On the Price of Concurrency in Group Ratcheting Protocols

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Chair for Network and Data Security
Ruhr University Bochum

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New York University

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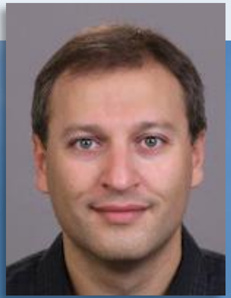
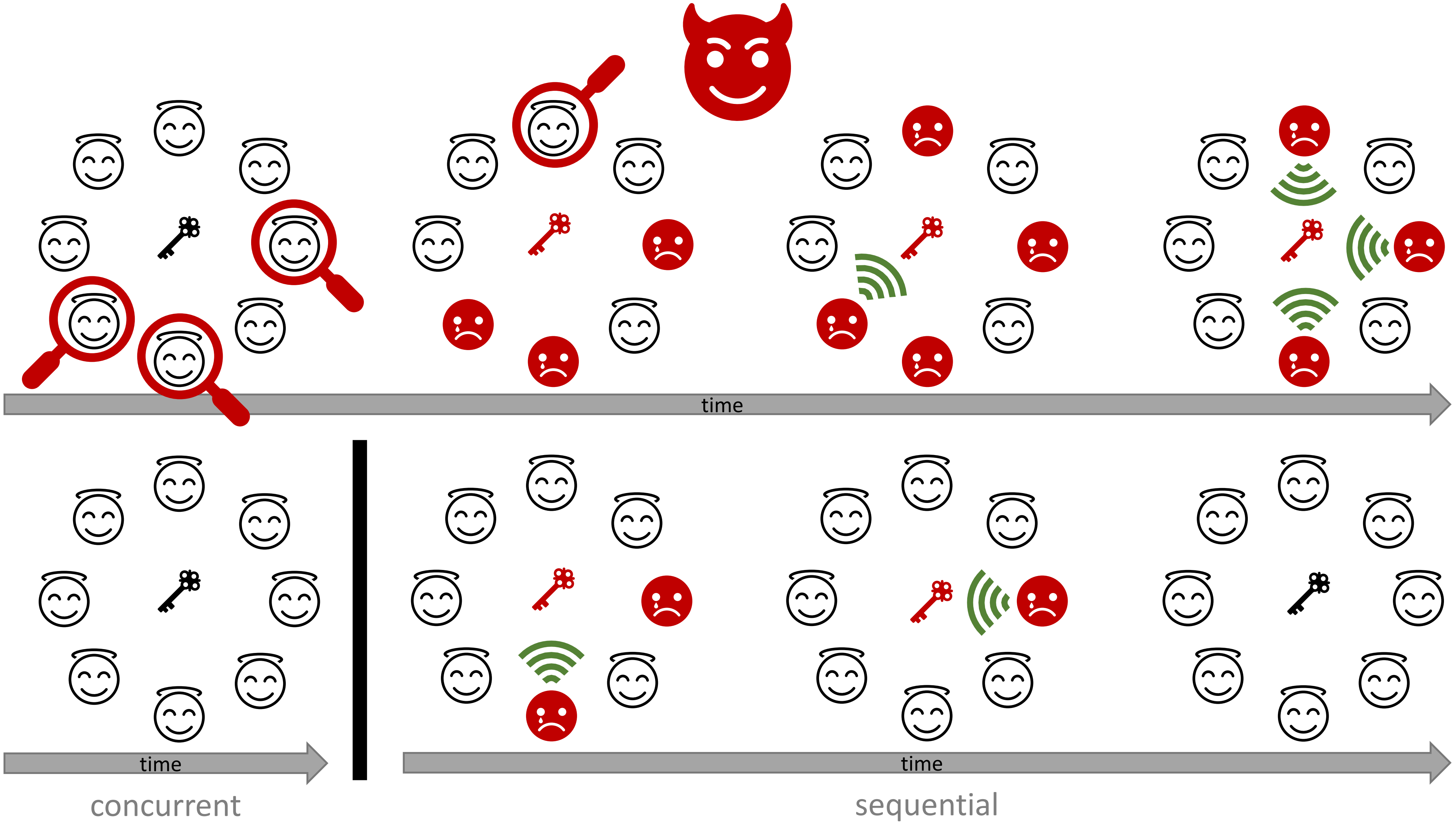
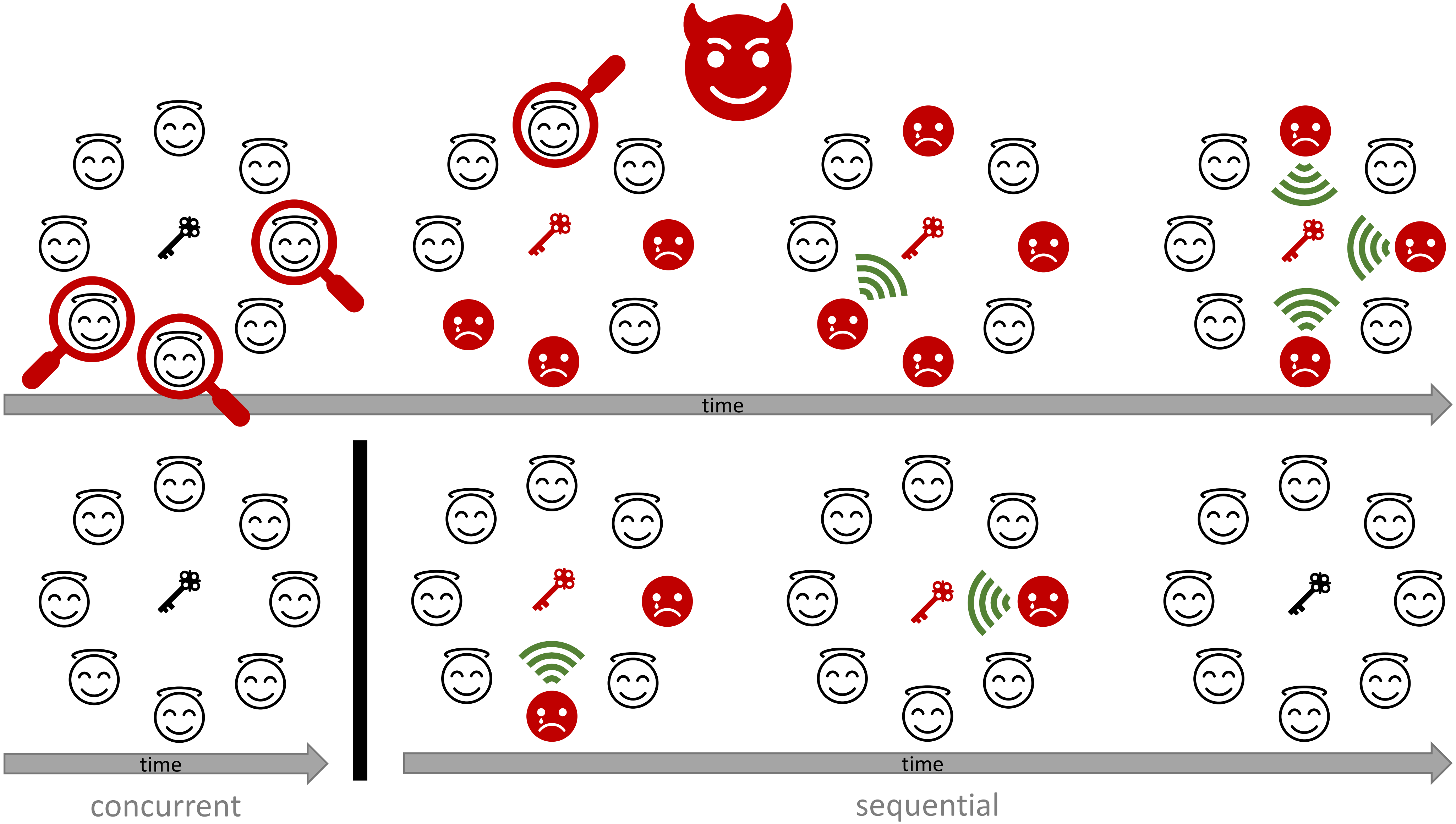



