Building an Efficient Key-Value Store in a Flexible Address Space

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  - `db.get("cat") => 2022` Point Query
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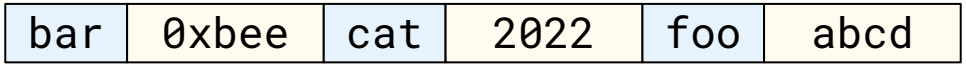
- Major KV stores manage **sorted data** for range queries

Managing Sorted Data

- Storing sorted data in structured files

(Simplified) File



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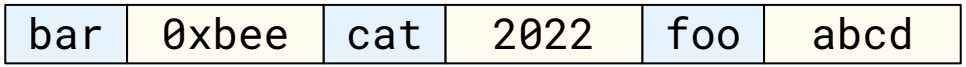

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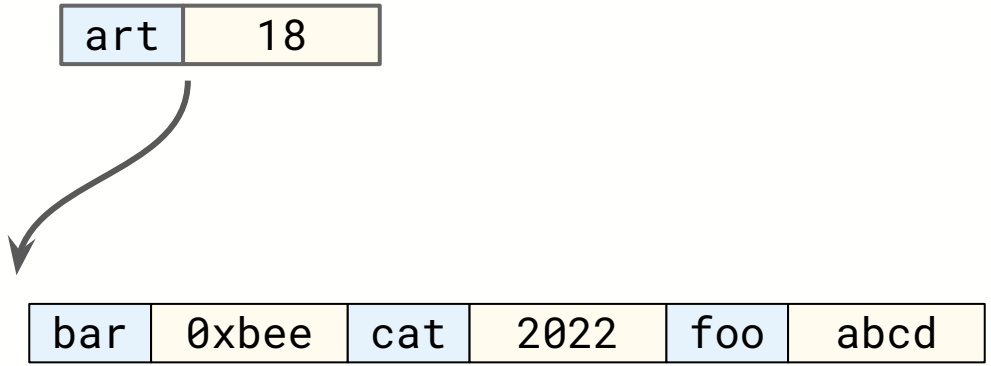

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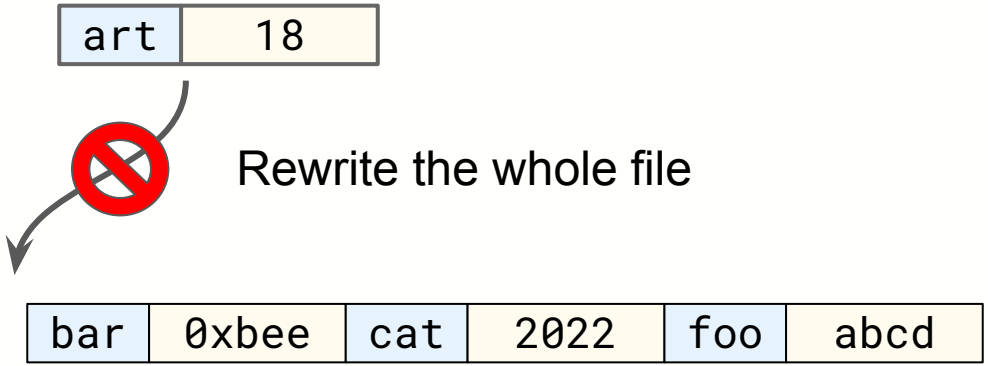

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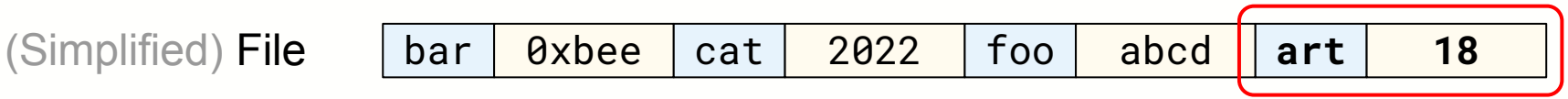

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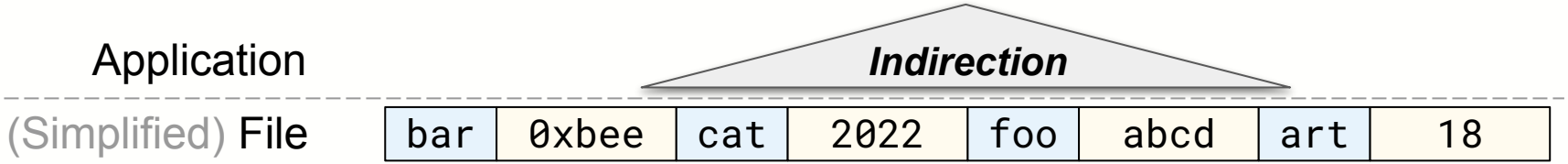

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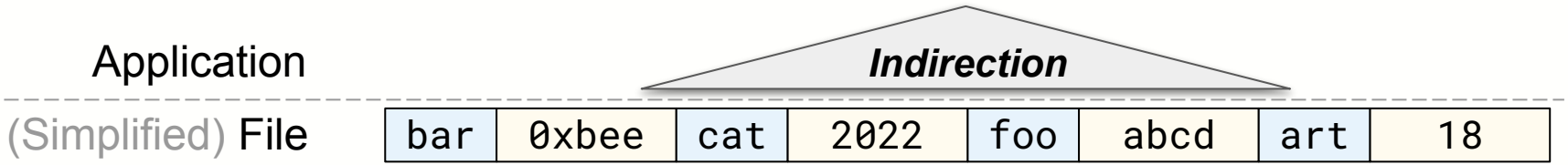

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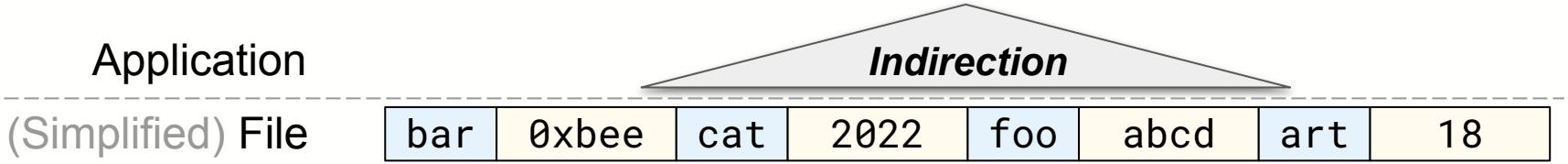

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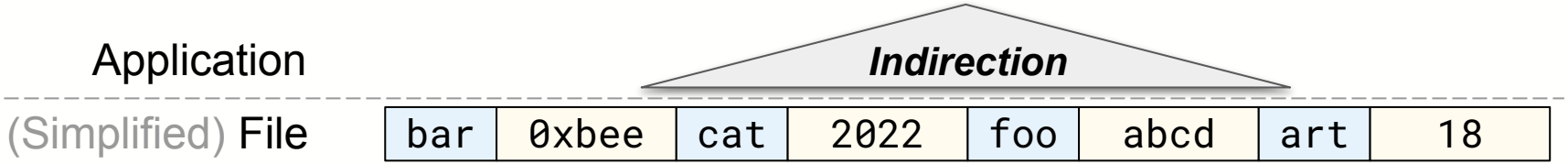

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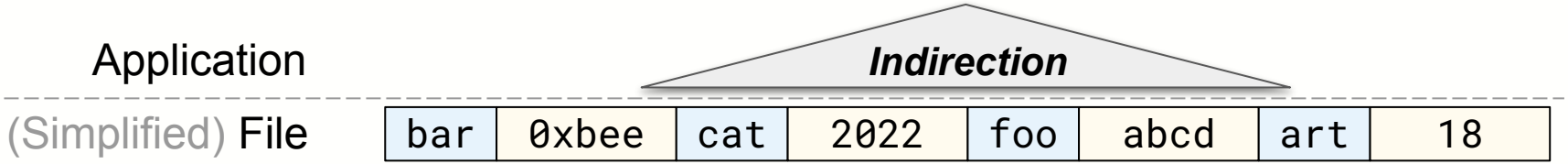

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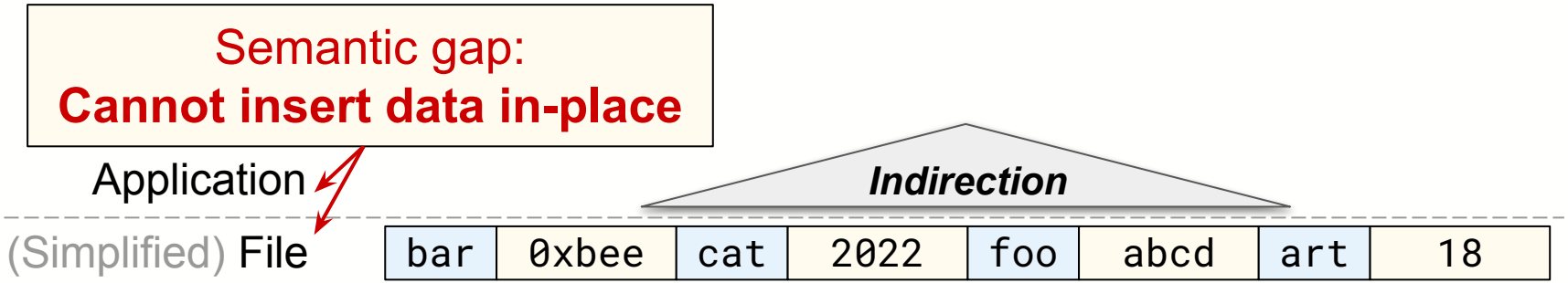

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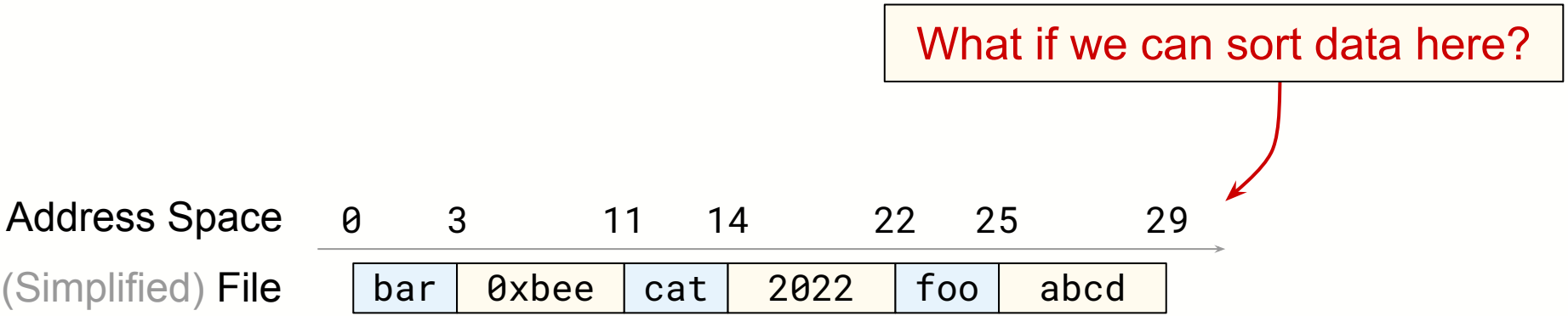

