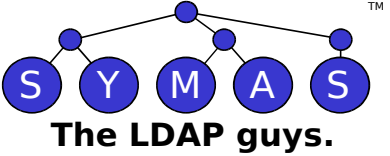

Life After BerkeleyDB: OpenLDAP's Memory-Mapped Database

Howard Chu
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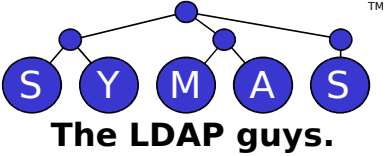
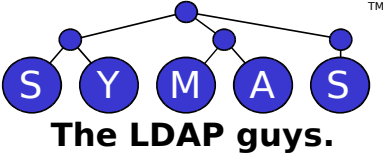
Chief Architect, OpenLDAP hyc@openldap.org



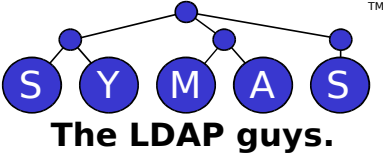
OpenLDAP Project

- 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

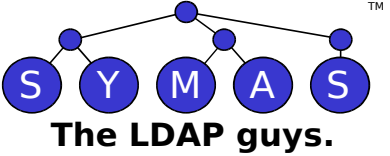


Topics

- Background
- Features
- API Overview
- Internals
- Special Features
- Results

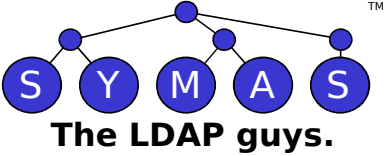
Background

- API Inspired by Berkeley DB (BDB)
  - OpenLDAP has used BDB extensively since 1999
  - Deep experience with pros and cons of BDB design and implementation
  - Omits BDB features that were found to be of no benefit
    - e.g. extensible hashing
  - Avoids BDB characteristics that were problematic
    - e.g. cache tuning, complex locking, transaction logs, recovery



Features

- OpenLDAP MDB At A Glance
  - Key/Value store using B+trees
  - Fully transactional, ACID compliant
  - MVCC, readers never block
  - Uses memory-mapped files, needs no tuning
  - Crash-proof, no recovery needed after restart
  - Highly optimized, extremely compact
    - under 40KB object code, fits in CPU L1 Icache
  - Runs on most modern OSs
    - Linux, Android, *BSD, MacOSX, Solaris, Windows, etc...

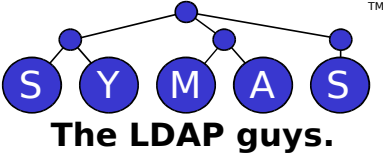


Features

- Concurrency Support
  - Both multi-process and multi-thread
  - Single Writer + N Readers
    - Writers don't block readers
    - Readers don't block writers
    - Reads scale perfectly linearly with available CPUs
    - No deadlocks
  - Full isolation with MVCC
  - Nested transactions
  - Batched writes

Features

- Uses Copy-on-Write
  - Live data is never overwritten
  - Database structure cannot be corrupted by incomplete operations (system crashes)
  - No write-ahead logs needed
  - No transaction log cleanup/maintenance
  - No recovery needed after crashes



Features

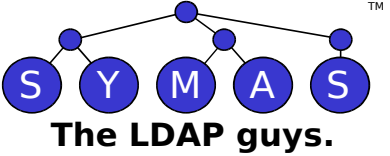
- Uses Single-Level-Store
  - Reads are satisfied directly from the memory map
    - no malloc or memcpy overhead
  - Writes can be performed directly to the memory map
    - no write buffers, no buffer tuning
  - Relies on the OS/filesystem cache
    - no wasted memory in app-level caching
  - Can store live pointer-based objects directly
    - using a fixed address map
    - minimal marshalling, no unmarshalling required

API Overview

- Based on BDB Transactional API
  - BDB apps can easily be migrated to MDB
- Written in C
  - C/C++ supported directly
  - Wrappers for Erlang available
  - Wrappers for other languages coming, as-needed
- All functions return 0 on success or a non-zero error code on failure
  - except some void functions which cannot fail

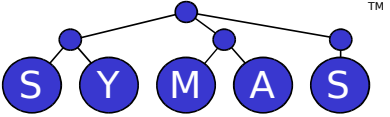
API Overview

- All DB operations are transactional
  - There is no non-transactional interface
- Results fetched from the DB are owned by the DB
  - Point directly to the mmap contents, not memcpy'd
  - Need no disposal, callers can use the data then forget about it
  - Read-only by default, attempts to overwrite data will trigger a SIGSEGV



API Overview

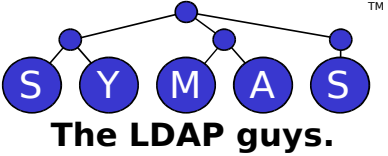
- Most function names are grouped by purpose:
  - Environment:
    - mdb_env_create, mdb_env_open, mdb_env_sync, mdb_env_close
  - Transaction:
    - mdb_txn_begin, mdb_txn_commit, mdb_txn_abort
  - Cursor:
    - mdb_cursor_open, mdb_cursor_close, mdb_cursor_get, mdb_cursor_put, mdb_cursor_del
  - Database/Generic:
    - mdb_open, mdb_close, mdb_get, mdb_put, mdb_del



API Overview

MDB Sample

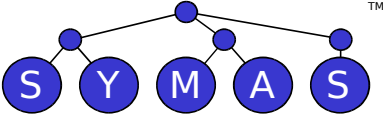
```
#include <stdio.h>
#include "mdb.h"

int main(int argc, char *argv[])
{
    int rc;
    MDB_env *env;
    MDB_txn *txn;
    MDB_cursor *cursor;
    MDB_dbi dbi;
    MDB_val key, data;
    char sval[32];

    rc = mdb_env_create(&env);
    rc = mdb_env_open(env,
      "./testdb", 0, 0664);
    rc = mdb_txn_begin(env, NULL,
      0, &txn);
    rc = mdb_open(txn, NULL, 0,
      &dbi);

    key.mv_size = sizeof(int);
    key.mv_data = sval;
    data.mv_size = sizeof(sval);
    data.mv_data = sval;
    sprintf(sval, "%03x %d foo bar", 32, 3141592);
    rc = mdb_put(txn, dbi, &key, &data, 0);
    rc = mdb_txn_commit(txn);
    if (rc) {
        fprintf(stderr, "mdb_txn_commit: (%d) %s\n",
          rc, mdb_strerror(rc));
        goto leave;
    }
    rc = mdb_txn_begin(env, NULL, MDB_RDONLY, &txn);
    rc = mdb_cursor_open(txn, dbi, &cursor);
    while ((rc = mdb_cursor_get(cursor, &key, &data,
      MDB_NEXT)) == 0) {
        printf("key: %p %.*s, data: %p %.*s\n",
            key.mv_data,
            (int) key.mv_size,
            (char *) key.mv_data,
            data.mv_data,
            (int) data.mv_size,
            (char *) data.mv_data);
    }
    mdb_cursor_close(cursor);
    mdb_txn_abort(txn);
leave:
    mdb_close(env, dbi);
    mdb_env_close(env);
    return rc;
}
```



API Overview

BDB Sample

```
#include <stdio.h>
#include <string.h>
#include <db.h>

int main(int argc, char *argv[])
{
    int rc;
    DB_ENV *env;
    DB_TXN *txn;
    DBC *cursor;
    DB *dbi;
    DBT key, data;
    char sval[32], kval[32];

#define FLAGS (DB_INIT_LOCK|DB_INIT_LOG|
DB_INIT_TXN|DB_INIT_MPOOL|DB_CREATE|DB_THREAD)
    rc = db_env_create(&env, 0);
    rc = env->open(env, "./testdb", FLAGS,
      0664);
    rc = db_create(&dbi, env, 0);
    rc = env->txn_begin(env, NULL, &txn, 0);
    rc = dbi->open(dbi, txn, "test.bdb", NULL,
      DB_BTREE, DB_CREATE, 0664);

    memset(&key, 0, sizeof(DBT));
    memset(&data, 0, sizeof(DBT));
    key.size = sizeof(int);
    key.data = sval;
    data.size = sizeof(sval);
    data.data = sval;
    sprintf(sval, "%03x %d foo bar", 32, 3141592);
    rc = dbi->put(dbi, txn, &key, &data, 0);
    rc = txn->commit(txn, 0);
    if (rc) {
        fprintf(stderr, "txn->commit: (%d) %s\n",
          rc, db_strerror(rc));
        goto leave;
    }
    rc = env->txn_begin(env, NULL, &txn, 0);
    rc = dbi->cursor(dbi, txn, &cursor, 0);
    key.flags = DB_DBT_USERMEM;
    key.data = kval;
    key.ulen = sizeof(kval);
    data.flags = DB_DBT_USERMEM;
    data.data = sval;
    data.ulen = sizeof(sval);
    while ((rc = cursor->c_get(cursor, &key, &data,
      DB_NEXT)) == 0) {
        printf("key: %p %.*s, data: %p %.*s\n",
            key.data,
            (int) key.size,
            (char *) key.data,
            data.data,
            (int) data.size,
            (char *) data.data);
    }
    rc = cursor->c_close(cursor);
    rc = txn->abort(txn);
leave:
    rc = dbi->close(dbi, 0);
    rc = env->close(env, 0);
    return rc;
}
```



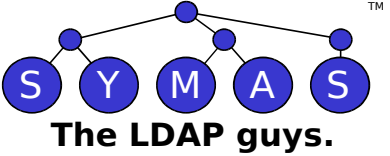
API Overview

MDB Sample

```
#include <stdio.h>

#include "mdb.h"

int main(int argc, char *argv[])
{
    int rc;
    MDB_env *env;
    MDB_txn *txn;
    MDB_cursor *cursor;
    MDB_dbi dbi;
    MDB_val key, data;
    char sval[32];



    rc = mdb_env_create(&env);
    rc = mdb_env_open(env, "./testdb", 0,
      0664);

    rc = mdb_txn_begin(env, NULL, 0, &txn);
    rc = mdb_open(txn, NULL, 0, &dbi);
```

BDB Sample

```
#include <stdio.h>
#include <string.h>
#include <db.h>

int main(int argc, char *argv[])
{
    int rc;
    DB_ENV *env;
    DB_TXN *txn;
    DBC *cursor;
    DB *dbi;
    DBT key, data;
    char sval[32], kval[32];

#define FLAGS (DB_INIT_LOCK|DB_INIT_LOG|
DB_INIT_TXN|DB_INIT_MPOOL|DB_CREATE|
DB_THREAD)
    rc = db_env_create(&env, 0);
    rc = env->open(env, "./testdb", FLAGS,
      0664);
    rc = db_create(&dbi, env, 0);
    rc = env->txn_begin(env, NULL, &txn, 0);
    rc = dbi->open(dbi, txn, "test.bdb",
      NULL, DB_BTREE, DB_CREATE, 0664);
```



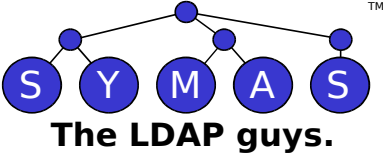
API Overview

MDB Sample

```
    key.mv_size = sizeof(int);
    key.mv_data = sval;
    data.mv_size = sizeof(sval);
    data.mv_data = sval;
    sprintf(sval, "%03x %d foo bar",
      32, 3141592);
    rc = mdb_put(txn, dbi, &key, &data, 0);
    rc = mdb_txn_commit(txn);
    if (rc) {
        fprintf(stderr, "mdb_txn_commit:
(%d) %s\n", rc, mdb_strerror(rc));
        goto leave;
    }
```

BDB Sample

```
    memset(&key, 0, sizeof(DBT));
    memset(&data, 0, sizeof(DBT));
    key.size = sizeof(int);
    key.data = sval;
    data.size = sizeof(sval);
    data.data = sval;
    sprintf(sval, "%03x %d foo bar",
      32, 3141592);
    rc = dbi->put(dbi, txn, &key, &data, 0);
    rc = txn->commit(txn, 0);
    if (rc) {
        fprintf(stderr, "txn->commit: (%d)
%s\n", rc, db_strerror(rc));
        goto leave;
    }
```



API Overview

MDB Sample

```
    rc = mdb_txn_begin(env, NULL, MDB_RDONLY,
      &txn);
    rc = mdb_cursor_open(txn, dbi, &cursor);
    while ((rc = mdb_cursor_get(cursor, &key,
      &data, MDB_NEXT)) == 0) {
       printf("key: %p %.*s, data: %p %.*s\n",
         key.mv_data,
         (int)key.mv_size,
         (char *)key.mv_data,
         data.mv_data,
         (int)data.mv_size,
         (char *)data.mv_data);
    }
    mdb_cursor_close(cursor);
    mdb_txn_abort(txn);
leave:
    mdb_close(env, dbi);
    mdb_env_close(env);
    return rc;
}
```

BDB Sample

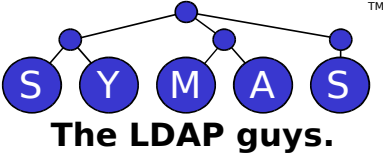
```
    rc = env->txn_begin(env, NULL, &txn,
      0);
    rc = dbi->cursor(dbi, txn, &cursor, 0);
    key.flags = DB_DBT_USERMEM;
    key.data = kval;
    key.ulen = sizeof(kval);
    data.flags = DB_DBT_USERMEM;
    data.data = sval;
    data.ulen = sizeof(sval);
    while ((rc = cursor->c_get(cursor, &key,
      &data, DB_NEXT)) == 0) {
        printf("key: %p %.*s, data: %p %.*s\n",
          key.data,
          (int)key.size,
          (char *)key.data,
          data.data,
          (int)data.size,
          (char *)data.data);
    }
    rc = cursor->c_close(cursor);
    rc = txn->abort(txn);
leave:
    rc = dbi->close(dbi, 0);
    rc = env->close(env, 0);
    return rc;
}
```

API Overview

- MDB naming is simple and consistent
  - MDB_xxx for all typedefs
  - BDB uses DB_XXX, DBX, DB_DBX_...
- MDB environment setup is simple
  - BDB requires multiple subsystems to be initialized
- MDB database setup is simple and reliable
  - BDB creates a file per DB
    - If the transaction containing the DB Open is aborted, rollback is very complicated because the filesystem operations to create the file cannot be rolled back atomically
    - Likewise during recovery and replay of a transaction log

API Overview

- MDB data is simple
  - BDB requires DBT structure to be fully zeroed out before use
  - BDB requires the app to manage the memory of keys and values returned from the DB
- MDB teardown is simple
  - BDB *-close functions can fail, and there's nothing the app can do if a failure occurs