(Concurrent) Group Ratcheting



- Group computes joint key**s**
- 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

(Concurrent) Group Ratcheting



Target:

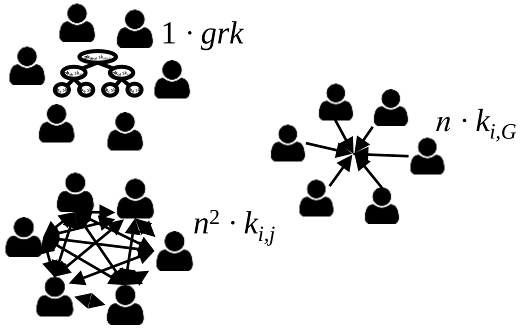
1. Post-Compromise Security
2. Small shares
3. Concurrency

Otherwise:

- Slow recovery from exposures
- Consensus required

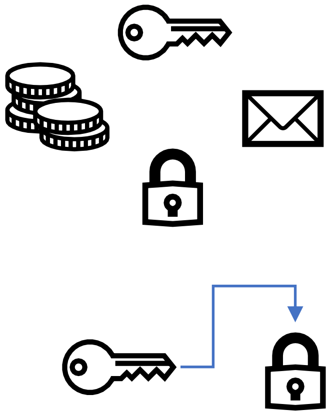
→ Inapplicable to decentralized networks

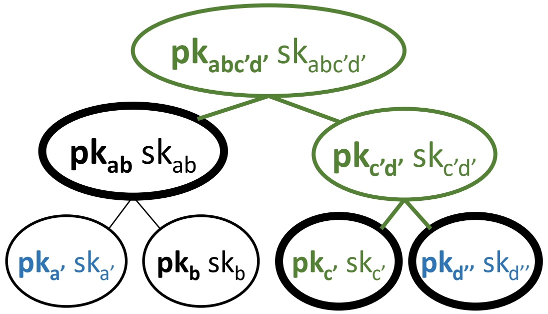
Agenda



Previous Work: What's the Problem?

Lower Bound: What's the minimal overhead?





Upper Bound: Almost optimal construction

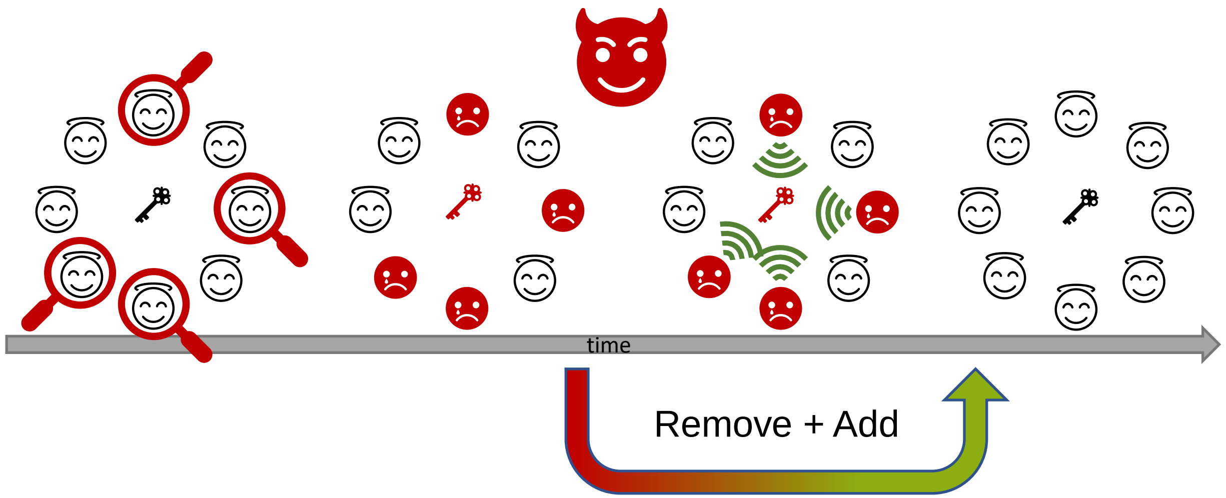
Open Questions …

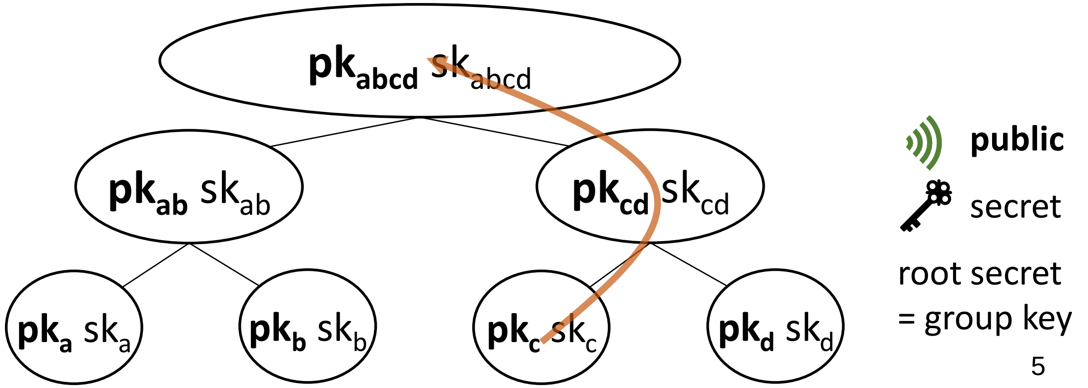
$\Omega(t)$ vs. $O(t\cdot(1+\log(n/t)))$?
Full asynchronicity
NIKE?
PCS-Delay?
Forward-secrecy?
Application to MLS

Previous Work: What's the Problem?

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

  - Many protocols from '80s – '00ers
  - Tree-based DGKE best suited for asynchronous settings





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RUHR
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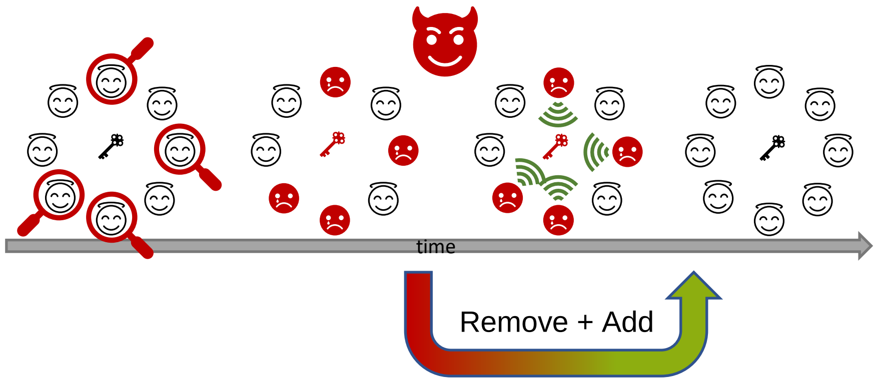
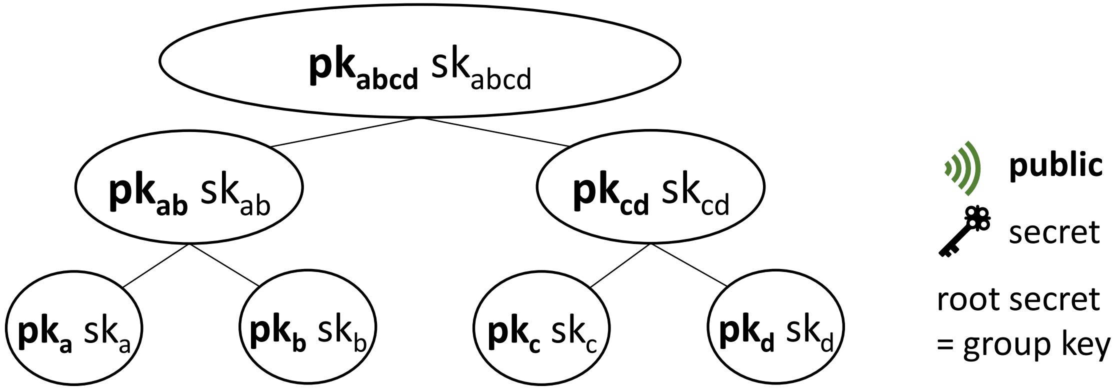
  - Merge R&A [CCGMM’18]
  - DH to KEM [BBR’18]