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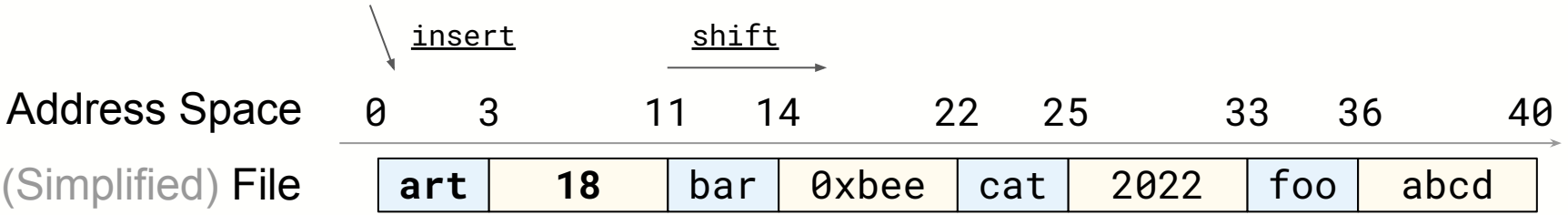

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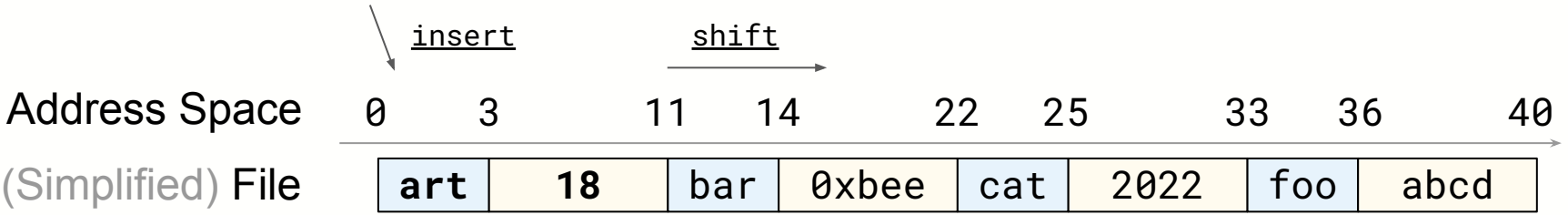

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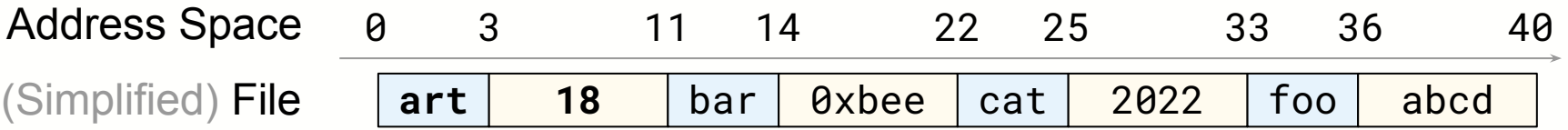

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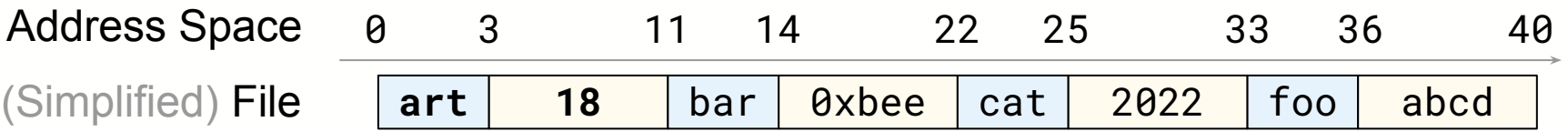
Logical offset -> physical address



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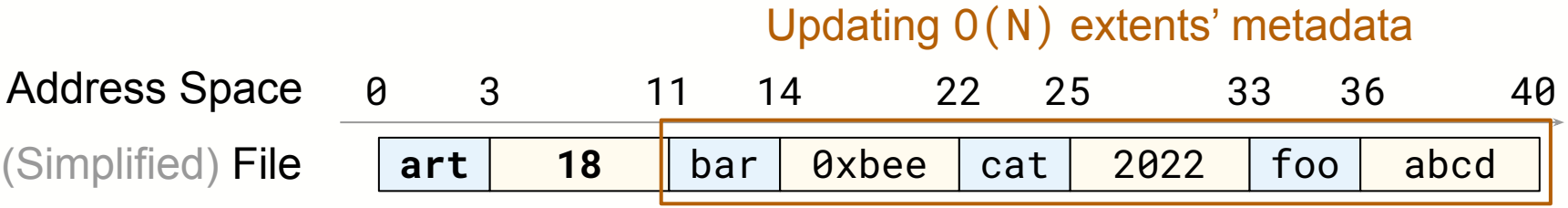

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    - In

3 orders of magnitude gap

Address Space

33 36 40

(Simplified) File

art	18	bar	0xbee	cat	2022	foo	abcd

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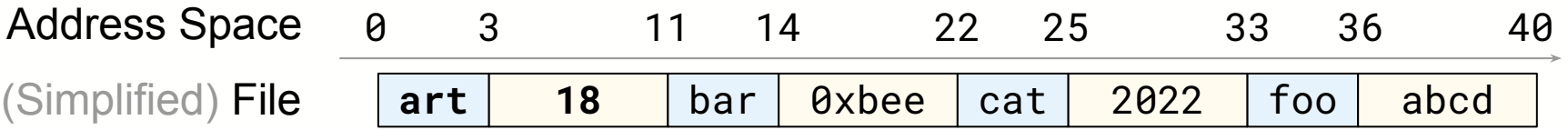

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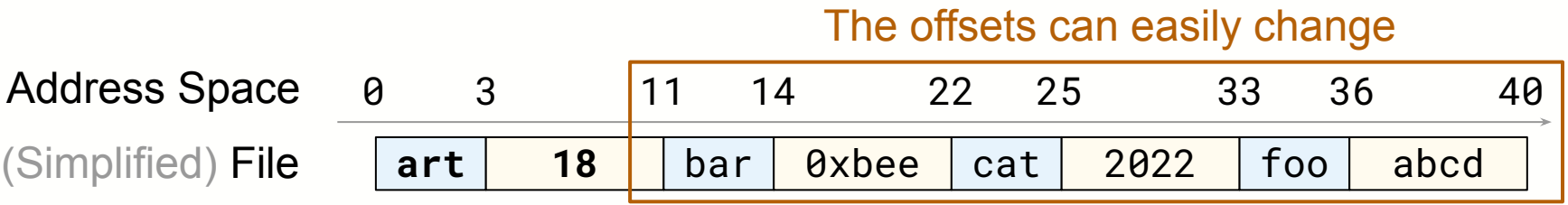

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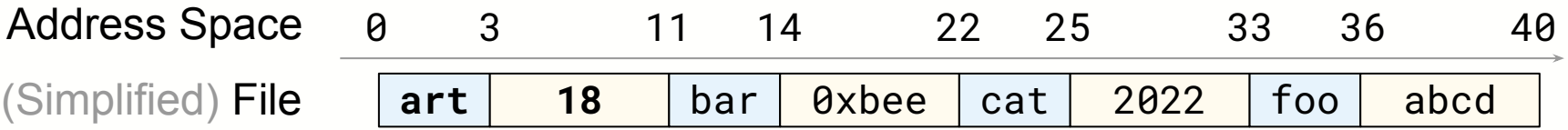
A more flexible storage abstraction to manage sorted data!



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- Challenges => The Solution
  - Inefficient shifting in extent index => Index structure with efficient shifting
  - Rigid block alignment requirements => No alignment requirements
  - Inability to track shifting data => Managing shifting data

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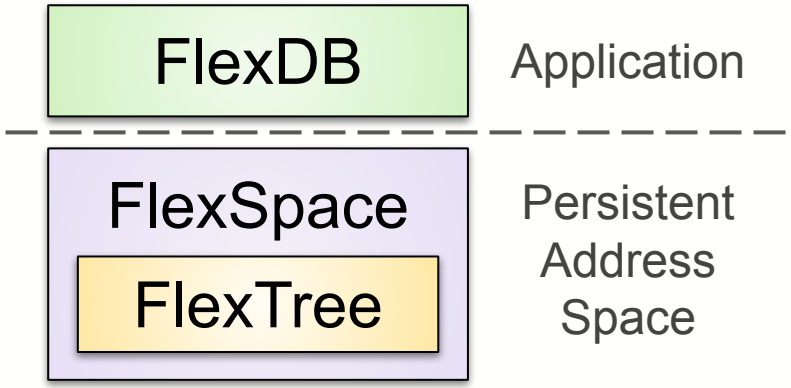

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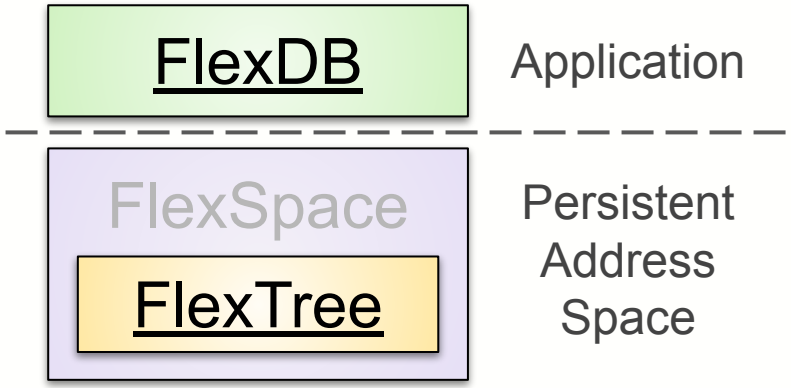

Starting from B$^+$-Tree

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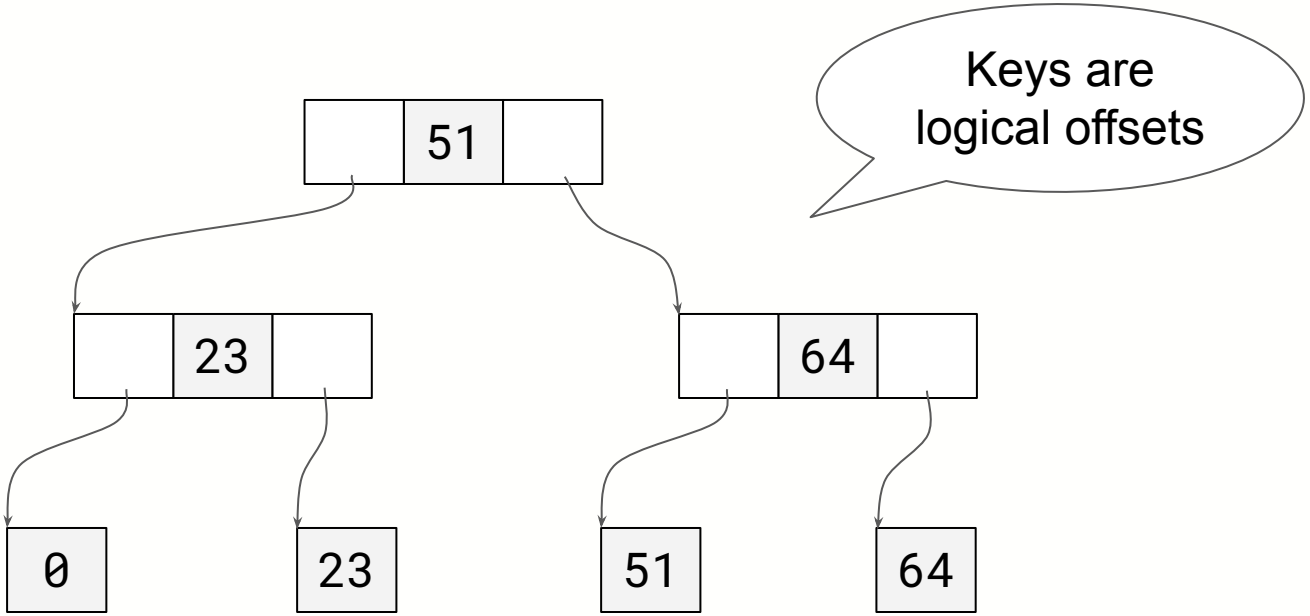

