Life After BerkeleyDB: OpenLDAP's Memory-Mapped Database

Howard Chu

CTO, Symas Corp. hyc@symas.com

Chief Architect, OpenLDAP hyc@openldap.org

OpenLDAP Project

- Open source code project
- Founded 1998
- Three core team members
- A dozen or so contributors
- Feature releases every 18-24 months
- Maintenance releases as needed

A Word About Symas

- Founded 1999
- Founders from Enterprise Software world
  - *platinum* Technology (Locus Computing)
  - IBM
- Howard joined OpenLDAP in 1999
  - One of the Core Team members
  - Appointed Chief Architect January 2007

Topics

- Overview
- Background / History
- Obvious Solutions
- Future Directions

Overview

- OpenLDAP has been delivering reliable, high performance for many years
- The performance comes at the cost of fairly complex tuning requirements
- The implementation is not as clean as it could be; it is not what was originally intended
- Cleaning it up requires not just a new server backend, but also a new low-level database
- The new approach has a huge payoff

Background

- OpenLDAP already provides a number of reliable, high performance transactional backends
  - Based on Oracle BerkeleyDB (BDB)
  - back-bdb released with OpenLDAP 2.1 in 2002
  - back-hdb released with OpenLDAP 2.2 in 2003
  - Intensively analyzed for performance
  - World's fastest since 2005
  - Many heavy users with zero downtime

Background

- These backends have always required careful, complex tuning
  - Data comes through three separate layers of caches
  - Each cache layer has different size and speed characteristics
  - Balancing the three layers against each other can be a difficult juggling act
  - Performance without the backend caches is unacceptably slow - over an order of magnitude...

Background

- The backend caching significantly increased the overall complexity of the backend code
  - Two levels of locking required, since the BDB database locks are too slow
  - Deadlocks occurring routinely in normal operation, requiring additional backoff/retry logic

Background

- The caches were not always beneficial, and were sometimes detrimental
  - data could exist in 3 places at once - filesystem, database, and backend cache - thus wasting memory
  - searches with result sets that exceeded the configured cache size would reduce the cache effectiveness to zero
  - malloc/free churn from adding and removing entries in the cache could trigger pathological heap behavior in libc malloc

Background

- Overall the backends require too much attention
  - Too much developer time spent finding workarounds for inefficiencies
  - Too much administrator time spent tweaking configurations and cleaning up database transaction logs

Obvious Solutions

- Cache management is a hassle, so don't do any caching
  - The filesystem already caches data, there's no reason to duplicate the effort
- Lock management is a hassle, so don't do any locking
  - Use Multi-Version Concurrency Control (MVCC)
  - MVCC makes it possible to perform reads with no locking

Obvious Solutions

- BDB supports MVCC, but it still requires complex caching and locking
- To get the desired results, we need to abandon BDB
- Surveying the landscape revealed no other database libraries with the desired characteristics
- Time to write our own...

MDB Approach

- Based on the "Single-Level Store" concept
  - Not new, first implemented in Multics in 1964
  - Access a database by mapping the entire database into memory
  - Data fetches are satisfied by direct reference to the memory map, there is no intermediate page or buffer cache

Single-Level Store

- The approach is only viable if process address spaces are larger than the expected data volumes
  - For 32 bit processors, the practical limit on data size is under 2GB
  - For common 64 bit processors which only implement 48 bit address spaces, the limit is 47 bits or 128 terabytes
  - The upper bound at 63 bits is 8 exabytes

MDB Approach

- Uses a read-only memory map
  - Protects the database structure from corruption due to stray writes in memory
  - Any attempts to write to the map will cause a SEGV, allowing immediate identification of software bugs
  - There's no point in making the pages writable anyway, since only existing pages may be written. Growing the database requires file ops (write, ftruncate) so for uniformity, file ops are also used for updates.

MDB Approach

- Implement MVCC using copy-on-write
  - In-use data is never overwritten, modifications are performed by copying the data and modifying the copy
  - Since updates never alter existing data, the database structure can never be corrupted by incomplete modifications
    - Write-ahead transaction logs are unnecessary
  - Readers always see a consistent snapshot of the database, they are fully isolated from writers
    - Read accesses require no locks

MVCC Details

- "Full" MVCC can be extremely resource intensive
  - Databases typically store complete histories reaching far back into time
  - The volume of data grows extremely fast, and grows without bound unless explicit pruning is done
  - Pruning the data using garbage collection or compaction requires more CPU and I/O resources than the normal update workload
    - Either the server must be heavily over-provisioned, or updates must be stopped while pruning is done
  - Pruning requires tracking of in-use status, which typically involves reference counters, which require locking

MDB Approach

- MDB nominally maintains only two versions of the database
  - Rolling back to a historical version is not interesting for OpenLDAP
  - Older versions can be held open longer by reader transactions
- MDB maintains a free list tracking the IDs of unused pages
  - Old pages are reused as soon as possible, so data volumes don't grow without bound
- MDB tracks in-use status without locks

Implementation Highlights

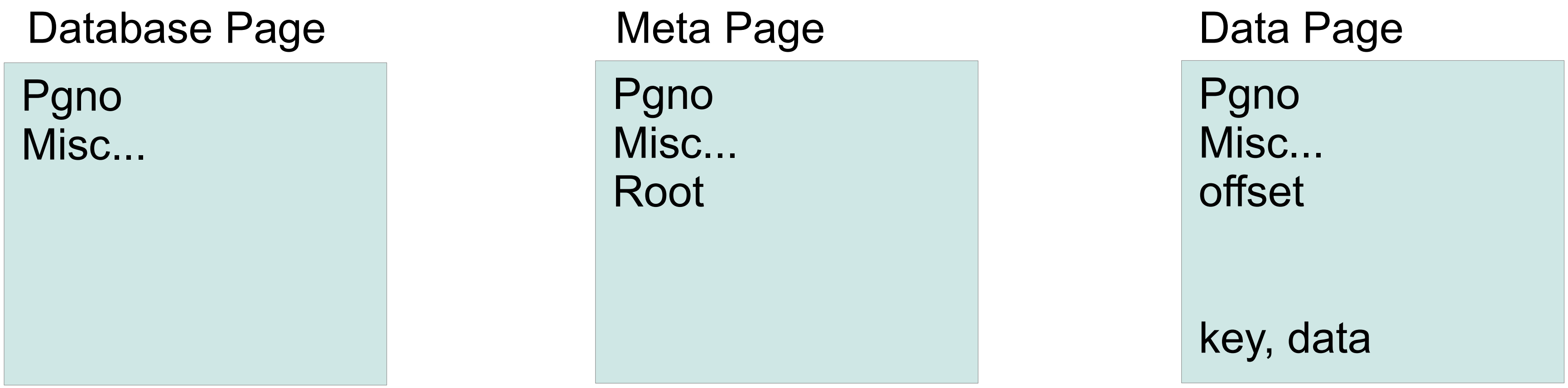
- MDB library started from the append-only btree code written by Martin Hedenfalk for his ldapd, which is bundled in OpenBSD
  - Stripped out all the parts we didn't need (page cache management)
  - Borrowed a couple pieces from back-bdb for expedience
  - Changed from append-only to page-reclaiming
  - Restructured to allow adding ideas from BDB that we still wanted

Implementation Highlights

- Resulting library was under 32KB of object code
  - Compared to the original btree.c at 39KB
  - Compared to BDB at 1.5MB
- API is loosely modeled after the BDB API to ease migration of back-bdb code to use MDB

Btree Operation

Basic Elements



Database Page

Pgno
Misc...