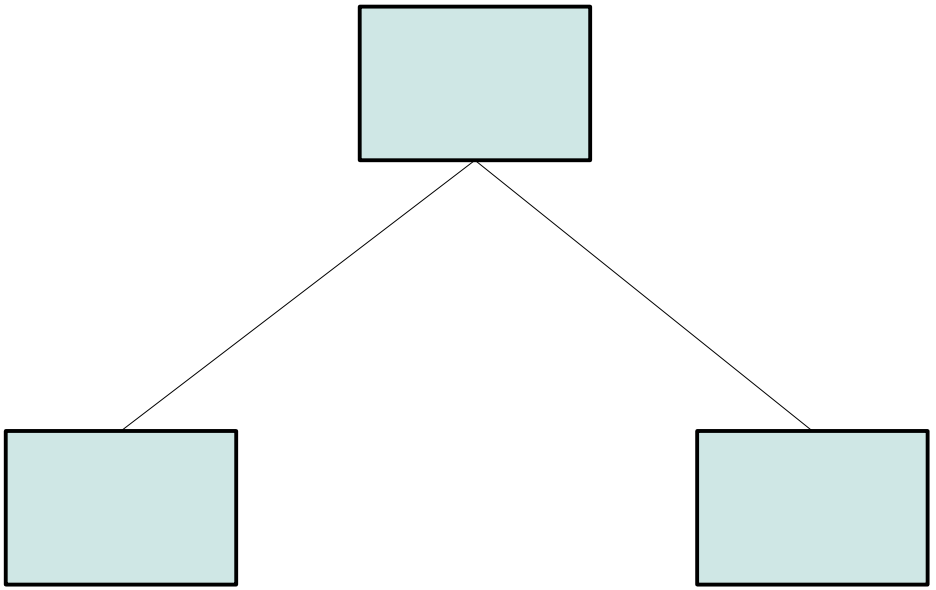
Internals

- B+tree Operation
  - Append-only, Copy-on-Write
  - Corruption-Proof
- Free Space Management
  - Avoiding Compaction/Garbage Collection
- Transaction Handling
  - Avoiding Locking

B+tree Operation

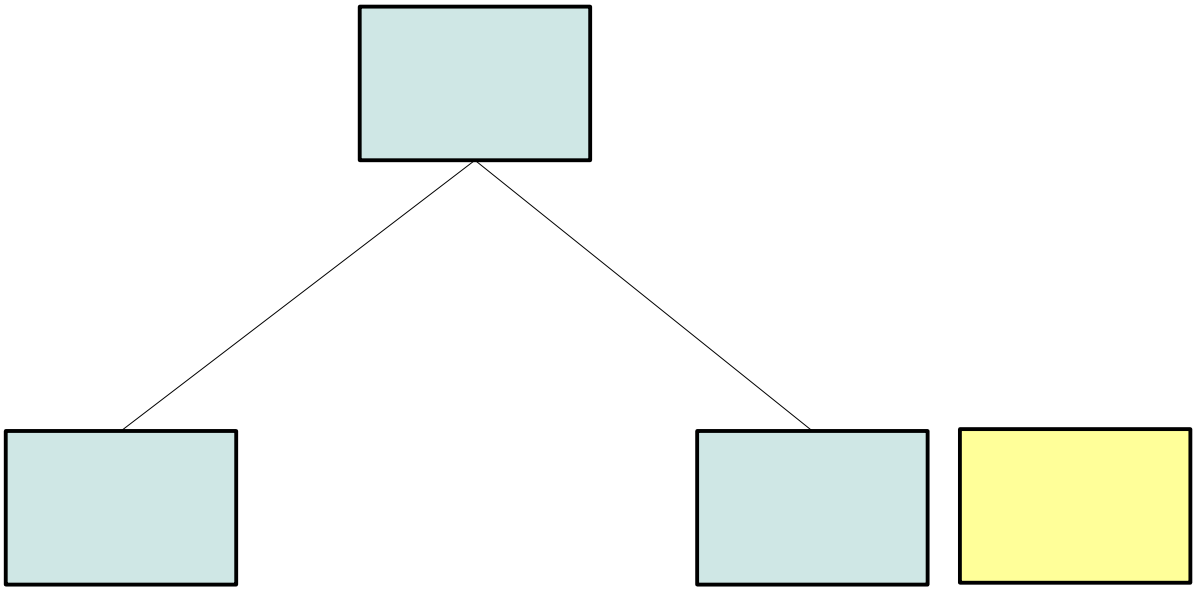
- How Append-Only/Copy-On-Write Works
  - In a pure append-only approach, no data is ever overwritten
  - Pages that are meant to be modified are copied
  - The modification is made on the copy
  - The copy is written to a new disk page
  - The structure is inherently multi-version; you can find any previous version of the database by starting at the root node corresponding to that version

B+tree Operation



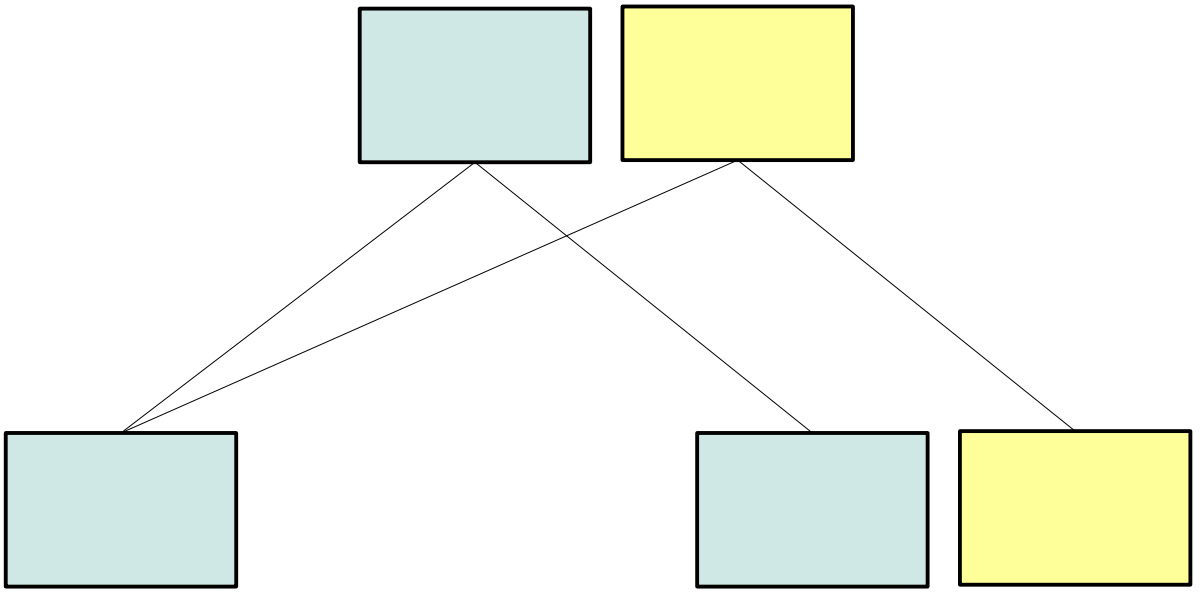
Start with a simple tree

B+tree Operation



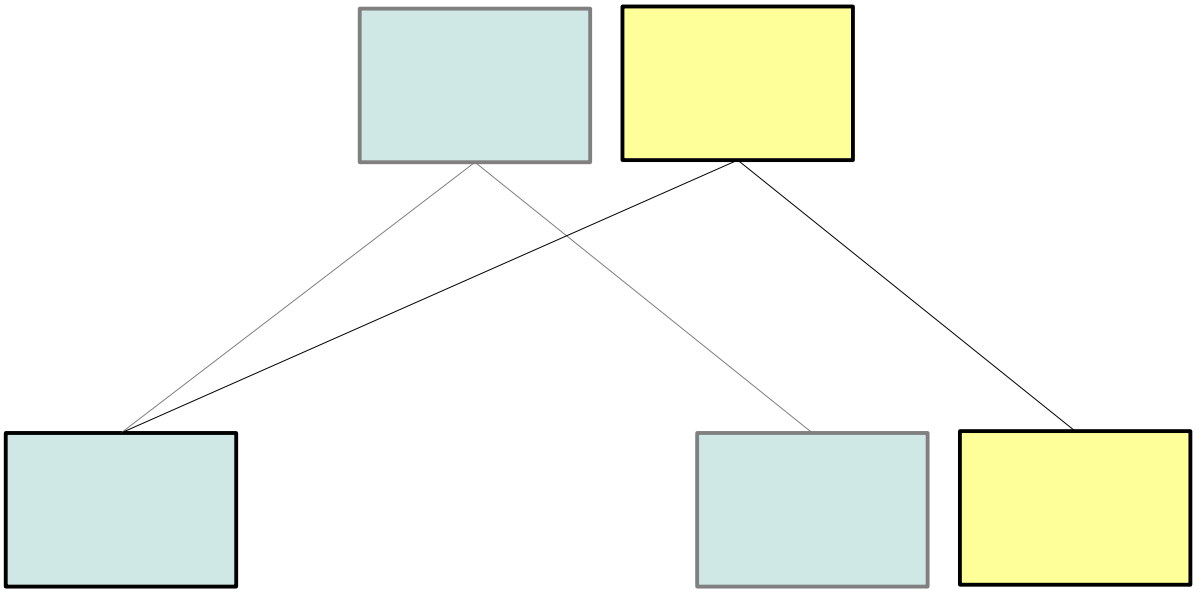
Update a leaf node by copying it and updating the copy

B+tree Operation



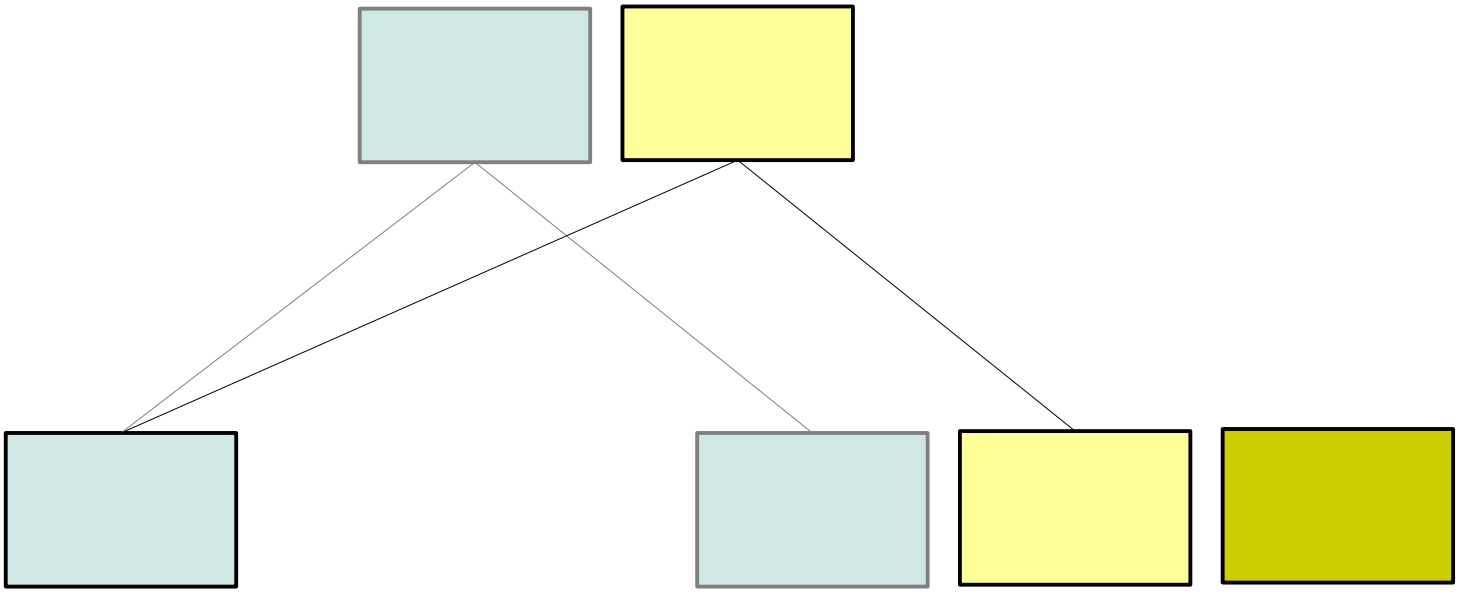
Copy the root node, and point it at the new leaf

B+tree Operation



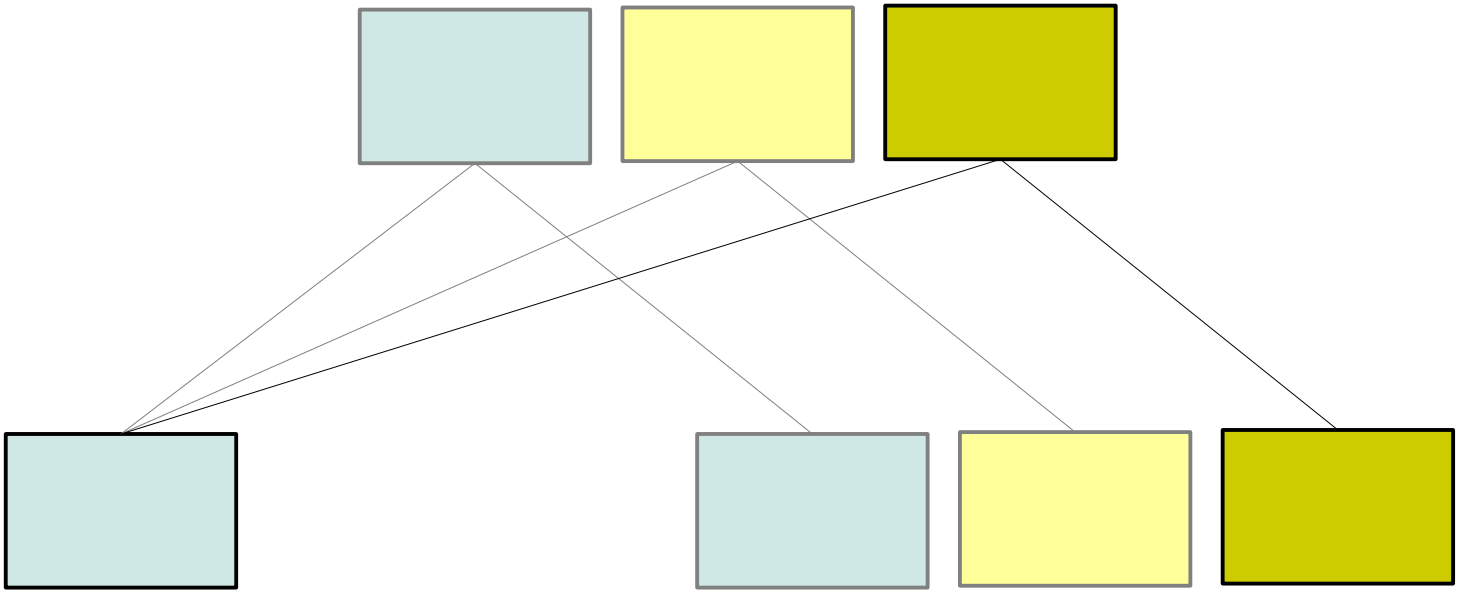
The old root and old leaf remain as a previous version of the tree

