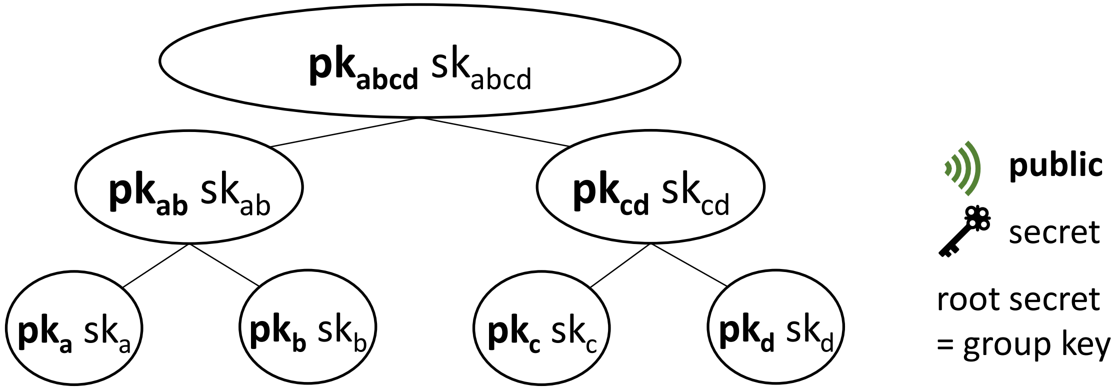

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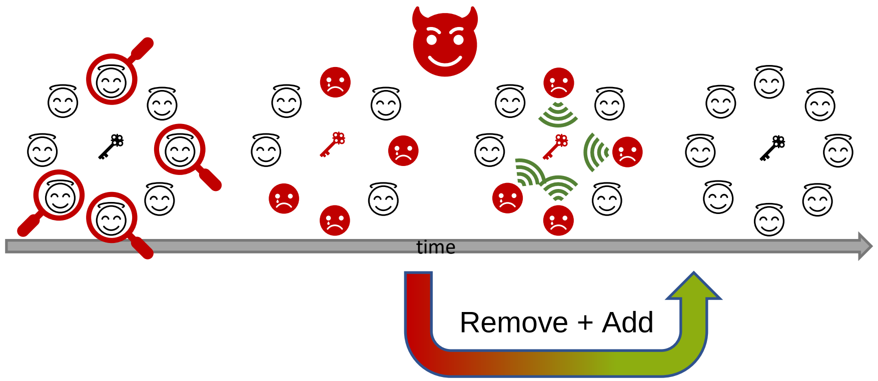
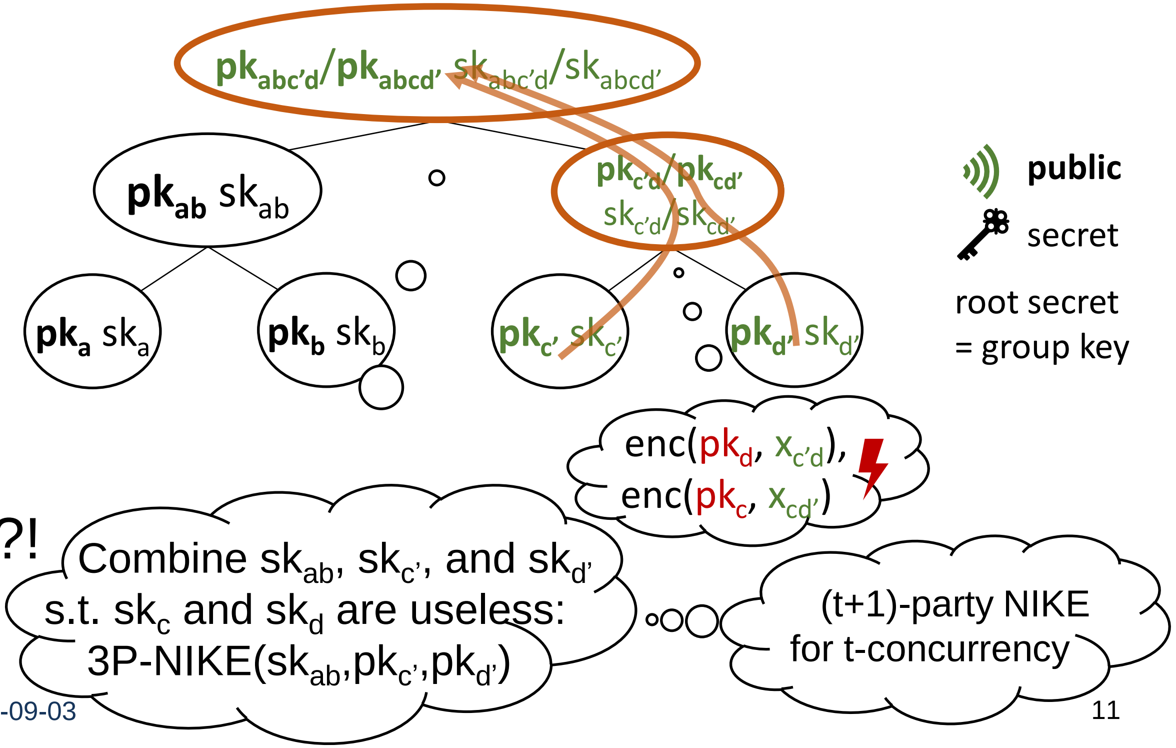
- No concurrency
  - Intersection of concurrently updated paths

  → Merging under PCS without multiparty-NIKE?!