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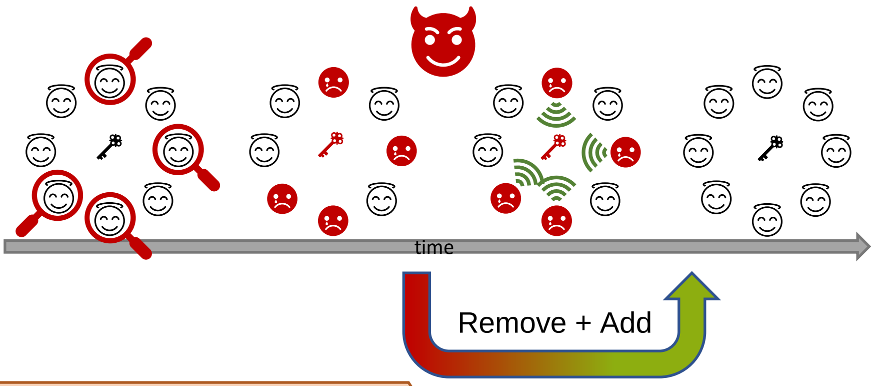

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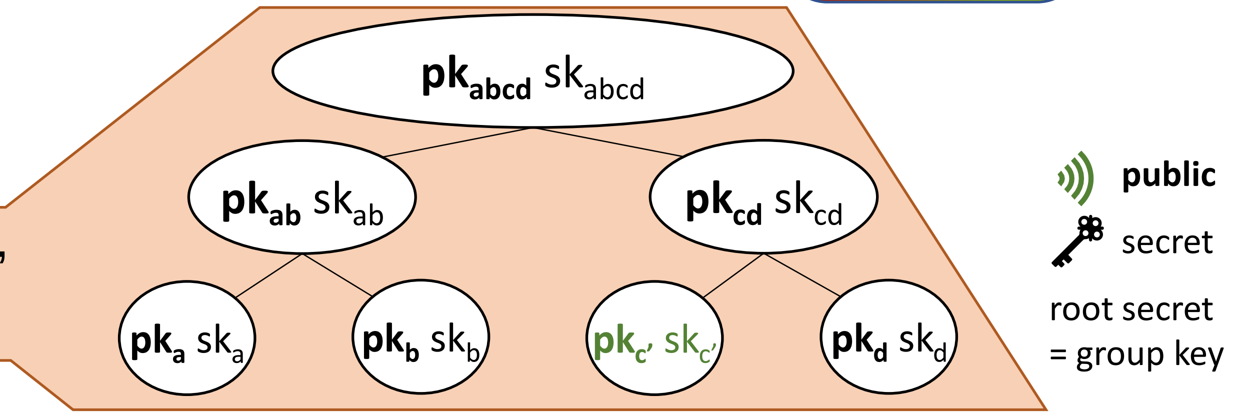

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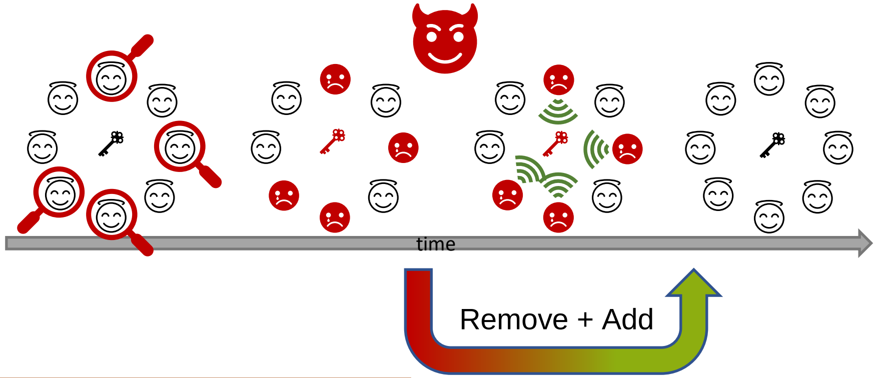

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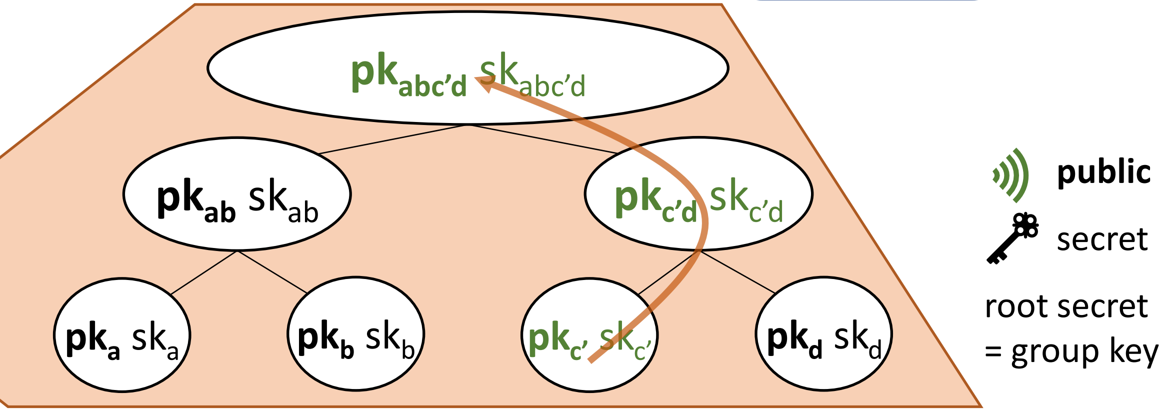

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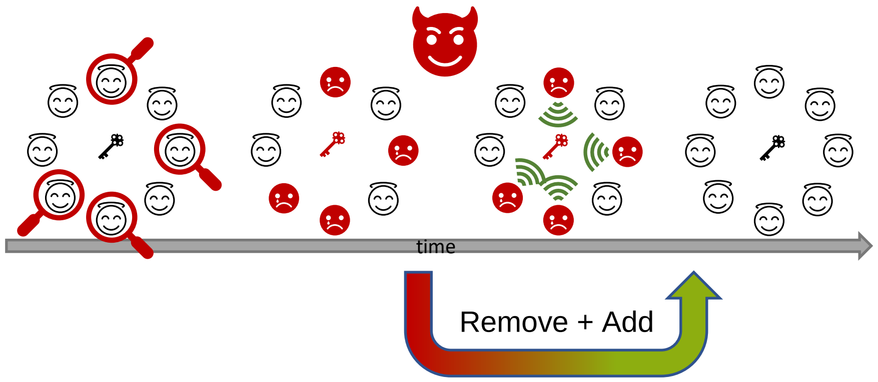

