

Range-Based Set Reconciliation

Aljoscha Meyer

Set Reconciliation

- set union over a network
- between (exactly) two machines
- unstructured data
- no shared state or history

Trivial Reconciliation



Sam Gwilym

Model and Analysis

- Alfie and Betty talk over a network
- reliable communication, rounds of unit length, unlimited bandwidth
- probabilistic solutions

Model and Analysis

- Alfie and Betty talk over a network
- reliable communication, rounds of unit length, unlimited bandwidth
- probabilistic solutions
- n : size of the union
- n_{\triangle} : size of the symmetric difference

Model and Analysis

- roundtrips
- communicated bytes
- computation time per reconciliation session
- computation space per reconciliation session
- computation time per item
- computation space per item

Peer-to-peer systems:

- iterating over local set infeasible
- loading local set into memory infeasible
- some peers are out to get us

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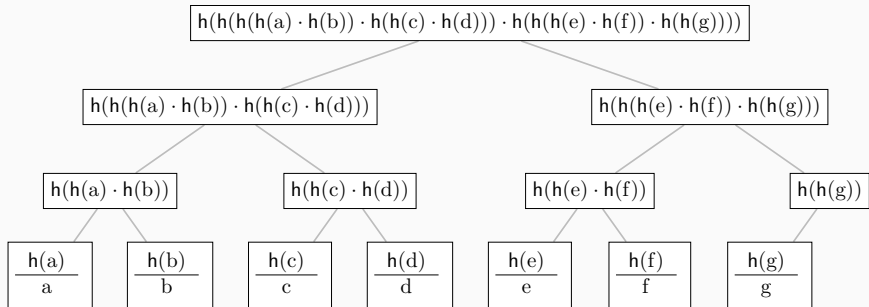
⇒ traditional approaches don't work

Reducing Computation Times

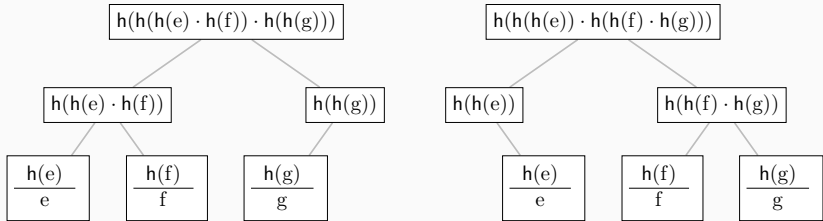
- Step 1: Put a Merkle tree on it
- Step 2: ???
- Step 3: Profit

Aurolat, Alex, and François Taïani. "Merkle search trees: Efficient state-based CRDTs in open networks." 2019 38th Symposium on Reliable Distributed Systems (SRDS). IEEE, 2019.

