DeltaNI: An Efficient Labeling Scheme for Versioned Hierarchical Data

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Motivation

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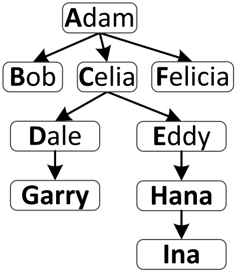

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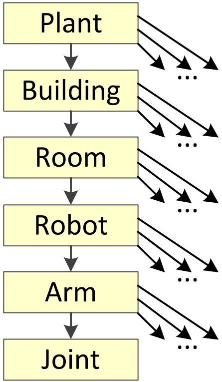

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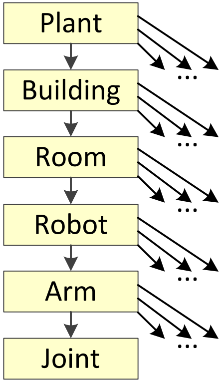

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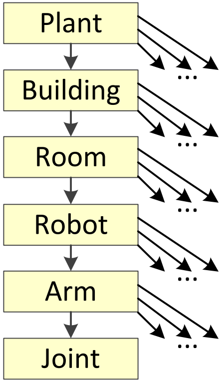
- Challenge: Versioning required for accountability



Hierarchical Data

- Hierarchical Relationship over tuples of a table

Name	Boss	Salary	...
Adam	NULL	80,000	...
Bob	Adam	55,000	...
Celia	Adam	70,000	...
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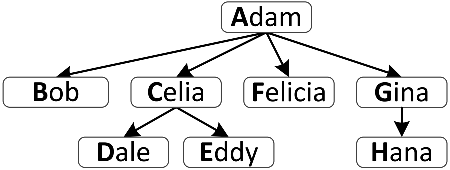

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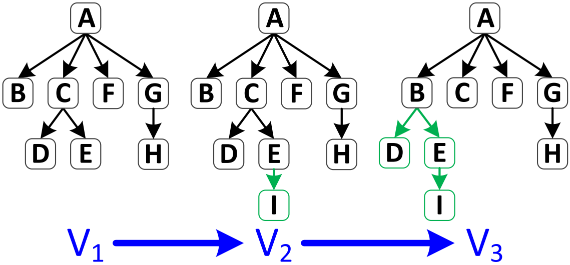
- Scope: Index the hierarchy structure

- Multiple versions of a hierarchy (1000+)
  - Updates at latest version create new version
  - Versioning of the table out of scope
  - Possibly branching history



- Versioned Queries

`SELECT name, salary FROM /Employee[name=‘‘Celia’’]//* IN` V_2

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Goal: An efficient index for versioned hierarchies to speed up ERP systems (and other hierarchical databases).

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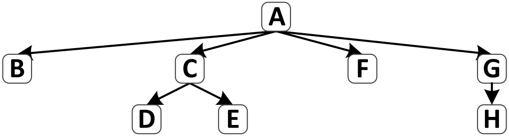

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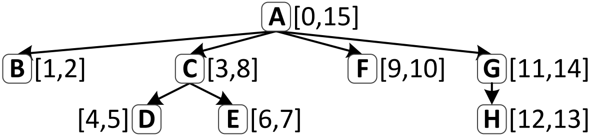

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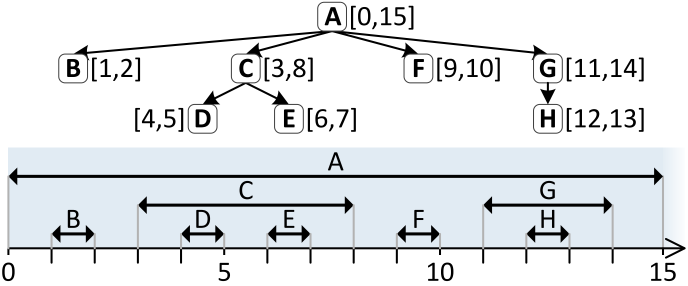

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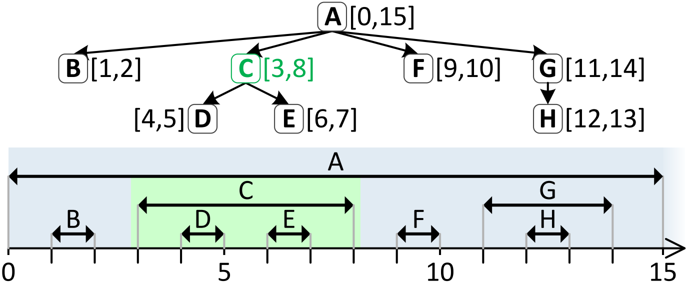

`/Employee[name=‘‘Celia’’]//*` ⇒ “All nodes in [3,8]”

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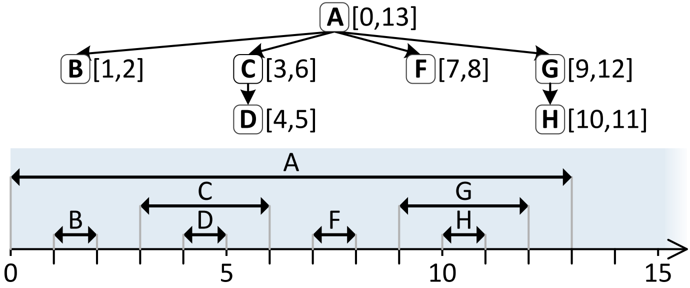

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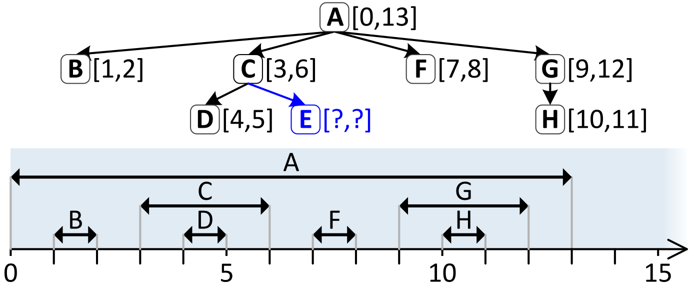

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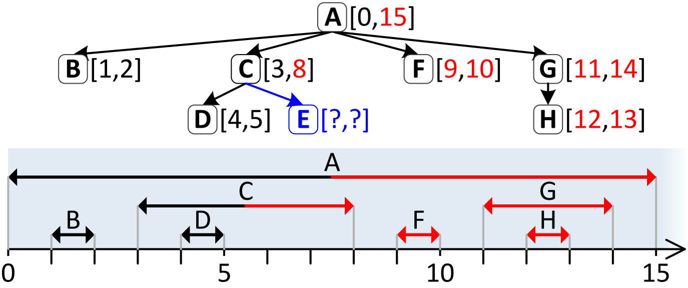