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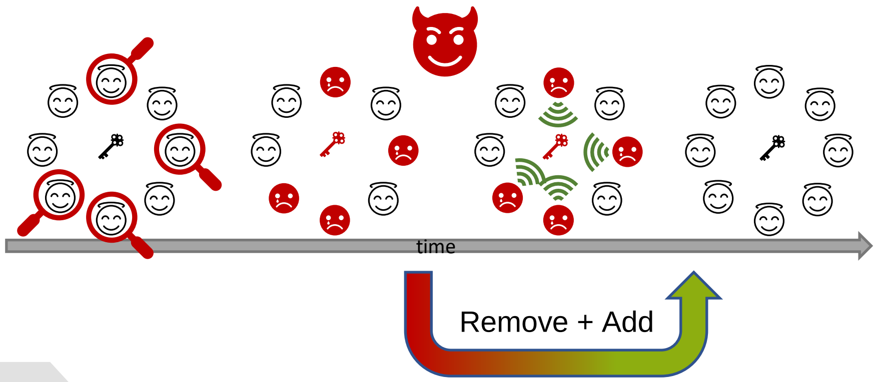

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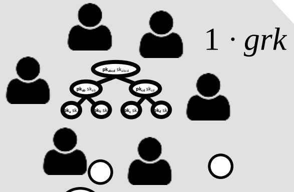

PCS	Overhead	Concurrency
✔	O(log n)	✘

MLSv9 worst-case:

(✔)	O(n)	(✔)

→ Rejects concurrent path updates
→ Degrades to "n-tree"

Merge DH Tree [Weidner'19]:

(✘)	O(log n)	✔

→ New DH paths are merged
→ Recovers only one user at a time

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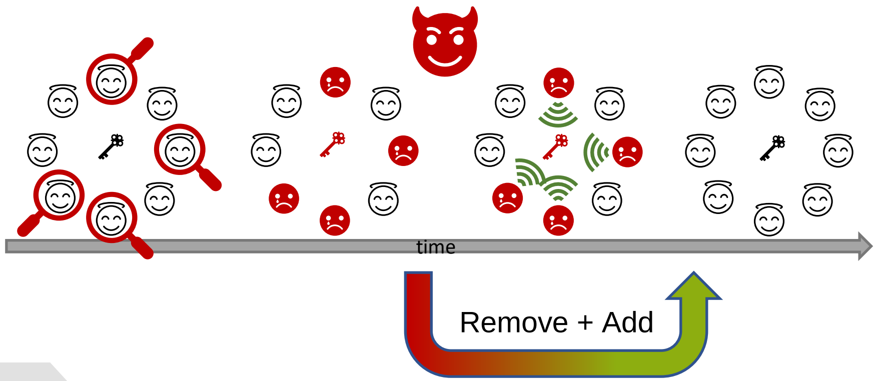

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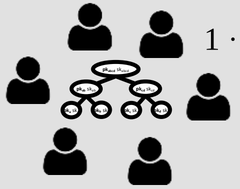

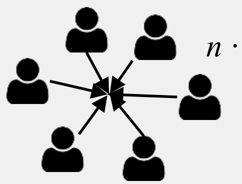

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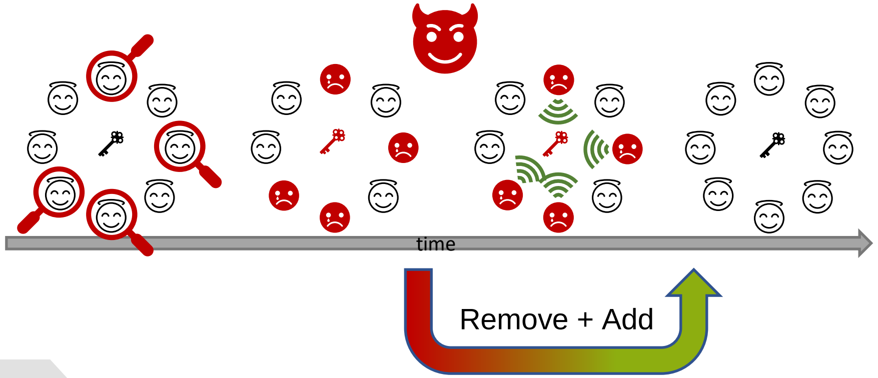

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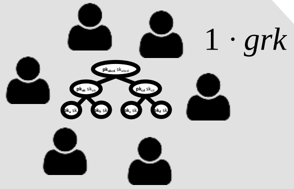

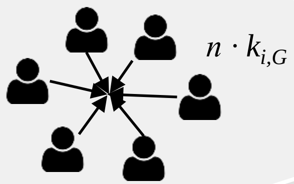

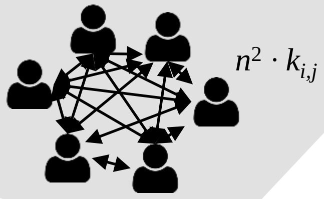

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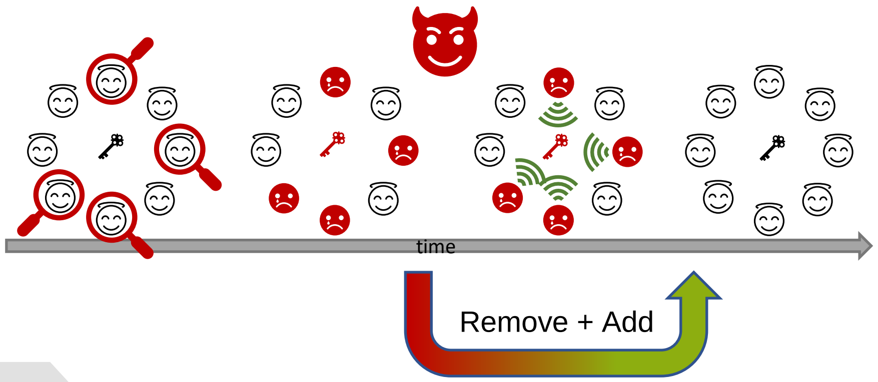

