



Modern BTree techniques

DMITRY DOLGOV

31-01-2019





@aspis7



@aspis7

→ 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

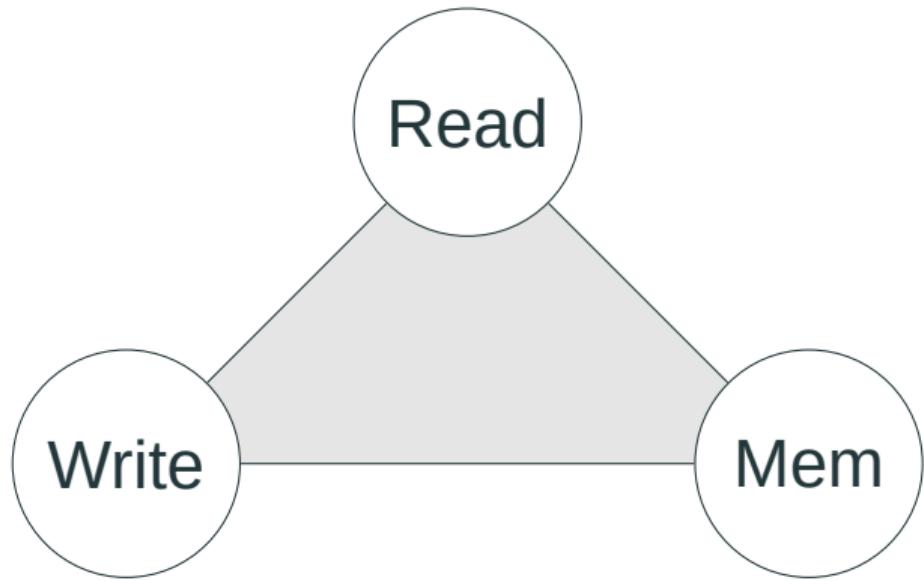
 MDAM

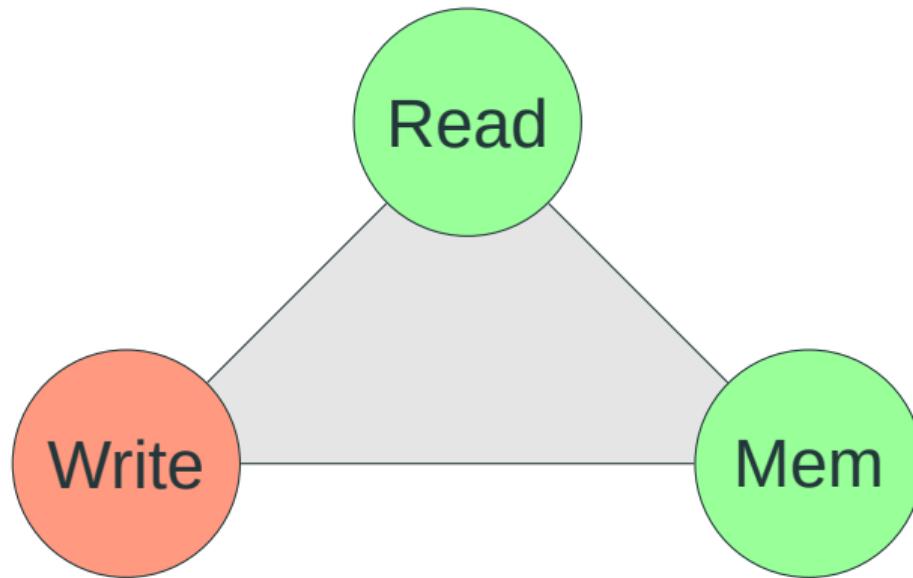
→ Hybrid, Bw-Tree, DPTree

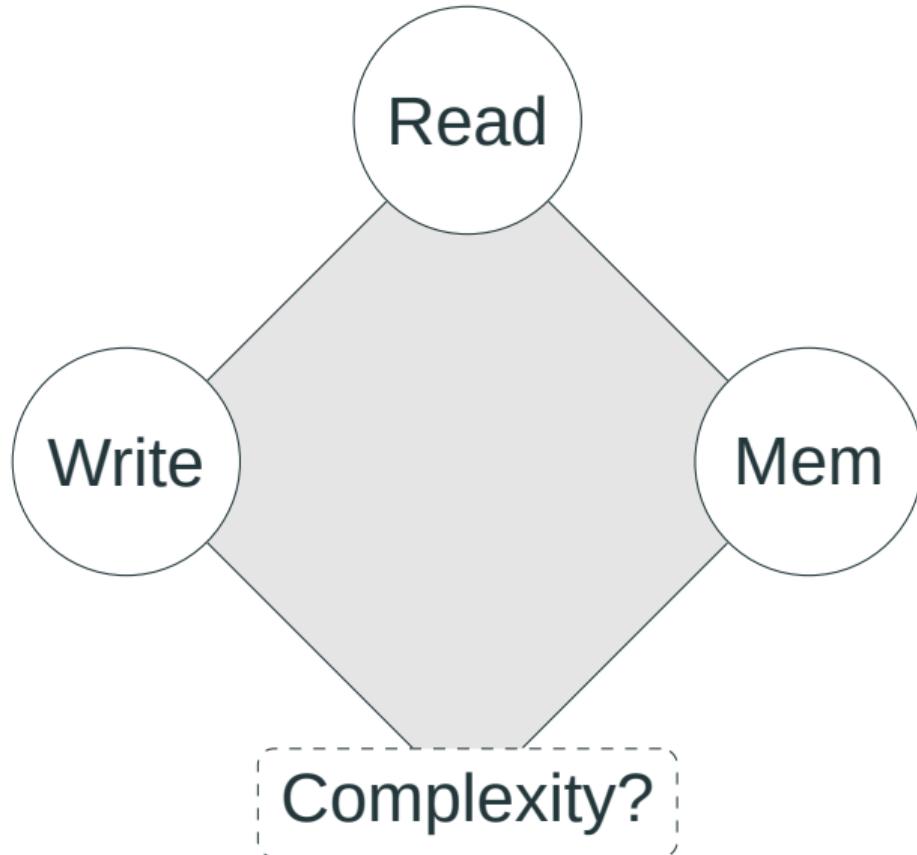
→ Trie

→ Everything else

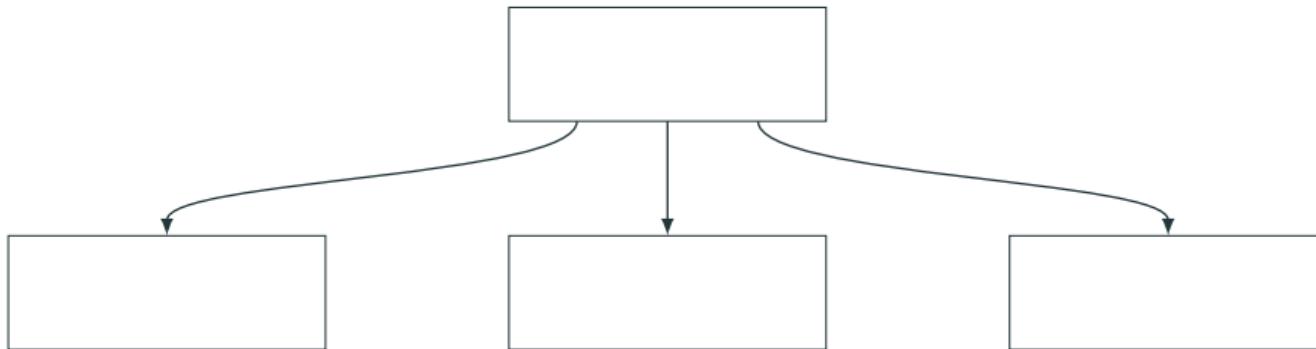
B-Tree	B ⁺ -Tree	B _{link} -Tree	DPTree
wB ⁺ -Tree	NV-Tree	FPTree	FASTFAIR
HiKV	Masstree	Skip List	ART
WORT	CDDS-Tree	Bw-Tree	HOT
KISS-Tree	VAST-Tree	FAST	HV-Tree
UB-Tree	LHAM	MDAM	Hybrid B ⁺ -Tree





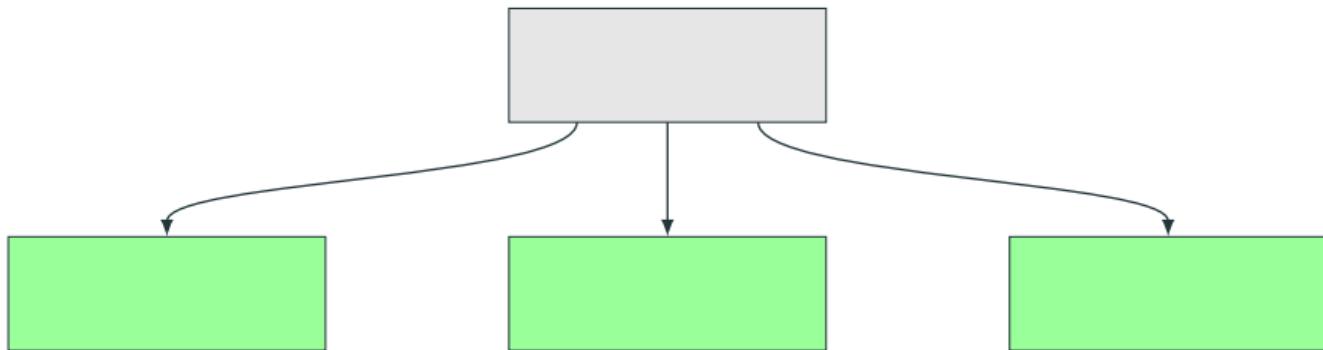


B⁺Tree



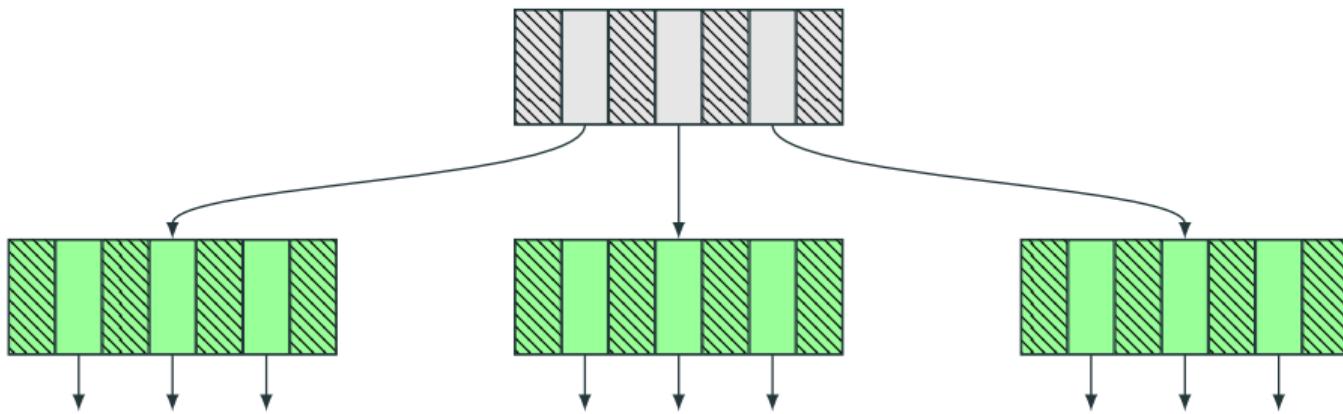
P. Lehman and S. Yao, Efficient Locking for Concurrent Operations on B-Trees, ACM Transactions on Database Systems, Vol 6, No. 4, December 1981, pp 650-670

