PERCONA

Innodb and XtraDB Architecture and Performance Optimization

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Architecture and Performance

- Advanced Performance Optimization requires transparency/X-ray Vision
- Impossible without understanding system architecture
- Focus on Conceptual Aspects
  - Exact Checksum algorithm Innodb uses is not important
  - What matters
    - How fast is that algorithm ?
    - How checksums are checked/updated

Aspects or Architecture

- General Architecture
- Storage and File Layout
- Threads
- Memory
- Disk IO
- Indexes
- Multi Versioning
- Row Locking and Latching

Aspects of Architecture 2

- Page flushing and Replacement
- Insert Buffering
- Adaptive Hash Index
- BLOB Storage
- Recovery
- Compression Features
- Foreign Keys

Innodb Versions

- MySQL 5.1 and below
  - Lots of limits. Poor Scalability.
- Innodb Plugin for MySQL 5.1 (1.0.x)
  - Scales Better, Fast index creation, Compression
- MySQL 5.5 (version 1.1.x) Current GA
  - Scalability further imroved
- MySQL 5.6 (current Beta)
  - Further improvements in Scalability
  - Full Text Search, fast checksums etc.

XtraDB

- Follows MySQL/Innodb Versions
- Included in Percona Server and MariaDB
  - No more available as separate plugin
- Includes all Innodb features and improvements plus more
- Percona Server 5.5 is latest GA version
- No release is made for MySQL 5.6 yet

General Architecture

- Traditional OLTP Engine
  - “Emulates Oracle Architecture”
- Implemented using MySQL Storage engine API
- Row Based Storage. Row Locking. MVCC
- Data Stored in Tablespaces
- Log of changes stored in circular log files
- Data pages as pages in “Buffer Pool”

Storage Files Layout

Physical Structure of Innodb Tabespaces and Logs

Innodb Tablespaces

- All data stored in Tablespaces
  - Changes to these databases stored in Circular Logs
  - Changes has to be reflected in tablespace before log record is overwritten
- Single tablespace or multiple tablespace
  - **innodb_file_per_table=1**
- System information always in main tablespace
  - Main tablespace can consist of many files
    - They are concatenated

Tablespace Format

- Collection of Segments
  - Segment is like a “file”
- Segment is number of extents
  - Typically 64 of 16K page sizes
  - Smaller extents for very small objects
- First Tablespace page contains header
  - Tablespace size
  - Tablespace id

Types of Segments

- Each table is Set of Indexes
  - Innodb has “index organized tables”
- Each index has
  - Leaf node segment
  - Non Leaf node segment
- Special Segments
  - Rollback Segment(s)
  - Insert buffer, etc

Innodb Space Allocation

- Small Segments (less than 32 pages) – by page
- Large Segments
  - Extent at the time (to avoid fragmentation)
- Free pages recycled within same segment
- All pages in extent must be free before it is used in different segment of same tablespace
  - **innodb_file_per_table=1** - free space can be used by same table only
- Innodb never shrinks its tablespaces

Innodb Log Files

- Set of log files (ib_logfile?)
  - 2 log files by default. Effectively concatenated
- Log Header
  - Stores information about last checkpoint
- Log is NOT organized in pages, but records
  - Records aligned 512 bytes, matching disk sector
- Log record format “physiological”
  - Stores Page# and operation to do on it
- Only REDO operations are stored in logs.

More on Log Files

- Total log file size Is limited to 4GB
  - In Percona Server and MySQL 5.6 this limit is removed
- Percona Server allows different log file block size
  - **innodb_log_block_size**
- If you're using compressed pages full pages can be logged to log file.
- Dramatic Recovery time improvement in Innodb Plugin and MySQL 5.5+
  - Can safely use longer log files than before

Storage Tuning Parameters

- **innodb_file_per_table**
  - Store each table in its own file/tablespace
- **innodb_autoextend_increment**
  - Extend **system** tablespace in this increment
- **innodb_log_file_size**
- **innodb_log_files_in_group**
  - Log file configuration
- **innodb_page_size**
  - Percona Server and MySQL 5.6 only

Using File per Table

- Typically more convenient
- Reclaim space from dropped table
- **ALTER TABLE ENGINE=INNODB**
  - reduce file size after data was deleted
- Store different tables/databases on different drives
- Backup/Restore tables one by one
- Support for compression in Innodb Plugin/XtraDB
- Will use more space with many tables
- Longer unclean restart time with many tables

Performance and Innodb File Per Table

- Performance is Similar in majority of cases
- Very large number of tables is a problem
- Can help with i-node level locking on some filesystems
  - EXT3

