Practical Hardware Transactional vEB Trees

PPoPP'24

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[1] 

[2] 

Introduction

Sets and Maps

DS	Look-up	Insert	Delete	Predecessor	Successor
Hash Table	$\ddot{e}(1)$	$\ddot{e}(1)$	$\ddot{e}(1)$	$\ddot{e}(\acute{Y})$	$\ddot{e}(\acute{Y})$
BST	$\ddot{e}(\lg \acute{Y})$	$\ddot{e}(\lg \acute{Y})$	$\ddot{e}(\lg \acute{Y})$	$\ddot{e}(\mathbf{lg}\ \acute{Y})$	$\ddot{e}(\mathbf{lg}\ \acute{Y})$
B-Tree	$\ddot{e}(\log_{@} \acute{Y})$	$\ddot{e}(\log_{@} \acute{Y})$	$\ddot{e}(\log_{@} \acute{Y})$	$\ddot{e}(\mathbf{log}_{@}\ \acute{Y})$	$\ddot{e}(\mathbf{log}_{@}\ \acute{Y})$

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vEB Tree	$\ddot{e}(\lg \lg \cdot)$	$\ddot{e}(\lg \lg \cdot)$	$\ddot{e}(\lg \lg \cdot)$	$\ddot{e}(\mathbf{lg}\ \mathbf{lg}\ \cdot)$	$\ddot{e}(\mathbf{lg}\ \mathbf{lg}\ \cdot)$

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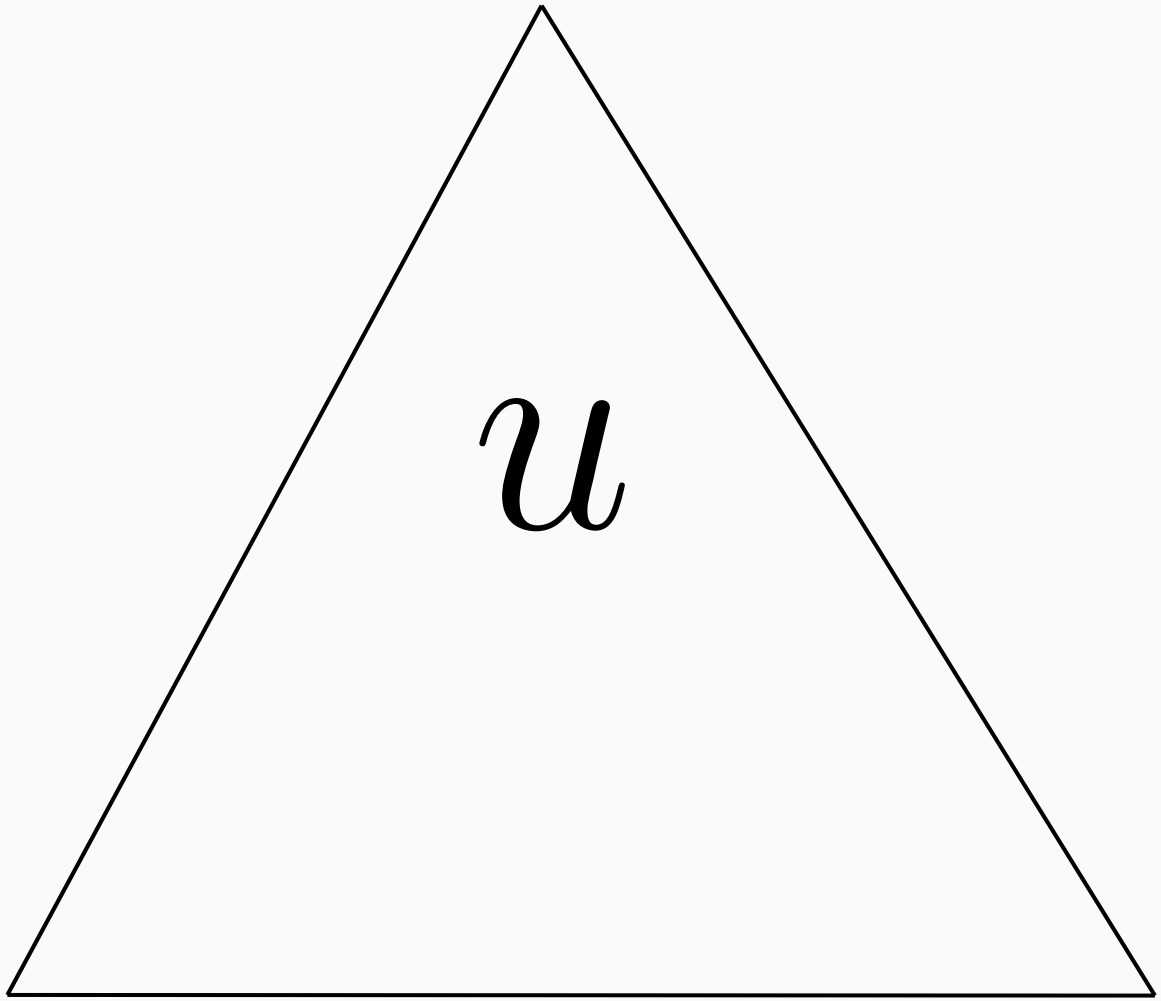
vEB Tree	$\ddot{e}(\lg \lg \acute{\iota})$	$\ddot{e}(\lg \lg \acute{\iota})$	$\ddot{e}(\lg \lg \acute{\iota})$	$\ddot{e}(\mathbf{lg}\ \mathbf{lg}\ \acute{\iota})$	$\ddot{e}(\mathbf{lg}\ \mathbf{lg}\ \acute{\iota})$

$\acute{\iota}$	$\lg \lg \acute{\iota}$
65K	4
1M	4;3
1B	4;9
1T	5;3

vEB Trees

- Introduced in 1977 by Peter van Emde Boas [4]
- Fixed universe size $\iota = 2^{\lg \iota}$: $f0; : : : ; \iota \quad 1g \rightarrow \lg \iota$ bit keys
- $\ddot{e}(\lg \lg \iota)$ complexity for all operations

vEB Tree Structure



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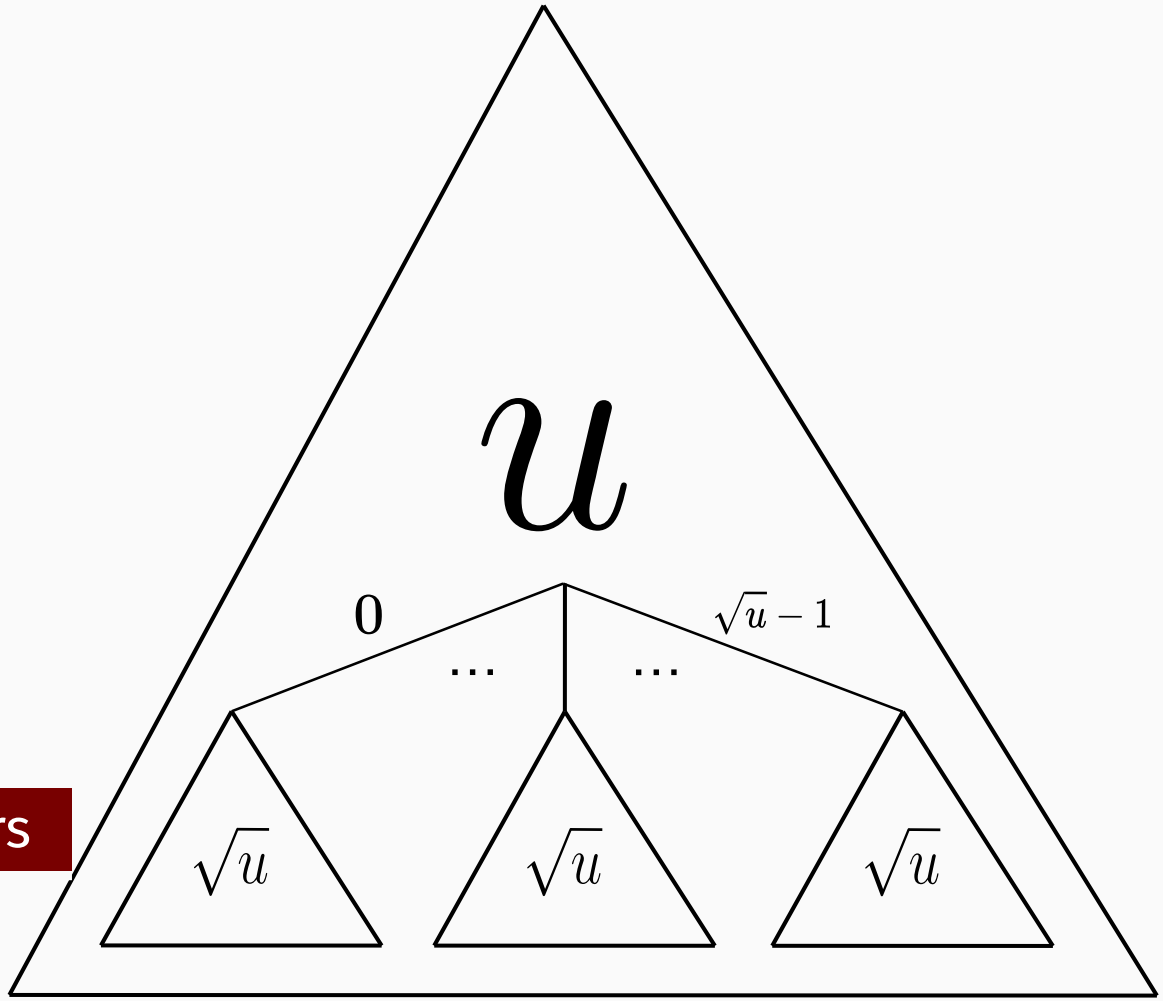
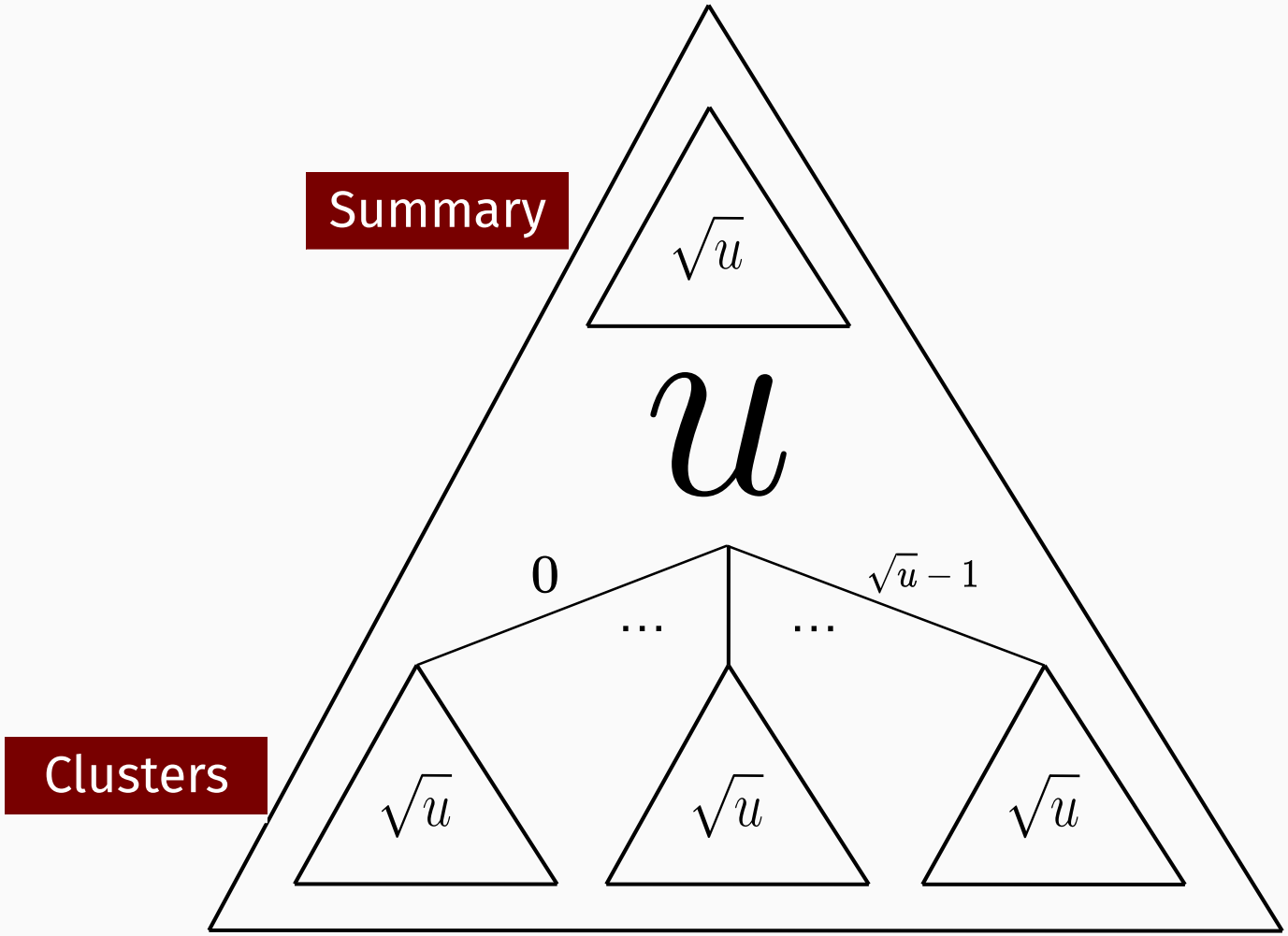


