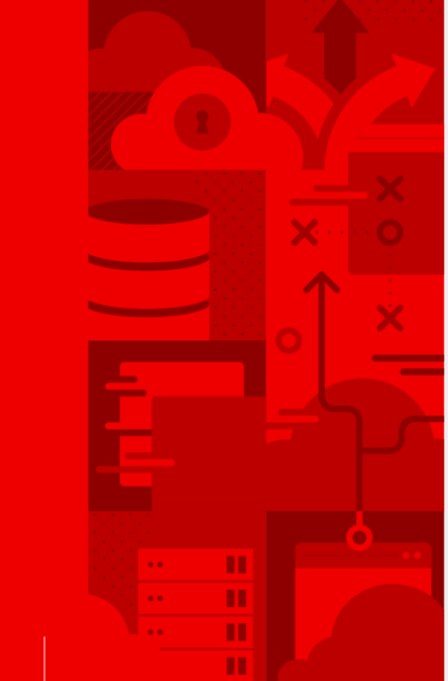

Modern BTree techniques

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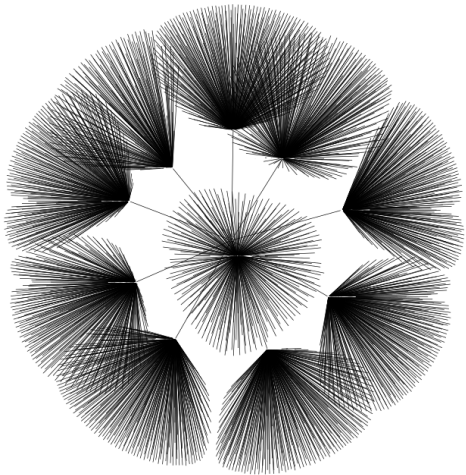

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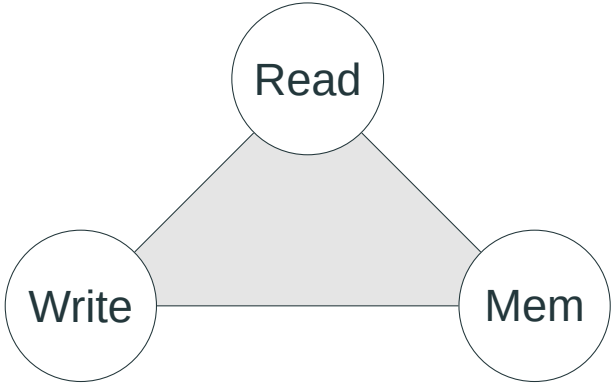
- Comer D. (1979). The Ubiquitous B-Tree. Computing Surveys, 11 (2).

- Comer D. (1979). The Ubiquitous B-Tree. Computing Surveys, 11 (2).
- Graefe G. (2011). Modern B-Tree Techniques. Foundations and Trends in Databases.

- ➔ RUM conjecture
- ➔ B-Tree internals
  - Key normalization
  - Prefix/Suffix truncation
- ➔ B-Tree as a component
  - Hybrid index
  - Bw-Tree
  - Partitioned B-Tree
- ➔ Learned Indexes
- ➔ Everything else

RUM conjecture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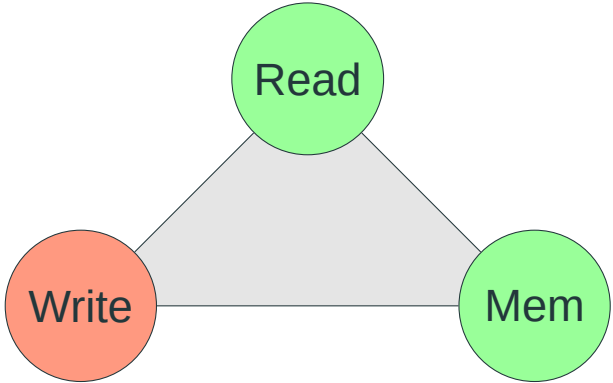

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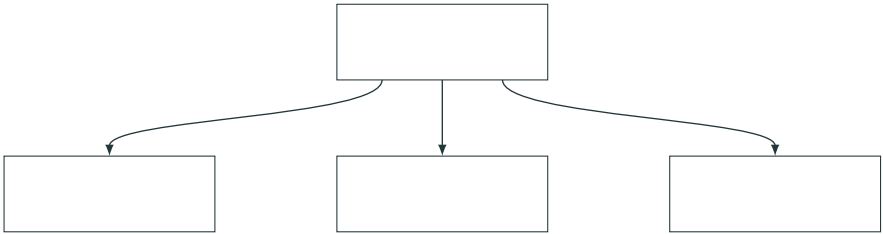
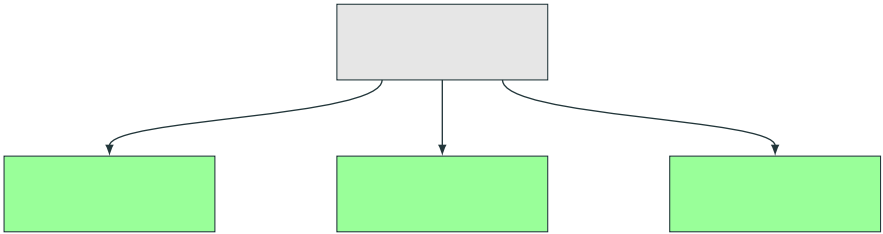
B-Tree internals

B-Tree $\rightarrow$ B$^+$Tree



Lehman P., Yao S. (1981). Efficient Locking for Concurrent Operations on B-Trees.
ACM Transactions on Database Systems.

