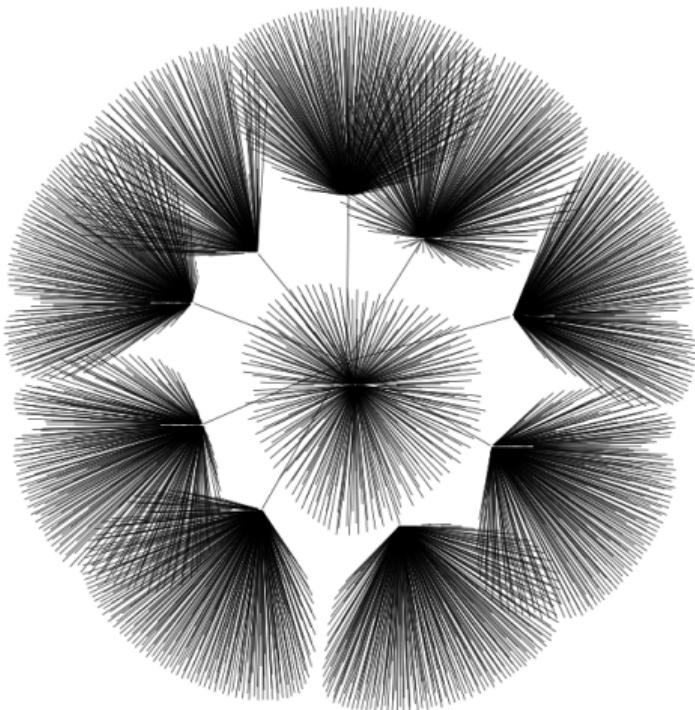




Modern BTree techniques

DMITRII DOLGOV

12-09-2022

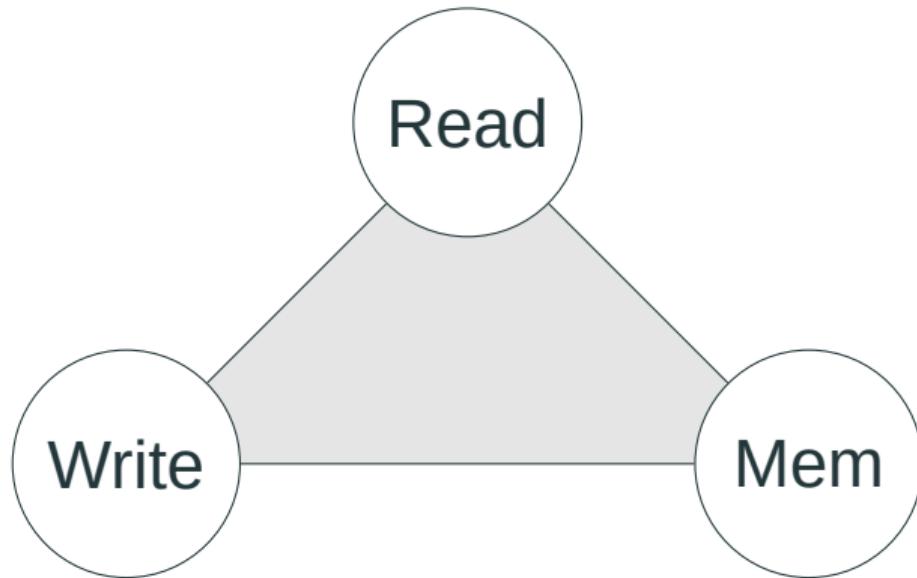


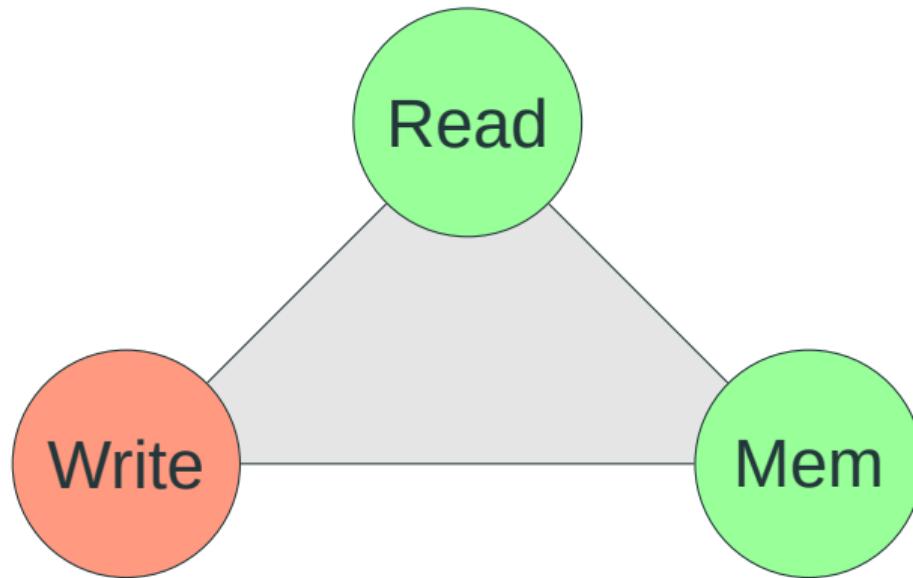
→ D. Comet, "Ubiquitous B-tree", ACM Comp. Surv.,
vol. 11, no. 2, 1979.

- D. Comet, "Ubiquitous B-tree", ACM Comp. Surv., vol. 11, no. 2, 1979.
- Graefe, Goetz and Harumi A. Kuno. "Modern B-tree techniques." IEEE 27th International Conference on Data Engineering, 2011.

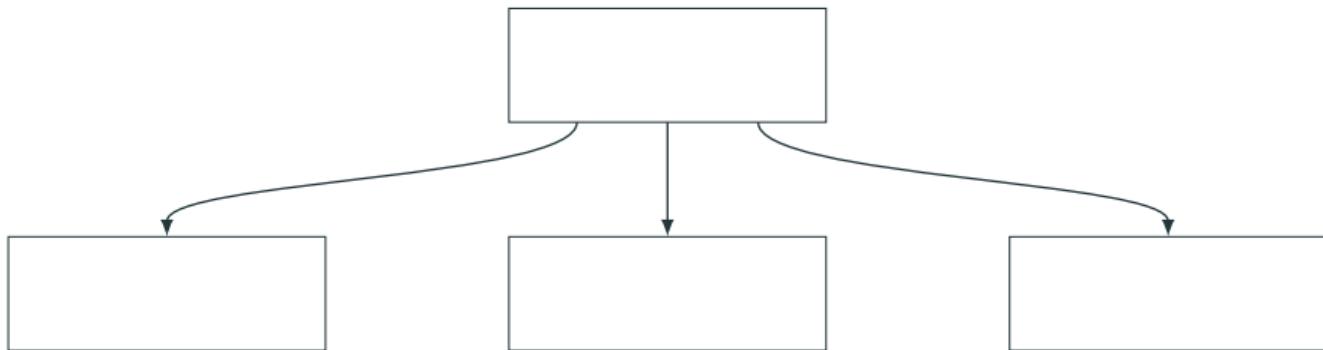
- RUM conjecture
- B-Tree
 - Key normalization & friends
 - SB-Tree
 - MDAM
- Hybrid, Bw-Tree, DPTree
- Trie
- Everything else

| | | | |
|-----------------------|-------------|------------------|--------------------|
| B-Tree | B^+ -Tree | B_{link} -Tree | DPTree |
| wB ⁺ -Tree | NV-Tree | FPTree | FASTFAIR |
| HiKV | Masstree | Skip List | ART |
| WORT | CDDS-Tree | Bw-Tree | HOT |
| KISS-Tree | VAST-Tree | FAST | HV-Tree |
| UB-Tree | LHAM | MDAM | Hybrid B^+ -Tree |



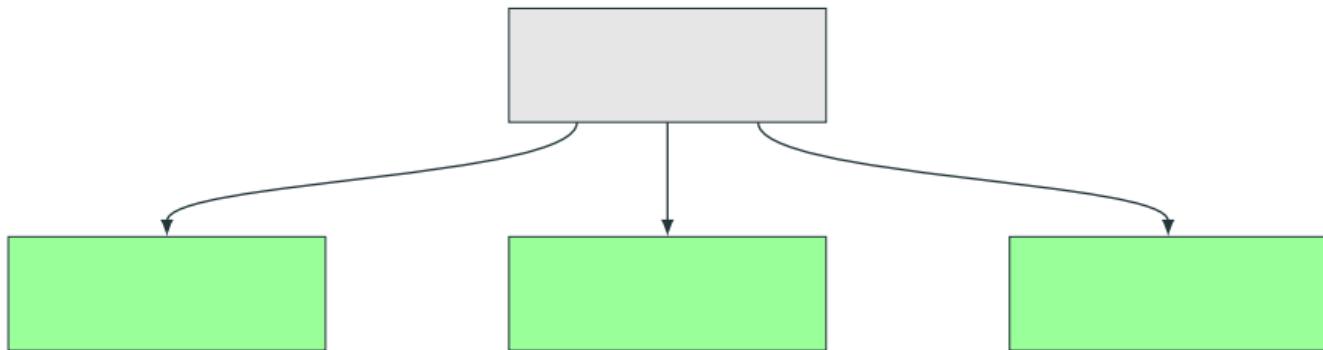


B⁺Tree



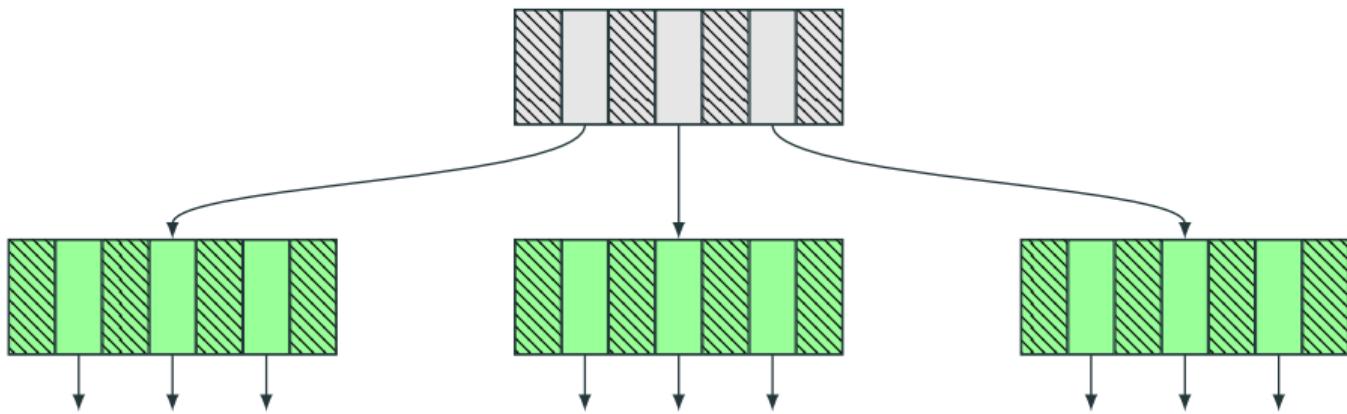
P. Lehman and S. Yao, Efficient Locking for Concurrent Operations on B-Trees, ACM Transactions on Database Systems, Vol 6, No. 4, December 1981, pp 650-670