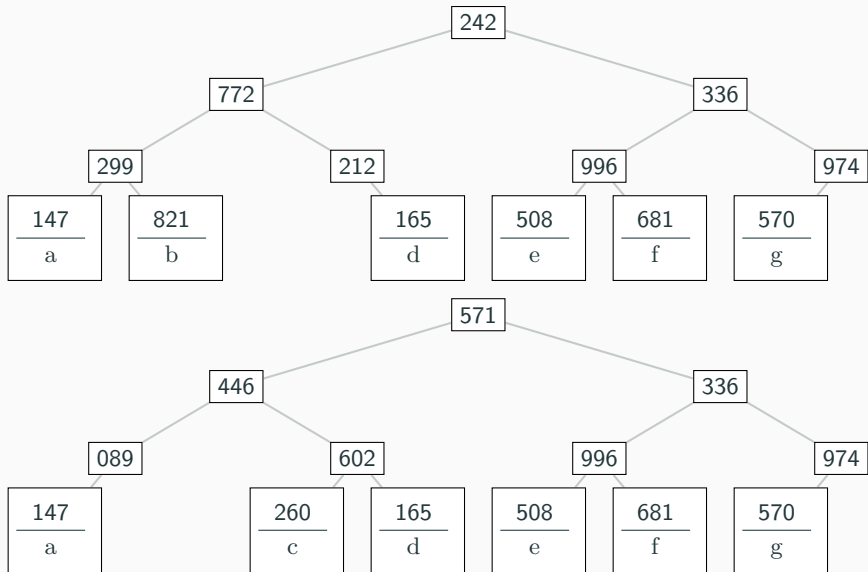
Merkle Trees



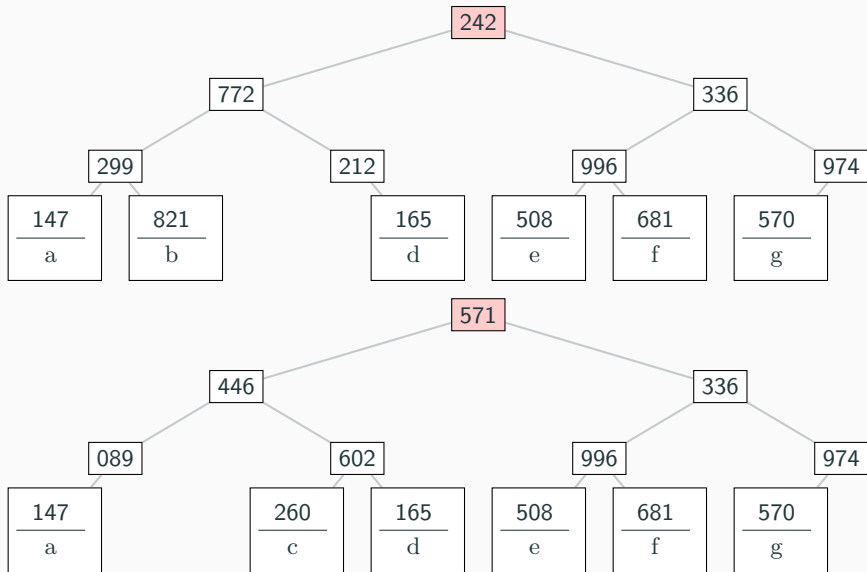
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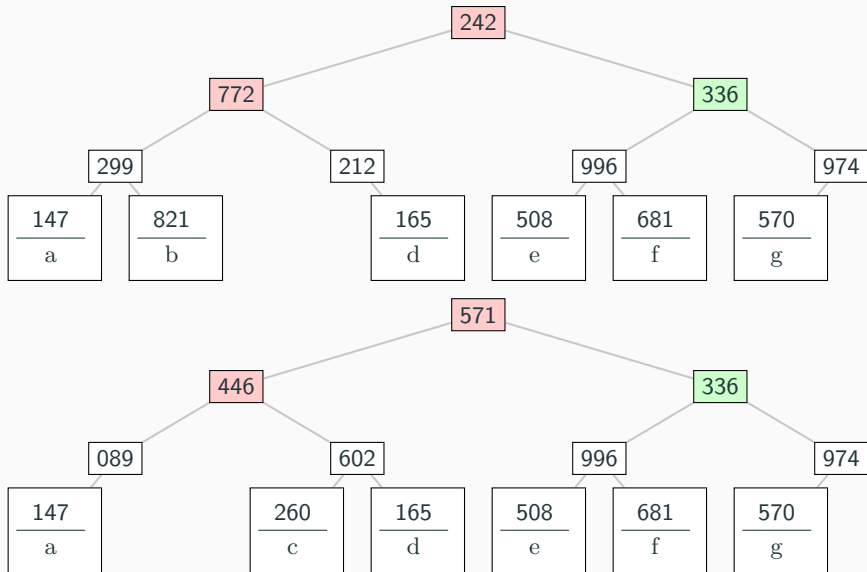
Merkle Tree Reconciliation