Drop Table with innodb_file_per_table

- Dropping the tablespace is expensive operation in Innodb
  - And gets slower the more memory you have
  - Drop operation have to scan buffer pool and remove all pages
  - It is done while holding the lock, essentially blocking server
  - See http://bugs.mysql.com/bug.php?id=51325
- Option in XtraDB
  - **innodb_lazy_drop_table=1**

Dealing with Run-away tablespace

- Main Tablespace does not shrink
  - Consider setting max size
  - **innodb_data_file_path=ibdata1:10M:autoextend:max:10G**
- Dump and Restore
- Export tables with XtraBackup
  - And import them into “clean” server
  - http://www.mysqlperformanceblog.com/2009/06/08/impossible-possible-moving-innodb-tables-between-servers/

Separate Undo Tablespace

- MySQL 5.6 allows to store unto tablespace in separate set of files
  - **innodb_undo_directory**
  - **innodb_undo_tablespaces**
  - **innodb_undo_logs**
- Note once you enable these options you can't downgrade
- Offers another flexibility of using fast storage (such as SSD)

Resizing Log Files

- You can't simply change log file size in my.cnf
  - InnoDB: Error: log file ./ib_logfile0 is of different size 0 5242880 bytes
  - InnoDB: than specified in the .cnf file 0 52428800 bytes
- Stop MySQL (make sure it is clean shutdow)
- Rename (or delete) ib_logfile*
- Start MySQL with new log file settings
  - It will create new set of log files

Innodb Threads Architecture

What threads are there and what they do

General Thread Architecture

- Using MySQL Threads for execution
  - Normally thread per connection
- Transaction executed mainly by such thread
  - Little benefit from Multi-Core for single query
- **innodb_thread_concurrency** can be used to limit number of executing threads
  - Reduce contention
- This limit is number of threads in kernel
  - Including threads doing Disk IO or storing data in TMP Table.

Helper Threads

- Main Thread
  - – Schedules activities – flush, purge, checkpoint, insert buffer merge
- IO Threads
  - – Read – multiple threads used for read ahead
  - – Write – multiple threads used for background writes
  - – Insert Buffer thread used for Insert buffer merge
  - – Log Thread used for flushing the log
- Purge thread(s) (MySQL 5.5 and XtraDB)
- Deadlock detection thread & Others

Memory Handling

How Innodb Allocates and Manages Memory

Innodb Memory Allocation

- Take a look at **SHOW INNODB STATUS**
  - XtraDB has more details

```
Total memory allocated 1100480512; in additional pool allocated 0
Internal hash tables (constant factor + variable factor)
    Adaptive hash index 17803896        (17701384 + 102512)
    Page hash           1107208
    Dictionary cache    8089464         (4427312 + 3662152)
    File system         83520   (82672 + 848)
    Lock system         2657544         (2657176 + 368)
    Recovery system     0       (0 + 0)
    Threads             407416  (406936 + 480)
Dictionary memory allocated 3662152
Buffer pool size        65535
Buffer pool size, bytes 1073725440
Free buffers            64515
Database pages          1014
Old database pages      393
```

Memory Allocation Basics

- Buffer Pool
  - – Set by **innodb_buffer_pool_size**
  - – Database cache; Insert Buffer; Locks
  - – Takes More memory than specified
    - Extra space needed for Latches, LRU etc
- Additional Memory Pool
  - – Dictionary and other allocations
  - – **innodb_additional_mem_pool_size**
    - Not used in newer releases
- Log Buffer (**innodb_log_buffer_size**)

Configuring Buffer Pool

- **innodb_buffer_pool_size** is the most important
  - Use all your memory nor committed to anything else
  - Keep overhead into account (~5%)
  - Never let Buffer Pool Swapping to happen
  - Up to 80-90% of memory on Innodb only Systems
  - **innodb_buffer_pool_instances=N**
    - MySQL 5.5+
    - Set to 8-32 depending number of cores to get better scalability

Configuring Innodb Log Buffer

- **innodb_log_buffer_size**
  - Values 32-256MB typically make sense
  - Larger values good to reduce contention
  - May need to be larger if using large BLOBs
  - See number of data written to the logs
  - Log buffer covering 10sec worth of writes is good enough

Ever wondered what is in BP ?