B⁺Tree



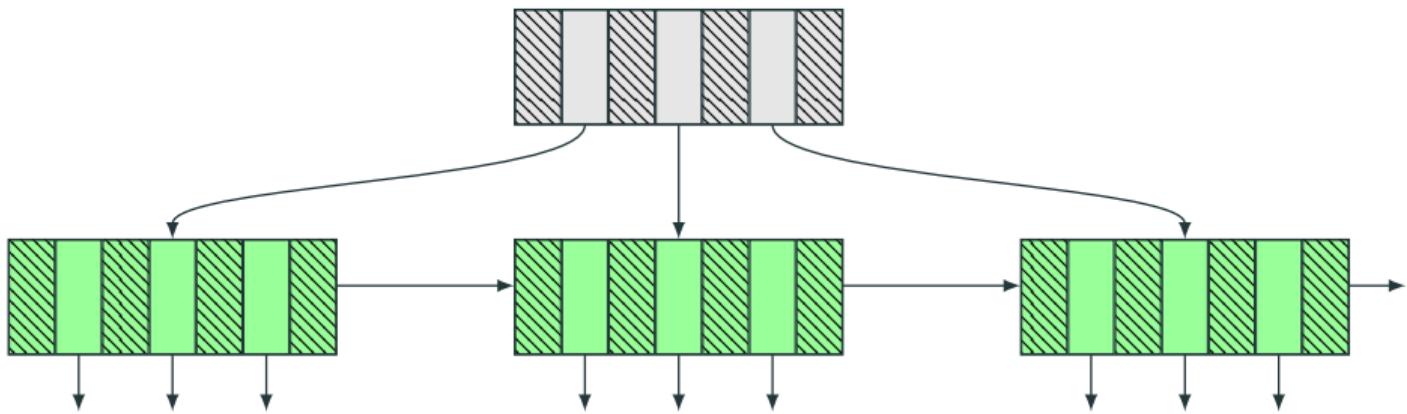
P. Lehman and S. Yao, Efficient Locking for Concurrent Operations on B-Trees, ACM Transactions on Database Systems, Vol 6, No. 4, December 1981, pp 650-670

B⁺Tree



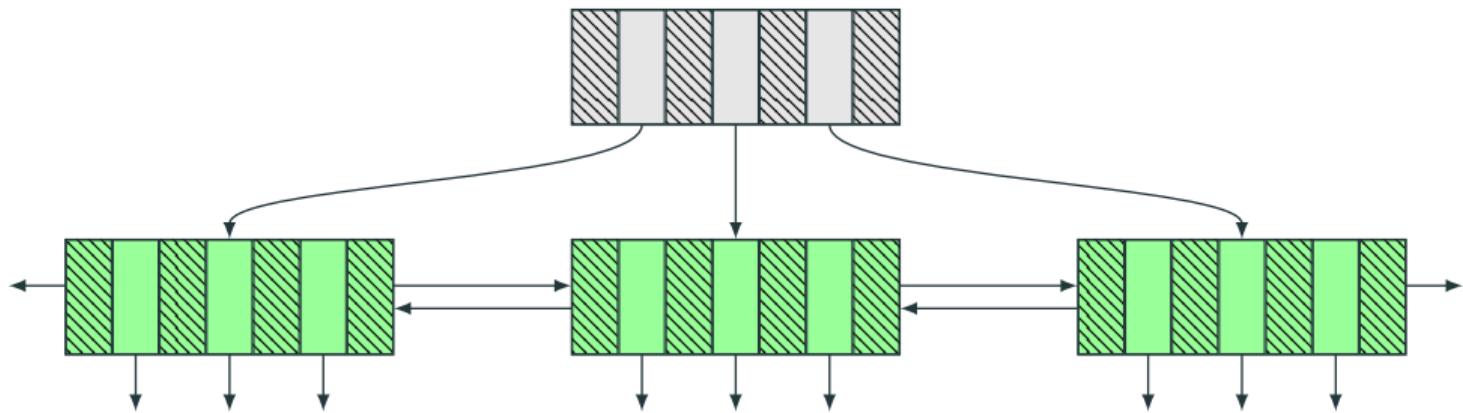
P. Lehman and S. Yao, Efficient Locking for Concurrent Operations on B-Trees, ACM Transactions on Database Systems, Vol 6, No. 4, December 1981, pp 650-670

B⁺Tree



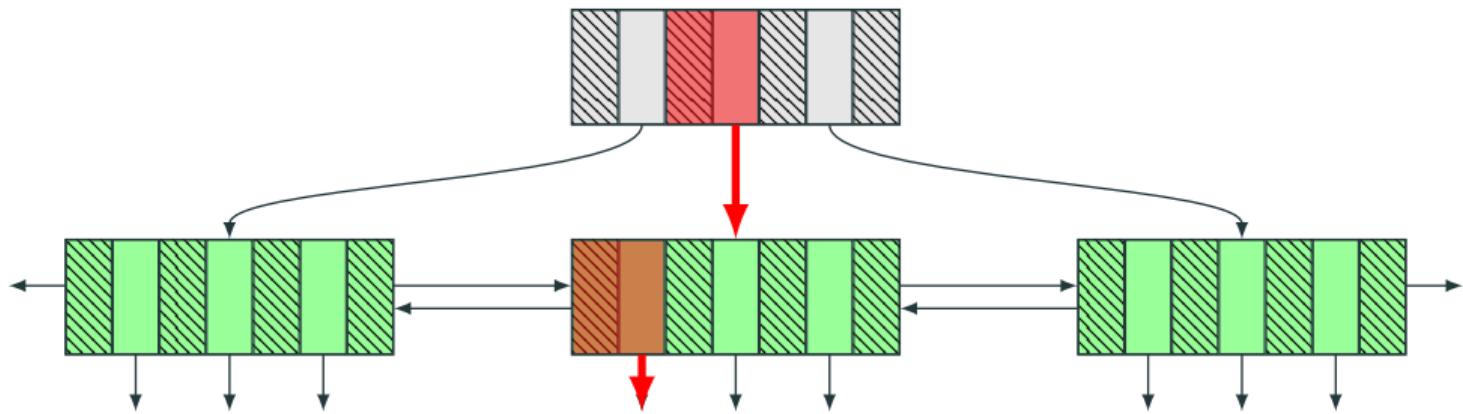
P. Lehman and S. Yao, Efficient Locking for Concurrent Operations on B-Trees, ACM Transactions on Database Systems, Vol 6, No. 4, December 1981, pp 650-670

B⁺Tree



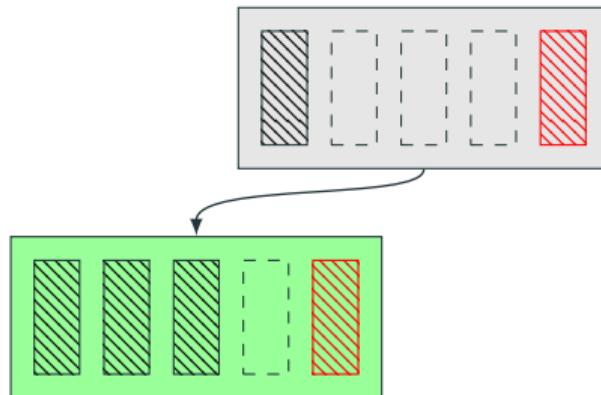
P. Lehman and S. Yao, Efficient Locking for Concurrent Operations on B-Trees, ACM Transactions on Database Systems, Vol 6, No. 4, December 1981, pp 650-670

B⁺Tree

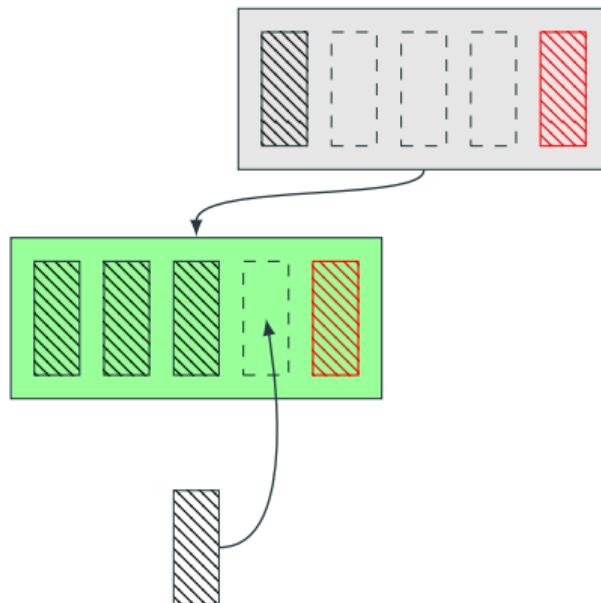


P. Lehman and S. Yao, Efficient Locking for Concurrent Operations on B-Trees, ACM Transactions on Database Systems, Vol 6, No. 4, December 1981, pp 650-670

