



PERCONA  
Performance Consulting Experts

---

# InnoDB and XtraDB Architecture and Performance Optimization

Apr 11-14, 2011

O'Reilly MySQL Conference  
and Expo

Santa Clara, CA

by Peter Zaitsev, Percona Inc

# 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
- Logging
- Indexes
- Multi Versioning
- Row Locking
- 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)
  - Scalability further improved
- XtraDB
  - Based on InnoDB Plugin 5.1 and version in 5.5
  - Has added features, performance improvements
  - Available in Percona Server and MariaDB

# 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 Tablespace 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
  - Ibdta1
  - 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)
  - Page at the time
- 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 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
  - 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 only

# Using to 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 is typically similar

# 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**
  - Do not remove blocks on drop, do it as they are replaced from LRU list.

# 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/>

# 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 shutdown)
- 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 (MySQL 5.5 and XtraDB)
- Deadlock detection thread.
- Monitoring Thread

# 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 Innodb Memory

- **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\_log\_buffer\_size**
  - Values 8-64MB typically make sense
  - Larger values may improve contention
  - May need to be larger if using large BLOBs
  - See number of data written to the logs
  - Log buffer covering 10sec is good enough

# Ever wondered what is in BP ?

- Check out INNODB\_BUFFER\_POOL\_\* tables
  - Available in XtraDB

```
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
  - Make it act as a real cache

# Disk IO

How Innodb Performs Disk IO

# Reads

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

# Writes

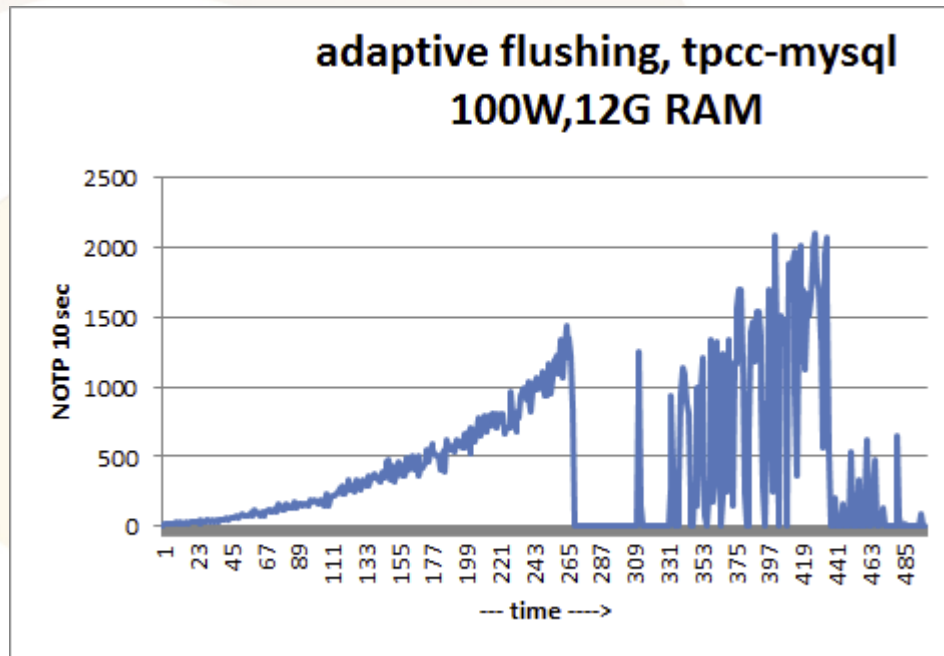
- Data Writes are Background in Most cases
  - As long as you can flush data fast enough you're good
- Synchronous flushes can happen if no free buffers available
- Log Writes can be sync or async depending on **innodb\_flush\_log\_at\_trx\_commit**
  - 1 – fsync log on transaction commit
  - 0 – do 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**

# 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
- XtraDB has option
  - **innodb\_flush\_neighbor\_pages**
  - Working on option to flush sequential pages only

# 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**
  - Not Recommended for Production
  - **innodb\_fast\_checksum** in XtraDB
    - Not compatible format. Several times faster.

# 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 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 blocks less than 4K
  - Read has to happen before write
- 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 need to 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 XtraDB building by sort
  - Faster
  - 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 tbi ENGINE=INNODB**
  - The only medicine available.

# 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 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 committed data at it was on start of transaction
- **READ-COMMITTED**
  - Read committed data as it was at start of statement
- **READ-UNCOMMITTED**
  - 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.

# 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

- Short rows are faster to update
  - Whole rows (excluding BLOBs) are versioned
  - 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-COMMITTED
  - Need to read everything at statement start
- Purge Thread 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 blobs unless they are touched by the query
  - No need to move BLOBs to separate table.

# InnoDB BLOG != MySQL BLOG

- 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 lock 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 & 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`
  - 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
- `Adaptive has latch`
  - Global latch. Problem with heavy read/write mix
  - **`innodb_adaptive_hash_index=0`**
    - Slow things down but reduce contention

# Recent Achievements

- MySQL 5.5 support for multiple buffer pools
  - **innodb\_buffer\_pool\_instances=8**
  - Reduces a lot of buffer pool related contention
  - Make sure each buffer pool is at least 1GB in size
- Partitioned Adaptive Index in recent XtraDB
  - **innodb\_adaptive\_hash\_index\_partitions=8**

# 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
  - Controlled 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 workload

# 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
  - Solution exists in Percona Patches for 5.0

# 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
  - Tune by **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 concurrency 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

# Fast Warmup

- Warmup can take very long time on restart
  - Especially with large amounts of memory
- XtraDB contains
  - `innodb_lru_dump=300`
  - Dump list of pages in LRU list
  - Will re-populate buffer pool with list on restart
  - Can improve warmup time 10x

# Percona Live, May 26, New York



[www.percona.com/live](http://www.percona.com/live)

# Thanks for Coming

- Questions ? Followup ?
  - [pz@percona.com](mailto:pz@percona.com)
- Yes, we do **MySQL and Web Scaling Consulting**
  - <http://www.percona.com>
- Check out our book
  - Complete rewrite of 1<sup>st</sup> edition