- Check out INNODB_BUFFER_POOL_* tables
  - Available in XtraDB
  - MySQL 5.6 came out with similar feature

```
mysql> select count(*),sum(dirty=1) from  INNODB_BUFFER_POOL_PAGES_INDEX where index_id
in(31,32);
+----------+--------------+
| count(*) | sum(dirty=1) |
+----------+--------------+
|       40 |           22 |
+----------+--------------+
1 row in set (0.00 sec)
```

Data Dictionary

- Holds information about Innodb Tables
  - Statistics; Auto Increment Value, System information
  - Can be 4-10KB+ per table
- Can consume a lot of memory with huge number of tables
  - Think hundreds of thousands
- **innodb_dict_size_limit**
  - Limit the size in Percona Server
  - MySQL 5.6 uses **table_definition_cache** as a limit

Disk IO

How Innodb Performs Disk IO

Reads

- Most reads done by executing threads
- Read-Ahead performed by background threads
  - Linear
  - Random
  - Do not count on read ahead a lot
- Insert Buffer merge process causes reads

Writes

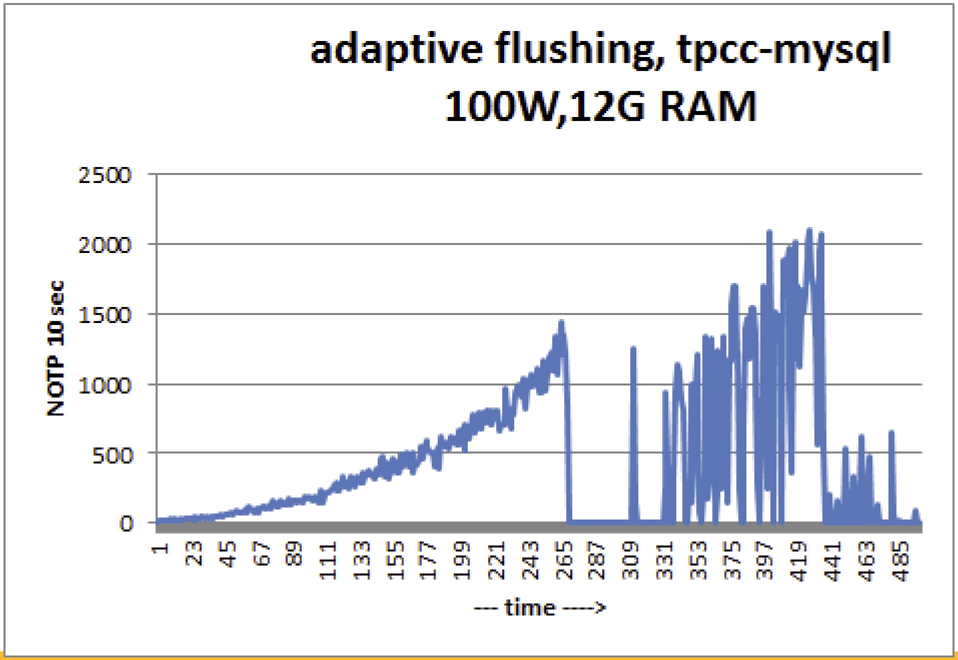
- Data Writes are Background in Most cases
  - As long as you can flush data fast enough you're good
- Synchronous flushes can happen if no free buffers available
- Log Writes can by sync or async depending on **innodb_flush_log_at_trx_commit**
  - 1 – fsync log on transaction commit
  - 0 – do not flush. Flushed in background ~ once/sec
  - 2 – Flush to OS cache but do not call fsync()
    - Data safe if MySQL Crashes but OS Survives

Flush List Writes

- Flushing to advance “earliest modify LSN”
  - To free log space so it can be reduced
- Most of writes typically happen this way
- Number of pages to flush per cycle depended on the load
  - “**innodb_adaptive_flushing**”
  - Percona Server has more flushing modes
    - See **innodb_adaptive_flushing_method**
- If Flushing can't keep up stalls can happen

Example of Misbehavior

- Data fits in memory and can be modified fast
  - – Yet we can't flush data fast enough
- Working on solution in XtraDB



LRU Flushes

- Can happen in workloads with data sets larger than memory
- If Innodb is unable to find clean page in 10% of LRU list
- LRU Flushes happen in user threads
- Hard to see exact number in standard Innodb
  - XtraDB adds **Innodb_buffer_pool_pages_LRU_flushed**

LRU Flushes in MySQL 5.6

- MySQL 5.6 adds “page_cleaner” to avoid LRU flushes in User Threads
- **innodb_lru_scan_depth=N**
  - Controlls how deeply page cleaner will examine Tail of LRU for dirty pages
  - Happens once per second