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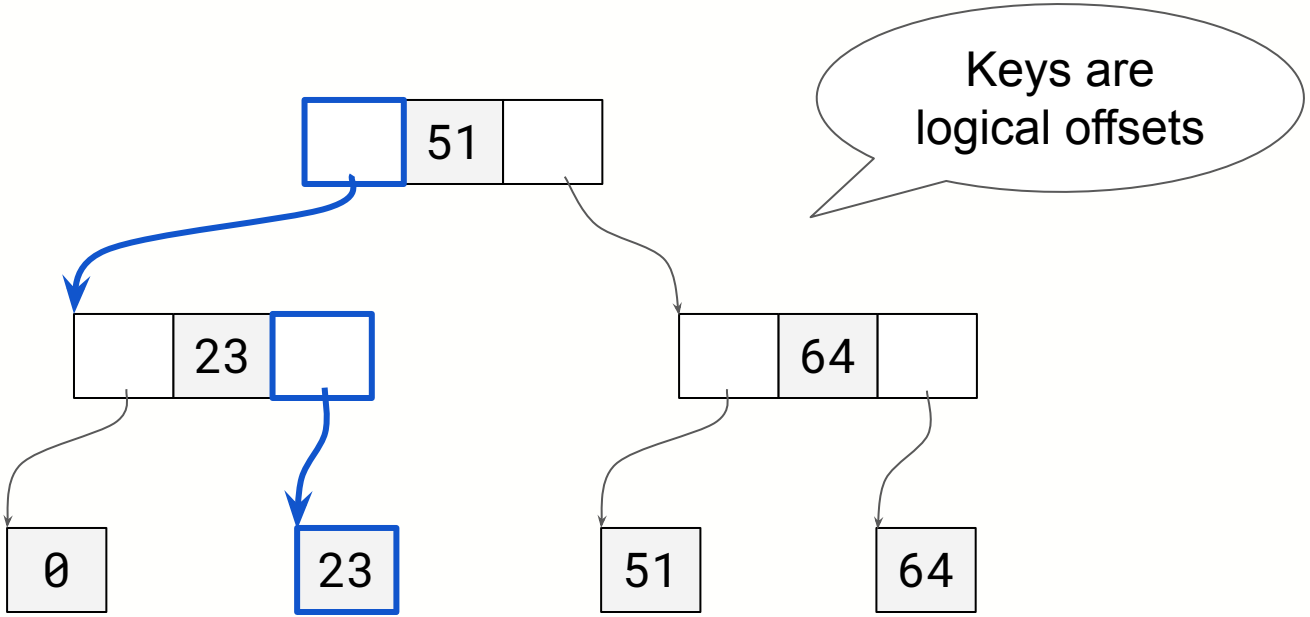

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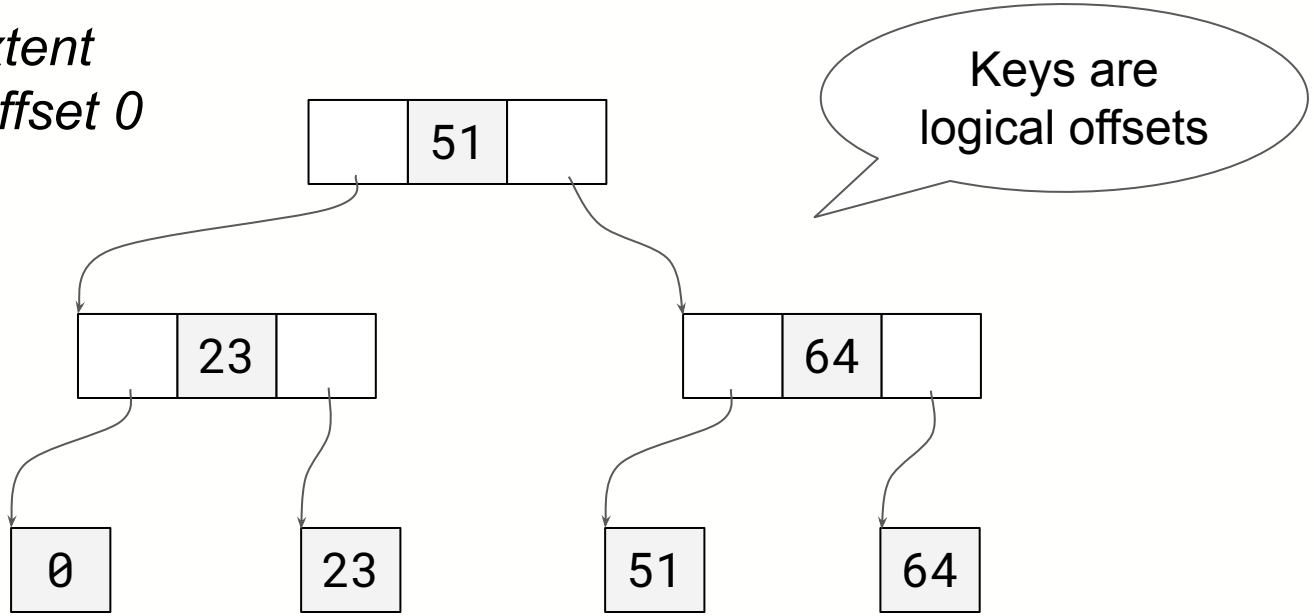

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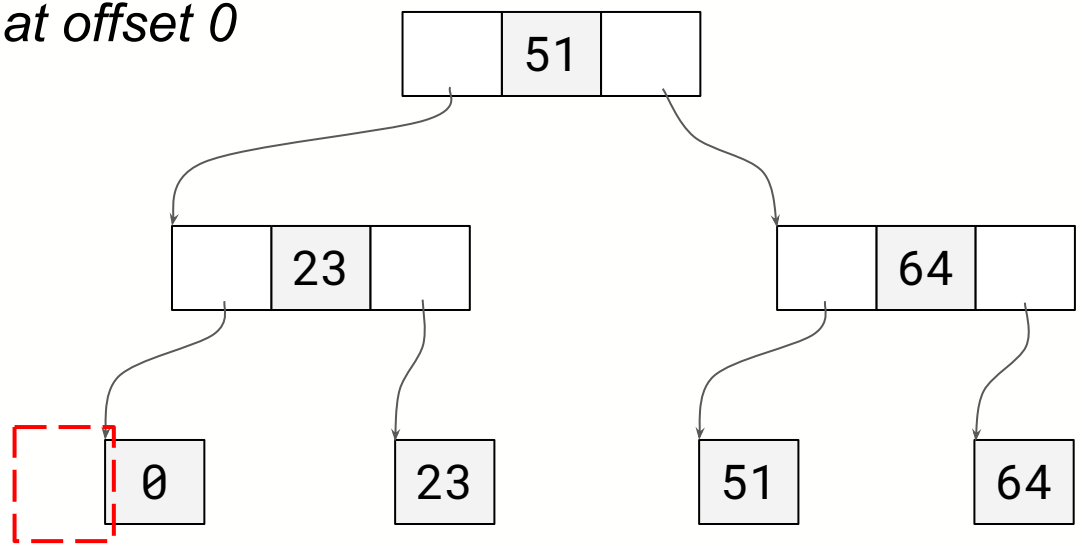

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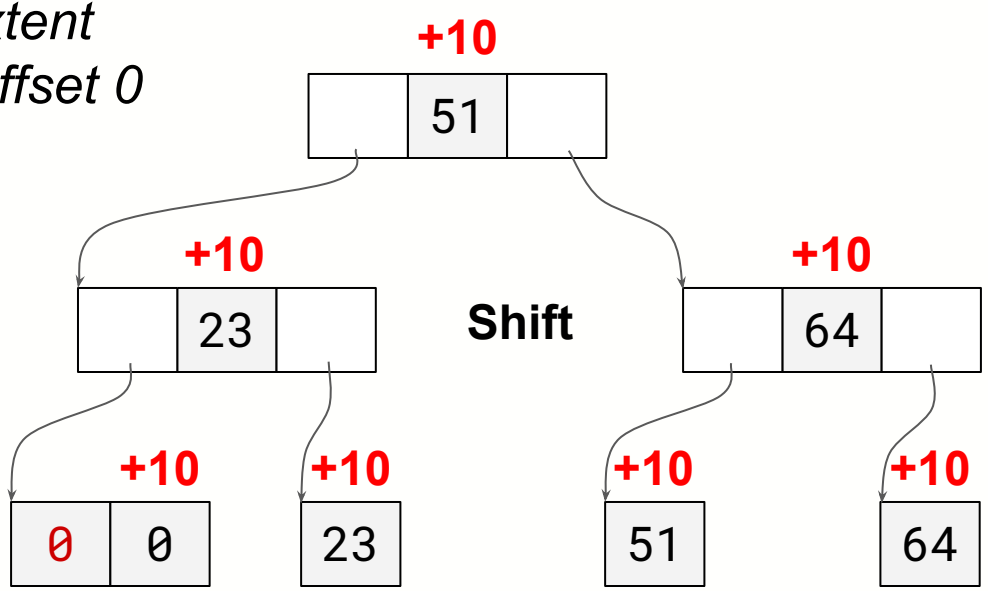
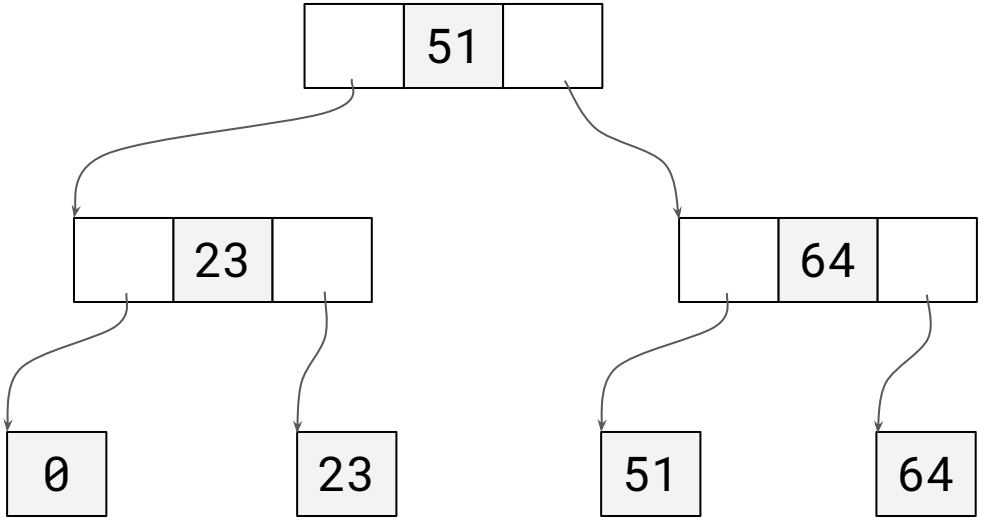