B-Tree $\rightarrow$ B$^+$Tree



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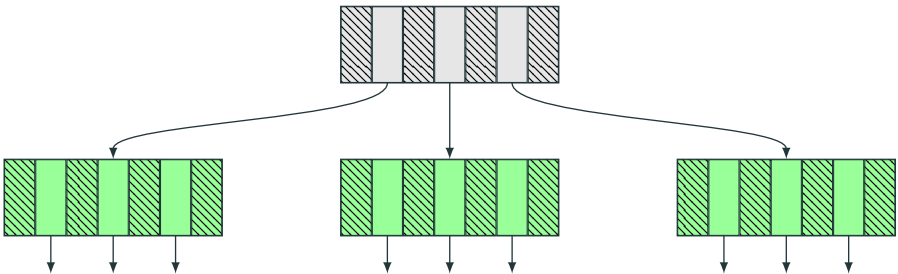

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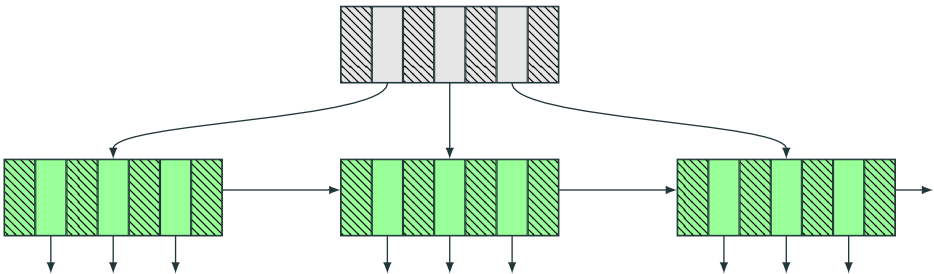

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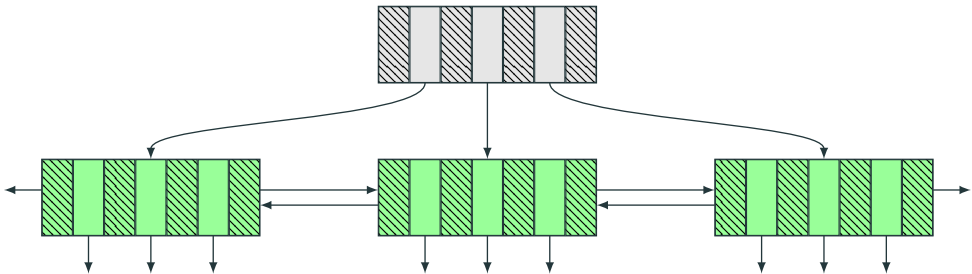

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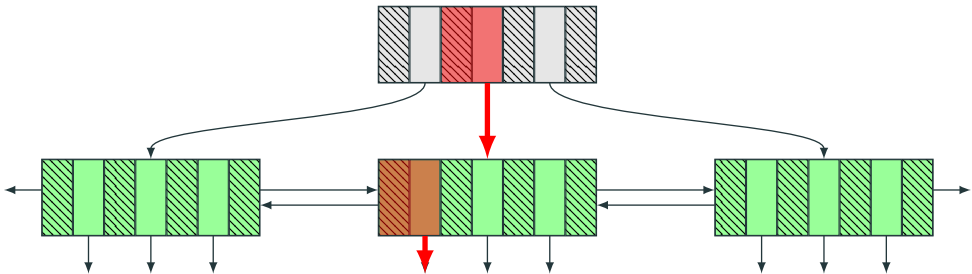

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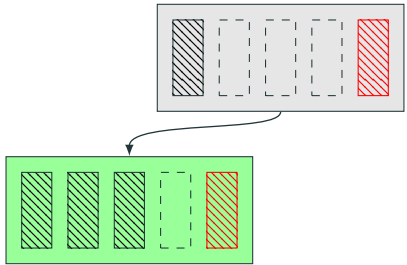

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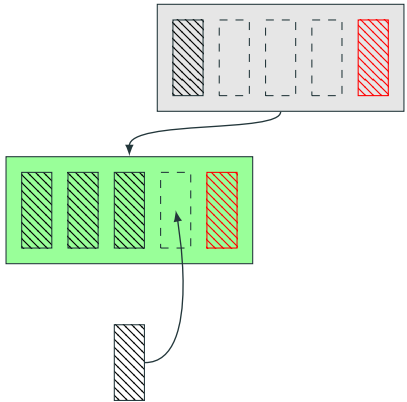