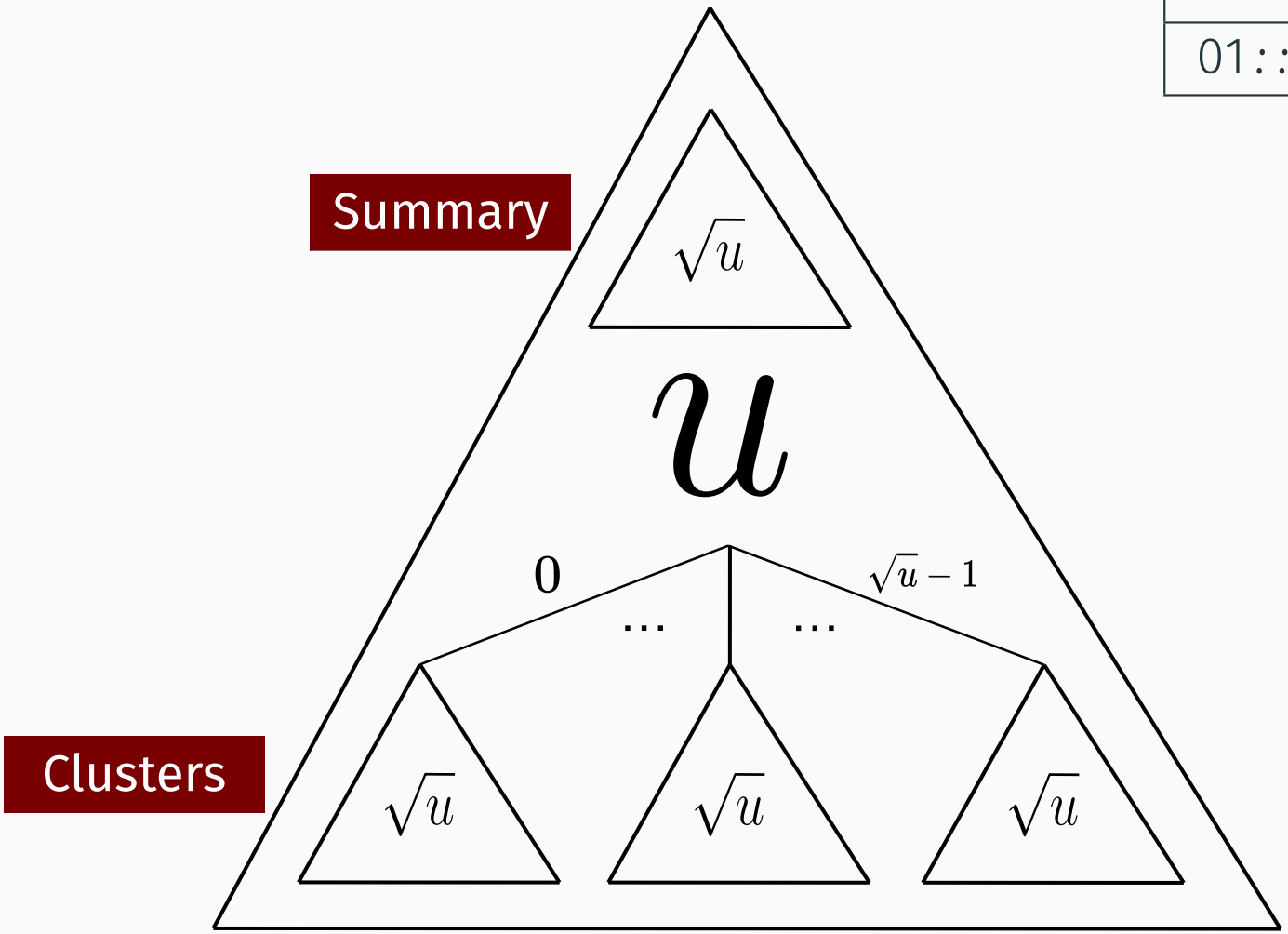
Clusters

vEB Tree Structure



vEB Insert Example

$\lg u$ bits
01 : : : : : : : : : : : : : 10



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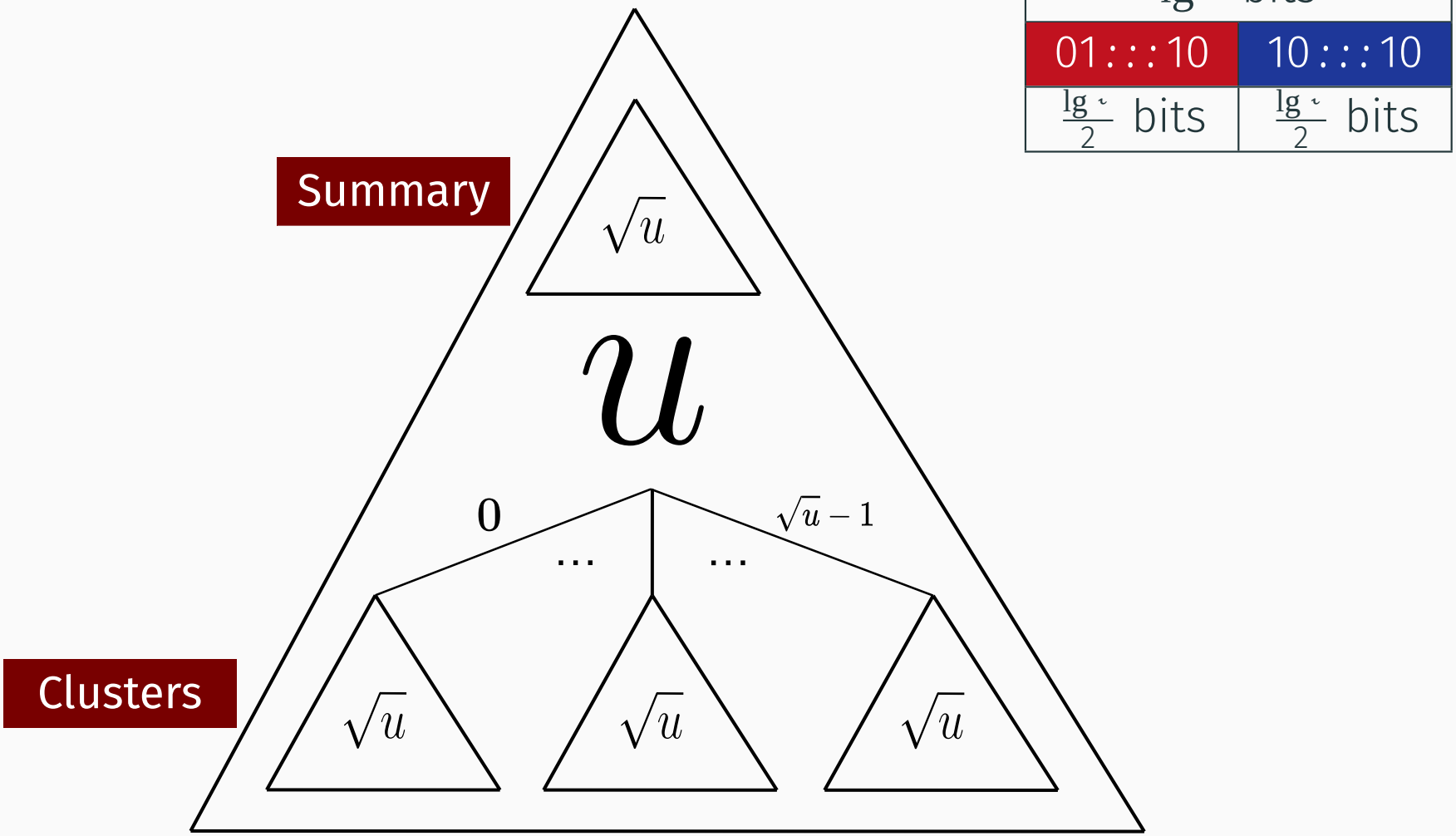

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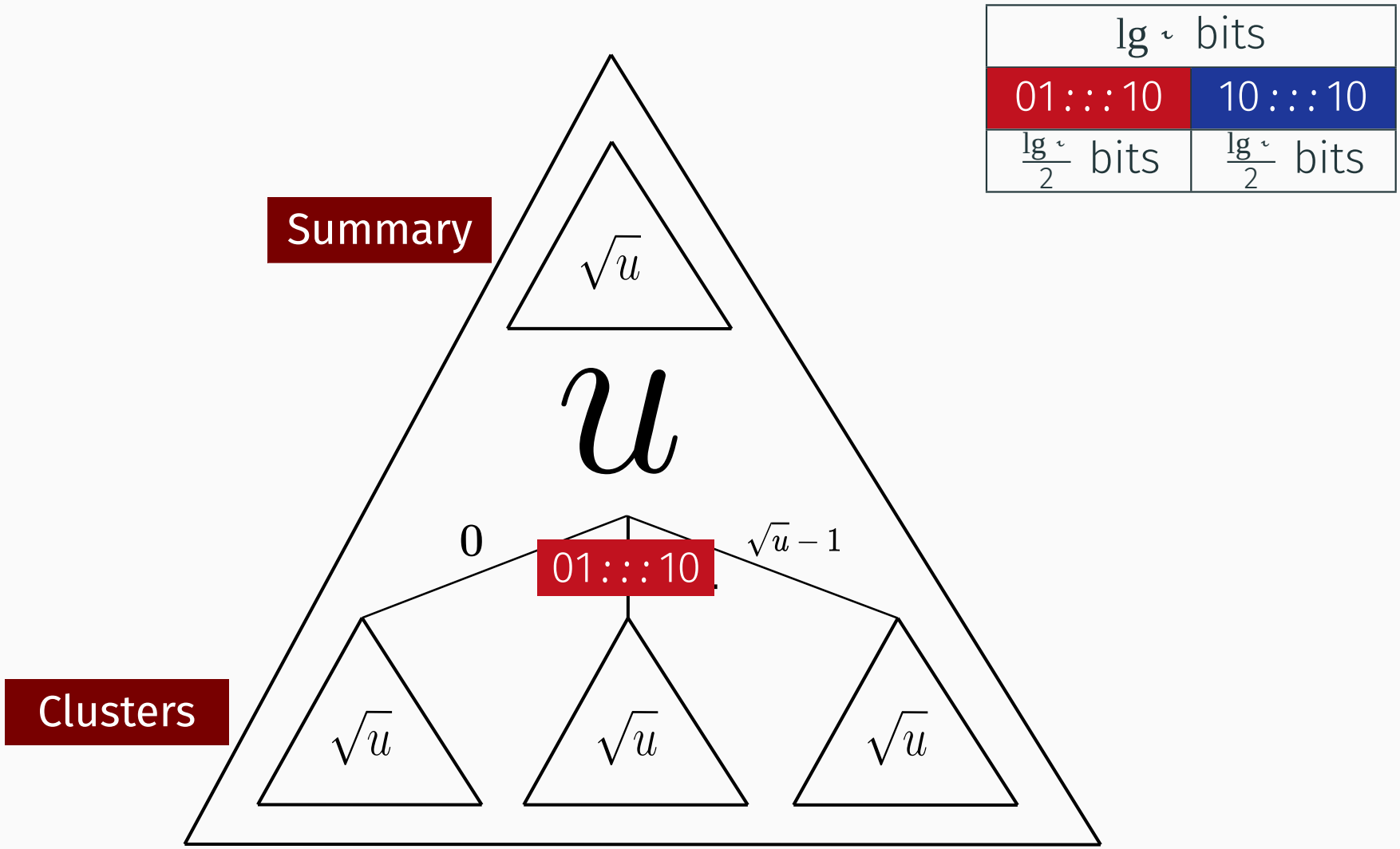

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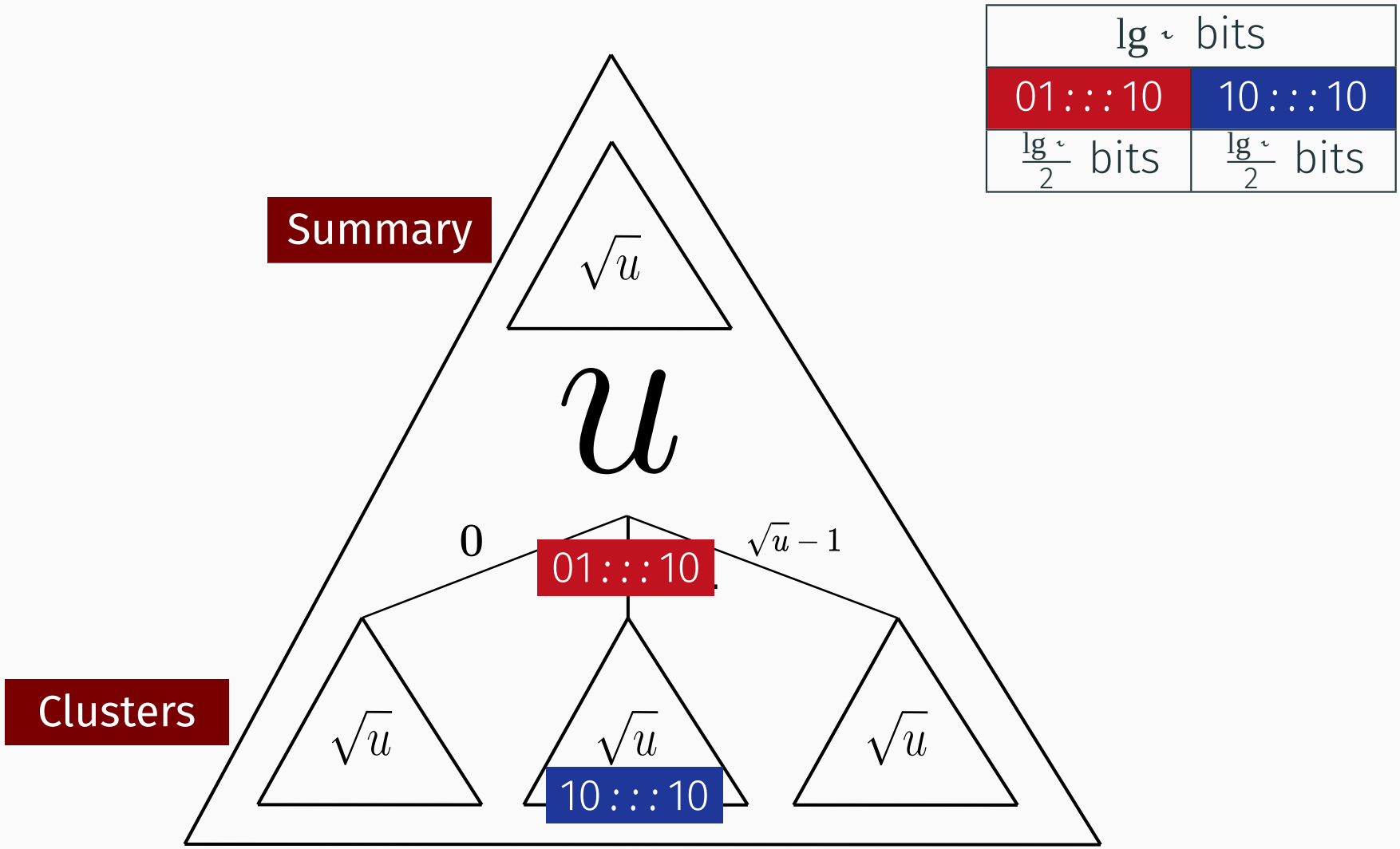

vEB Insert Example

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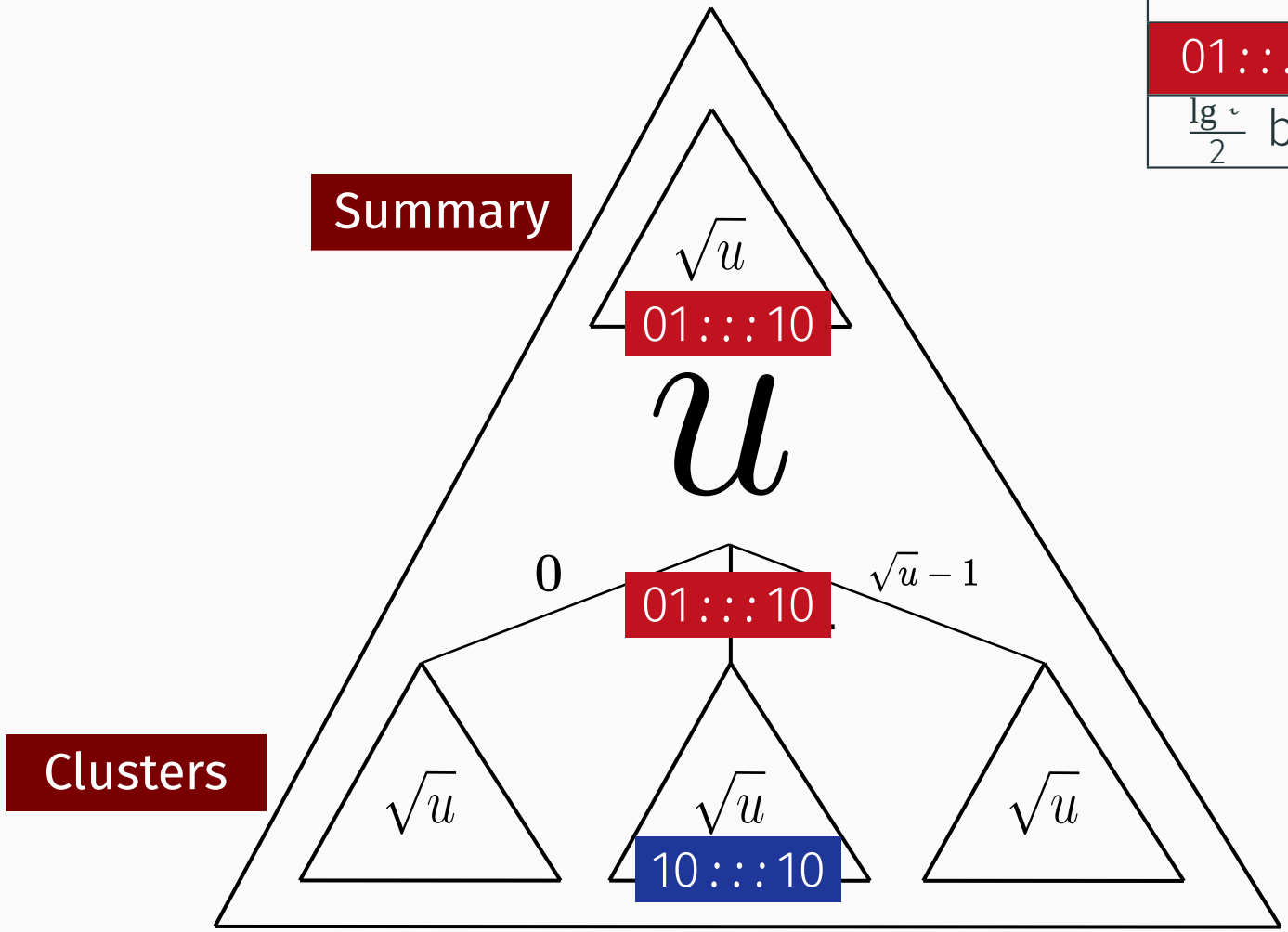
01 : : : 10	10 : : : 10
$\frac{\lg u}{2}$ bits	$\frac{\lg u}{2}$ bits