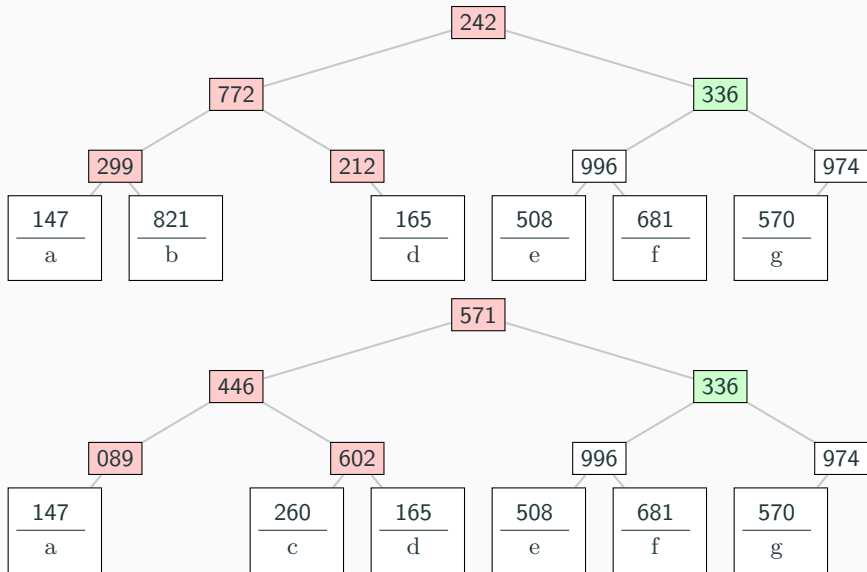
Merkle Tree Reconciliation



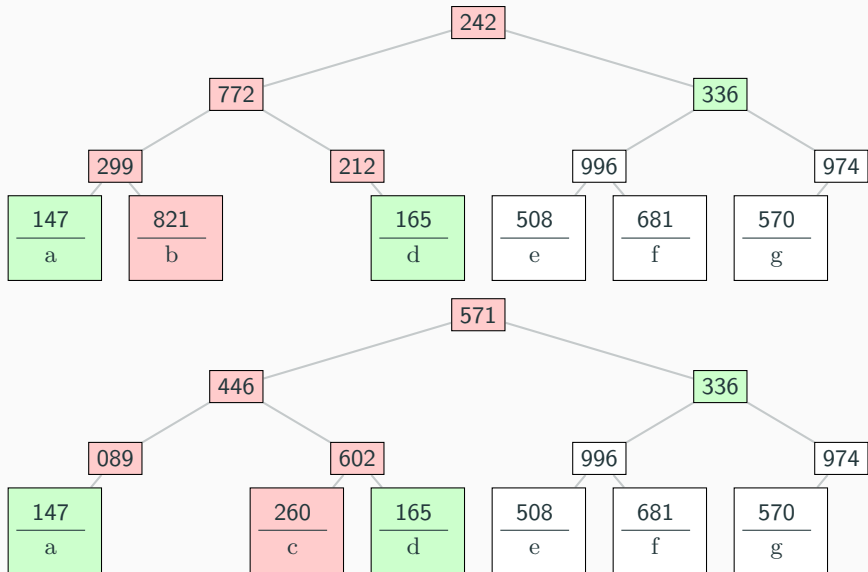
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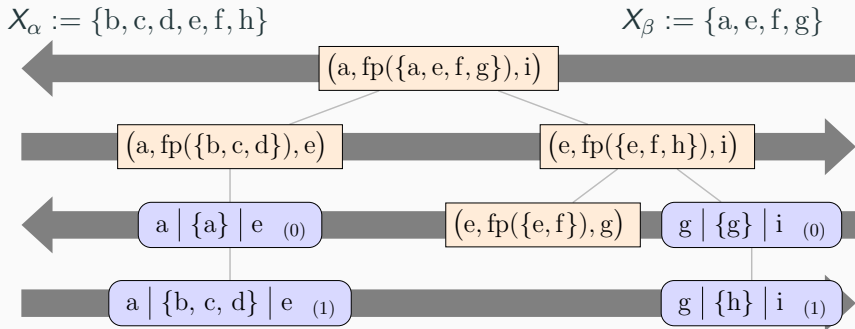
Merkle Tree Reconciliation



Merkle Tree Reconciliation

- inflexible data representation
- unacceptable worst-case complexity
 - remember, some peers are out to get us

Range-Based Set Reconciliation



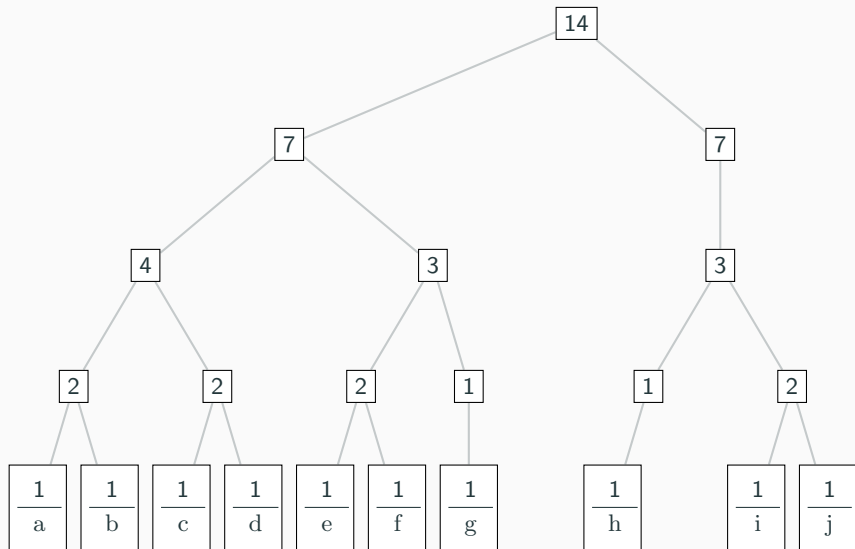
Some Nice Properties

- reasonably efficient: $\mathcal{O}(\min(n_{\Delta} \cdot \log(n), n))$ bytes communication, $\mathcal{O}(1)$ working memory
- can interpolate toward trivial
- arbitrary recursion anchor protocols
- arbitrary partition techniques