B⁺Tree



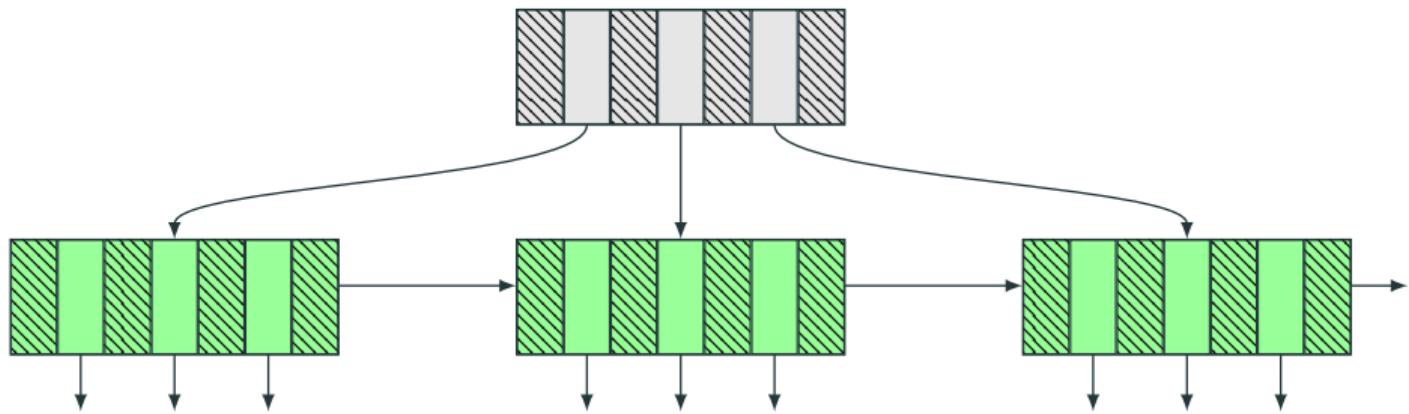
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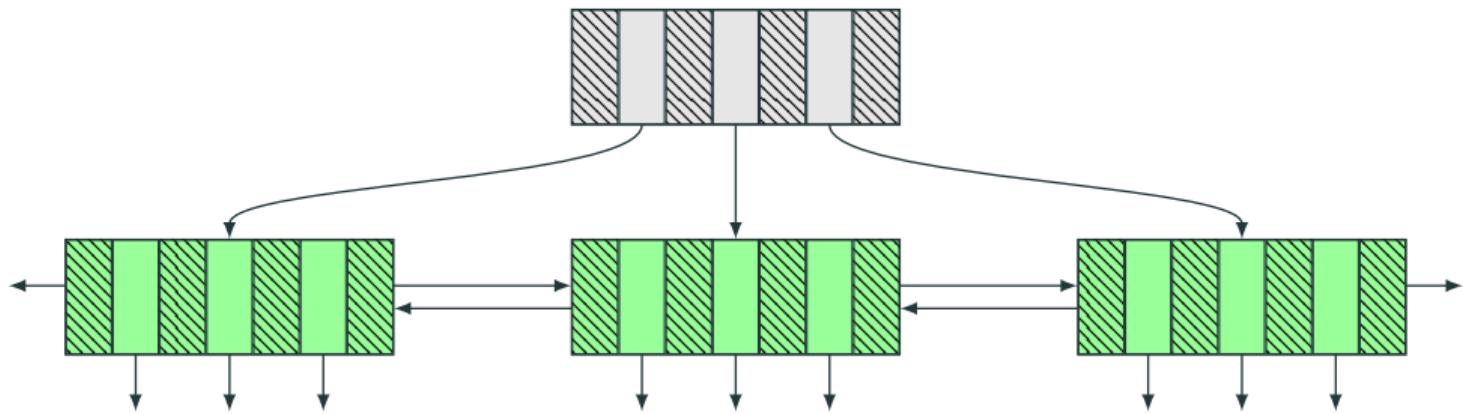
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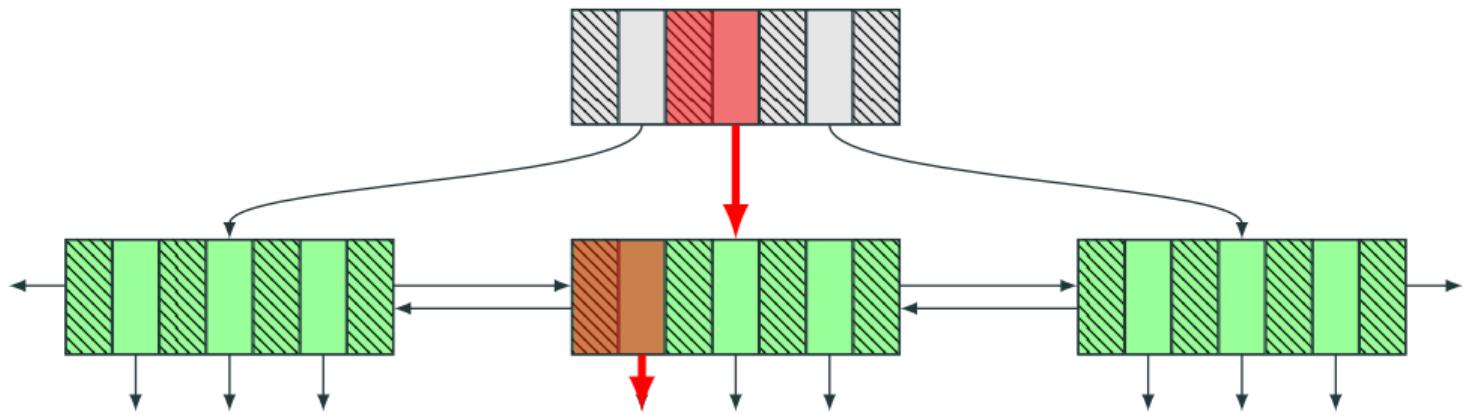
P. Lehman and S. Yao, Efficient Locking for Concurrent Operations on B-Trees, ACM Transactions on Database Systems, Vol 6, No. 4, December 1981, pp 650-670

B⁺Tree



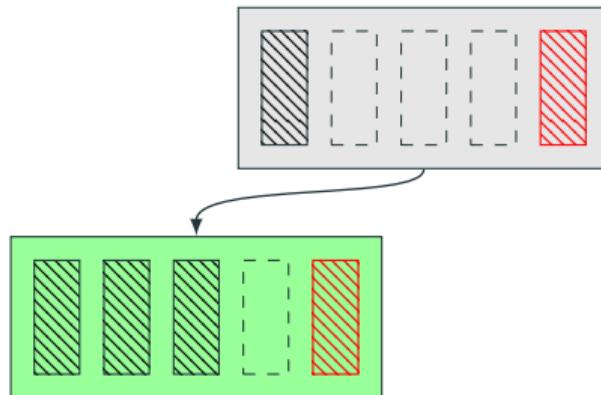
P. Lehman and S. Yao, Efficient Locking for Concurrent Operations on B-Trees, ACM Transactions on Database Systems, Vol 6, No. 4, December 1981, pp 650-670

B⁺Tree

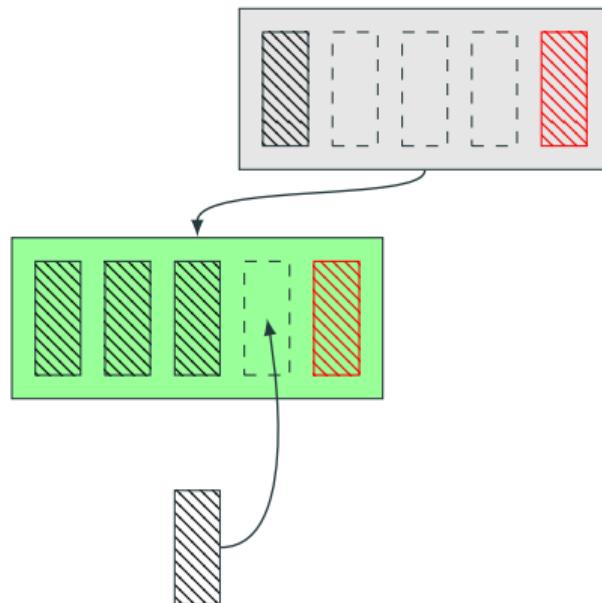


P. Lehman and S. Yao, Efficient Locking for Concurrent Operations on B-Trees, ACM Transactions on Database Systems, Vol 6, No. 4, December 1981, pp 650-670

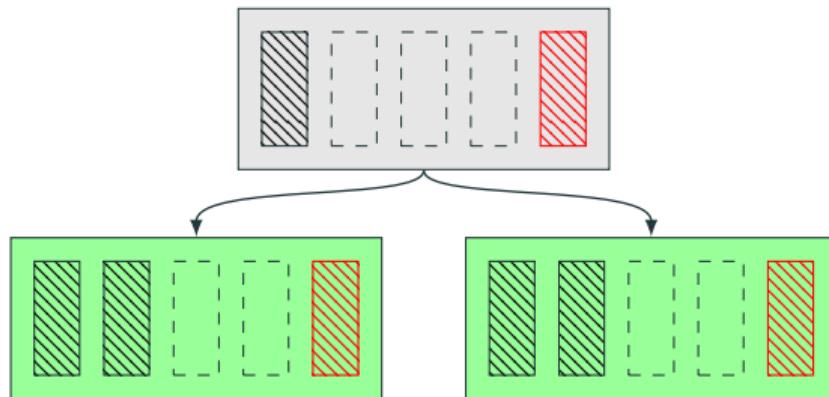
Page split



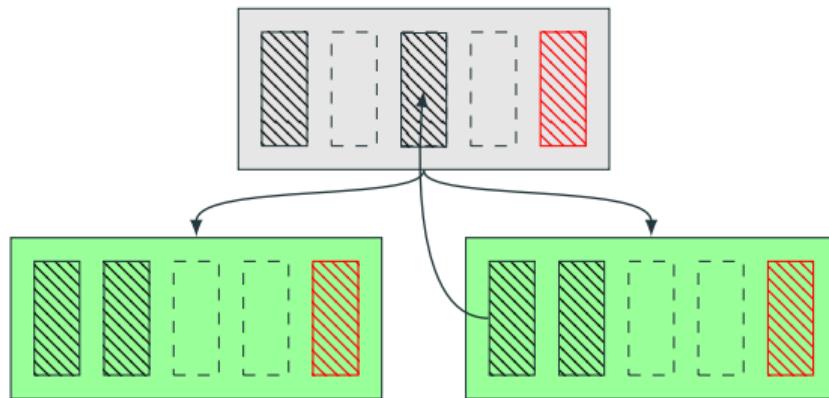
Page split



Page split



Page split



Page merge

"By adding periodic rebuilding of the tree, we obtain a data structure that is theoreticaly superior to standard B-trees in many ways. Our results suggest that rebalancing on deletion no only unnecessary but may be harmful."