Merging Neighbor Pages

- To make IO more Sequential Innodb will look for neighbor pages and flush them again
  - It is ALL “old” pages in the page proximity (+- 32 pages)
    - It does not have to be sequential range of pages
- Such behavior may be very poor choice
  - Especially for SSD which do not have random IO Penalty
  - **innodb_flush_neighbor_pages –** XtraDB
  - **innodb_flush_neighbors** - MySQL 5.6

Page Checksums

- Protection from corrupted data
  - Bad hardware, OS Bugs, Innodb Bugs
  - Are not completely replaced by Filesystem Checksums
- Checked when page is Read to Buffer Pool
- Updated when page is flushed to disk
- Can be significant overhead
  - Especially for very fast storage
- Can be disabled by **innodb_checksums=0**

Fast Checksums

- For Fast Storage you might use faster checksums
- **innodb_fast_checksums=1**
  - in XtraDB
- **innodb_checksum_algorithm=crc32**
  - In MySQL 5.6

Double Write Buffer

- Innodb log requires consistent pages for recovery
- Page write may complete partially
  - Updating part of 16K and leaving the rest
- Double Write Buffer is short term page level log
- The process is:
  - Write pages to double write buffer; Sync
  - Write Pages to their original locations; Sync
  - Pages contain tablespace_id+page_id
- On crash recovery pages in buffer are compared to their original location

Disabling Double Write

- Overhead less than 2x because write is sequential
- Relatively larger overhead on SSD;
  - Also impacts Flash Life time
  - Can be stored in Separate Location in XtraDB
- Can be disabled if FS guaranties atomic writes
  - ZFS
- **innodb_doublewrite=0**

Direct IO Operation

- Default IO mode for Innodb data is **Buffered**
- Good
  - Faster flushes when no write cache
  - Faster warmup on restart
  - Reduce problems with inode locking on EXT3
- Bad
  - Lost of effective cache memory due to double buffering
  - OS Cache could be used to cache other data
  - Increased tendency to swap due to IO pressure
- **innodb_flush_method=O_DIRECT**

Log IO

- Log are opened in buffered mode
  - Even with **innodb_flush_method=O_DIRECT**
  - XtraDB can use O_DIRECT for logs
    - **innodb_flush_method=ALL_O_DIRECT**
- Flushed by fsync() - default or O_SYNC
- Logs are often written in 512 byte blocks
  - **innodb_log_block_size=4096 in XtraDB**
- Logs which fit in cache may improve performance
  - Small transactions and **innodb_flush_log_at_trx_commit=1 or 2**

Indexes

How Indexes are Implemented in Innodb

Everything is the Index

- Innodb tables are “Index Organized”
  - PRIMARY KEY contains data instead of data pointer
- Hidden PRIMARY KEY is used if not defined (6b)
- Data is “Clustered” by PRIMARY KEY
  - Data with close PK value is stored close to each other
  - Clustering is within page ONLY
- Leaf and Non-Leaf nodes use separate Segments
  - Makes IO more sequential for ordered scans
- Innodb system tables **SYS_TABLES** and **SYS_INDEXES** hold information about index “root”

Index Structure

- Secondary Indexes refer to rows by Primary Key
  - No update when row is moved to different page
- Long Primary Keys are expensive
  - Increase size of all Indexes
- Random Primary Key Inserts are expensive
  - Cause page splits; Fragmentation
  - Make page space utilization low
- AutoIncrement keys are often better than artificial keys, UUIDs, SHA1 etc.

SYS_TABLES Example

- Table can be viewed in XtraDB:

```
mysql> select * from  INNODB_SYS_TABLES limit 10;
+----------+---------+-----------------+-----+-------+------+
| TABLE_ID | SCHEMA  | NAME            | FLAG | N_COLS | SPACE |
+----------+---------+-----------------+-----+-------+------+
|       11 |         | SYS_FOREIGN     |    0 |      7 |     0 |
|       12 |         | SYS_FOREIGN_COLS |    0 |      7 |     0 |
|       17 | percona | transactions    |    1 |     18 |     0 |
|       23 | sbtest  | sbtest#P#p0     |    1 |      7 |     0 |
|       24 | sbtest  | sbtest#P#p1     |    1 |      7 |     0 |
|       25 | sbtest  | sbtest#P#p2     |    1 |      7 |     0 |
|       26 | sbtest  | sbtest#P#p3     |    1 |      7 |     0 |
|       18 | stats   | tables          |    1 |     12 |     0 |
|       62 | test    | a               |   41 |      5 |    12 |
|       55 | test    | btest           |    1 |      5 |     0 |
+----------+---------+-----------------+-----+-------+------+
10 rows in set (0.00 sec)
```