Meta Page

Pgno
Misc...
Root

Data Page

Pgno
Misc...
offset

key, data

Btree Operation

Write-Ahead Logger

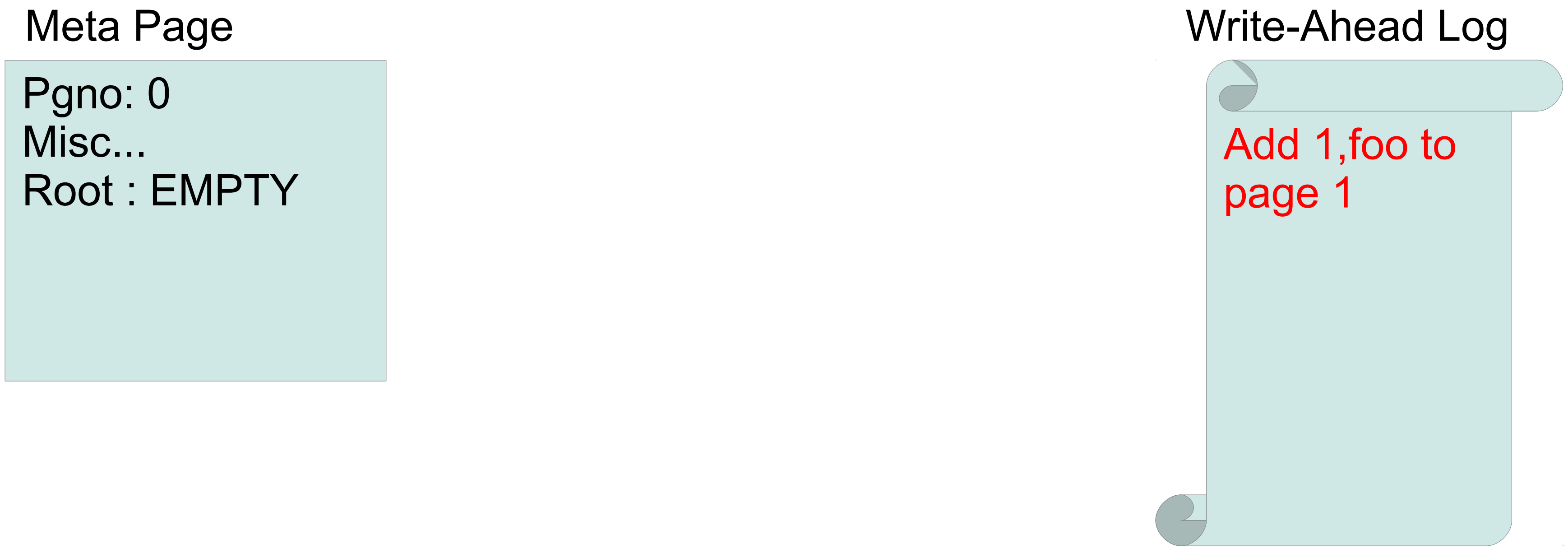
Meta Page

Pgno: 0
Misc...
Root : EMPTY

Write-Ahead Log

Btree Operation

Write-Ahead Logger



Meta Page

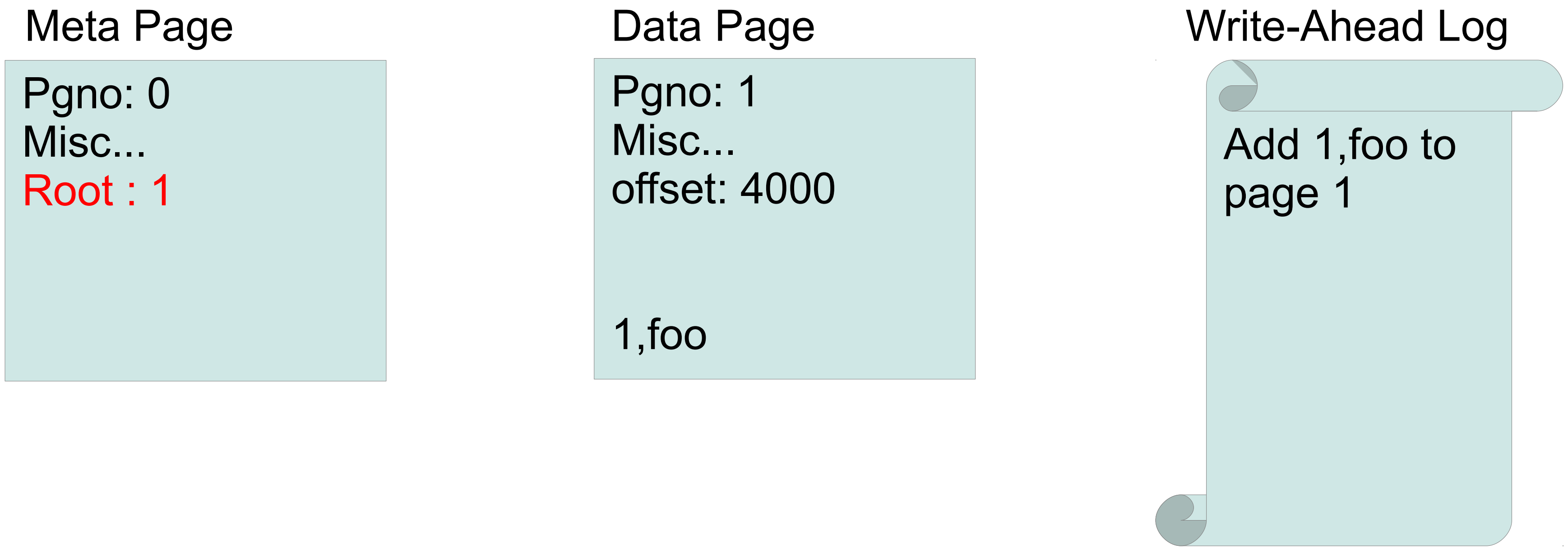
Pgno: 0
Misc...
Root : EMPTY

Write-Ahead Log

Add 1,foo to page 1

Btree Operation

Write-Ahead Logger



Meta Page

Pgno: 0
Misc...
Root : 1

Data Page

Pgno: 1
Misc...
offset: 4000

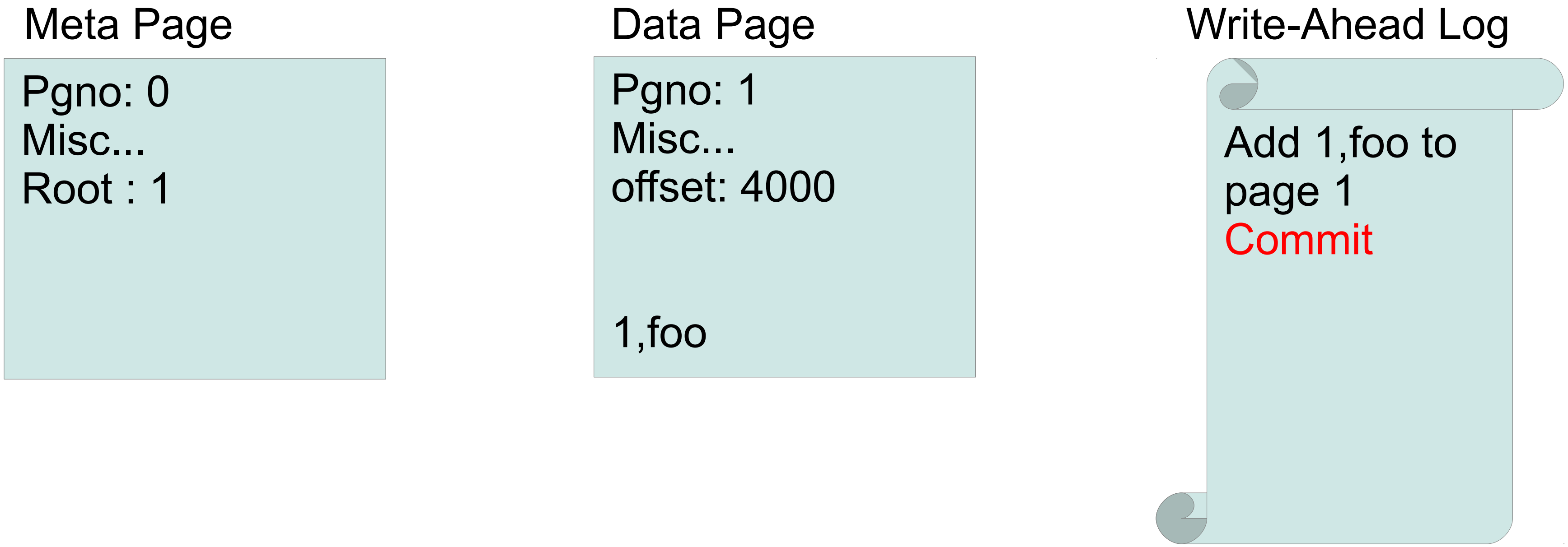
1,foo

Write-Ahead Log

Add 1,foo to page 1

Btree Operation

Write-Ahead Logger



Meta Page

Pgno: 0
Misc...
Root : 1

Data Page

Pgno: 1
Misc...
offset: 4000

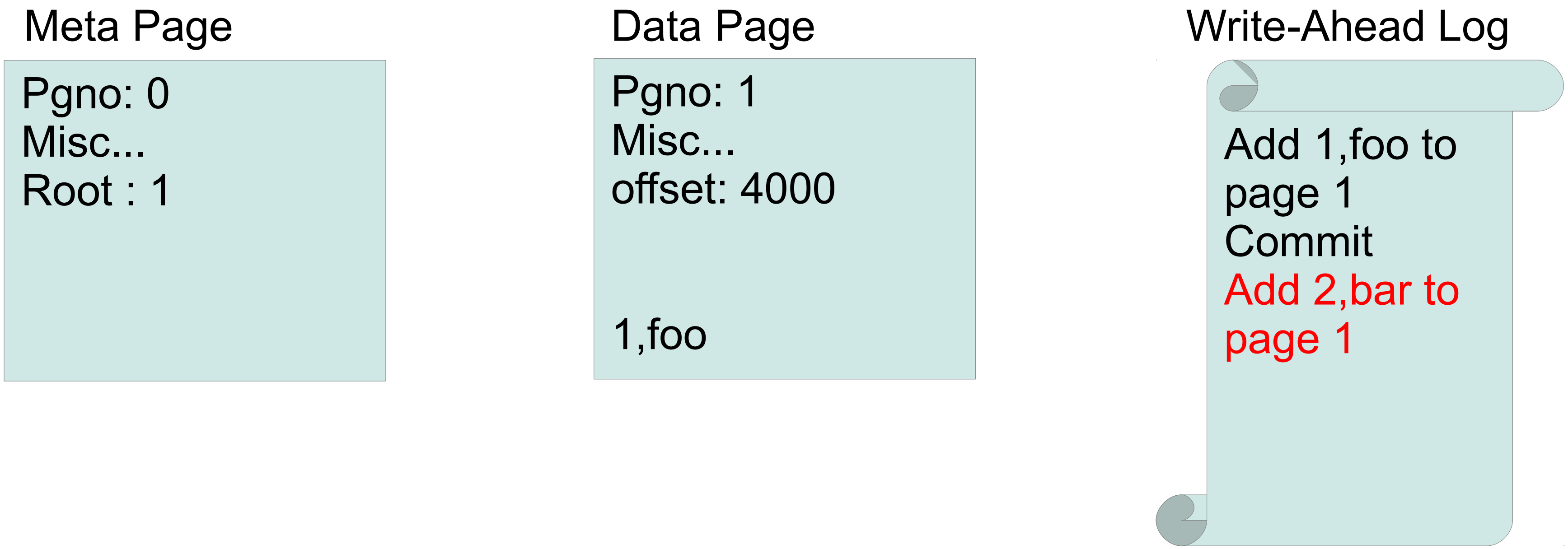
1,foo

Write-Ahead Log

Add 1,foo to page 1
Commit

Btree Operation

Write-Ahead Logger



Meta Page

Pgno: 0
Misc...
Root : 1

Data Page

Pgno: 1
Misc...
offset: 4000

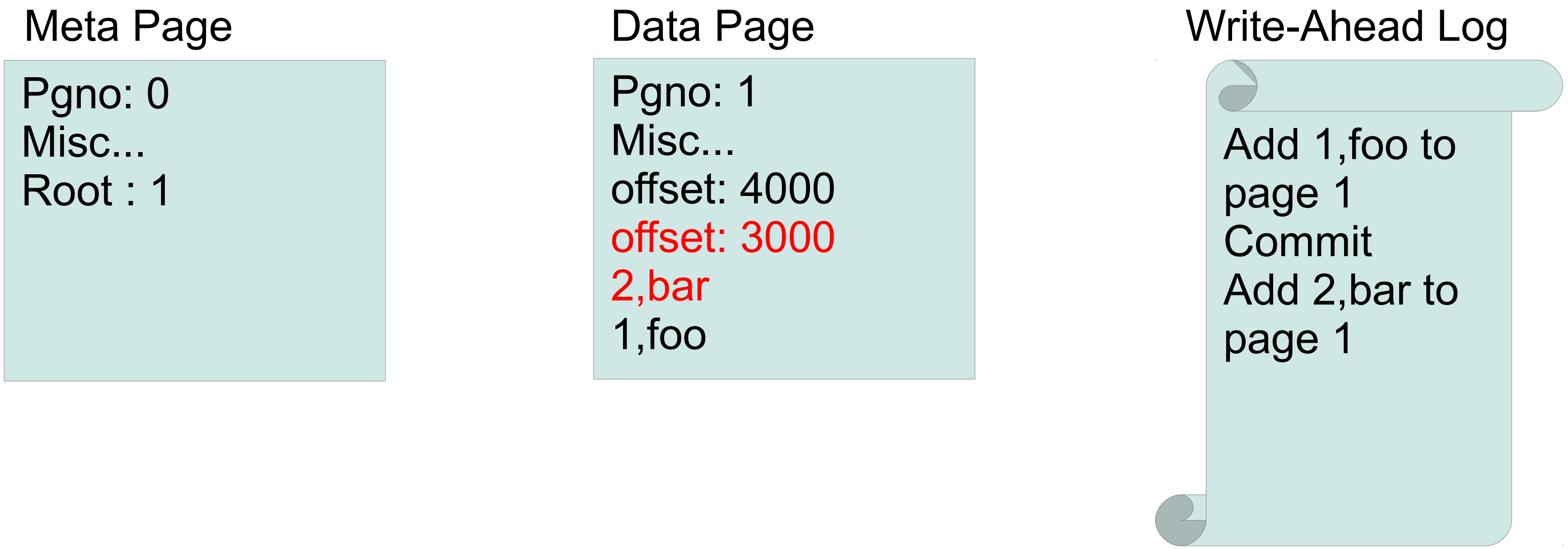
1,foo

Write-Ahead Log

Add 1,foo to page 1
Commit
Add 2,bar to page 1

Btree Operation

Write-Ahead Logger



Meta Page

Pgno: 0
Misc...
Root : 1

Data Page

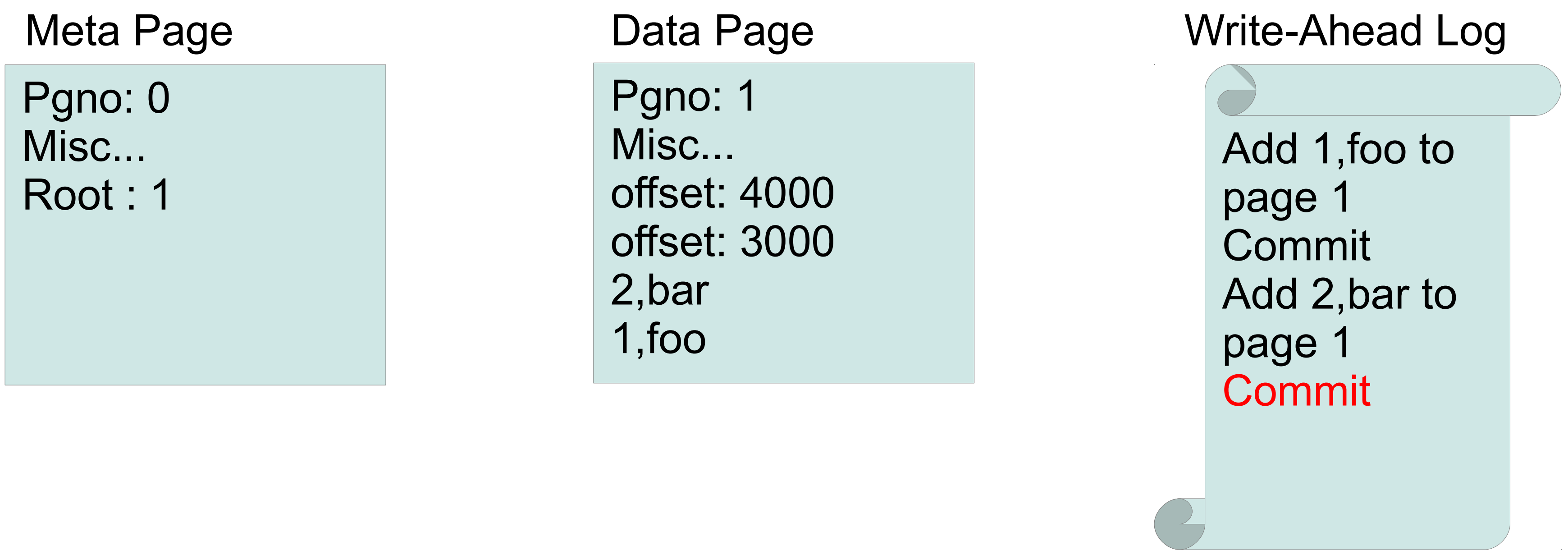
Pgno: 1
Misc...
offset: 4000
offset: 3000
2,bar
1,foo

Write-Ahead Log

Add 1,foo to page 1
Commit
Add 2,bar to page 1

Btree Operation

Write-Ahead Logger



Meta Page

Pgno: 0
Misc...
Root : 1

Data Page

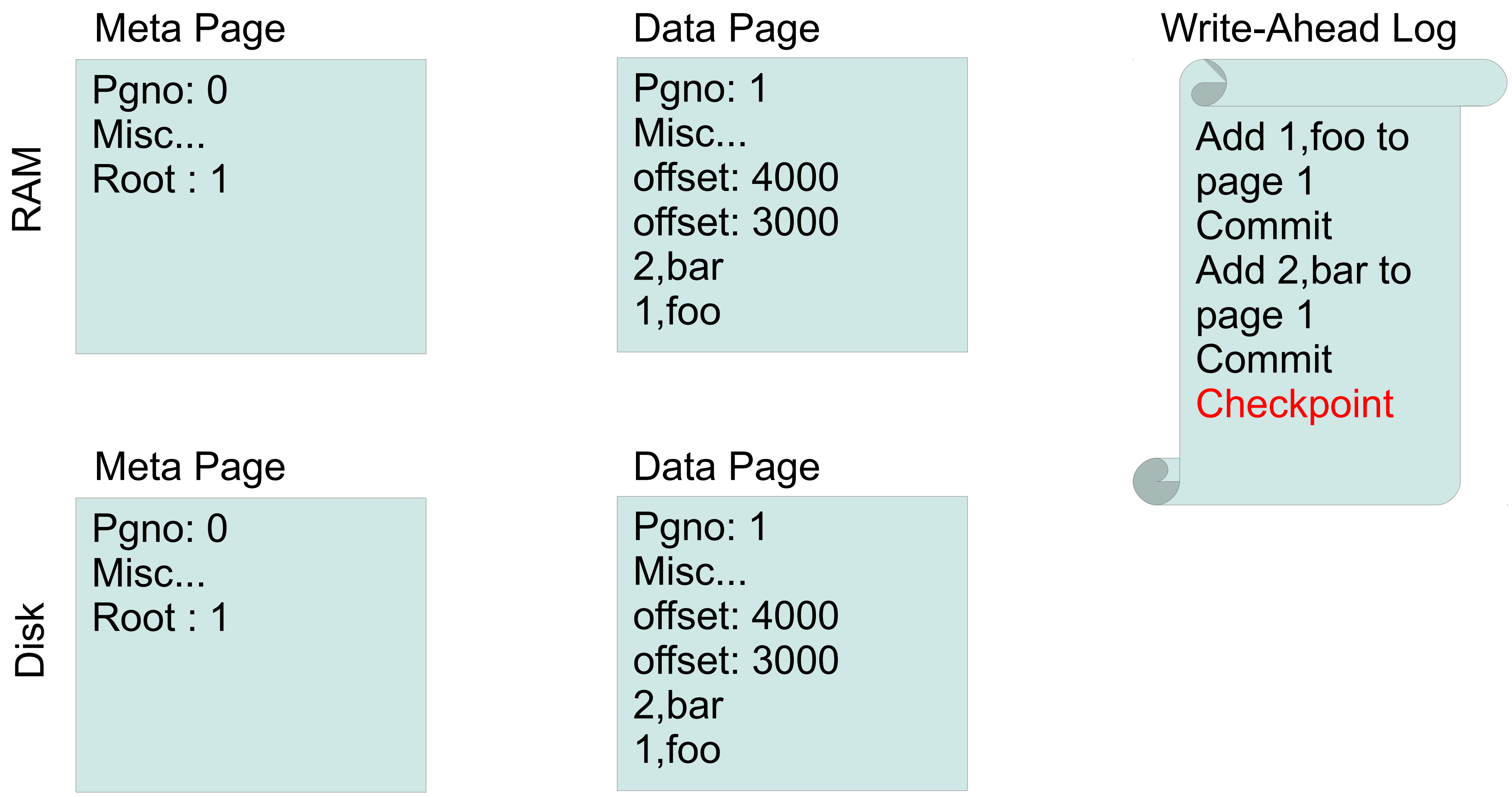
Pgno: 1
Misc...
offset: 4000
offset: 3000
2,bar
1,foo

Write-Ahead Log

Add 1,foo to page 1
Commit
Add 2,bar to page 1
Commit

Btree Operation

Write-Ahead Logger



RAM

Meta Page

Pgno: 0
Misc...
Root : 1

Data Page

Pgno: 1
Misc...
offset: 4000
offset: 3000
2,bar
1,foo

Write-Ahead Log

Add 1,foo to page 1
Commit
Add 2,bar to page 1
Commit
Checkpoint

Disk

Meta Page

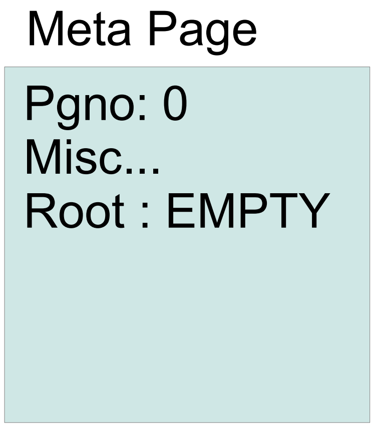
Pgno: 0
Misc...
Root : 1

Data Page

Pgno: 1
Misc...
offset: 4000
offset: 3000
2,bar
1,foo

Btree Operation

Append-Only

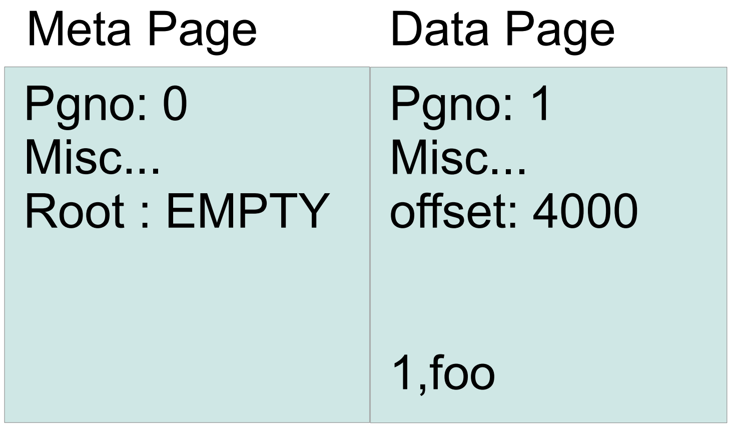


Meta Page

Pgno: 0
Misc...
Root : EMPTY

Btree Operation

Append-Only



Meta Page

Pgno: 0
Misc...
Root : EMPTY

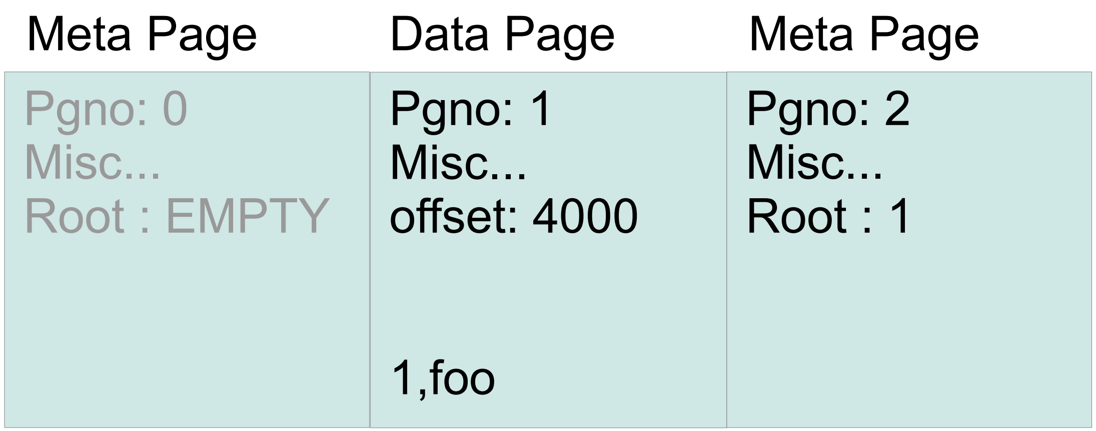
Data Page

Pgno: 1
Misc...
offset: 4000

1,foo

Btree Operation

Append-Only



Meta Page	Data Page	Meta Page
Pgno: 0 Misc... Root : EMPTY	Pgno: 1 Misc... offset: 4000 1,foo	Pgno: 2 Misc... Root : 1

Btree Operation

Append-Only

Meta Page	Data Page	Meta Page	Data Page
Pgno: 0 Misc... Root : EMPTY	Pgno: 1 Misc... offset: 4000 1,foo	Pgno: 2 Misc... Root : 1	Pgno: 3 Misc... offset: 4000 offset: 3000 2,bar 1,foo