B+tree Operation

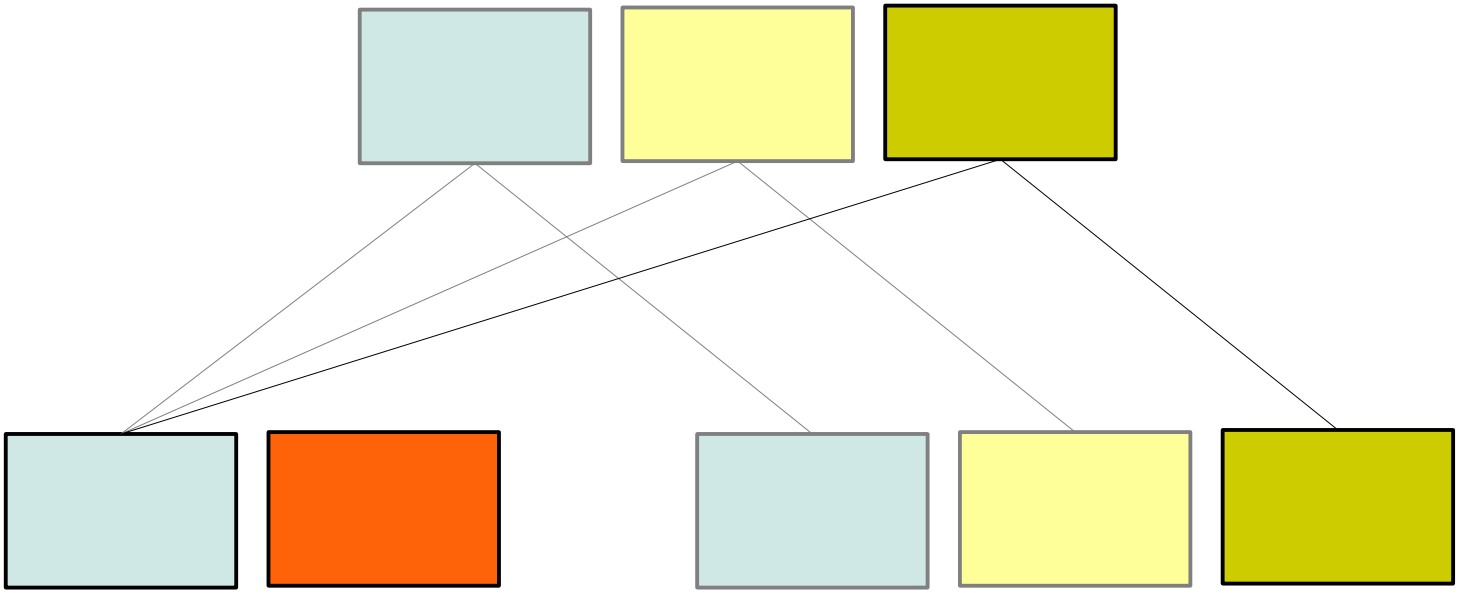


Further updates create additional versions

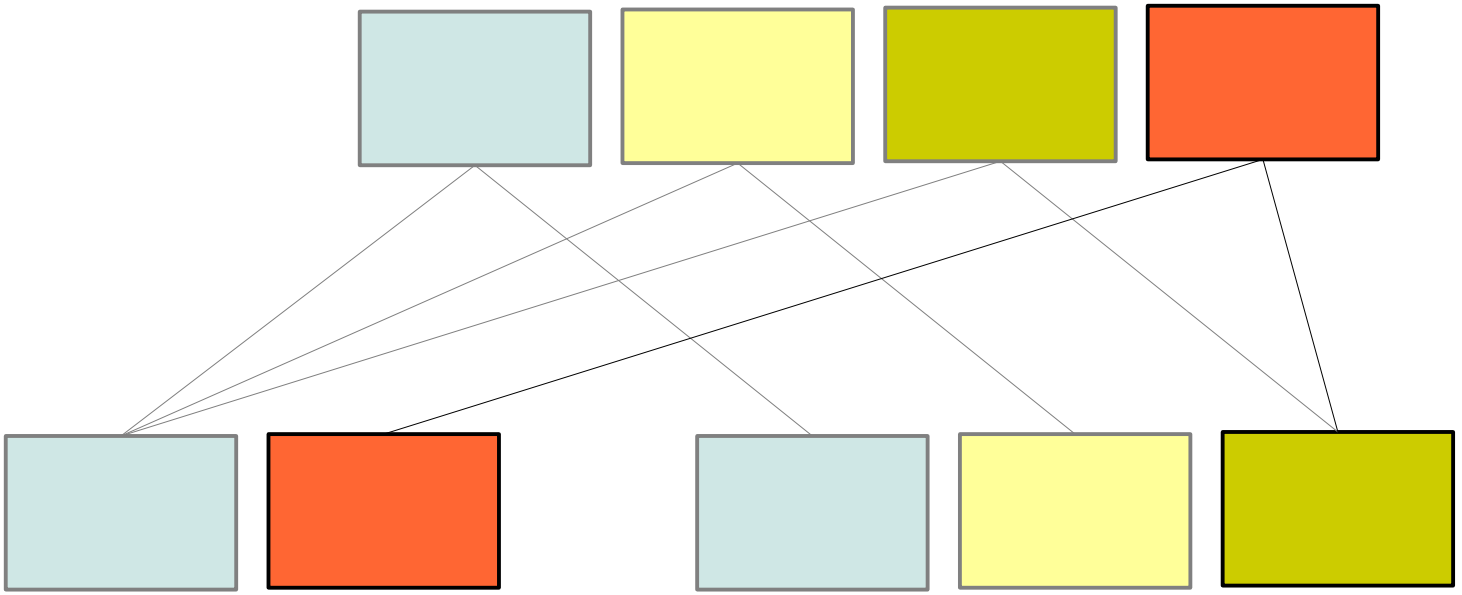
B+tree Operation



B+tree Operation



B+tree Operation



B+tree Operation

- How Append-Only/Copy-On-Write Works
  - Updates are always performed bottom up
  - Every branch node from the leaf to the root must be copied/modified for any leaf update
  - Any node not on the path from the leaf to the root is left unaltered
  - The root node is always written last

B+tree Operation

- In the Append-Only tree, new pages are always appended sequentially to the database file
  - While there's significant overhead for making complete copies of modified pages, the actual I/O is linear and relatively fast
  - The root node is always the last page of the file, unless there was a system crash
  - Any root node can be found by searching backward from the end of the file, and checking the page's header
  - Recovery from a system crash is relatively easy
    - Everything from the last valid root to the beginning of the file is always pristine
    - Anything between the end of the file and the last valid root is discarded

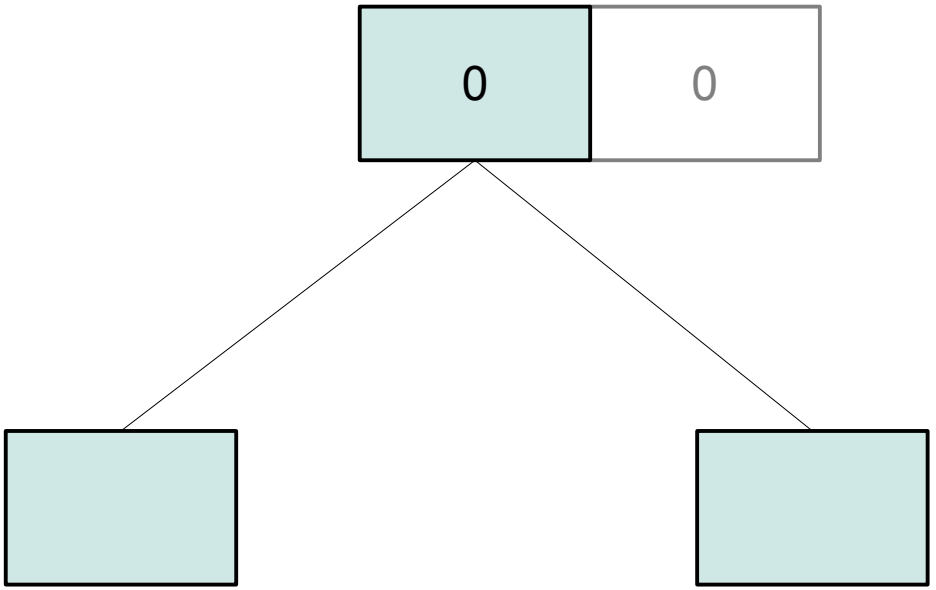
B+tree Operation

- Append-Only disk usage is very inefficient
  - Disk space usage grows without bound
  - 99+% of the space will be occupied by old versions of the data
  - The old versions are usually not interesting
  - Reclaiming the old space requires a very expensive compaction phase
  - New updates must be throttled until compaction completes

B+tree Operation

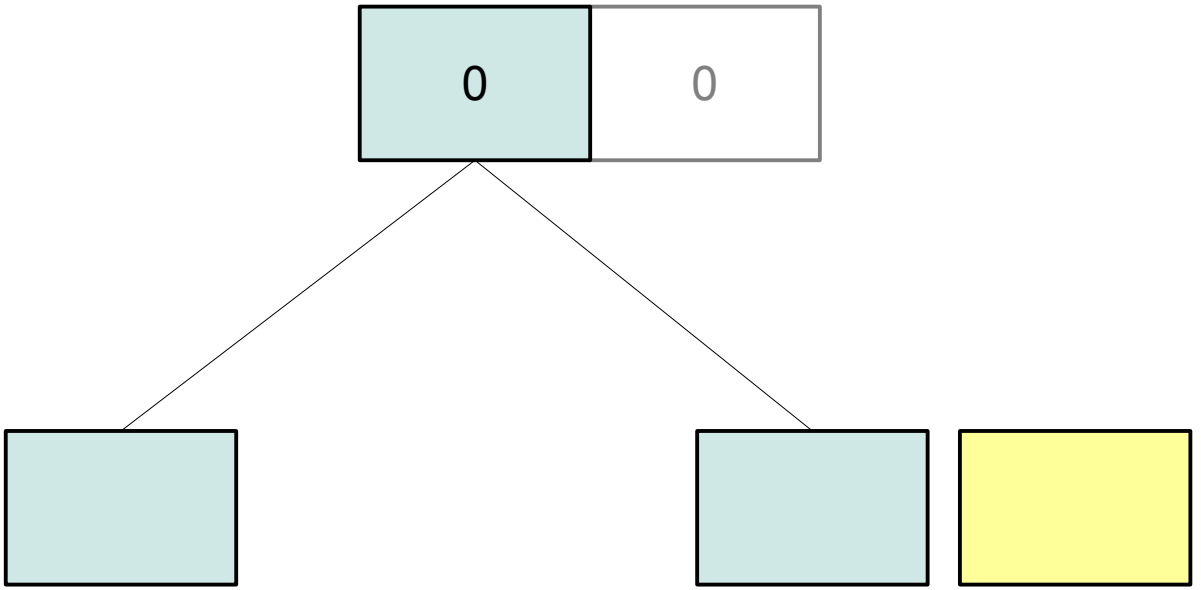
- The MDB Approach
  - Still Copy-on-Write, but using two fixed root nodes
    - Page 0 and Page 1 of the file, used in double-buffer fashion
    - Even faster cold-start than Append-Only, no searching needed to find the last valid root node
    - Any app always reads both pages and uses the one with the greater Transaction ID stamp in its header
    - Consequently, only 2 outstanding versions of the DB exist, not fully "multi-version"