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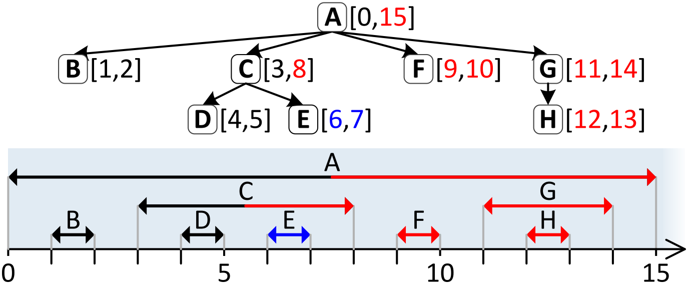

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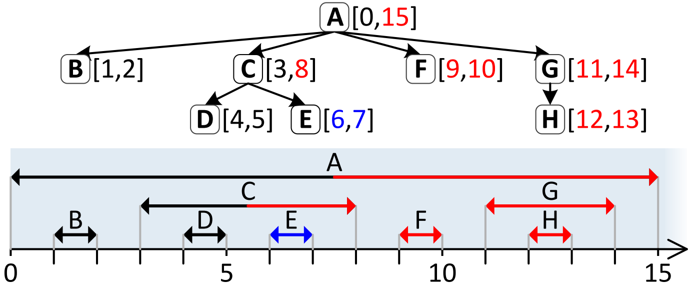

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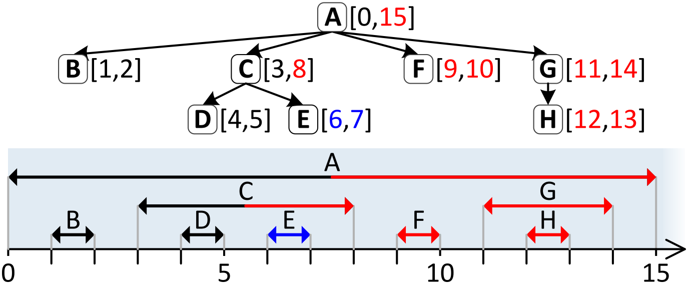
  - $\mathcal{O}(n)$ bounds change per update need to be stored ☹



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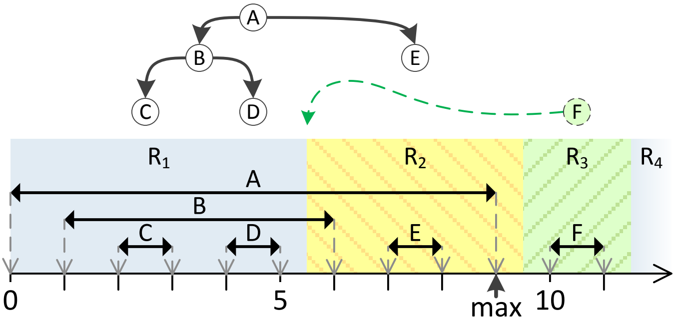

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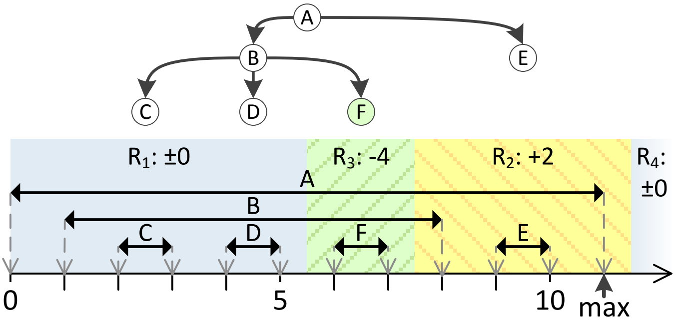

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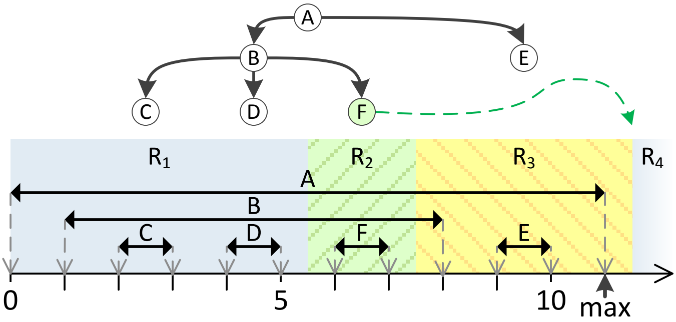

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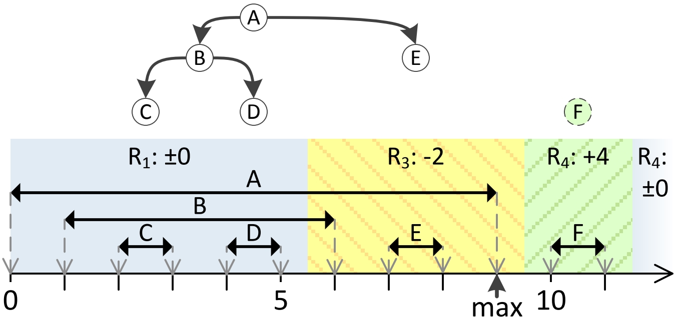

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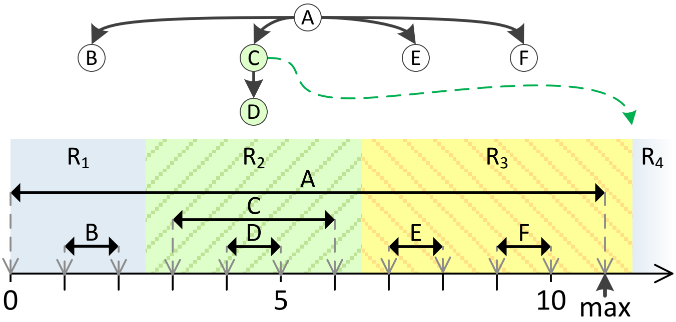

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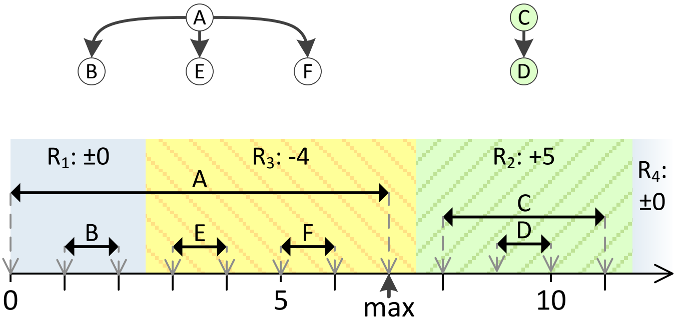