SYS_INDEXES example

- Available in XtraDB too

```
mysql> select * from  INNODB_SYS_INDEXES where table_id=23;
+----------+---------+----------+------+----------+---------+-------+
| INDEX_ID | NAME    | TABLE_ID | TYPE | N_FIELDS | PAGE_NO | SPACE |
+----------+---------+----------+------+----------+---------+-------+
|       31 | PRIMARY |       23 |    3 |        1 |   98306 |     0 |
|       32 | k       |       23 |    0 |        1 |   98307 |     0 |
+----------+---------+----------+------+----------+---------+-------+
2 rows in set (0.00 sec)
```

More on Clustered Index

- PRIMARY KEY lookups are the most efficient
  - Secondary key lookup is essentially 2 key lookups
  - Optimized with Adaptive Hash Index
- PRIMARY KEY ranges are very efficient
  - Build Schema keeping it in mind
  - (user_id,message_id) may be better than (message_id)
- Changing PRIMARY KEY is expensive
  - Effectively removing row and adding new one.
- Sequential Inserts give compact, least fragmented storage
  - ALTER TABLE tbl=INNODB can be optimization

More on Indexes

- There is no Prefix Index compressions
  - – Index can be 10x larger than for MyISAM table
  - – Innodb has page compression. Not the same thing.
- Indexes contain transaction information = fat
  - – Allow to see row visibility = index covering queries
- Secondary Keys built by insertion
  - – Often outside of sorted order = inefficient
- Innodb Plugin and later build Faster – by Sorting
  - – Indexes have good page fill factor
  - – Indexes are not fragmented

Fragmentation

- Inter-row fragmentation
  - The row itself is fragmented
  - Happens in MyISAM but NOT in Innodb
- Intra-row fragmentation
  - Sequential scan of rows is not sequential
  - Happens in Innodb, outside of page boundary
- Empty Space Fragmentation
  - A lot of empty space can be left between rows
- **ALTER TABLE tbl ENGINE=INNODB**
  - Table rebuild for defragmentation

Online Defragmentation

- Not available in Server itself
- Can be done doing “null” online ALTER TABLE
  - Pt-online-schema-change
    - New advanced version is just released
  - oak-online-alter-table
  - Facebook OSC
- Works by double writes through triggers
  - Overhead can be relatively high

Multi Versioning

Implementation of Multi Versioning and Locking

Multi Versioning at Glance

- Multiple versions of row exist at the same time
- Read Transaction can read old version of row, while it is being modified
  - No need for locking
- Locking reads can be performed with SELECT FOR UPDATE and LOCK IN SHARE MODE Modifiers

Transaction isolation Modes

- SERIALIZABLE
  - Locking reads. Bypass multi versioning
- REPEATABLE-READ (default)
  - Read commited data at it was on start of transaction
- READ-COMMITED
  - Read commited data as it was at start of statement
- READ-UNCOMMITED
  - Read non committed data as it is changing live

Updates and Locking Reads

- Updates bypass Multi Versioning
  - You can only modify row which currently exists
- Locking Read bypass multi-versioning
  - Result from SELECT vs SELECT .. LOCK IN SHARE MODE will be different
- Locking Reads are slower
  - Because they have to set locks
  - Can be 2x+ slower !
  - SELECT FOR UPDATE has larger overhead

Multi Version Implementaition

- The most recent row version is stored in the page
  - Even before it is committed
- Previous row versions stored in undo space
  - Located in System tablespace
- The number of versions stored is not limited
  - Can cause system tablespace size to explode.
- Access to old versions require going through linked list
  - Long transactions with many concurrent updates can impact performance.

Dealing with Run Away Transactions

- Monitor SHOW INNODB STATUS for transactions ACTIVE for long time
  - Looking for large Innodb History Length is also good idea
- Percona Server has feature to kill idle transactions (open but inactive)
  - **innodb_kill_idle_transaction=600**

Multi-Versioning Internals

- Each row in the database has
  - DB_TRX_ID (6b) – Transaction inserted/updated row
  - DB_ROLL_PTR (7b) - Pointer to previous version
  - Significant extra space for short rows !
- Deletion handled as Special Update
- DB_TRX_ID + list of currently running transactions is used to check which version is visible
- Insert and Update Undo Segments
  - Inserts history can be discarded when transaction commits.
  - Update history is used for MVCC implementation

Undo Segment Limits

- Undo Segment was often limited factor
- Innodb Plugin and Before
  - Max 1024 undo segments
  - May cap at 512 active transactions
    - Transaction may require 2 undo segments
- Increased in XtraDB to 4072
- MySQL 5.5 Increases it to some 128K