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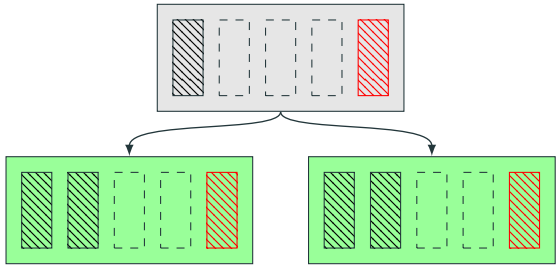

Red Hat

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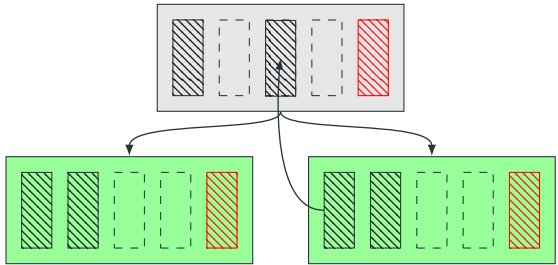

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Page merge

”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.”

Sen S., Tarjan R. E. (2009). Deletion without rebalancing in multiway search trees ACM Transactions on Database Systems

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

Singleton, R. C. (1969). An efficient algorithm for sorting with minimal storage. Communications of the ACM.

Prefix truncation

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

Prefix truncation

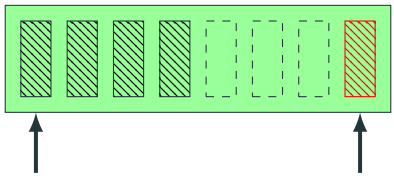
Smith Jack	01-02-2019
Smith Jane	02-03-2019
Smith James	03-04-2019

Prefix truncation

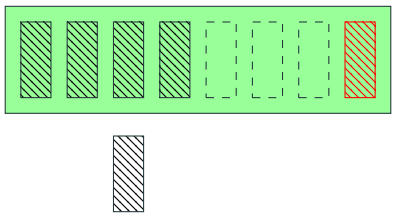
Smith Ja

ck	01-02-2019
ne	02-03-2019
mes	03-04-2019

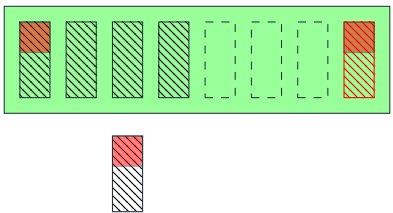
Prefix truncation



Dynamic prefix truncation



Dynamic prefix truncation



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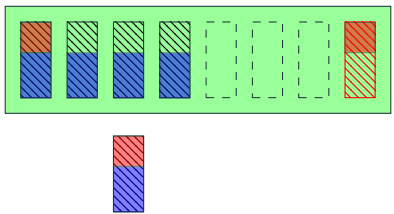
Dynamic prefix truncation



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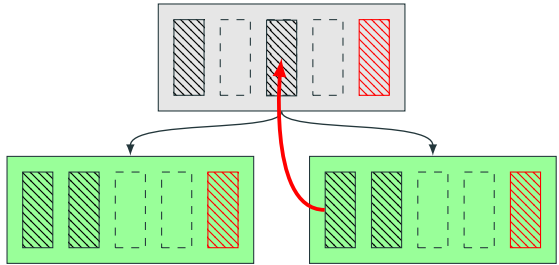
Suffix truncation

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

Bayer, R., Unterauer, K. (1977). Prefix B-trees.
ACM Transactions on Database Systems.

Suffix truncation



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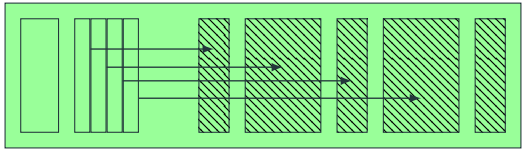
Indirection vector



Graefe G., Larson P. (2001). B-tree indexes and CPU caches. International Conference on Data Engineering.