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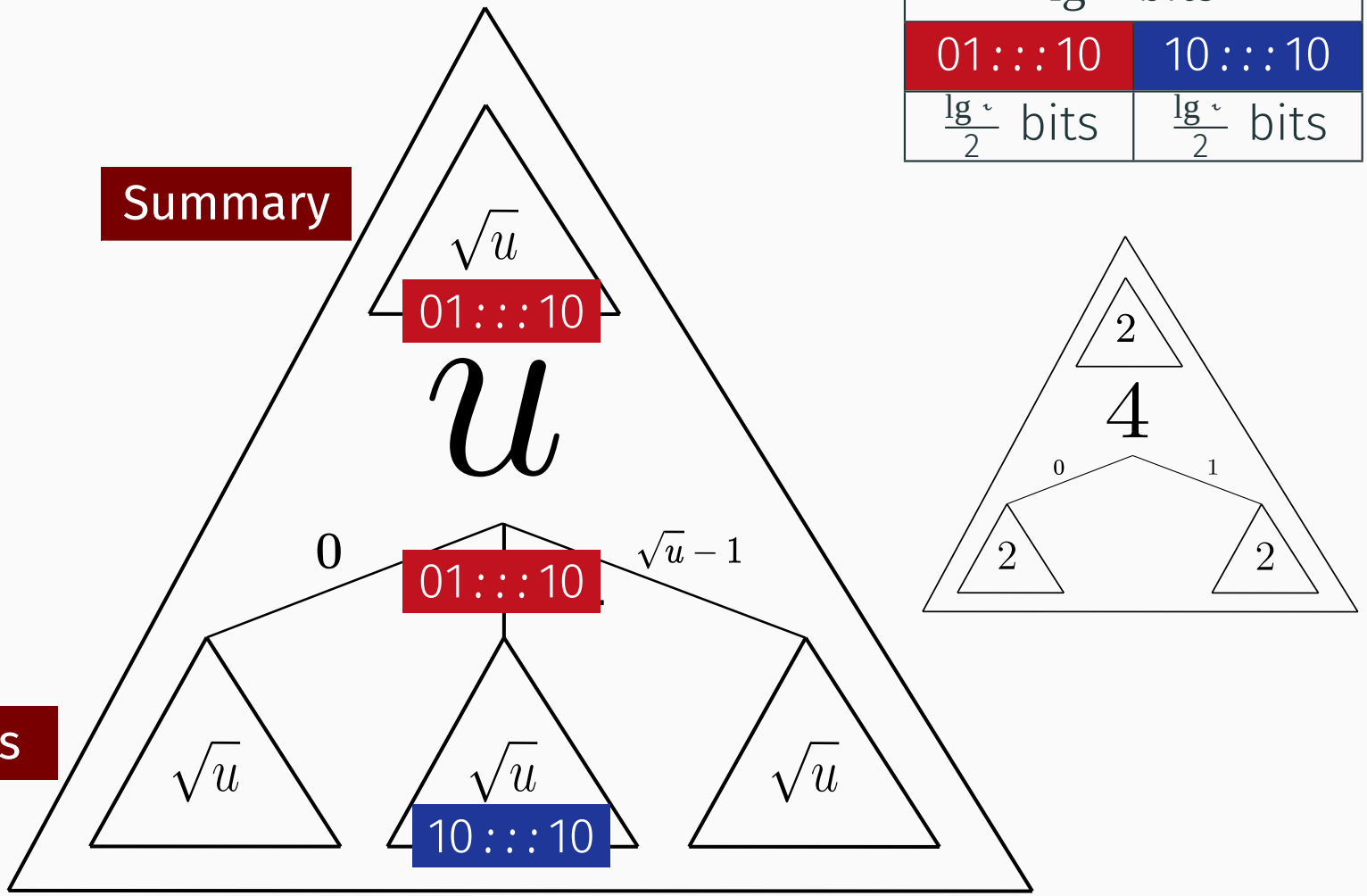

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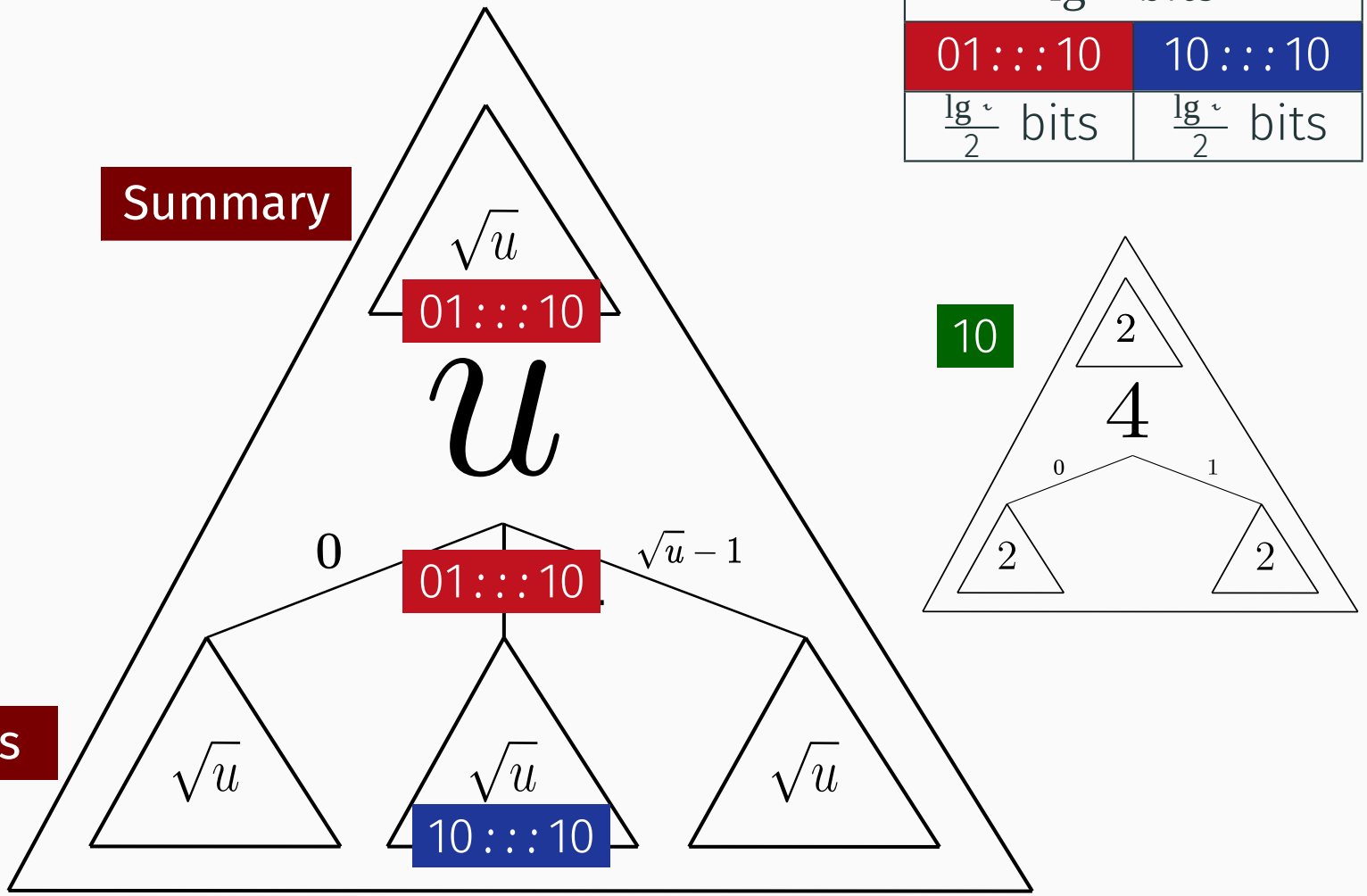

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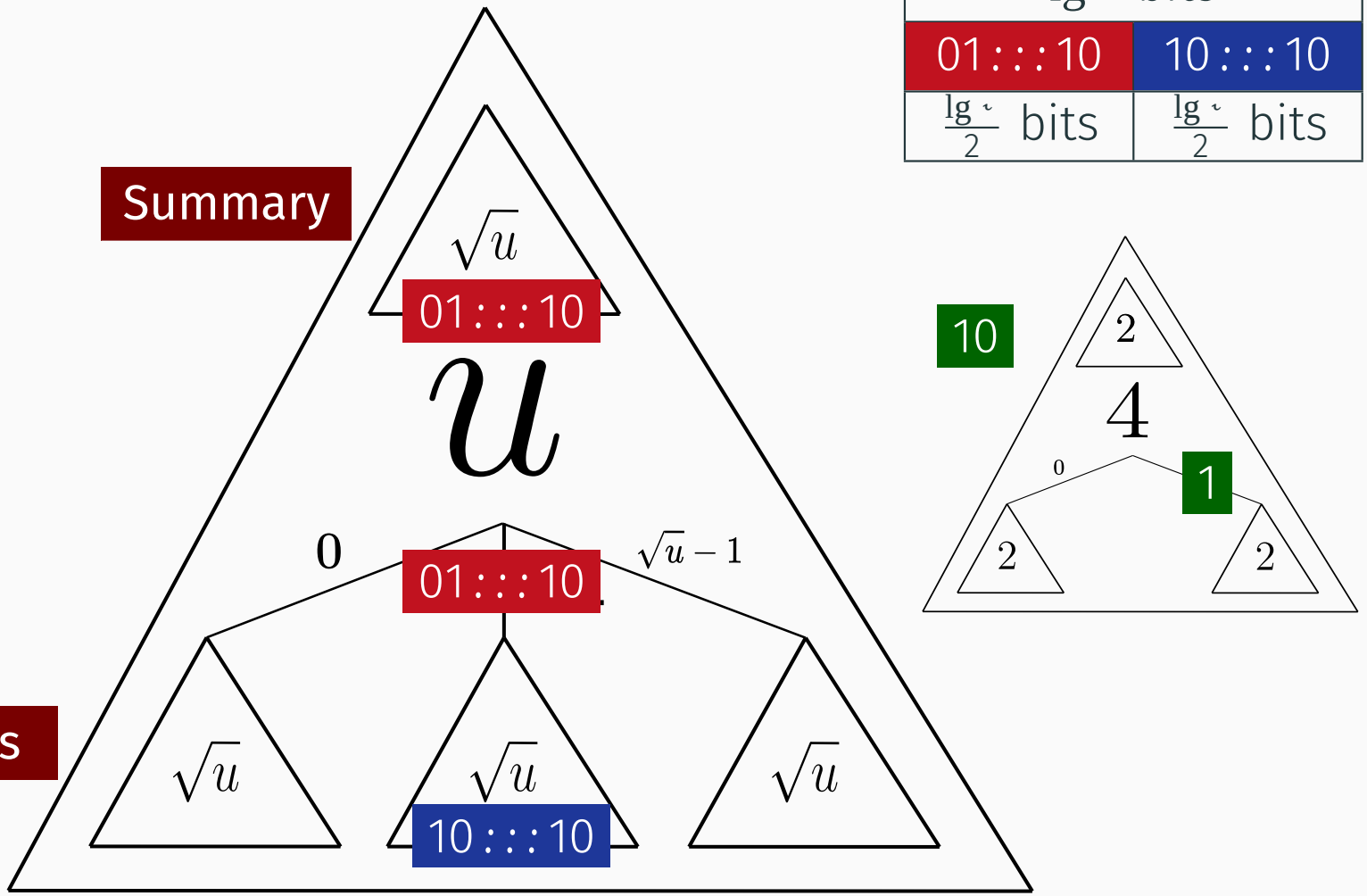

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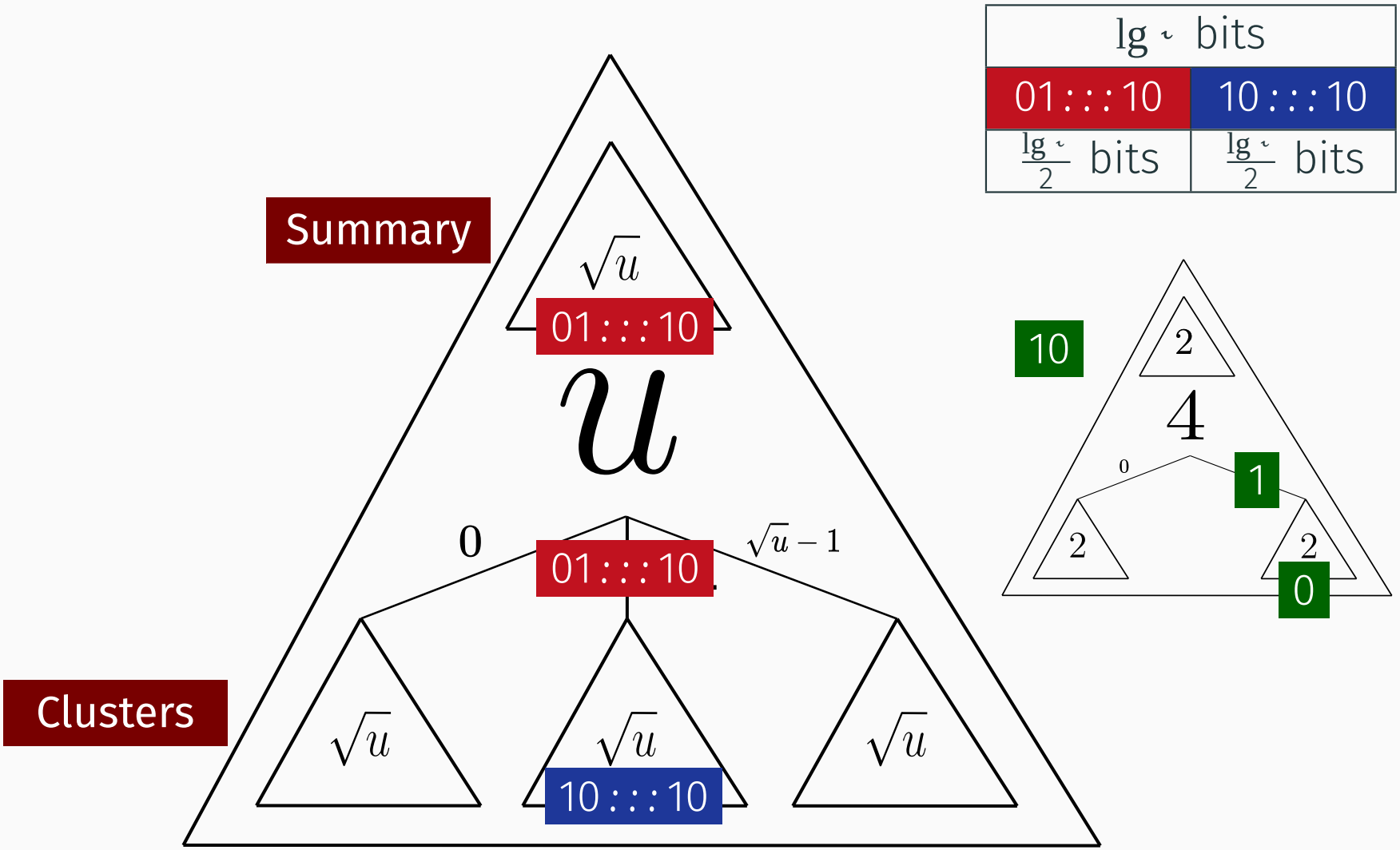