S. Sen and R. E. Tarjan, "Deletion without rebalancing in multiway search trees." ISAAC, pp. 832-841, 2009

Key normalization

| | | | | | | | | | | |
|------|--------|--------|---|-------|---|--------|---|---|--------|---|
| 1 | "Dirk" | "Bart" | 1 | 0..01 | 1 | 11..00 | ∅ | 1 | 10..10 | ∅ |
| 2 | "Todd" | Null | 1 | 0..10 | 1 | 01..00 | ∅ | 0 | | |
| Null | "" | Null | 0 | 1 | ∅ | 0 | | | | |

R. C. Singleton, "An efficient algorithm for sorting with minimal storage", Communications of the ACM, vol. 12, no.3 pp. 185-186, 1969

Prefix truncation

| | |
|-------------|------------|
| Smith Jack | 01-02-2019 |
| Smith Jane | 02-03-2019 |
| Smith James | 03-04-2019 |

Prefix truncation

| | |
|-------------|------------|
| Smith Jack | 01-02-2019 |
| Smith Jane | 02-03-2019 |
| Smith James | 03-04-2019 |

Prefix truncation

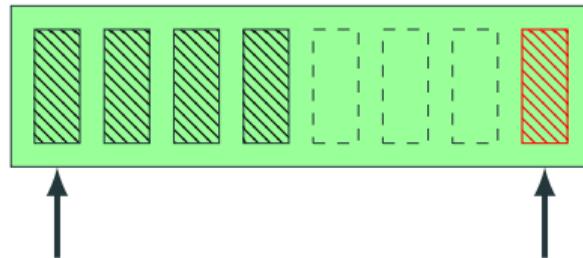
Smith Ja

ck 01-02-2019

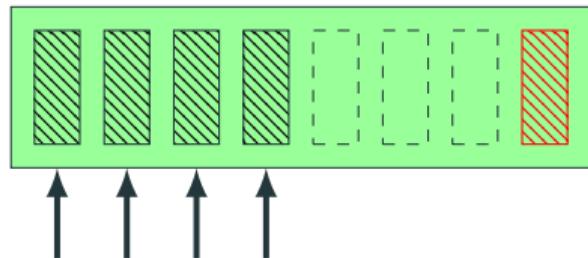
ne 02-03-2019

mes 03-04-2019

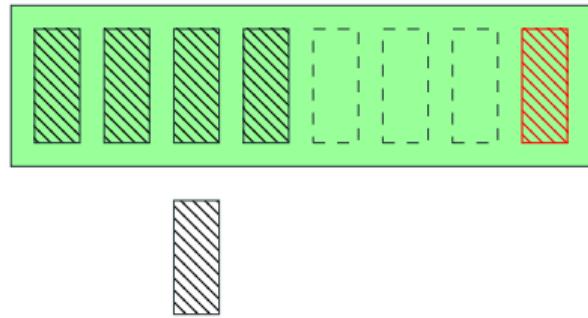
Prefix truncation



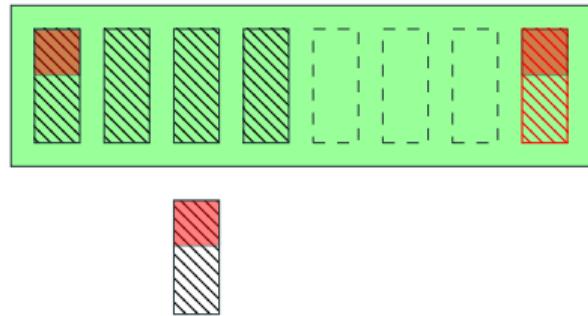
Prefix truncation



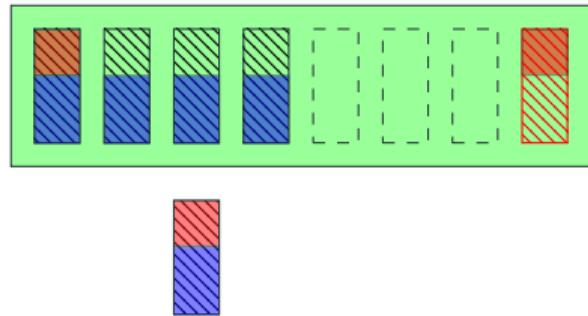
Dynamic prefix truncation



Dynamic prefix truncation



Dynamic prefix truncation



Suffix truncation

| | |
|---------------|------------|
| Cohen Richard | 02-02-2019 |
| Johnson David | 04-02-2019 |
| Miller Kevin | 01-02-2019 |
| Miller Mary | 02-03-2019 |
| Miller Steven | 03-04-2019 |
| Smith Susan | 01-02-2019 |

R. Bayer, K. Unterauer, "Prefix B-trees", ACM Transactions on Database Systems, vol. 2, no. 1, pp. 11-26, 1977

Suffix truncation

Cohen Richard 02-02-2019

Johnson David 04-02-2019

Miller Kevin 01-02-2019

Miller Mary 02-03-2019

Miller Steven 03-04-2019

Smith Susan 01-02-2019

R. Bayer, K. Unterauer, "Prefix B-trees", ACM Transactions on Database Systems, vol. 2, no. 1, pp. 11-26, 1977

Suffix truncation

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Johnson David 04-02-2019

Miller Kevin 01-02-2019

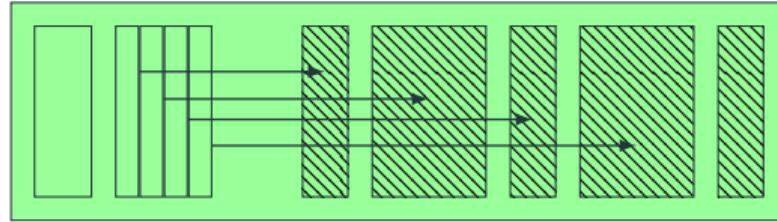
Miller Mary 02-03-2019

Miller Steven 03-04-2019

Smith Susan 01-02-2019

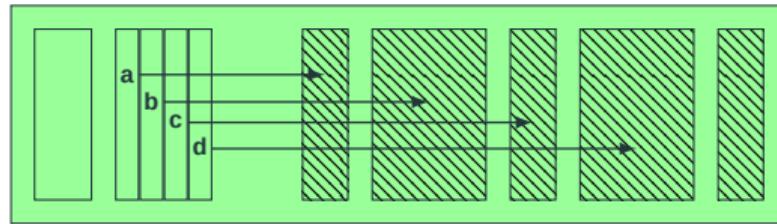
R. Bayer, K. Unterauer, "Prefix B-trees", ACM Transactions on Database Systems, vol. 2, no. 1, pp. 11-26, 1977

Indirection vector



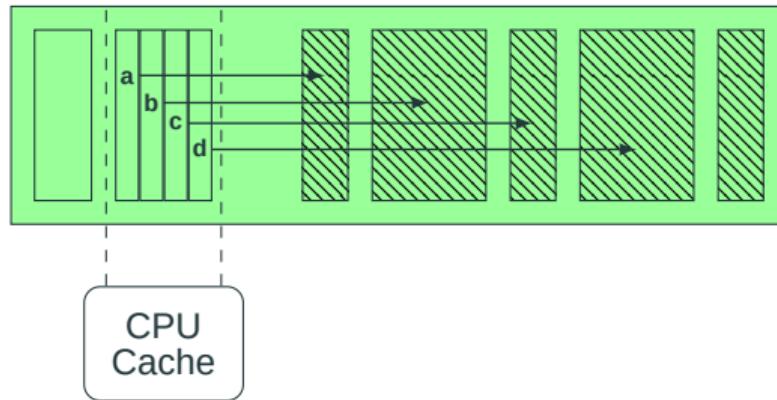
G. Graefe, Per-Ake Larson, "B-tree indexes and CPU caches", International Conference on Data Engineering, pp. 349-358, 2001

Indirection vector



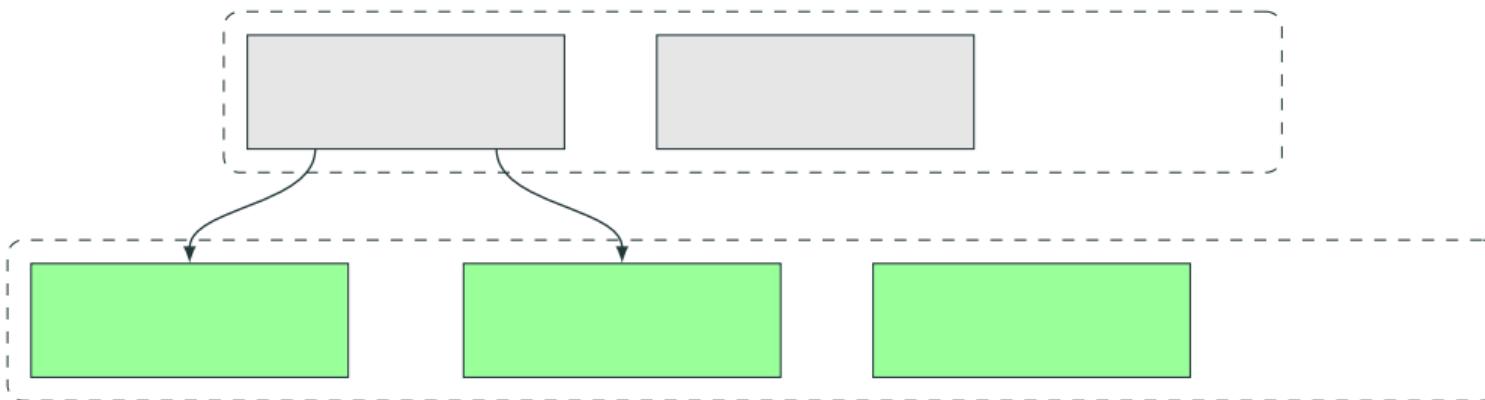
G. Graefe, Per-Ake Larson, "B-tree indexes and CPU caches", International Conference on Data Engineering, pp. 349-358, 2001

Indirection vector



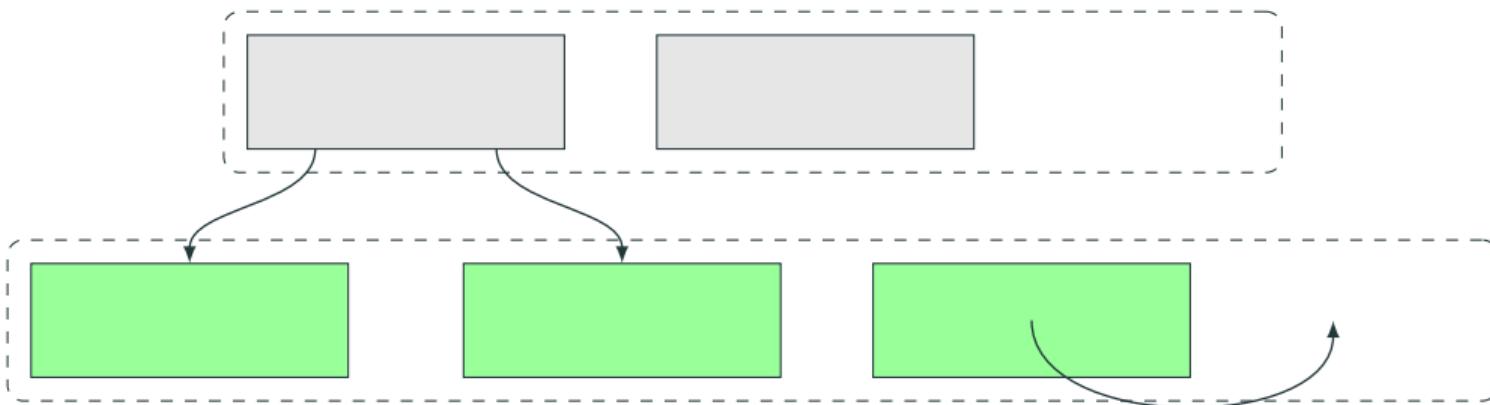
G. Graefe, Per-Ake Larson, "B-tree indexes and CPU caches", International Conference on Data Engineering, pp. 349-358, 2001