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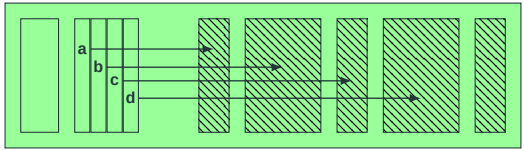
Indirection vector



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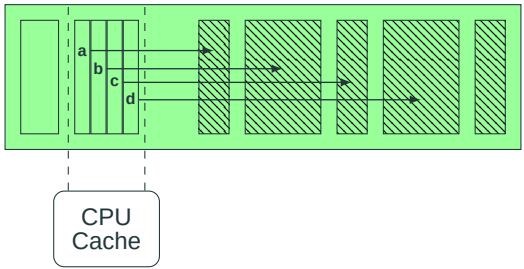

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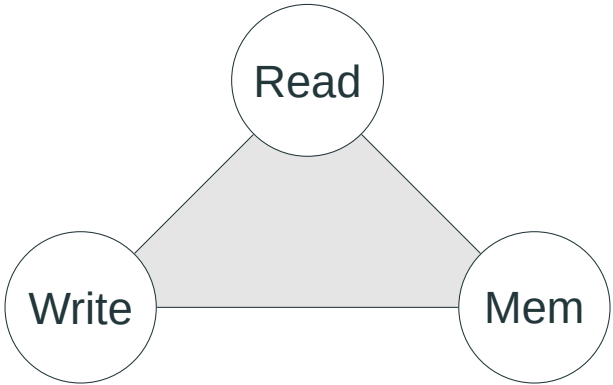
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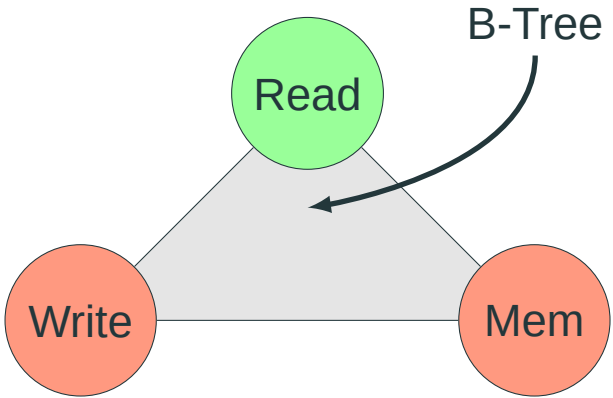

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T. Grust et al. (Hrsg.): Datenbanksysteme für Business, Technologie und Web (BTW 2019),
Lecture Notes in Informatics (LNI), Gesellschaft für Informatik, Bonn 2019 77

Waves of misery after index creation

Nikolaus Glombiewski[1] Bernhard Seeger[2] Goetz Graefe[3]

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 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

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B-Tree as a component

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	PBT	Hybrid B$^+$-Tree

B-Tree	B^+-Tree	B_{link}-Tree	DPTree
wB^+-Tree	NV-Tree	FPTree	FASTFAIR
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B-Tree	B^+-Tree	B_{link}-Tree	DPTree
wB^+-Tree	NV-Tree	FPTree	FASTFAIR
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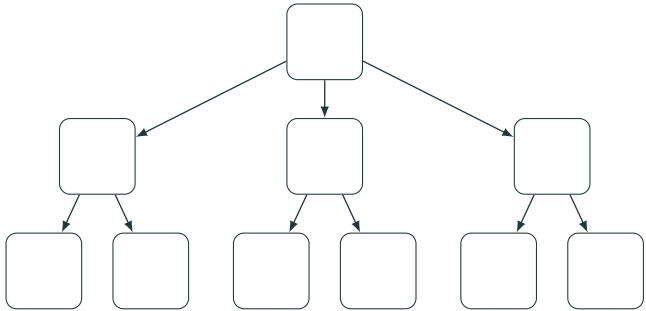
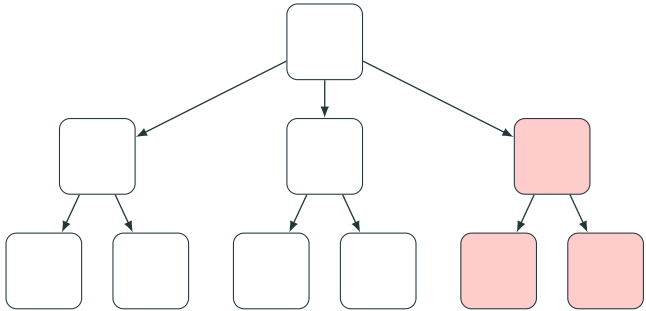
KISS-Tree	VAST-Tree	FAST	HV-Tree
UB-Tree	LHAM	PBT	Hybrid B^+-Tree