FlexTree: Structure

- An index structure derived from B^+-Tree
  - A new metadata representation scheme



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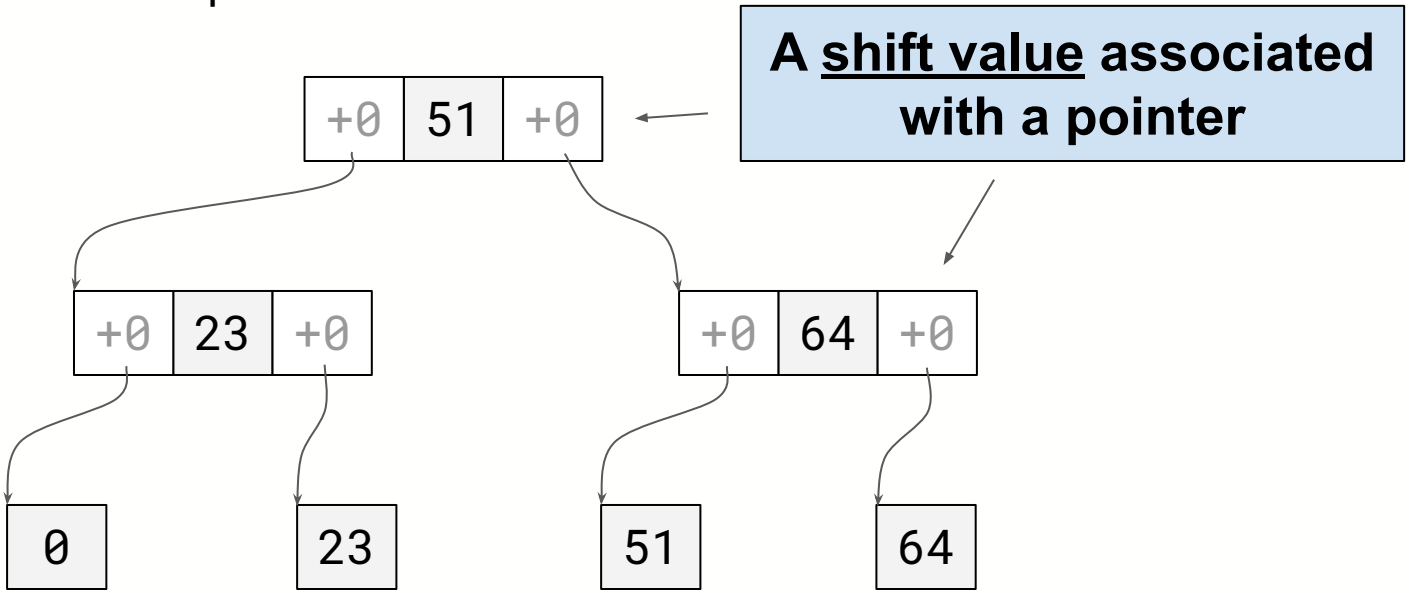

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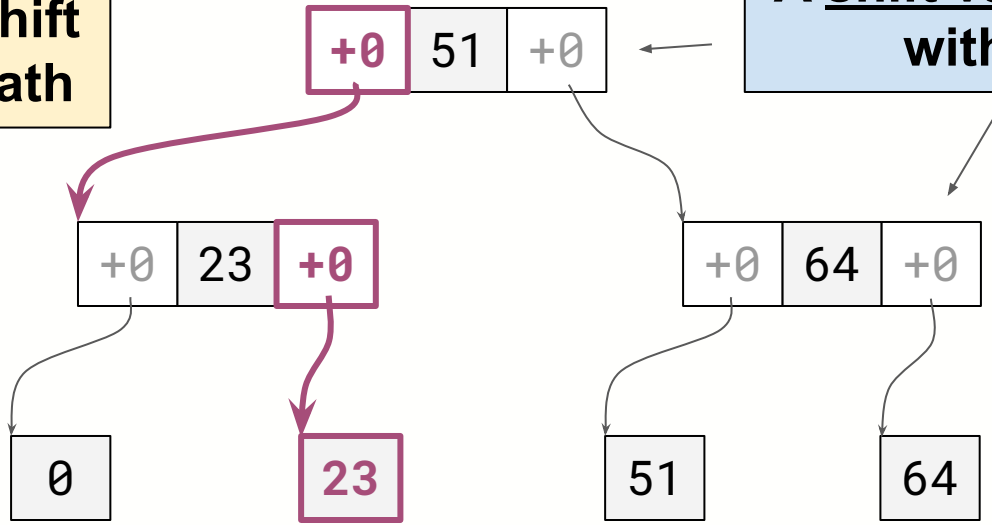
Adding all the shift values on the path

A shift value associated with a pointer



23 + (+0) + (+0) = 23

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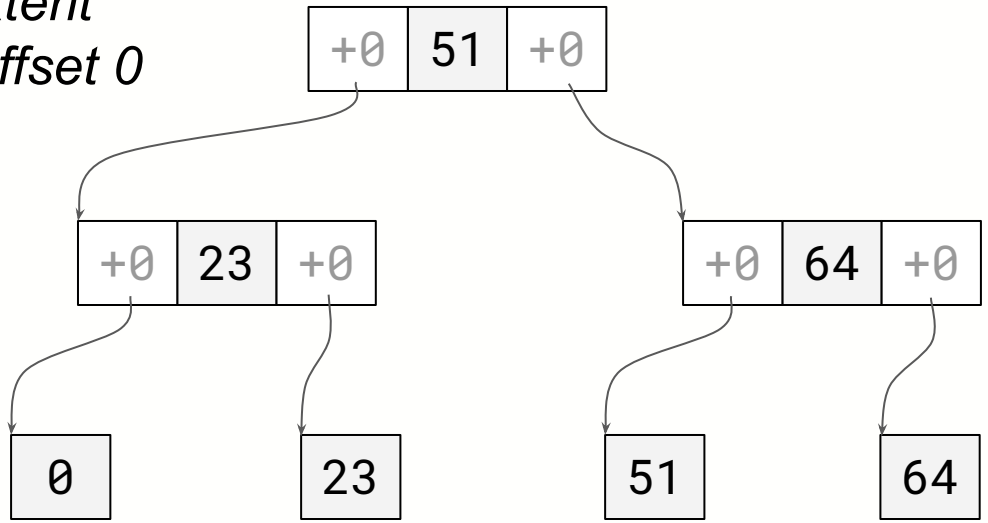

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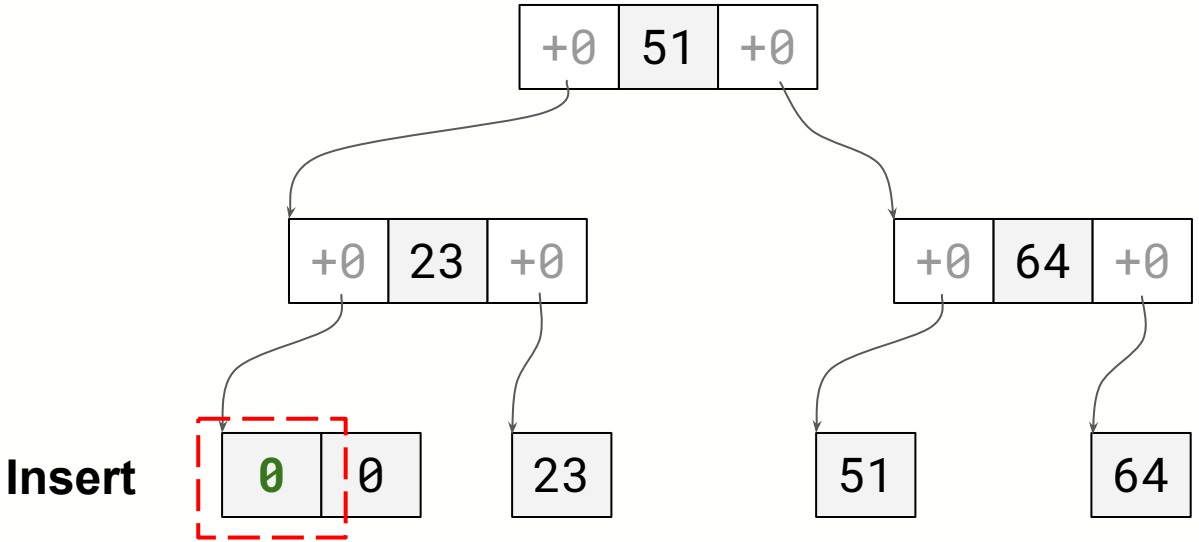

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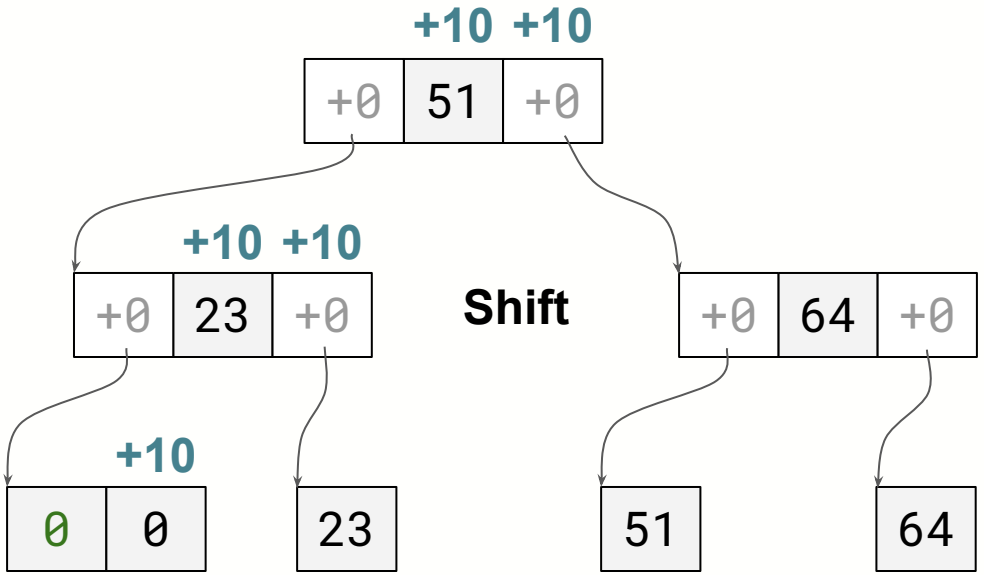