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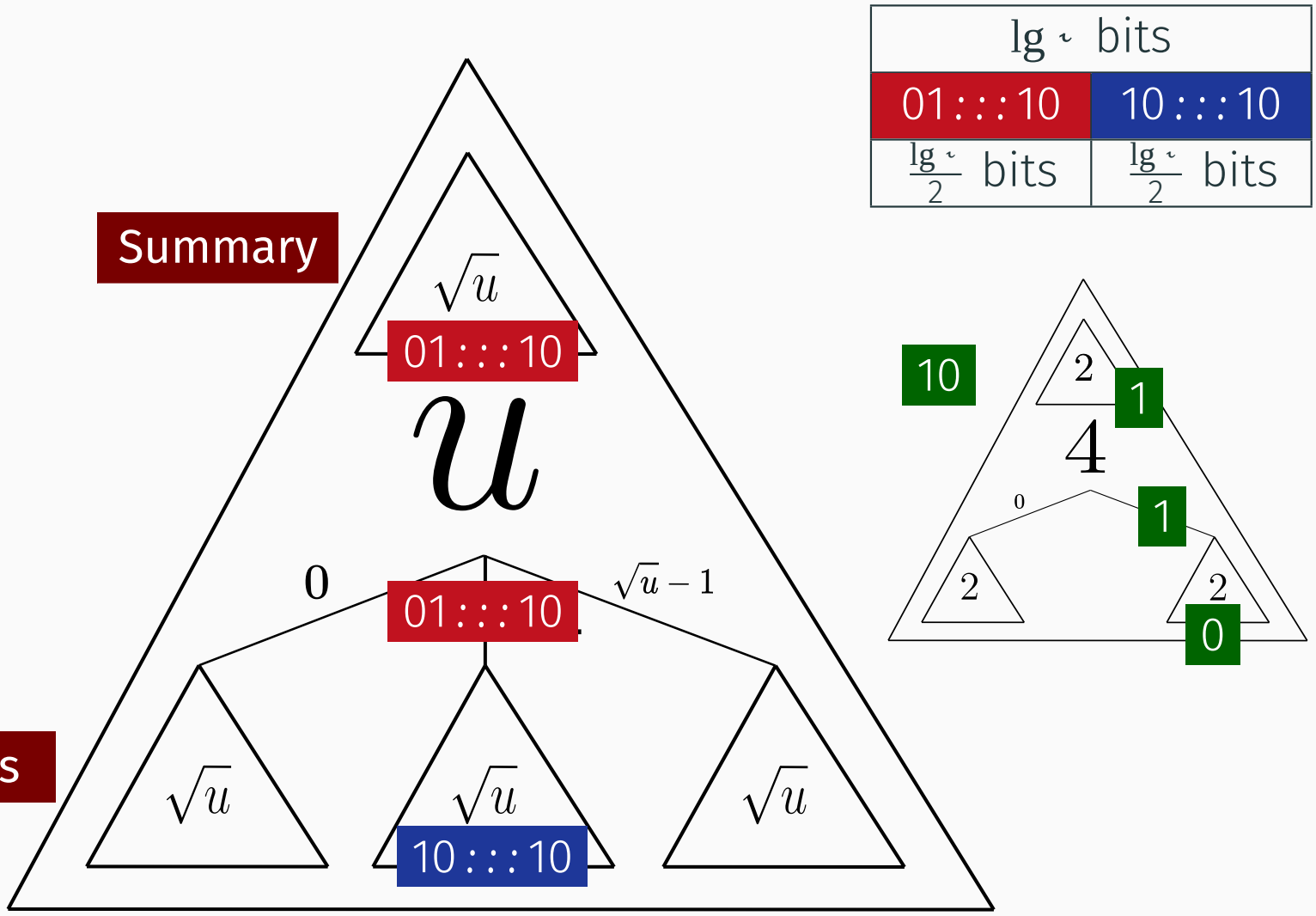

Hardware Transactional Memory (HTM)

- Atomic blocks of code
  - Take effect as a single indivisible unit (Commit)
  - Or rolled back with no effect on shared memory (Abort)
- Hardware level → Efficient

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dkrd z
    knbj'(:
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    tmknbj'(:
|
```

Fallback Path

Transactional Lock Elision (TLE)

Fast Path

Fallback Path

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    he knbj hr `kqd`cx gdkc
        `anqs'(:

    Sq`mr`bshnm ancx---

    ^wdmc'(:
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|
```

Methodology

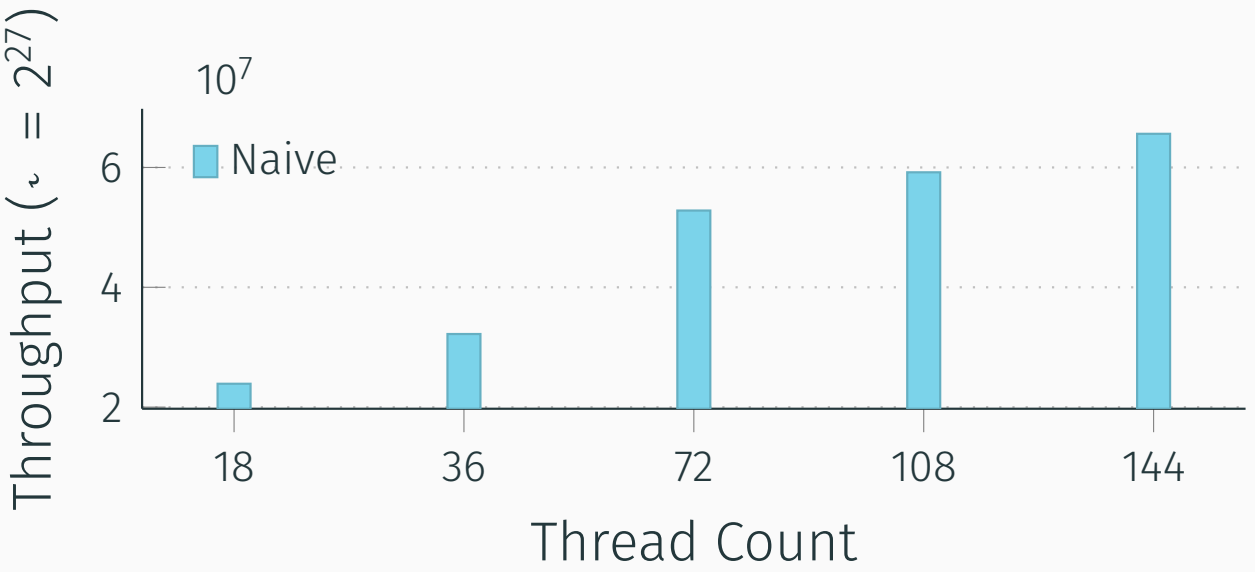
Overview

- Concurrent vEB trees with recursive summaries
- Full support for successor and predecessor queries
- Starting with a naive vEB set implementation
- Use simple building blocks to end up with a performant vEB map

First Step: Naive

Idea

Wrap sequential vEB operations in TLE blocks



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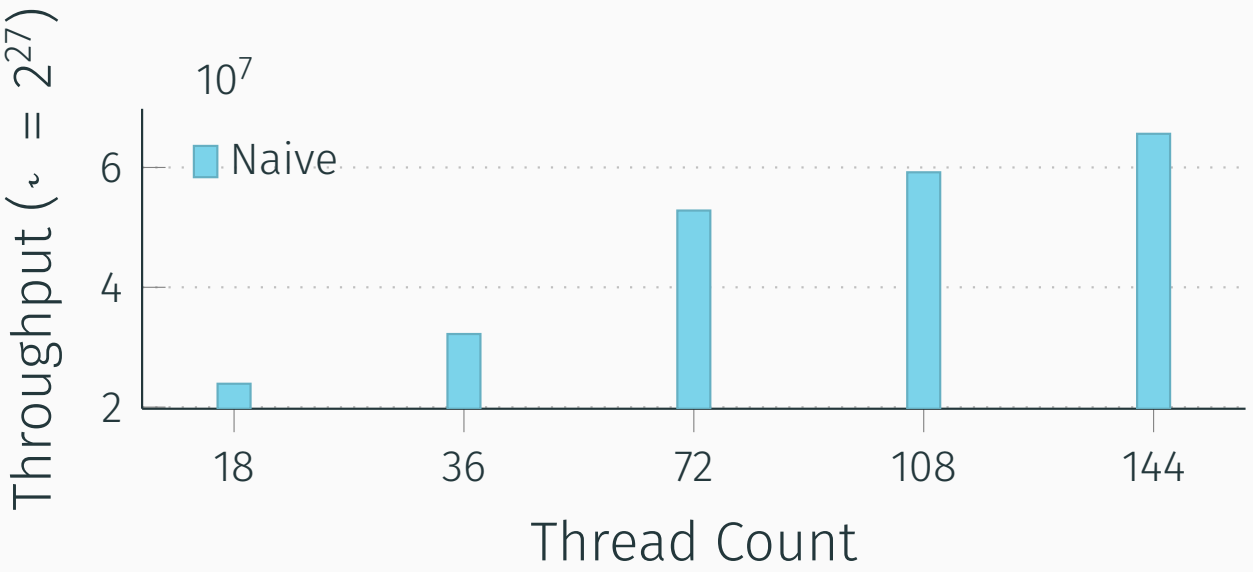

Problem

Memory usage does not depend on the number of keys!

Improve Memory Footprint: Dynamic

Can we save memory?

In the Naive variation, the entire tree is pre-allocated

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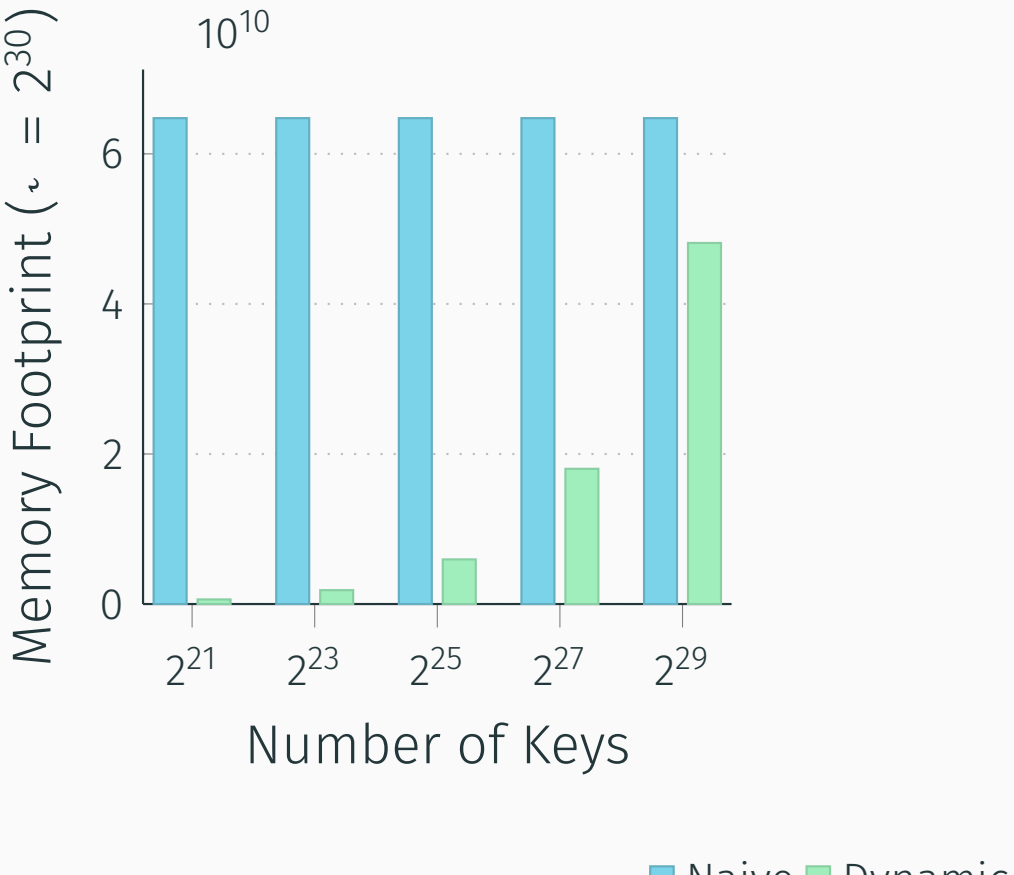

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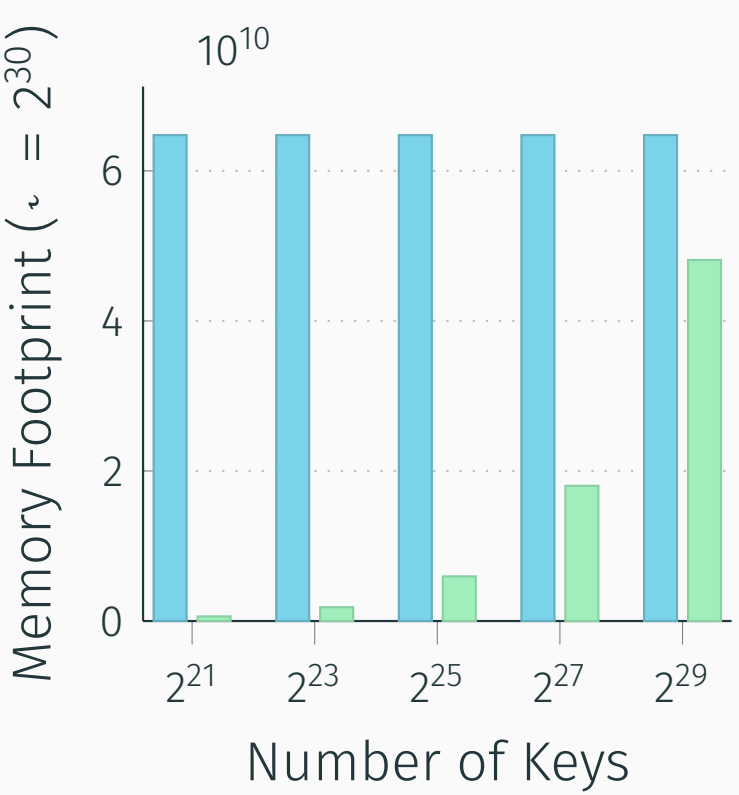
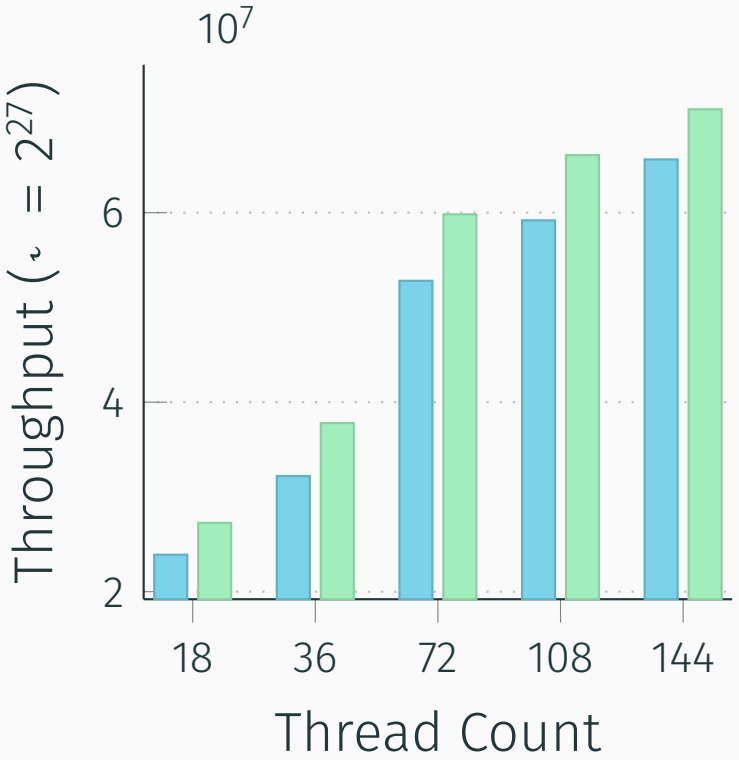