SB-tree



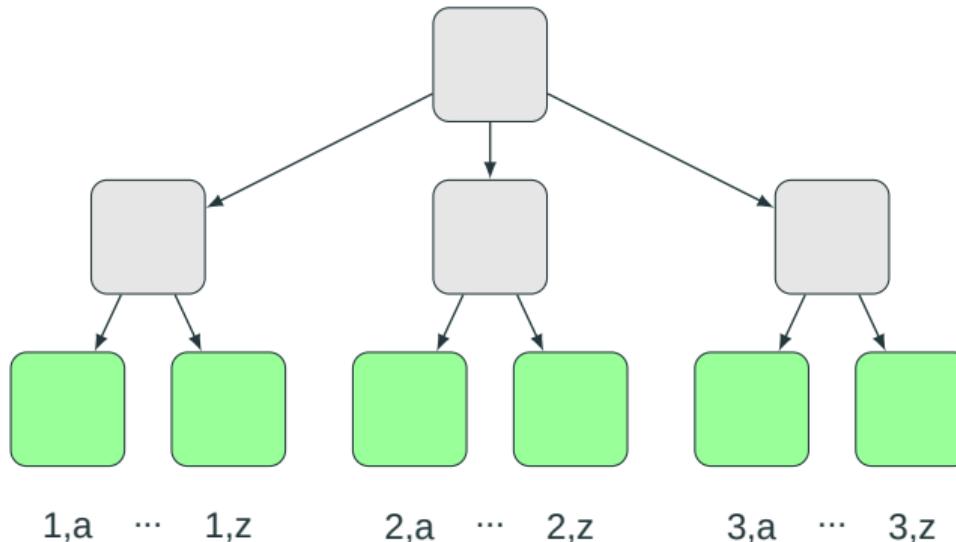
P. E. O'Neil, "The SB-tree: An index-sequential structure for high performance sequential access", Acta Informatica, vol. 29, no. 3. pp. 241-265, 1992

SB-tree



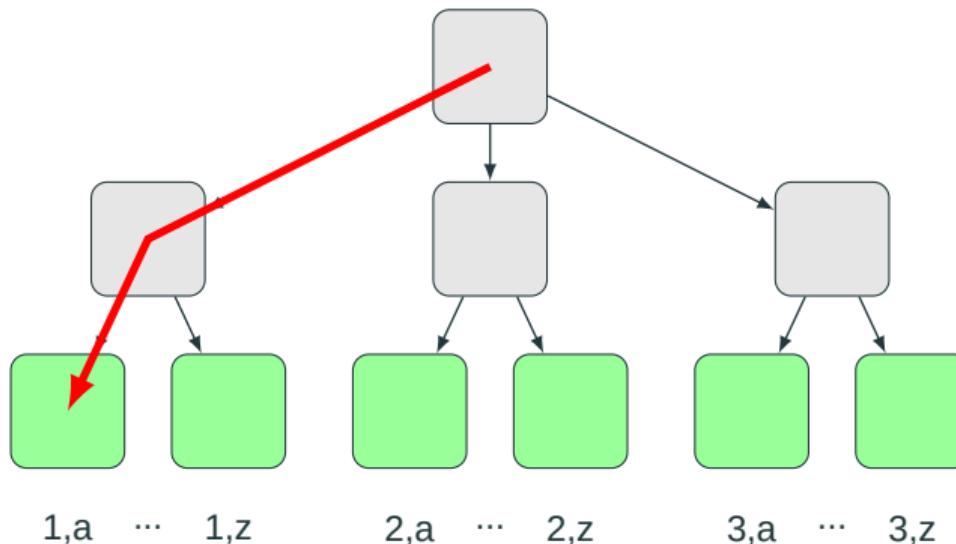
P. E. O'Neil, "The SB-tree: An index-sequential structure for high performance sequential access", Acta Informatica, vol. 29, no. 3. pp. 241-265, 1992

Multidimensional Access Method



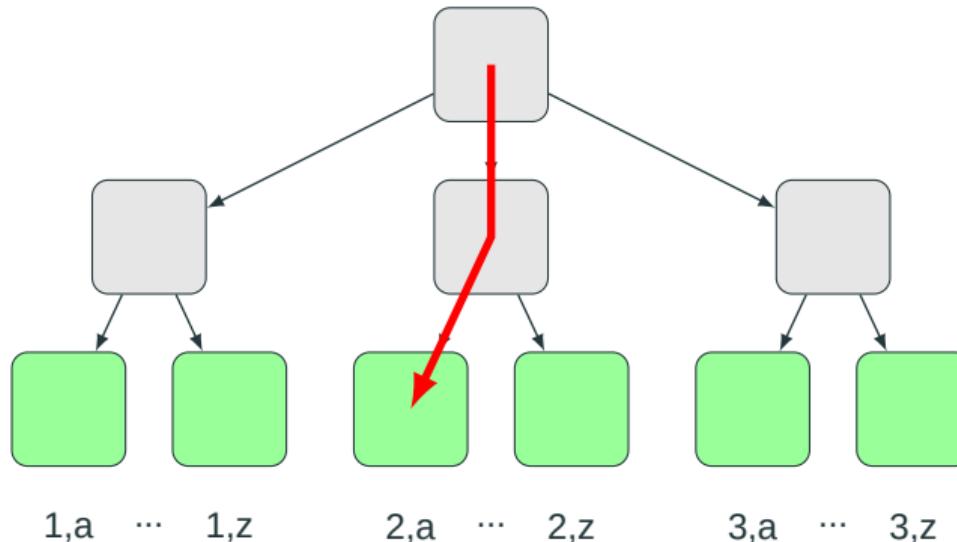
H. Leslie, R. Jain, D. Birdsall, H. Yaghmai, "Efficient search of multidimensional B-trees",
ACM Transactions on Database Systems, vol. 6, no. 4, pp. 650-670, 1995

Multidimensional Access Method



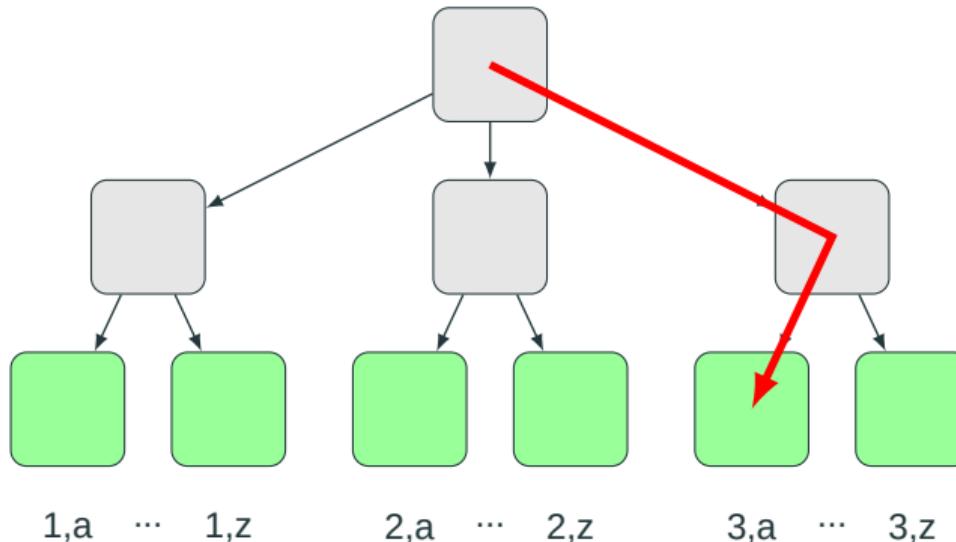
H. Leslie, R. Jain, D. Birdsall, H. Yaghmai, "Efficient search of multidimensional B-trees",
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Multidimensional Access Method

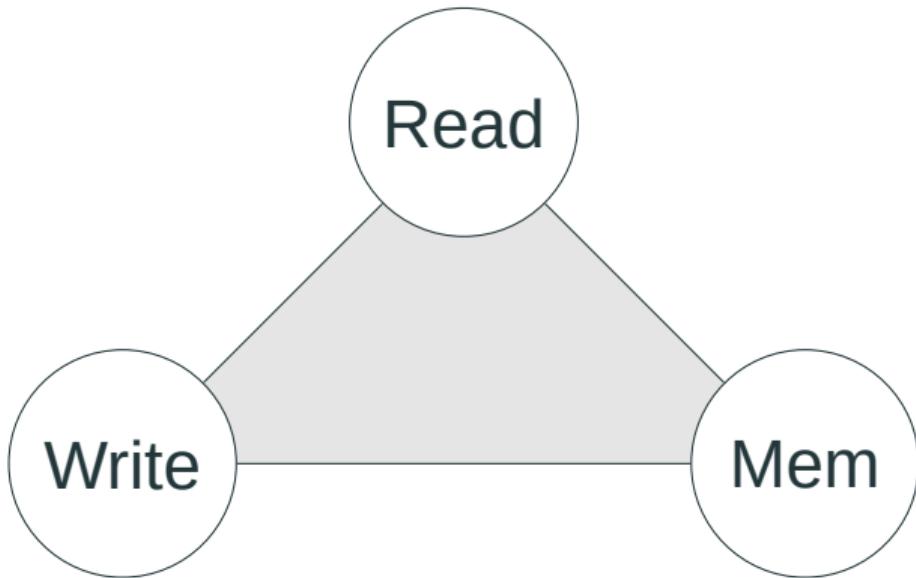


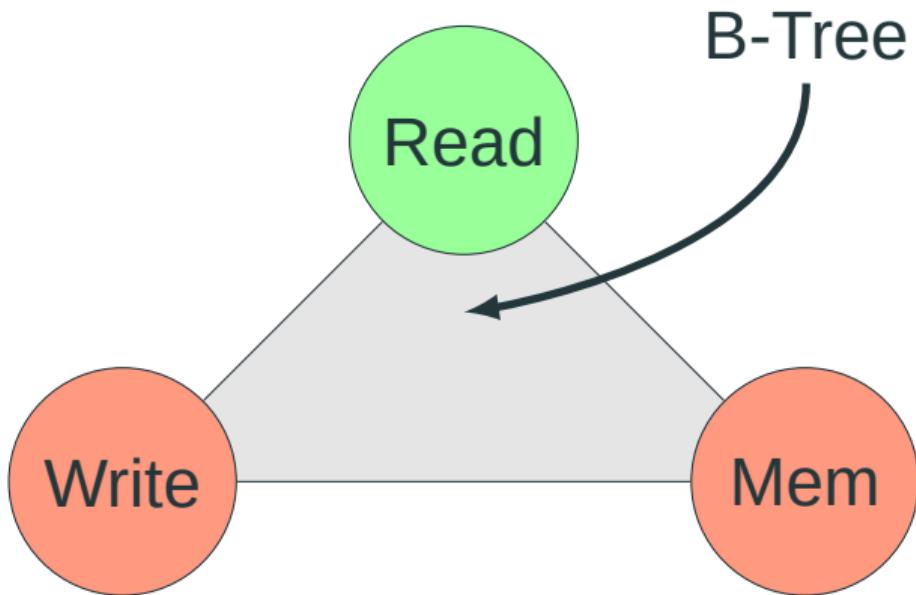
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Multidimensional Access Method



H. Leslie, R. Jain, D. Birdsall, H. Yaghmai, "Efficient search of multidimensional B-trees",
ACM Transactions on Database Systems, vol. 6, no. 4, pp. 650-670, 1995