B+tree Operation

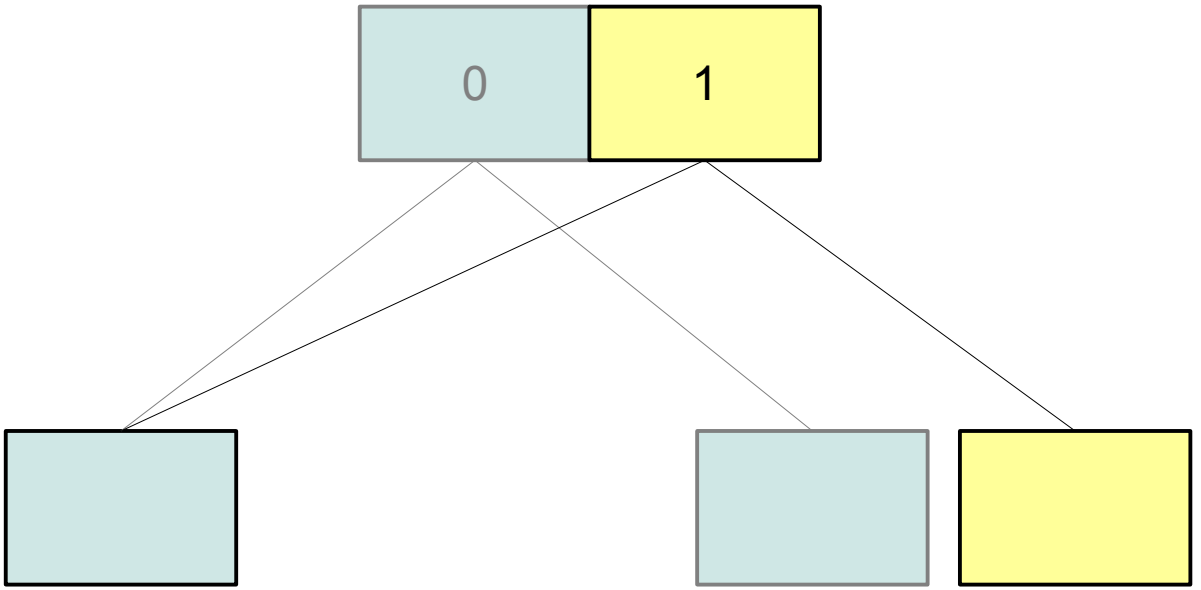


The root nodes have a transaction ID stamp

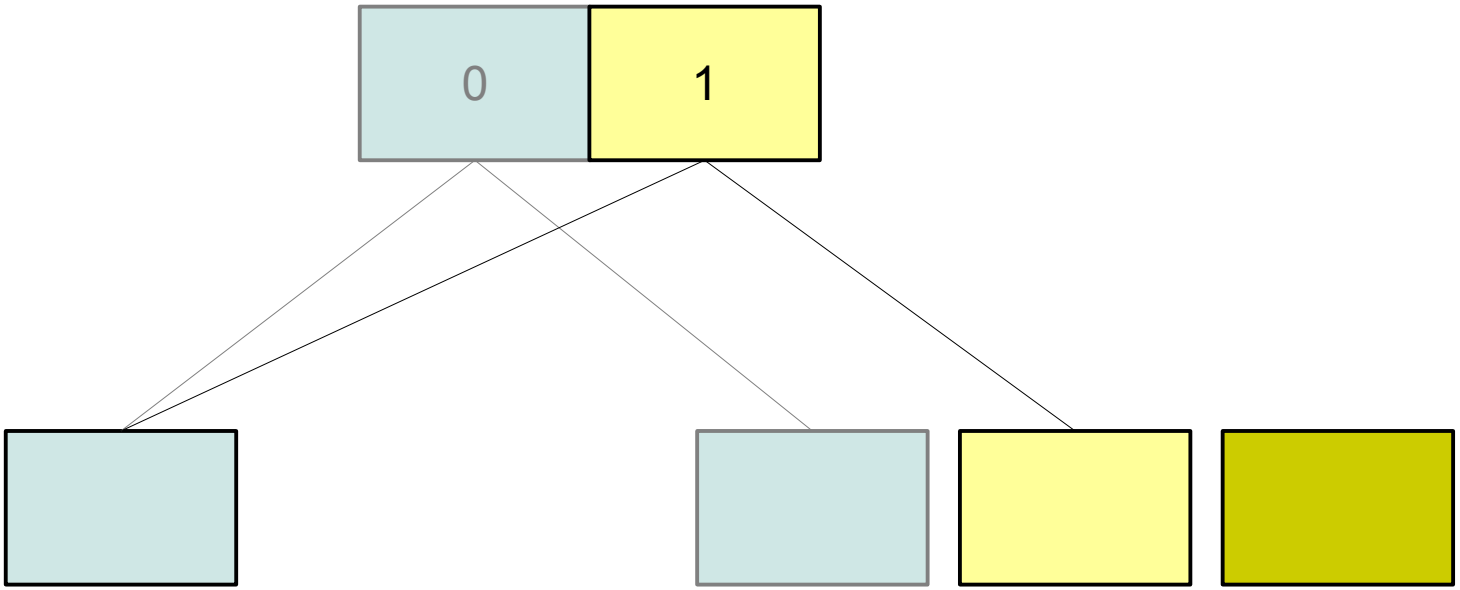
B+tree Operation



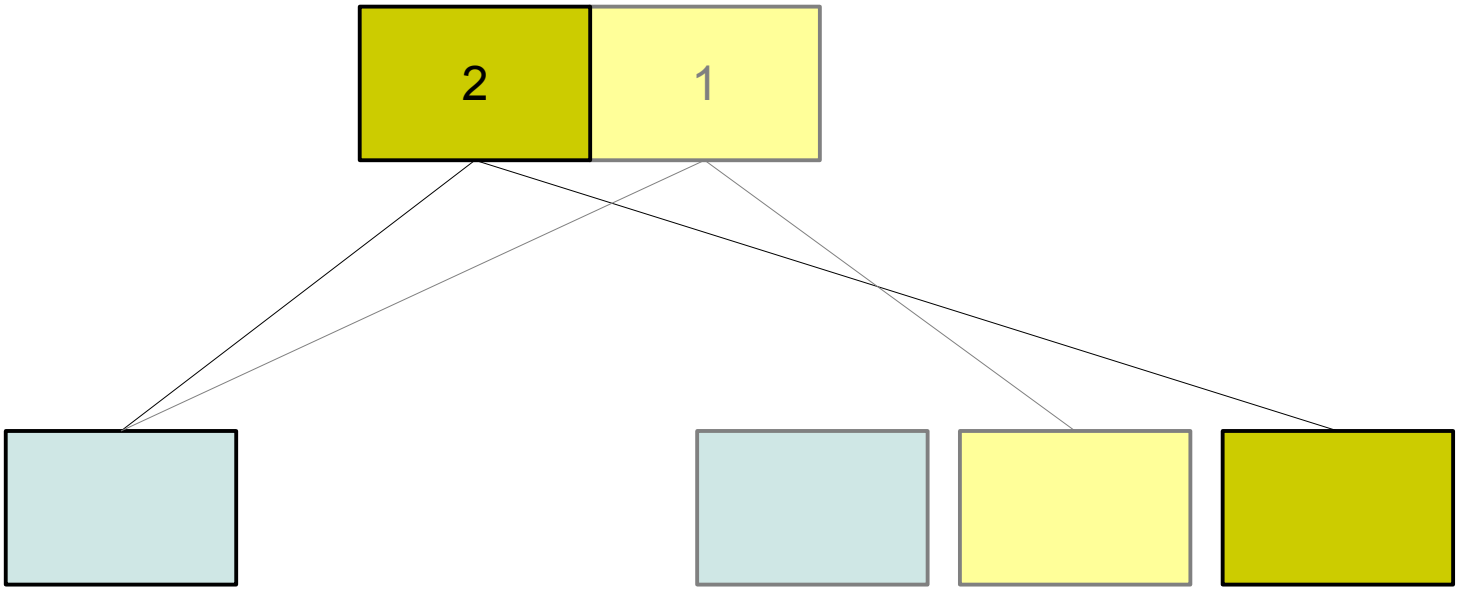
B+tree Operation



B+tree Operation

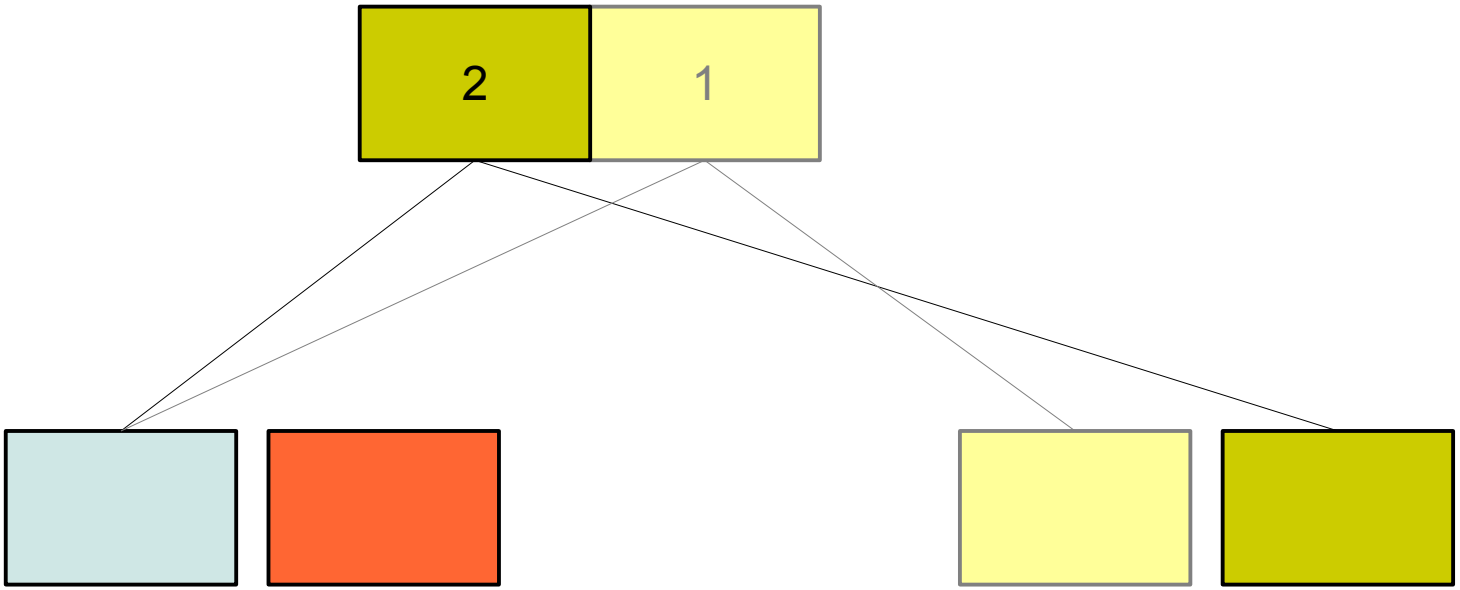


B+tree Operation

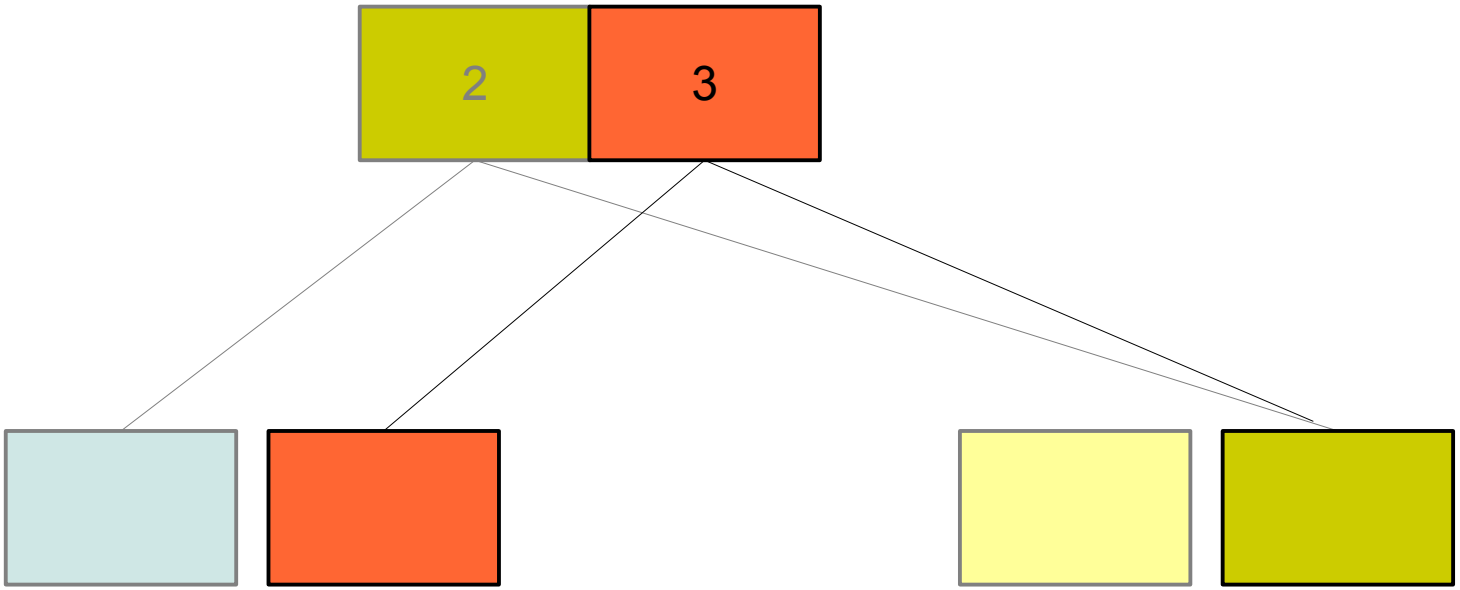


After this step the old blue page is no longer referenced by anything else in the database, so it can be reclaimed

B+tree Operation



B+tree Operation



After this step the old yellow page is no longer referenced by anything else in the database, so it can also be reclaimed

Free Space Management

- MDB maintains two B+trees per root node
  - One storing the user data, as illustrated above
  - One storing lists of IDs of pages that have been freed in a given transaction
  - Old, freed pages are used in preference to new pages, so the DB file size remains relatively static over time
  - No compaction or garbage collection phase is ever needed

Free Space Management

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

Free Space Management

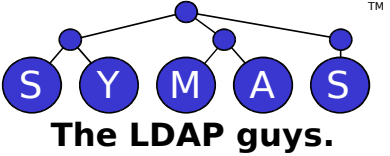
Meta Page	Meta Page	Data Page
Pgno: 0 Misc... TXN: 0 FRoot: EMPTY DRoot: EMPTY	Pgno: 1 Misc... TXN: 0 FRoot: EMPTY DRoot: EMPTY	Pgno: 2 Misc... offset: 4000 1,foo

Free Space Management

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

Free Space Management

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



Free Space Management

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

Free Space Management

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

Free Space Management

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

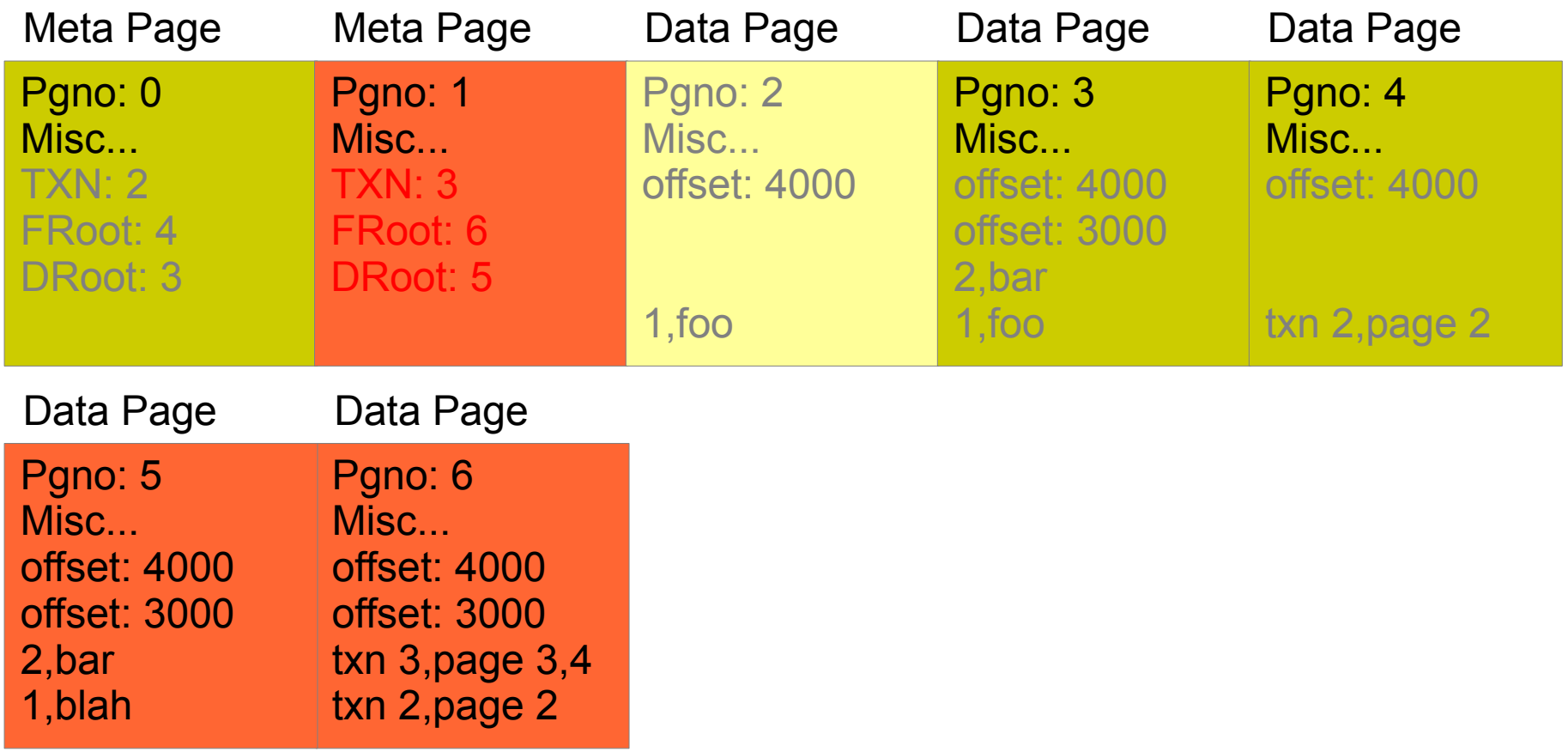
Pgno: 5
Misc...
offset: 4000
offset: 3000
2,bar
1,blah