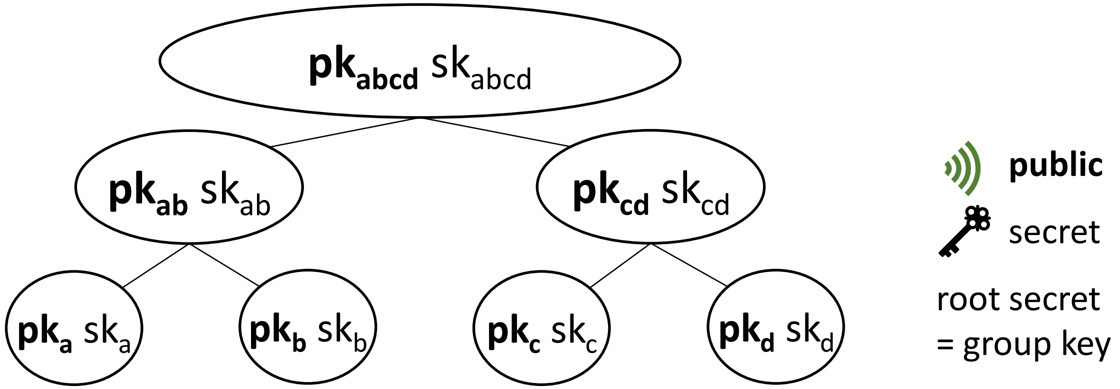

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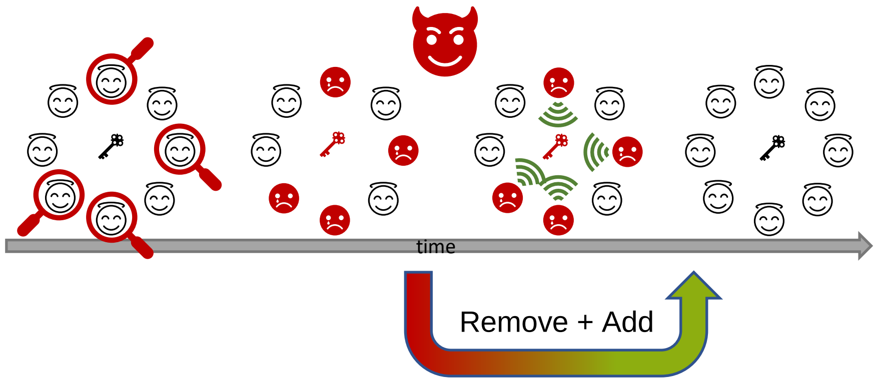
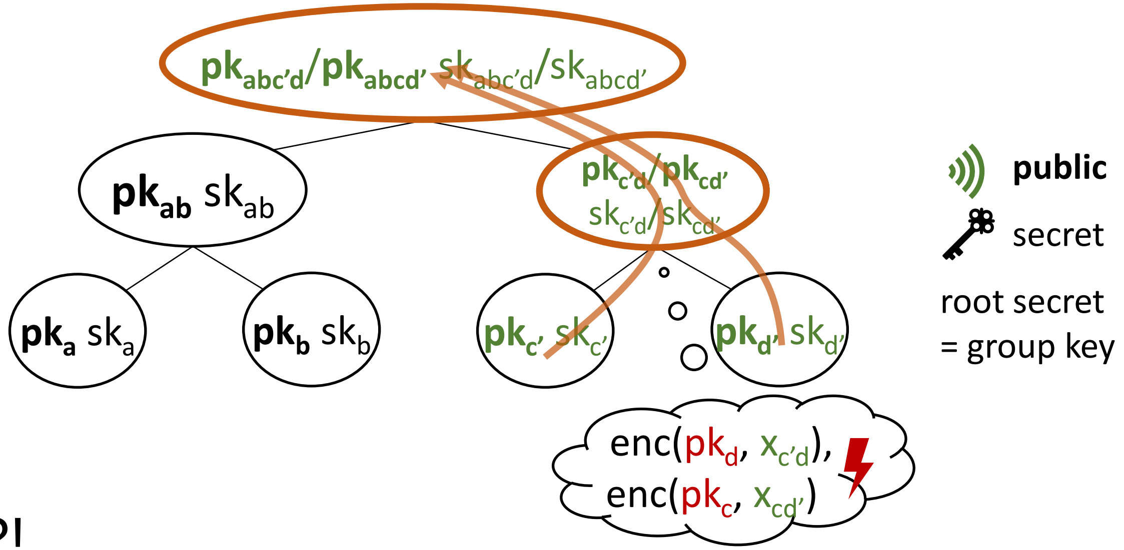
- No concurrency
  - Intersection of concurrently updated paths

  → Merging under PCS without multiparty-NIKE?!





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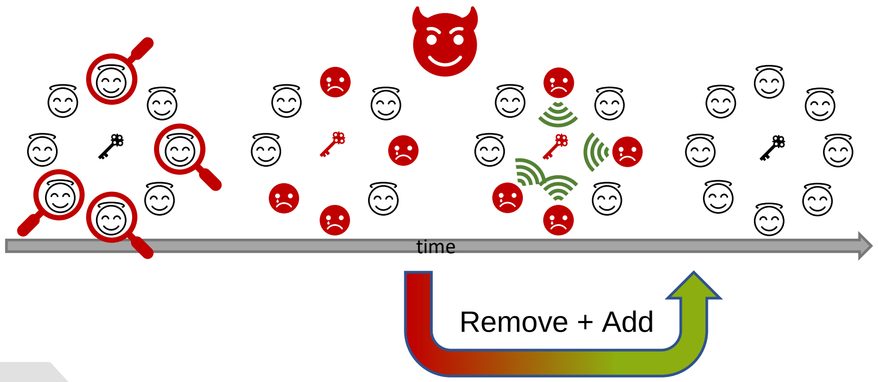

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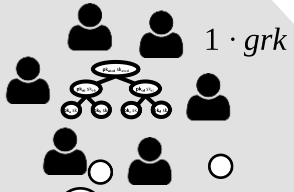

PCS	Overhead	Concurrency
✔	O(log n)	✗

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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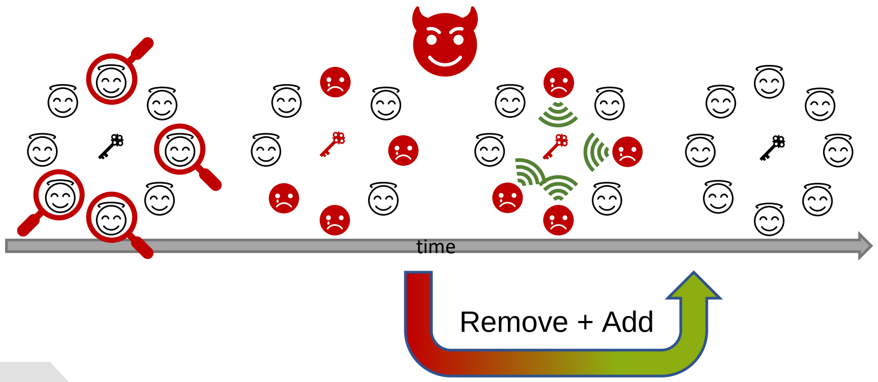

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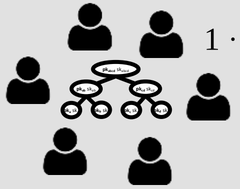
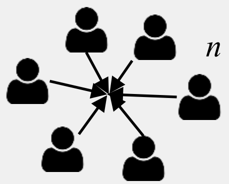
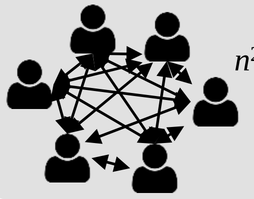
- Real-World
  - Forward-secure hash chain [WhatsApp]
  - Parallel pair-wise communication [Signal,WKHB'20]







PCS	Overhead	Concurrency
✔	O(log n)	✘
✘	O(1)	✔
✔	**O(n)**	✔

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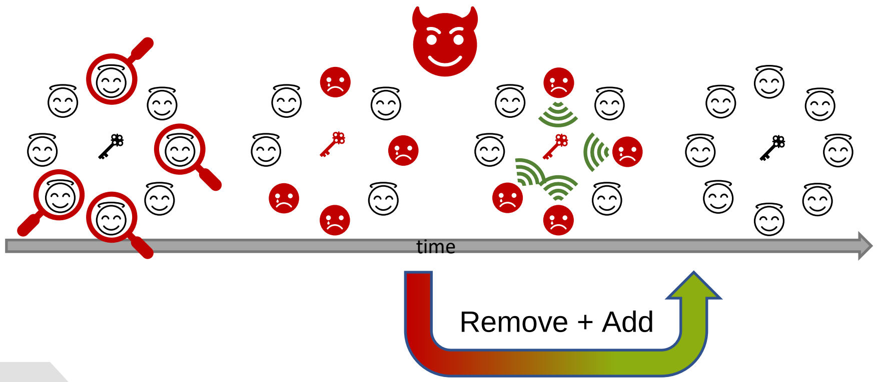