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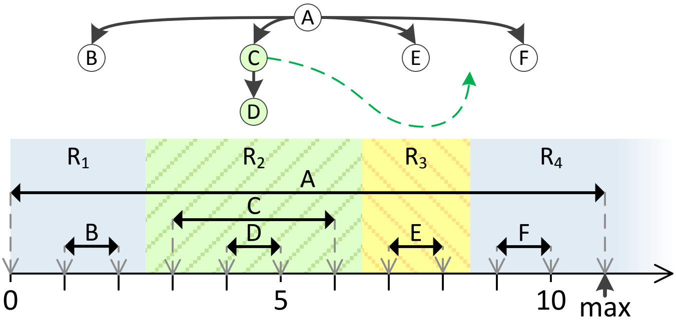

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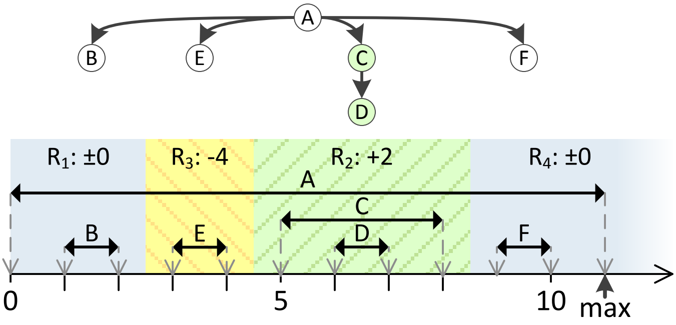

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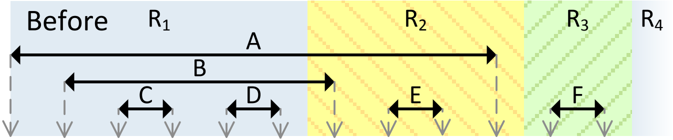

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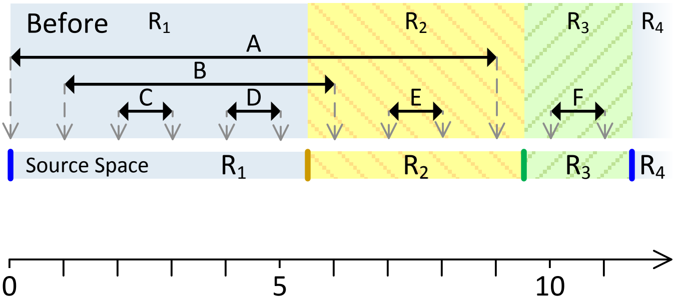

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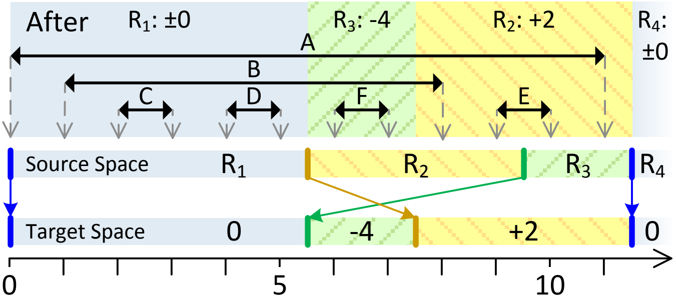
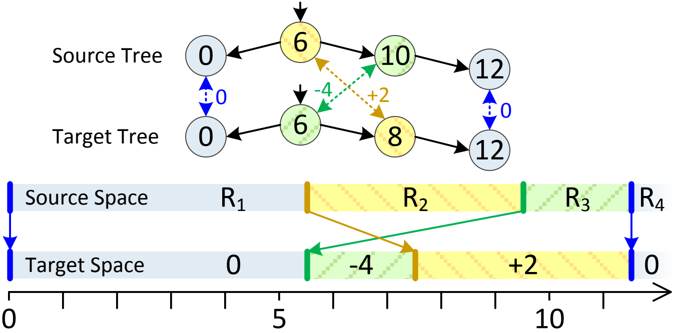


- Representation: Two balanced (binary) search trees (*"double tree"*)
- Node content: Lower border and link to other tree



NI Deltas

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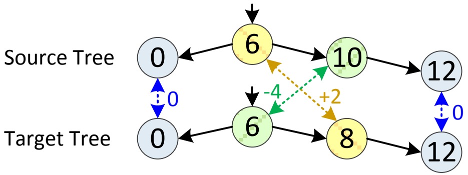

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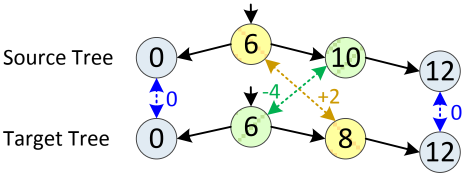

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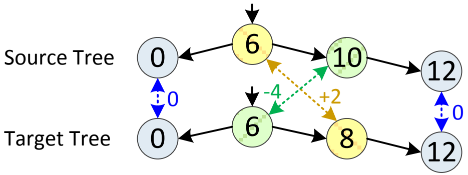

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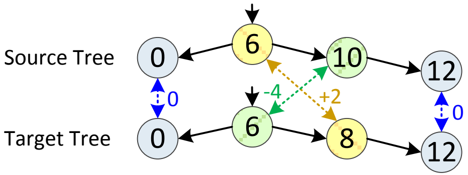
- Given an NI encoding in version V_i and a delta $\delta_{V_i \rightarrow V_j}$ from version V_i to another version V_j, we can answer queries in V_j



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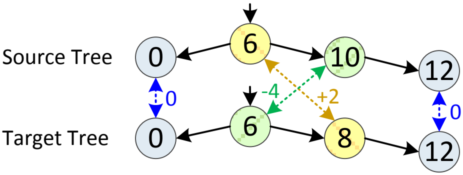

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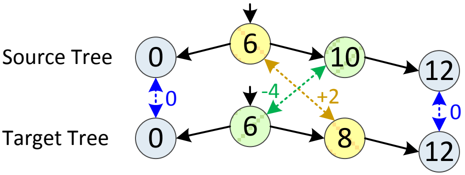

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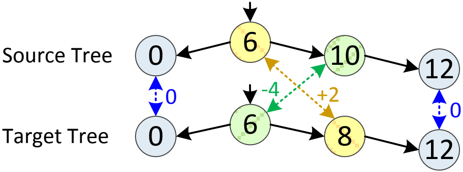

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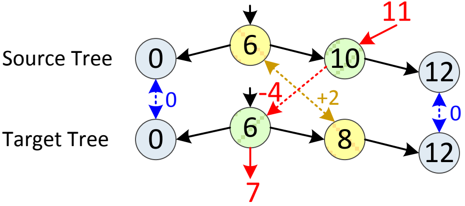