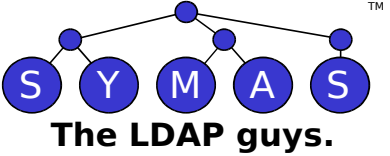
Free Space Management

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

Free Space Management



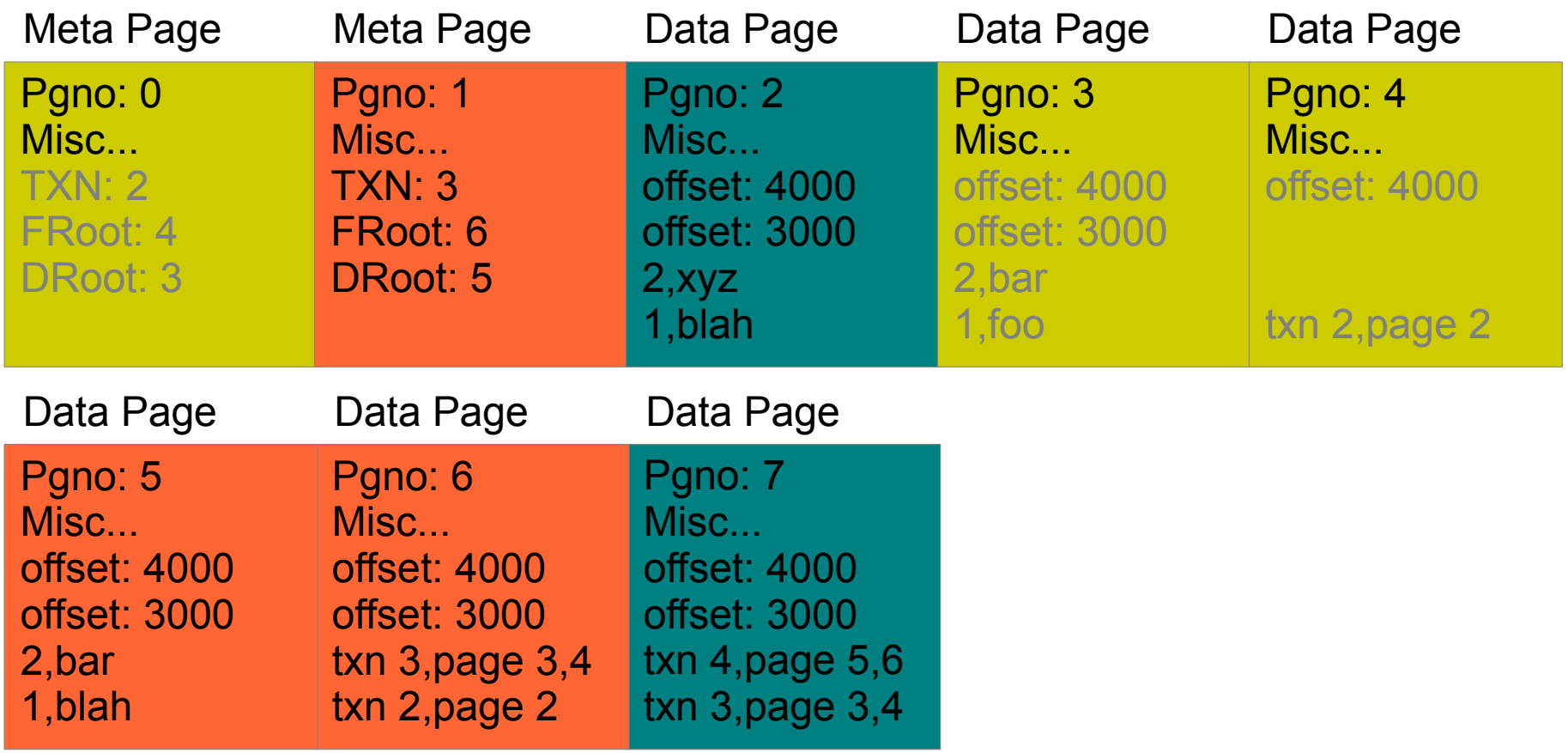


Free Space Management

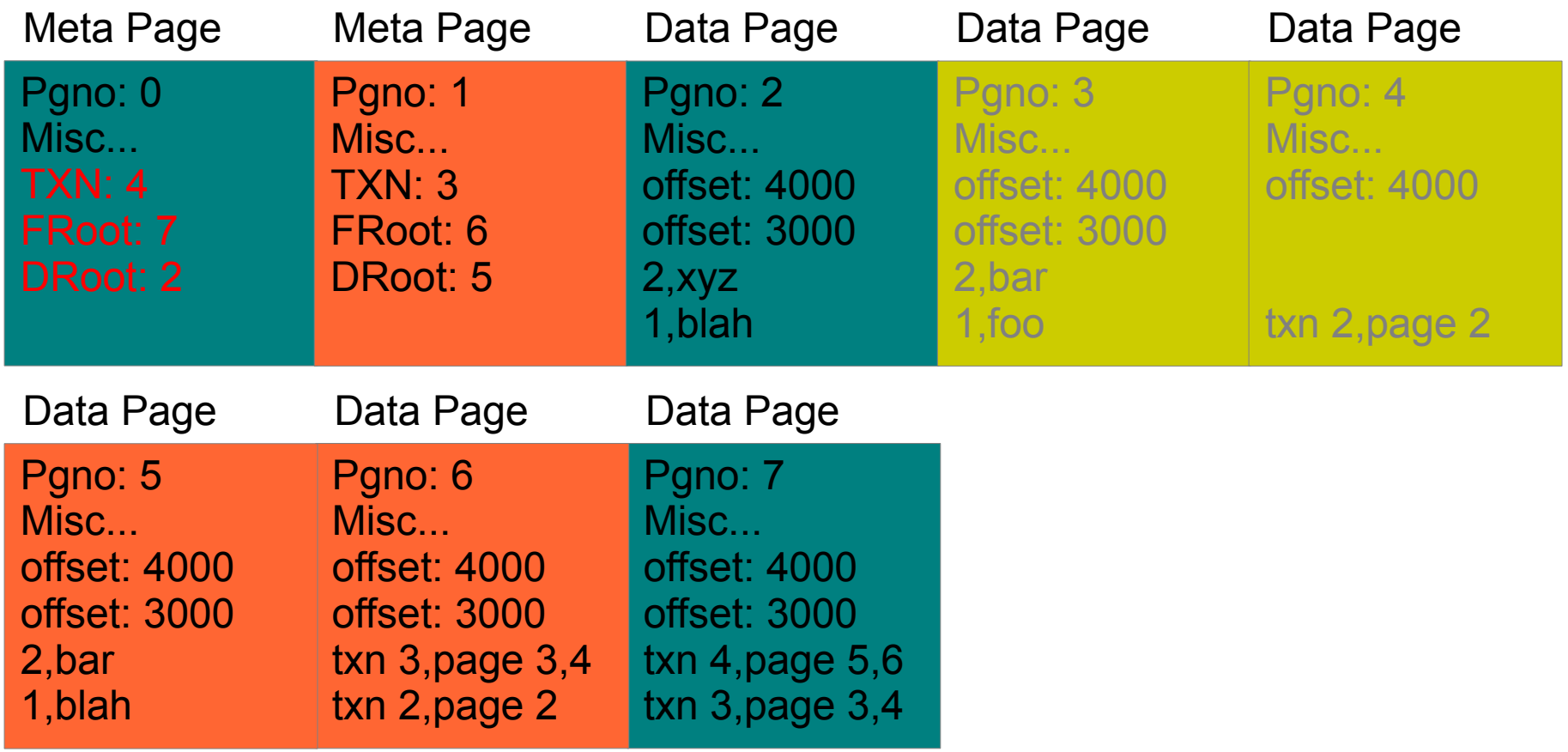
Meta Page	Meta Page	Data Page	Data Page	Data Page
Pgno: 0 Misc... TXN: 2 FRoot: 4 DRoot: 3	Pgno: 1 Misc... TXN: 3 FRoot: 6 DRoot: 5	Pgno: 2 Misc... offset: 4000 offset: 3000 2,xyz 1,blah	Pgno: 3 Misc... offset: 4000 offset: 3000 2,bar 1,foo	Pgno: 4 Misc... offset: 4000 txn 2,page 2

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

Free Space Management



Free Space Management



Free Space Management

- Caveat: If a read transaction is open on a particular version of the DB, that version and every version after it are excluded from page reclaiming
- Thus, long-lived read transactions should be avoided, otherwise the DB file size may grow rapidly, devolving into the Append-Only behavior until the transactions are closed

Transaction Handling

- MDB supports a single writer concurrent with many readers
  - A single mutex serializes all write transactions
  - The mutex is shared/multiprocess
- Readers run lockless and never block
  - But for page reclamation purposes, readers are tracked
- Transactions are stamped with an ID which is a monotonically increasing integer
  - The ID is only incremented for Write transactions that actually modify data
  - If a Write transaction is aborted, or committed with no changes, the same ID will be reused for the next Write transaction

Transaction Handling

- Transactions take a snapshot of the currently valid meta page at the beginning of the transaction
- No matter what write transactions follow, a read transaction's snapshot will always point to a valid version of the DB
- The snapshot is totally isolated from subsequent writes
- This provides the Consistency and Isolation in ACID semantics

Transaction Handling

- The currently valid meta page is chosen based on the greatest transaction ID in each meta page
  - The meta pages are page and CPU cache aligned
  - The transaction ID is a single machine word
  - The update of the transaction ID is atomic
  - Thus, the Atomicity semantics of transactions are guaranteed

Transaction Handling

- During Commit, the data pages are written and then synchronously flushed before the meta page is updated
  - Then the meta page is written synchronously
  - Thus, when a commit returns "success", it is guaranteed that the transaction has been written intact
  - This provides the Durability semantics
  - If the system crashes before the meta page is updated, then the data updates are irrelevant

Transaction Handling

- For tracking purposes, Readers must acquire a slot in the readers table
  - The readers table is also in a shared memory map, but separate from the main data map
  - This is a simple array recording the Process ID, Thread ID, and Transaction ID of the reader
  - The first time a thread opens a read transaction, it must acquire a mutex to reserve a slot in the table
  - The slot ID is stored in Thread Local Storage; subsequent read transactions performed by the thread need no further locks

Transaction Handling

- Write transactions use pages from the free list before allocating new disk pages
  - Pages in the free list are used in order, oldest transaction first
  - The readers table must be scanned to see if any reader is referencing an old transaction
  - The writer doesn't need to lock the reader table when performing this scan - readers never block writers
    - The only consequence of scanning with no locks is that the writer may see stale data
    - This is irrelevant, newer readers are of no concern; only the oldest readers matter

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
    - Reduces the danger of corruption that Berkeley databases were vulnerable to, when custom key comparators were used

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

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

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

Special Features

- Sub-databases
  - Store multiple independent named B+trees in a single MDB environment
  - A SubDB is simply a key/data pair in the main DB, where the data item is the root node of another tree
  - Allows many related databases to be managed easily
    - Used in back-mdb for the main data and all of the associated indices
    - Used in SQLightning for multiple tables and indices

Special Features

- Sorted Duplicates
  - Allows multiple data values for a single key
  - Values are stored in sorted order, with customizable comparison functions
  - When the data values are all of a fixed size, the values are stored contiguously, with no extra headers
    - maximizes storage efficiency and performance
  - Implemented by the same code as SubDB support
    - maximum coding efficiency

Special Features

- Atomic Hot Backup
  - The entire database can be backed up live
  - No need to stop updates while backups run
  - The backup runs at the maximum speed of the target storage medium
  - Essentially: write(outfd, map, mapsize);
    - no memcpy's in or out of user space
    - pure DMA from the database to the backup

Results

- Support for MDB is already available for many open source projects:
  - OpenLDAP slapd - back-mdb backend
  - Cyrus SASL - sasldb plugin
  - Heimdal Kerberos - hdb plugin
  - OpenDKIM - main data store
  - SQLite3 - replacing the original Btree code
  - MemcacheDB - replacing BerkeleyDB
  - Postfix - replacing BerkeleyDB

Results

- Coming Soon
  - Riak - Erlang MDB wrapper already available
  - SQLite4 - in progress
  - XDAndroid - port of Android using SQLite3 based on MDB

Results

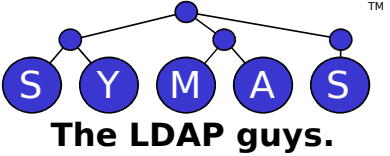
- In OpenLDAP slapd
  - MDB reads are 5-20x faster than BerkeleyDB
  - Writes are 2-5x faster than BerkeleyDB
  - Consumes 1/4 as much RAM as BerkeleyDB
- In SQLite3
  - Writes are 10-25x faster than stock SQLite3
  - Reads .. performance is overshadowed by SQL inefficiency

Results

- In MemcacheDB
  - MDB reads are 2-200x faster than BerkeleyDB
  - Writes are 5-900x faster than BerkeleyDB
  - Multi-thread reads are 2-8x faster than pure-memory Memcached
    - Single-thread reads are about the same
    - Writes are about 20% slower

Results

- Full benchmark reports are available on the MDB page
  - http://www.symas.com/mdb/
- Supported builds of MDB-based packages available from Symas
  - http://www.symas.com/
  - OpenLDAP, Cyrus-SASL, Heimdal Kerberos
  - MemcacheDB coming soon



Microbenchmark Results

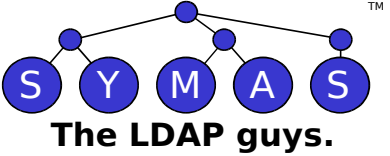
- Comparisons based on Google's LevelDB
- Also tested against Kyoto Cabinet's TreeDB, SQLite3, and BerkeleyDB
- Tested using RAM filesystem (tmpfs), reiserfs on SSD, and multiple filesystems on HDD
  - btrfs, ext2, ext3, ext4, jfs, ntfs, reiserfs, xfs, zfs
  - ext3, ext4, jfs, reiserfs, xfs also tested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

Microbenchmark Results

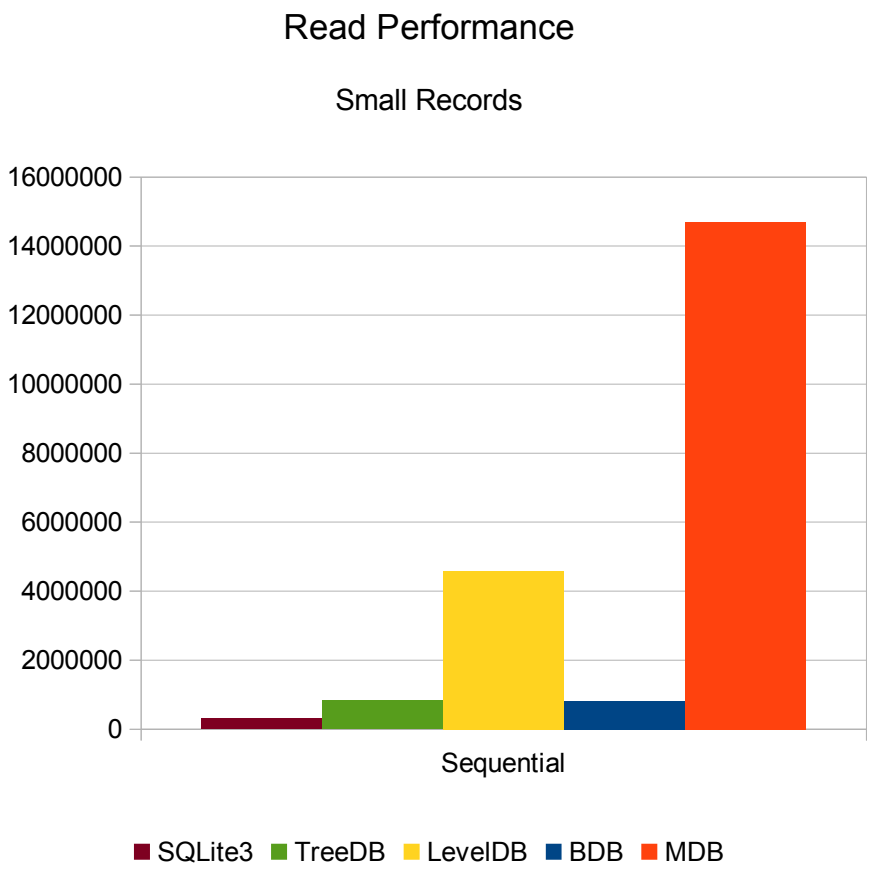
- Relative Footprint

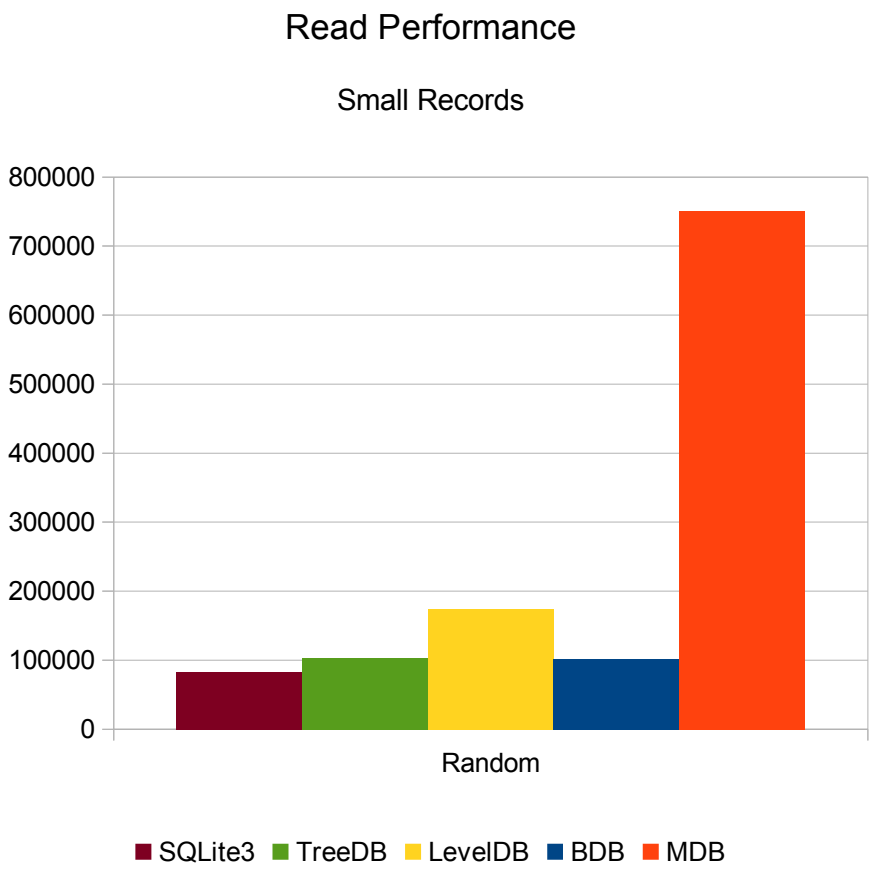
text	data	bss	dec	hex	filename
272247	1456	328	274031	42e6f	db_bench
1675911	2288	304	1678503	199ca7	db_bench_bdb
90423	1508	304	92235	1684b	db_bench_mdb
653480	7768	1688	662936	a2764	db_bench_sqlite3
296572	4808	1096	302476	49d8c	db_bench_tree_db