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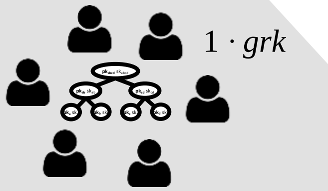

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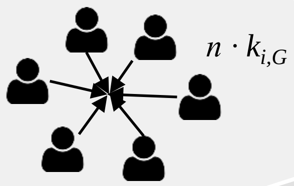
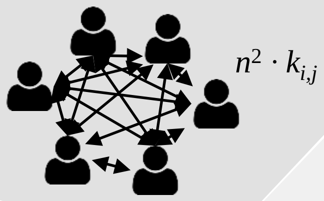


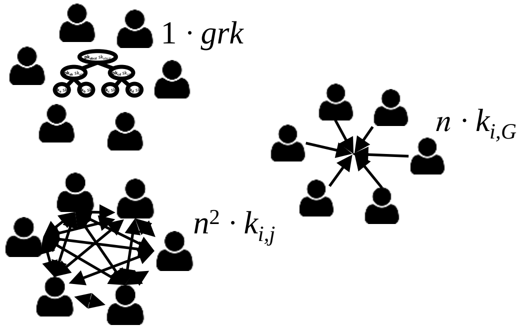
  - Parallel pair-wise communication [Signal,WKHB'20]



- We

PCS	Overhead	Concurrency
✓	O(log n)	✗
✗	O(1)	✓
✓	O(n)	✓
✓	?	✓

Agenda



PCS & ~~Concurrency~~ & Small overhead
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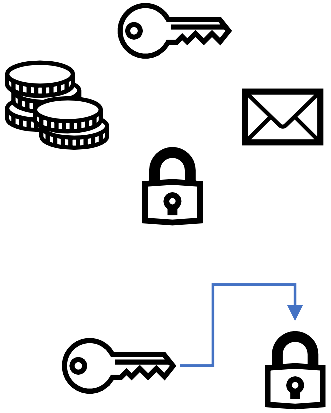
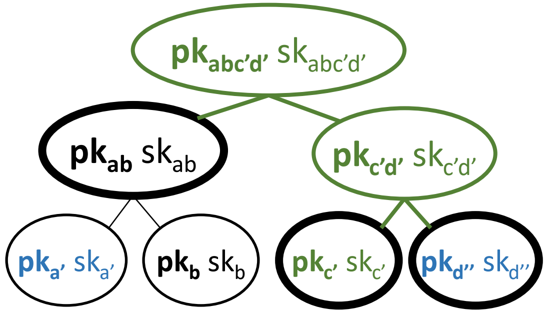
Previous Work: What's the Problem?

Lower Bound: What's the minimal overhead?





Upper Bound: Almost optimal construction

Open Questions …

Ω(t) vs. O(t·(1+log(n/t))?
Full asynchronicity
NIKE?
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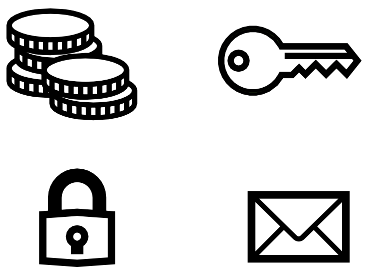
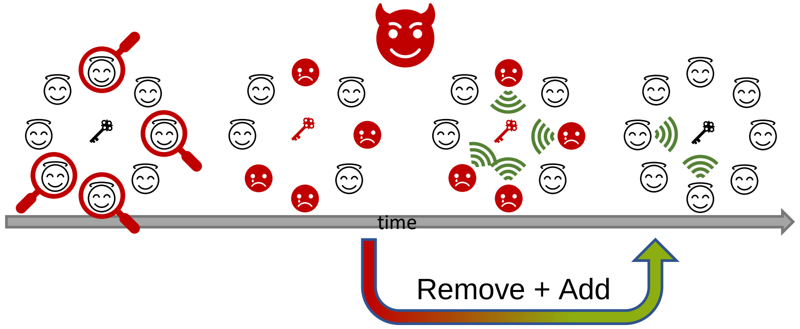
Application to MLS

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



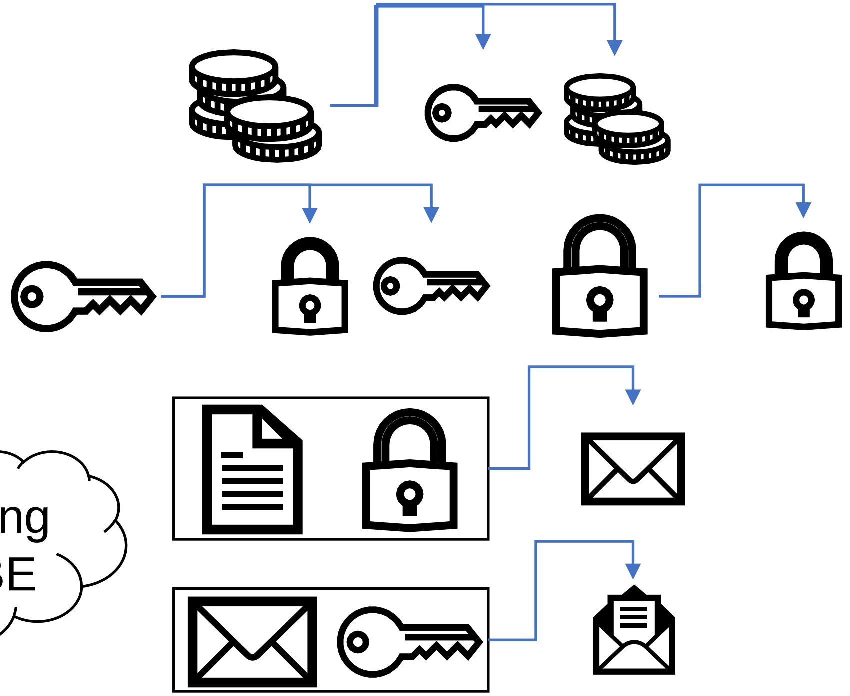


- Fixed set of allowed building blocks
  (for constructions with minimal overhead under PCS)

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

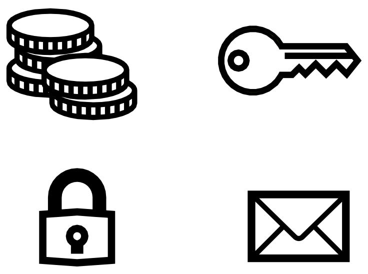
  → *More* than what previous constructions used