Multi Versioning Performance

- Only changed columns stored in the undo segment
- Short rows are faster to update
  - Separate table to store counters often make sense
- Beware of long transactions
  - Especially containing many updates
- “Rows Read” can be misleading
  - Single row may correspond to scanning thousand of versions/index entries

Multi Versioning Indexes

- Indexes contain pointers to all versions
  - Index key 5 will point to all rows which were 5 in the past
- Indexes contain TRX_ID
  - Easy to check entry is visible
  - Can use “Covering Indexes”
- Many old versions is performance problem
  - Slow down accesses
  - Will leave many “holes” in pages when purged

Cleaning up the Garbage

- Old Row and index entries need to be removed
  - When they are not needed for any active transaction
- REPEATABLE READ
  - Need to be able to read everything at transaction start
- READ-COMMITED
  - Need to read everything at statement start
- Purge Thread(s) may be unable to keep up with intensive updates
  - Innodb “History Length” will grow high
- **innodb_max_purge_lag** slows updates down
  - Not very reliable

Handling Blobs

- Blobs are handled specially by Innodb
  - And differently by different versions
- Small blobs
  - Whole row fits in ~8000 bytes stored on the page
- Large Blobs
  - Can be stored full on external pages (Barracuda)
  - Can be stored partially on external page
    - First 768 bytes are stored on the page (Antelope)
- Innodb will NOT read external blobs unless they are touched by the query

Blobs in the separate table

- It Depends :)
- No need to store Large blobs in the separate table as they are already stored outside of the row
- Storing medium side blobs (which fit on the page) in the separate table makes sense
- Only split blobs to separate table if they are accessed infrequently.

Innodb BLOB != MySQL BLOB

- MySQL Has limit of 65535 bytes per row excluding BLOB and TEXT column
  - This limit applies to VARCHAR() columns
- Innodb limit is only 8000 (half a page)
  - So long VARCHAR fields may be stored as a BLOB inside Innodb

```
mysql> create table ai(c varchar(40000), d varchar(40000));
ERROR 1118 (42000): Row size too large. The maximum row size for the used table type, not counting
BLOBs, is 65535. You have to change some columns to TEXT or BLOBs
```

Blob Allocation

- Each BLOB Stored in separate segment
  - Normal allocation rules apply. By page when by extent
  - One large BLOB is faster than several medium ones
  - Many BLOBs can cause extreme waste
    - 500 byte blobs will require full 16K page if it does not fit with row
- External BLOBs are NOT updated in place
  - Innodb always creates the new version
- Large VARCHAR/TEXT are handled same as BLOB

Innodb Locking

How Innodb Locking Works

Innodb Locking Basics

- Pessimistic Locking Strategy
- Graph Based Deadlock Detection
  - Takes shortcut for very large lock graphs
- Row Level lock wait timeout
  - **innodb_lock_wait_timeout**
- Traditional “S” and “X” locks
- Intention locks on tables “IS” “IX”
  - Restricting table operations
- Locks on Rows AND Index Records
- No Lock escalation

Gap Locks

- Innodb does not only locks rows but also gap between them
- Needed for consistent reads in Locking mode
  - Also used by update statements
- Innodb has no Phantoms even in Consistent Reads
- Gap locks often cause complex deadlock situations
- “infinum”, “supremum” records define bounds of data stored on the page
  - May not correspond to actual rows stored
- Only record lock is needed for PK Update

Types of Locks in Innodb

- Next-Key-Lock
  - Lock Key and gap before the key
- Gap-Lock
  - Lock just the gap before the key
- Record-Only-Lock
  - Lock record only
- Insert intention gap locks
  - Held when waiting to insert into the gap

Advanced Gap Locks Stuff

- Gaps can change on row deletion
  - Actually when Purge thread removes record
- Leaving conflicting Gap locks held
- Gap Locks are “purely inhibitive”
  - Only block insertion.
  - Holding lock does not allow insertion. Must also wait for conflicting locks to be released
- “supremum” record can have lock, “infinum” can't
- This is all pretty complicated and you rarely need it in practice

Lock Storage

- Innodb locks storage is pretty compact
  - This is why there is no lock escalation !
- Lock space needed depends on lock location
  - Locking sparse rows is more expensive
- Each Page having locks gets bitmap allocated for it
  - Bitmap holds lock information for all records on the page
- Locks typically take 3-8 bits per locked row

Auto Increment Locks

- Major Changes in MySQL 5.1 !
- MySQL 5.0 and before
  - Table level AUTO_INC lock for duration of INSERT
  - Even if INSERT provided key value !
  - Serious bottleneck for concurrent Inserts
- MySQL 5.1 and later
  - **innodb_autoinc_lock_mode –** set lock behavior
  - "1" - Does not hold lock for simple Inserts
  - "2" - Does not hold lock in any case.
    - Only works with Row level replication