Waves of misery after index creation

Nikolaus Glombiewski¹, Bernhard Seeger², Goetz Graefe³

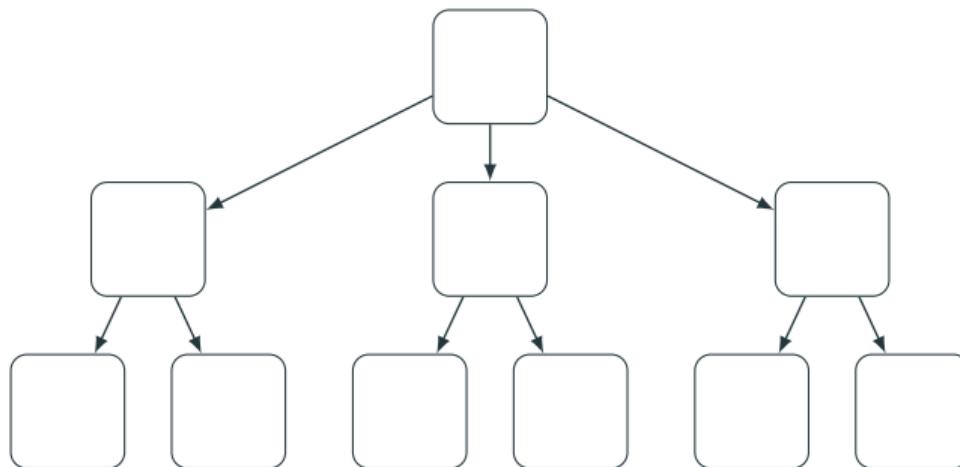
Abstract: After creation of a new b-tree, the ordinary course of database updates and index maintenance causes waves of node splits. Thus, a new index may at first speed up database query processing but then the first “wave of misery” requires effort for frequent node splits and imposes spikes of buffer pool contention and of I/O. Waves of misery continue over multiple instances although eventually the waves widen, flatten, and spread further apart. Free space in each node left during index creation fails to prevent the problem; it merely delays the onset of the first wave. We have found a theoretically sound way to avoid these waves of misery as well as some simple and practical means to reduce their amplitude to negligible levels. Experiments demonstrate that these techniques are also effective. Waves of misery occur in databases and in key-value stores, in primary and in secondary b-tree indexes, after load operations, and after b-tree reorganization or rebuild. The same remedies apply with equal effect.

Keywords: Indexing, Bulk Loading, B-tree

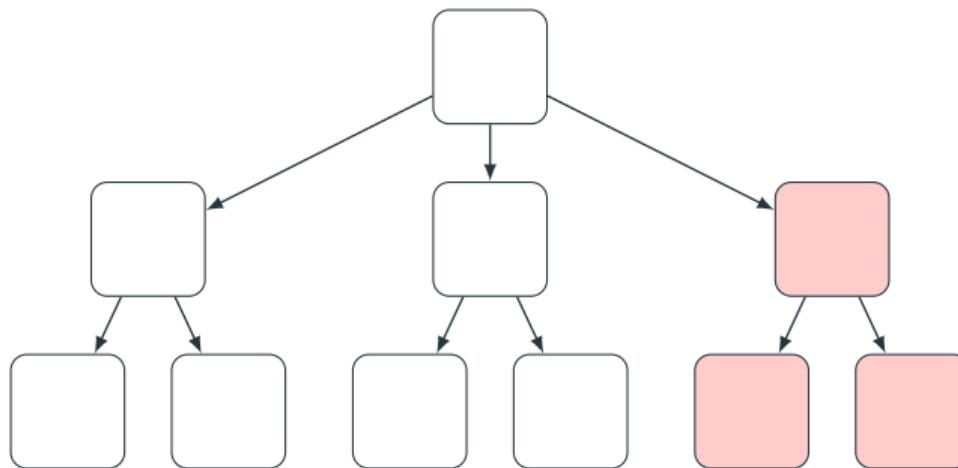
1 Introduction

The purpose of adding an index to a database table is to improve the performance of query processing. Unfortunately, after an initial “honey moon” of using a new index and of enjoying fast queries, the index may grow and require many node splits – thus creating a spike in buffer pool contention and I/O activity. In other words, the index may actually reduce query performance or at least fail to achieve the expected performance. Consider the following example. First, a new secondary b-tree index enables fast look-ups and fast ordered scans. In order to absorb updates without node splits, each node might start with 10% free space – often a parameter of index creation. However, once the table and the

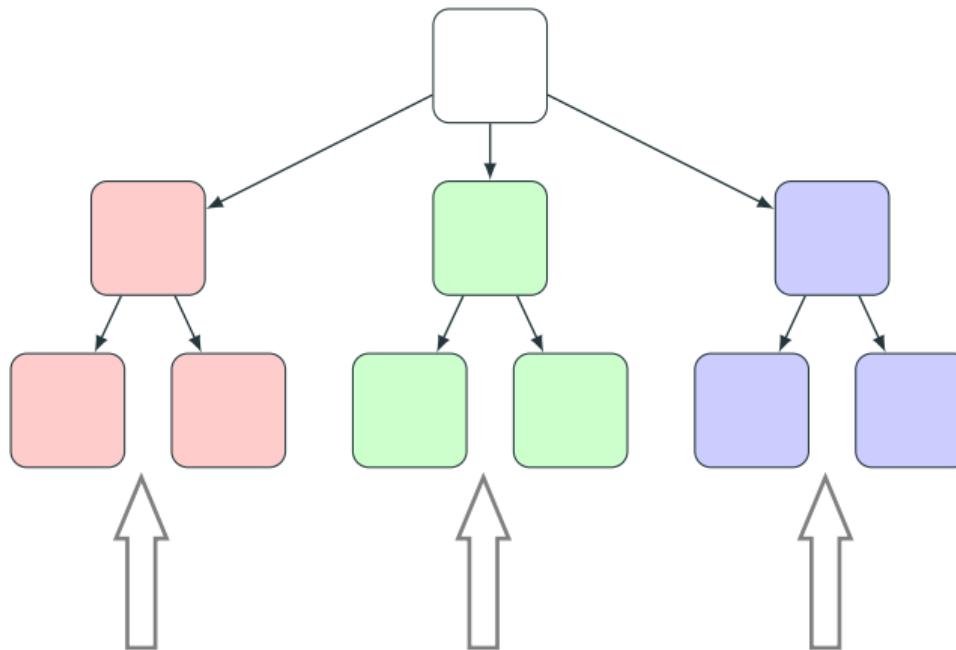
Partitioned B-tree



Partitioned B-tree

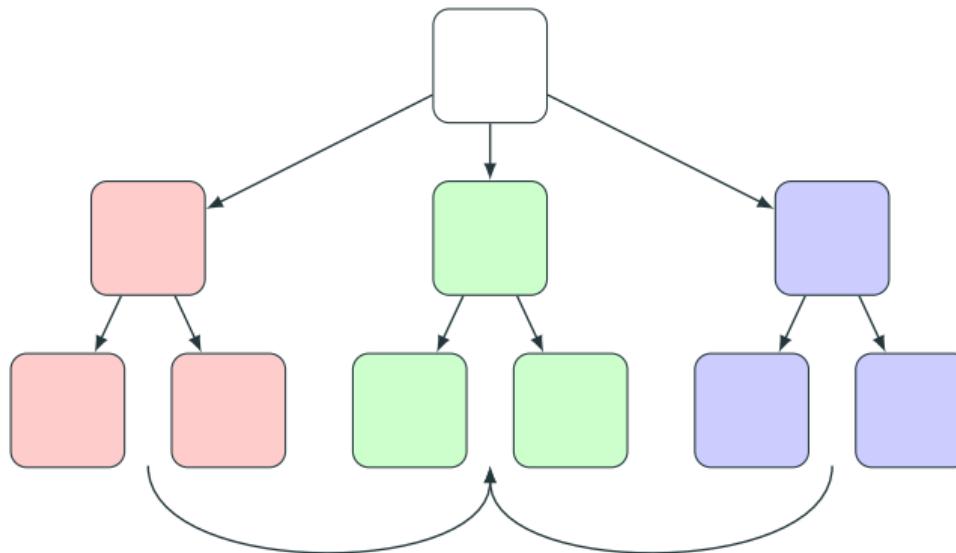


Partitioned B-tree



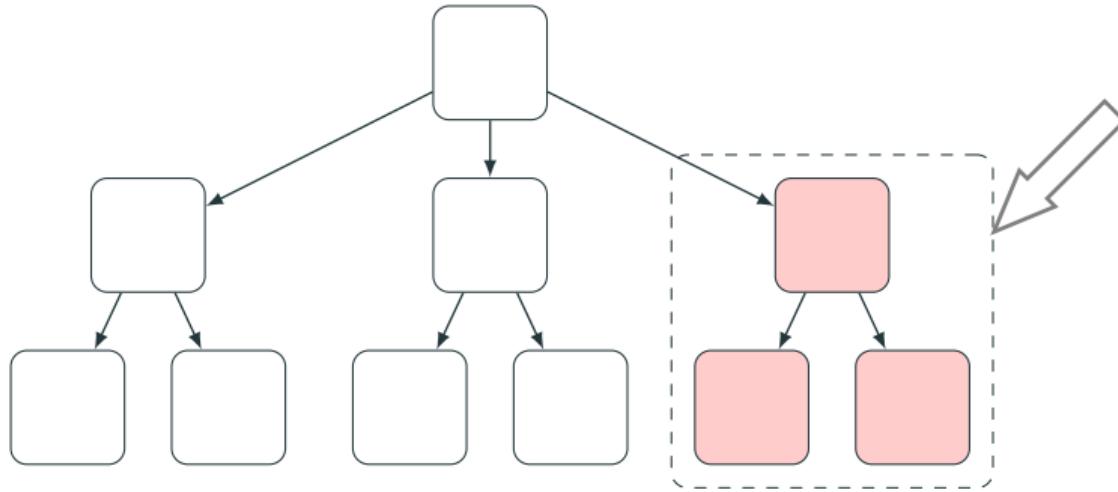
G. Graefe, "Sorting and indexing with partitioned B-Trees", Classless Inter Domain Routing, 2003

Partitioned B-tree



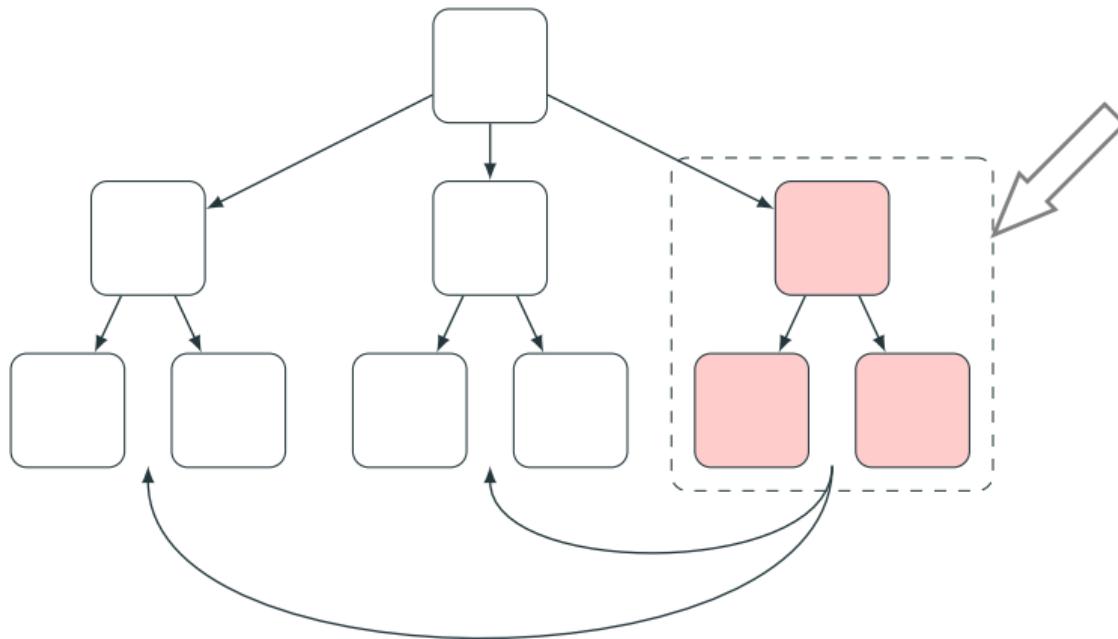
G. Graefe, "Sorting and indexing with partitioned B-Trees", Classless Inter Domain Routing, 2003

Partitioned B-tree



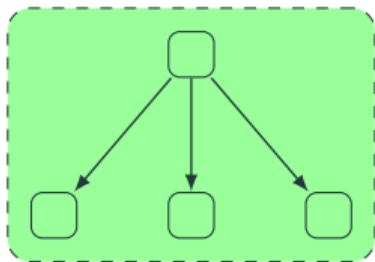
Riegger Christian, Vincon Tobias, Petrov Ilia. (2017). Write-optimized indexing with partitioned b-trees. 296-300.