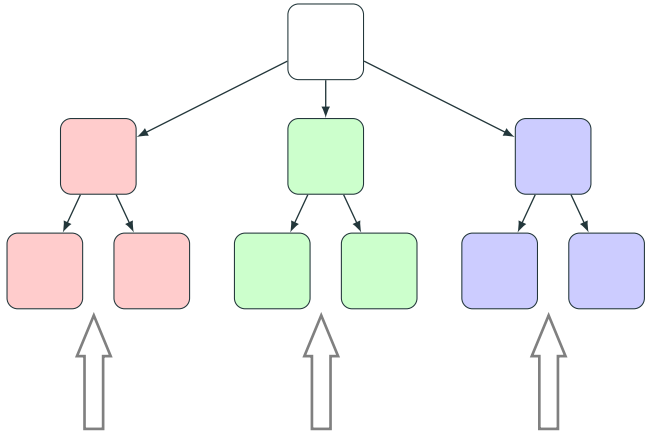
Partitioned B-tree



Partitioned B-tree

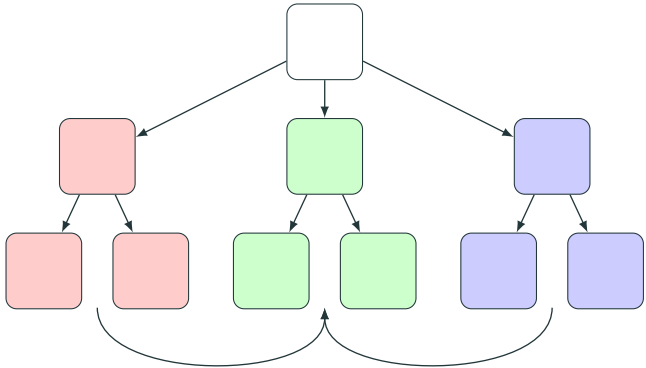


Partitioned B-tree



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

Partitioned B-tree



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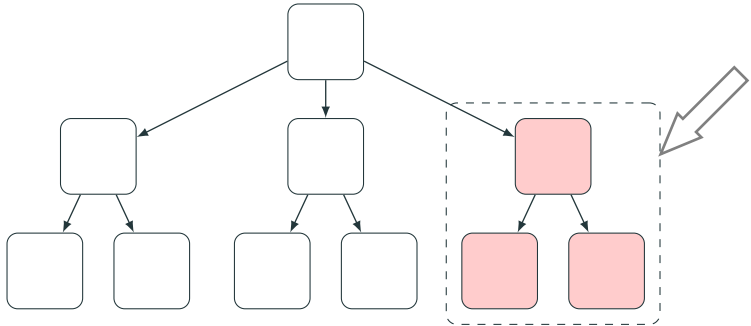
Partitioned B-tree



Riegger C., Vincon T., Petrov I. (2017). Write-optimized indexing with partitioned b-trees.
Proceedings of the 19th International Conference on Information Integration and Web-based Applications & Services

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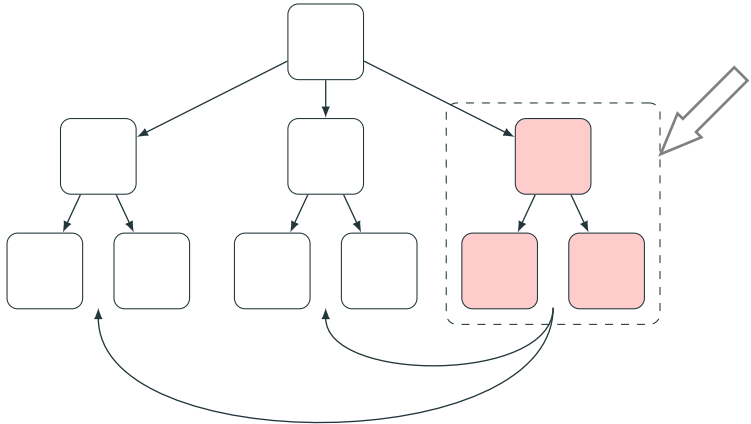
Partitioned B-tree



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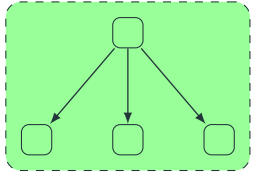
Hybrid indexes



Zhang H., Andersen D. G., Pavlo A., Kaminsky M., Ma L., Shen R. (2016).
Reducing the Storage Overhead of Main-Memory OLTP Databases with Hybrid Indexes.
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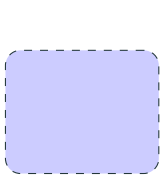
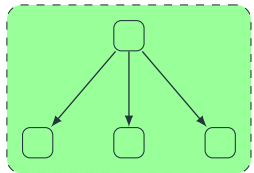
Hybrid indexes





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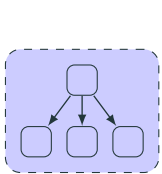
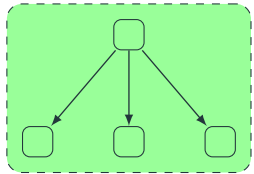
Hybrid indexes





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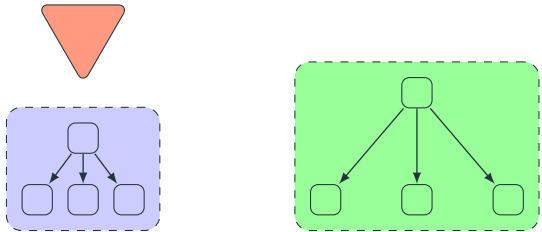