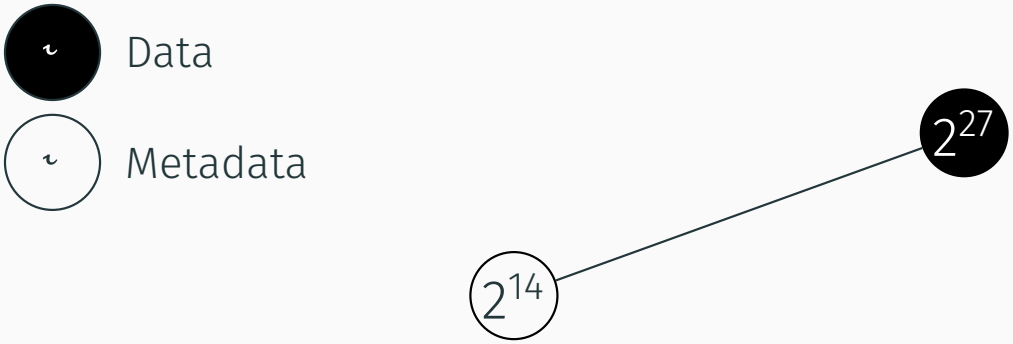
Naive Dynamic

Room For Improvement: Cut-Off

Data

2^{27}

Room For Improvement: Cut-Off



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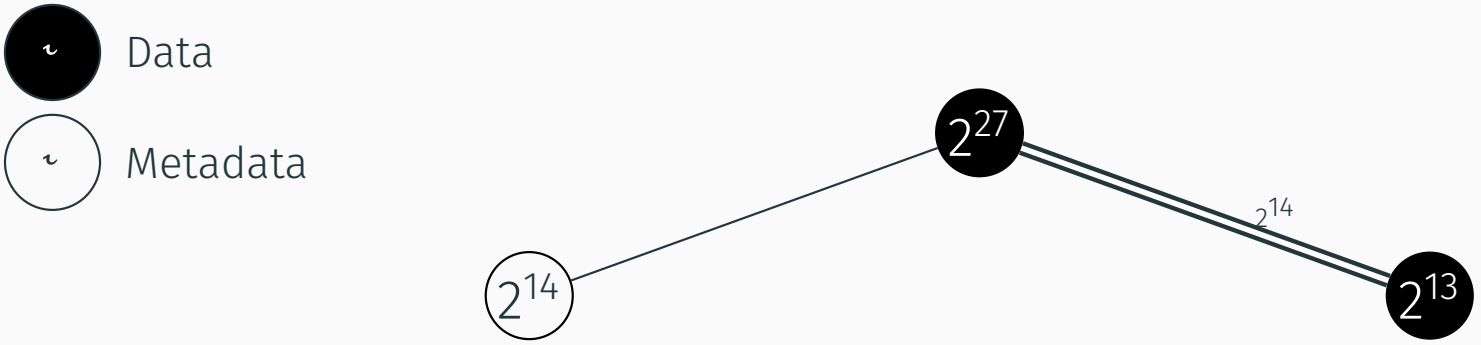

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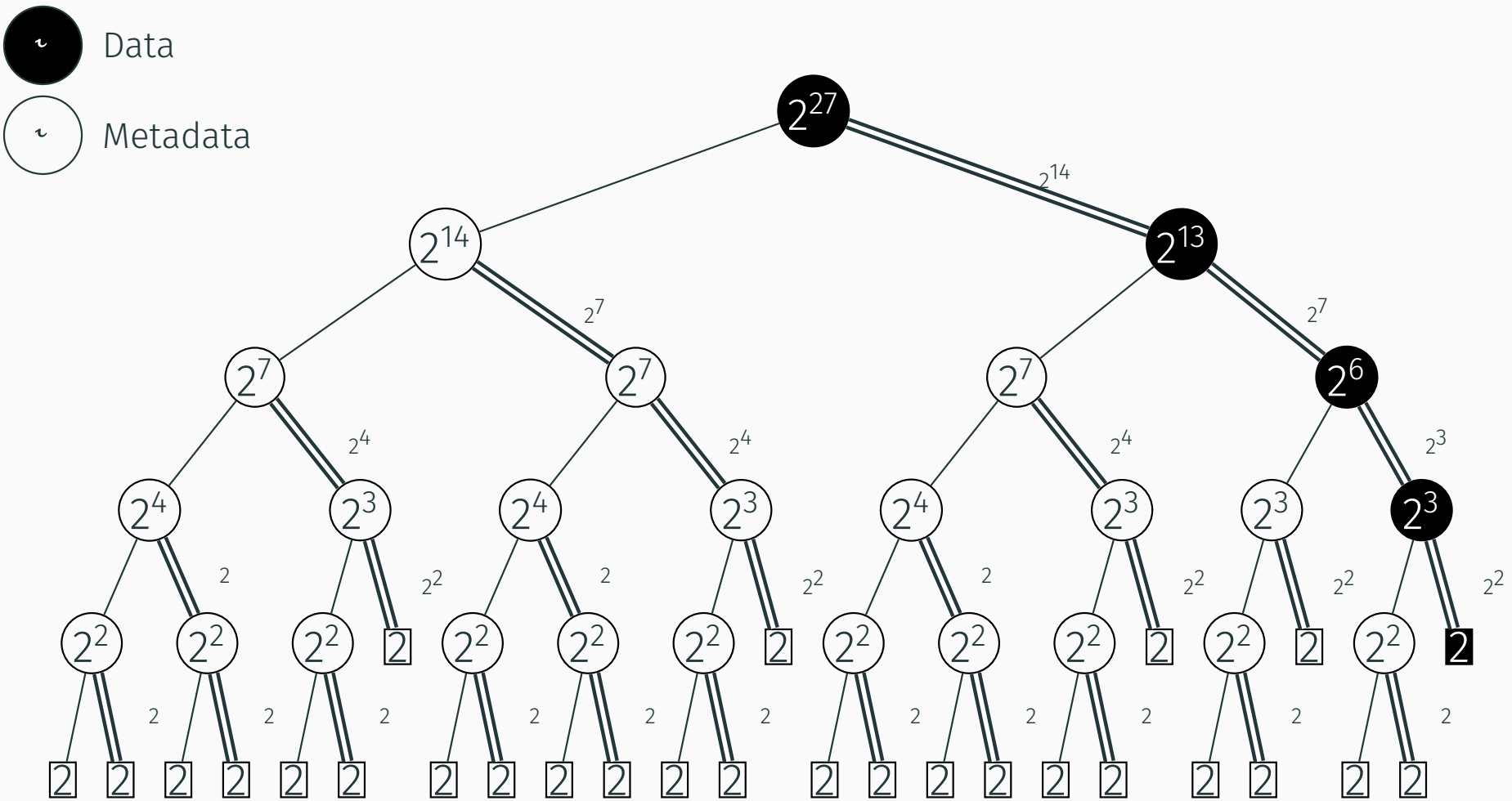

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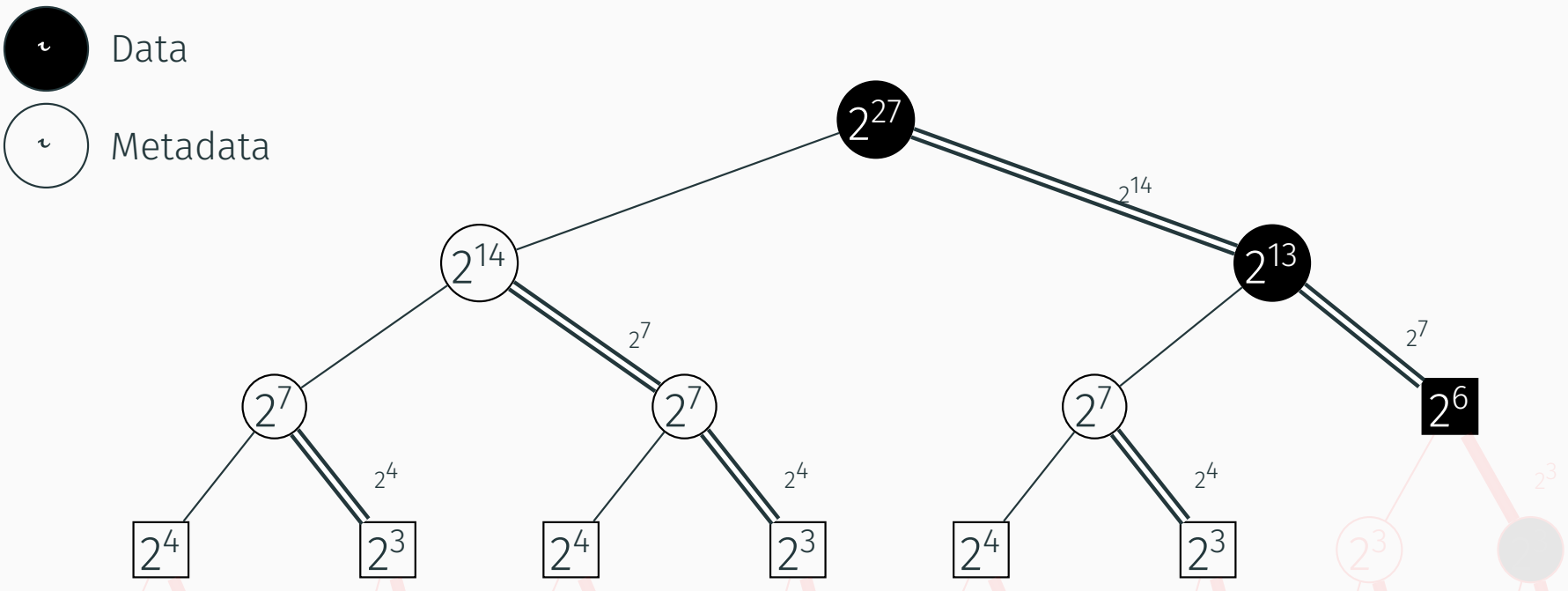
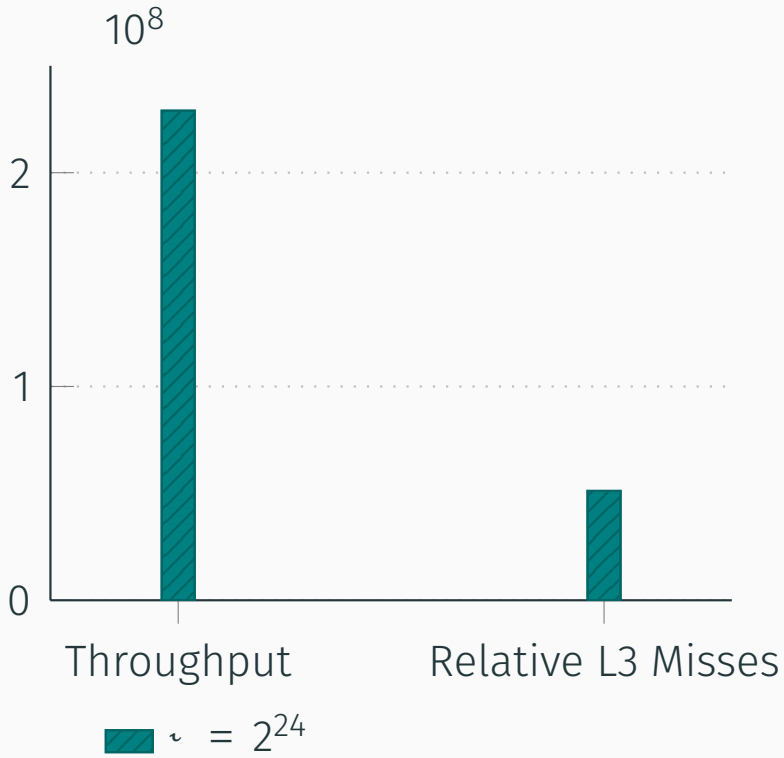
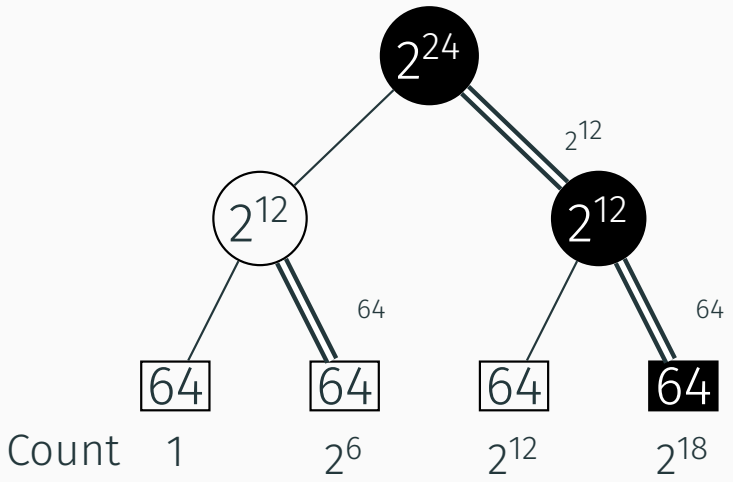


Stop the recursion at ι 64

- 98.6% fewer nodes at $\iota = 2^{27}$
- One L3 cache miss vs. 7
- 3 faster
- 75% less memory

Problem with Cut-Off





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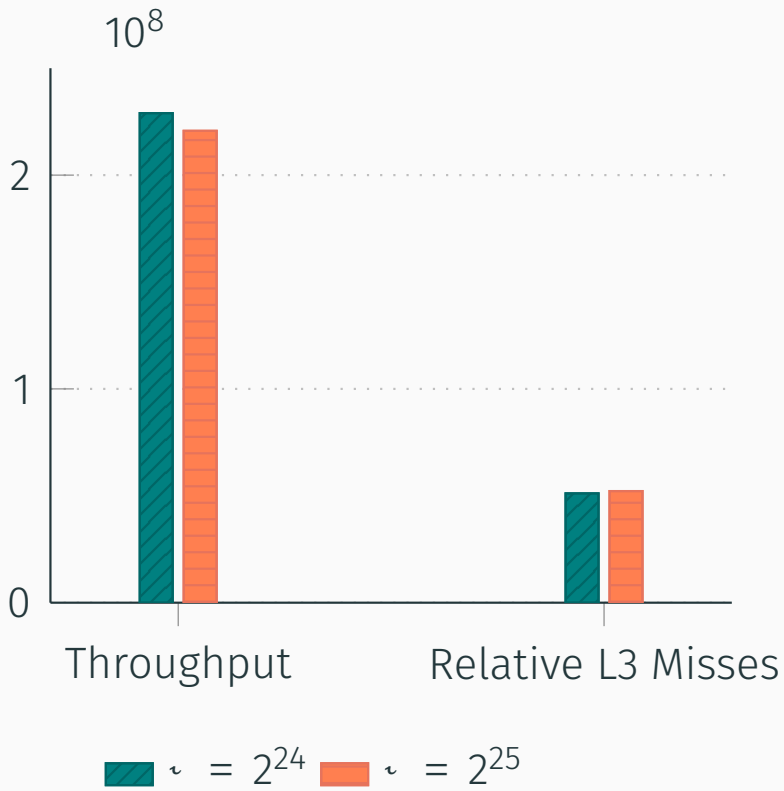