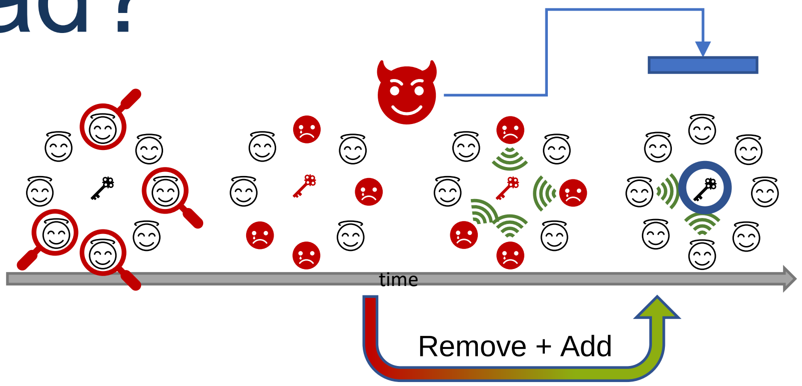
As strong as HIBE



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

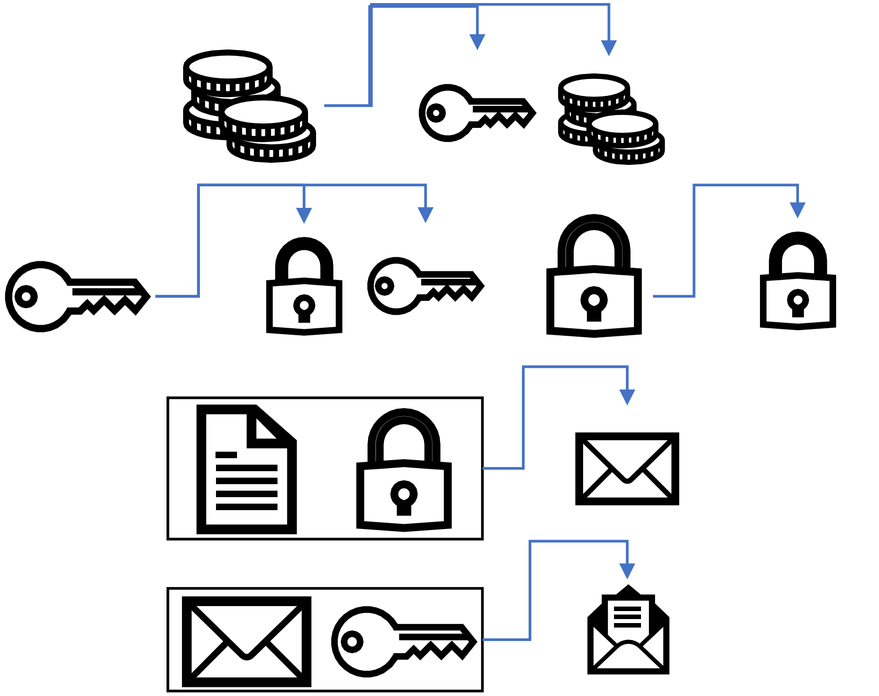
Lower Bound: What’s the minimal overhead?





Proof idea:

- Group ratcheting constructions…
  - Can only use our symbolic building blocks
  - Compute a *secure* group key when *required*
- Secure group keys…
  - Def: Cannot be obtained by symbolic adversaries
  - Are required after all exposed members sent and afterwards someone sent once more
- We prove:
  establishing secure group keys under t-*concurrency*
  ⇒ every sent message contains ≥ t-1 symbols



Lower Bound: What's the minimal overhead?

i-2 Exposure:
- No (shared) secrets

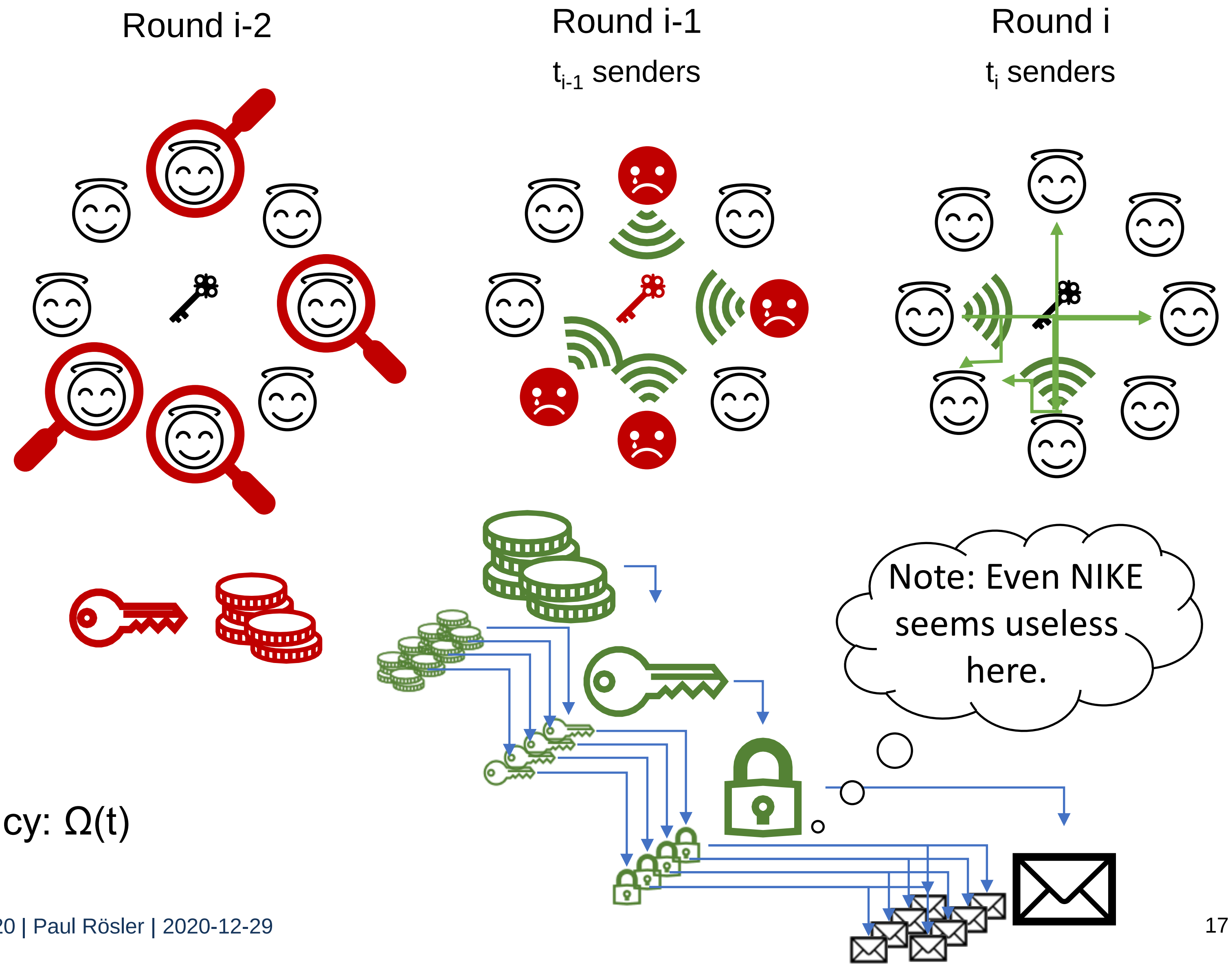
i-1 Recovery 1:
- Still no (shared) secrets
- Sampling of new secrets
- Sharing of derived values

→ Still no (shared) secrets
→ t_{i-1} distinct public values of new secrets

i Recovery 2:
- Respond to (all new) 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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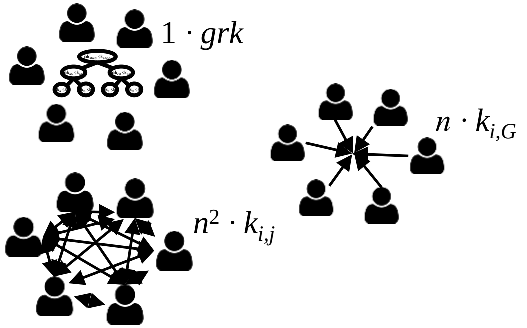

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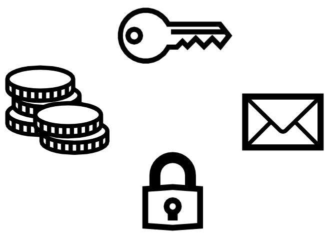
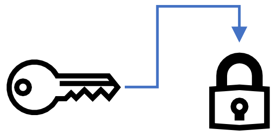
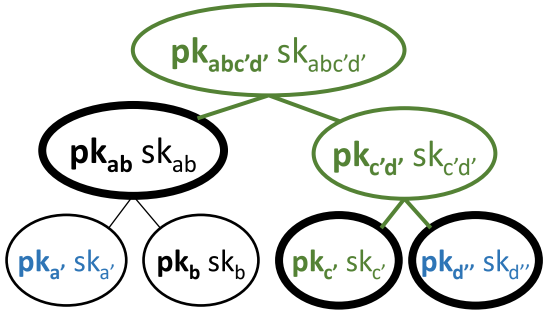