Partitioned B-tree



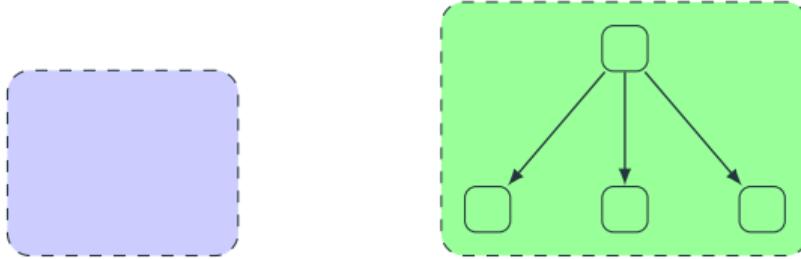
Riegger Christian, Vincon Tobias, Petrov Ilia. (2017). Write-optimized indexing with partitioned b-trees. 296-300.

Hybrid indexes



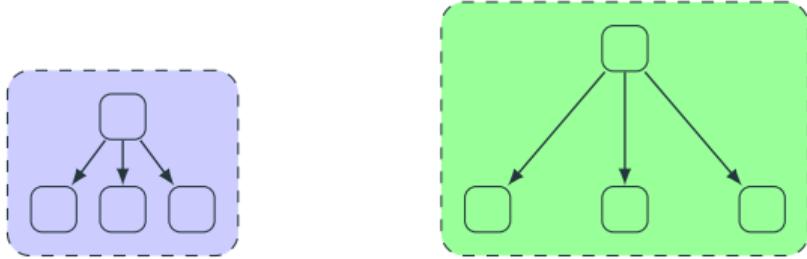
Huachen Zhang, David G. Andersen, Andrew Pavlo, Michael Kaminsky, Lin Ma, and Rui Shen. 2016. Reducing the Storage Overhead of Main-Memory OLTP Databases with Hybrid Indexes. In Proceedings of the 2016 International Conference on Management of Data (SIGMOD '16). Association for Computing Machinery, New York, NY, USA, 1567–1581.

Hybrid indexes



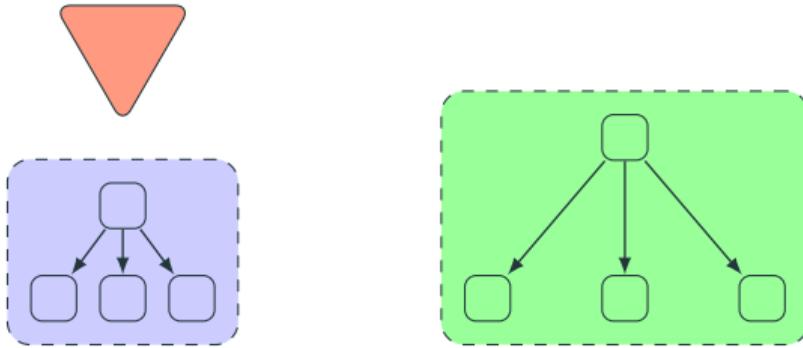
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Hybrid indexes



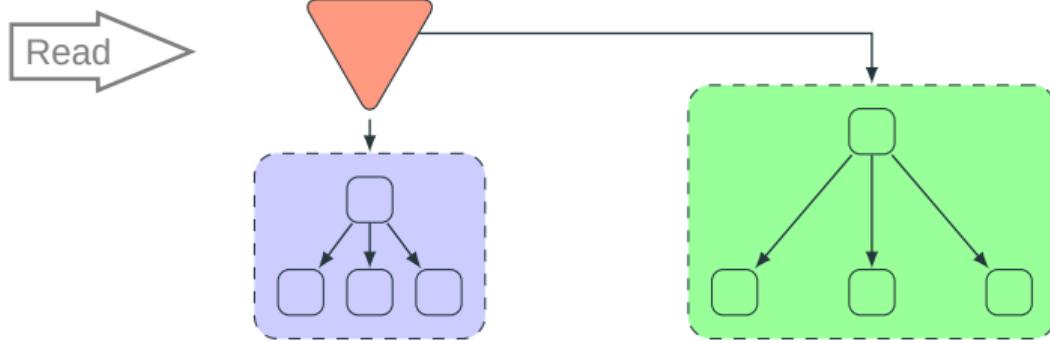
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Hybrid indexes



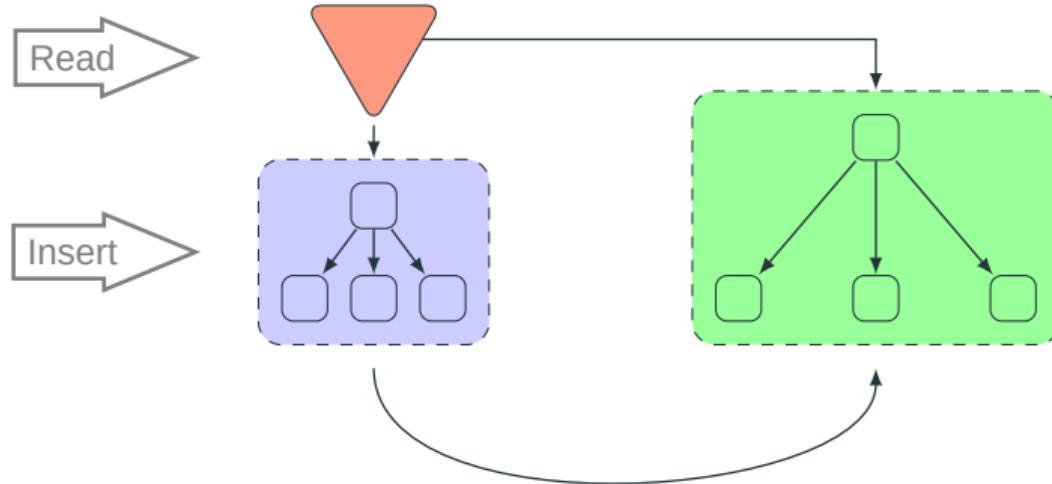
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Hybrid indexes



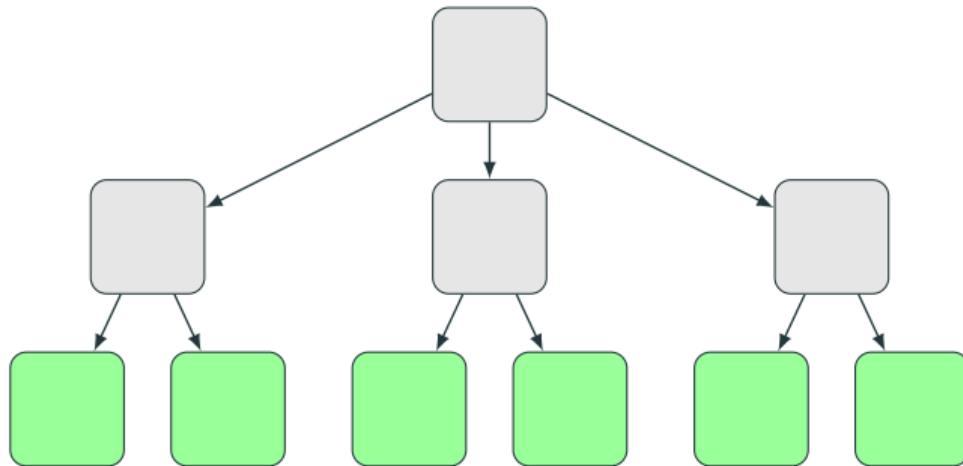
Huachen Zhang, David G. Andersen, Andrew Pavlo, Michael Kaminsky, Lin Ma, and Rui Shen. 2016. Reducing the Storage Overhead of Main-Memory OLTP Databases with Hybrid Indexes. In Proceedings of the 2016 International Conference on Management of Data (SIGMOD '16). Association for Computing Machinery, New York, NY, USA, 1567–1581.

Hybrid indexes



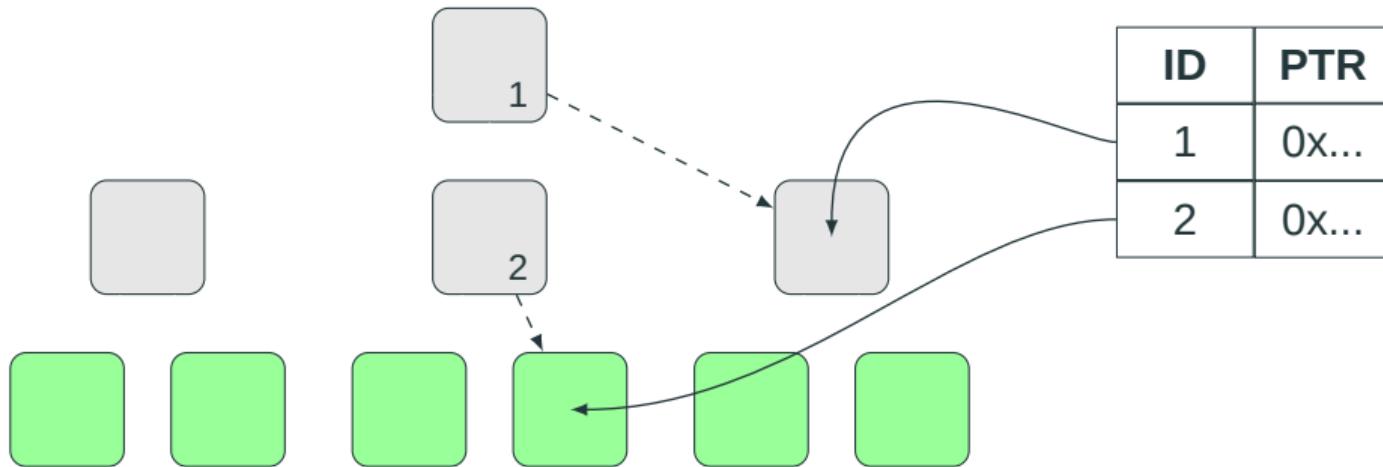
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Bw-Tree



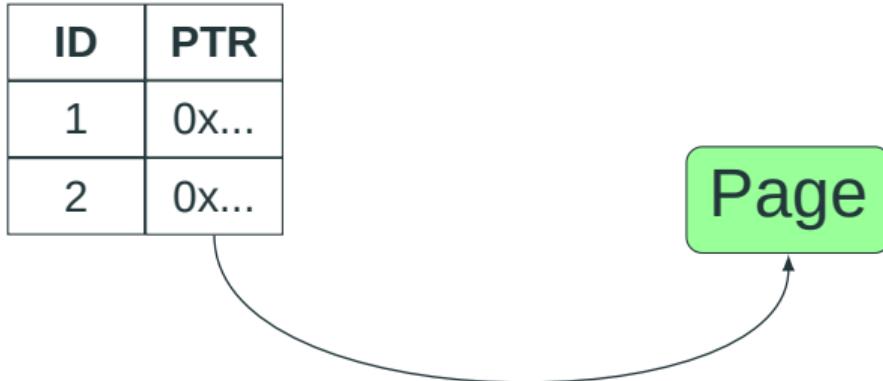
Levandoski Justin, Lomet David, Sengupta Sudipta. (2012). The Bw-Tree: A B-tree for New Hardware Platforms. Proceedings - International Conference on Data Engineering.