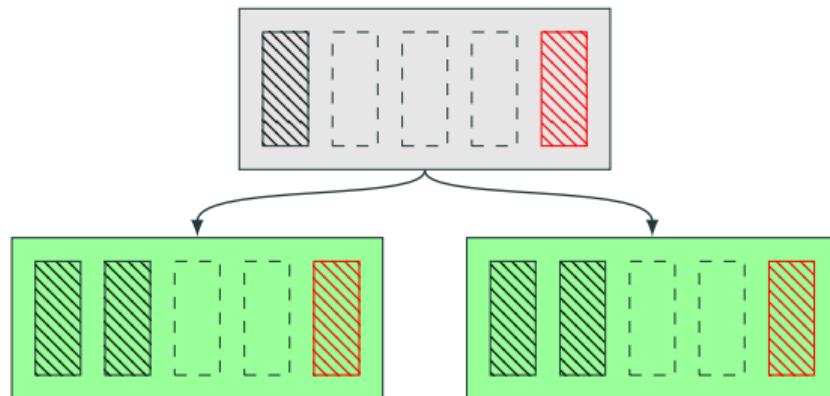
Page split



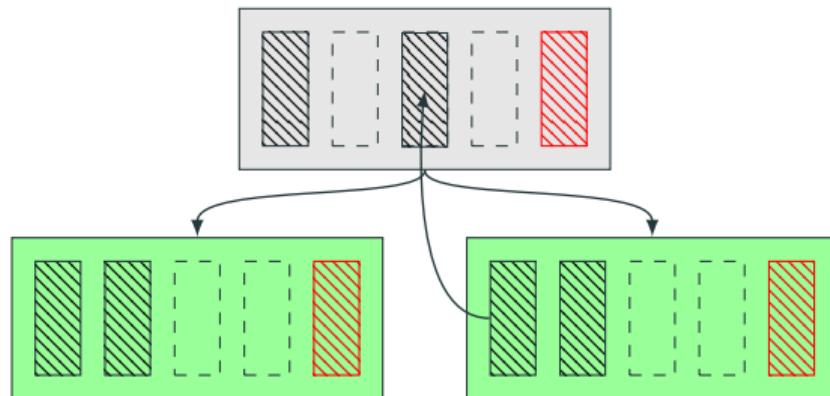
Page split



Page split



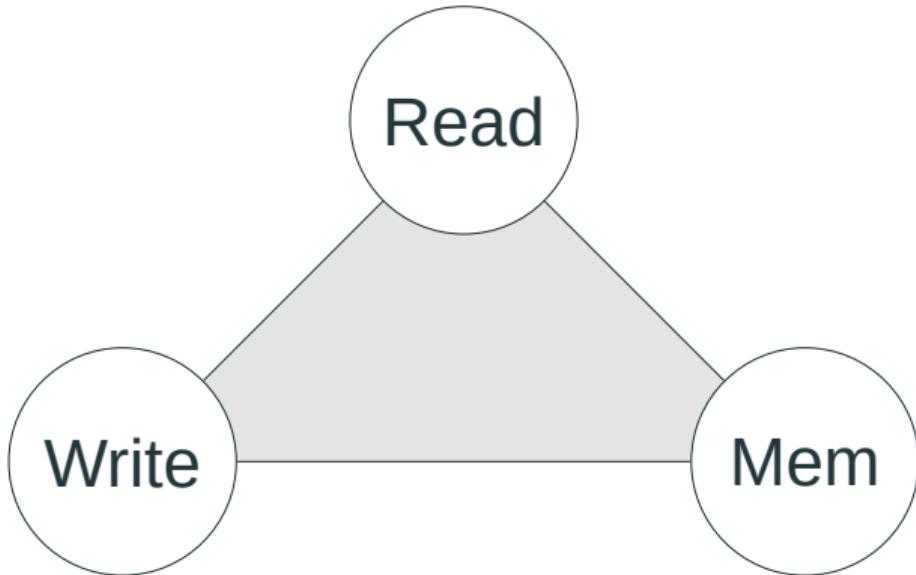
Page split

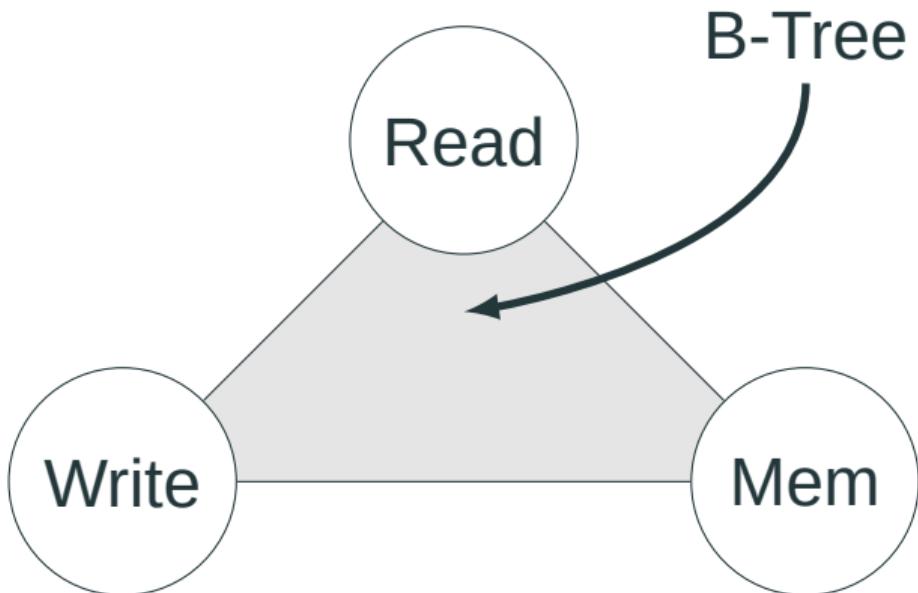


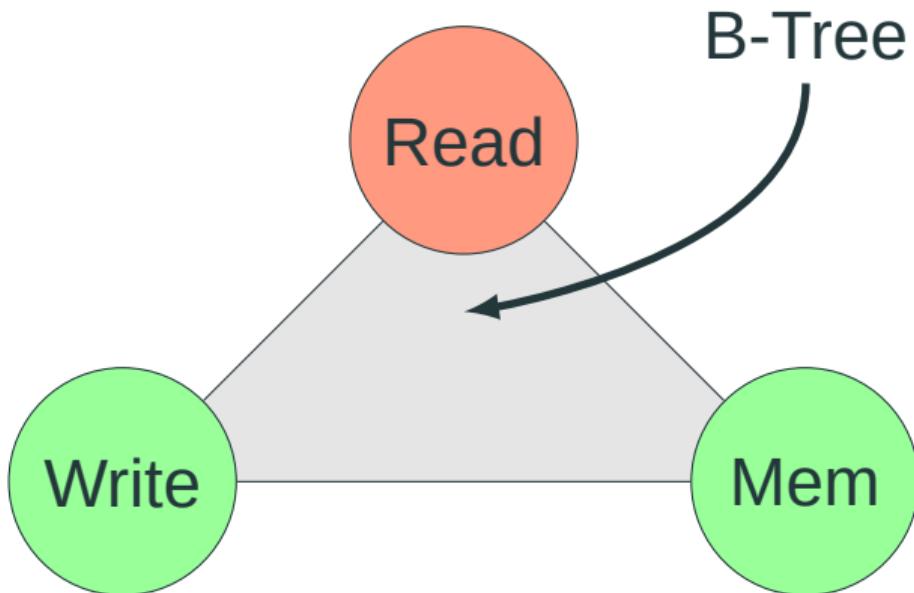
Page merge

"By adding periodic rebuilding of the tree, we obtain a data structure that is theoretically 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

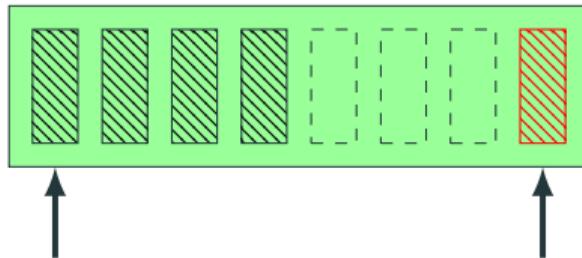
Smith Ja

ck 01-02-2019

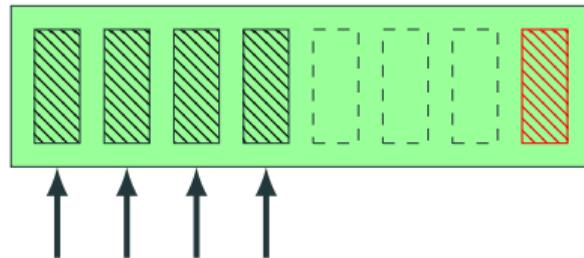
ne 02-03-2019

mes 03-04-2019

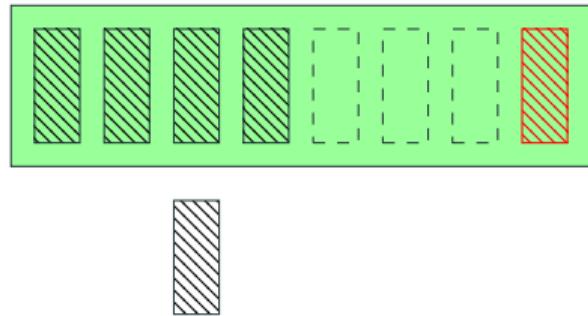
Prefix truncation



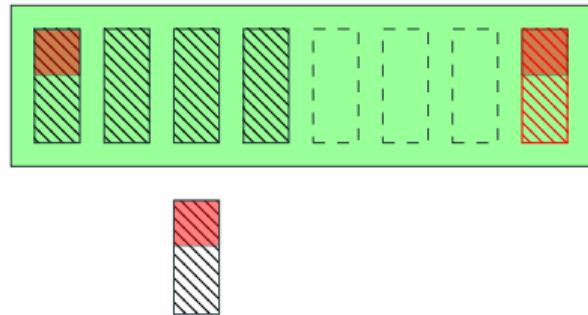
Prefix truncation



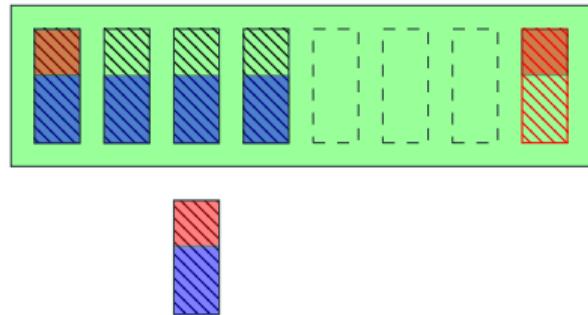
Dynamic prefix truncation



Dynamic prefix truncation



Dynamic prefix truncation



Suffix truncation

Johnson David	04-02-2019
Miller Kevin	01-02-2019
Miller Ned	02-03-2019
Miller Steven	03-04-2019
Smith Jack	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

Johnson David	04-02-2019
Miller Kevin	01-02-2019
 Miller Ned	02-03-2019
Miller Steven	03-04-2019
Smith Jack	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

Johnson David	04-02-2019
Miller Kevin	01-02-2019
Miller N ed	02-03-2019
Miller Steven	03-04-2019
Smith Jack	01-02-2019

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

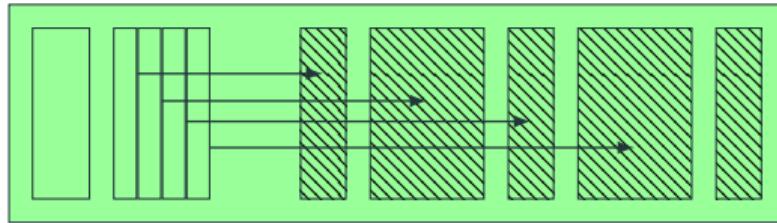
Suffix truncation



Johnson David	04-02-2019
Miller Kevin	01-02-2019
Miller Ned	02-03-2019
Miller Steven	03-04-2019
Smith Jack	01-02-2019

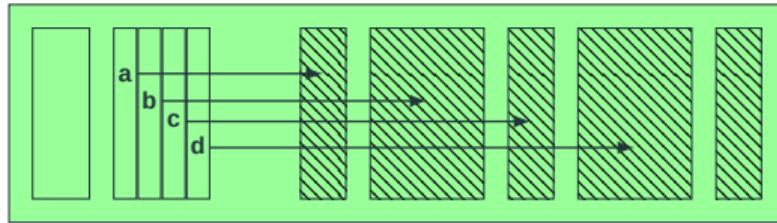
R. Bayer, K. Unterauer, "Prefix B-trees", ACM Transactions on Database Systems, vol. 2, no. 1, pp. 11-26, 1977

Indirection vector



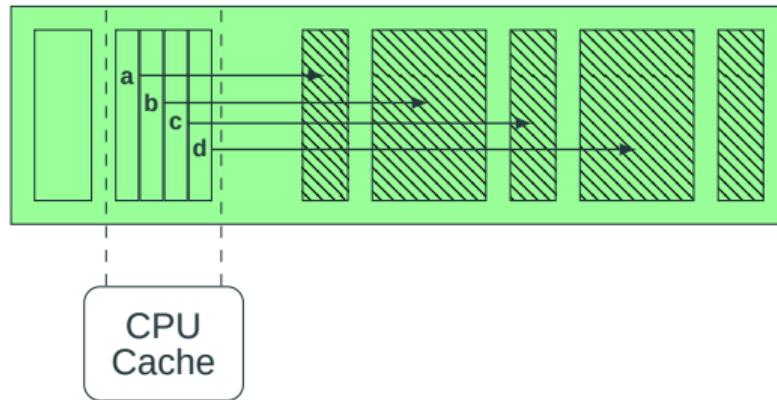
G. Graefe, Per-Ake Larson, "B-tree indexes and CPU caches", International Conference on Data Engineering, pp. 349-358, 2001

Indirection vector



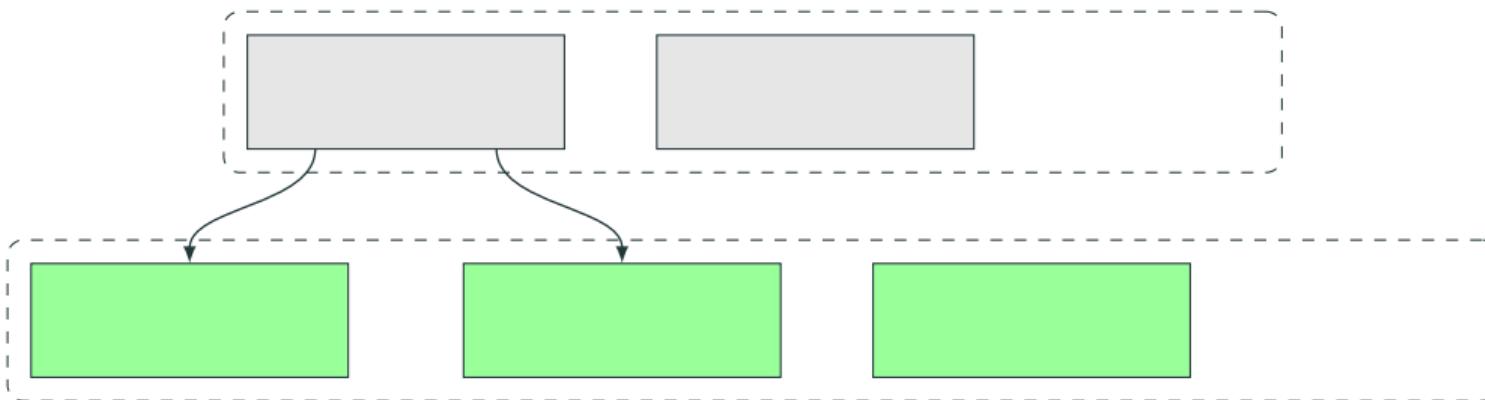
G. Graefe, Per-Ake Larson, "B-tree indexes and CPU caches", International Conference on Data Engineering, pp. 349-358, 2001