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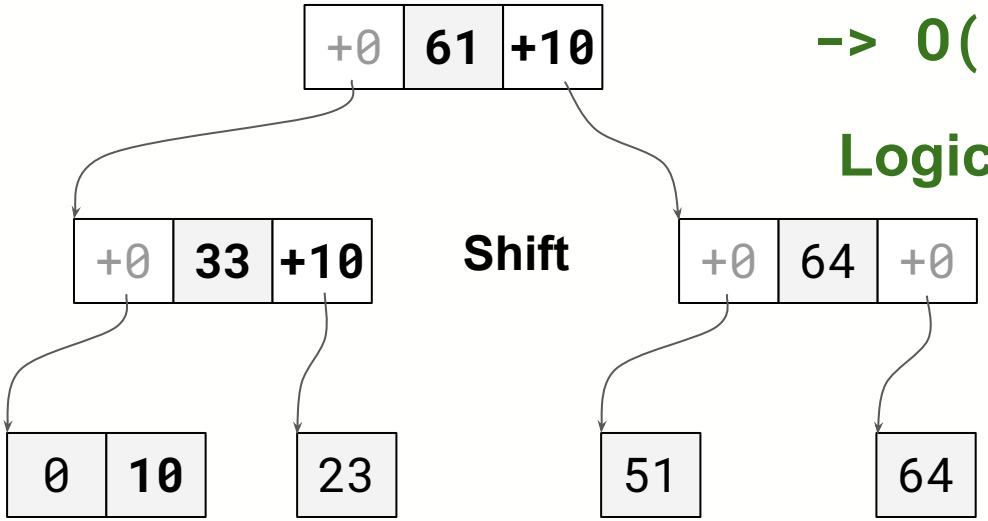
Nodes on the path updated
-> O(logN) cost

Logical logging



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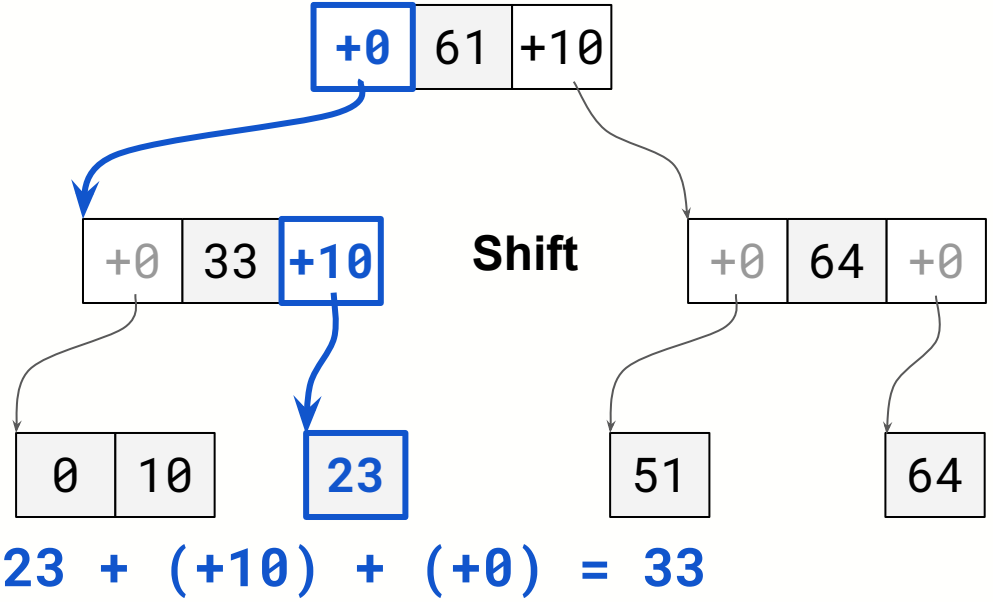

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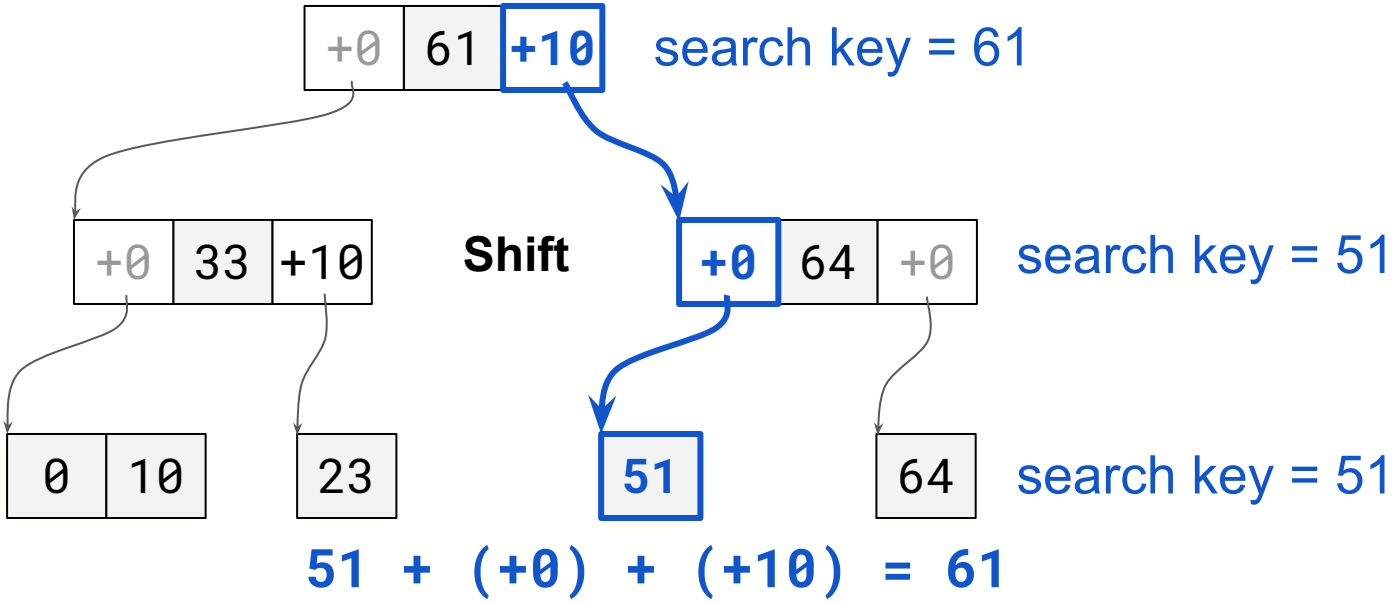


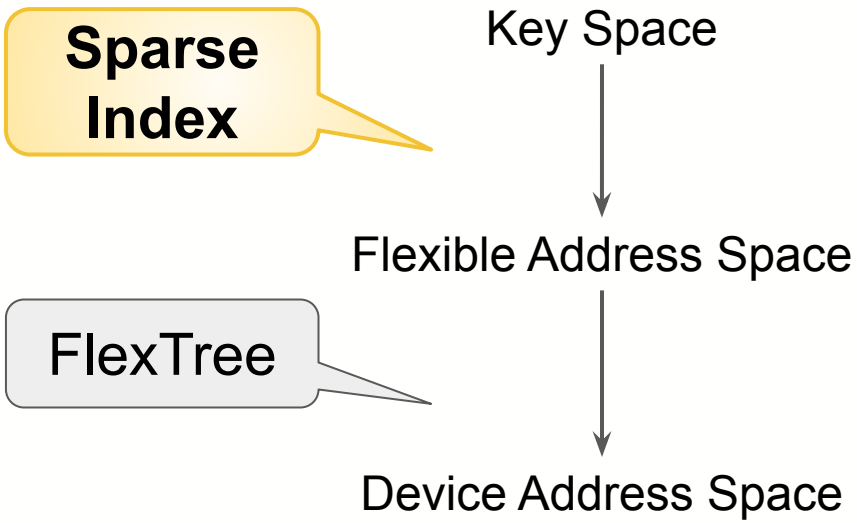
Based on FlexTree

- FlexSpace: Log-structured data storage indexed by FlexTree
  - Supporting read/write/insert-range operations etc.

- FlexDB: Keeping all KV pairs sorted in a FlexSpace

FlexDB

- Keeping all KV pairs sorted in a flexible address space



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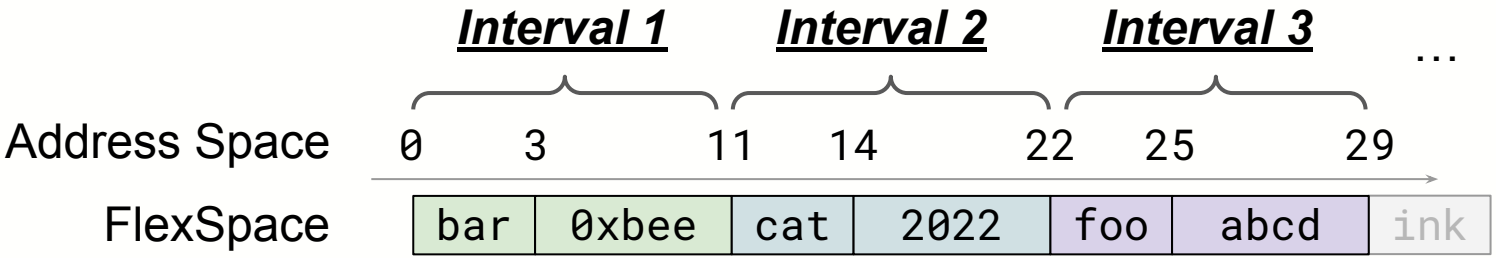

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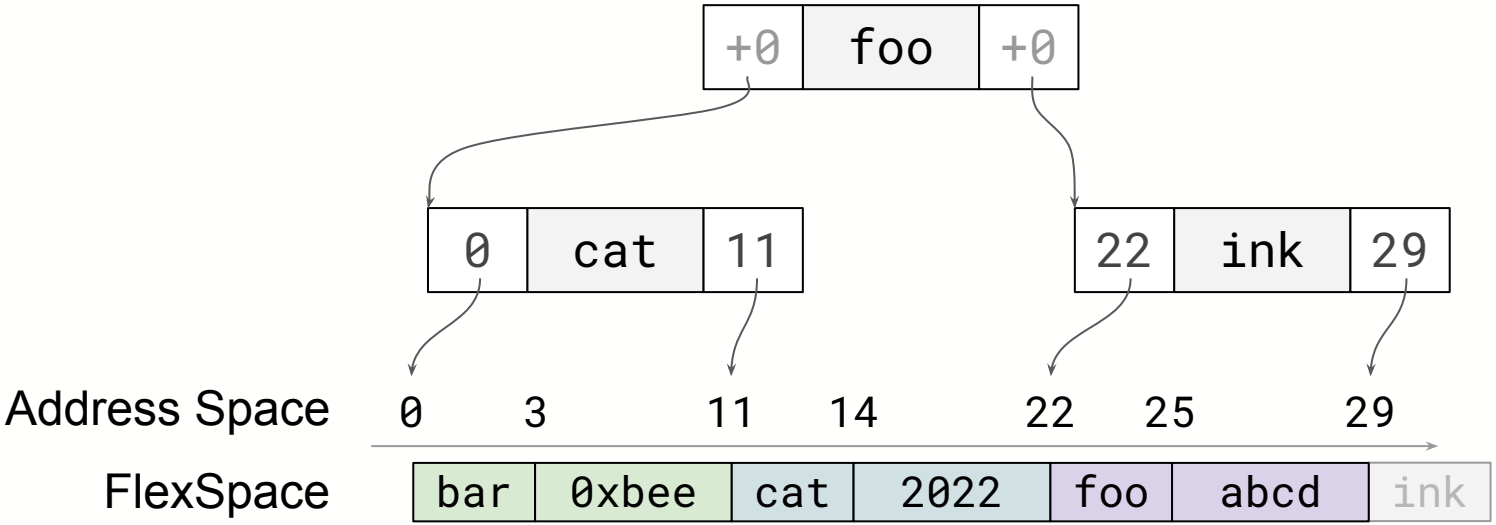