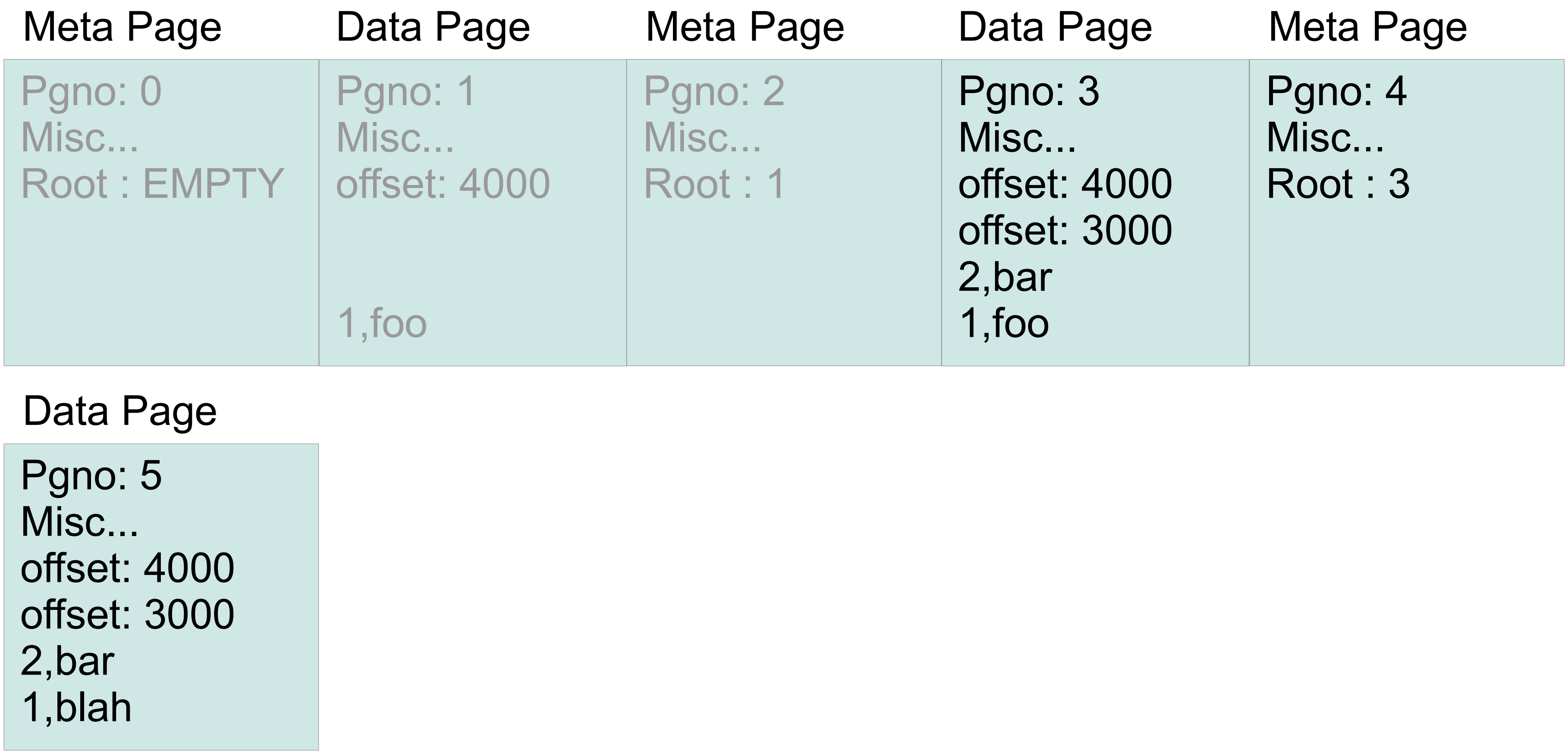
Btree Operation

Append-Only

Meta Page	Data Page	Meta Page	Data Page	Meta Page
Pgno: 0 Misc... Root : EMPTY	Pgno: 1 Misc... offset: 4000 1,foo	Pgno: 2 Misc... Root : 1	Pgno: 3 Misc... offset: 4000 offset: 3000 2,bar 1,foo	Pgno: 4 Misc... Root : 3

Btree Operation

Append-Only



Meta Page	Data Page	Meta Page	Data Page	Meta Page
Pgno: 0 Misc... Root : EMPTY	Pgno: 1 Misc... offset: 4000 1,foo	Pgno: 2 Misc... Root : 1	Pgno: 3 Misc... offset: 4000 offset: 3000 2,bar 1,foo	Pgno: 4 Misc... Root : 3

Data Page
Pgno: 5 Misc... offset: 4000 offset: 3000 2,bar 1,blah

Btree Operation

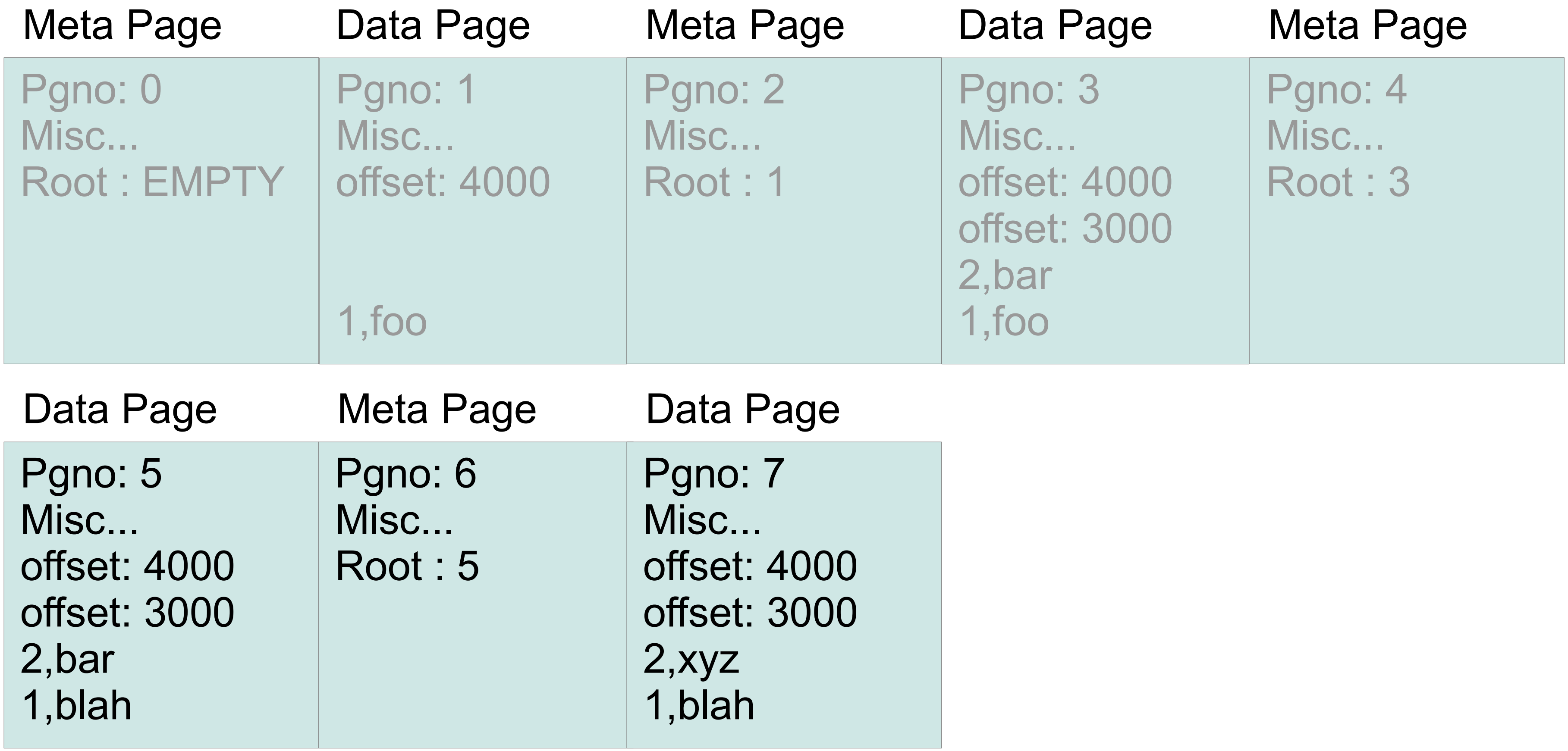
Append-Only

Meta Page	Data Page	Meta Page	Data Page	Meta Page
Pgno: 0 Misc... Root : EMPTY	Pgno: 1 Misc... offset: 4000 1,foo	Pgno: 2 Misc... Root : 1	Pgno: 3 Misc... offset: 4000 offset: 3000 2,bar 1,foo	Pgno: 4 Misc... Root : 3

Data Page	Meta Page
Pgno: 5 Misc... offset: 4000 offset: 3000 2,bar 1,blah	Pgno: 6 Misc... Root : 5

Btree Operation

Append-Only



Meta Page
Pgno: 0
Misc...
Root : EMPTY

Data Page
Pgno: 1
Misc...
offset: 4000
1,foo

Meta Page
Pgno: 2
Misc...
Root : 1

Data Page
Pgno: 3
Misc...
offset: 4000
offset: 3000
2,bar
1,foo

Meta Page
Pgno: 4
Misc...
Root : 3

Data Page
Pgno: 5
Misc...
offset: 4000
offset: 3000
2,bar
1,blah

Meta Page
Pgno: 6
Misc...
Root : 5

Data Page
Pgno: 7
Misc...
offset: 4000
offset: 3000
2,xyz
1,blah

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Btree Operation

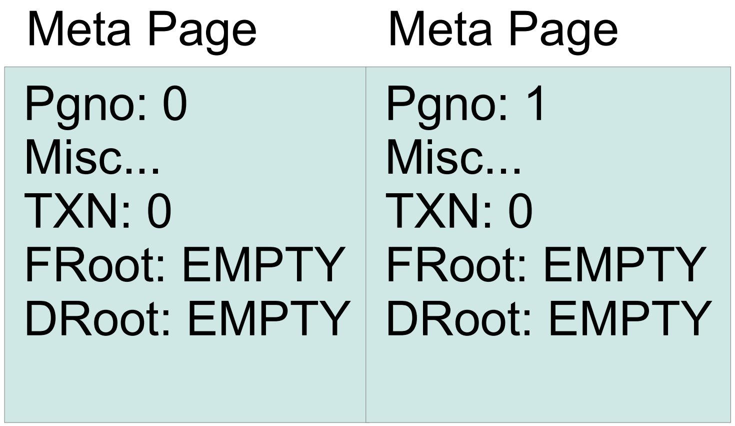
Append-Only

Meta Page	Data Page	Meta Page	Data Page	Meta Page
Pgno: 0 Misc... Root : EMPTY	Pgno: 1 Misc... offset: 4000 1,foo	Pgno: 2 Misc... Root : 1	Pgno: 3 Misc... offset: 4000 offset: 3000 2,bar 1,foo	Pgno: 4 Misc... Root : 3

Data Page	Meta Page	Data Page	Meta Page
Pgno: 5 Misc... offset: 4000 offset: 3000 2,bar 1,blah	Pgno: 6 Misc... Root : 5	Pgno: 7 Misc... offset: 4000 offset: 3000 2,xyz 1,blah	Pgno: 8 Misc... Root : 7

Btree Operation

MDB



Meta Page

Pgno: 0
Misc...
TXN: 0
FRoot: EMPTY
DRoot: EMPTY

Meta Page

Pgno: 1
Misc...
TXN: 0
FRoot: EMPTY
DRoot: EMPTY

Btree Operation

MDB

Meta Page	Meta Page	Data Page
Pgno: 0 Misc... TXN: 0 FRoot: EMPTY DRoot: EMPTY	Pgno: 1 Misc... TXN: 0 FRoot: EMPTY DRoot: EMPTY	Pgno: 2 Misc... offset: 4000 1,foo

Btree Operation

MDB

Meta Page	Meta Page	Data Page
Pgno: 0 Misc... TXN: 0 FRoot: EMPTY DRoot: EMPTY	Pgno: 1 Misc... TXN: 1 FRoot: EMPTY DRoot: 2	Pgno: 2 Misc... offset: 4000 1,foo

Btree Operation

MDB

Meta Page	Meta Page	Data Page	Data Page
Pgno: 0 Misc... TXN: 0 FRoot: EMPTY DRoot: EMPTY	Pgno: 1 Misc... TXN: 1 FRoot: EMPTY DRoot: 2	Pgno: 2 Misc... offset: 4000 1,foo	Pgno: 3 Misc... offset: 4000 offset: 3000 2,bar 1,foo

Btree Operation

MDB

Meta Page	Meta Page	Data Page	Data Page	Data Page
Pgno: 0 Misc... TXN: 0 FRoot: EMPTY DRoot: EMPTY	Pgno: 1 Misc... TXN: 1 FRoot: EMPTY DRoot: 2	Pgno: 2 Misc... offset: 4000 1,foo	Pgno: 3 Misc... offset: 4000 offset: 3000 2,bar 1,foo	Pgno: 4 Misc... offset: 4000 txn 2,page 2

Btree Operation

MDB

Meta Page	Meta Page	Data Page	Data Page	Data Page
Pgno: 0	Pgno: 1	Pgno: 2	Pgno: 3	Pgno: 4
Misc...	Misc...	Misc...	Misc...	Misc...
TXN: 2	TXN: 1	offset: 4000	offset: 4000	offset: 4000
FRoot: 4	FRoot: EMPTY		offset: 3000	
DRoot: 3	DRoot: 2		2,bar	
		1,foo	1,foo	txn 2,page 2

Btree Operation

MDB

Meta Page	Meta Page	Data Page	Data Page	Data Page
Pgno: 0 Misc... TXN: 2 FRoot: 4 DRoot: 3	Pgno: 1 Misc... TXN: 1 FRoot: EMPTY DRoot: 2	Pgno: 2 Misc... offset: 4000 1,foo	Pgno: 3 Misc... offset: 4000 offset: 3000 2,bar 1,foo	Pgno: 4 Misc... offset: 4000 txn 2,page 2

Data Page
Pgno: 5 Misc... offset: 4000 offset: 3000 2,bar 1,blah

Btree Operation

MDB

Meta Page	Meta Page	Data Page	Data Page	Data Page
Pgno: 0 Misc... TXN: 2 FRoot: 4 DRoot: 3	Pgno: 1 Misc... TXN: 1 FRoot: EMPTY DRoot: 2	Pgno: 2 Misc... offset: 4000 1,foo	Pgno: 3 Misc... offset: 4000 offset: 3000 2,bar 1,foo	Pgno: 4 Misc... offset: 4000 txn 2,page 2

Data Page	Data Page
Pgno: 5 Misc... offset: 4000 offset: 3000 2,bar 1,blah	Pgno: 6 Misc... offset: 4000 offset: 3000 txn 3,page 3,4 txn 2,page 2

Btree Operation

MDB

Meta Page	Meta Page	Data Page	Data Page	Data Page
Pgno: 0 Misc... TXN: 2 FRoot: 4 DRoot: 3	Pgno: 1 Misc... TXN: 3 FRoot: 6 DRoot: 5	Pgno: 2 Misc... offset: 4000 1,foo	Pgno: 3 Misc... offset: 4000 offset: 3000 2,bar 1,foo	Pgno: 4 Misc... offset: 4000 txn 2,page 2

Data Page	Data Page
Pgno: 5 Misc... offset: 4000 offset: 3000 2,bar 1,blah	Pgno: 6 Misc... offset: 4000 offset: 3000 txn 3,page 3,4 txn 2,page 2

Btree Operation

MDB

Meta Page	Meta Page	Data Page	Data Page	Data Page
Pgno: 0 Misc... TXN: 2 FRoot: 4 DRoot: 3	Pgno: 1 Misc... TXN: 3 FRoot: 6 DRoot: 5	Pgno: 2 Misc... offset: 4000 offset: 3000 2,xyz 1,blah	Pgno: 3 Misc... offset: 4000 offset: 3000 2,bar 1,foo	Pgno: 4 Misc... offset: 4000 txn 2,page 2

Data Page	Data Page
Pgno: 5 Misc... offset: 4000 offset: 3000 2,bar 1,blah	Pgno: 6 Misc... offset: 4000 offset: 3000 txn 3,page 3,4 txn 2,page 2

Btree Operation

MDB

Meta Page	Meta Page	Data Page	Data Page	Data Page
Pgno: 0 Misc... TXN: 2 FRoot: 4 DRoot: 3	Pgno: 1 Misc... TXN: 3 FRoot: 6 DRoot: 5	Pgno: 2 Misc... offset: 4000 offset: 3000 2,xyz 1,blah	Pgno: 3 Misc... offset: 4000 offset: 3000 2,bar 1,foo	Pgno: 4 Misc... offset: 4000 txn 2,page 2

Data Page	Data Page	Data Page
Pgno: 5 Misc... offset: 4000 offset: 3000 2,bar 1,blah	Pgno: 6 Misc... offset: 4000 offset: 3000 txn 3,page 3,4 txn 2,page 2	Pgno: 7 Misc... offset: 4000 offset: 3000 txn 4,page 5,6 txn 3,page 3,4

Btree Operation

MDB

Meta Page	Meta Page	Data Page	Data Page	Data Page
Pgno: 0 Misc... TXN: 4 FRoot: 7 DRoot: 2	Pgno: 1 Misc... TXN: 3 FRoot: 6 DRoot: 5	Pgno: 2 Misc... offset: 4000 offset: 3000 2,xyz 1,blah	Pgno: 3 Misc... offset: 4000 offset: 3000 2,bar 1,foo	Pgno: 4 Misc... offset: 4000 txn 2,page 2