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



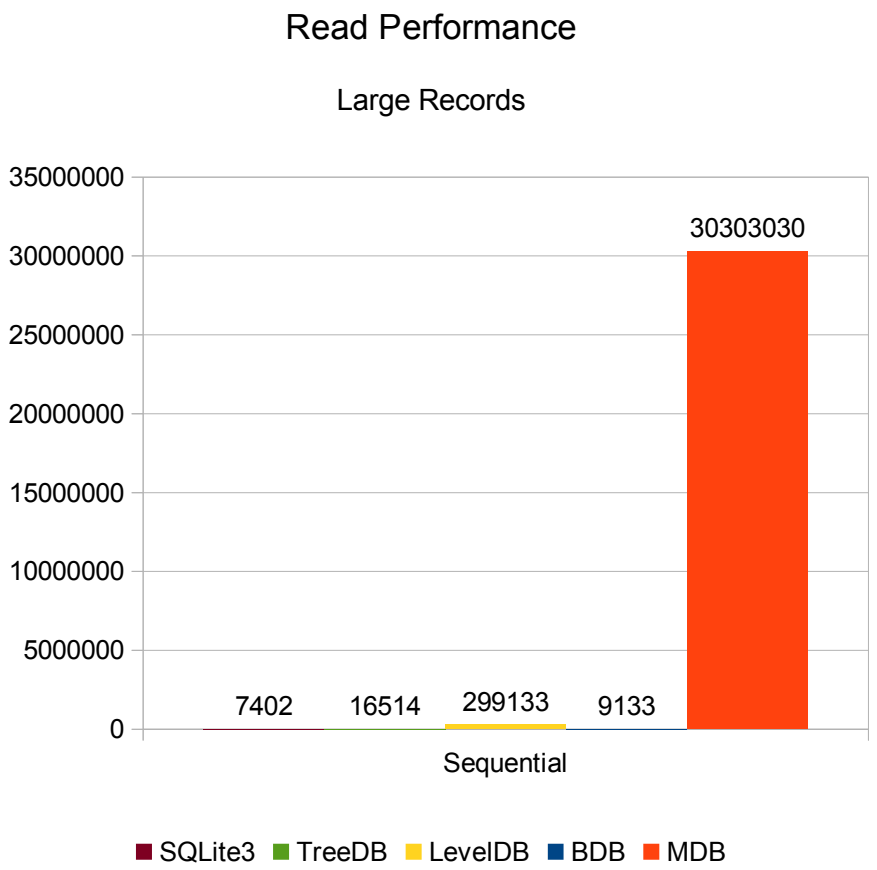
Microbenchmark Results

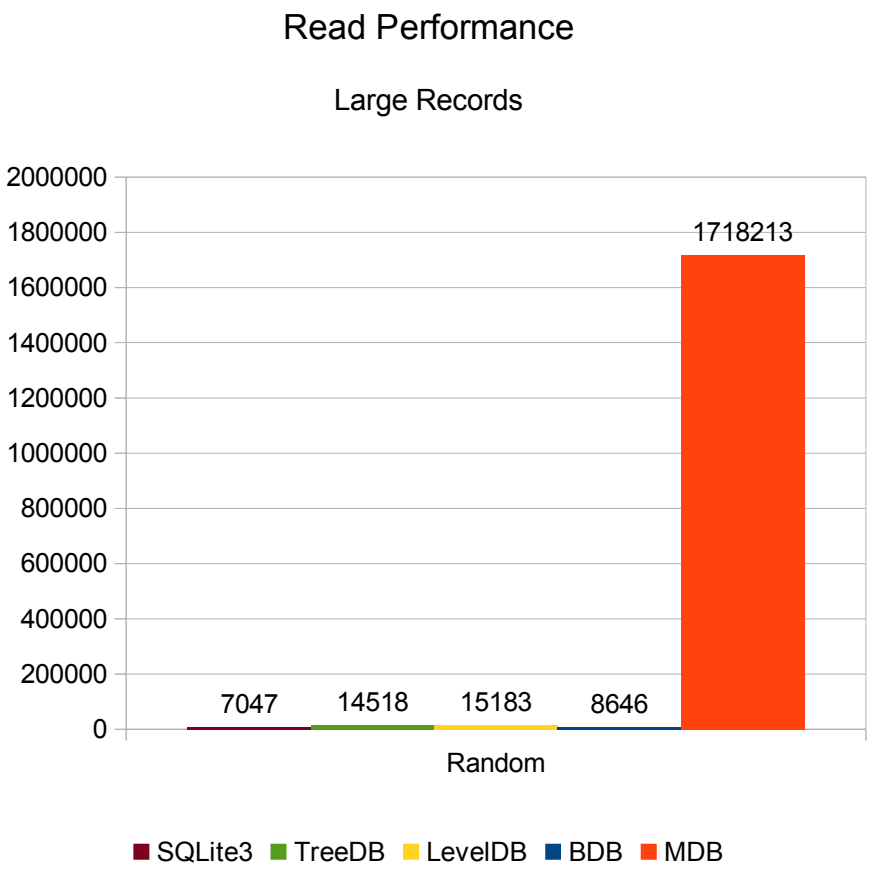




The LDAP guys.

Microbenchmark Results

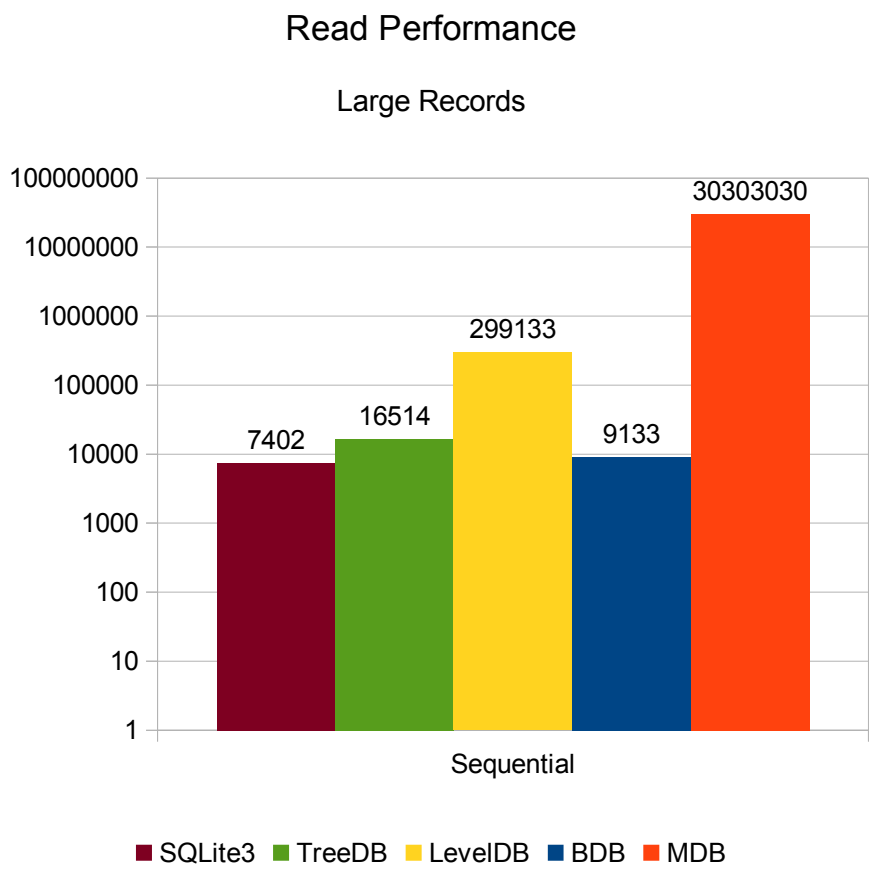


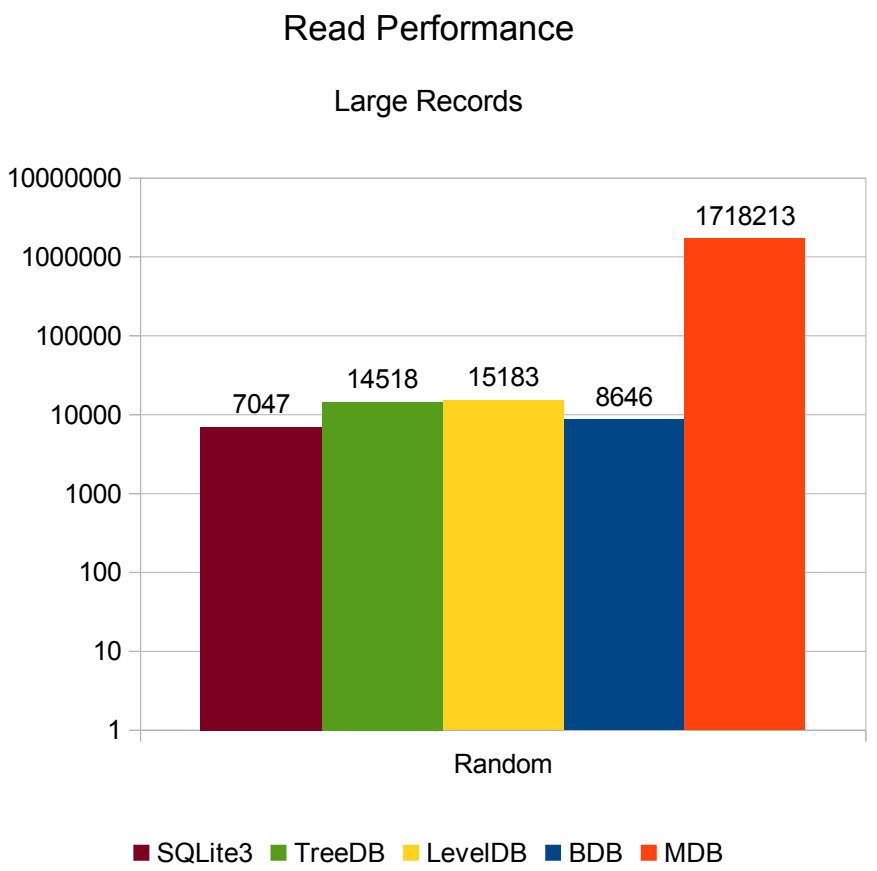


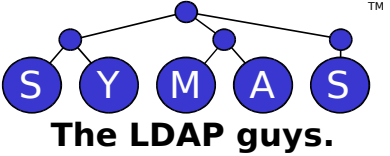
The LDAP guys.