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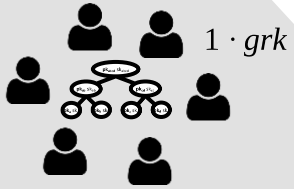

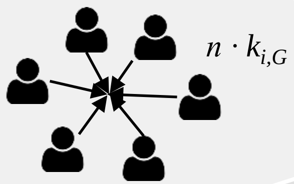

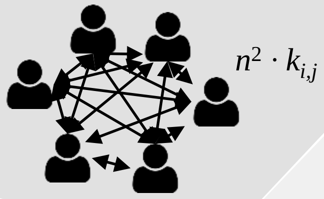

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✓	?	✓

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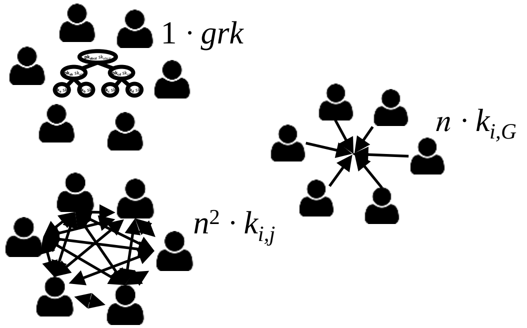

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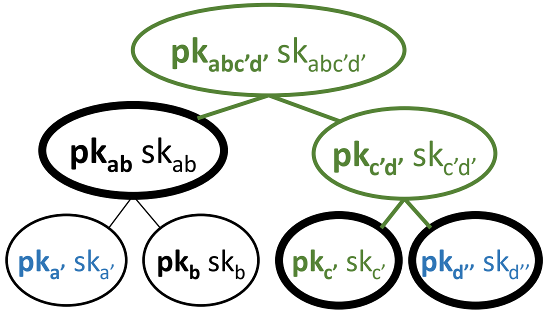
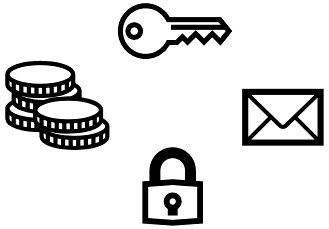
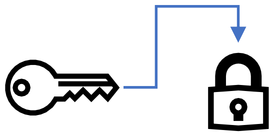


Previous Work: What's the Problem? → **Lower Bound: What's the minimal overhead?** → Upper Bound: Almost optimal construction → Open Questions …

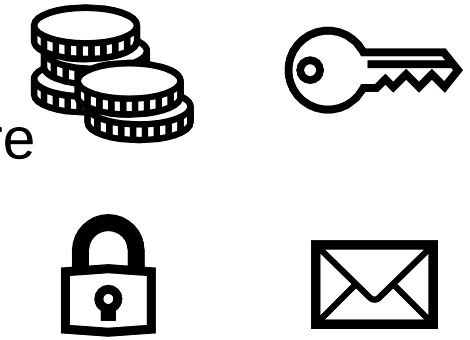


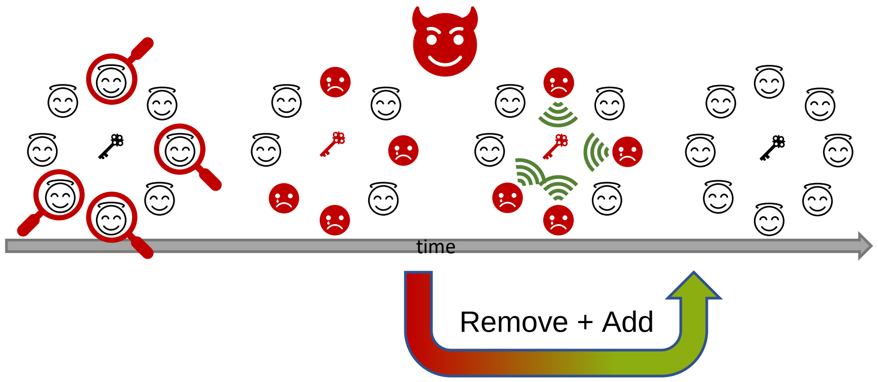


Ω(t) vs. O(t·(1+log(n/t))?
NIKE?
PCS-Delay?
Forward-secrecy?
Application to MLS

Lower Bound: What's the minimal overhead?

