

# High Concurrency B-Trees for Insert Heavy Workloads

## An in-depth comparison

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### ABSTRACT

Code can be found here [Fill this in once we're done](#)

You should try to write the best research paper that you can using the results of your project. You have read many good papers throughout this class, so by this point you should have a good idea of what makes a good research paper! Basically, your report needs to clearly present the following:

1. the problem statement
2. The motivation, why its important
3. The literature review (the previous work in this area)
4. Main idea and approach
5. Implementation techniques
6. Experimental setup
7. Results

### Keywords

B-Trees, Reader Writer Locks, B-Link, Lock-Free

## 1. INTRODUCTION/MOTIVATION

Databases systems are usually run in multiple threads or processes, so that they can handle many users at the same time, take advantage of multiple processor cores, and using async I/O, multiple disks [2]. Systems with larger number of processors, and cores-per-processor are becoming more common, and main memories are becoming much larger. B-trees were first built for single-threaded DBMS, which stored everything on disks - including the index itself. Later systems

<sup>\*</sup>A note about this author

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allowed the index to fit in memory, and allowed some concurrency - multiple threads could read from the index.

We attempt to look B-Tree's for insert-heavy workloads. WE WILL ASSUME THE INDEX, OR THE WHOLE DB, CAN FIT IN MEMORY It should be noted that we are not looking at transactional level locking, but concurrent execution within a transaction, or in a transaction free environment. We are not concerned, then, with provide any kind of predicate locks to protect against "phantom" inserts.

## 2. PREVIOUS WORK

B-trees have long been the primary access data structure for databases, file systems, and various other systems because of their logarithmic `insert()` and `get()`. They also have a host of other properties that make them also for large systems. A short list:

1. Maintain everything in order. This means that merge operations can be done without sort, and SMJ, and often used join in database systems, is very efficient
2. Block access. The structure can store as much data as it can on a single page, and doing locking on a single page. This made B-Tree's very popular early on, when database's could not fit in memory, and had to be dumped onto disk.

Over there 40 year history, there have been many different variations and flavors of B-Trees. The original version of this data structure stored data in both the leaf and inner nodes. These structures were optimized for block access - the entire b-tree index could not fit into memory, and the fact that its nodes size could be made to match the disk block size. This, coupled with buffer pools, made them the dominant structure even in early database systems.

Later versions (B\*Trees or B+Trees, depending on who you ask) stored all the data in leaf nodes, and the inner nodes served only as lookup keys. Later version would ensure the entire tree was height balanced, and put pointers on the leaf nodes so that scan could be done with only one tree traversal.

Later (fancier) techniques attempted to put links on inner nodes as well, so that they could do "overflow" nodes, to try to prolong splitting. The idea here was that when a key was inserted into a node that should then split, it would look at its neighbors in the same of the tree. If they have enough room, the node could offload some of its keys and values onto its siblings. This could allow the tree to become more 'full' - the average occupancy of each node will be higher

- before nodes split. Depending on the cost of splitting, and the number that occur, this could provide a benefit to performance.

There have been a few approaches to locking in B-Trees so far.

The first, naive, approach, is to lock any node that could split on an insert. However, since any split could propagate all the way back up to the root node, each insert would need to have an exclusive lock on every node that it touches - making the tree single threaded.

Another slightly better way to do locking is to acquire a shared lock at first, and then scan through the node to find where the key will be inserted. If the child cannot split, then we can hold an shared lock on the node while the rest of the insert finishes in the tree below. If the child can split, we must hold an exclusive lock. The reader will notice that this can still lead to high lock contention on the root node, especially with small fan out.

### 3. OUR APPROACH

We first wanted to see what worked well on a sequential model, so that we can compare those same factors on our concurrent models.

We knew that we wanted to be able to test the effect of the fan out of the nodes - what size of fan out favors insert-heavy workloads? We decided to test the fan out of the inner nodes, and the number of data elements stored in a leaf node separately. We plan on seeing whether one of these fan outs has more of an input on performance. Both of these constants can be modified in `node.h`

We also want to see what the performance is under different read and write percentage workloads. We use `std::rand()` to decide if a given operation should be a read or write in our testing setup. This value is input into the program through standard input at start up.

There were a few things that we decided to change, given that this tree is to be optimized for writes instead of reads. We do not concern ourselves with keeping all the leaf nodes at equal depth. This makes sense for reads - you want to make sure each key gets access in the same amount of time, and if you are trying to get multiple elements, you can do the lookup once and then just scan across the leaf nodes. However, maintain this global depth is expensive in the face of multiple threads. We chose to abandon this requirement, and let the tree have varying depths of nodes - the root node could point to some leaf nodes, and other trees with various children. This could increase lookup time (as well as insert time, since it must do a lookup to find the insert location, however, as long as the key values are not VERY skewed, the tree should perform well.) We believe that additional lookup time is not a problem, as long as it is concurrent - the real performance limitation is when the tree structure must change, because this requires exclusive locks. If we can keep the "structure" of the tree the same, then we can maximize for inserts, and always have some number of threads doing something useful, instead of waiting as the tree is balanced.