Indirection vector



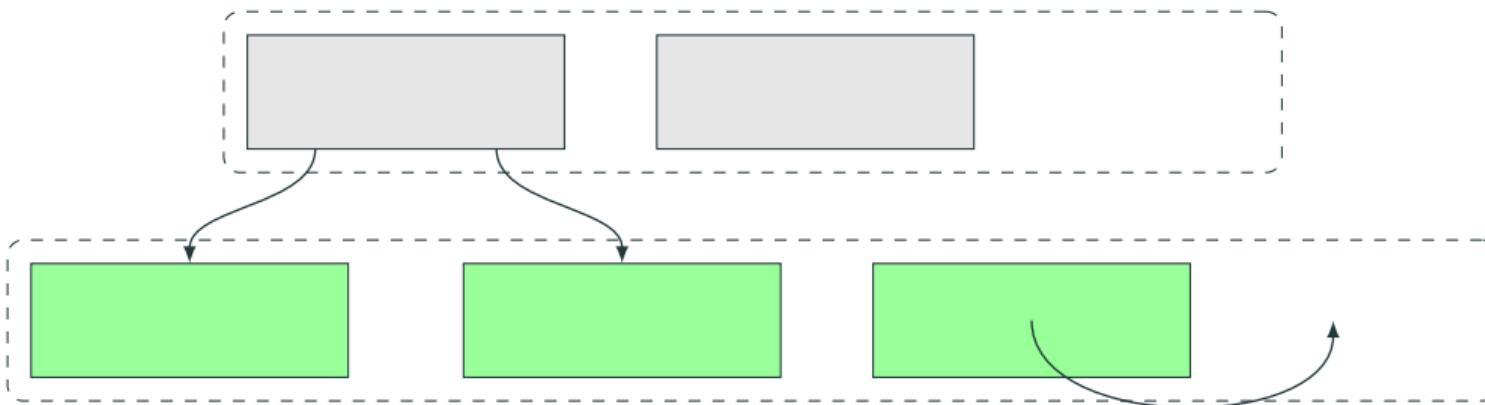
G. Graefe, Per-Ake Larson, "B-tree indexes and CPU caches", International Conference on Data Engineering, pp. 349-358, 2001

SB-tree



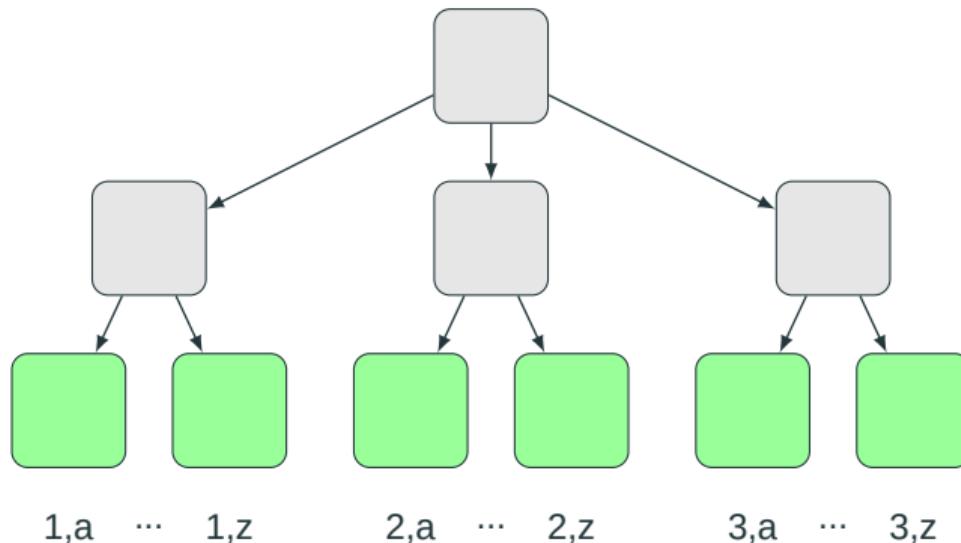
P. E. O'Neil, "The SB-tree: An index-sequential structure for high performance sequential access", Acta Informatica, vol. 29, no. 3. pp. 241-265, 1992

SB-tree

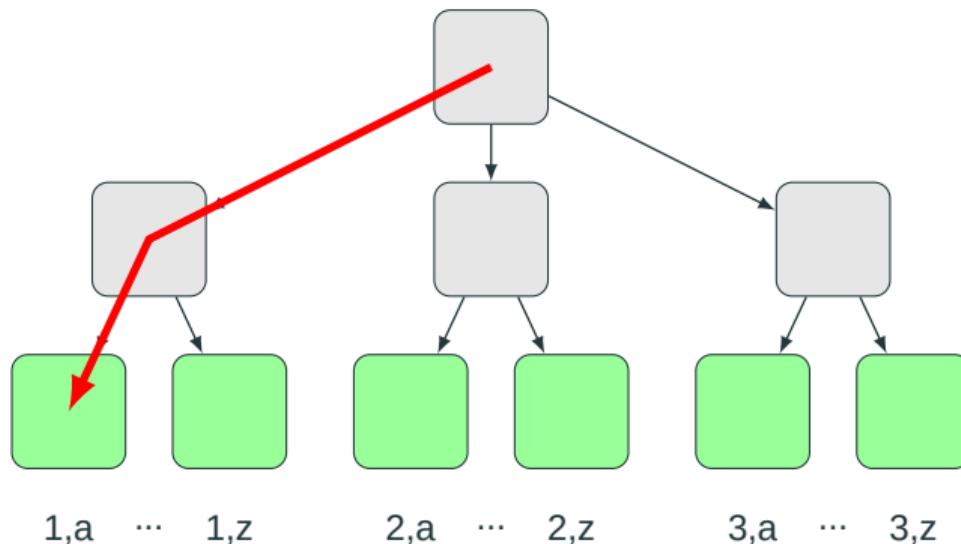


P. E. O'Neil, "The SB-tree: An index-sequential structure for high performance sequential access", Acta Informatica, vol. 29, no. 3. pp. 241-265, 1992

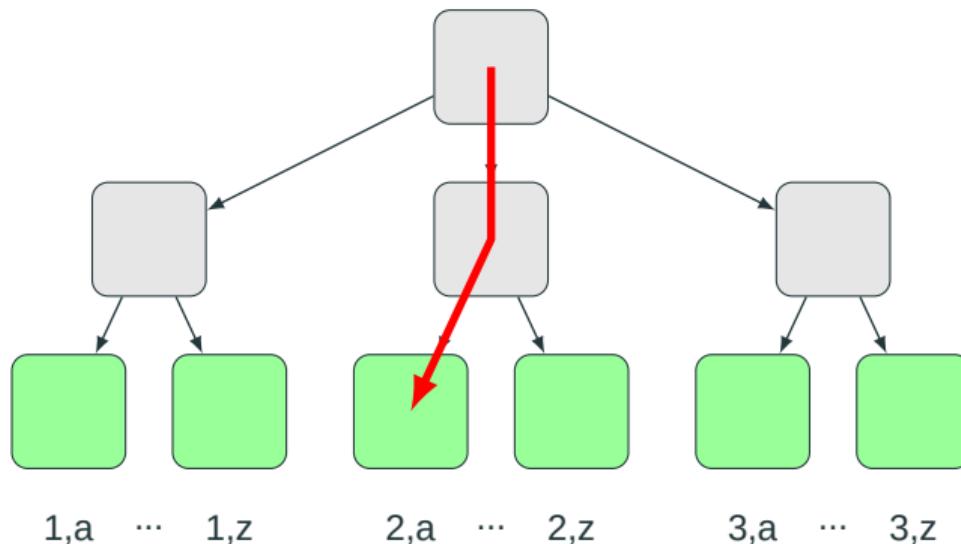
Multidimensional Access Method



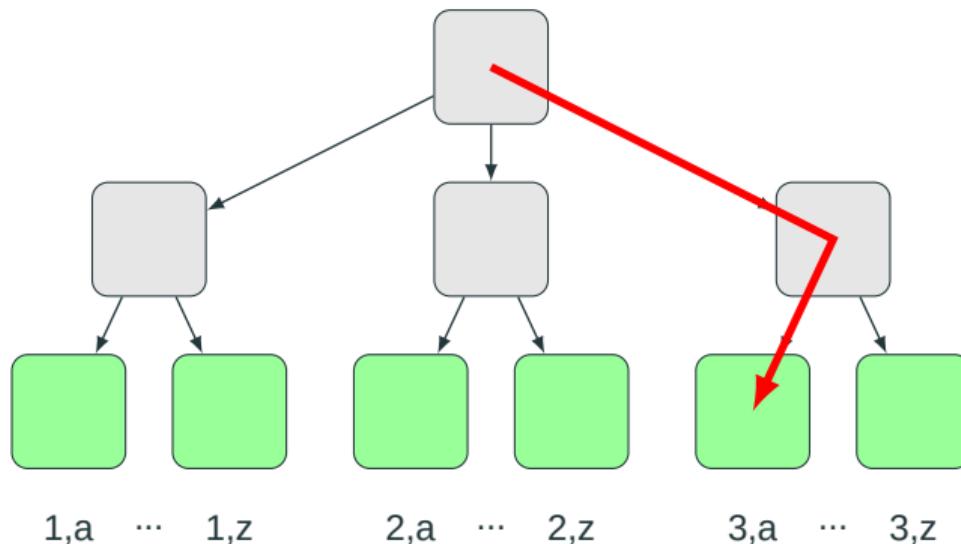
Multidimensional Access Method



Multidimensional Access Method



Multidimensional Access Method



Waves of misery after index creation

Nikolaus Glombiewski¹, Bernhard Seeger², Goetz Graefe³

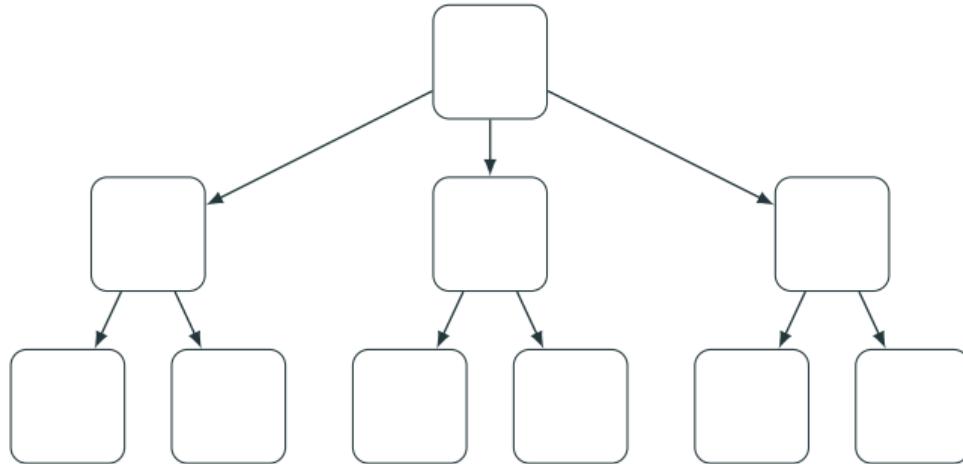
Abstract: After creation of a new b-tree, the ordinary course of database updates and index maintenance causes waves of node splits. Thus, a new index may at first speed up database query processing but then the first “wave of misery” requires effort for frequent node splits and imposes spikes of buffer 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 avoiding 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