Data Page	Data Page	Data Page
Pgno: 5 Misc... offset: 4000 offset: 3000 2,bar 1,blah	Pgno: 6 Misc... offset: 4000 offset: 3000 txn 3,page 3,4 txn 2,page 2	Pgno: 7 Misc... offset: 4000 offset: 3000 txn 4,page 5,6 txn 3,page 3,4

Notable Special Features

- Explicit Key Types
  - Support for reverse byte order comparisons, as well as native binary integer comparisons
  - Minimizes the need for custom key comparison functions, allows DBs to be used safely by applications without special knowledge

Notable Special Features

- Append Mode
  - Ultra-fast writes when keys are added in sequential order
  - Bypasses standard page-split algorithm when pages are filled, avoids unnecessary memcpy's
  - Allows databases to be bulk loaded at the full sequential write speed of the underlying storage system

Notable Special Features

- Reserve Mode
  - Allocates space in write buffer for data of user-specified size, returns address
  - Useful for data that is generated dynamically instead of statically copied
  - Allows generated data to be written directly to DB output buffer, avoiding unnecessary memcpy

Notable Special Features

- Fixed Mapping
  - Uses a fixed address for the memory map
  - Allows complex pointer-based data structures to be stored directly with minimal serialization
  - Objects using persistent addresses can thus be read back with no deserialization
  - Useful for object-oriented databases, among other purposes

Microbenchmark Results

- Comparisons based on Google's LevelDB
- Also tested against Kyoto Cabinet's TreeDB, SQLite3, and BerkeleyDB
- Tested using RAM filesystem (tmpfs), reiserfs on SSD, and multiple filesystems on HDD
  - btrfs, ext2, ext3, ext4, jfs, ntfs, reiserfs, xfs, zfs
  - ext3, ext4, jfs, reiserfs, xfs also tested with external journals

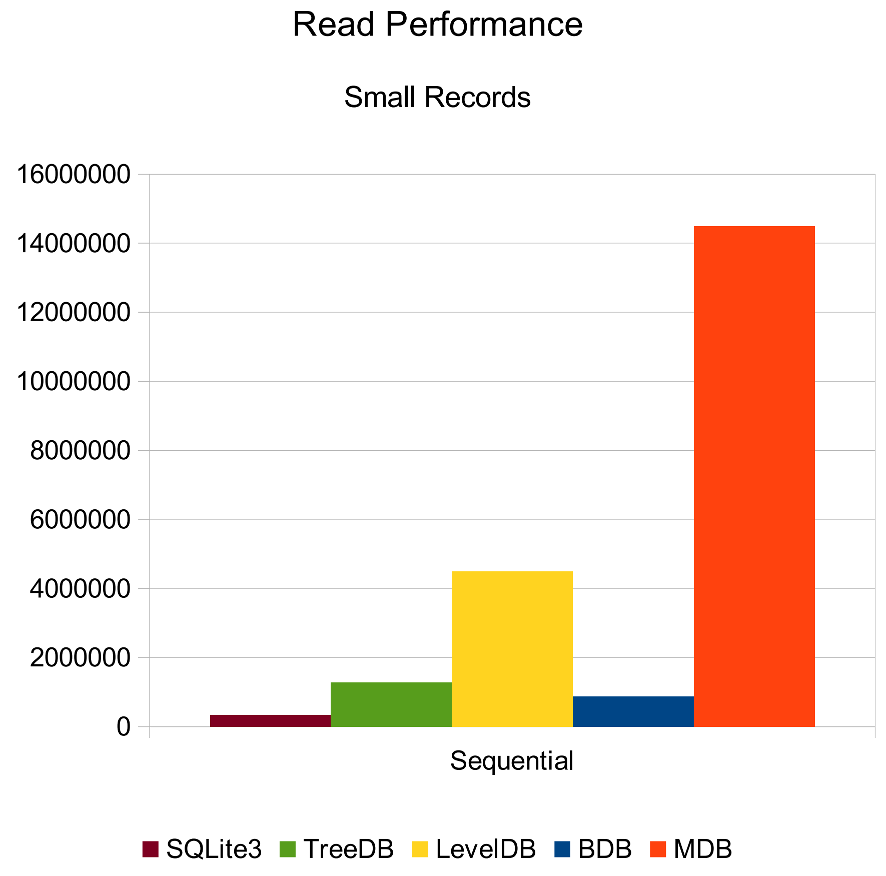
Microbenchmark Results

- Relative Footprint

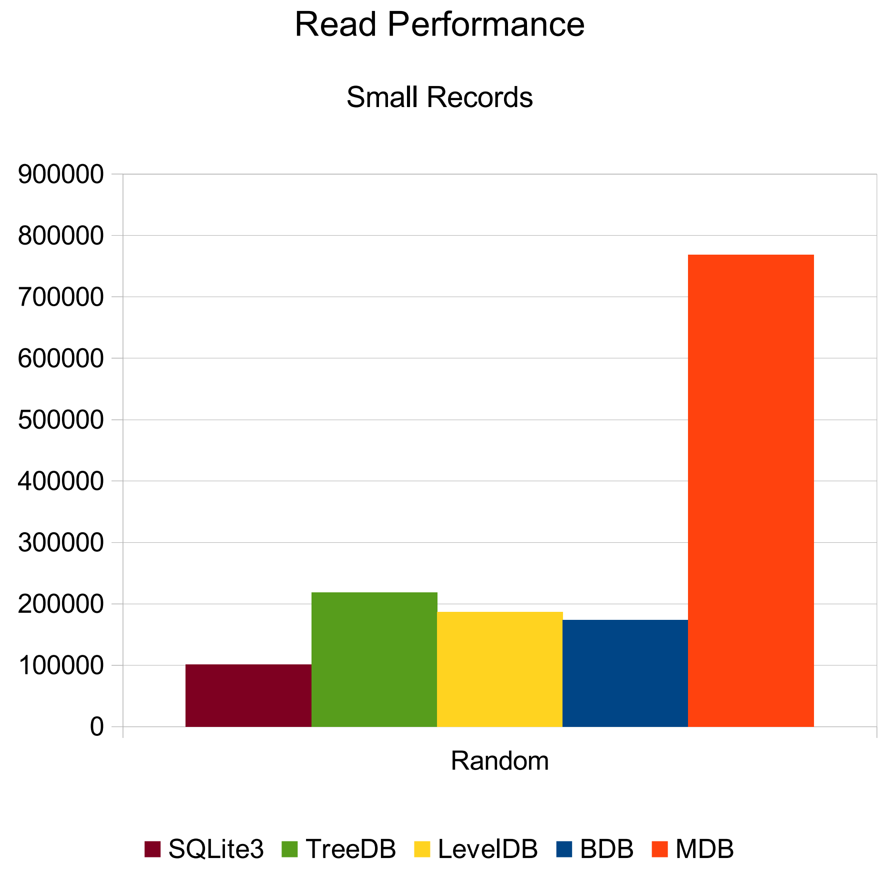
text	data	bss	dec	hex	filename
271991	1456	320	273767	42d67	db_bench
1682579	2288	296	1685163	19b6ab	db_bench_bdb
96879	1500	296	98675	18173	db_bench_mdb
655988	7768	1688	665444	a2764	db_bench_sqlite3
296244	4808	1080	302132	49c34	db_bench_tree_db

- Clearly MDB has the smallest footprint
  - Carefully written C code beats C++ every time