Many B-Tree implement pointers to the neighboring nodes at the same level, both for leaf and inner nodes. While this is certainly helpful for range-based read workloads, there is a cost that has to be paid on every insert. In an insert-heavy workload, these become much more important. Also, in the inner nodes, these pointers are used to push off the tree splitting, to lower cost. This was assuming, however,

that the tree was balanced. Without this invariant, there is no reason to do this. In concurrent code, managing all of these pointers become incredibly difficult to do correctly, and has minimal benefit. Therefore, we decided to forgo these pointers. This means that range queries become less efficient, because we can no longer scan across the leaf nodes. However, for an insert heavy workload, range queries are not well defined. They would require some form of predicate locking, MVCC, or some other complication that we do not want - simple put, workloads that are insert heavy should know that range based queries do not make sense, as the data is always being changed.

### 4. ARCHITECTURE

What all did we have to build to make this work and test out our ideas?

- Testing Framework: We want to test the system at different levels of
  - Input Size
  - Number of Threads
  - Read Write Percent Workload
  - Fan out on inner nodes
  - Data slots on leaf nodes

To testing all of these things, I will be creating a dope ass `main.ccp` that can read input from test cases

- Sequential Tree: We had to build a simple, single-thread B-tree first. We built on this for our other version, and will also use it as the baseline for testing.
- ReaderWriter Tree: This tree uses different kinds of locks, shared and exclusive, and also does checking to see if the child node can split, to see if this node is "safe" from splitting. This version uses `std::list<>` within the nodes
- ReaderWriter Array: How does sequential access of nodes affect performance? We'll see. We would think that as the size of the inner and leaf node fanout increases, the array based B-Tree should perform better and better compared to the list based tree. Could this show promise for further extension - putting the whole B-tree into an array?
- BLink Tree: This structure is different in that it inserts into the leaf node, and acquires locks on the way back up

### 5. IMPLEMENTATION AND TEST SETUP

We implemented our B-Trees in C++, using new features only available in C++14, most notably `std::shared_time_mutex`, which allows both exclusive and shared locking. This requires a compiler with `gcc -4.9` or greater. Because this is so new, few systems have made version 4.9 available - it is not available on `bigdata.eecs.umich.edu`, for example, we decided to set up our own testing environment.

We set up a virtual machine using Oracle Virtual Box. The VM is running Ubuntu Server 15.10 with `gcc 4.9.3`. The host system is a Windows 7 machine with a FX-8350 (8

cores @ 4Ghz) and 32GB of RAM. We allocated 4 cores and 24GB of RAM to the VM. All test were run with minimal applications running on the Windows side.

## 6. PERFORMANCE

We tested all of our implementations under several different conditions.

We begin with our sequential tree implementation, so that we have a baseline to compare our concurrent versions to.

Sequential Tree, F = 4

Input Size	Time (ms)
1000	2
10000	12
100000	80
1000000	586
10000000	5620
100000000	59000

Sequential Tree, F = 16

Input Size	Time (ms)
1000	2
10000	20
100000	123
1000000	754
10000000	7045
100000000	70318

Sequential Tree, F = 64

Input Size	Time (ms)
1000	4
10000	31
100000	283
1000000	3607
10000000	128447
100000000	384118

Sequential Tree, F = 256

Input Size	Time (ms)
1000	7
10000	67
100000	968
1000000	14840
10000000	267131
100000000	2543760

Note the dramatic difference in performance as the fanout increases. We discuss the significance of these results in the next section.

We wanted to compare are tree to standard implementations to a standard, to verify that our concurrent versions were not built on top of something slow. To that end, we compared it to `std::map` on gcc 4.9.3.

`std::map`

Input Size	Time (ms)
1000	1
10000	6
100000	63
1000000	720
10000000	12780
100000000	228835

## 7. DISCUSSION

It is curious that the fannout increases seems to slow things down

- Stonebraker is right - locking is bad, single threads fast to completion is better - Fan out is bad - We though fannout would help cache, but it turns out not - Based on old schol block access with buffer pool - Now, its all in memory - hoping down a few levels of trees doesn't matter

## 8. CITATIONS

Some papers that we read to give ourselves background on the topics:

- "Concurrent B-trees with Lock-free Techniques"[1] gives us the inspiration for the lock free B-tree. They, however, didn't not have access to the large memory, built in C++14 atomics, and they were not focusing on writes - they were trying to build a general purpose lock free btree for NUMA computers.
- "A survey of B-tree locking techniques"[2], much like the title says, presents an over of many of the different approaches that have been taken so far. However, it reallys skims over, almost dismissing, lock free techniques.
- "Efficient Locking for Concurrent Operations on B-Trees" [3] This one gave us the idea of the `can_split()` function, and gave background on reader writer locks and other, etc
- "Concurrent Cache-Oblivious B-Trees" [4] I need to read this one again
- "A Concurrent Blink-Tree Algorithm Using a Cooperative Locking Protocol" [5] Ryan is making this verion
- "A paper" A paper

## 9. EXPERIMENTAL RESULTS

We will need some tables. I have some data from the sequential tree

## 10. CONCLUSIONS

Conclusions

## 11. ACKNOWLEDGMENTS

Acknowledgments

## 12. REFERENCES

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