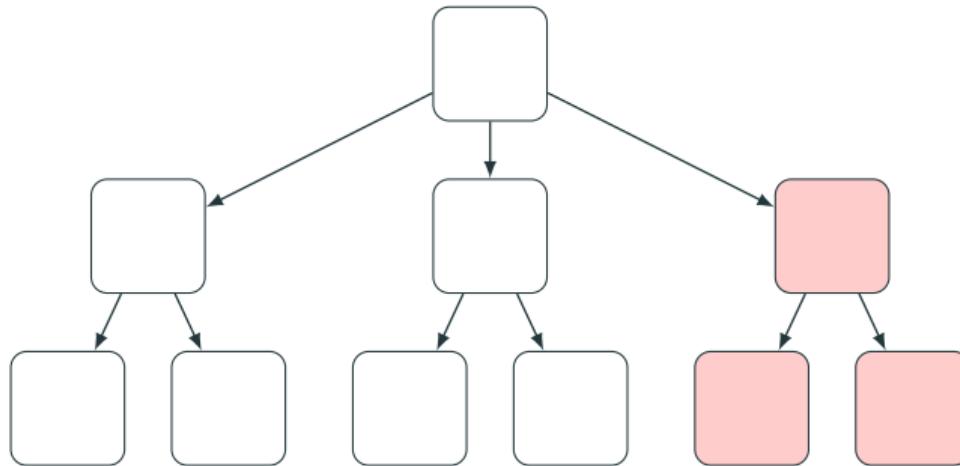
1 Introduction

The purpose of adding an index to a database table is to improve the performance of

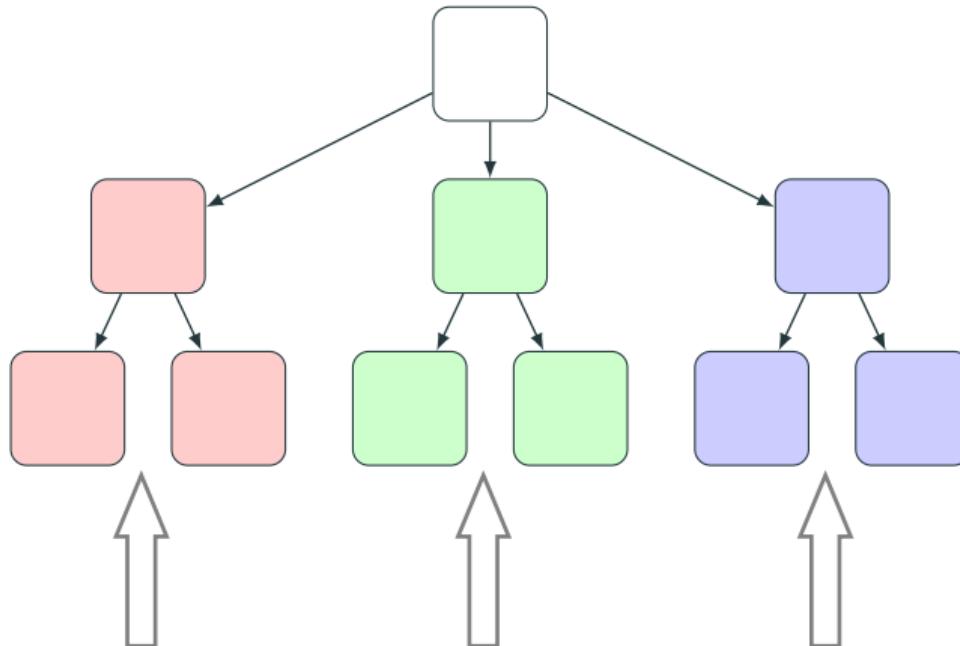
Partitioned B-tree



Partitioned B-tree

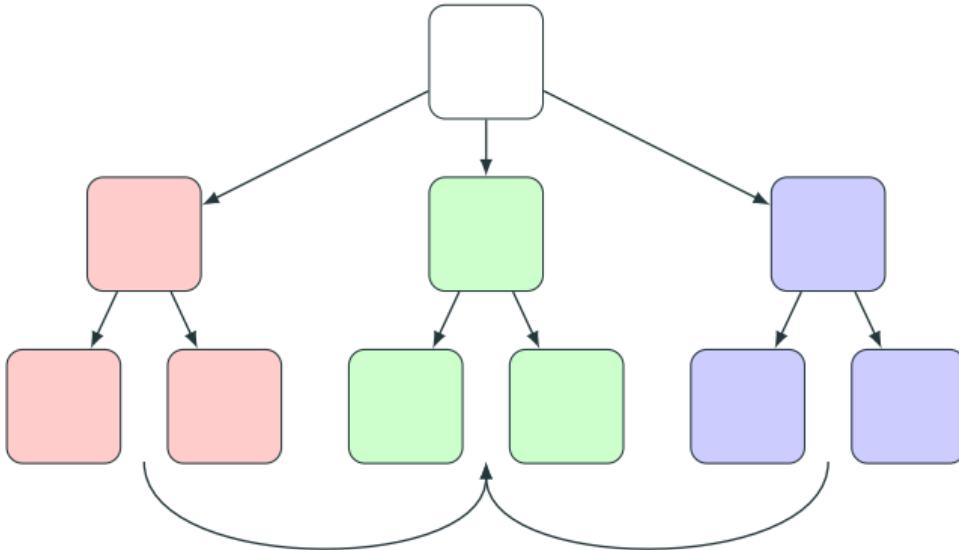


Partitioned B-tree



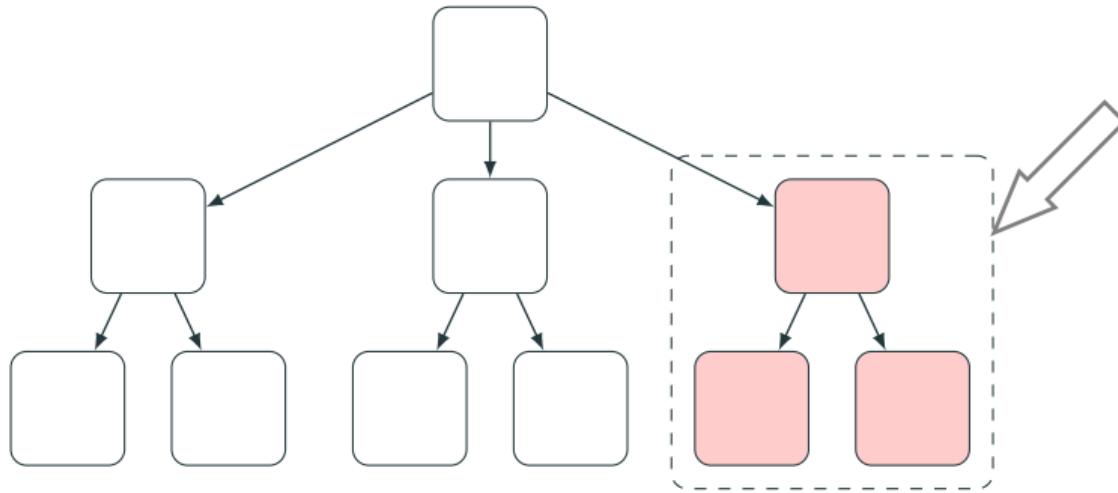
G. Graefe, "Sorting and indexing with partitioned B-Trees", Classless Inter Domain Routing, 2003

Partitioned B-tree



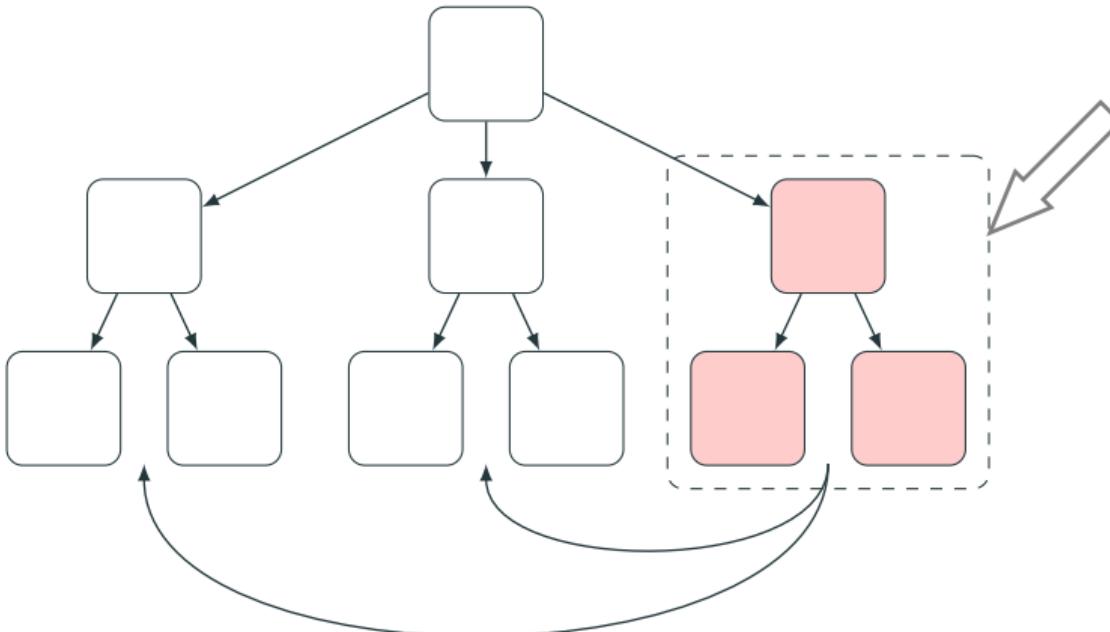
G. Graefe, "Sorting and indexing with partitioned B-Trees", Classless Inter Domain Routing, 2003

Partitioned B-tree



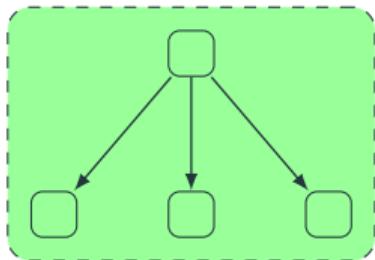
Riegger Christian, Vincon Tobias, Petrov Ilia. (2017). Write-optimized indexing with partitioned b-trees. 296-300.

Partitioned B-tree



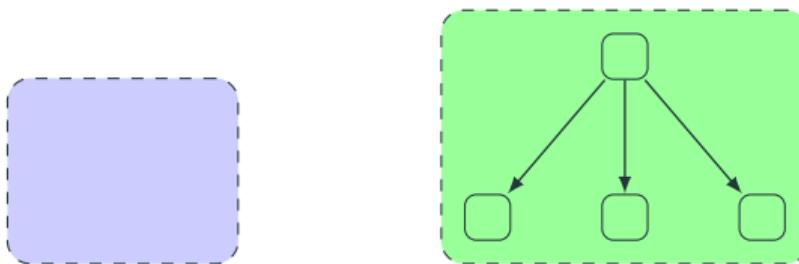
Riegger Christian, Vincon Tobias, Petrov Ilia. (2017). Write-optimized indexing with partitioned b-trees. 296-300.