Realistic symbolic model:
No coordination + PCS
⇒ Ω(t)

→ Upper Bound: Almost optimal construction



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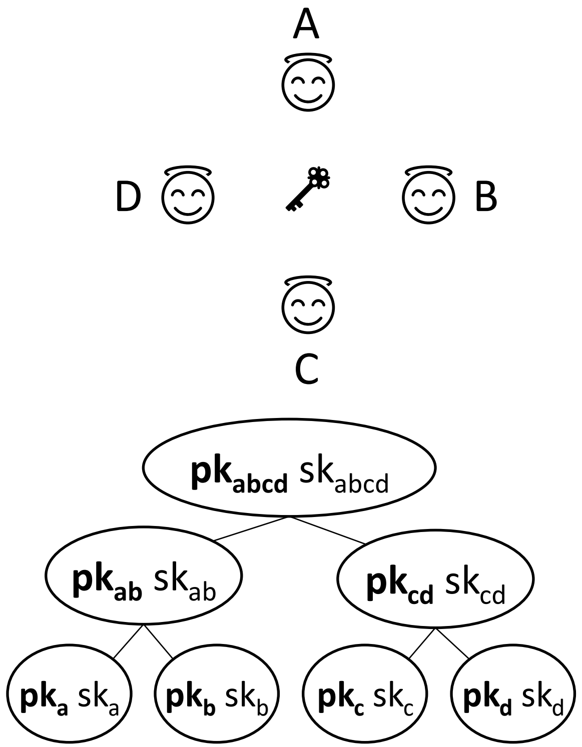
Key tree (with updatable KEM)

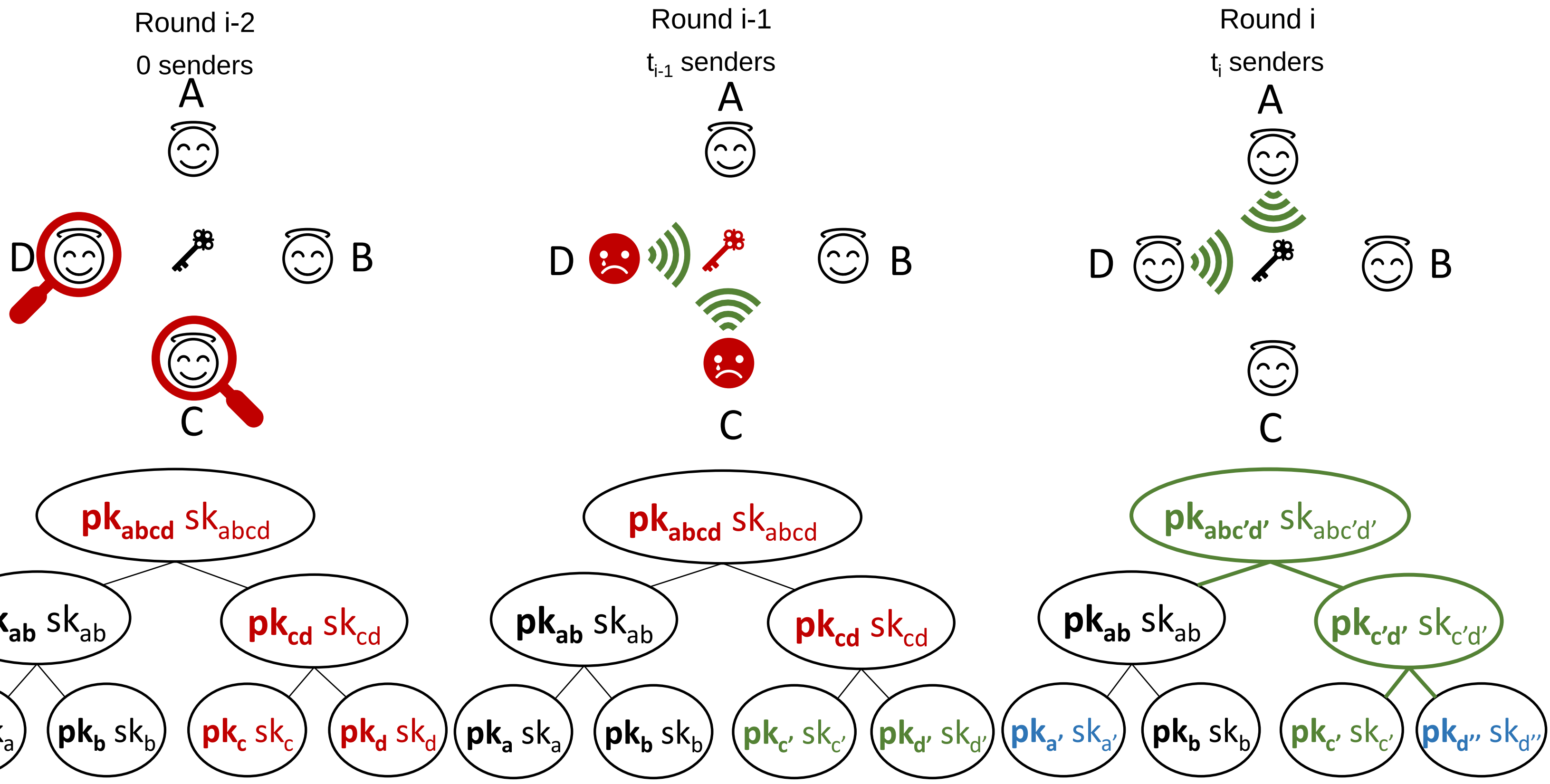


public

secret

root secret
= group key

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 for A and D

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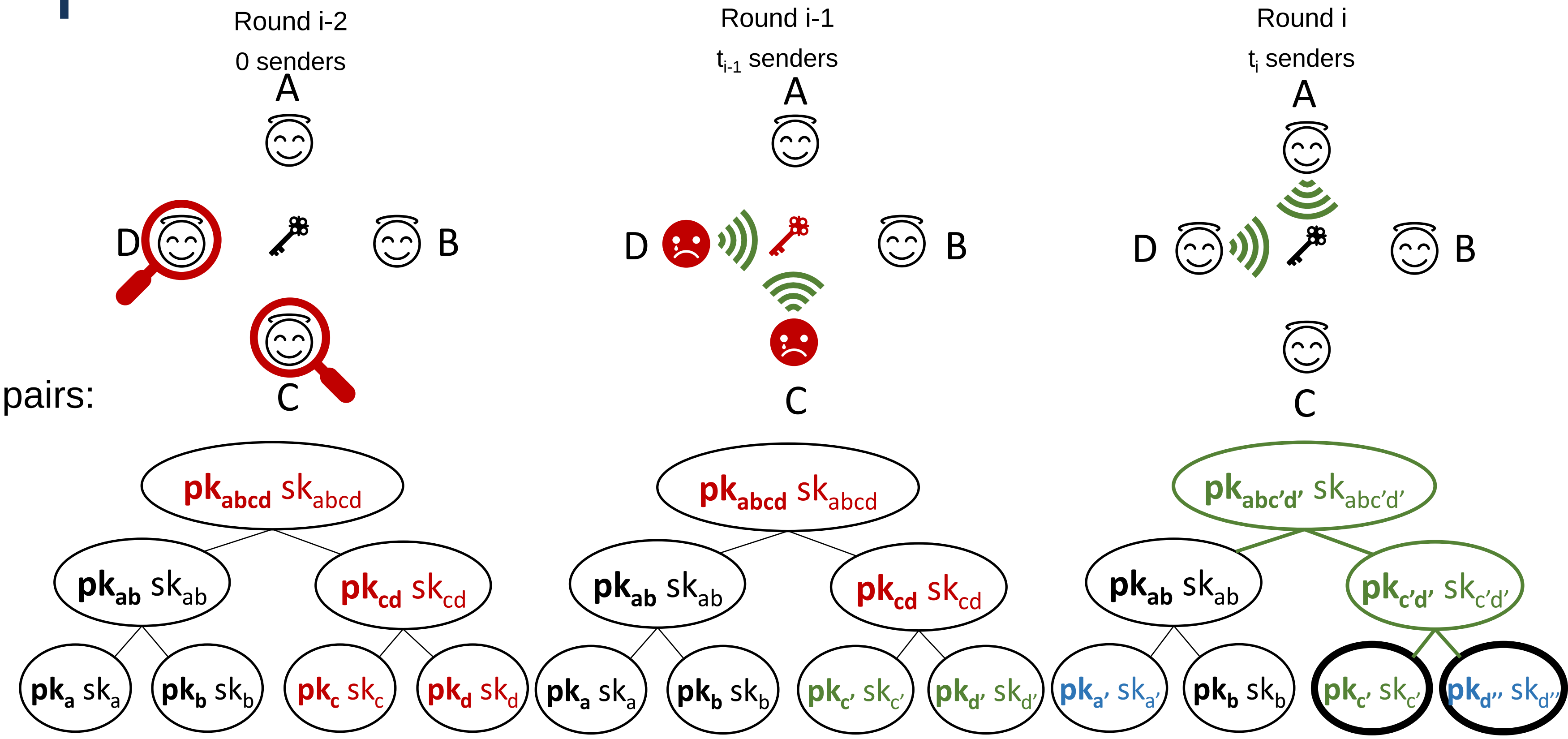
d) Send $enc(pk_{c'}, x_{c'd'})$, $enc(pk_{d'}, x_{c'd'})$