Microbenchmark Results

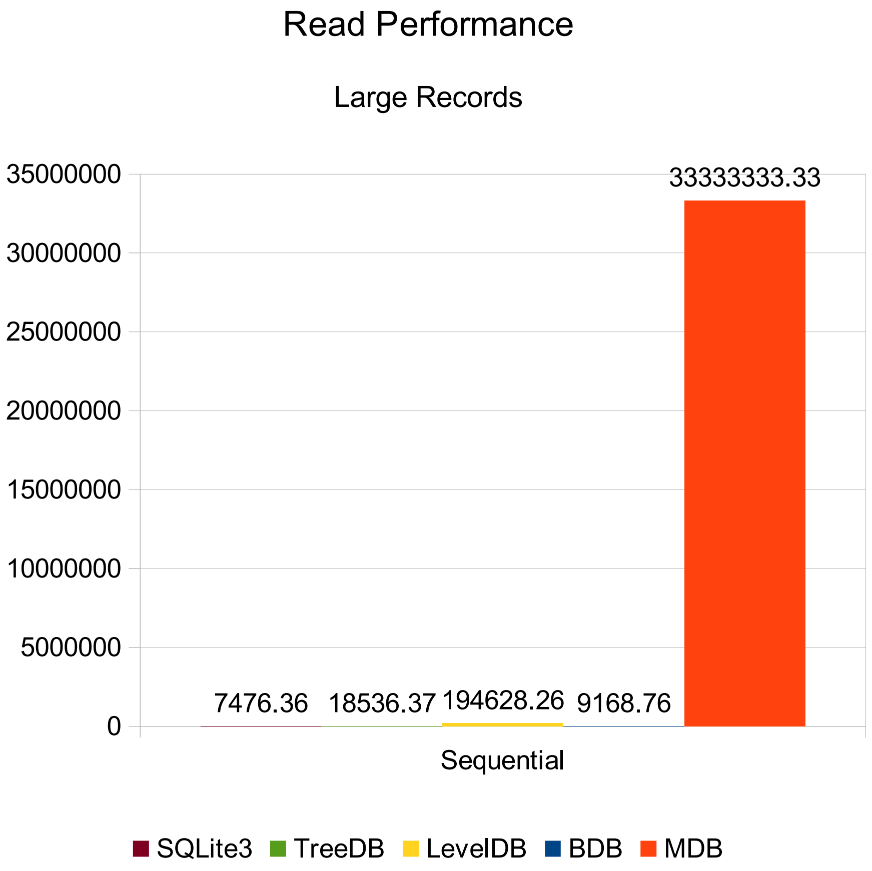

Read Performance

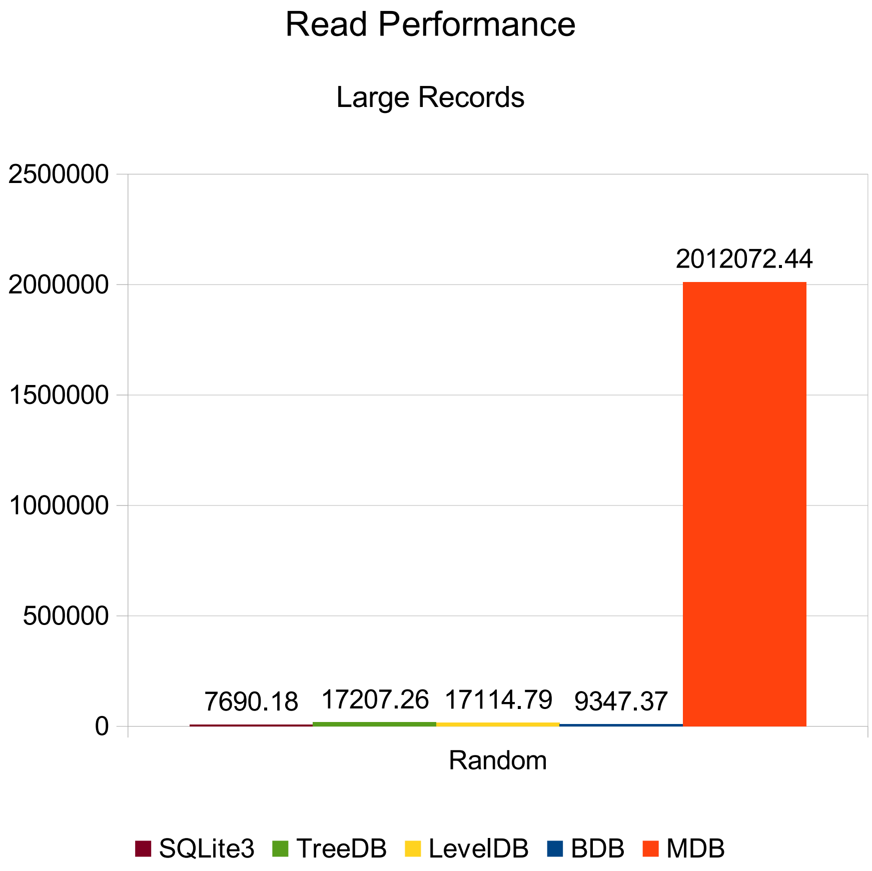
Small Records


Read Performance

Small Records

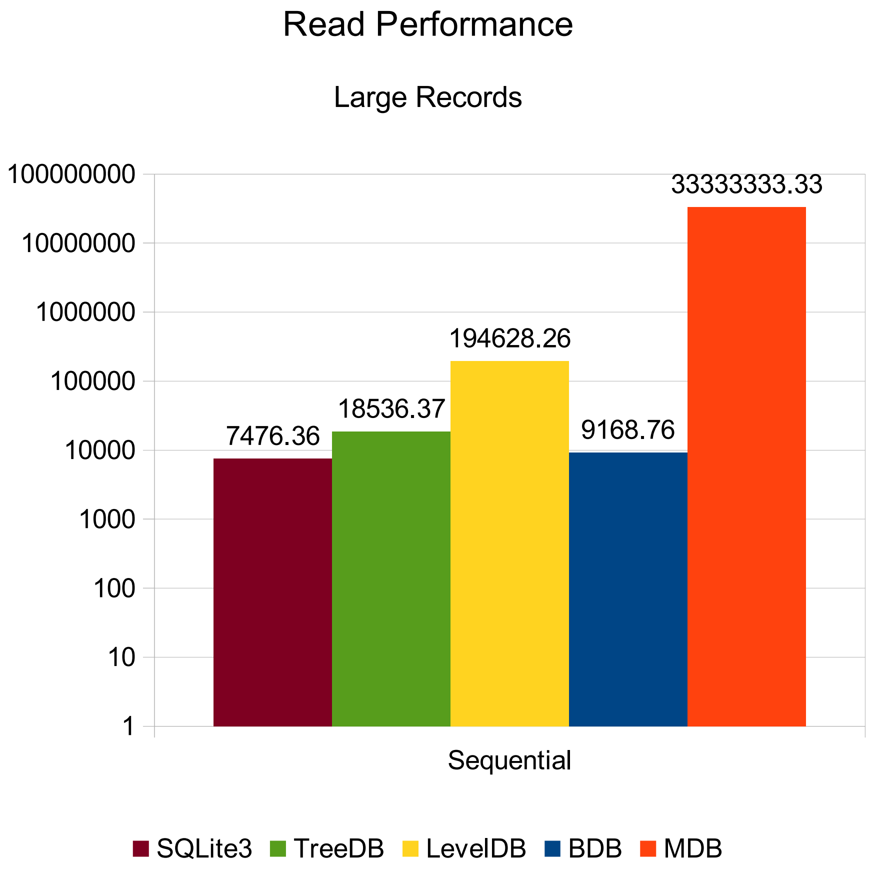
Microbenchmark Results





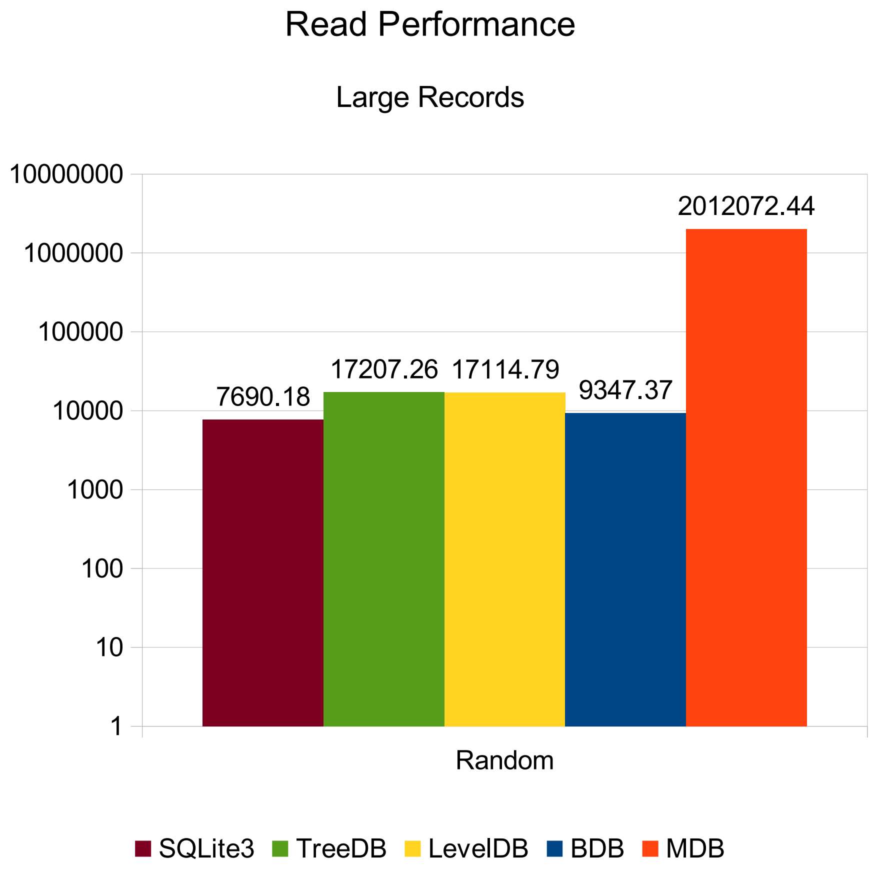
Microbenchmark Results

Log Scale



Read Performance

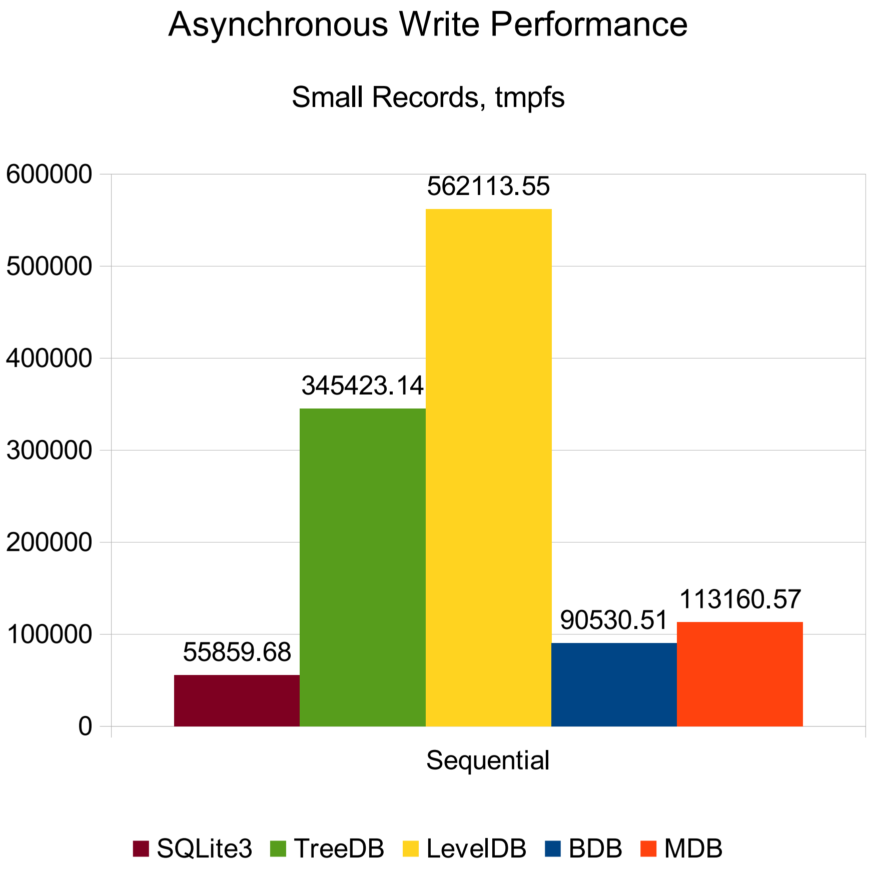
Large Records

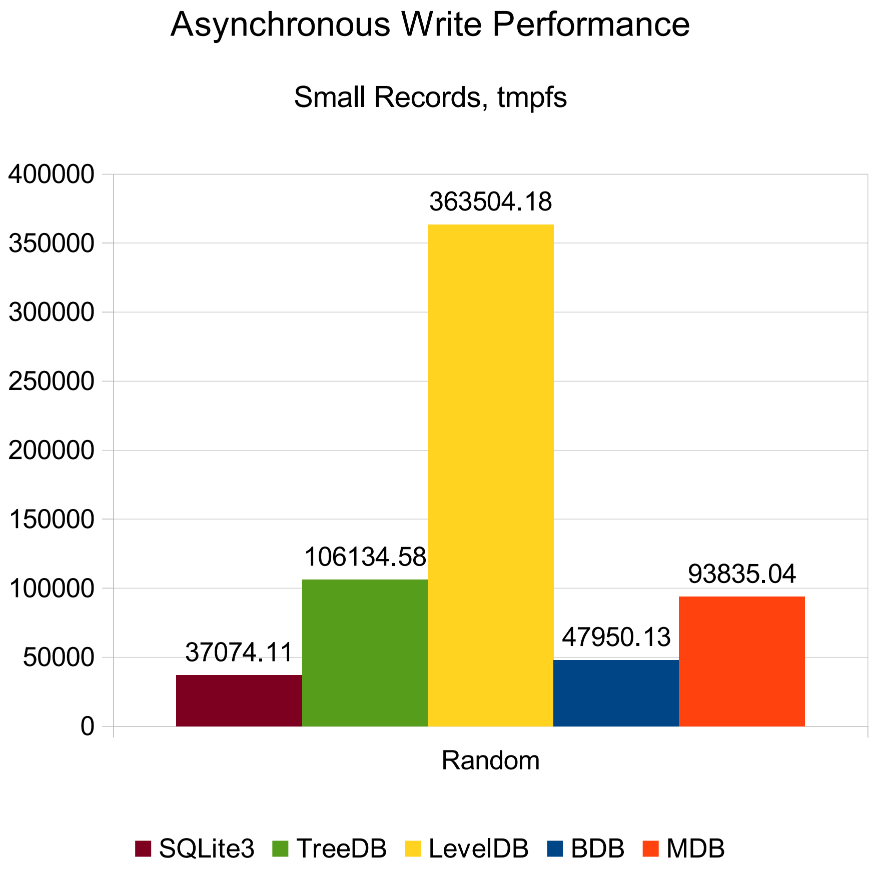


Read Performance

Large Records

Microbenchmark Results





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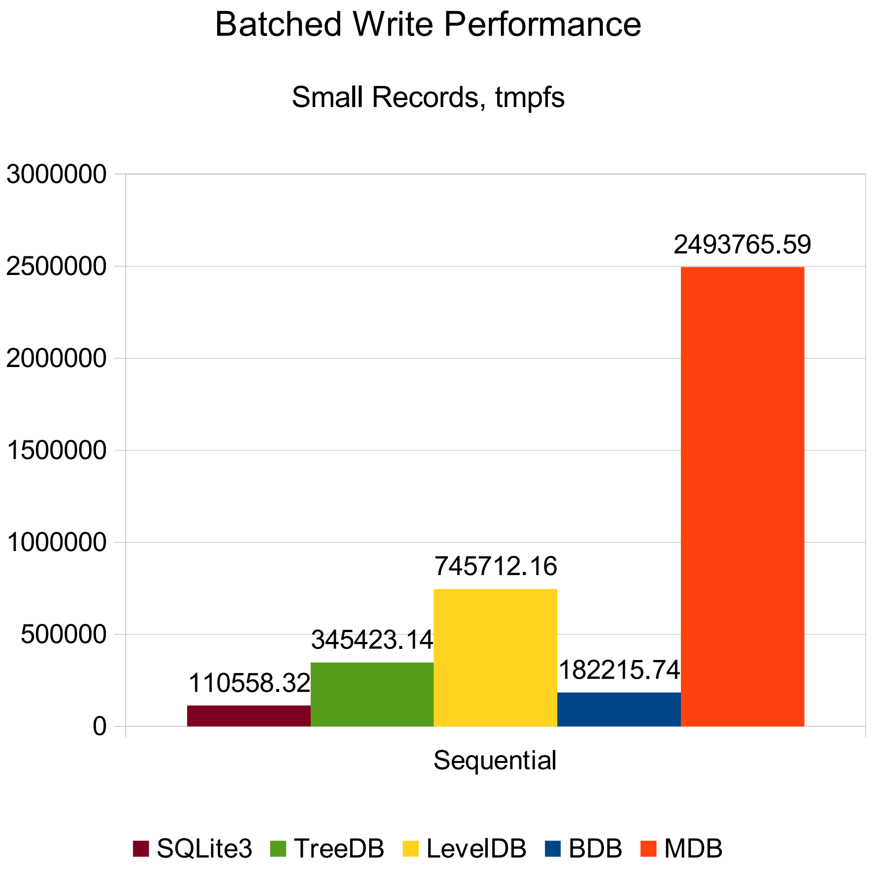
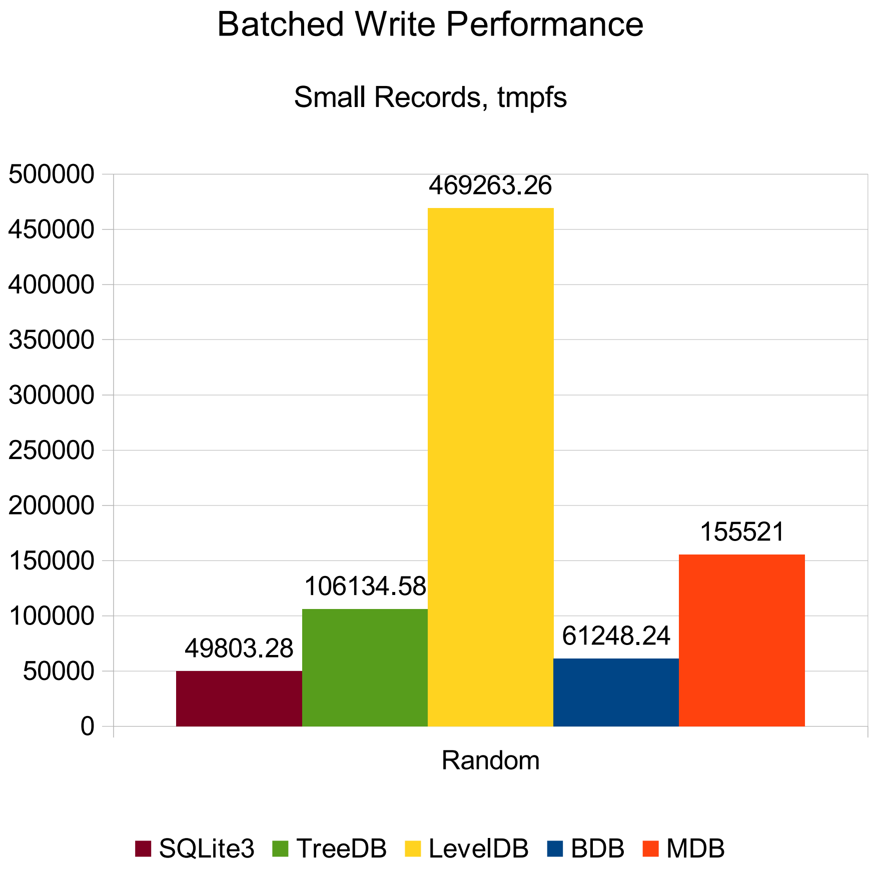
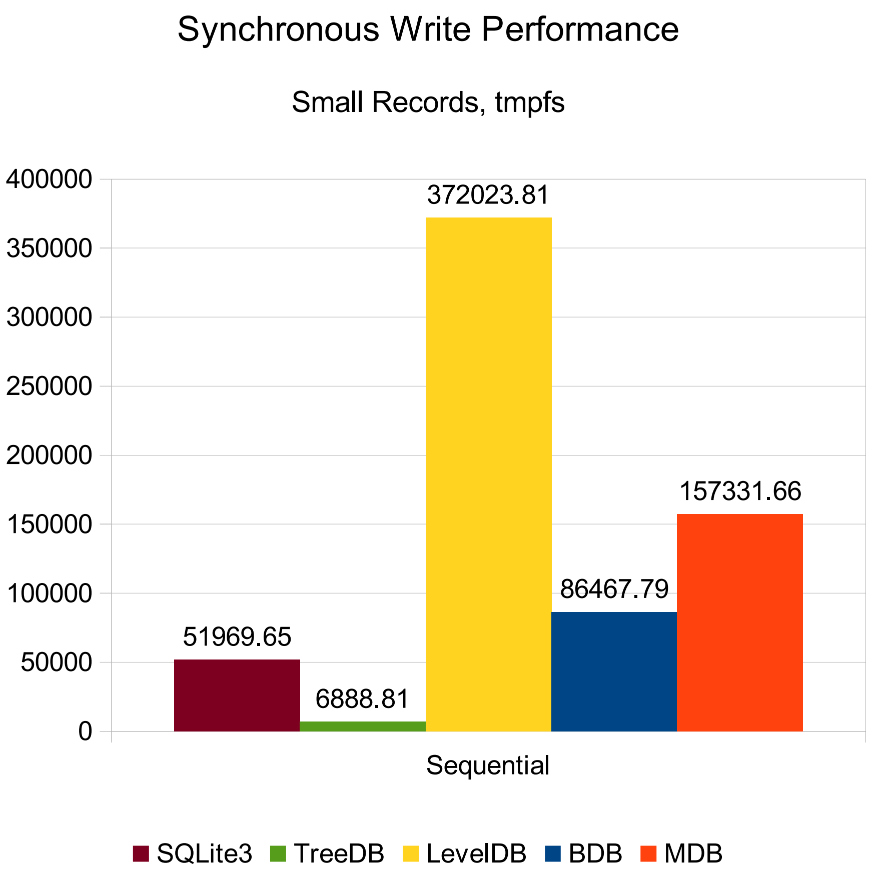
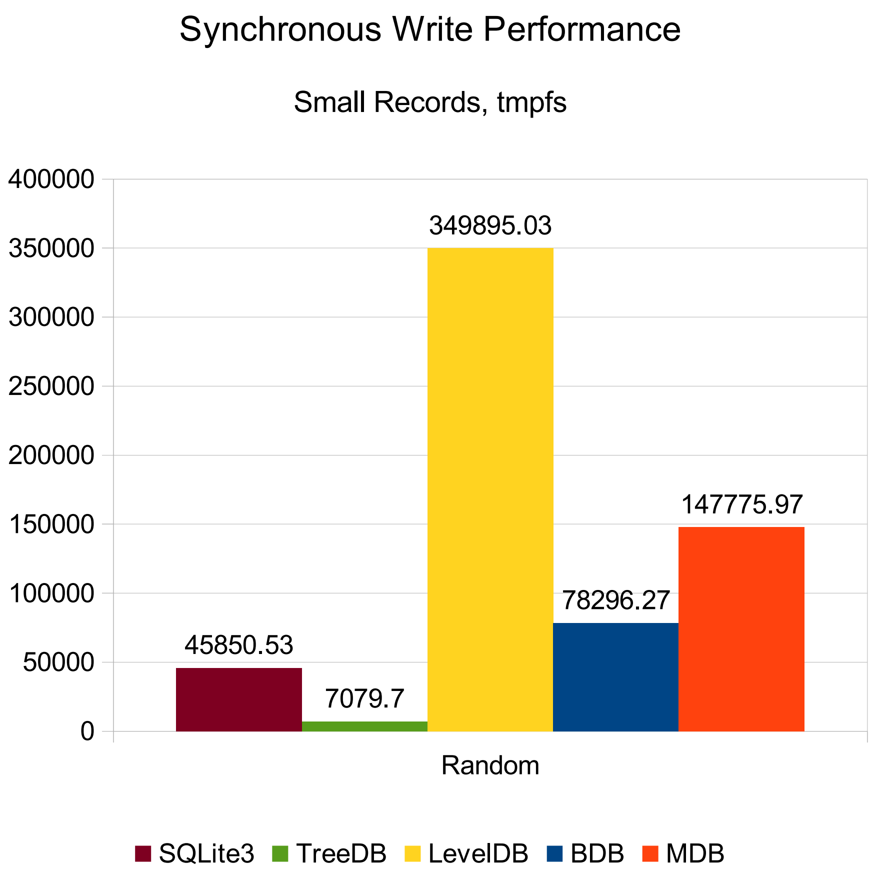
Microbenchmark Results