- Symbolic model
  - Variables are symbols without bit representation or algebraic structure
  - Algorithms follow "transition rules"
  - Round based execution

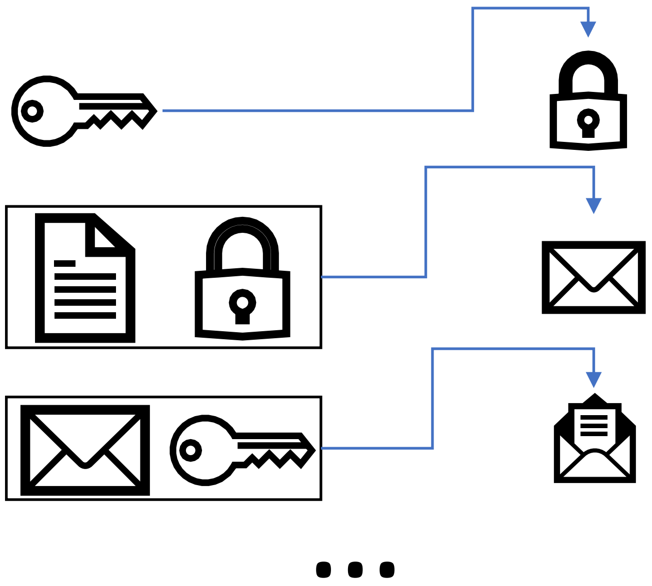




- Fixed set of allowed building blocks (for constructions with minimal overhead under PCS)

  Our "transition rules" model:
  - (Dual) pseudo-random functions
  - Key-updatable public key encryption (see [BRV20])
  - Broadcast encryption

  → *More* than what previous constructions used



- Inspired by [MP04]: Lower bound O(log n) for forward-secure DGKE

Lower Bound:
What’s the minimal overhead?

i-2 **Exposure:**
- No (shared) secrets

i-1 **Recovery 1:**
- Still no (shared) secrets
- Sampling of new secrets
- Sharing of derived values

→ Still no (shared) secrets

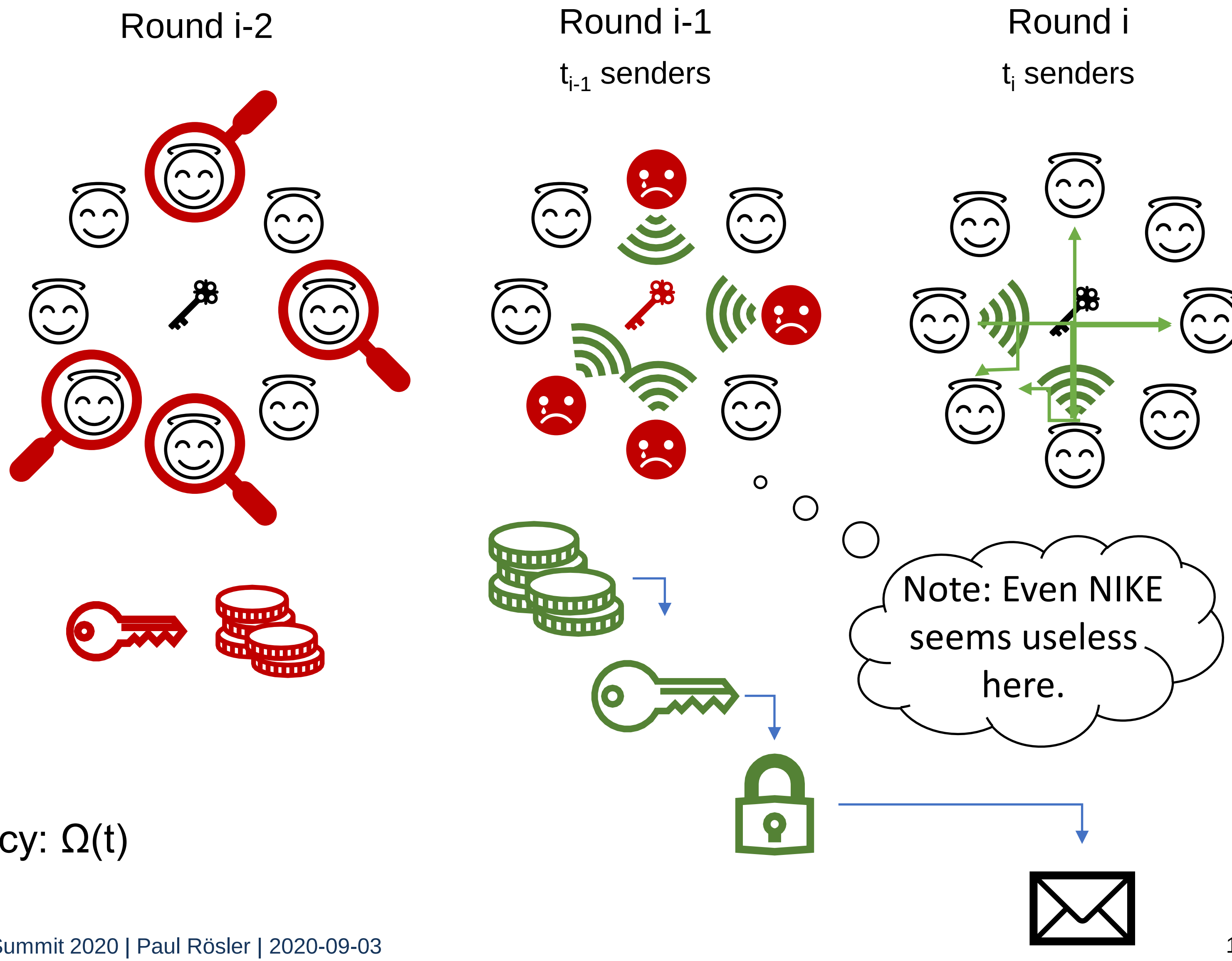
→ Though, public values of shared secrets

i **Recovery 2:**
- Respond to public values
- All senders must respond as they cannot coordinate