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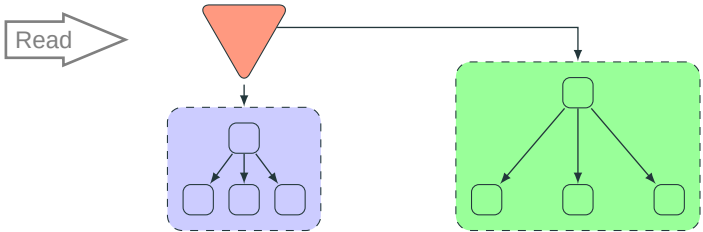
Hybrid indexes



Zhang H., Andersen D. G., Pavlo A., Kaminsky M., Ma L., Shen R. (2016).
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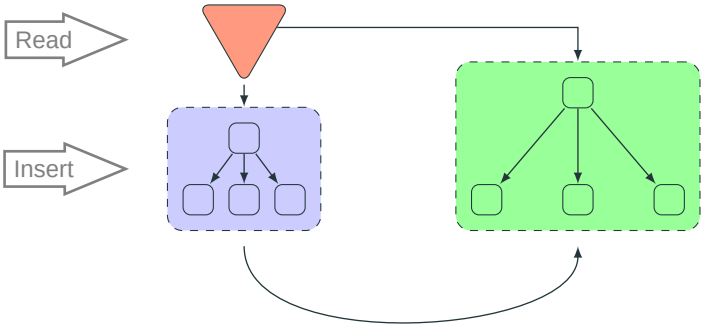
Hybrid indexes



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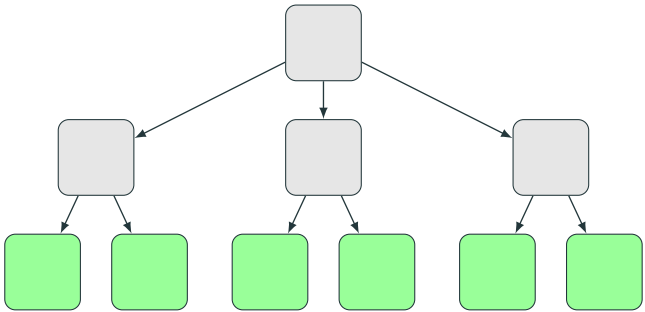
Bw-Tree



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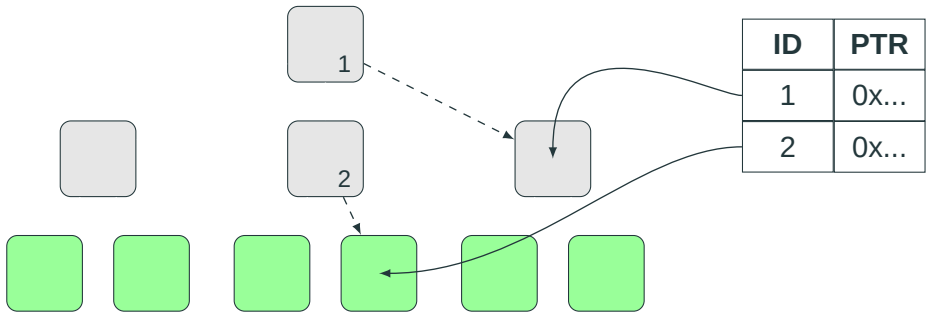
Bw-Tree



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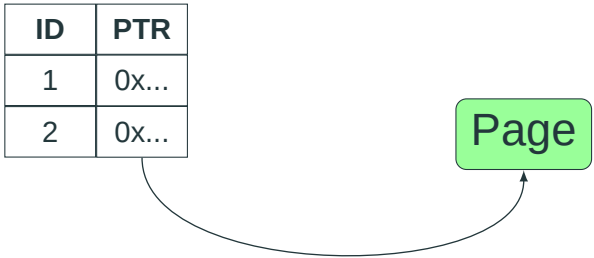

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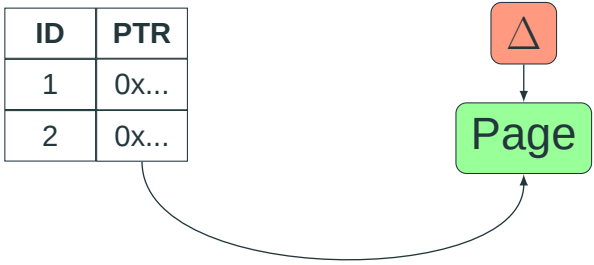

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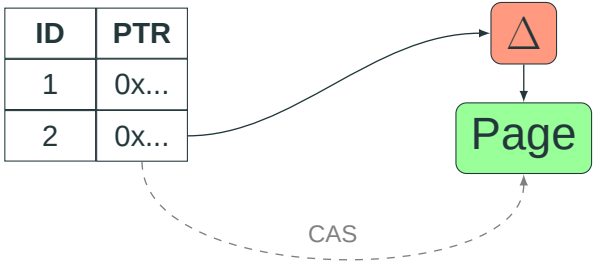