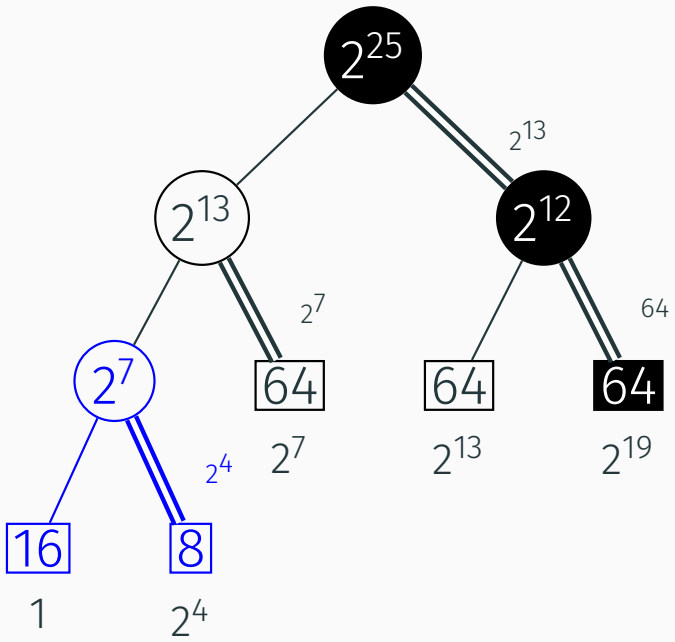

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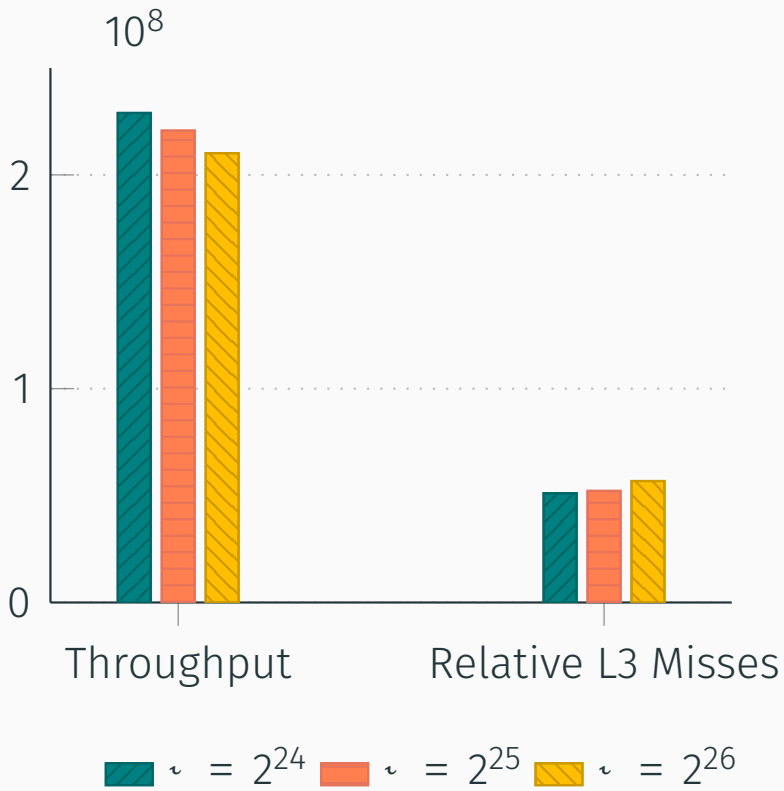

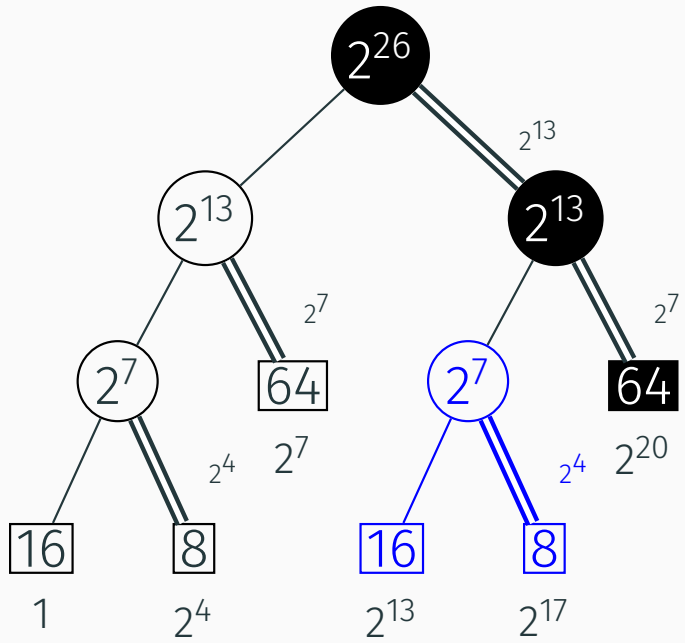

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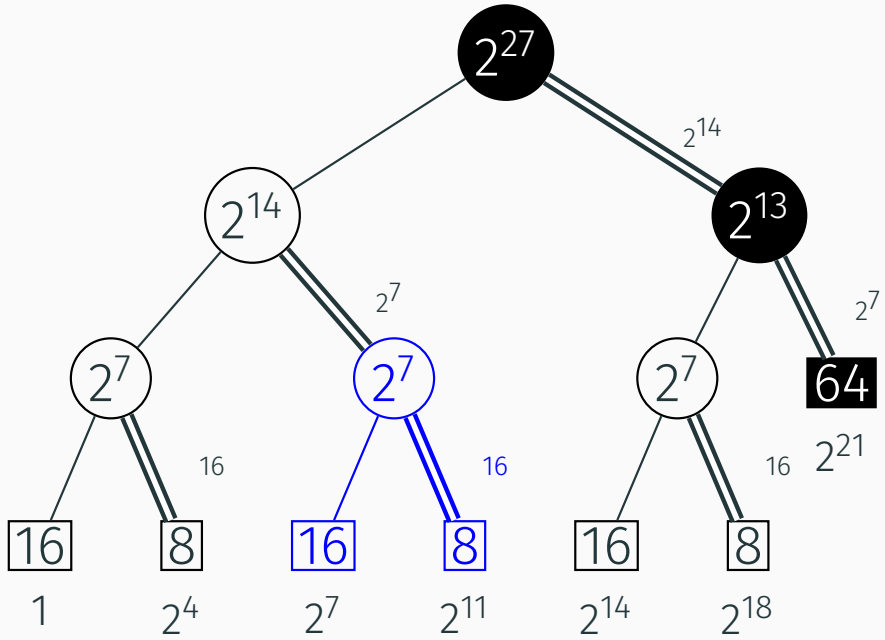

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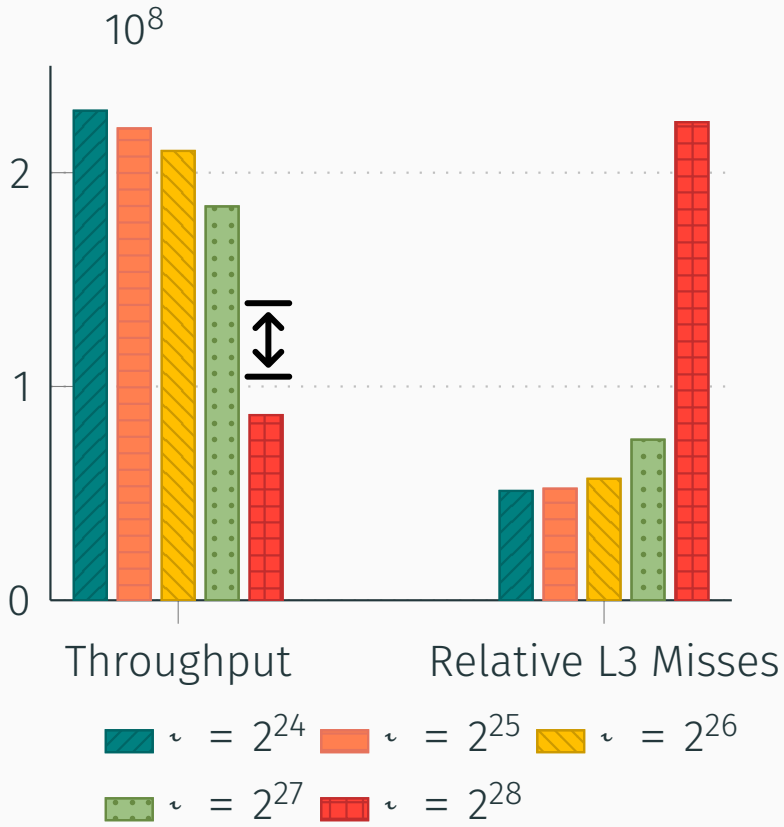

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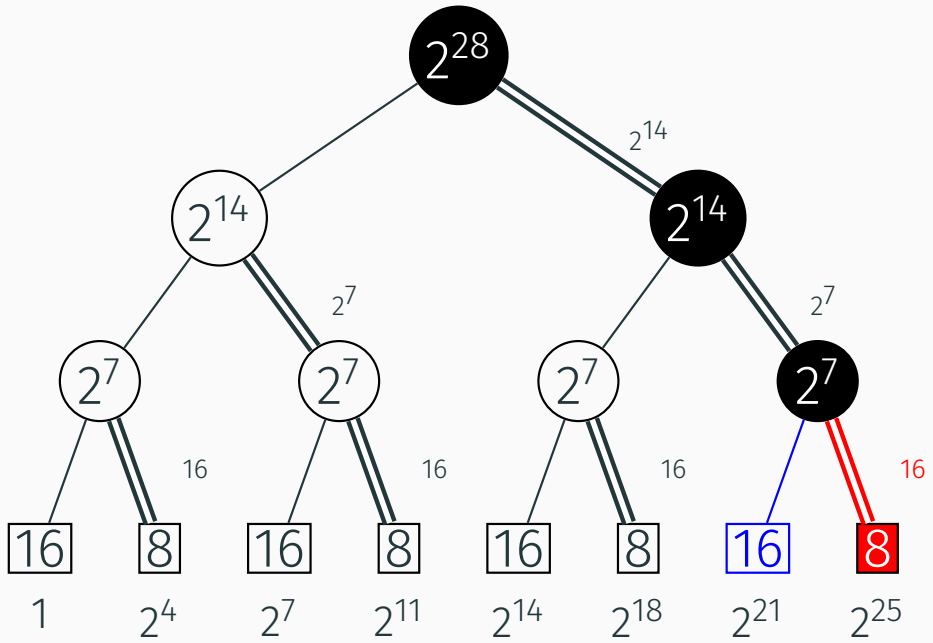
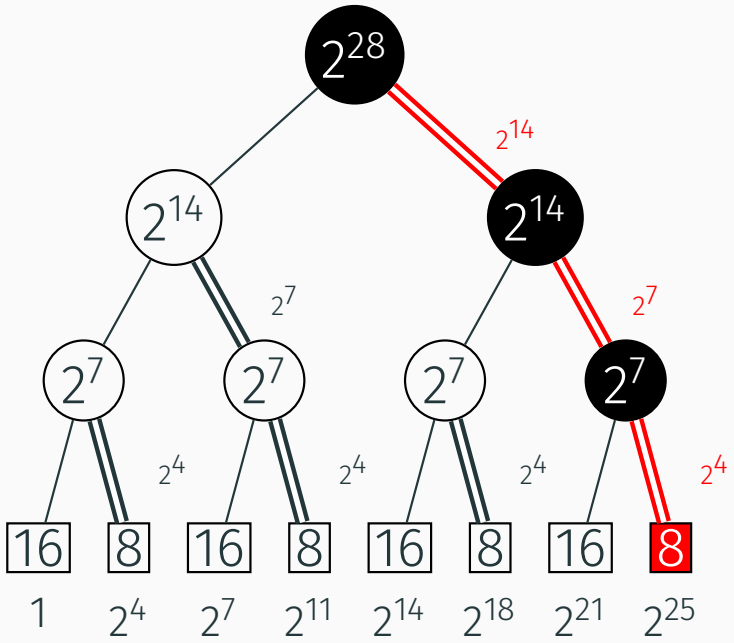


Solution: New-Root

Before



Universe Size	2^{24}	2^{25}	2^{26}	2^{27}	2^{28}	2^{29}
Data Leaf Count	2^{18}	2^{19}	2^{20}	2^{21}	2^{25}	2^{26}
Data Leaf Size	64	64	64	64	8	8

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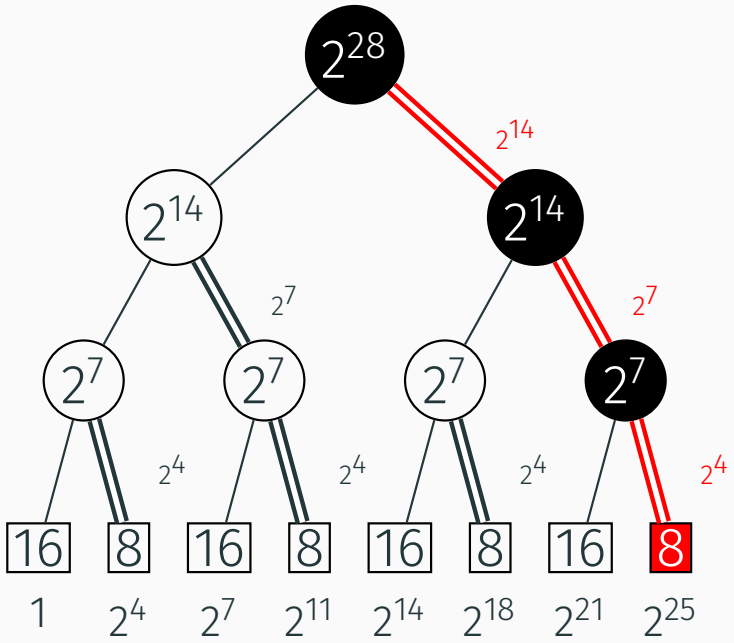
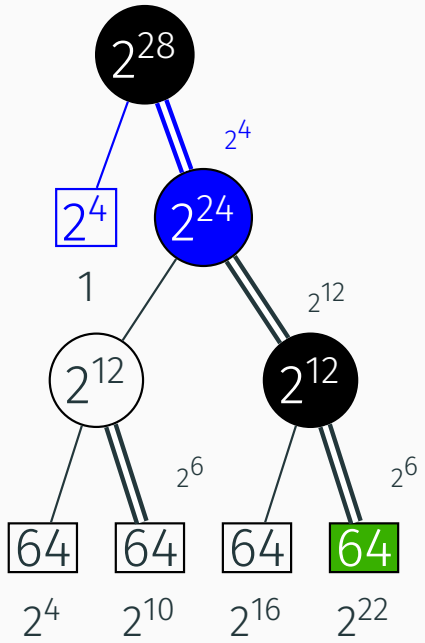