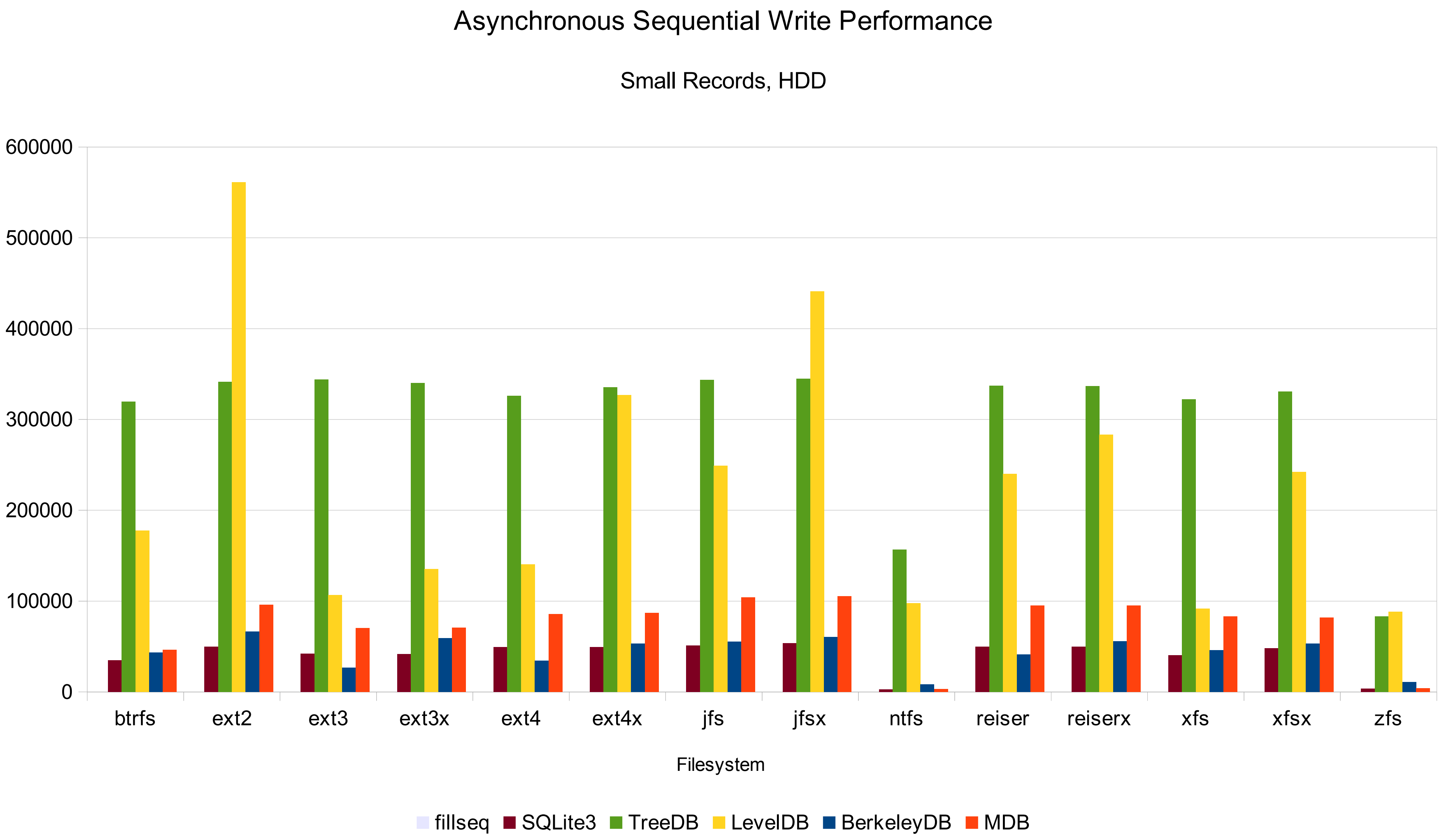


Microbenchmark Results





Microbenchmark Results



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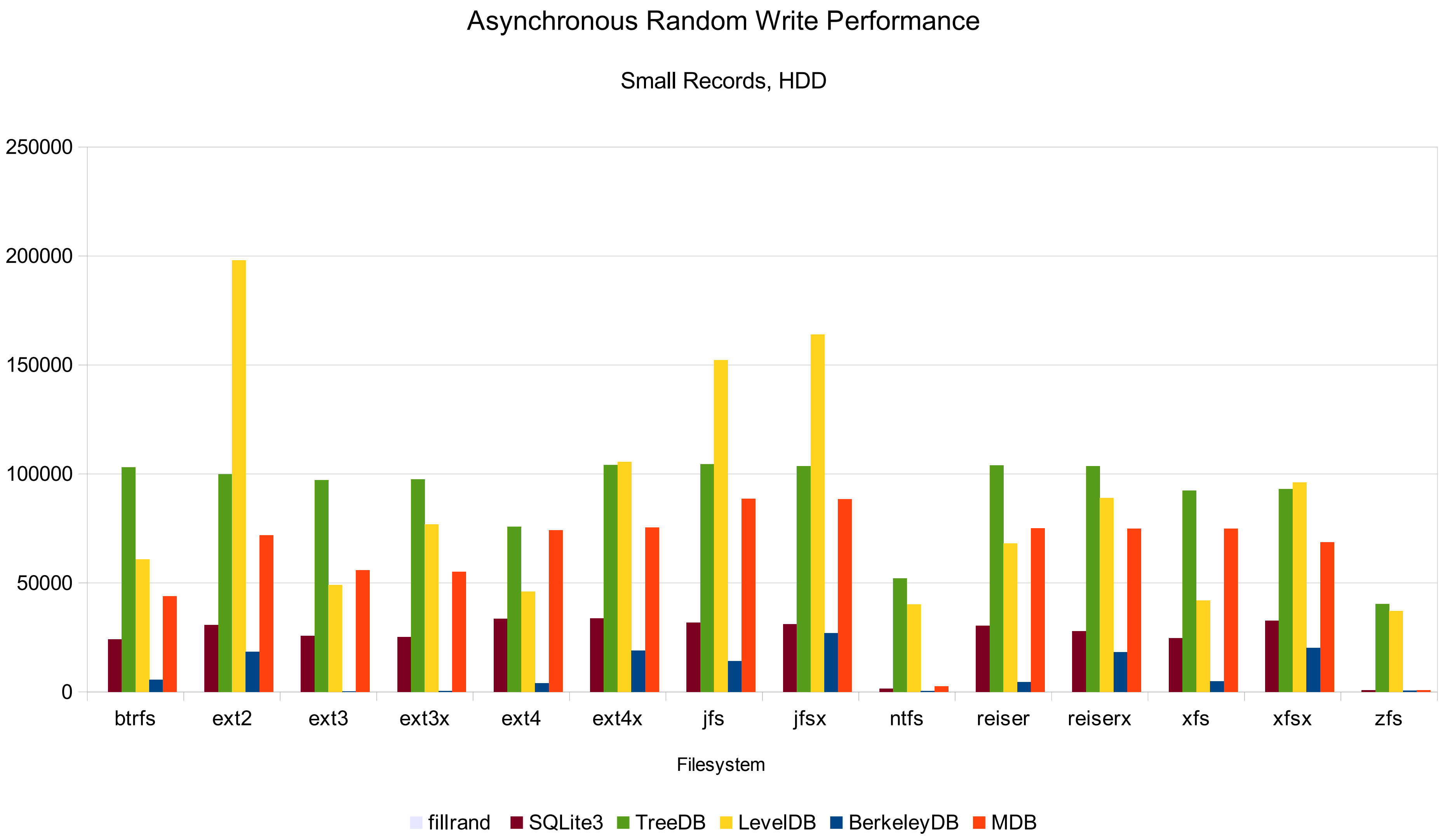
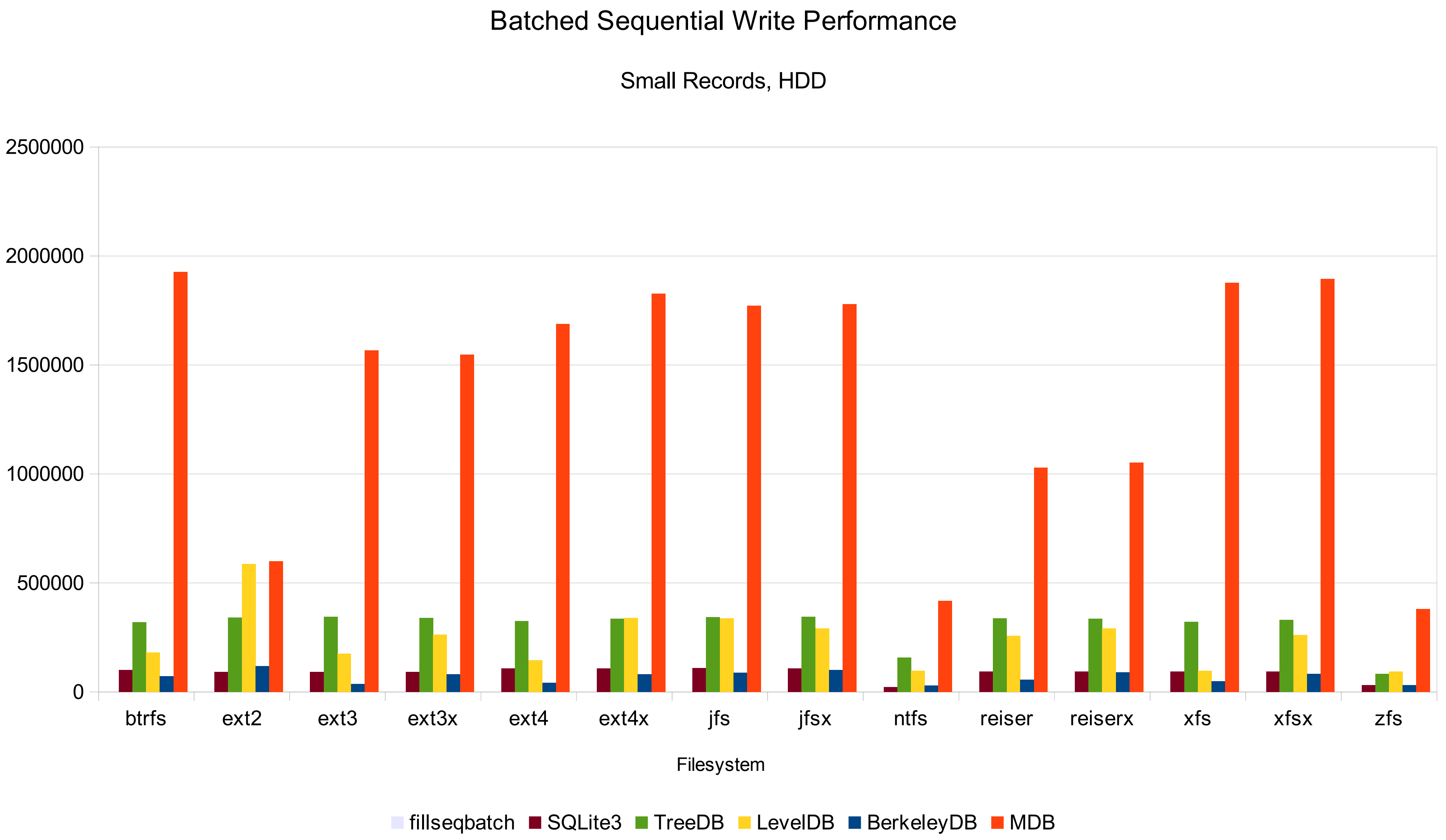
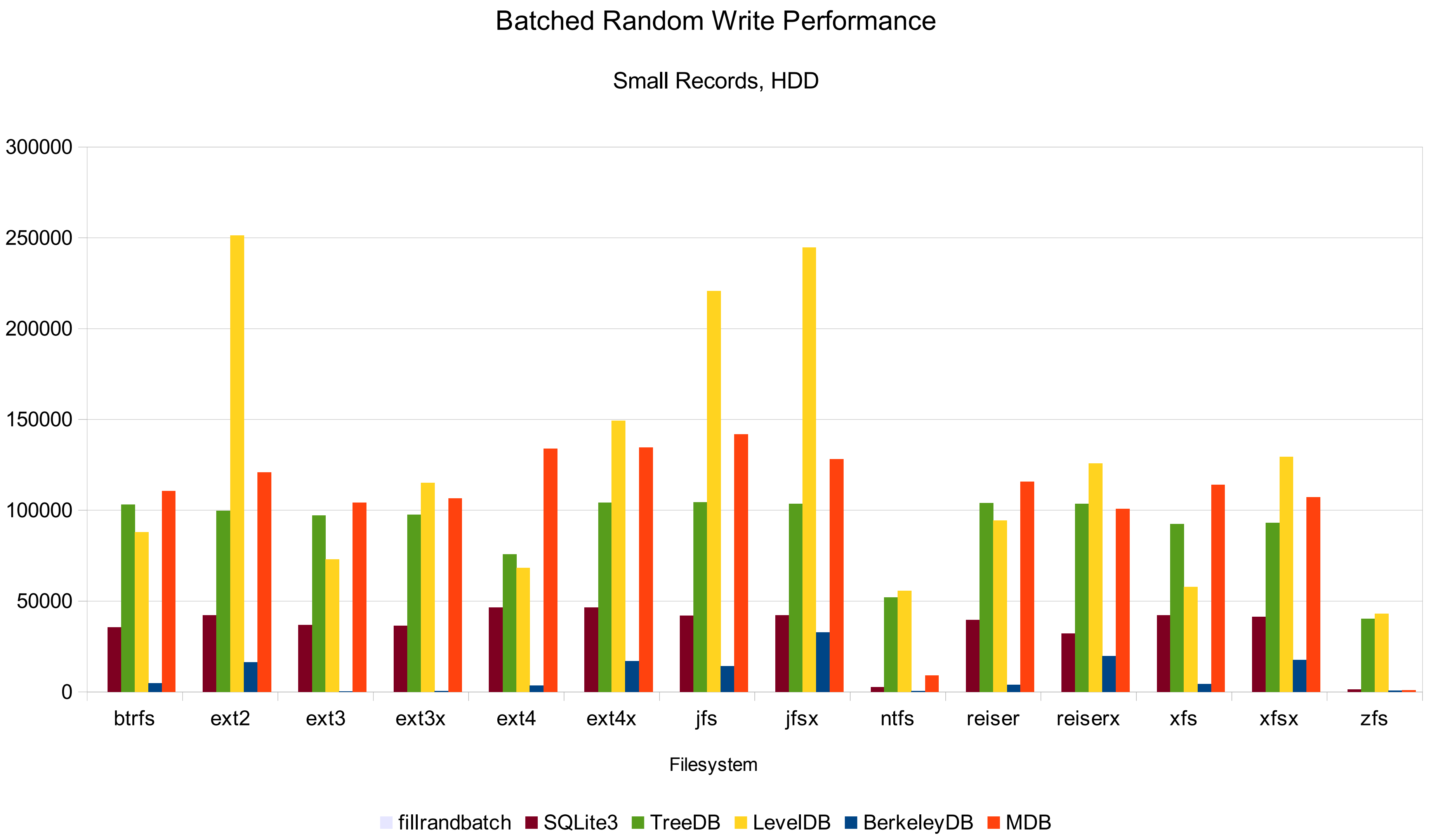