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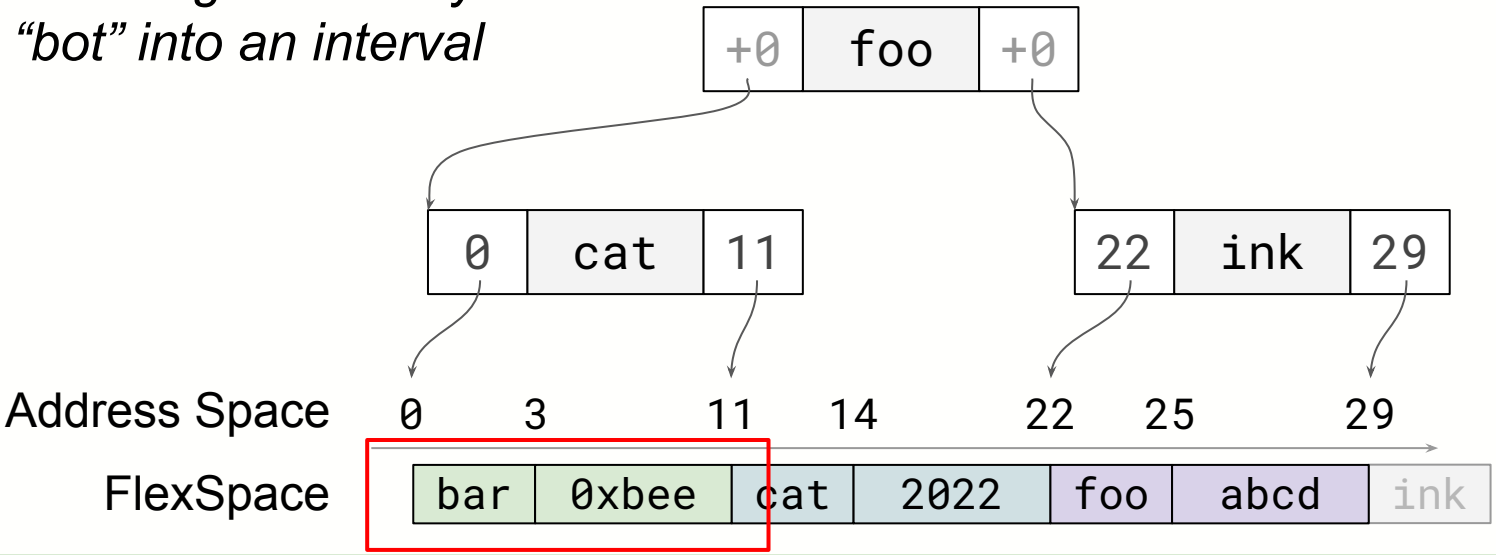
Inserting a new key “bot” into an interval



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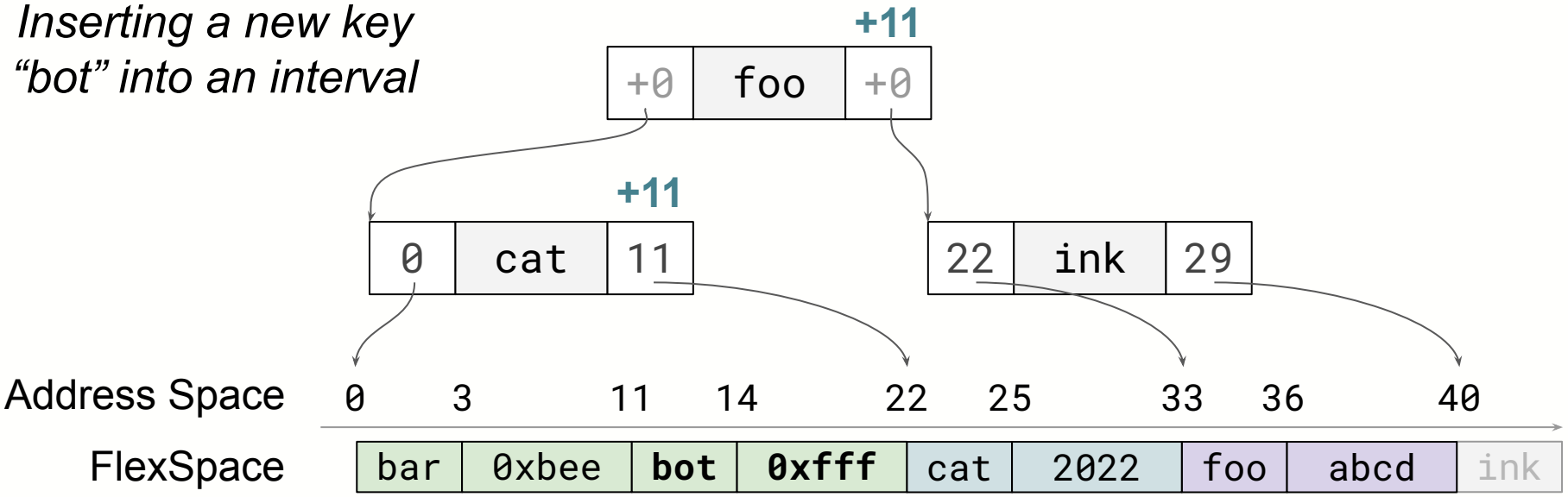
Inserting a new key “bot” into an interval



FlexDB: Sparse Index

- Managing sorted keys in *intervals*
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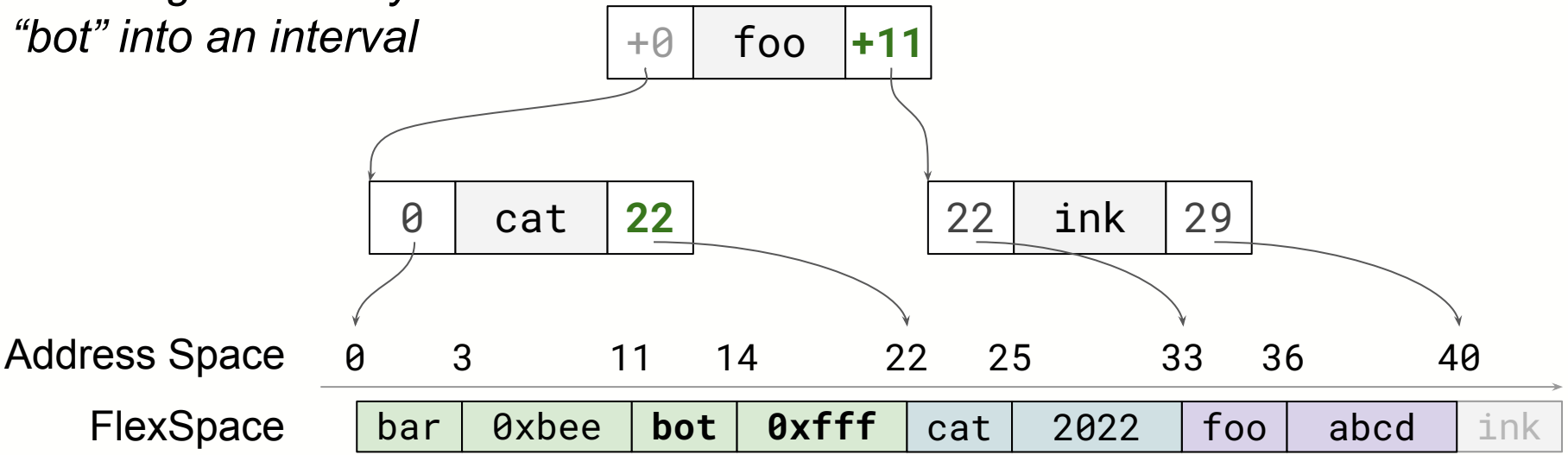

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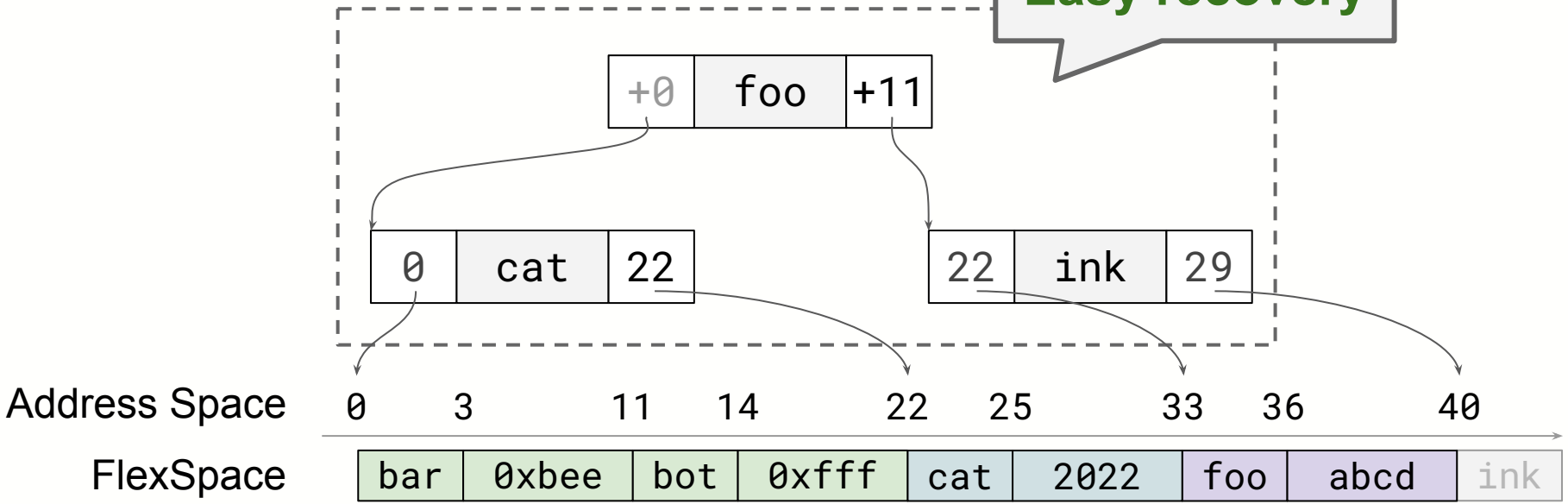