Microbenchmark Results

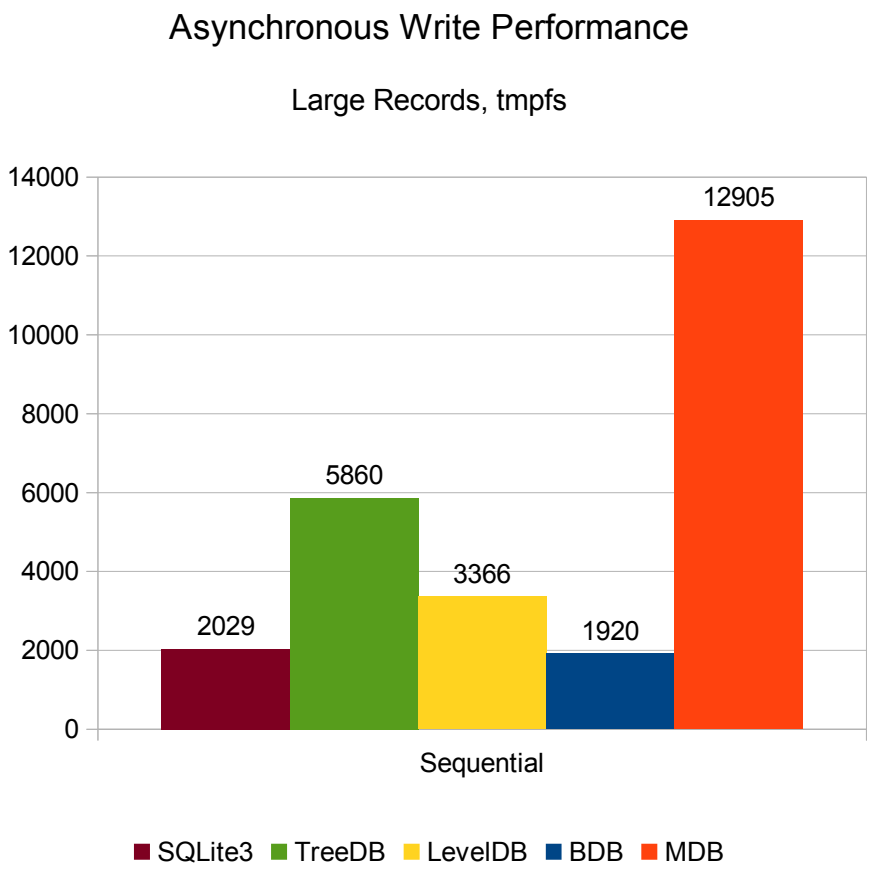
Log Scale

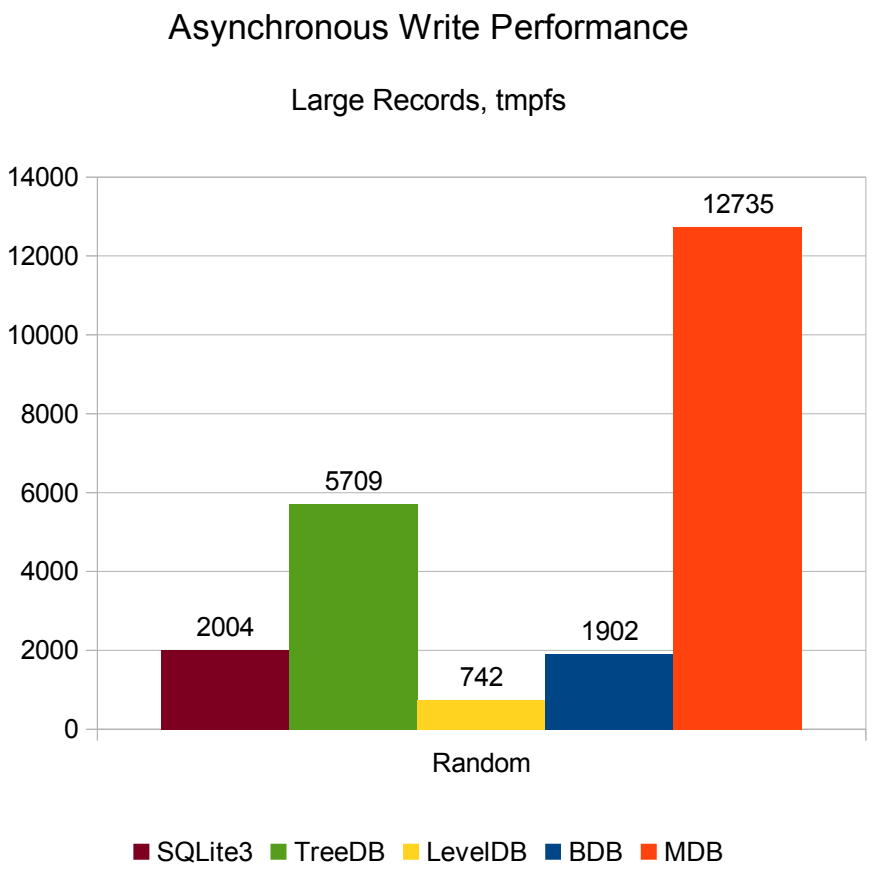


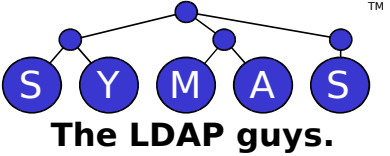




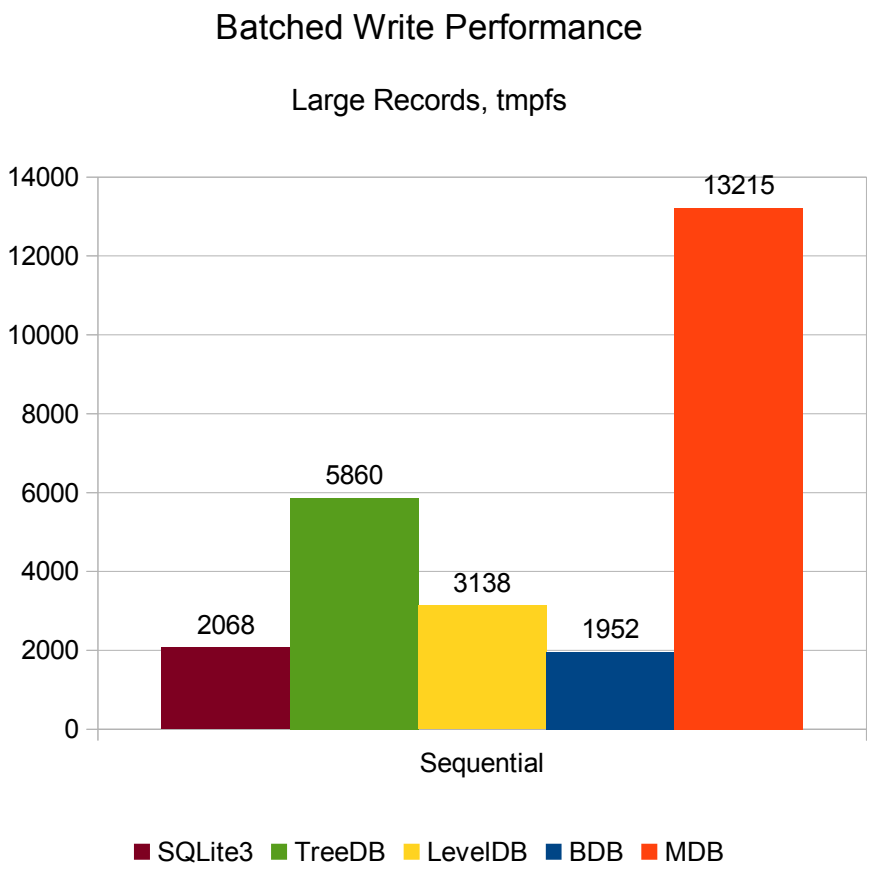
Microbenchmark Results

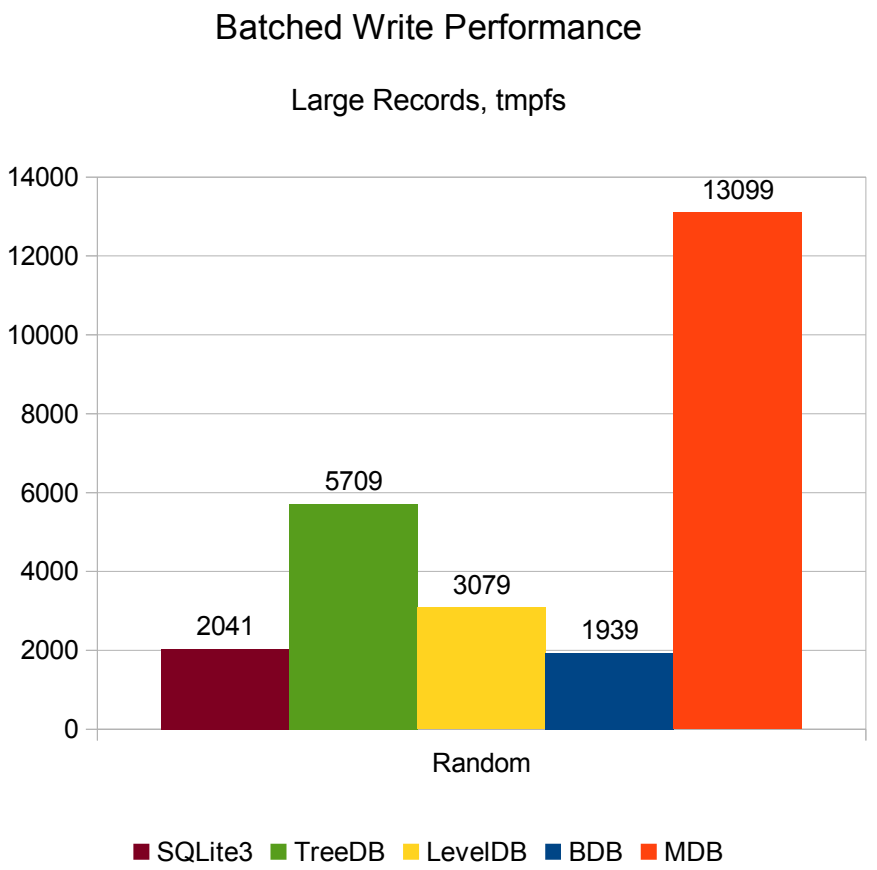


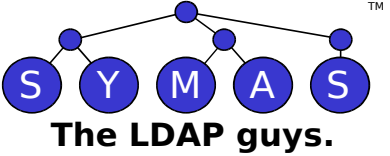




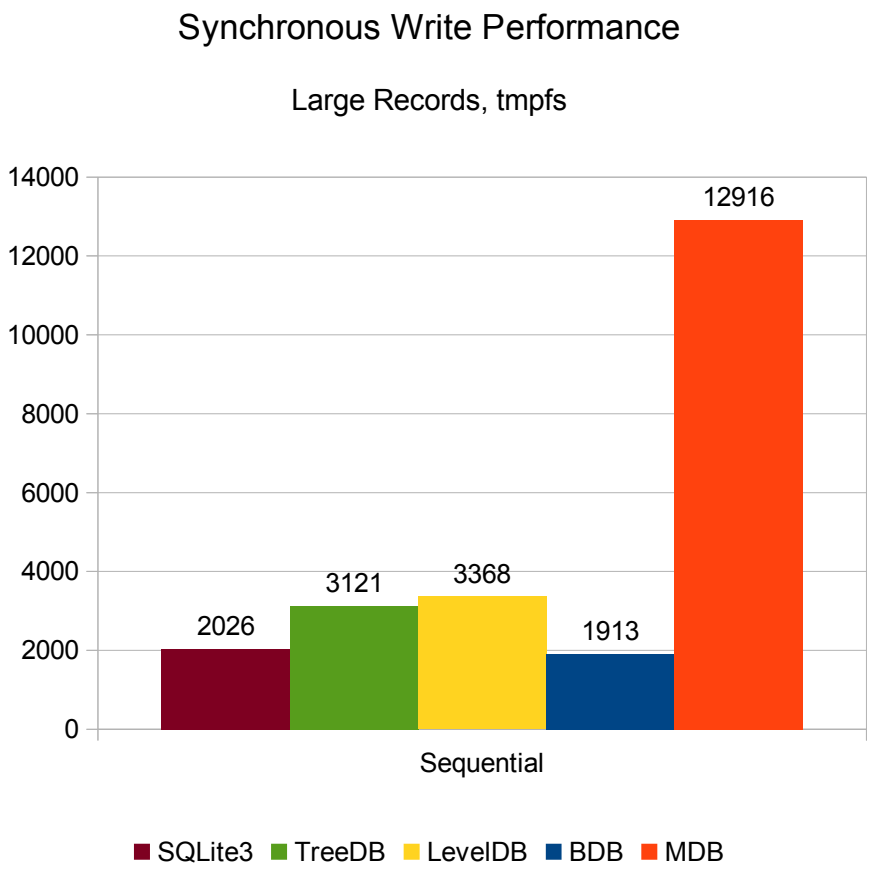
Microbenchmark Results

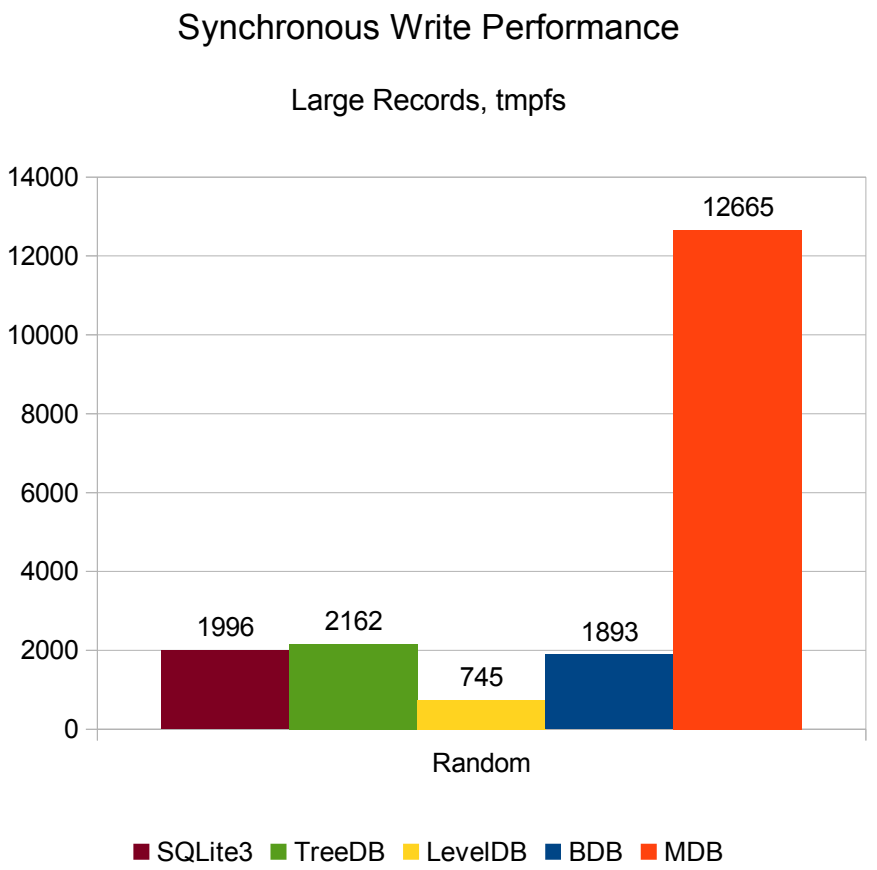






Microbenchmark Results



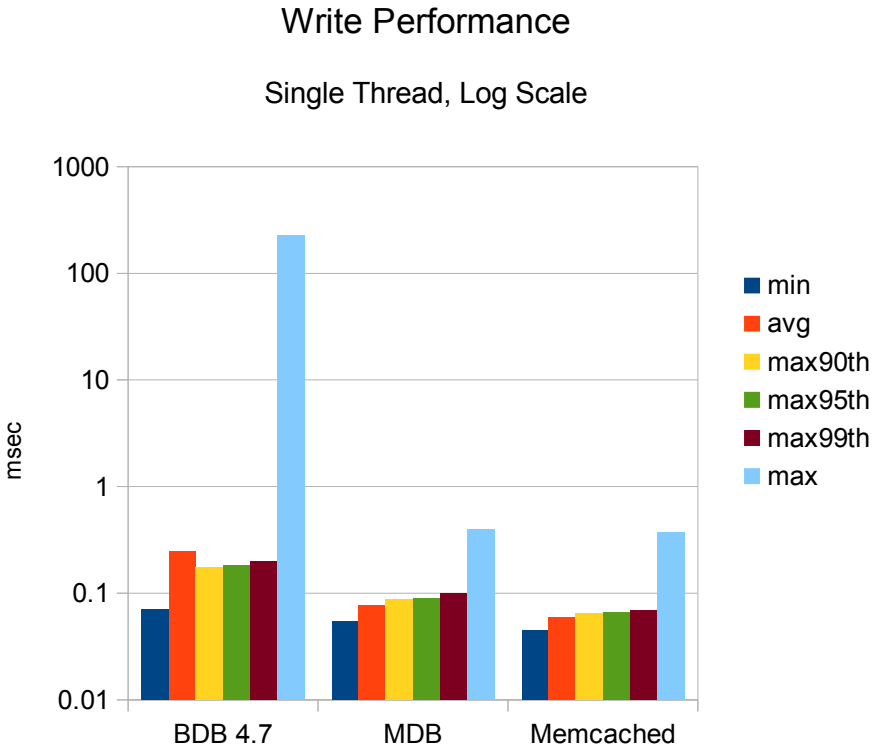


Benchmarking...