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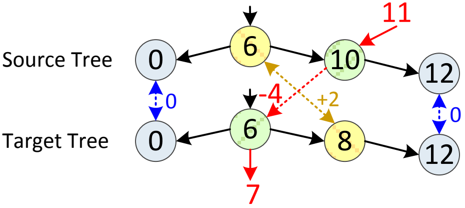

- Computation of $\delta^{-1}(b)$ similar

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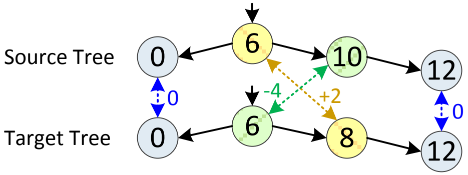

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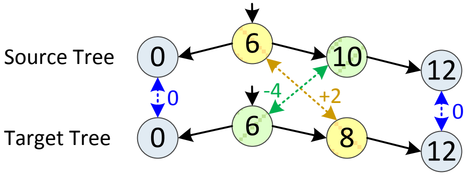

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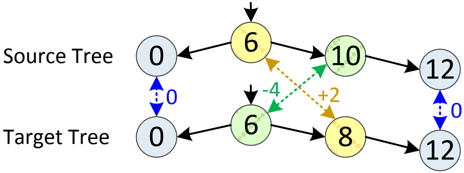

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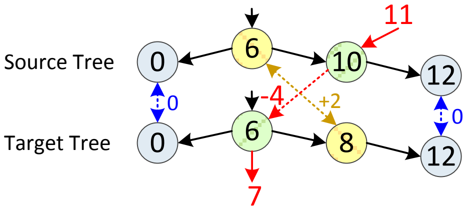
  - Calculating $\delta(b)$ (search tree lookup) is in $\mathcal{O}(\log c)$ ✓



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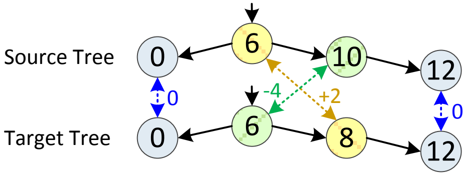

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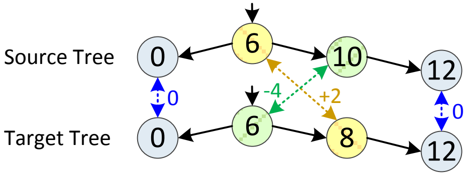

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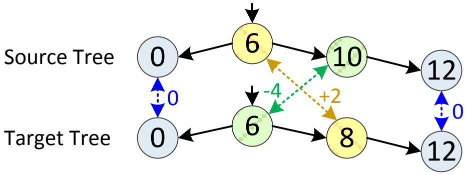
  - Storing only range borders: $\mathcal{O}(c)$ space ☺

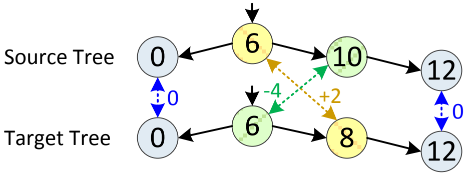


n = number of nodes, c = number of changes in delta

Double tree feasible?

Does the double tree delta solve the problems?

- Challenge 1: Efficient Query Support ✓
- Challenge 2: Space Consumption ✓
- Challenge 3: Efficient Update Support



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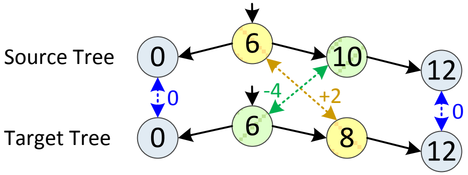

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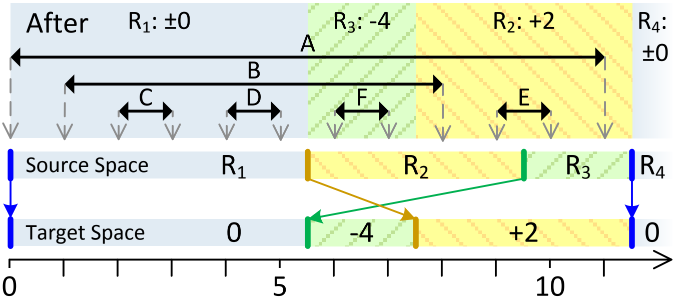
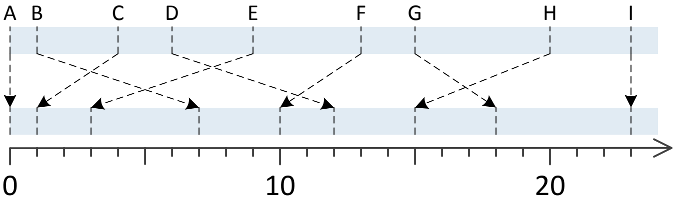


Updating Deltas

- Until now, we only considered deltas with one change
- How to build deltas with more changes?



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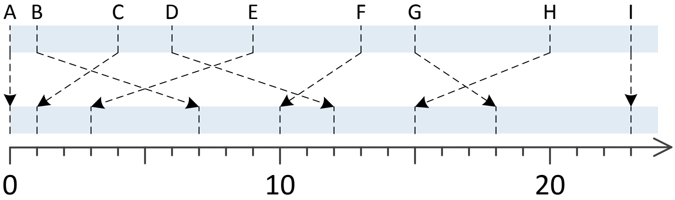
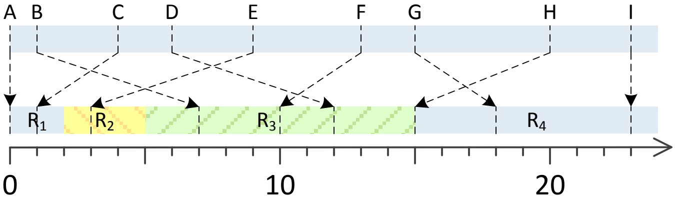
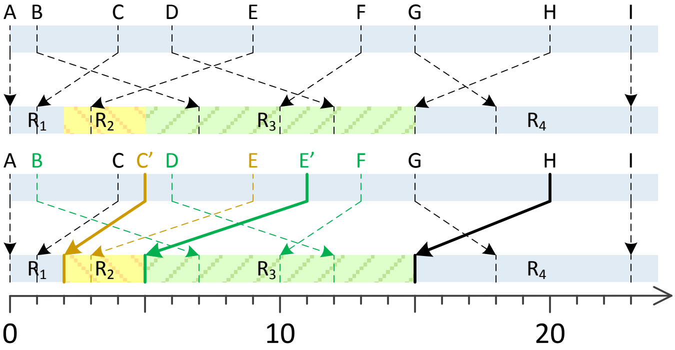