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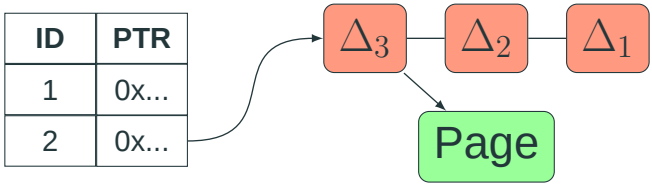

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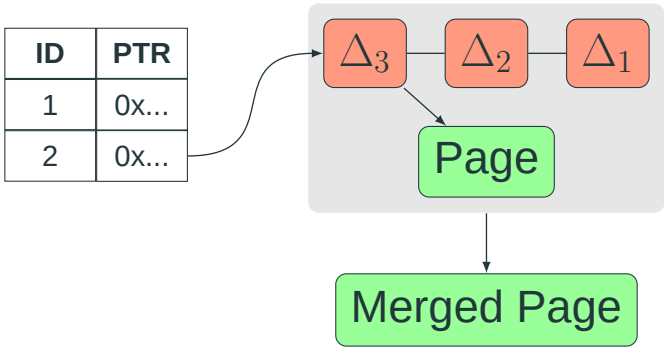

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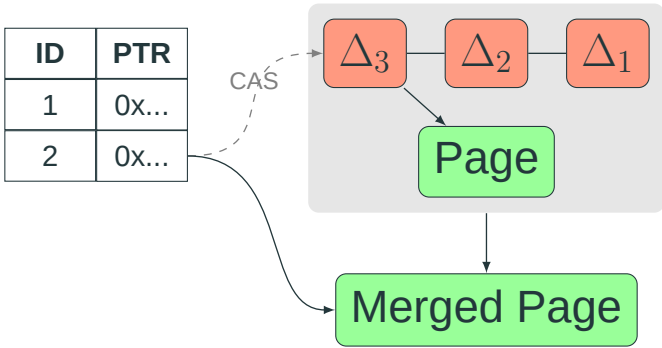

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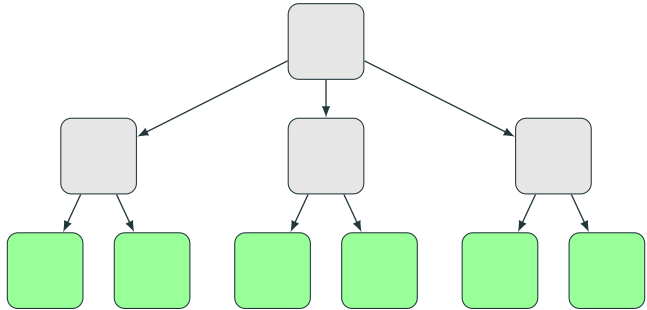
DPTree



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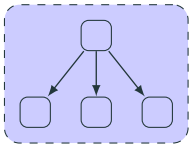

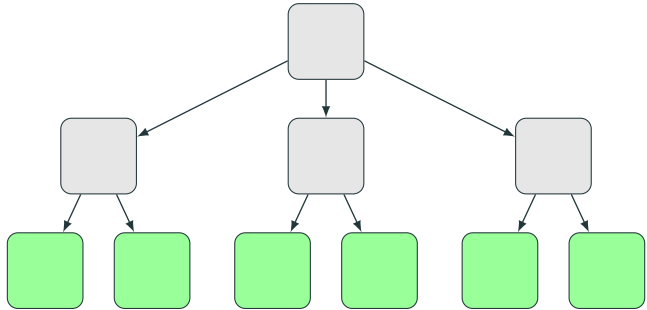

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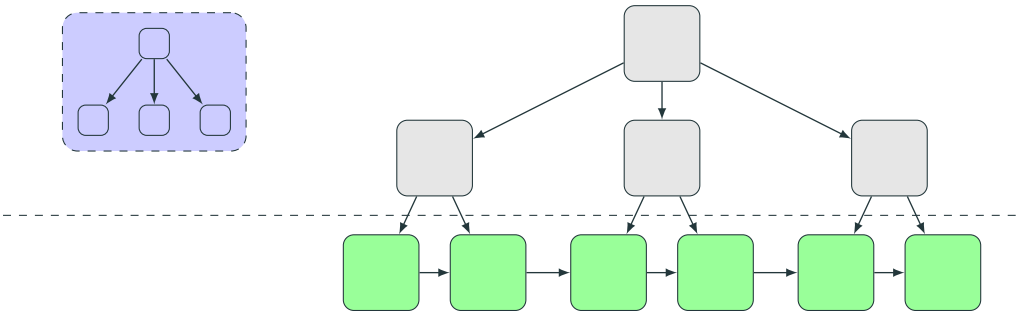