→ Each sender sends ≥ $(t_{i-1}-1)$ responses

→ ≥ $(t_{i-1}-1)\cdot t_i$ shares in round i

⇒ Overhead per recovery under t-concurrency: $\Omega(t)$



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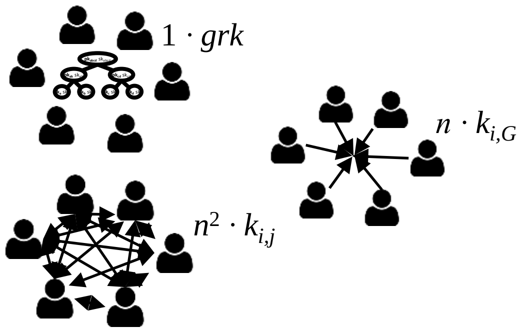

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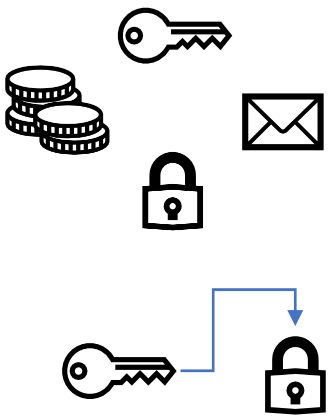
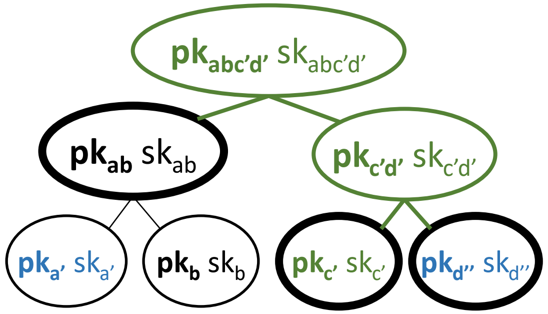


Realistic symbolic model:
No coordination + PCS
⇒ Ω(t)



Upper Bound: Almost optimal construction

Open Questions …

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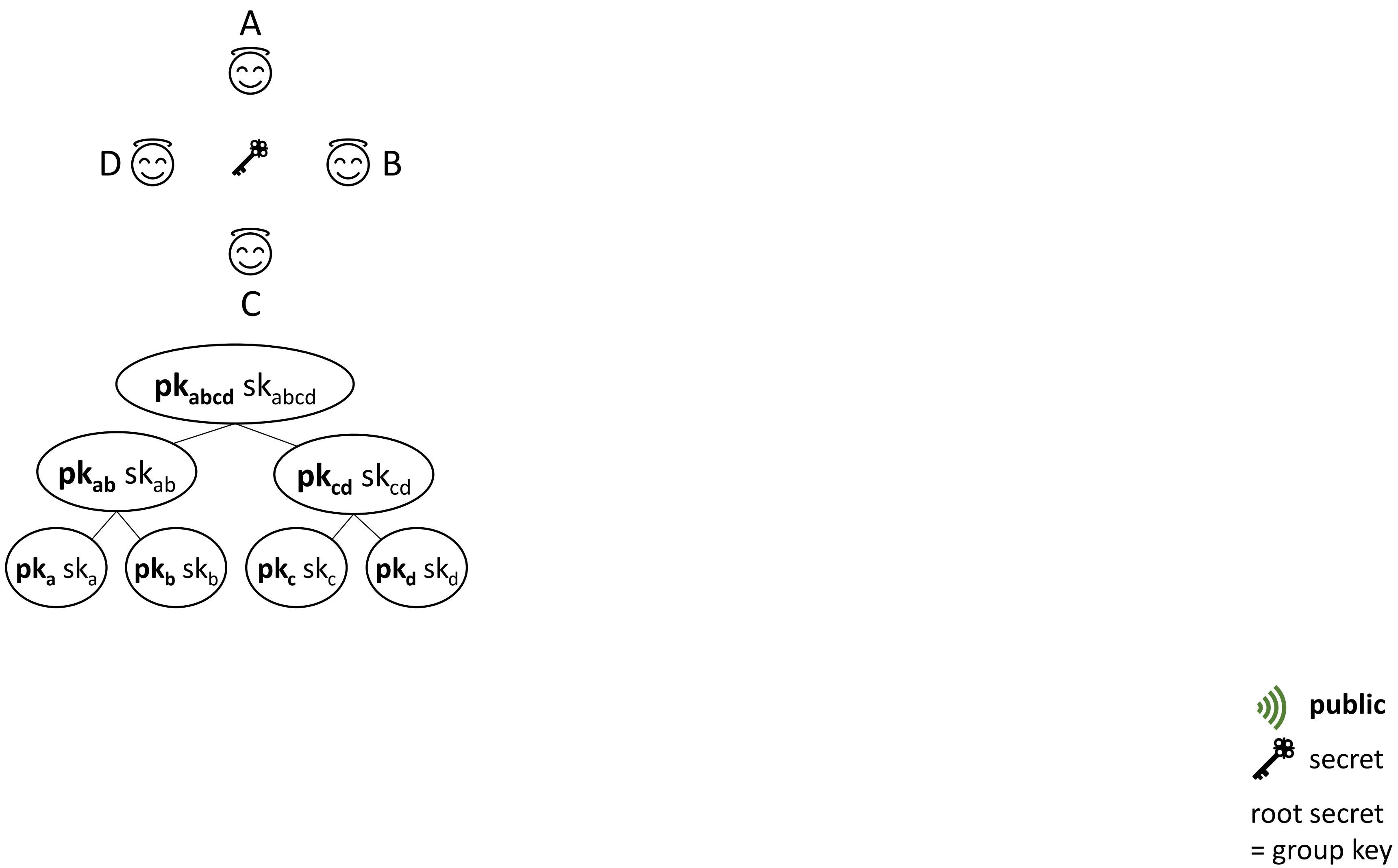
Key tree (with updatable KEM)