- Task: Swap range R_2 with R_3



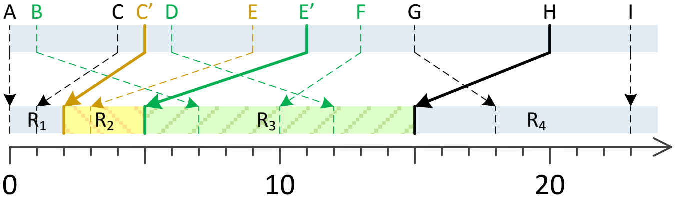
Updating Deltas

- Step 1: Insert range borders

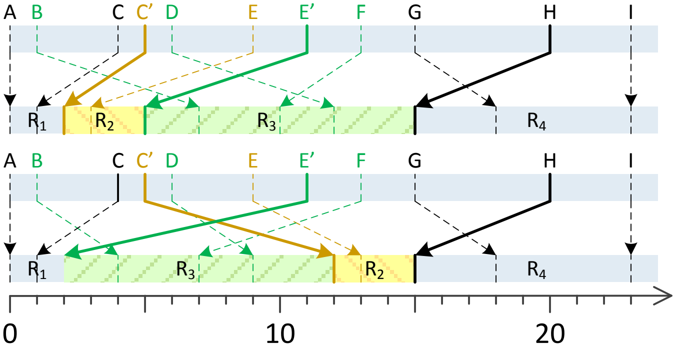


- Search tree insert: $\mathcal{O}(\log c)$ ✓

Updating Deltas



- Step 2: Swap borders in R_2 and R_3



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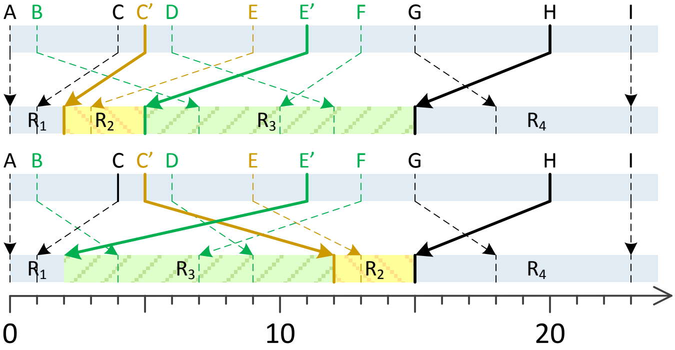
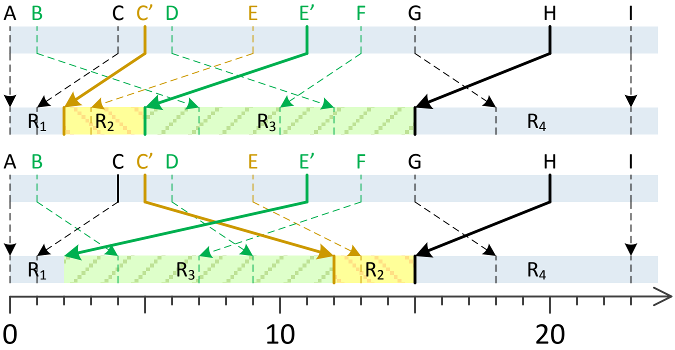


- Naive: Delete and reinsert all changed borders: $\mathcal{O}(c \log c)$ ☹
- $\Rightarrow$ Better approach required

- Observation: Only target space changes



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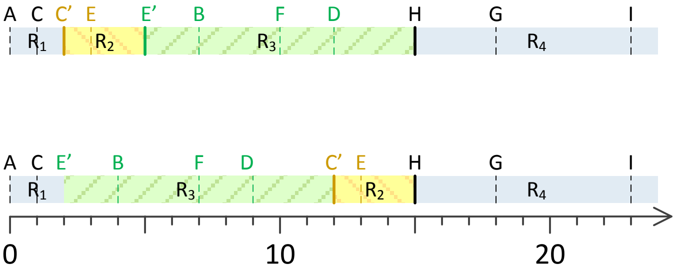
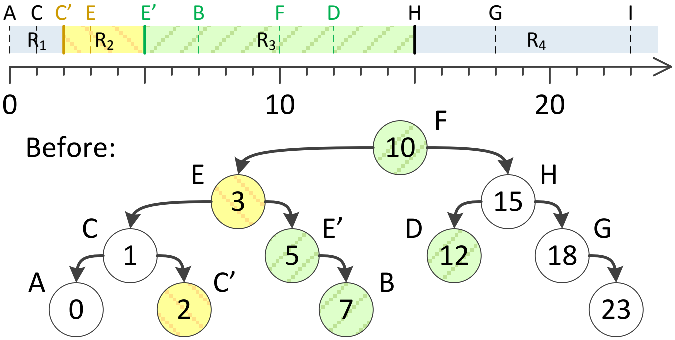


Efficient Border Swap

- Observation: Only target space changes
- Steps: Adjust keys $\mathcal{O}(c)$ keys, swap $\mathcal{O}(c)$ nodes



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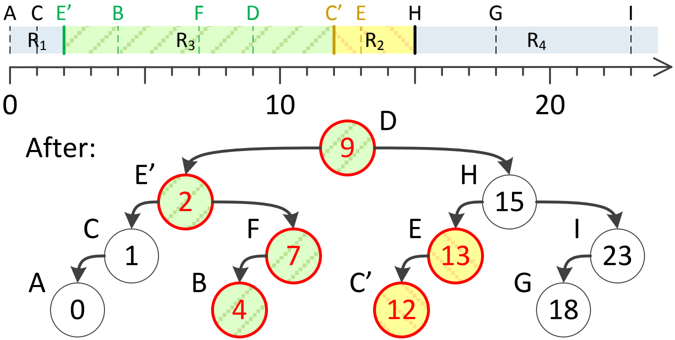
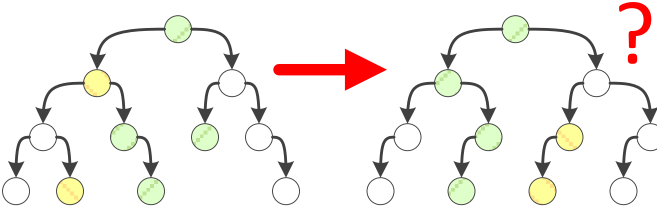
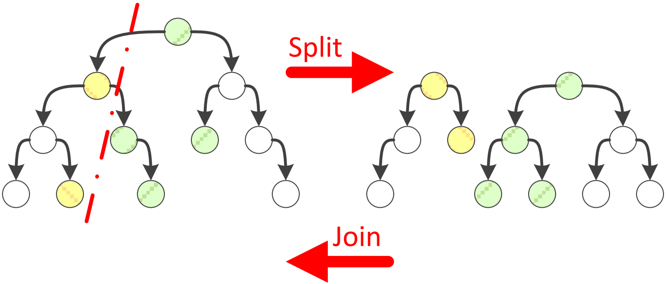


Efficient Node Rearrangement

- How to swap $\mathcal{O}(c)$ nodes in a search tree in $\mathcal{O}(\log c)$?