After



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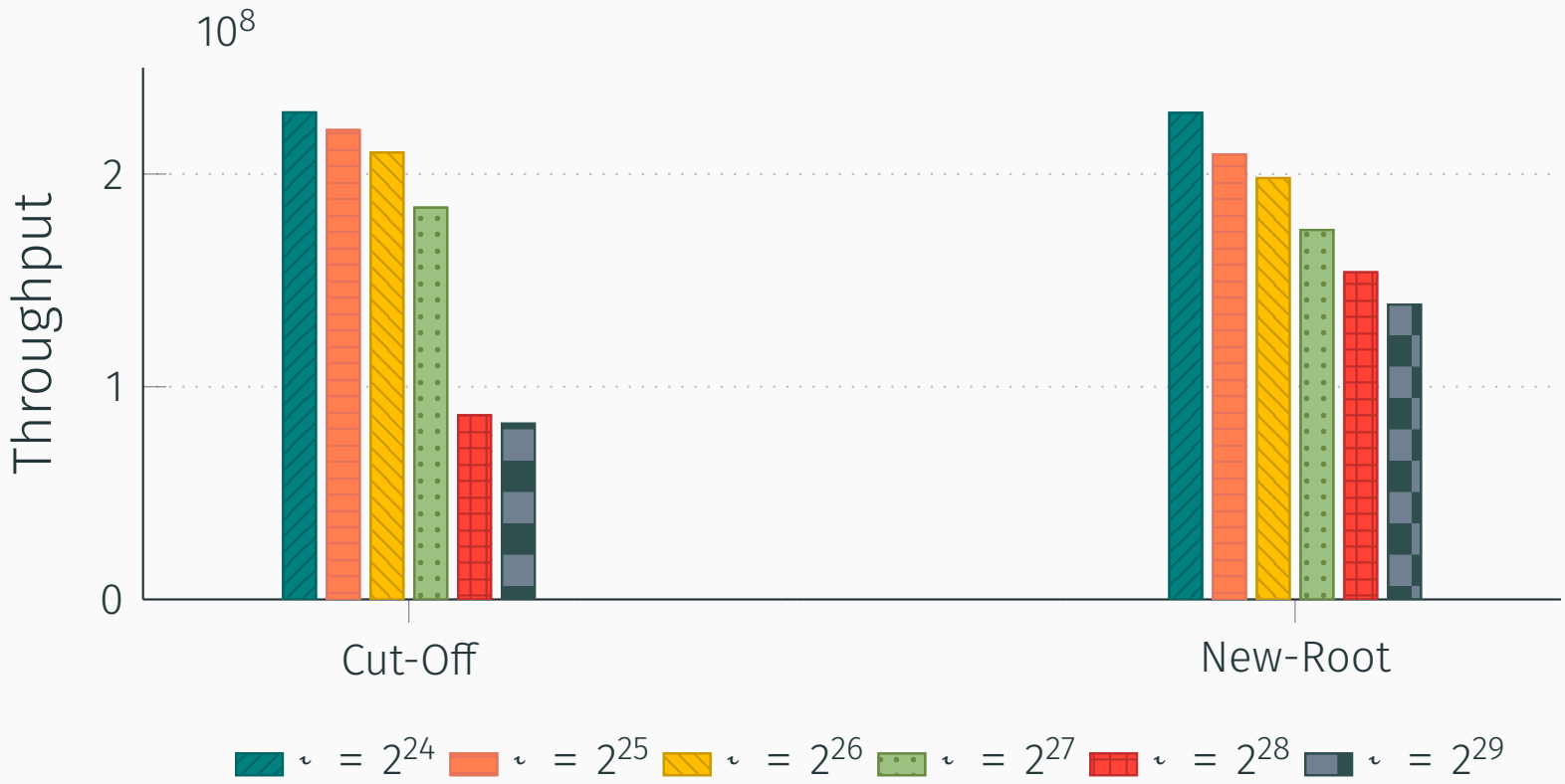
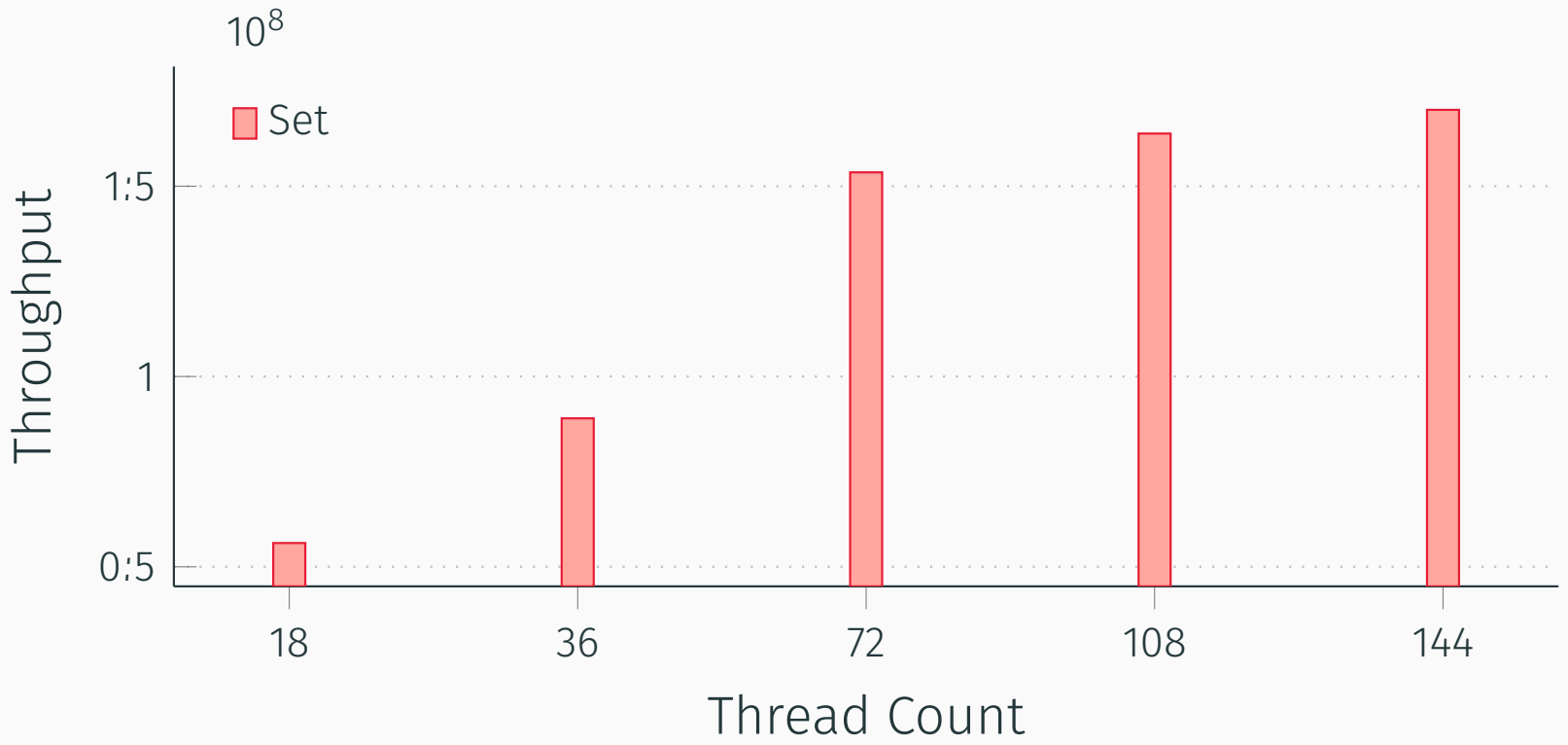


Moving On to Maps



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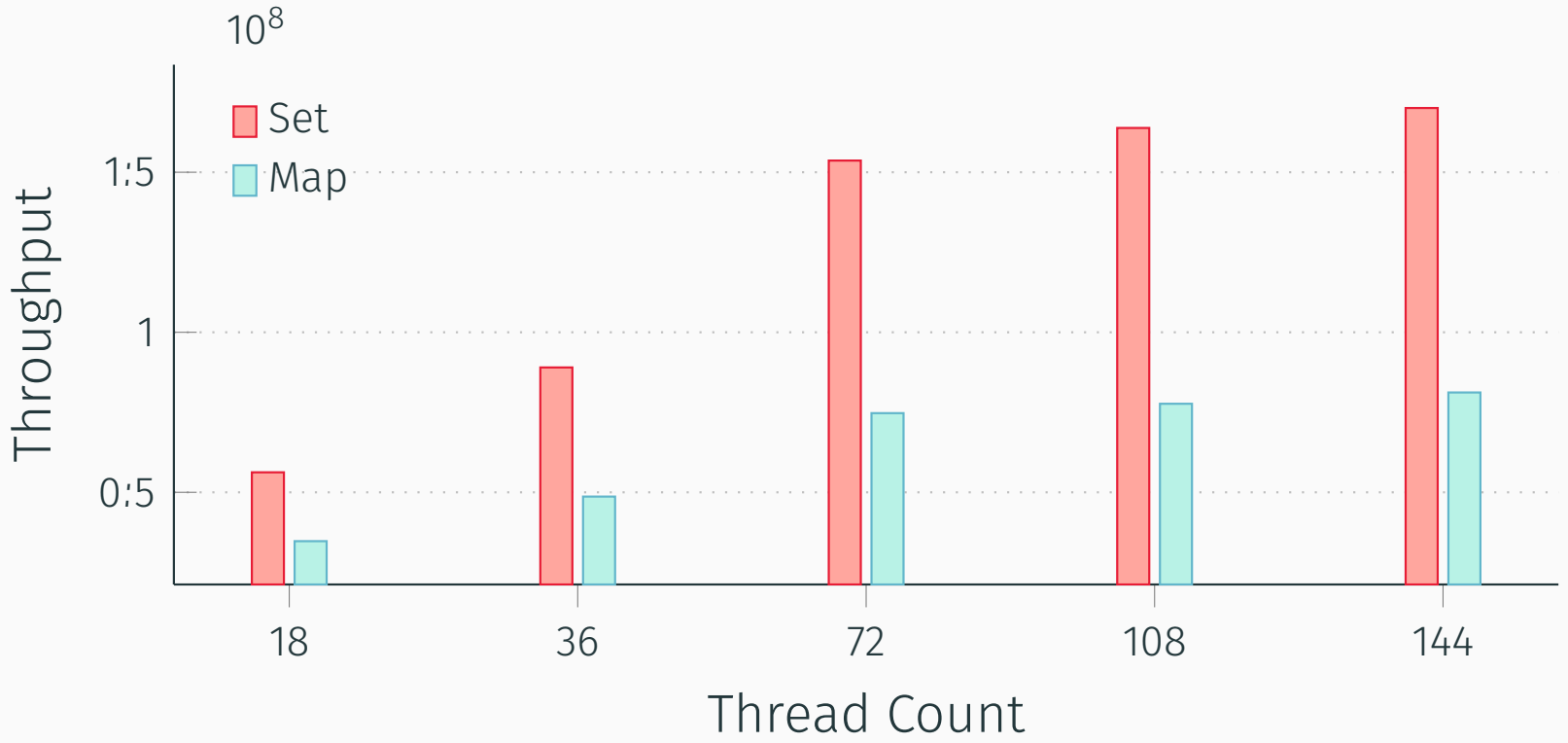

Map

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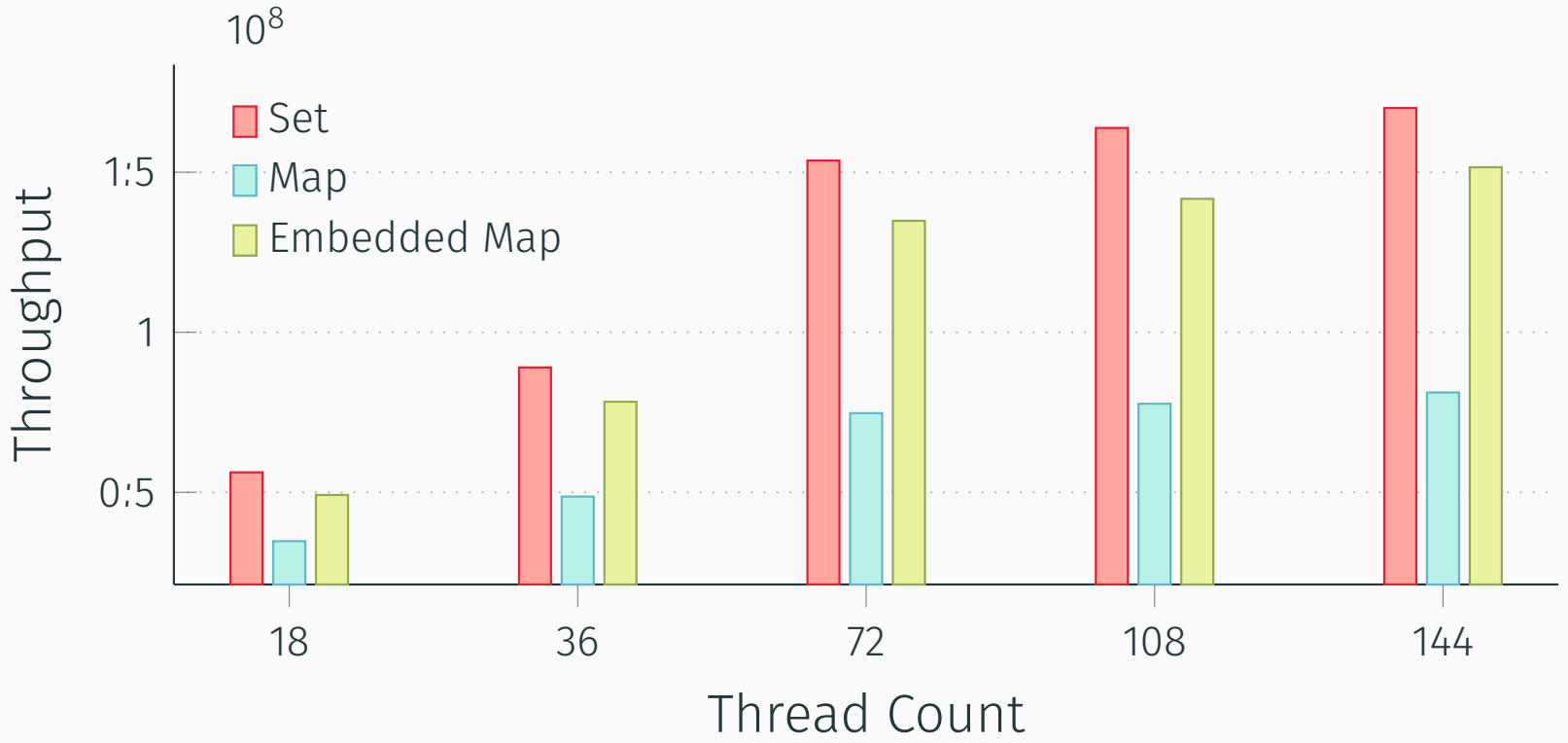
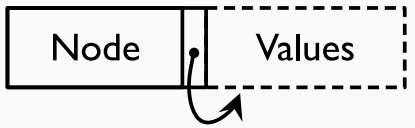