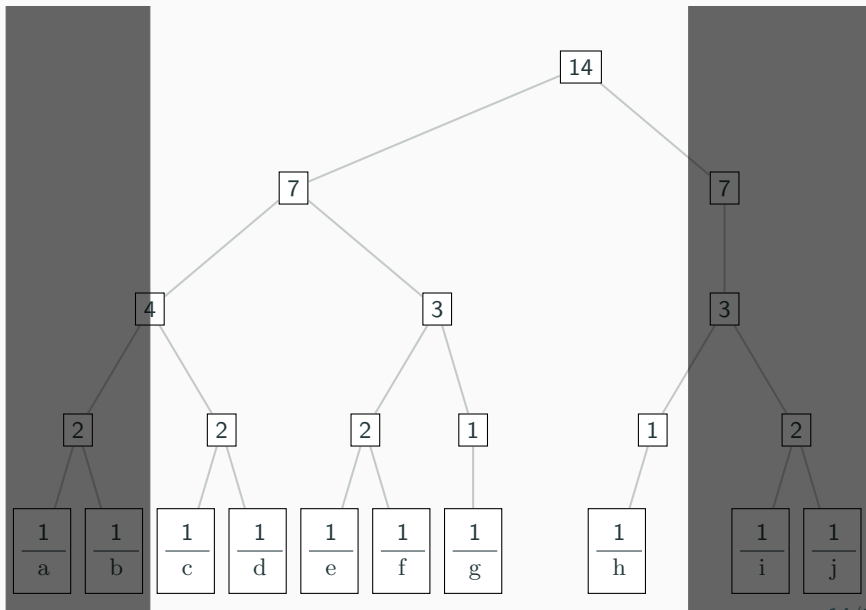
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- reasonably efficient: $\mathcal{O}(\min(n_{\Delta} \cdot \log(n), n))$ bytes communication, $\mathcal{O}(1)$ working memory
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- but: linear computation times

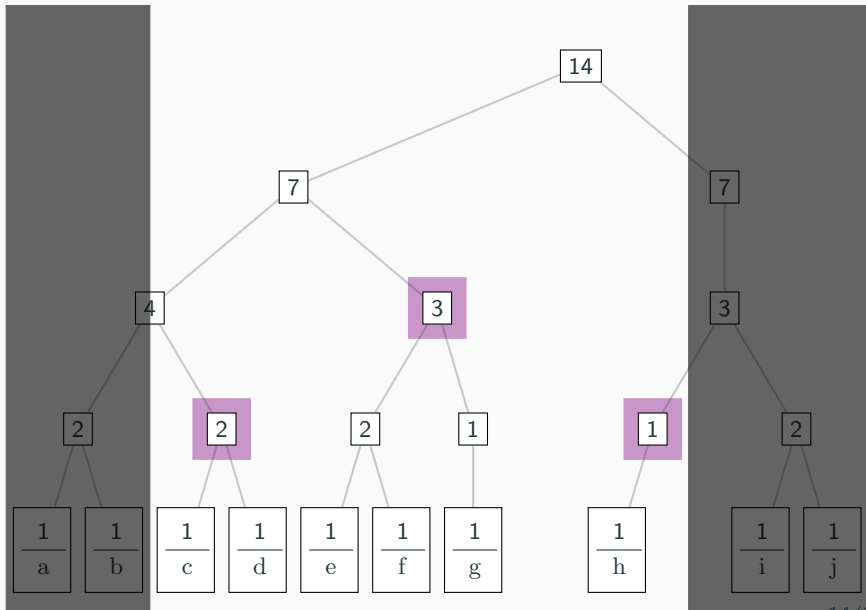
Order-Statistic Trees



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Monoid Trees

- set of labels: \mathbb{N}
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- set of labels: \mathbb{N}
- binary associative function: $+$
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- lifting into the monoid: $\lambda x.1$

- let's backtrack and solve the first problem - λ associativity
- example tree (using counts, then hashes)
- definition
- arbitrary ranges: collections of maximal subtrees, complexity analysis
- successive ranges yay
- this gives us worst-case bounds on roundtrips
- implementation independence
- more datastructure-neutral formulation: monoids
- paper actually uses different data structure, also B-trees, skip lists, radix trees, no data structure, ... and all interoperable
- malicious adversaries: active vs passive
- even passive finds collisions in relatively small sets

- but: collision must actually affect a session - λ brittle, and randomization ftw
- But what if there are many collisions? - λ collision-resistant hash functions
- must always lift into the monoid with a secure hash function. Interesting part is the selection of the monoid
- bellare: xor, addition, multiplication, vectorized addition (lattices)
- multiset homomorphic hashing adds rsa and elliptic curves
- we are weaker: homomorphism-flavored characterization
- in particular, no need for commutativity (because we use search trees) - λ matrix multiplication - λ cayley hashes
- Don't know anything else, but cayley still has unnecessary structure, as we do not need inverses

- conclusion: first non-trivial reconciliation algorithm to work in resource-constrained settings and adversarial environments
- also: comparatively simple - had multiple open source developers reach out to me