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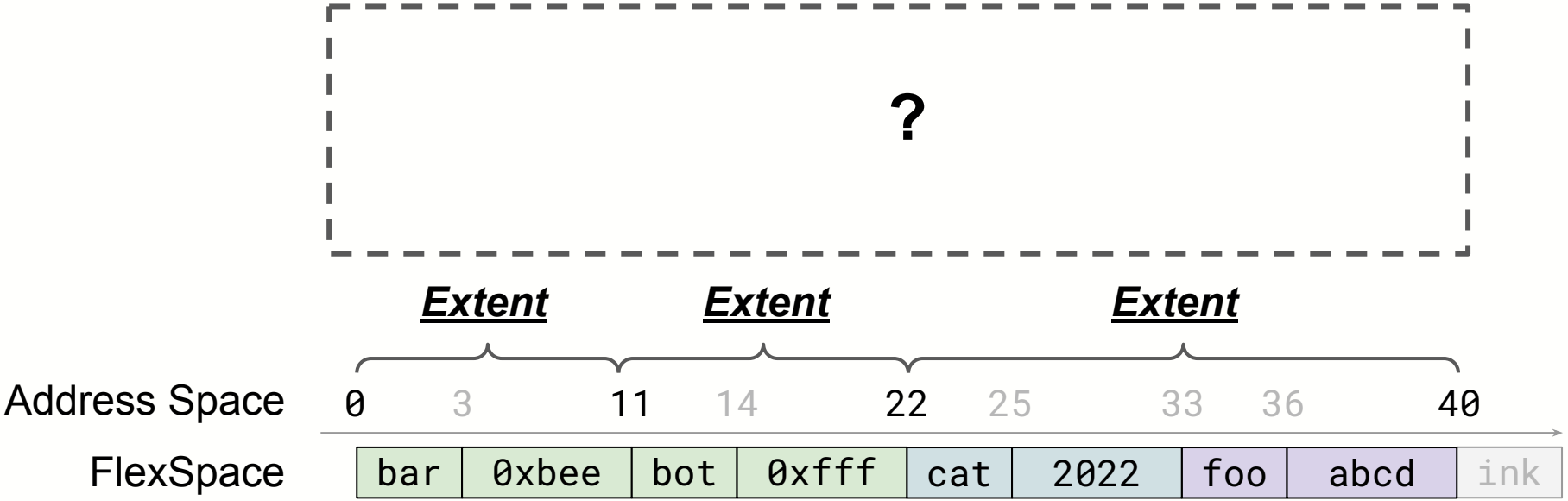

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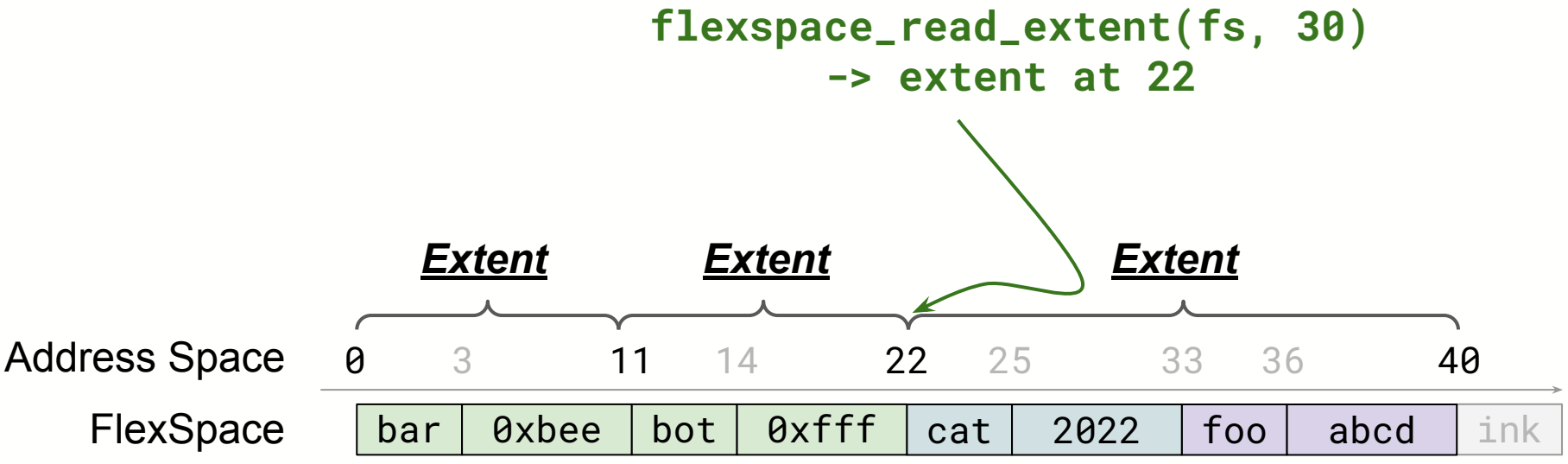

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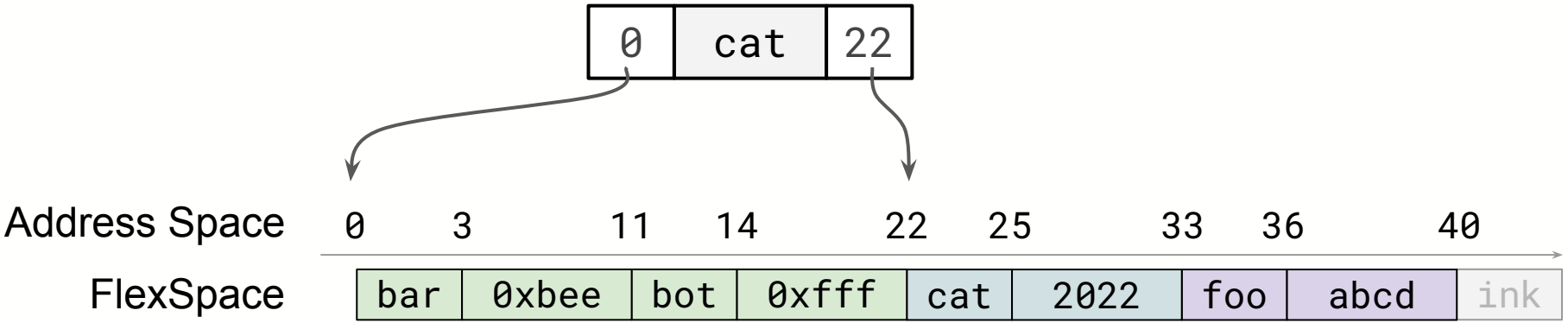


Recap

- FlexTree enables lightweight data insertions in a flexible address space.
- FlexDB manages sorted data without using extra persistent indirections.

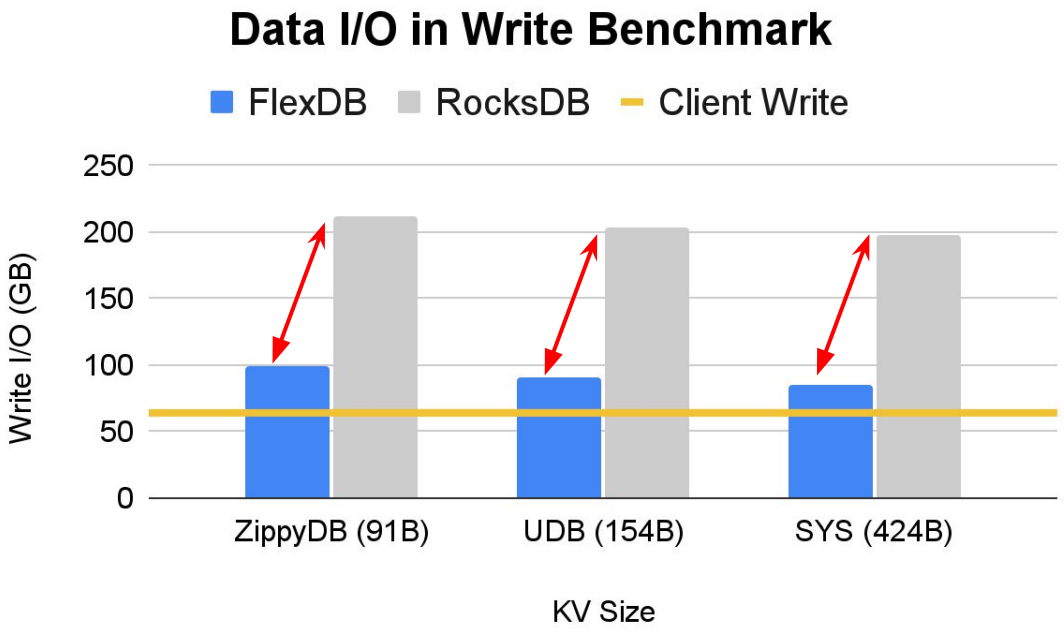
Evaluation: Setup

- Intel Xeon Silver 4210 w/ 10 cores
- 64GB RAM
- Optane 905P SSD
- Key-Value Sizes:
  - ZippyDB: 91 bytes *
  - UDB: 154 bytes *
  - SYS: 424 bytes **
- 4 Client Threads

* Zhichao Cao, Siying Dong, Sagar Vemuri, and David H. C. Du. “Characterizing, Modeling, and Benchmarking RocksDB Key-Value Workloads at Facebook”. In: 18th USENIX Conference on File and Storage Technolo gies (FAST’20). 2020, pp. 209–223.
** Berk Atikoglu, Yuehai Xu, Eitan Frachtenberg, Song Jiang, and Mike Paleczny. “Workload Analysis of a Large-Scale Key-Value Store”. In: SIGMETRICS Per form. Eval. Rev. 40.1 (2012), pp. 53–64.