- How to swap $\mathcal{O}(c)$ nodes in a search tree in $\mathcal{O}(\log c)$?
- Solution: Split and join



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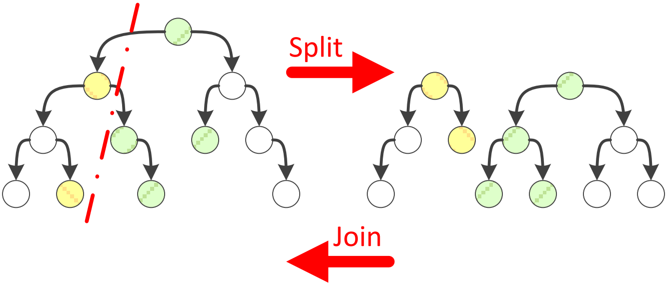

- Split: Split a tree into two new balanced trees

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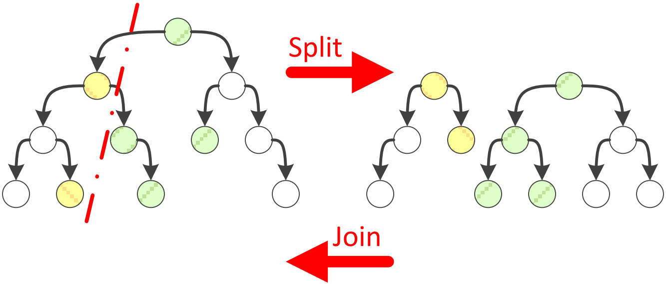

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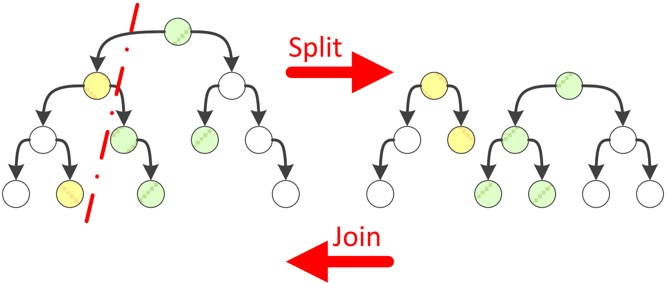

- Split: Split a tree into two new balanced trees
- Join: Concatenate two trees to one balanced one
- Both operations run in $\mathcal{O}(\log c)$ ✓

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- Split and join can rearrange nodes efficiently
- But: Keys are not updated $\Rightarrow$ search tree condition violated!
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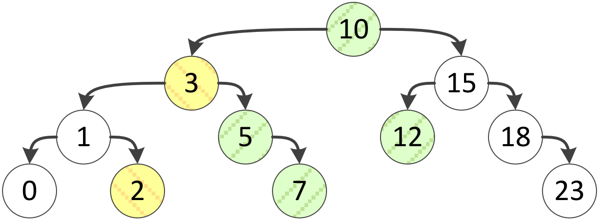

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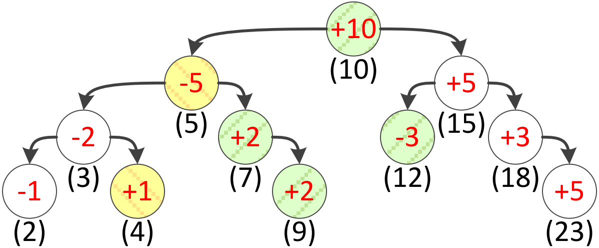

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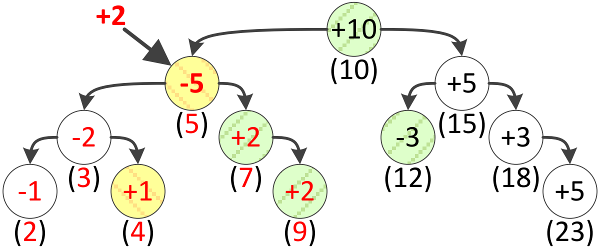
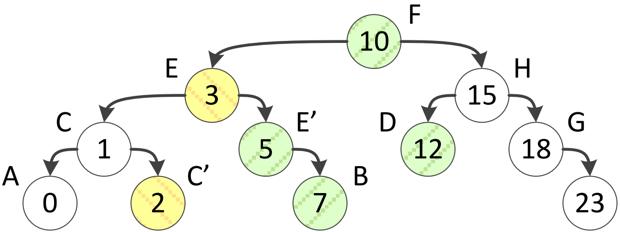


- Changing all keys in a subtree: $\mathcal{O}(1)$

- Using split/join and the accumulation tree, updating in $\mathcal{O}(\log c)$ is possible
- Target tree before update:



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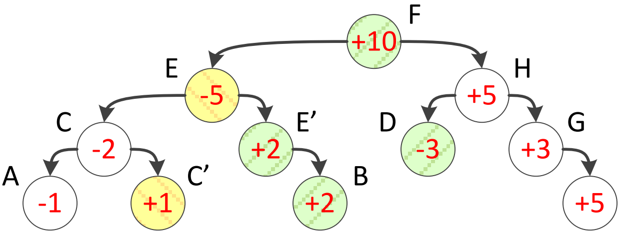
- Target tree with accumulation before update:



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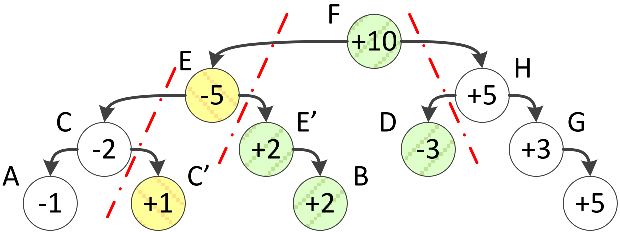

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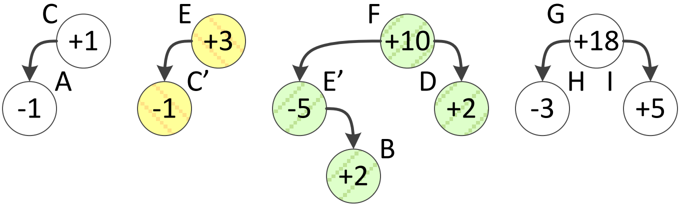