Microbenchmark Results



Microbenchmark Results



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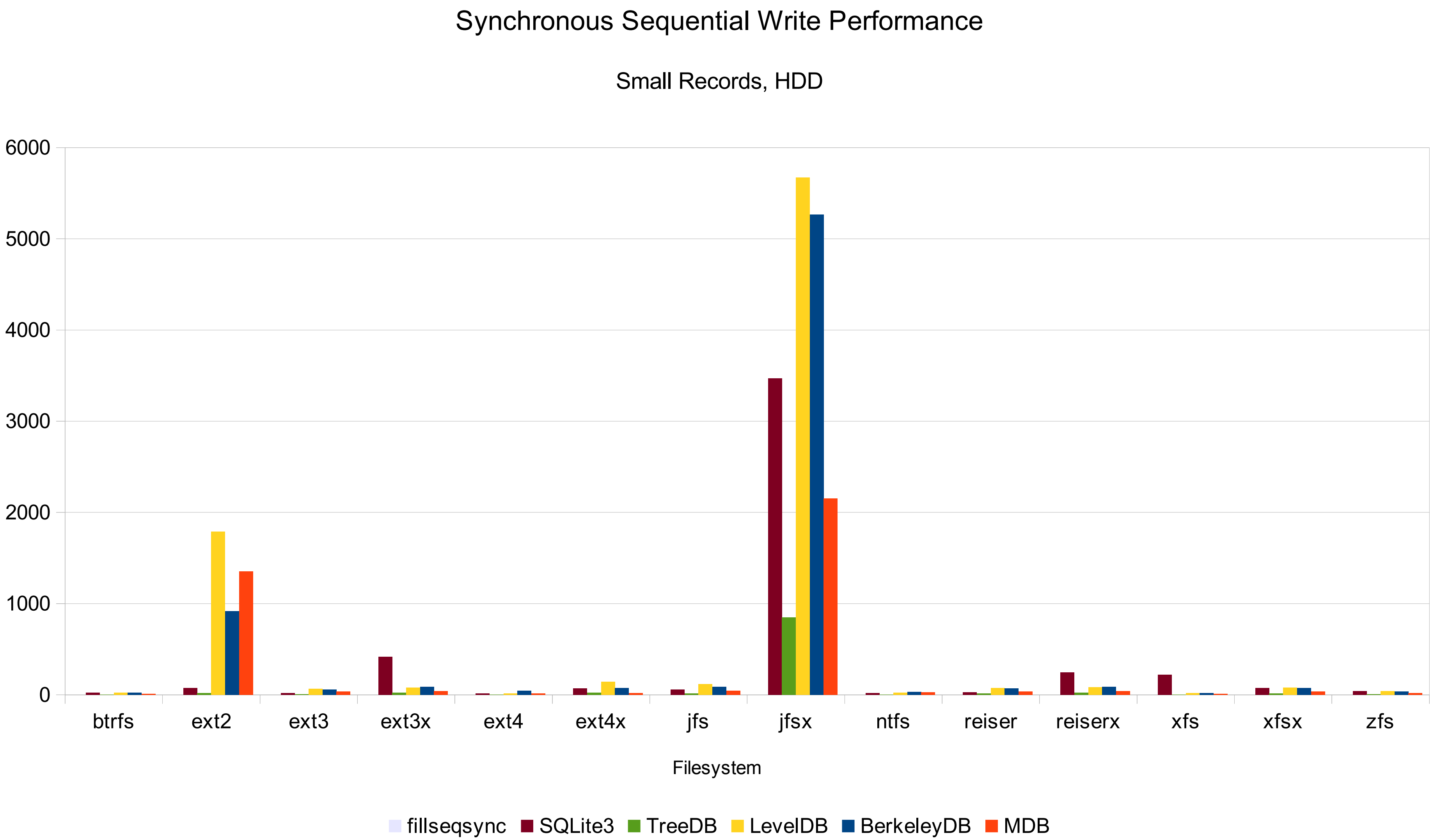
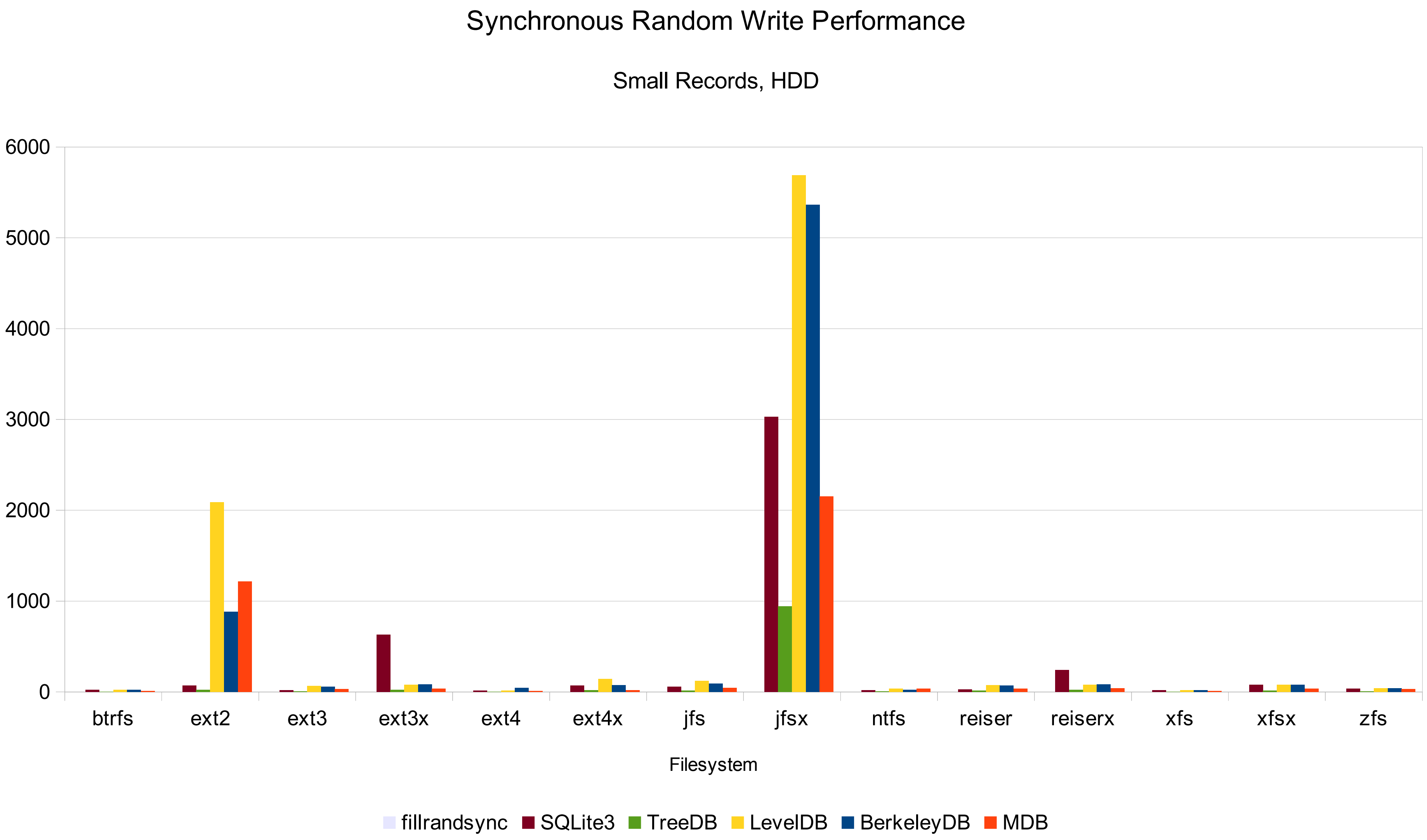
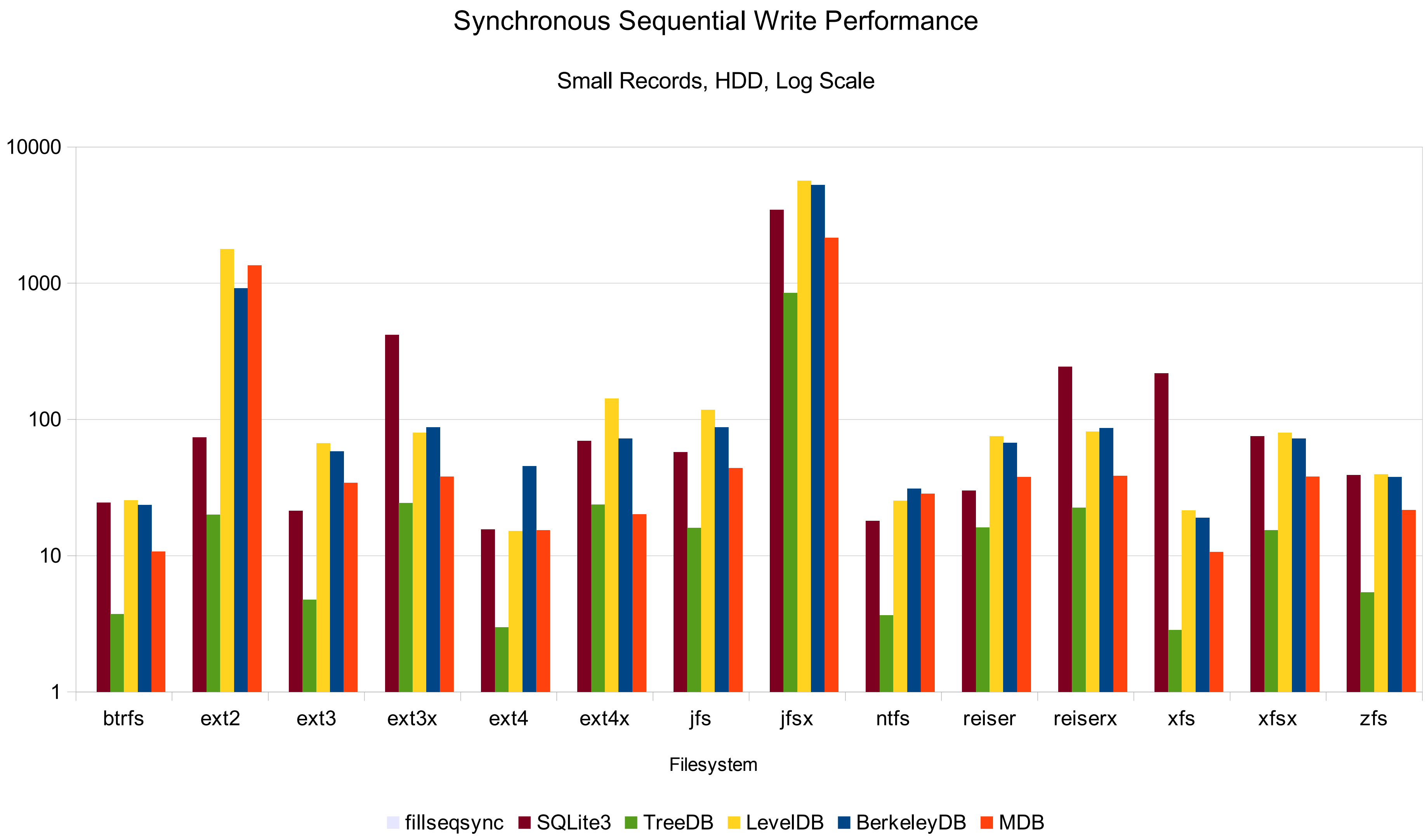


Microbenchmark Results



Microbenchmark Results



Microbenchmark Results

- Clearly the filesystem type has a huge impact on database performance
- Each database behaves differently; benchmark sites that talk about "synthetic database workloads" have no clue what they're measuring
- The only way to really know is to measure your actual application in your actual deployment
- Additional test results available on http://highlandsun.com/hyc/mdb/

Benchmarking...

- MDB in a real application - the OpenLDAP slapd server, using the new back-mdb slapd backend

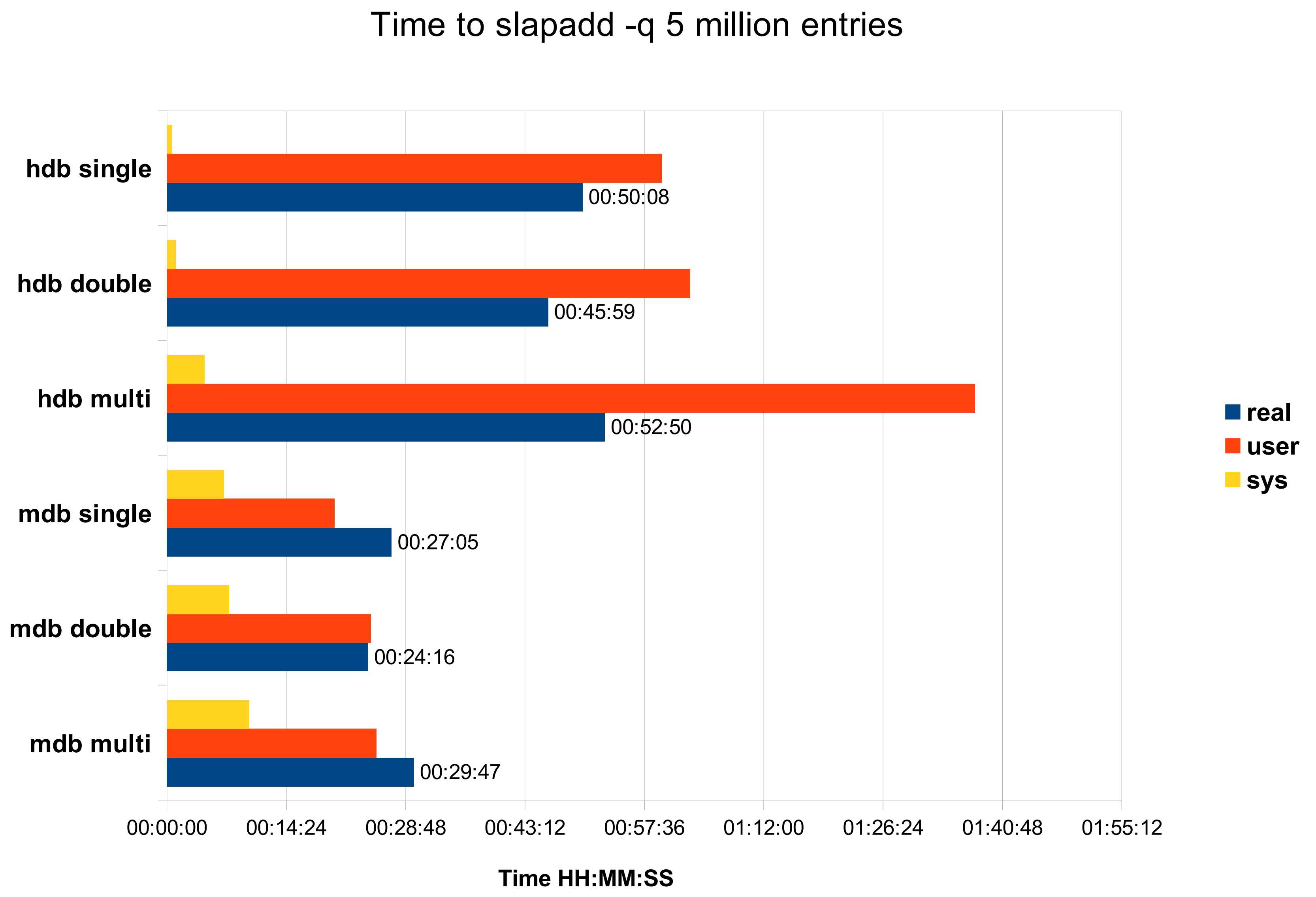
Implementation Highlights

- back-mdb code is based on back-bdb/hdb
  - Copied the back-bdb source tree
  - Deleted all cache-management code
  - Adapted to MDB API
    - conversion was feature-complete in only 5 days
  - Source comprises 340KB, compared to 476KB for back-bdb/hdb - 30% smaller
  - Nothing sacrificed - supports all the same features as back-hdb

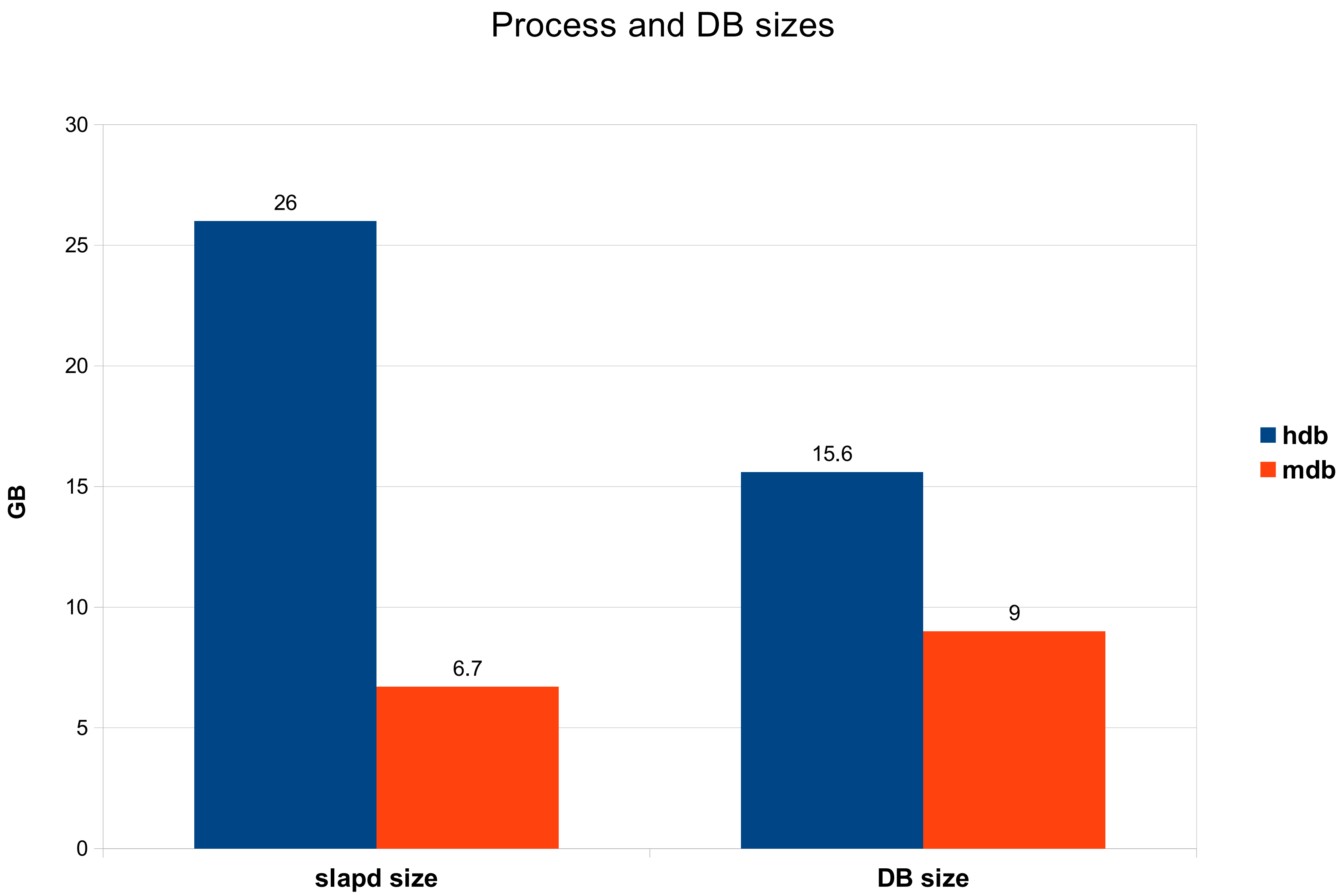
Tradeoffs?