Latching

Innodb Internal Locks

Innodb Latching

- Innodb implements its own Mutexes and RW-Locks
  – For transparency not only Performance
- Latching stats shown in SHOW INNODB STATUS

```
----------
SEMAPHORES
----------
OS WAIT ARRAY INFO: reservation count 13569, signal count 11421
--Thread 1152170336 has waited at ./../include/buf0buf.ic line 630 for 0.00 seconds the semaphore:
Mutex at 0x2a957858b8 created file buf0buf.c line 517, lock var 0
waiters flag 0
wait is ending
--Thread 1147709792 has waited at ./../include/buf0buf.ic line 630 for 0.00 seconds the semaphore:
Mutex at 0x2a957858b8 created file buf0buf.c line 517, lock var 0
waiters flag 0
wait is ending
Mutex spin waits 5672442, rounds 3899888, OS waits 4719
RW-shared spins 5920, OS waits 2918; RW-excl spins 3463, OS waits 3163
```

Latching Performance

- Was improving over the years
- Still is problem for certain workloads
  - Great improvements in MySQL 5.5,5.6 & XtaDB
  - Still hotspots remain
- **innodb_thread_concurrency**
  - Limiting concurrency can reduce contention
  - Introduces contention on its own
- **innodb_sync_spin_loops**
  - Trade Spinning for context switching
  - Typically limited production impact

Current Hotspots

- kernel_mutex (removed in MySQL 5.6)
  - A lot of operations use global kernel mutex
- log_mutex
  - Writing data to the log buffer
- Index->lock
  - Lock held for duration of low level index modification
  - Can be serious hot spot for heavy write workloads
  - Partitioning can often be of help

Adaptive Hash Latch

- Global latch. Problem with heavy read/write mix
  - **innodb_adaptive_hash_index=0**
    - Slow things down but reduce contention
- Percona Server/XtraDB can use multiple hashes
  - **innodb_adaptive_hash_partitions=N**
  - Helps when workload is spent among multiple tables.

Page Replacement

Page Replacement Flushing and Checkpointing

Basic Page Replacement

- Innodb uses LRU for page replacement
  - With Midpoint Insertion
- Innodb Plugin and XtraDB configure
  - **innodb_old_blocks_pct, innodb_old_blocks_time**
  - Offers Scan resistance from large full table scans
- Scan LRU Tail to find clean block for replacement
- May schedule synchronous flush if no clean pages for replacement

Page Flushing

- Scheduled by Main Thread in Background
  - Keep portion of the pages clean
  - Make sure we have log space
- **innodb_io_capacity**
  - Amount of writes per second server can do
  - Affects number of background flushes and insert buffer merges (5% for each)
- Server will do merges and flushes faster when it is idle

Maintaining clean pages

- **innodb_max_dirty_pages_pct**
  - Default 90, later 75
- Innodb will start flushing pages faster if it is reached
  - This is not the hard limit
- Value 0 is helpful for Fast Shutdown
  - Set to 0 and wait until number of dirty pages is low
- Innodb looks for next/prev dirty pages and flushes it as well to keep IO more bulky
  - Can be harmful for SSD storage
  - Controled by **innodb_flush_neighbor_pages** in XtraDB

Checkpointing

- Fuzzy Checkpointing
  - Flush few pages to advance min unflushed LSN
  - Flush List is maintained in this order
- MySQL 5.1 often has “hiccups”
  - No more space left in log files. Need to wait for flush to complete
- Percona Patches for 5.0 and XtraDB
  - Adaptive checkpointing: **innodb_adaptive_checkpoint**
- Innodb Plugin **innodb_adaptive_flushing**
  - Best behavior depends on worload

Recovery

How Innodb Recovers from Crash

Recovery Stages

- Physical Recovery
  - Recover partially written pages from double write buffer
- Redo Recovery
  - Redo all the changes stored in transactional logs
- Undo Recovery
  - Roll back not committed transactions

Redo Recovery

- Foreground
  - Server is not started until it is complete
- Larger Logs = Longer recovery time
  - Though row sizes, database size, workload also matter
- Scan Log files
  - Buffer modifications on per page basics
  - Apply modifications to data file
- LSN stored in the page tells if change needs to be applied