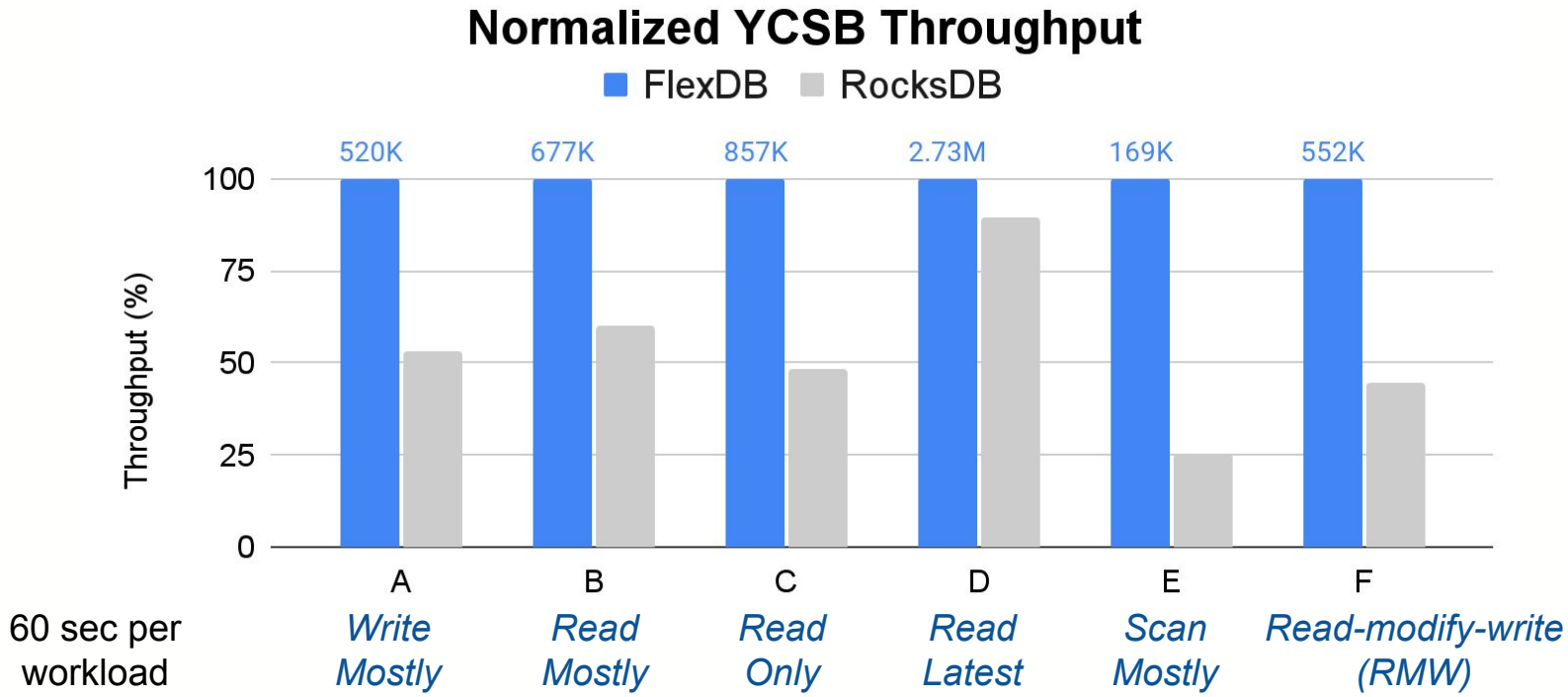
Evaluation: Disk I/O

- Write 64GB into an empty store; Zipfian distribution



Evaluation: YCSB

- Starting from a 500GB UDB store; Zipfian distribution



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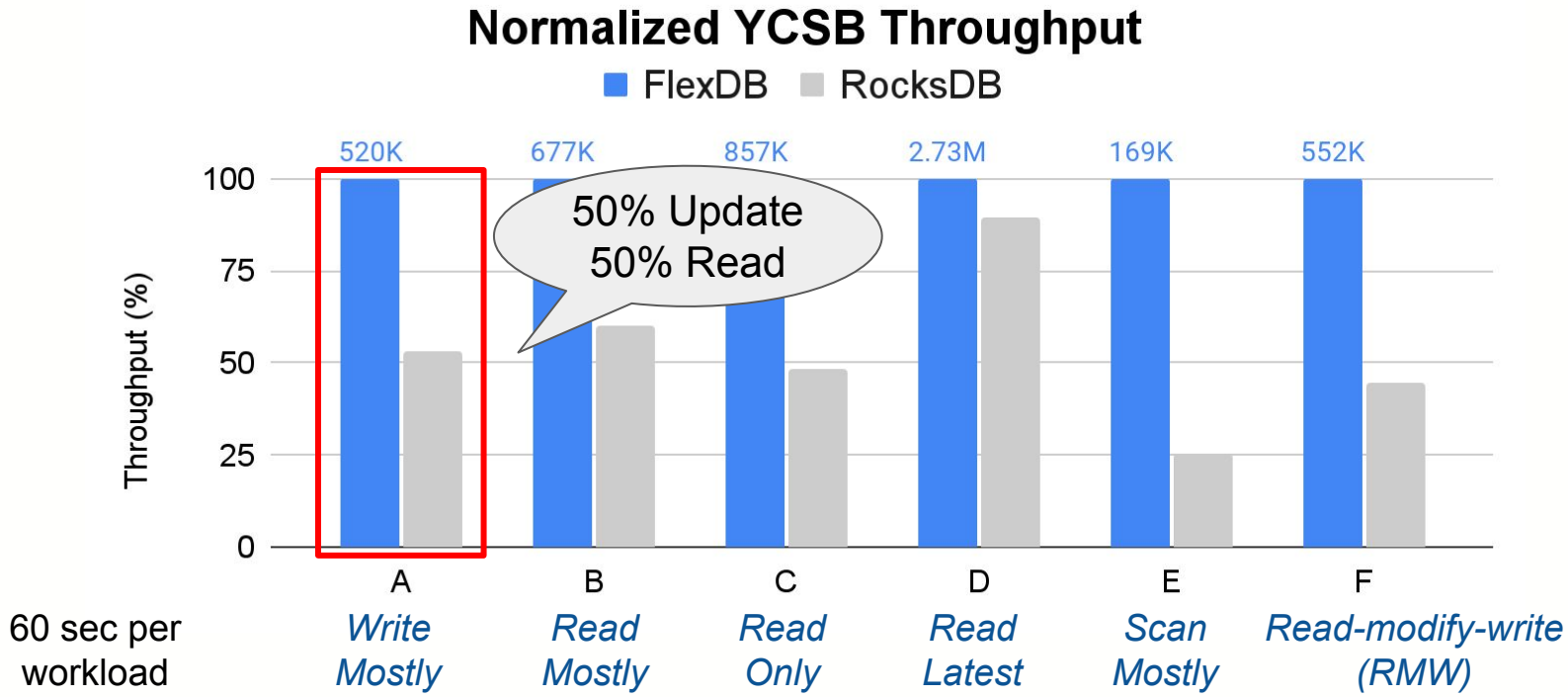

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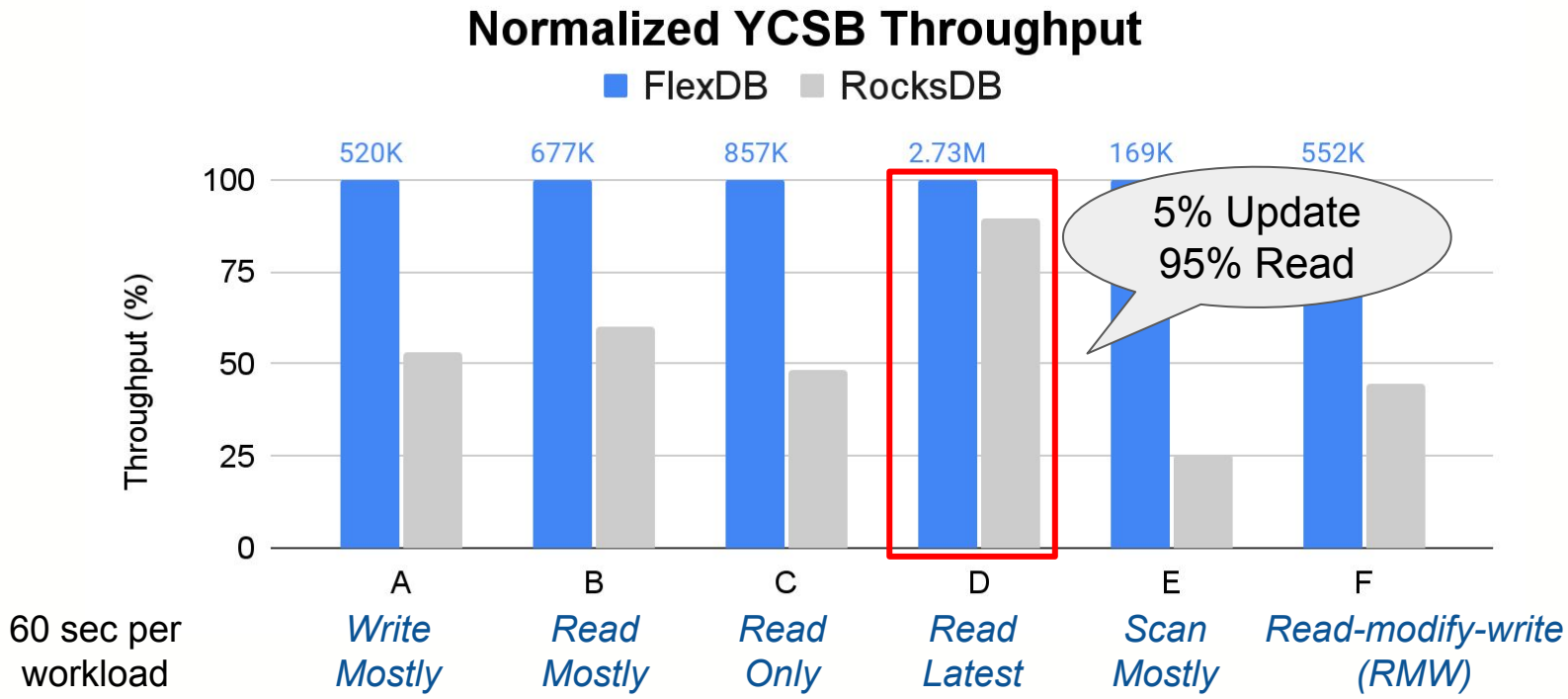

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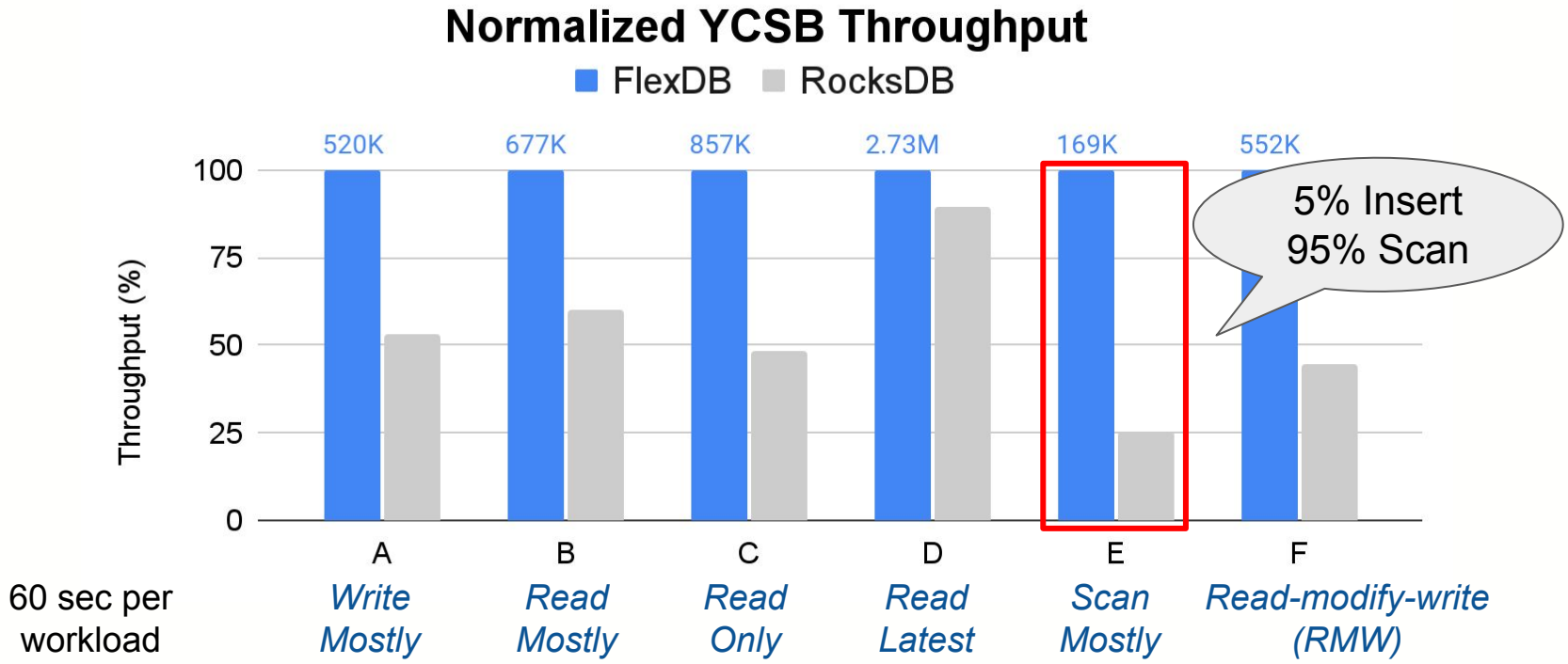

Summary

- Flexible address space enables lightweight data management.
- FlexDB achieves low WA and high throughput.

- The code of this project is available at:
  https://github.com/flexible-address-space/flexspace