- Dropping the entry cache means we incur a cost to decode entries on every query, instead of simply operating on a fully-decoded entry in a cache
  - No problem, just make entry decoding in back-mdb cost less than an entry cache access in back-hdb
- The copy-on-write approach allows only a single writer at a time
  - BDB allows multiple concurrent writers, theoretically greater throughput
  - Under heavy load, BDB txn deadlocks slow it down to slower than MDB; MDB performance remains constant

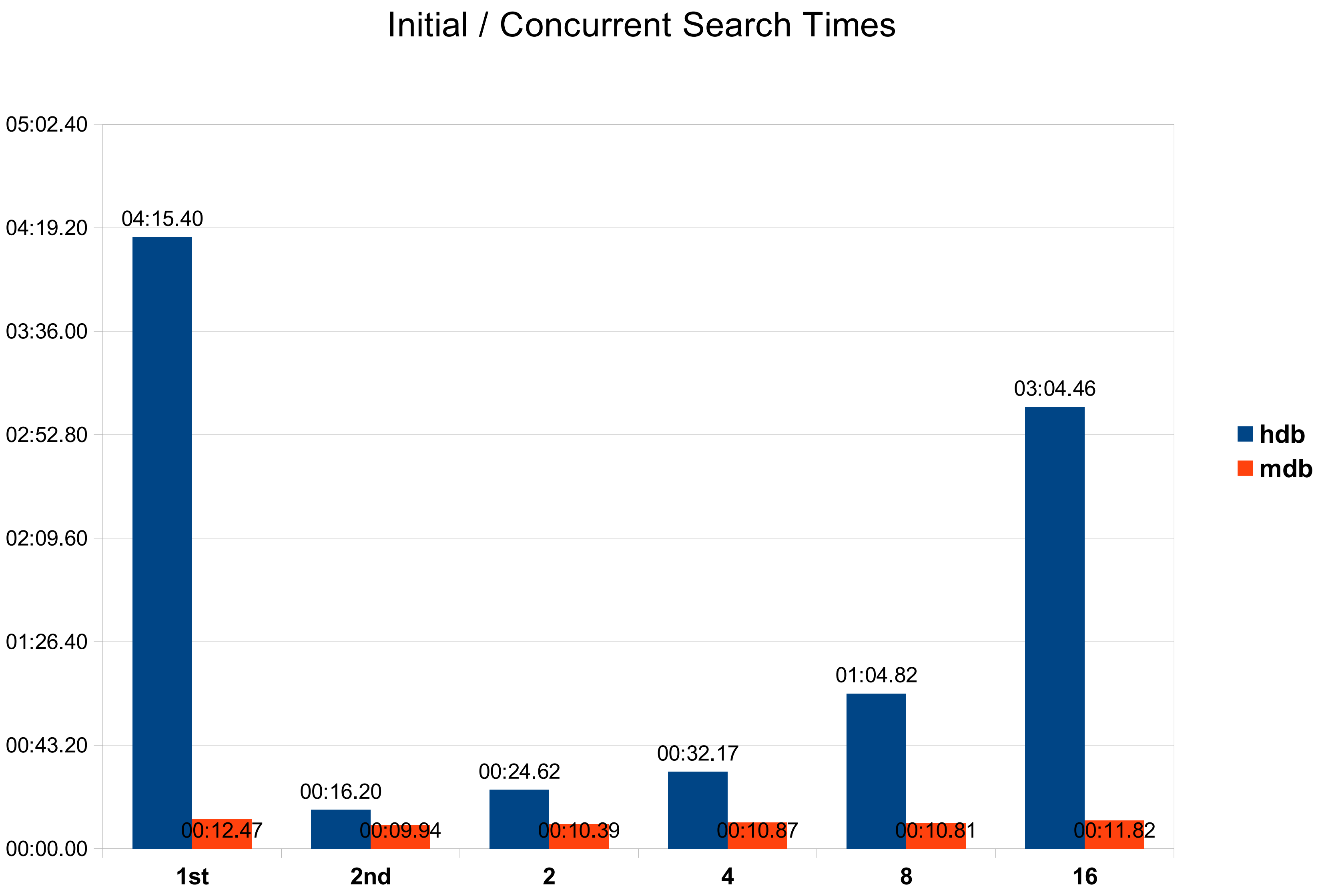
Results


Time to slapadd -q 5 million entries
hdb single
hdb double
hdb multi
mdb single
mdb double
mdb multi
00:50:08
00:45:59
00:52:50
00:27:05
00:24:16
00:29:47
00:00:00
00:14:24
00:28:48
00:43:12
00:57:36
01:12:00
01:26:24
01:40:48
01:55:12
Time HH:MM:SS
real
user
sys

Results


Process and DB sizes
GB
30
25
20
15
10
5
0
26
6.7
15.6
9
slapd size
DB size
hdb
mdb

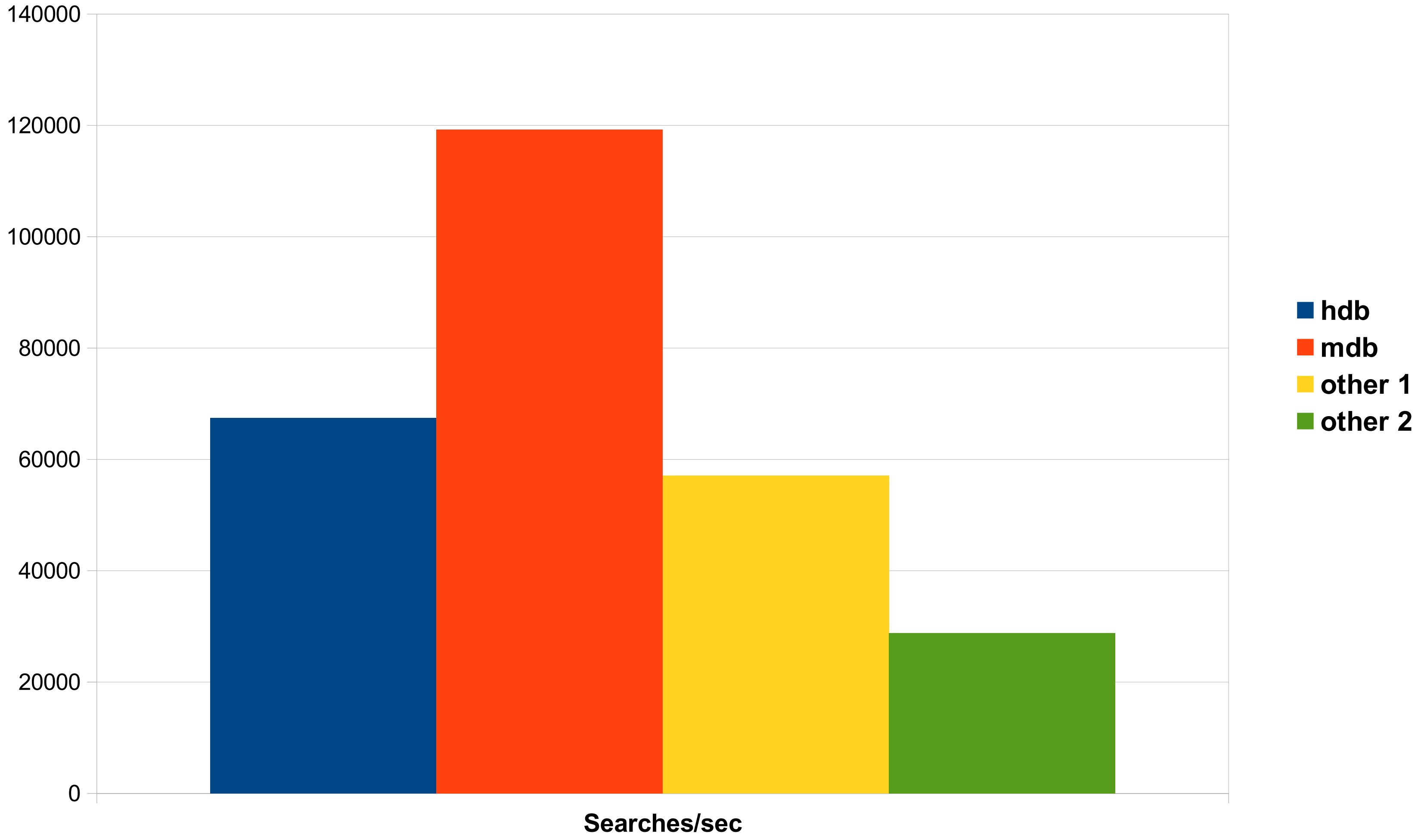
Results



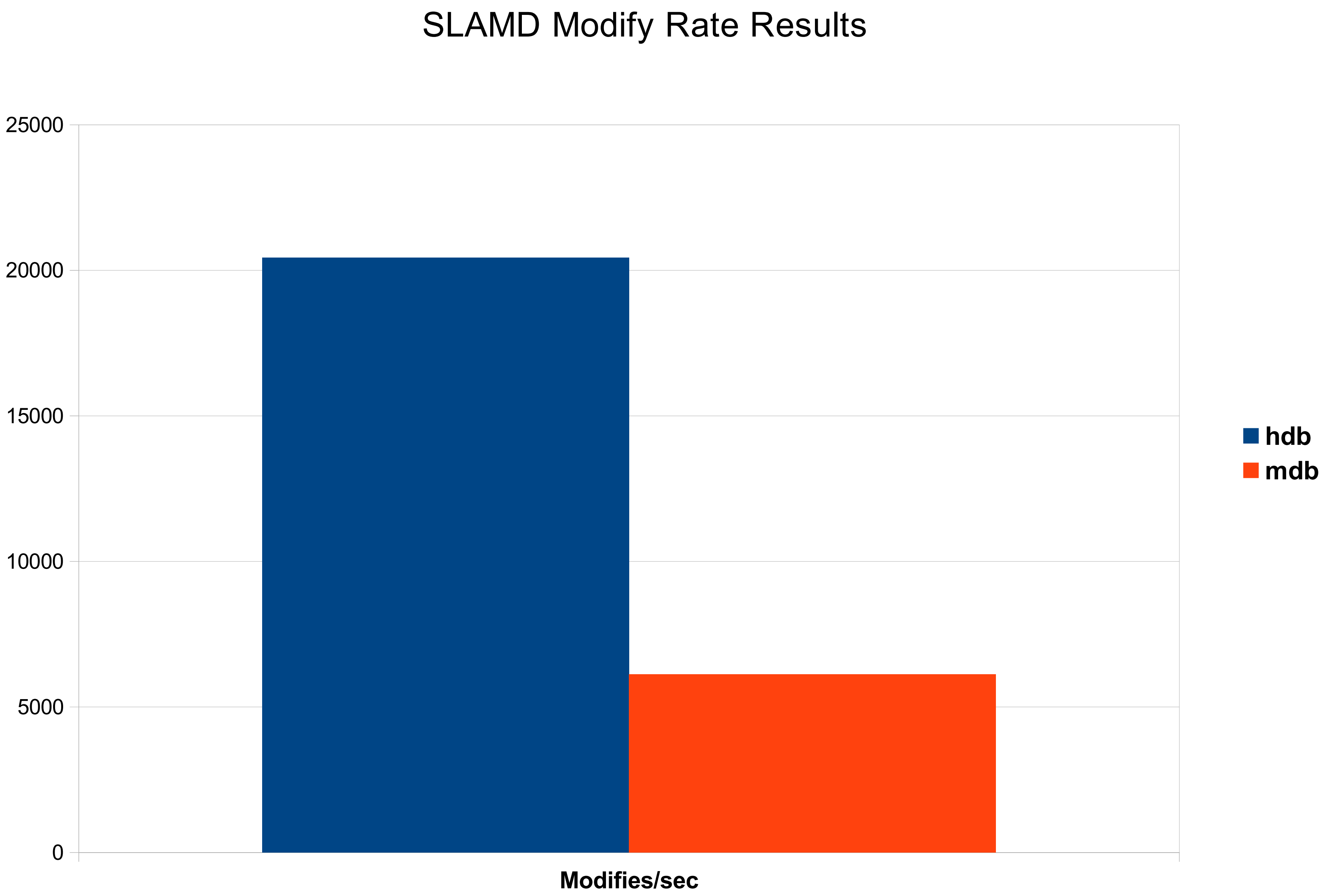
Initial / Concurrent Search Times
05:02.40
04:19.20
03:36.00
02:52.80
02:09.60
01:26.40
00:43.20
00:00.00
04:15.40
00:12.47
00:16.20
00:09.94
00:24.62
00:10.39
00:32.17
00:10.87
01:04.82
00:10.81
03:04.46
00:11.82
1st
2nd
2
4
8
16
hdb
mdb

Results

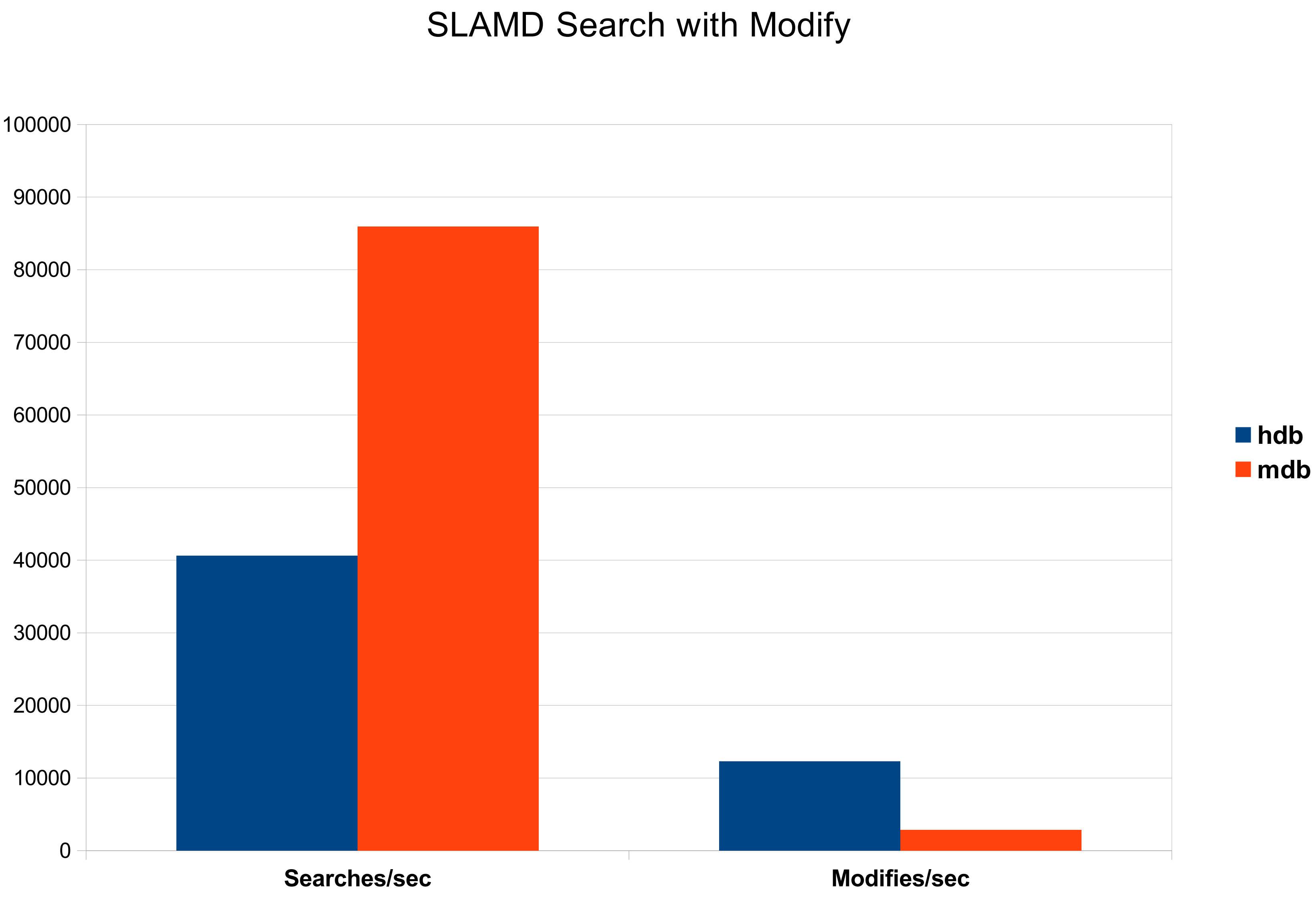
SLAMD Search Rate Comparison



Results


SLAMD Modify Rate Results
25000
20000
15000
10000
5000
0
Modifies/sec
🟦 hdb
🟥 mdb

Results


SLAMD Search with Modify
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
Searches/sec
Modifies/sec
hdb
mdb

Conclusions

- The combination of memory-mapped operation with MVCC is extremely potent for read-oriented databases
    - Reduced administrative overhead
        - no periodic cleanup / maintenance required
        - no particular tuning required
    - Reduced developer overhead
        - code size and complexity drastically reduced
    - Enhanced efficiency
        - read performance is significantly increased

Conclusions

- The MDB approach is not just a one-off solution
  - While initially developed on desktop Linux, it has also been ported to Windows, MacOSX, and Android with no particular difficulty
  - While developed specifically for OpenLDAP, porting to other code bases is also under way
    - A port to SQLite 3.7.1 is available on gitorious
    - Replacements for BerkeleyDB in Cyrus-SASL, Heimdal, OpenDKIM are available
    - Replacement for BerkeleyDB in perl DBD planned
    - There are probably many other suitable applications for a small-footprint database library with low write rates and near-zero read overhead

Future Work

- A number of items remain on the TODO list
  - Investigate optimizations for write performance
  - Allow database max size and other settings to be grown dynamically instead of statically configured
  - Functions to facilitate incremental and/or full backups
  - Storing back-mdb entries in native format, so no decoding is needed at all
- None of these are show-stoppers, MDB and back-mdb already meet or exceed all expectations

Where Next?

- Symas Corp. is offering (for a limited time) 6 months free support to anyone using back-mdb
- Several large Symas partners are testing and deploying MDB in their own applications, as well as back-mdb in their LDAP deployments
- A port of XDAndroid using the MDB port of SQLite3 is in progress
- A port of MemcacheDB using MDB is planned
- Internal testing and benchmarking continues...

SQLite Footnotes

- Time to Insert 1000 random records
  - Original SQLite 3.7.7.1: 22.43 seconds
  - SQLite with MDB: 1.06 seconds
- Time to read (Select) 1000 records
  - Difference unmeasurable
  - Instruction-level profile shows >95% of execution time is spent in SQL parsing, only 2-3% in actual DB fetch

SQLite Footnotes

- How "Lite" is SQLite?
  - MDB is over an order of magnitude more efficient for writes
  - Writes are most power intensive
  - The big story here isn't the absolute speed, it's the efficiency - SQLite is used extensively in smartphones, tablets, and other devices
  - a 23:1 improvement in write efficiency translates to a significant gain in battery life