Tuning Redo recovery

- **innodb_log_file_size** - large logs longer recovery
- **innodb_max_dirty_pages_pct**
  - Fewer dirty pages faster recovery
- **innodb_buffer_pool_size**
  - Larger buffer faster IO recovery
  - Bug from 2007 which makes recovery slower with large buffer pool
    - http://bugs.mysql.com/bug.php?id=29847
  - Fixed in Innodb Plugin, MySQL 5.5

Undo Recovery

- Is Background since MySQL 5.0
  - Performed after MySQL is started
- Speed depends on transaction length
  - Very large UPDATE, INSERT... SELECT is problem.
- Is NOT problem with ALTER TABLE
  - Commits every 10000 rows to avoid this problem
  - Unless it is Partitioned table
- Faster with larger **innodb_log_file_size**
- Be careful killing MySQL with run away update queries.

Advanced Features

Insert Buffering, Adaptive Hash Index, Foreign Keys, Compression

Insert Buffer

- Designed to speed up Inserts into large Indexes
  - Reported up to 15 times IO reduction for some cases
- Works for Non-Unique Secondary Indexes only
- If leaf index page is not in buffer pool
  - Store a note the page should be updated in memory
- If page containing buffered entries is read from disk they are merged transparently
- Innodb performs gradual insert buffer merges in background

Change buffer in MySQL 5.5

- Buffer not only Insert but also Update and Purge operations
  - Delete is covered as it is special update on the low level
- Can improve bulk update/delete 10x or more
- Read for more details
  - http://blogs.innodb.com/wp/2010/09/mysql-5-5-innodb-change-buffering/

Insert Buffer Problems

- Can take up to half of buffer pool size
  - Persists in tablespace to keep things safe
  - **innodb_ibuf_max_size** in XtraDB to restrict it
  - Full Insert Buffer is useless and wastes memory
- Delayed Insert Buffer merge can cause slowdown
  - Too many merges need to happen on page reads
- Background merge speed may not be enough
  - Tun **innodb_io_capacity**, **innodb_ibuf_accel_rate**
- After Restart Merge speed can slow down
  - Finding index entries to merge needs random IO

More tuning of Insert Buffer

- Innodb Plugin, XtraDB you can disable insert buffering
  - **innodb_change_buffering=0**
  - Can be good for SSDs

Adaptive Hash Index

- Built on top of existing BTREE Indexes to speed up lookups
  - Both PRIMARY and Secondary indexes
- Can be built for full index and prefixes
- Partial Index
  - Only built for index values which are accessed often

```
Hash table size 8850487, used cells 2381348, node heap has 4091
buffer(s)
2208.17 hash searches/s, 175.05 non-hash searches/s
```

Tuning Adaptive Hash Index

- Self tuning
  - No tuning options are available.
- Can be disabled for performance reasons
  - **innodb_adaptive_hash_index**
  - Improves concurency but reduces performance
- Can be Partitioned in newer XtraDB versions
  - **innodb_adaptive_hash_index_partitions=8**

Foreign Keys

- Implemented on Innodb level
- Require indexes on both tables
  - Can be very expensive sometimes
- Checks happen when row is modified
  - No delayed checks till transaction commit
- Foreign Keys introduce additional locking overhead
  - Many tricky deadlock situations are foreign key related

Compression

- New in Innodb Plugin and XtraDB
  - Requires “Barracuda” and **innodb_file_per_table=1**
- Per Page compression (mostly)
- Uses zlib for compression (no settings available)
- Uses fancy tricks
  - Per page update log to avoid re-compression
  - Both Compressed and Uncompressed page can be stored in Buffer Pool
- **ROW_FORMAT=COMPRESSED KEY_BLOCK_SIZE=8;**
  - Estimate how well the data will compress

Problems with Compression

- Filesystem level compression may be more efficient
  - ZFS
- Page size is too small for good compression
- Have to “Guess” Compression
- Compression setting is Per table
  - Though some indexes compress better than others
- **KEY_BLOCK_SIZE=16;**
  - Only compress externally stored BLOBs
  - Can reduce size without overhead

More problems with compression

- Problems with scaling
- Algorithm inefficiencies balancing compressed and uncompressed pages in the buffer pool
- Logging of complete pages in the redo log file
- Work on a way. Expect significant improvements by the time MySQL 5.6 is stable

Fast Warmup

- Warmup can take very long time on restart
  - Especially with large amounts of memory
- XtraDB & MySQL 5.6
  - **innodb_lru_dump=300 (XtraDB)**
  - **innodb_buffer_pool_dump_at_shutdown (5.6)**
  - Dump list of pages in LRU list
  - Will re-populate buffer pool with list on restart
  - Can improve warmup time 10x

Thank You !

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