Map **Embedded Map**

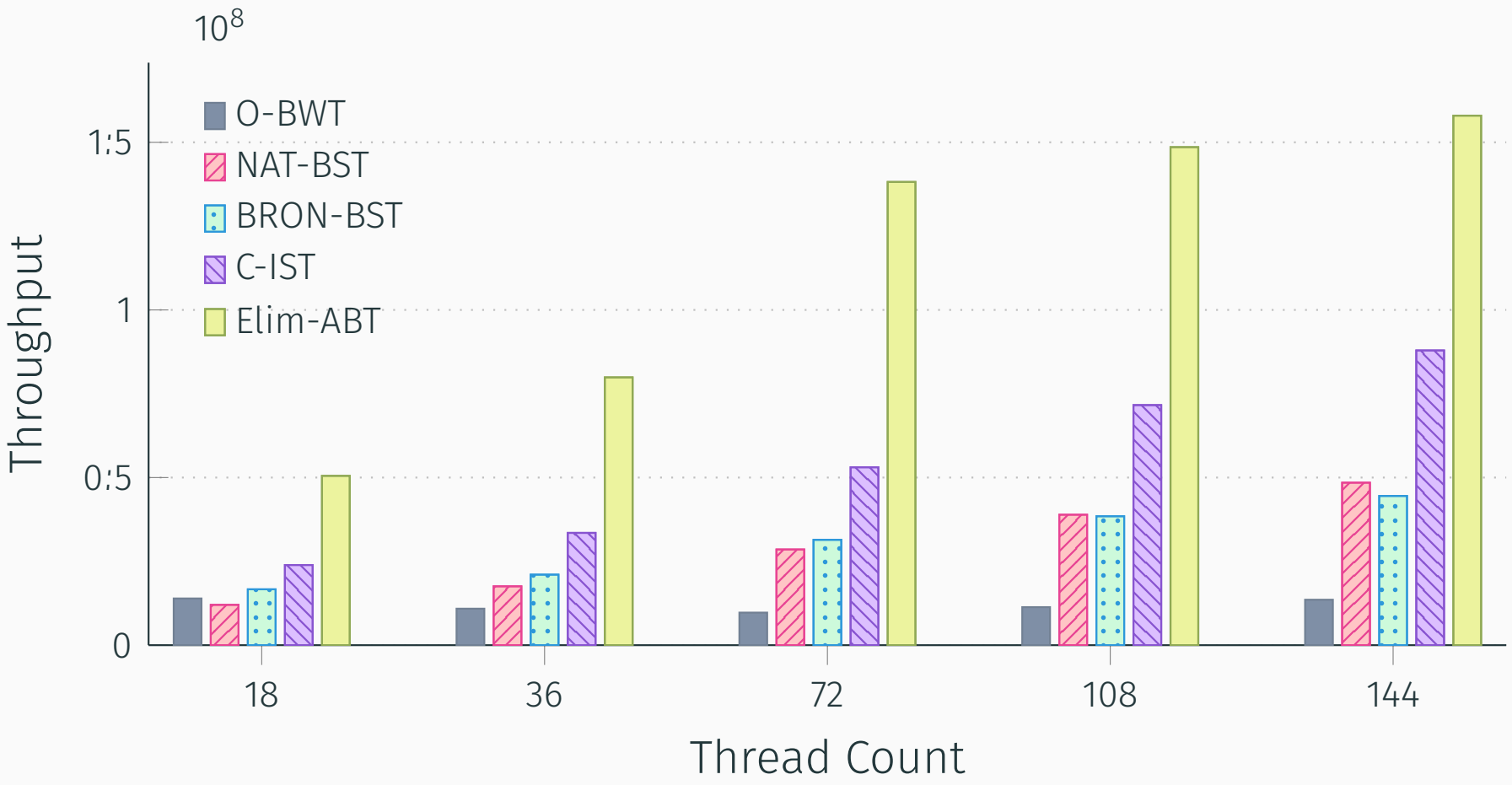


Experimental Evaluation

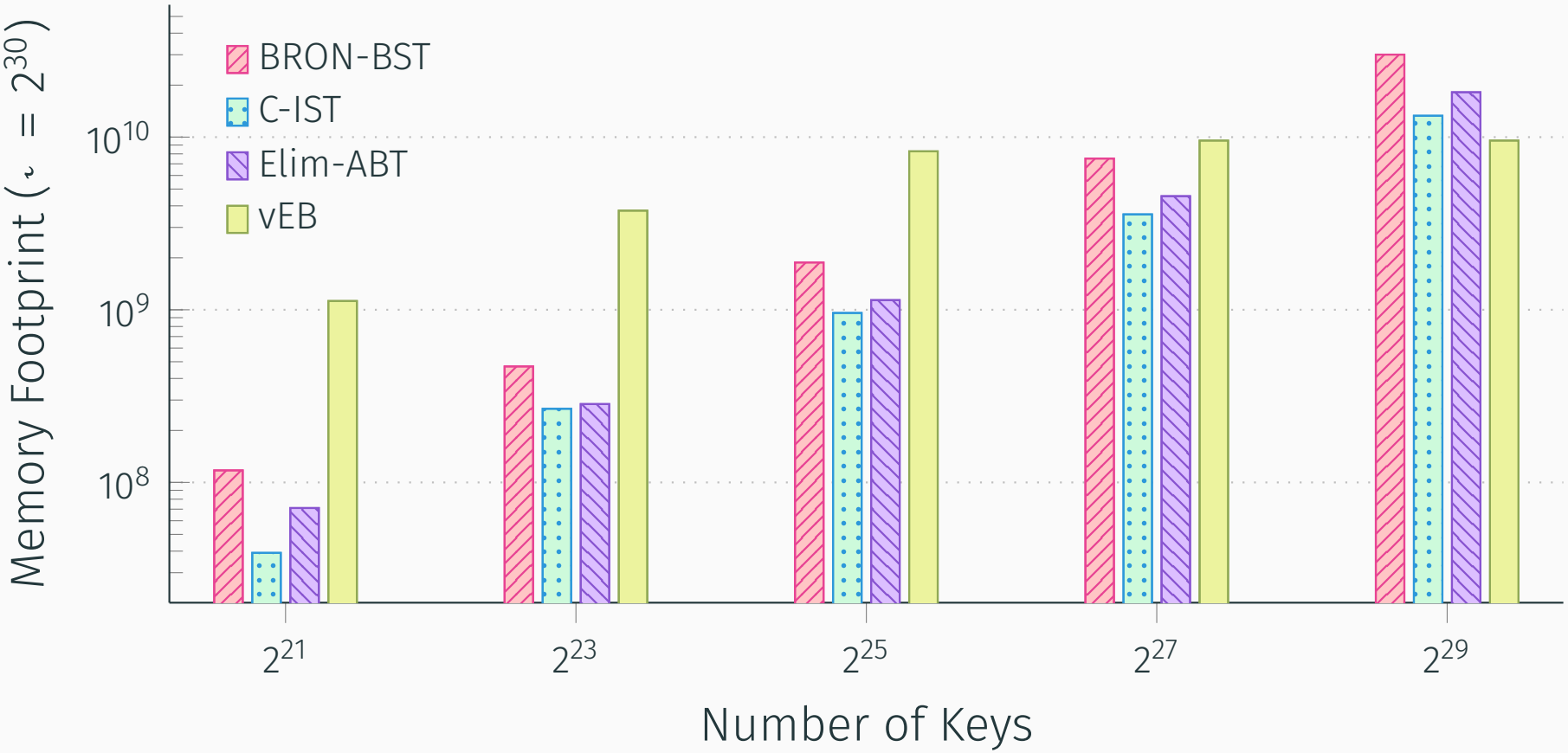
Experimental Setup

- Test harness: SetBench [2]
- 4 sockets 18 cores per socket = 72 cores, 144 hardware threads
- Comparison points:
  - **Elim-ABT:** A concurrent (a,b)-tree [3]
  - **C-IST:** A doubly logarithmic interpolation search tree [2]
  - **BRON-BST:** An OCC BST [1]
  - **O-BWT:** The open-source implementation of BW-Tree [5]

Performance

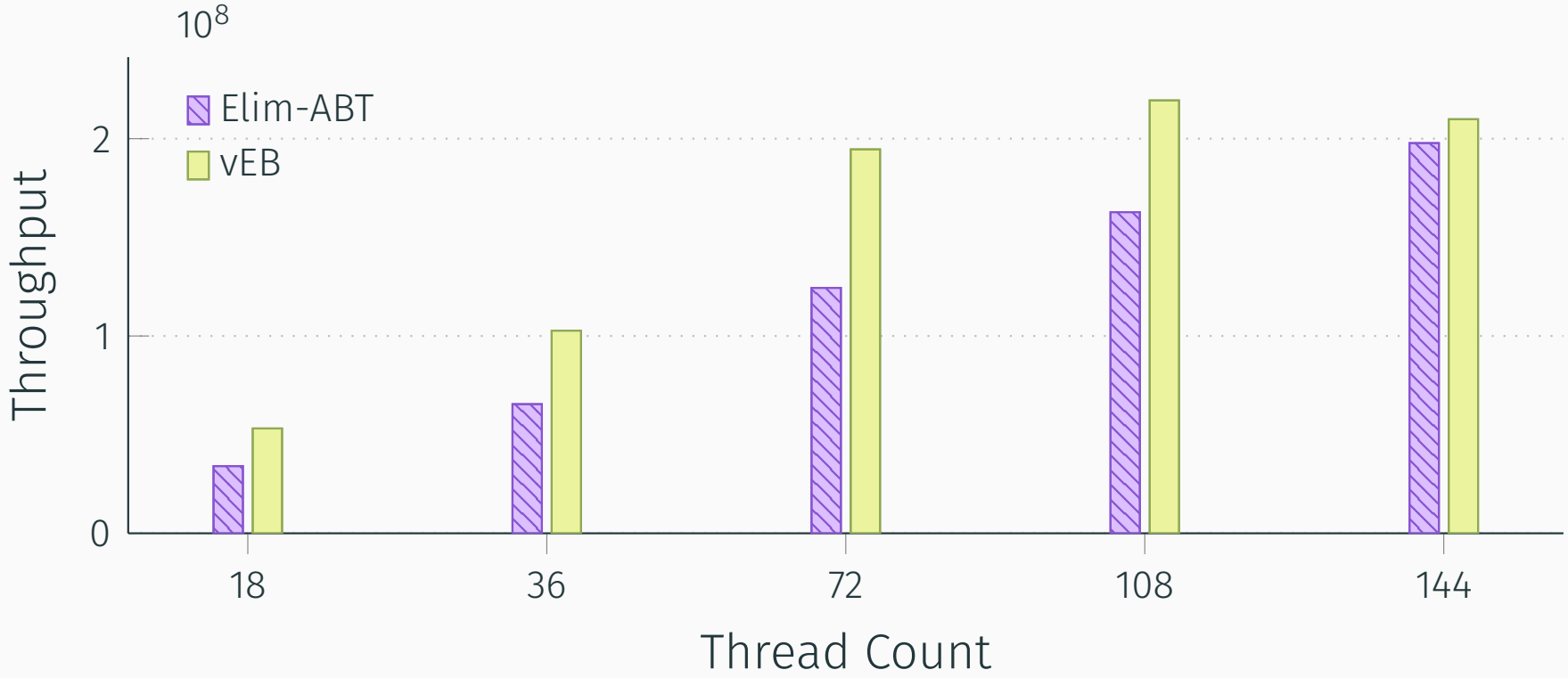


Memory Footprint



Successor Queries

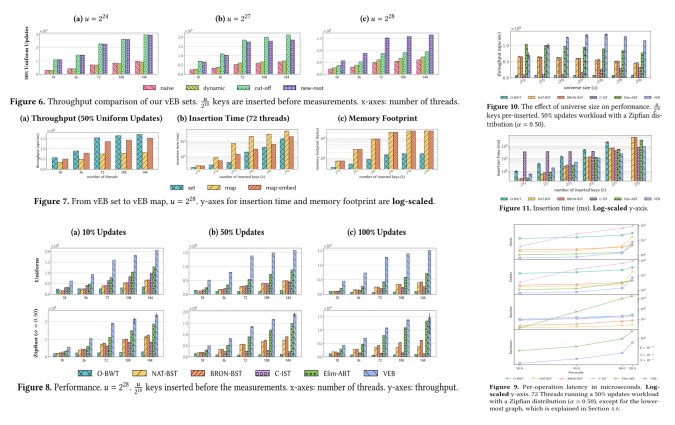
- The successor operation for Elim-ABT is non-linearizable
- Workload: 98% successor queries (Zipfian with = 0:50)



Summary

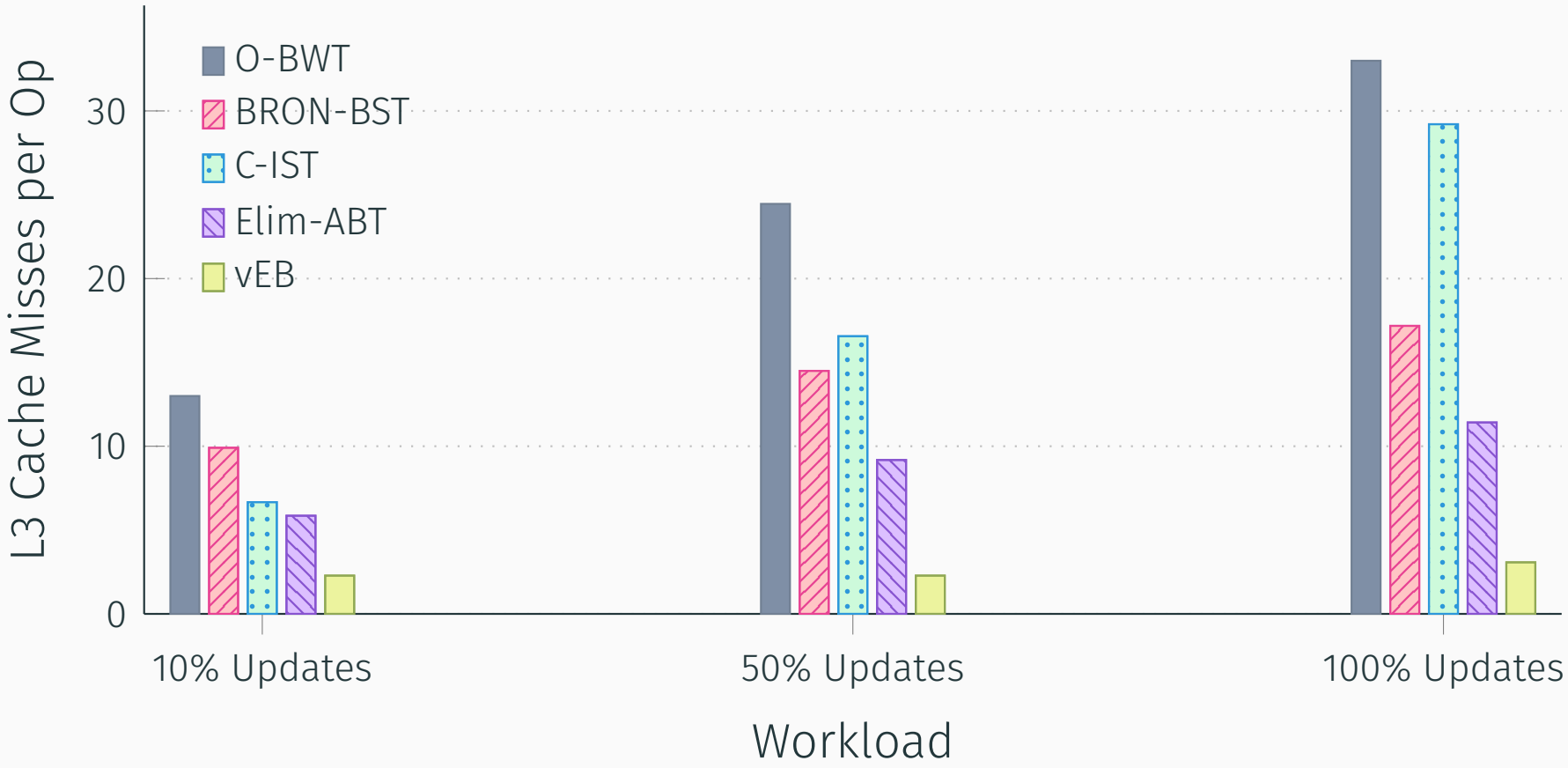
Summary

- Concurrent vEB trees utilizing HTM
- Low-overhead thread synchronization
- On average 5× faster
- More in the paper: **https://bit.ly/htmveb**
  - Zipfian workloads
  - Cache performance
  - Insertion time



Questions?

L3 Cache Misses



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