Upper Bound: Almost optimal construction

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Key tree (with updatable KEM)

i-2 Exposure:

- Paths of c and d *public*: sk_c, sk_d, sk_{cd}, sk_{abcd}

i-1 Recovery 1:

- Generate and share new leaf key pairs: $(sk_{c'}, pk_{c'})$, $(sk_{d'}, pk_{d'})$

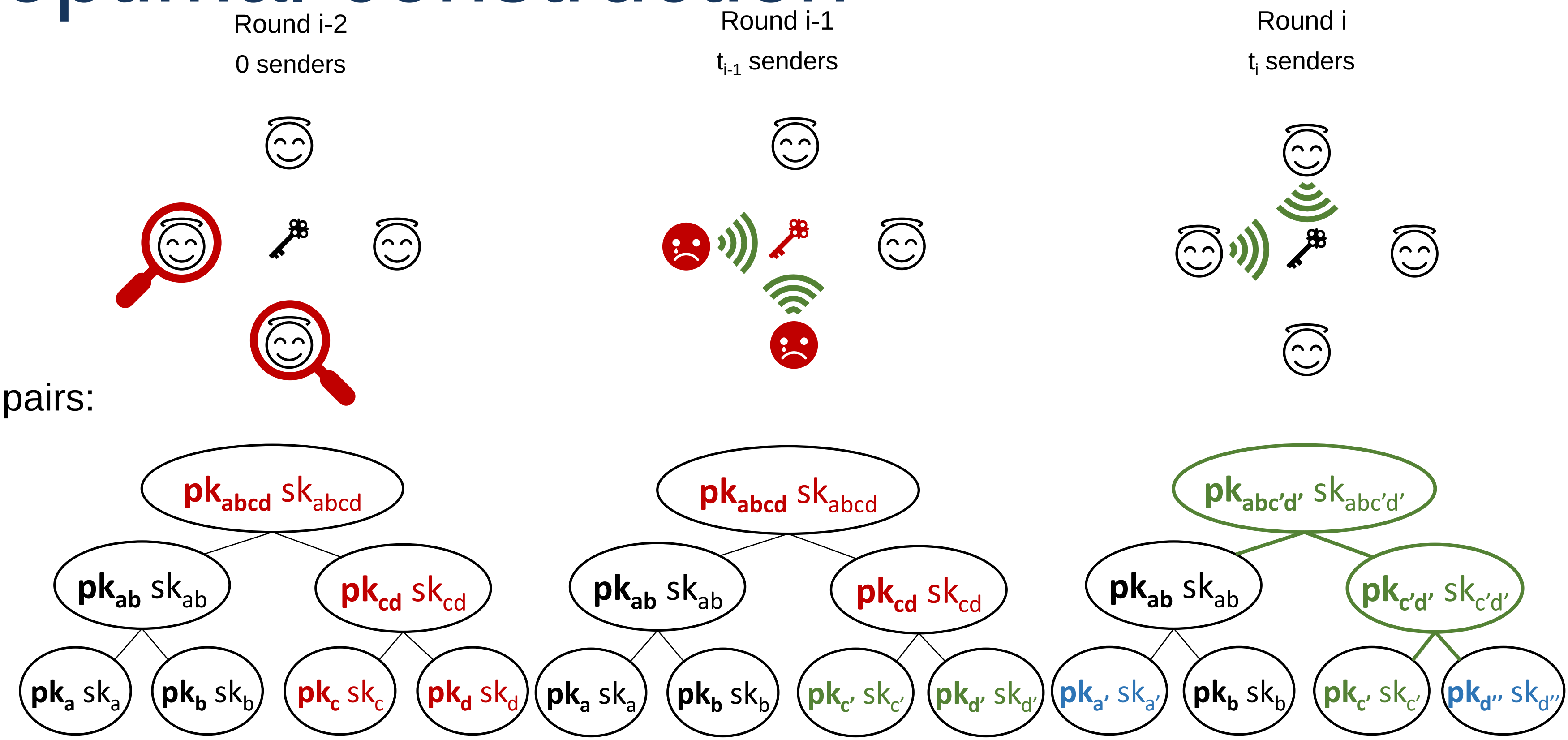
i Recovery 2:

a) See Recovery 1

- Each sender generates new paths for previous senders:

b) Sample $x_{c'd'}$

c) Derive $sk_{c'd'} = x_{c'd'}$, $x_{abc'd'} = H(x_{c'd'})$, $sk_{abc'd'} = x_{abc'd'}$, $pk_{c'd'} = gen(sk_{c'd'})$, $pk_{abc'd'} = gen(sk_{abc'd'})$