Hybrid indexes



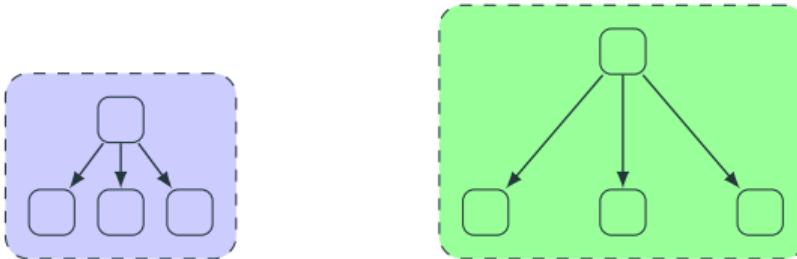
Huachen Zhang, David G. Andersen, Andrew Pavlo, Michael Kaminsky, Lin Ma, and Rui Shen. 2016. Reducing the Storage Overhead of Main-Memory OLTP Databases with Hybrid Indexes. In Proceedings of the 2016 International Conference on Management of Data (SIGMOD '16). Association for Computing Machinery, New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

Hybrid indexes



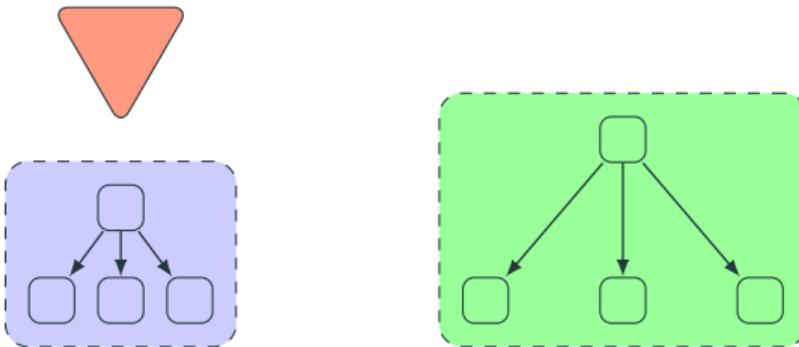
Huachen Zhang, David G. Andersen, Andrew Pavlo, Michael Kaminsky, Lin Ma, and Rui Shen. 2016. Reducing the Storage Overhead of Main-Memory OLTP Databases with Hybrid Indexes. In Proceedings of the 2016 International Conference on Management of Data (SIGMOD '16). Association for Computing Machinery, New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

Hybrid indexes



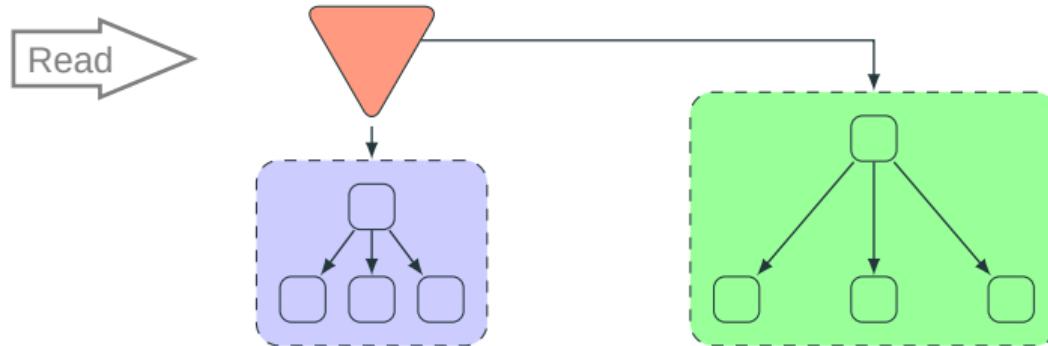
Huachen Zhang, David G. Andersen, Andrew Pavlo, Michael Kaminsky, Lin Ma, and Rui Shen. 2016. Reducing the Storage Overhead of Main-Memory OLTP Databases with Hybrid Indexes. In Proceedings of the 2016 International Conference on Management of Data (SIGMOD '16). Association for Computing Machinery, New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

Hybrid indexes



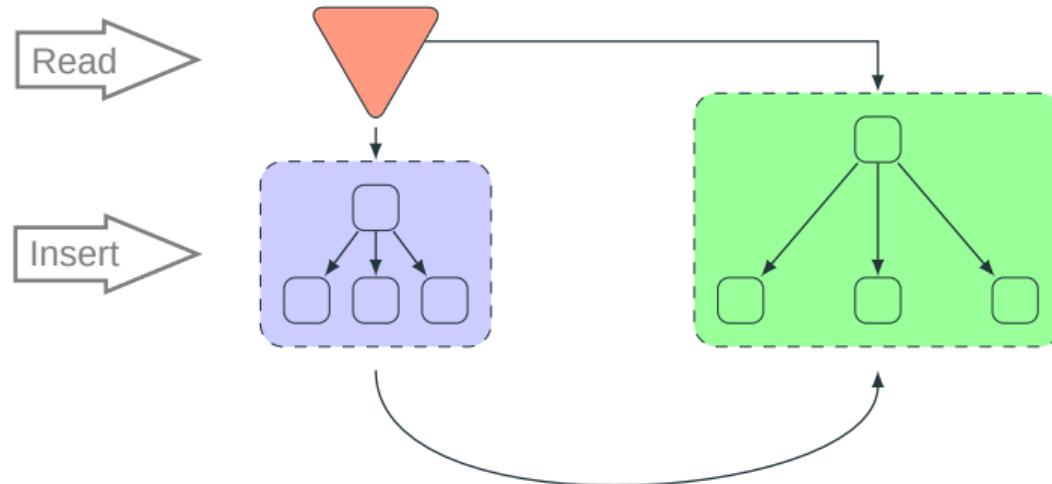
Huachen Zhang, David G. Andersen, Andrew Pavlo, Michael Kaminsky, Lin Ma, and Rui Shen. 2016. Reducing the Storage Overhead of Main-Memory OLTP Databases with Hybrid Indexes. In Proceedings of the 2016 International Conference on Management of Data (SIGMOD '16). Association for Computing Machinery, New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

Hybrid indexes



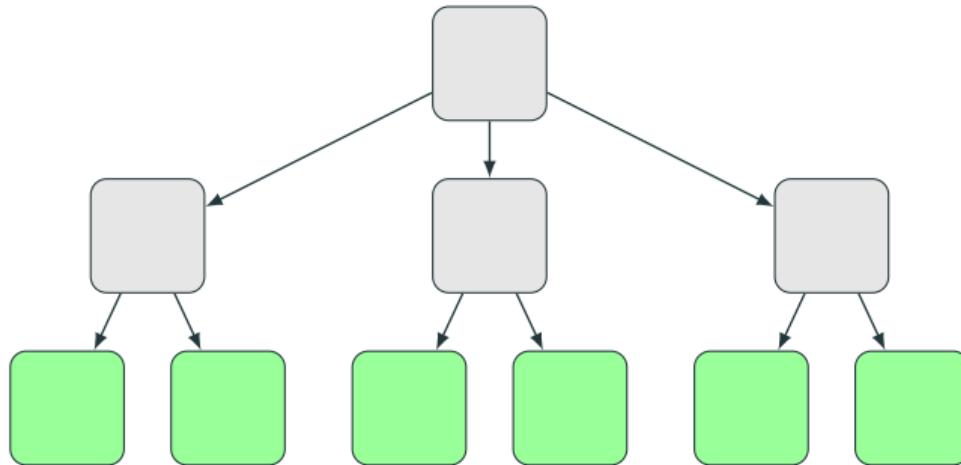
Huachen Zhang, David G. Andersen, Andrew Pavlo, Michael Kaminsky, Lin Ma, and Rui Shen. 2016. Reducing the Storage Overhead of Main-Memory OLTP Databases with Hybrid Indexes. In Proceedings of the 2016 International Conference on Management of Data (SIGMOD '16). Association for Computing Machinery, New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

Hybrid indexes



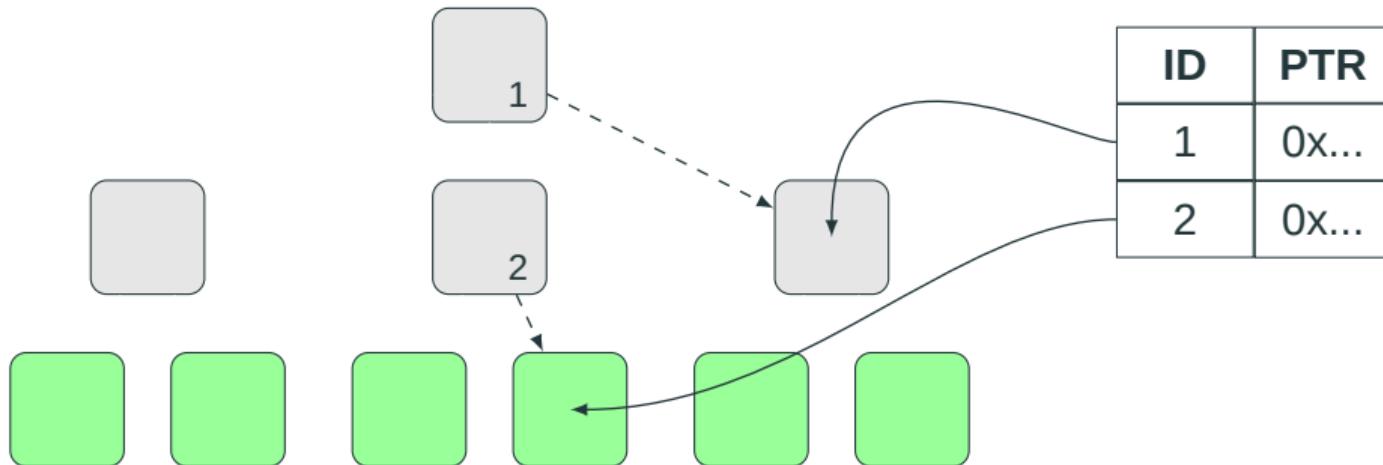
Huachen Zhang, David G. Andersen, Andrew Pavlo, Michael Kaminsky, Lin Ma, and Rui Shen. 2016. Reducing the Storage Overhead of Main-Memory OLTP Databases with Hybrid Indexes. In Proceedings of the 2016 International Conference on Management of Data (SIGMOD '16). Association for Computing Machinery, New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

Bw-Tree



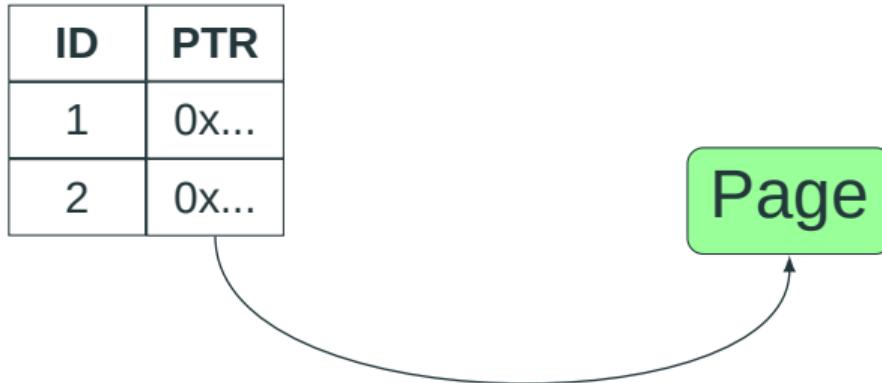
Levandoski Justin, Lomet David, Sengupta Sudipta. (2012). The Bw-Tree: A B-tree for New Hardware Platforms. Proceedings - International Conference on Data Engineering.

Bw-Tree



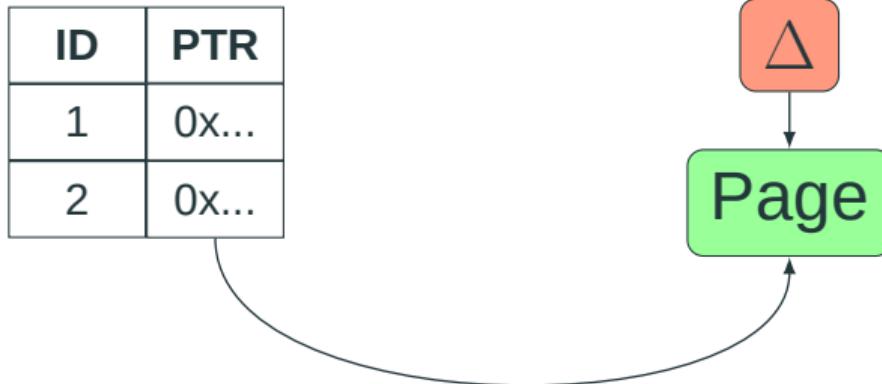
Levandoski Justin, Lomet David, Sengupta Sudipta. (2012). The Bw-Tree: A B-tree for New Hardware Platforms. Proceedings - International Conference on Data Engineering.