→ **Number of leafs: t_{i-1}**



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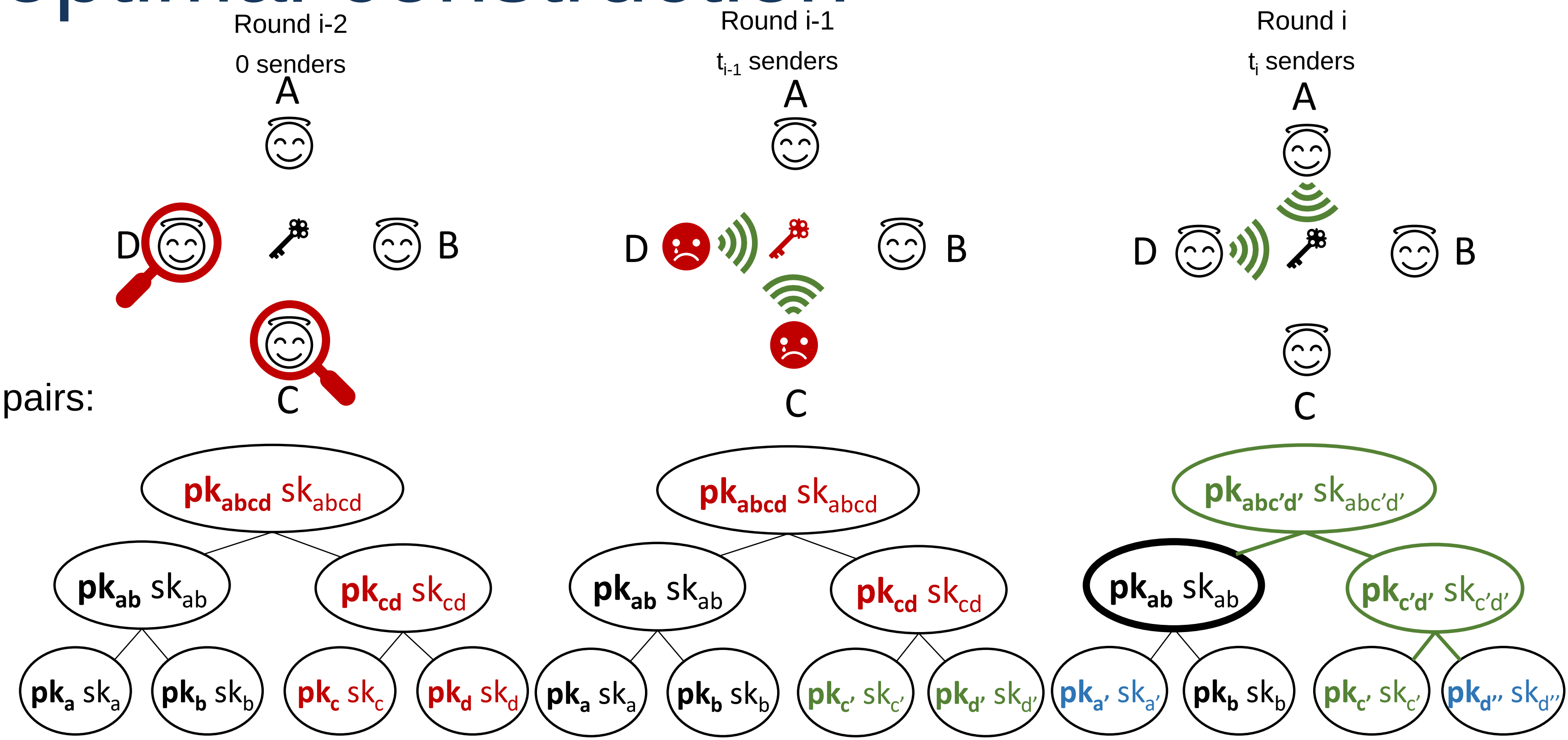

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b) Sample $x_{c'd'}$

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

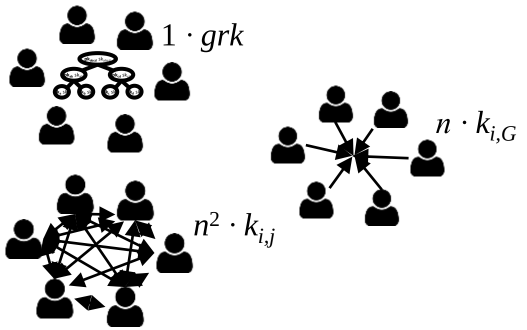
→ Number of leafs: t_{i-1}, **number of update-tree-siblings: $O(t_{i-1} \cdot \log(n/t_{i-1}))$**

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

1-"concurrency": → O(log n)

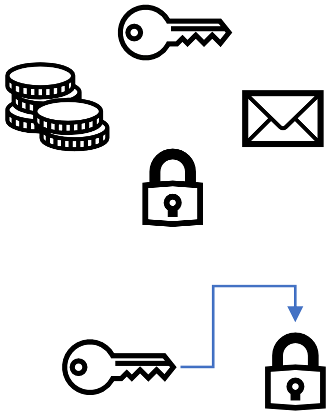
n-concurrency: → O(n)

Agenda

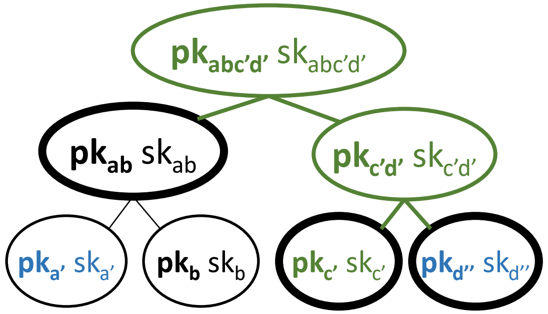


PCS & ~~Concurrency~~ & Small overhead
~~PCS~~ & Concurrency & Small overhead
PCS & Concurrency & ~~Small overhead~~

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))?
Full asynchronicity
NIKE?
PCS-Delay?
Forward-secrecy?
Application to MLS

@roeslpa Full details & formal proofs: ia.cr/2020/1171