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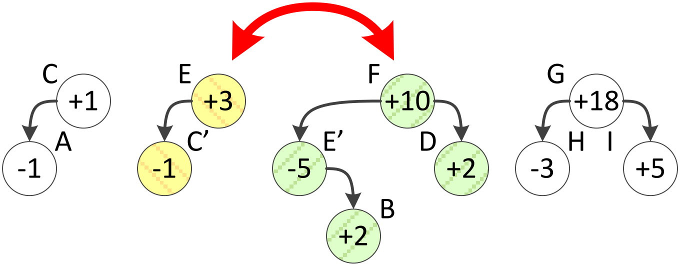

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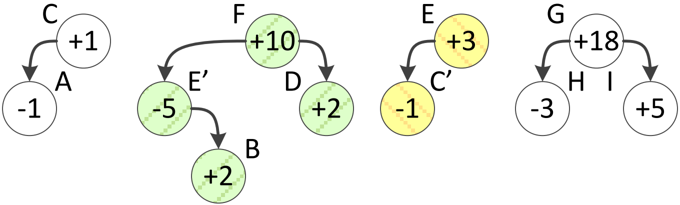
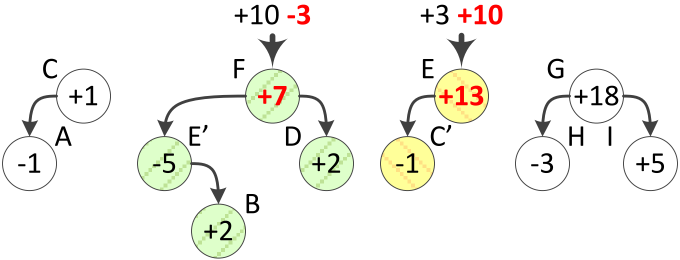
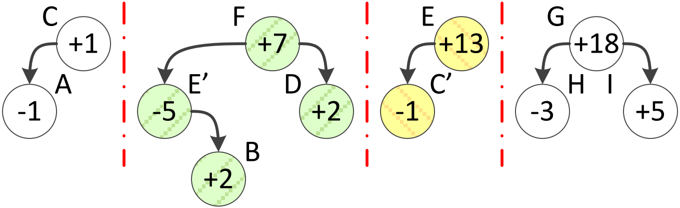


- Using split/join and the accumulation tree, updating in $\mathcal{O}(\log c)$ is possible
- Step 2: Translate keys ($\mathcal{O}(1)$)

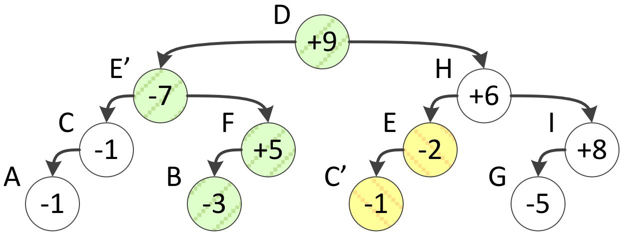


The Swap Algorithm

- Using split/join and the accumulation tree, updating in $\mathcal{O}(\log c)$ is possible
- Step 3: Join trees ($\mathcal{O}(\log c)$)



- Using split/join and the accumulation tree, updating in $\mathcal{O}(\log c)$ is possible
- Final result:



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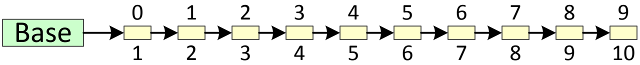
Overview

- What we have shown:
  - Double tree delta efficiently represents the changes in a version
    - Efficient Queries (NI Encoding)
    - Efficient Updates (Swap Algorithm)
    - Low Space Consumption ($\mathcal{O}(c)$)
- What is missing:
  - How to represent whole version histories efficiently?

- Assume:
  - Linear history of n versions $V_0, \ldots, V_{n-1}$
  - Constantly bounded number of changes c per version
- What we need:
  - V_0 has a fully materialized NI encoding
  - We need deltas that lead to each other version (transitively)
  - E.g., $\delta_{0\rightarrow 3}$ and $\delta_{3\rightarrow 5}$ lead to V_5 by applying $\delta_{3\rightarrow 5}(\delta_{0\rightarrow 3}(b))$
- Which deltas to store in order to...
  - minimize space consumption?
  - minimize query runtime?

- Minimize space consumption: linear topology



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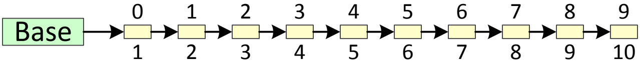

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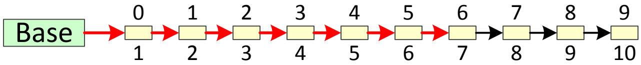

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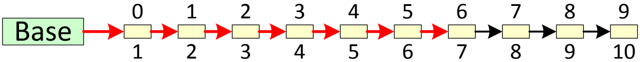

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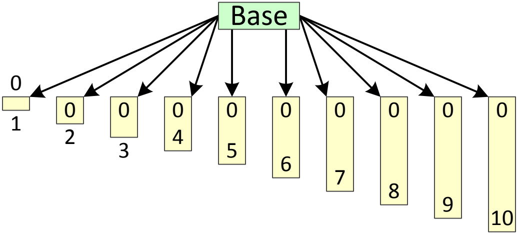

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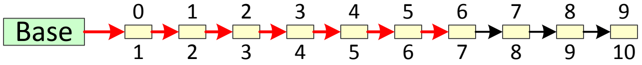

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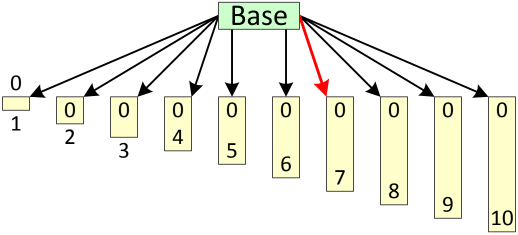
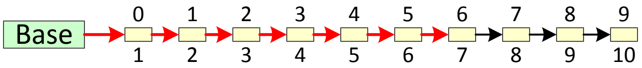
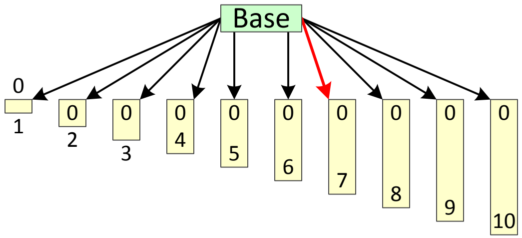


Simple Schemes

- Minimize space consumption: linear topology
  - ⇒ $O(n)$ space consumption ✓
  - ⇒ $O(n)$ query time ☹



- Minimize query time: star topology
  - ⇒ $O(\log n)$ query time ✓
  - ⇒ $O(n^2)$ space consumption ☹