Bw-Tree



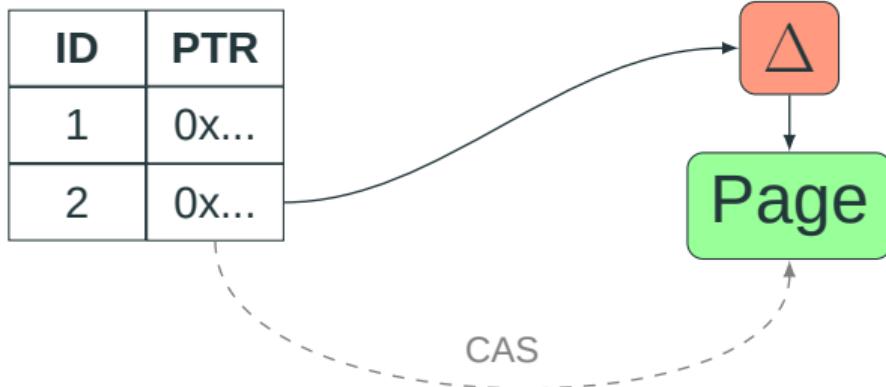
Levandoski Justin, Lomet David, Sengupta Sudipta. (2012). The Bw-Tree: A B-tree for New Hardware Platforms. Proceedings - International Conference on Data Engineering.

Bw-Tree



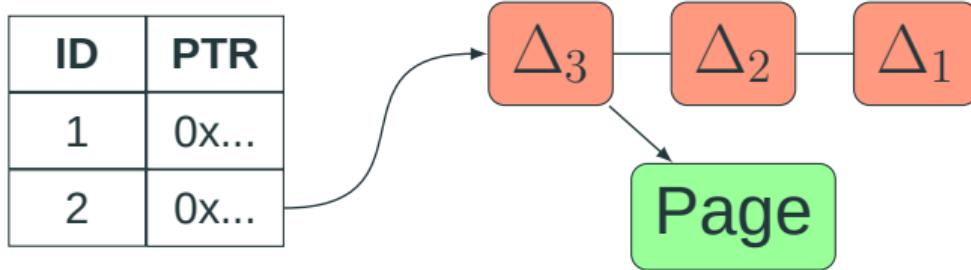
Levandoski Justin, Lomet David, Sengupta Sudipta. (2012). The Bw-Tree: A B-tree for New Hardware Platforms. Proceedings - International Conference on Data Engineering.

Bw-Tree



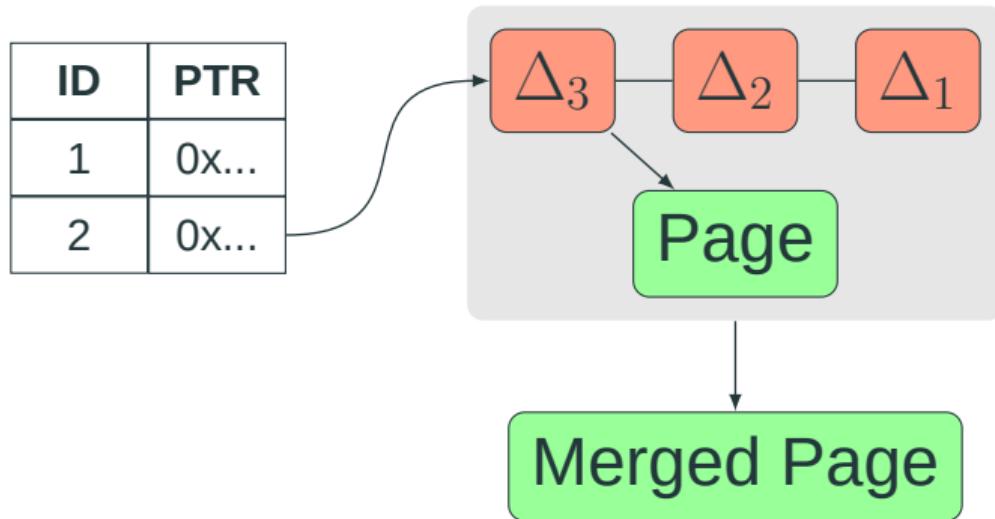
Levandoski Justin, Lomet David, Sengupta Sudipta. (2012). The Bw-Tree: A B-tree for New Hardware Platforms. Proceedings - International Conference on Data Engineering.

Bw-Tree



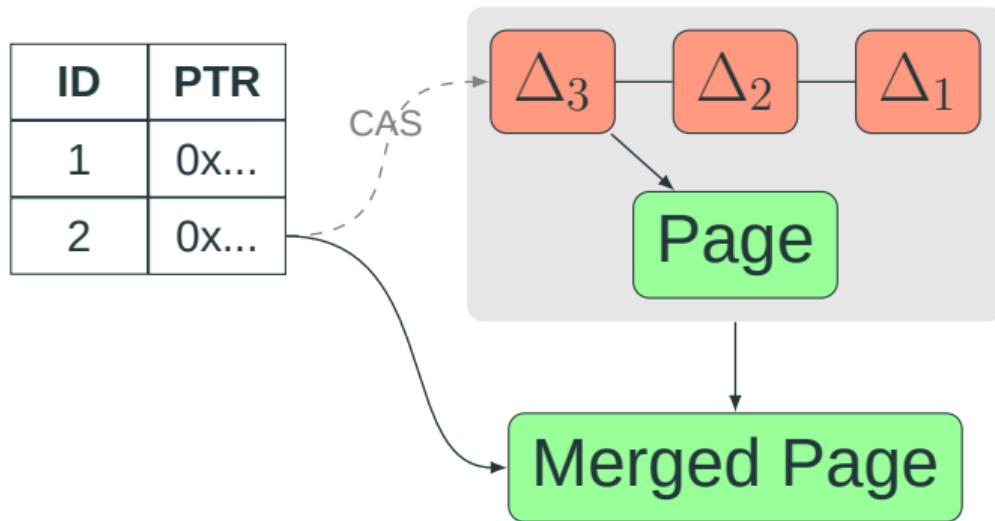
Levandoski Justin, Lomet David, Sengupta Sudipta. (2012). The Bw-Tree: A B-tree for New Hardware Platforms. Proceedings - International Conference on Data Engineering.

Bw-Tree



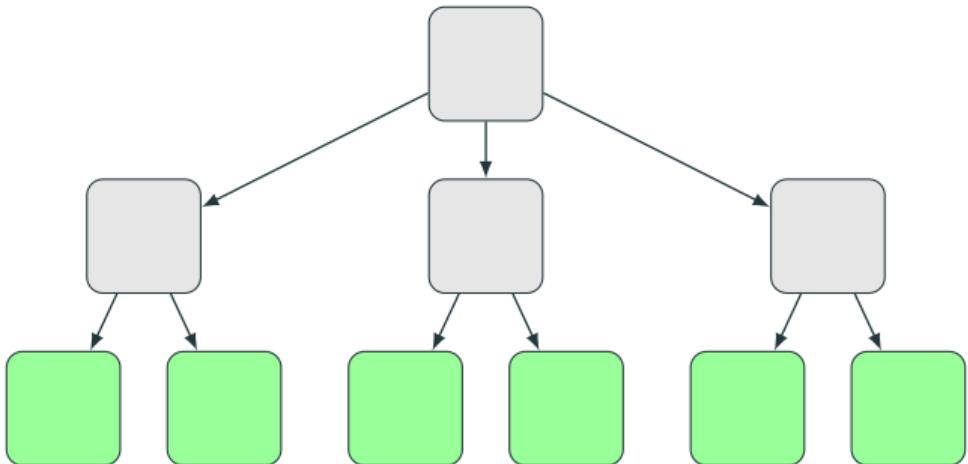
Levandoski Justin, Lomet David, Sengupta Sudipta. (2012). The Bw-Tree: A B-tree for New Hardware Platforms. Proceedings - International Conference on Data Engineering.

Bw-Tree



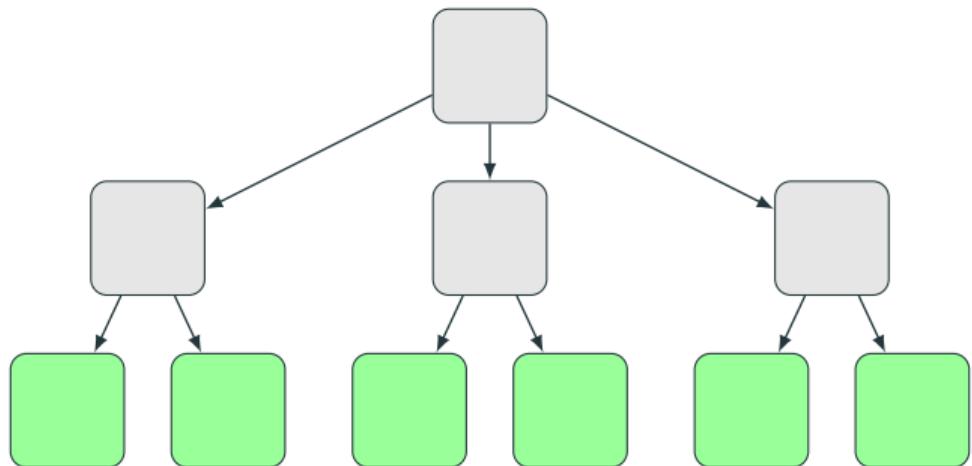
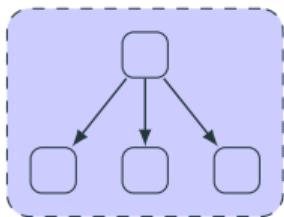
Levandoski Justin, Lomet David, Sengupta Sudipta. (2012). The Bw-Tree: A B-tree for New Hardware Platforms. Proceedings - International Conference on Data Engineering.

DPTree



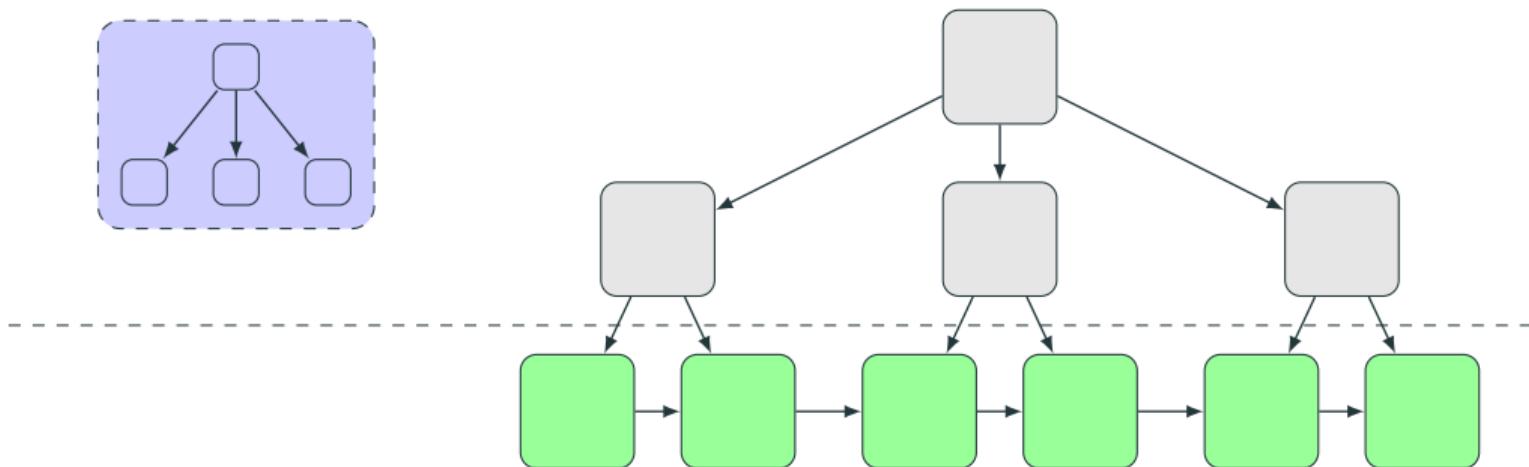
Zhou Xinjing, Shou Lidan, Chen Ke, Hu Wei, Chen Gang. (2019). DPTree: differential indexing for persistent memory. Proceedings of the VLDB Endowment.