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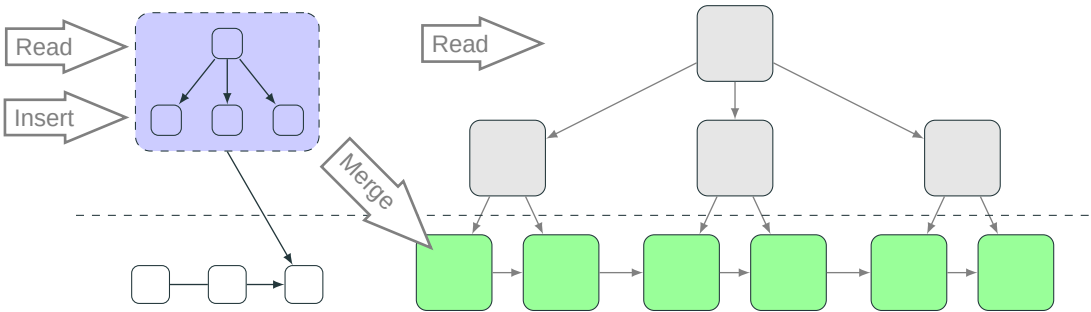
DPTree



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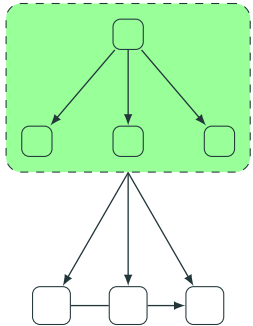
Learned Indexes

Learned Indexes



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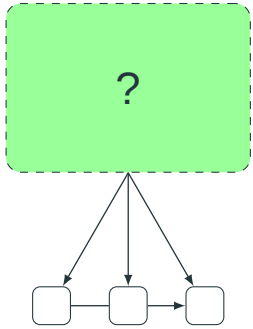
Learned Indexes



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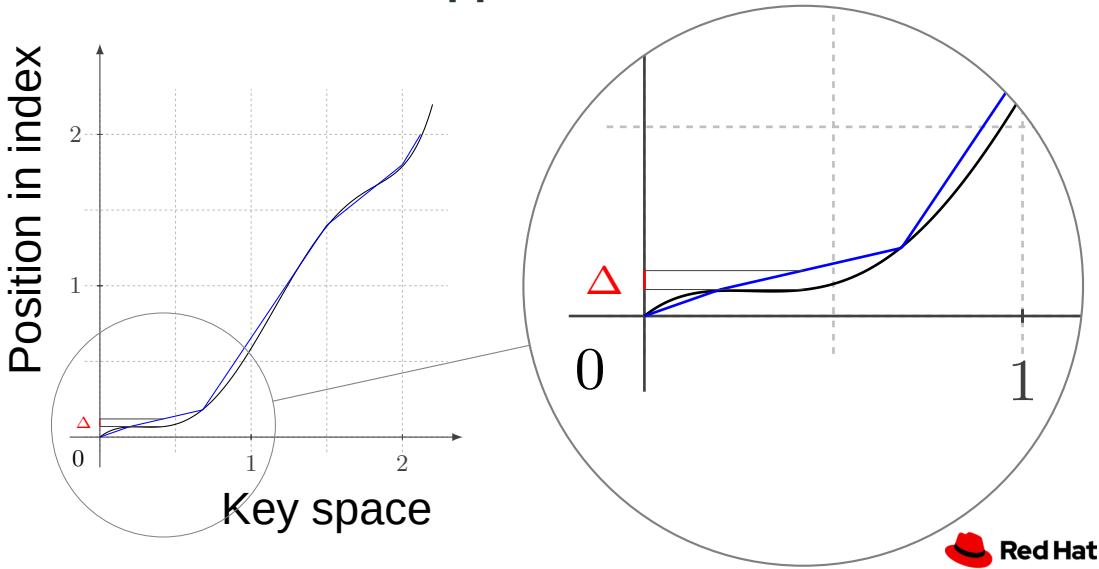
Data approximation



Is that all?

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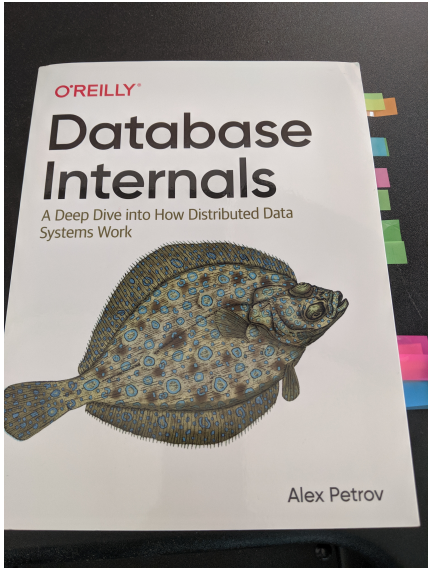
- ➔ Buffered (Lazy) B-Tree
- ➔ Cache conscious B-Tree
- ➔ Distributed B-Tree
- ➔ SB-Tree
- ➔ MDAM
- ➔ LSM Tree
- ➔ Trie
- ➔ ...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Questions?

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