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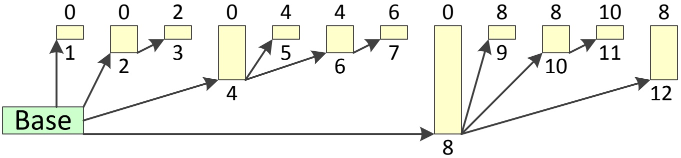

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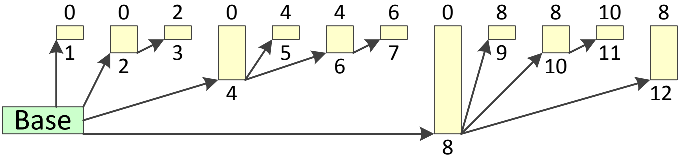

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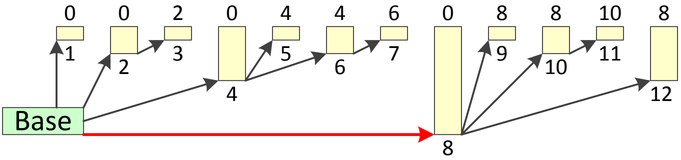

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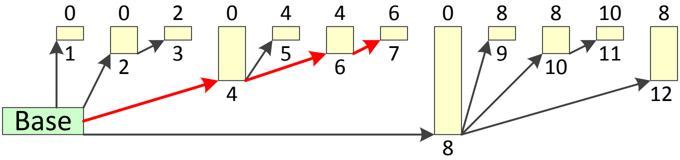

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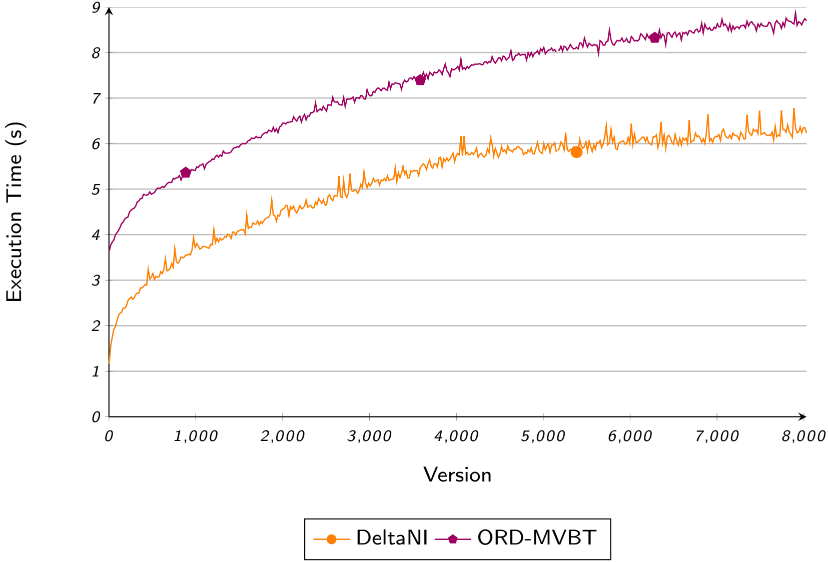
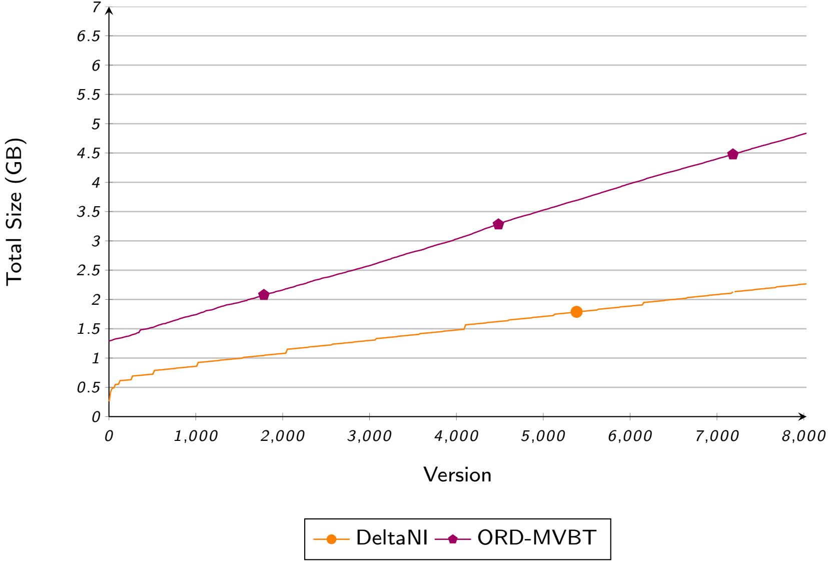
    - Asymptotically optimal query time and space consumption
- Improvements with DeltaNI
  - Support of subtree relocation and deletion
  - Branching histories
  - Simple integer comparisons instead of bytewise comparisons

Time for one million queries



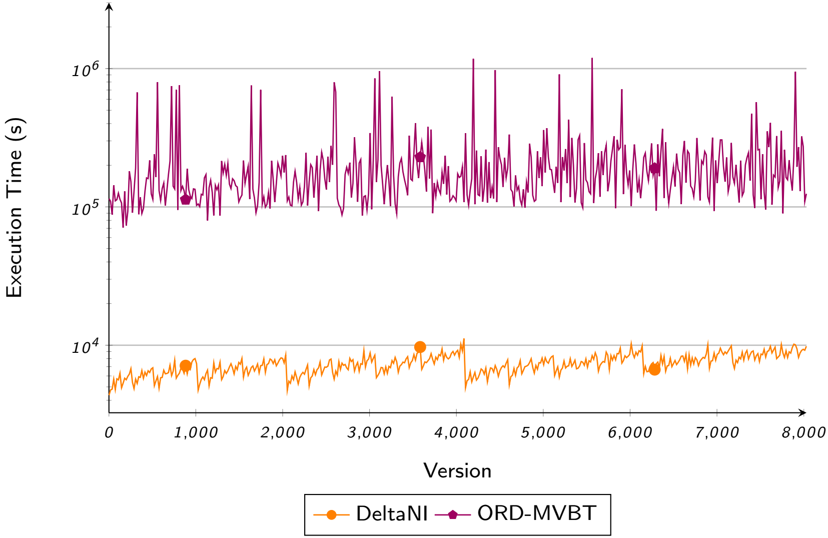
Evaluation: Space Consumption

Space consumption



Evaluation: Update Performance

Time for one million updates



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  - $\mathcal{O}(\log c)$ update complexity
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- Versioning via exponential delta-packing scheme
  - Yields reasonable space/time tradeoff

Thank you for your attention!

Any questions?