DPTree



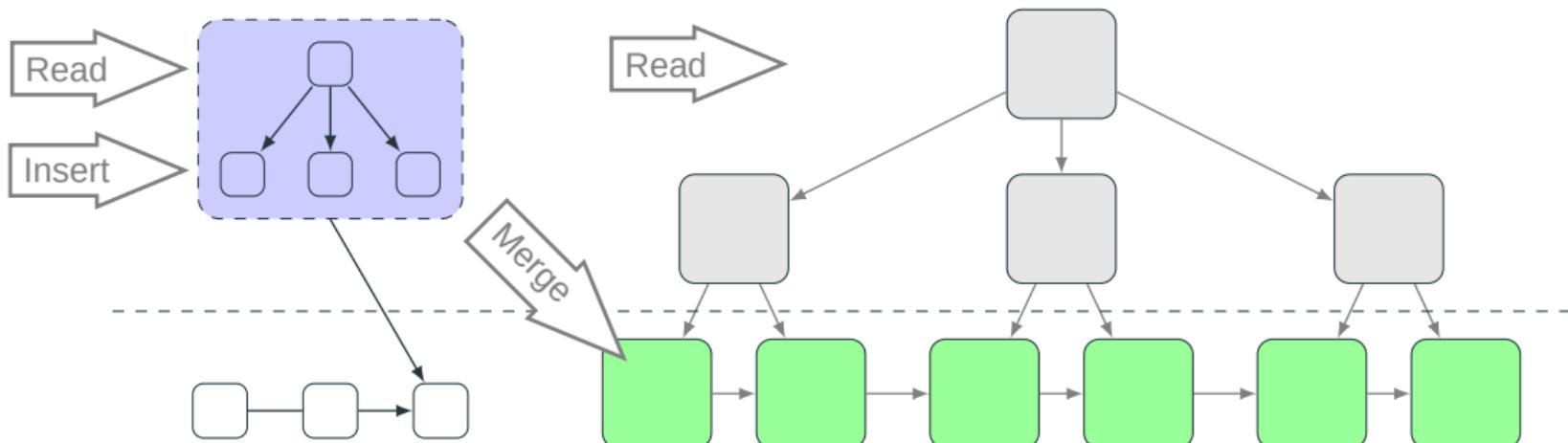
Zhou Xinjing, Shou Lidan, Chen Ke, Hu Wei, Chen Gang. (2019). DPTree: differential indexing for persistent memory. Proceedings of the VLDB Endowment.

DPTree



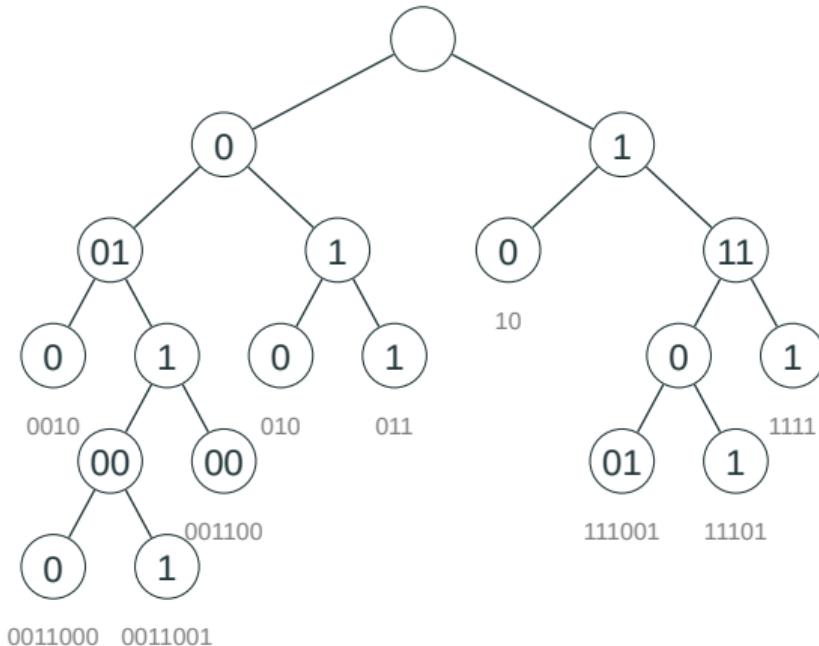
Zhou Xinjing, Shou Lidan, Chen Ke, Hu Wei, Chen Gang. (2019). DPTree: differential indexing for persistent memory. Proceedings of the VLDB Endowment.

DPTree

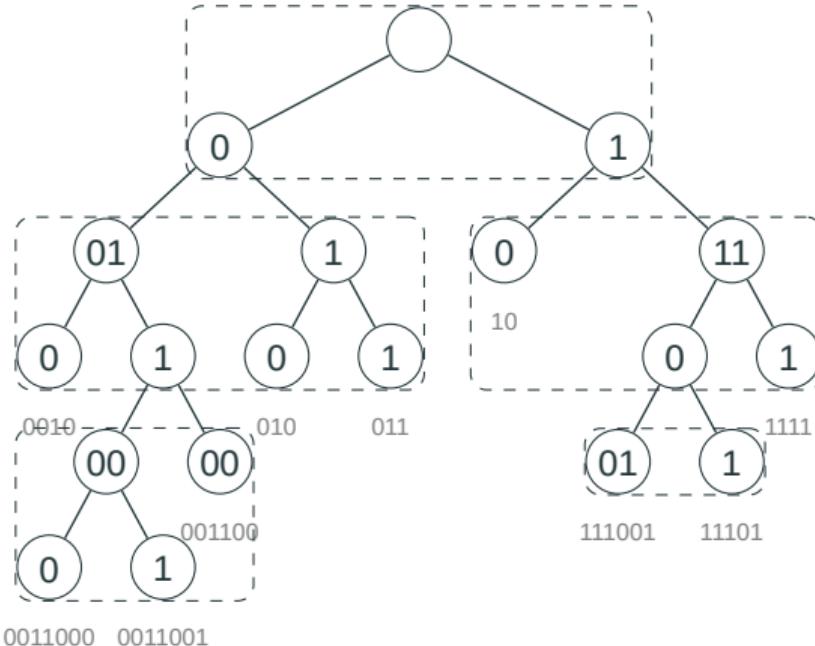


Zhou Xinjing, Shou Lidan, Chen Ke, Hu Wei, Chen Gang. (2019). DPTree: differential indexing for persistent memory. Proceedings of the VLDB Endowment.

Trie

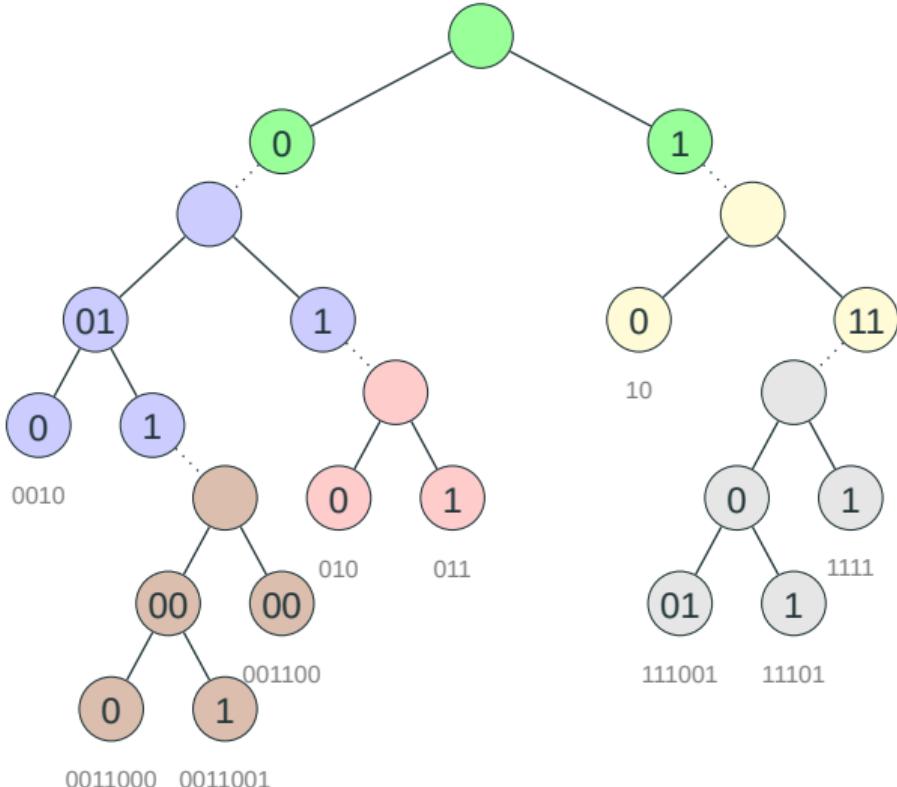


Trie



Leis V., Kemper Alfons, Neumann Thomas. (2013). The adaptive radix tree: ARTful indexing for main-memory databases. Proceedings - International Conference on Data Engineering. 38-49.

Trie



Is that all?



→ Buffered (Lazy) B-Tree

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

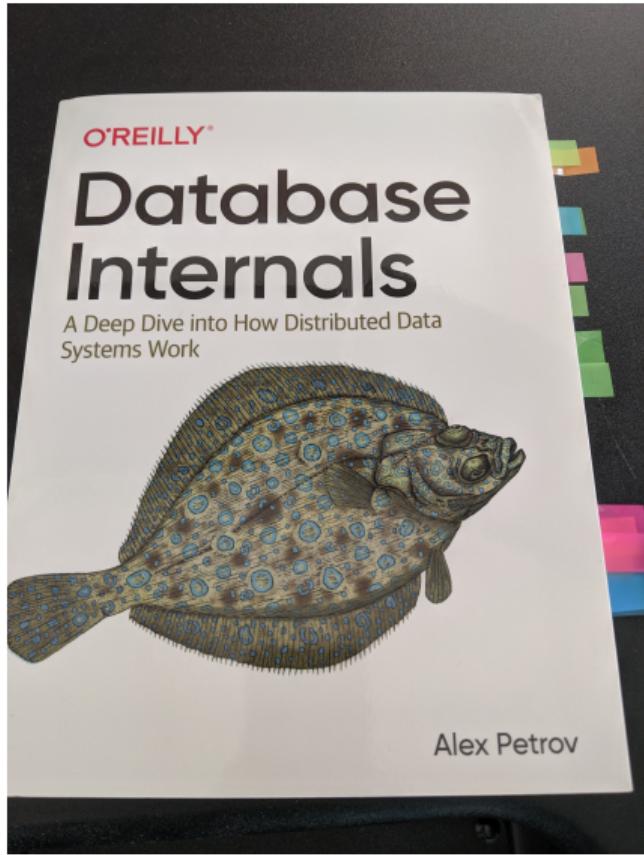
- Buffered (Lazy) B-Tree
- Cache conscious B-Tree
- Learned indexes

- Buffered (Lazy) B-Tree
- Cache conscious B-Tree
- Learned indexes
- UB-Tree

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

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

- Buffered (Lazy) B-Tree
- Cache conscious B-Tree
- Learned indexes
- UB-Tree
- Skip List
- LSM Tree
- ...



Questions?

🐦 @erthalion

✉️ dmitrii.dolgov at zalando dot de

✉️ 9erthalion6 at gmail dot com