Bw-Tree



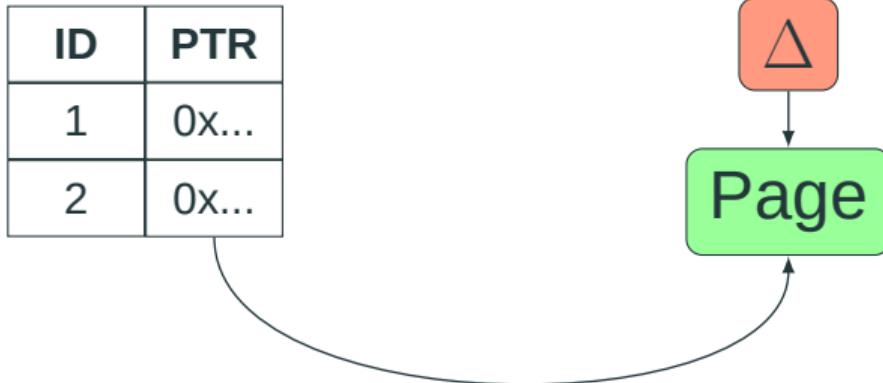
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Bw-Tree



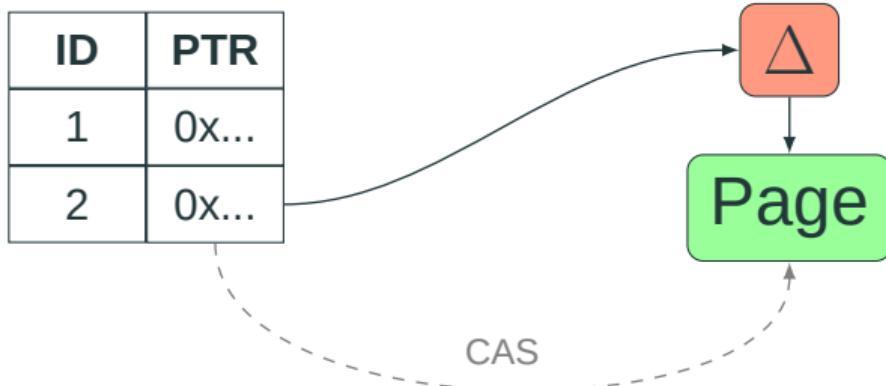
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Bw-Tree



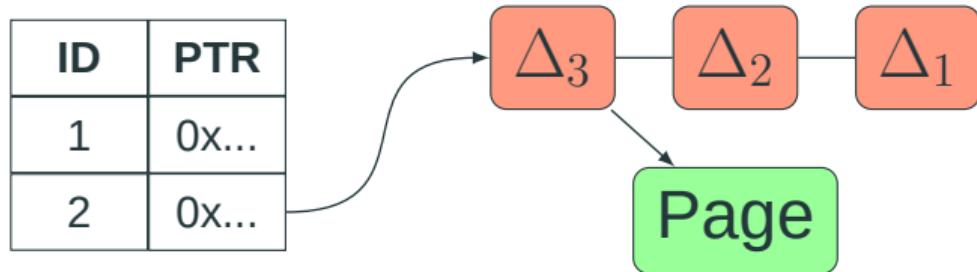
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Bw-Tree



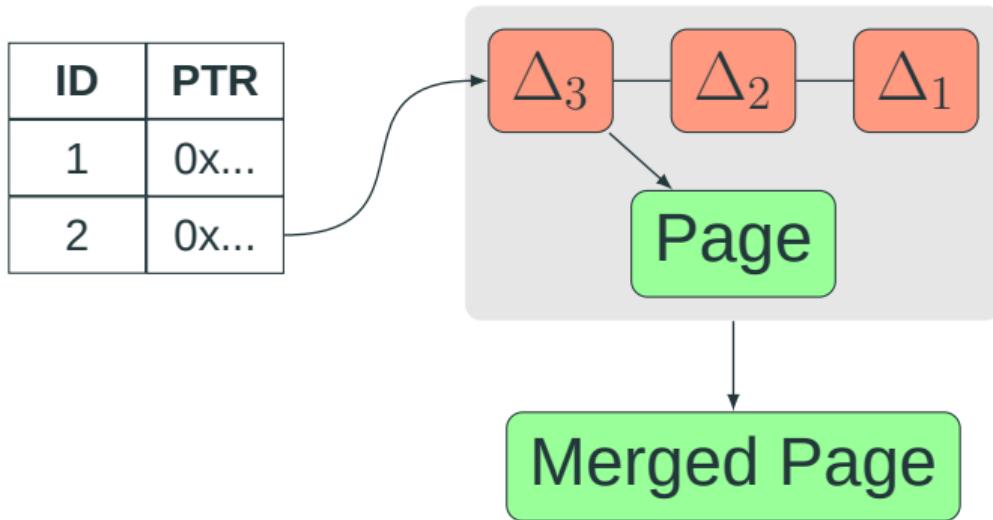
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Bw-Tree



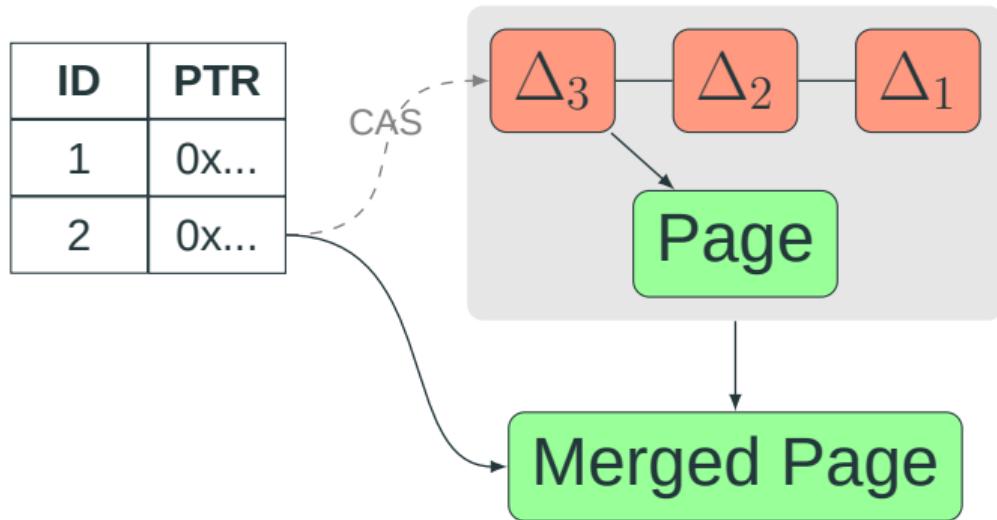
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Bw-Tree



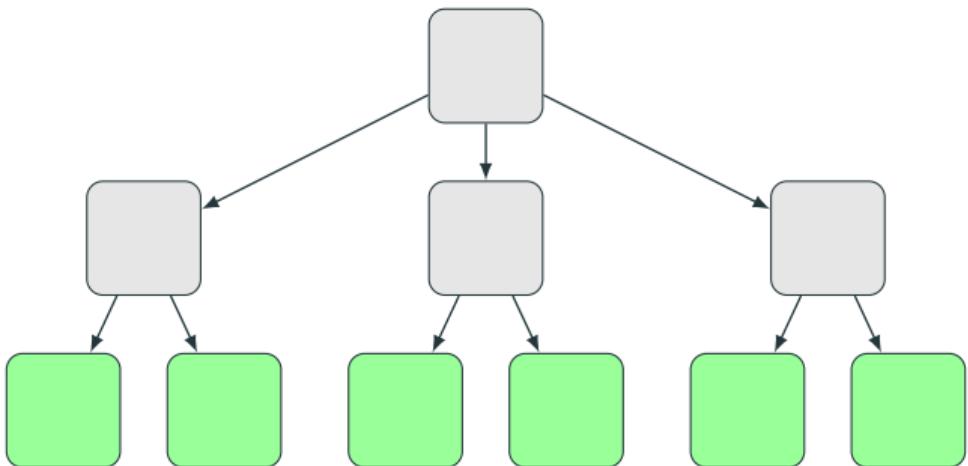
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Bw-Tree



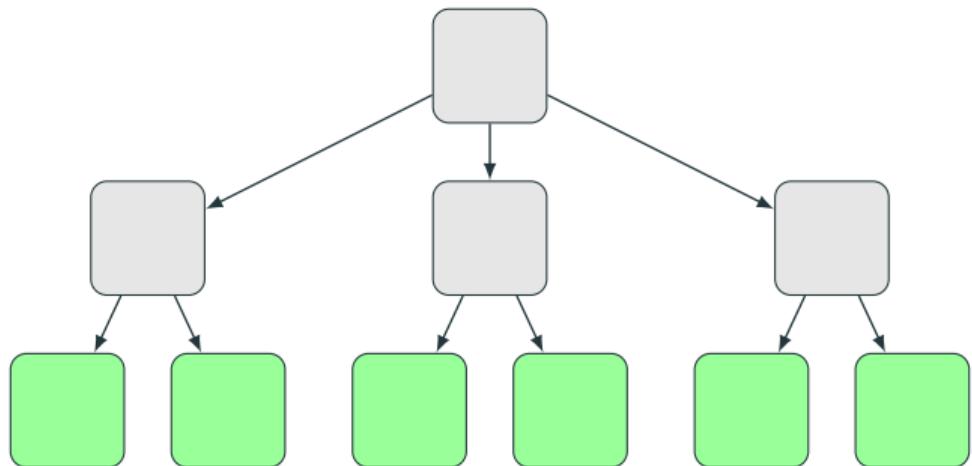
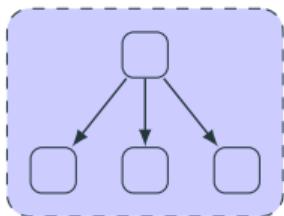
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DPTree