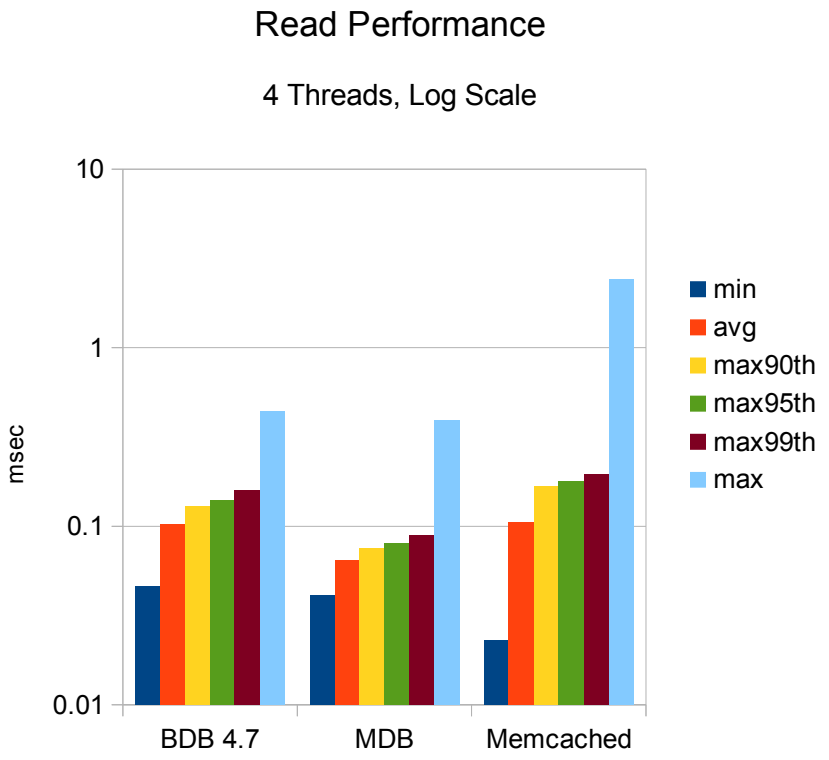
- MDB in real applications
  - MemcacheDB, tested with memcachetest
  - The OpenLDAP slapd server, using the back-mdb slapd backend

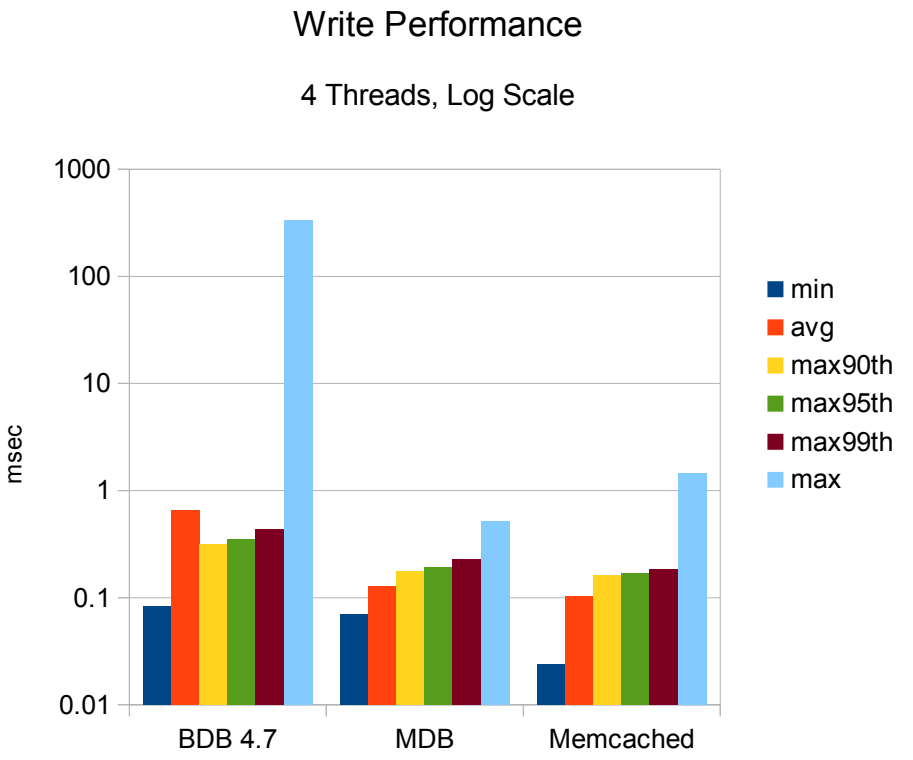
MemcacheDB


Read Performance
Single Thread, Log Scale
msec
100
10
1
0.1
0.01
BDB 4.7
MDB
Memcached
min
avg
max90th
max95th
max99th
max


Write Performance
Single Thread, Log Scale
msec
1000
100
10
1
0.1
0.01
BDB 4.7
MDB
Memcached
min
avg
max90th
max95th
max99th
max

MemcacheDB


Read Performance
4 Threads, Log Scale
msec
10
1
0.1
0.01
BDB 4.7
MDB
Memcached
min
avg
max90th
max95th
max99th
max


Write Performance
4 Threads, Log Scale
msec
1000
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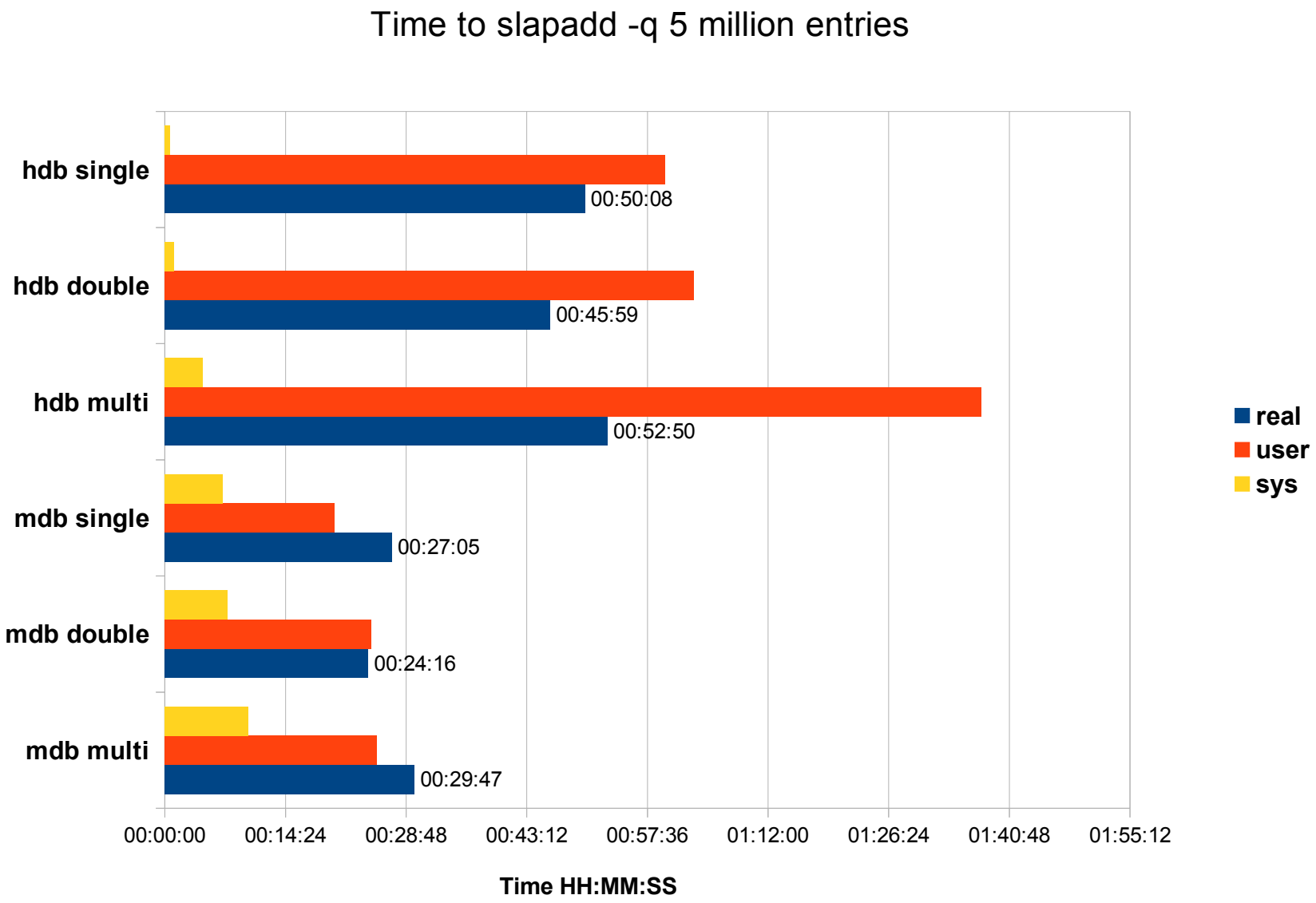
0.1
0.01
BDB 4.7
MDB
Memcached
min
avg
max90th
max95th
max99th
max

The LDAP guys.

Slapd Results



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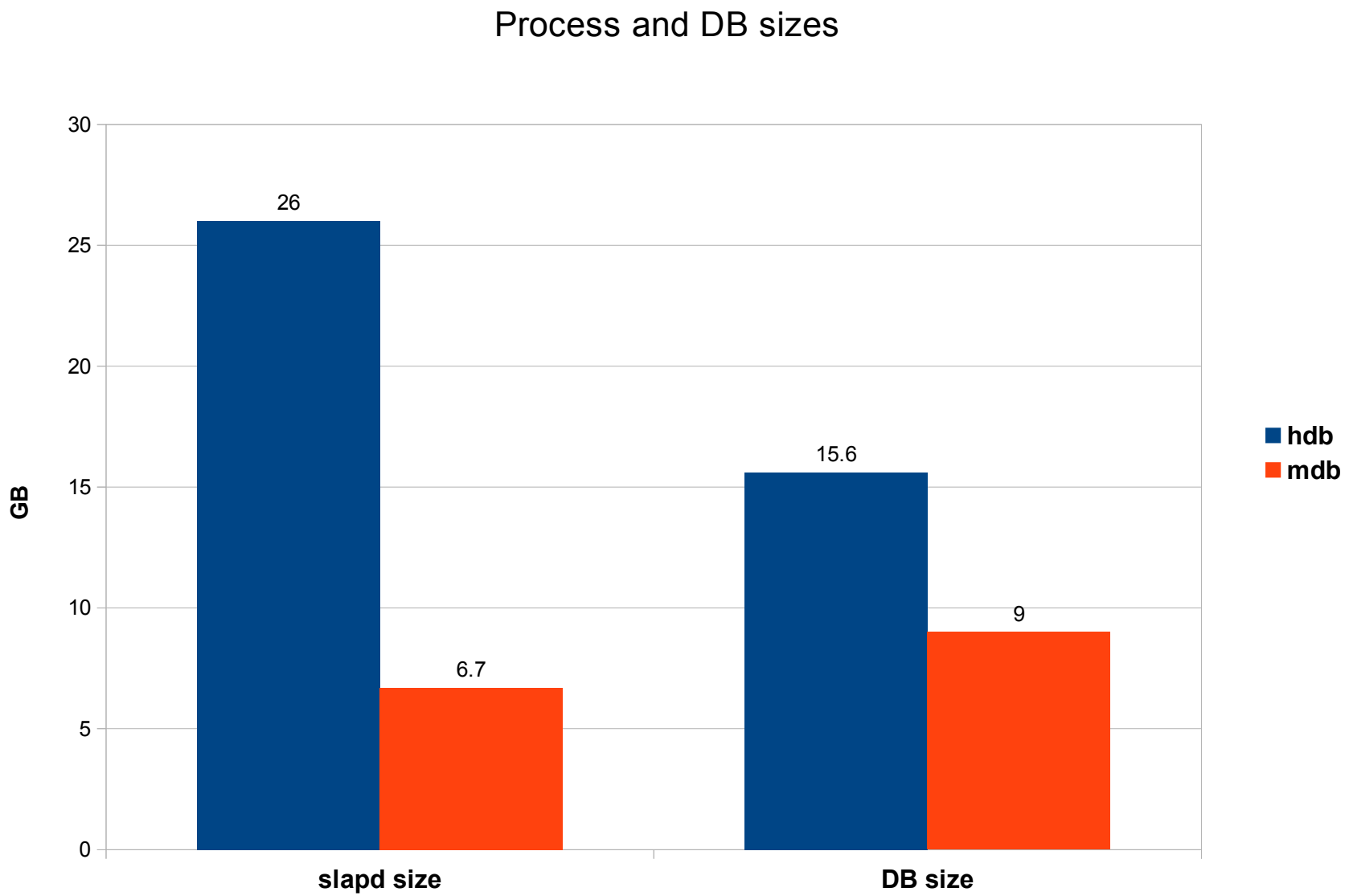
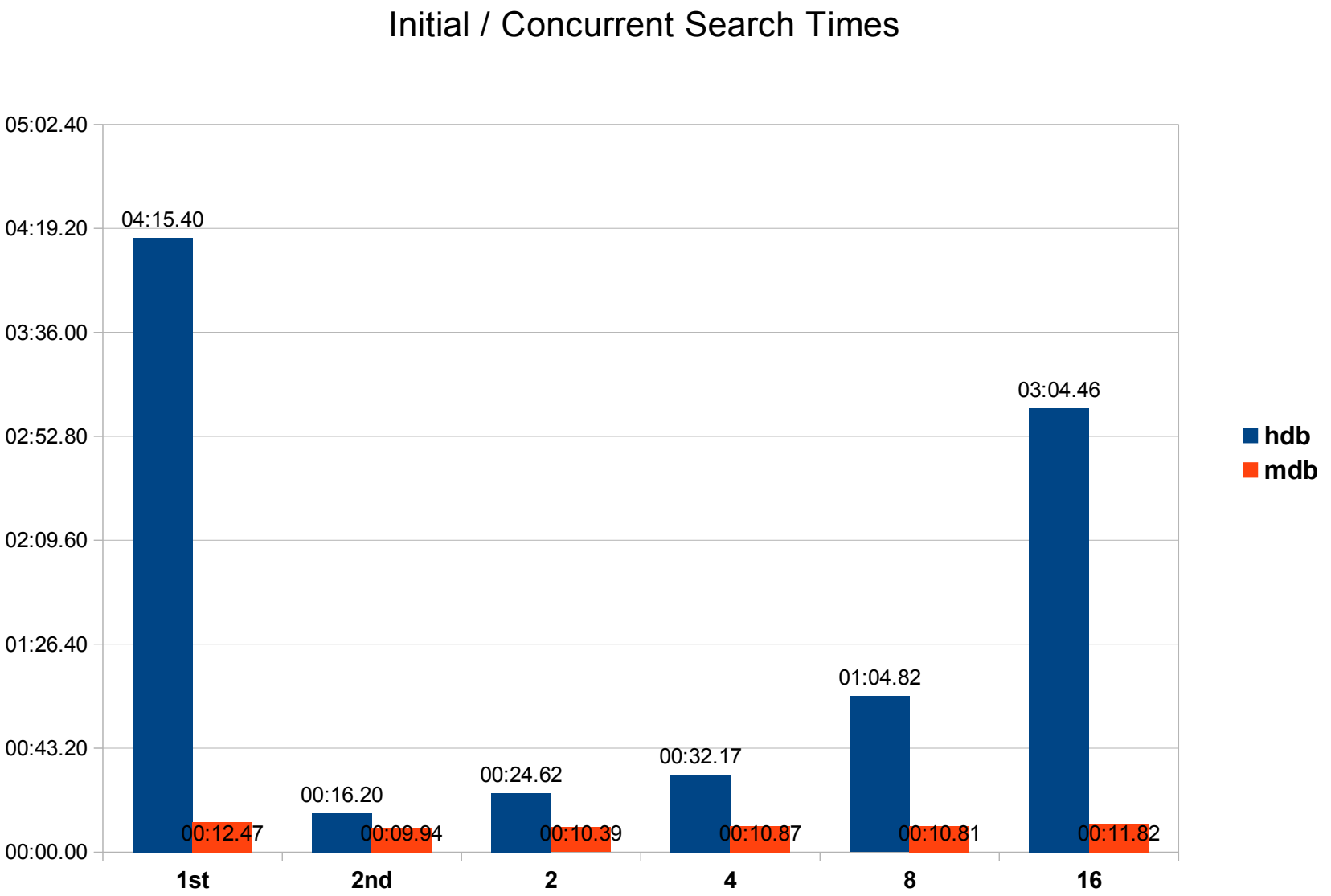
Slapd Results



SYMAS™
The LDAP guys.

Slapd Results



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Slapd Results