root secret = group key

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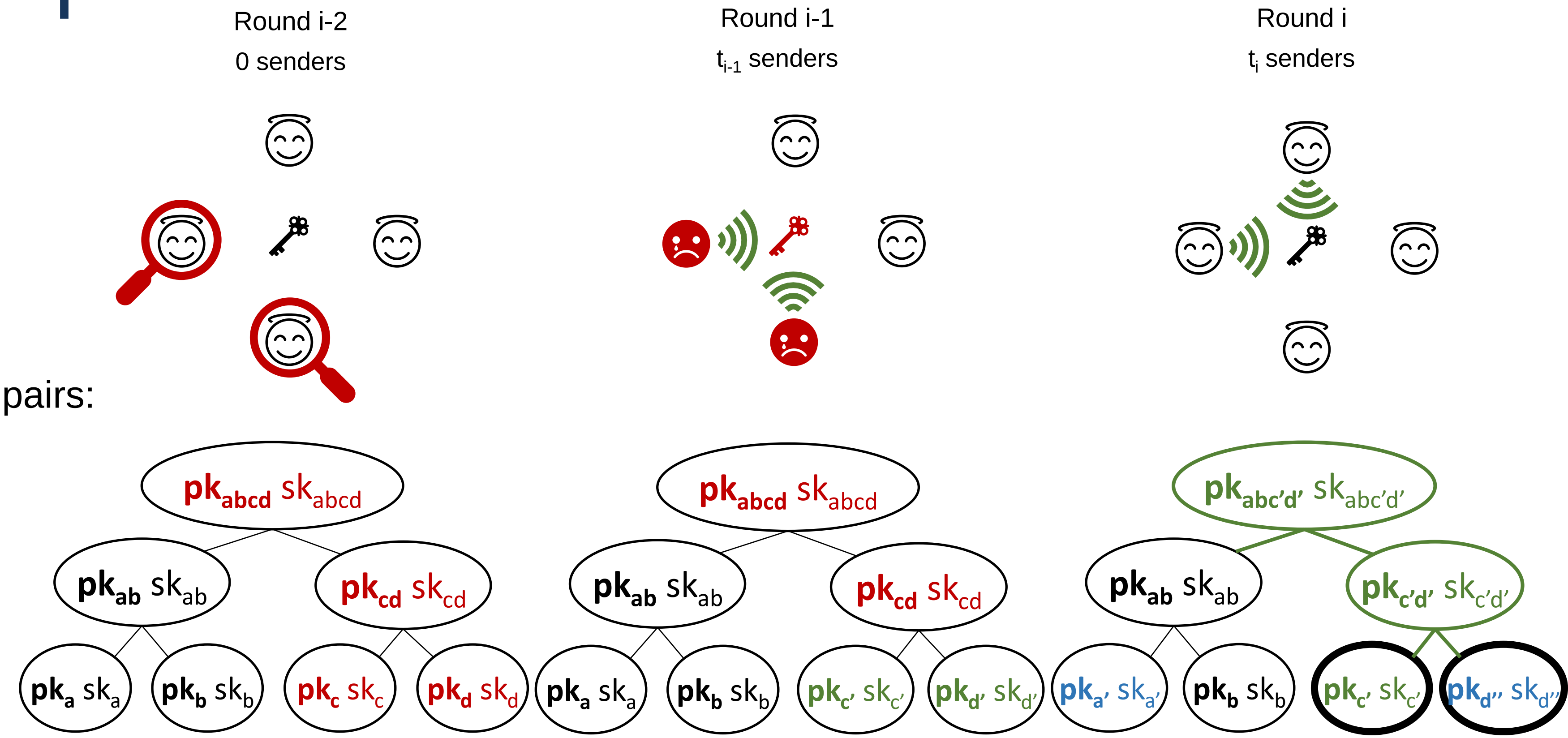

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- Each sender generates new paths for previous senders:

b) Sample $x_{c'd'}$

c) Derive $sk_{c'd'}=x_{c'd'}$, $x_{abc'd'}=H(x_{c'd'})$, $sk_{abc'd'}=x_{abc'd'}$, $pk_{c'd'}=gen(sk_{c'd'})$, $pk_{abc'd'}=gen(sk_{abc'd'})$

d) Send $enc(pk_{c'},x_{c'd'})$, $enc(pk_{d'},x_{c'd'})$

→ **Number of leafs: t_{i-1}**

Upper Bound: Almost optimal construction

Key tree (with updatable KEM)

i-2 Exposure:

- Paths of c and d *public*: sk_c, sk_d, sk_{cd}, sk_{abcd}

i-1 Recovery 1:

- Generate and share new leaf key pairs: $(sk_{c'}, pk_{c'})$, $(sk_{d'}, pk_{d'})$

i Recovery 2:

a) See Recovery 1

- Each sender generates new paths for previous senders:

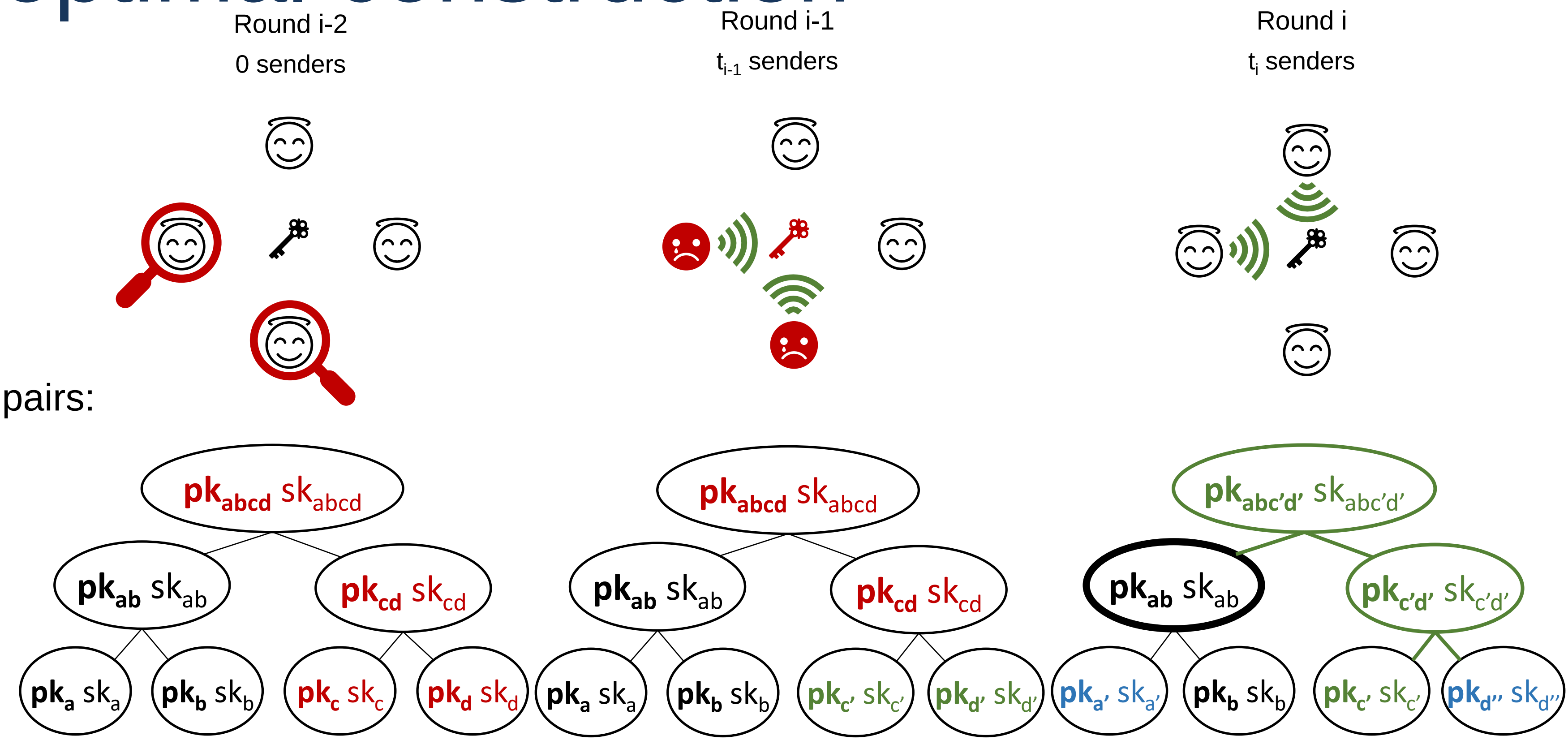
b) Sample $x_{c'd'}$

c) Derive $sk_{c'd'} = x_{c'd'}$, $x_{abc'd'} = H(x_{c'd'})$, $sk_{abc'd'} = x_{abc'd'}$, $pk_{c'd'} = gen(sk_{c'd'})$, $pk_{abc'd'} = gen(sk_{abc'd'})$

d) Send $enc(pk_{c'}, x_{c'd'})$, $enc(pk_{d'}, x_{c'd'})$, $pk_{c'd'}$, $enc(pk_{ab}, x_{abc'd'})$

→ Number of leafs: t_{i-1}, **number of update-tree-siblings: $O(t_{i-1} \cdot \log(n/t_{i-1}))$**

⇒ Overhead per recovery under t-concurrency: $O(t + t \cdot \log(n/t))$



1-"concurrency": → O(log n)

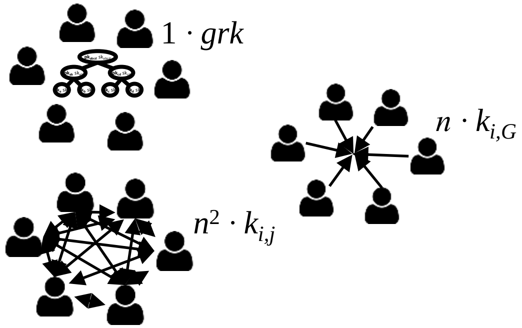
n-concurrency: → O(n)

public

secret

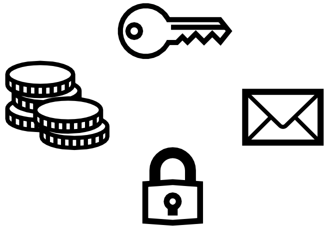
root secret = group key

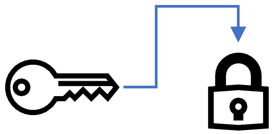
Agenda



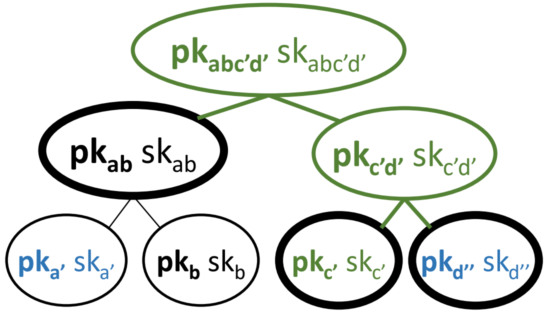
PCS & ~~Concurrency~~ & Small overhead
~~PCS~~ & Concurrency & Small overhead
PCS & Concurrency & ~~Small overhead~~

Previous Work: What's the Problem? → **Lower Bound: What's the minimal overhead?** → **Upper Bound: Almost optimal construction** → **Open Questions …**





Realistic symbolic model:
No coordination + PCS
⇒ Ω(t)



Two-step recovery
⇒ O(t·(1+log(n/t))

Ω(t) vs. O(t·(1+log(n/t))?
NIKE?
PCS-Delay?
Forward-secrecy?
Application to MLS

@roeslpa Full details & formal proofs online *soonish*