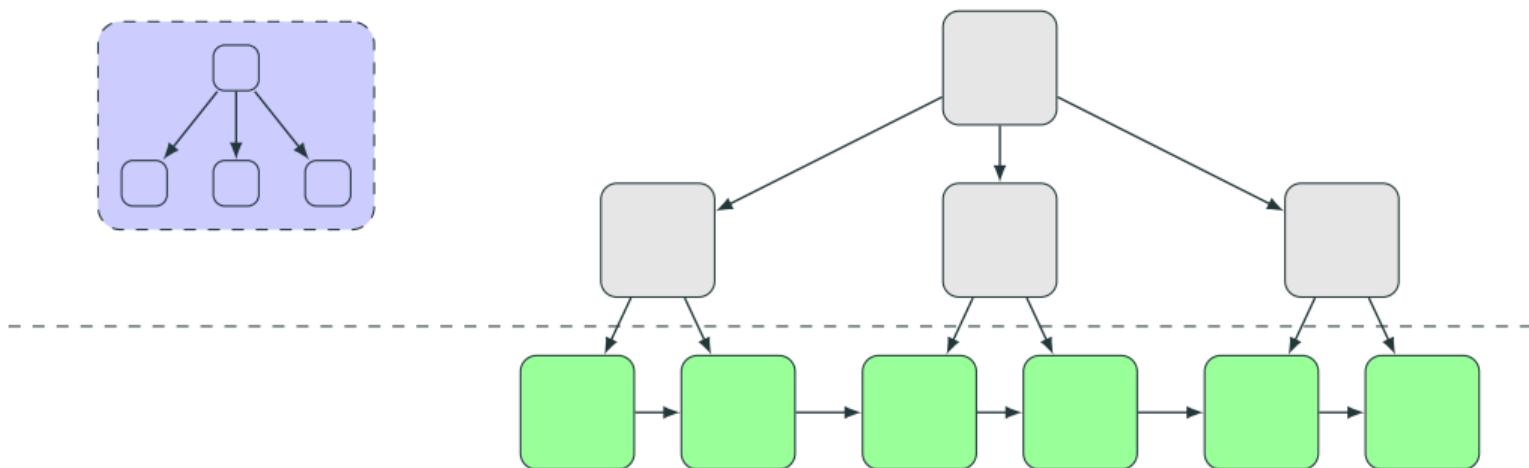
Zhou Xinjing, Shou Lidan, Chen Ke, Hu Wei, Chen Gang. (2019). DPTree: differential indexing for persistent memory. Proceedings of the VLDB Endowment.

DPTree



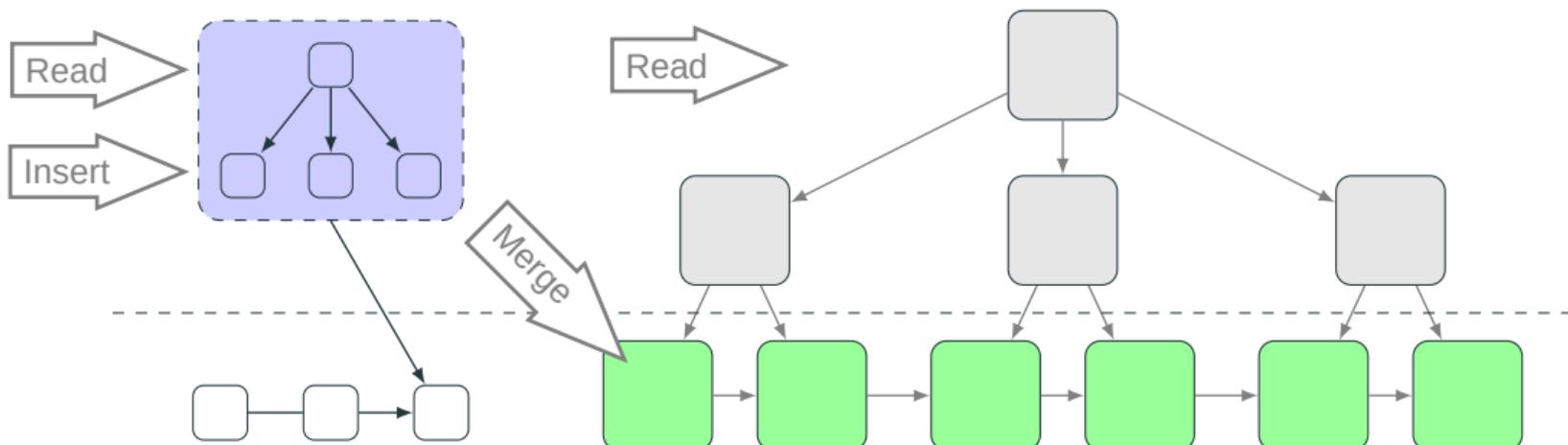
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DPTree



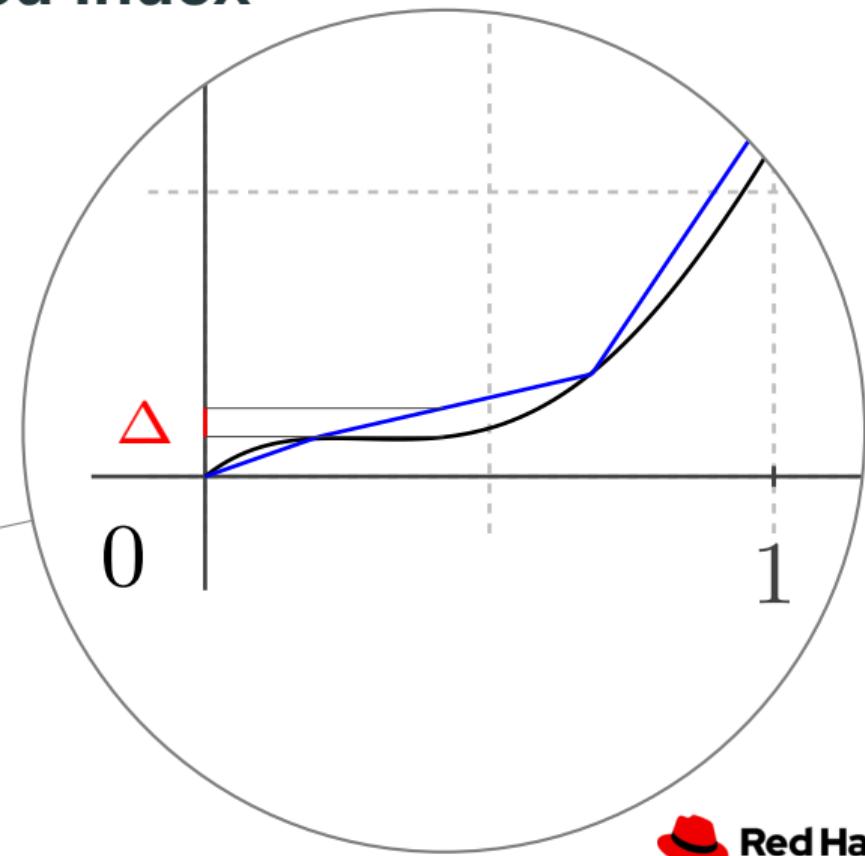
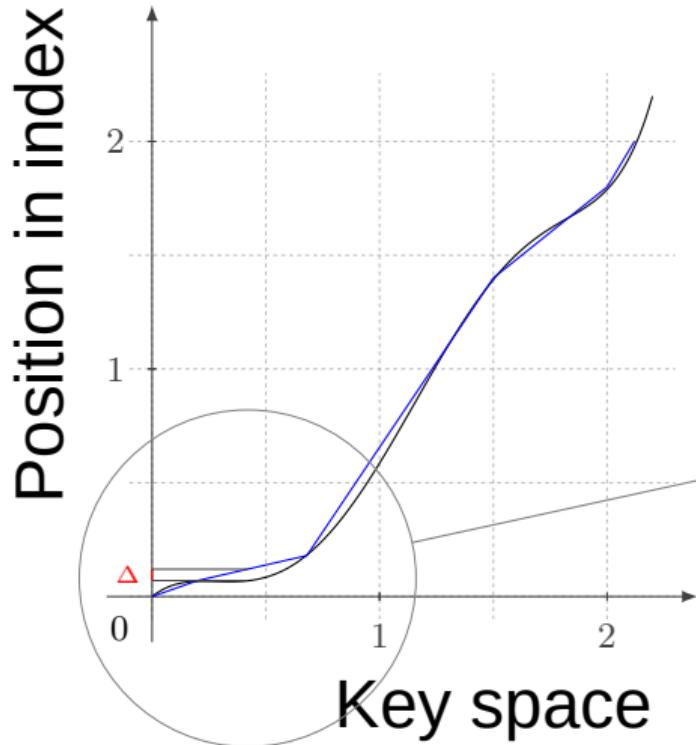
Zhou Xinjing, Shou Lidan, Chen Ke, Hu Wei, Chen Gang. (2019). DPTree: differential indexing for persistent memory. Proceedings of the VLDB Endowment.

DPTree



Zhou Xinjing, Shou Lidan, Chen Ke, Hu Wei, Chen Gang. (2019). DPTree: differential indexing for persistent memory. Proceedings of the VLDB Endowment.

Learned Index



Is that all?



→ Buffered (Lazy) B-Tree

- Buffered (Lazy) B-Tree
- Cache conscious B-Tree

- Buffered (Lazy) B-Tree
- Cache conscious B-Tree
- Distributed B-Tree

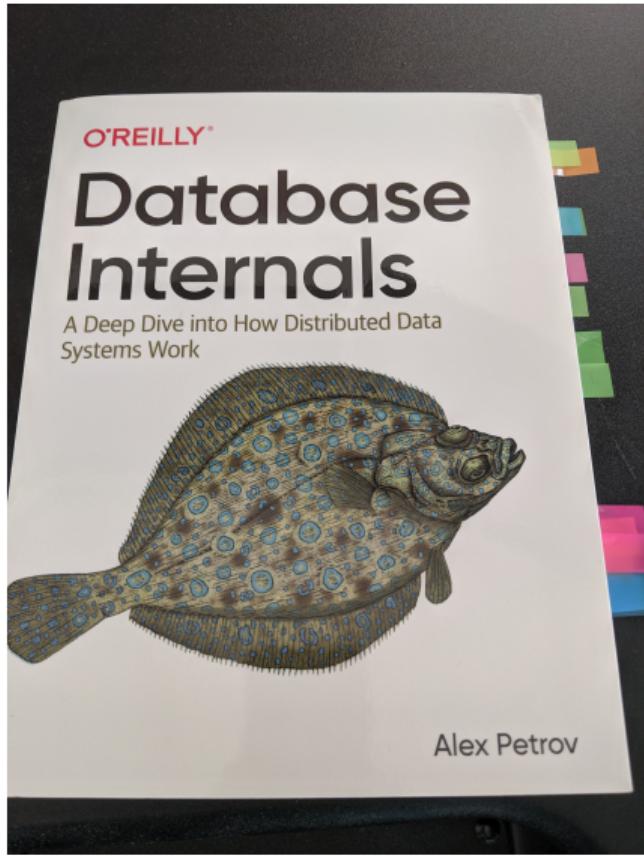
- Buffered (Lazy) B-Tree
- Cache conscious B-Tree
- Distributed B-Tree
- UB-Tree

- Buffered (Lazy) B-Tree
- Cache conscious B-Tree
- Distributed B-Tree
- UB-Tree
- Skip List

- Buffered (Lazy) B-Tree
- Cache conscious B-Tree
- Distributed B-Tree
- UB-Tree
- Skip List
- LSM Tree

- Buffered (Lazy) B-Tree
- Cache conscious B-Tree
- Distributed B-Tree
- UB-Tree
- Skip List
- LSM Tree
- Trie

- Buffered (Lazy) B-Tree
- Cache conscious B-Tree
- Distributed B-Tree
- UB-Tree
- Skip List
- LSM Tree
- Trie
- ...



Questions?

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