Advanced InnoDB Optimization

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MySQL Users Conference 2005
Santa Clara, CA April 18-22

Introductions

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  - MySQL Performance consulting and partner relationships

Table of Contents

- InnoDB storage engine at glance
- InnoDB vs other storage engines
- Table design issues
- Loading data
- Workload optimization
- Server Settings
- OS and Hardware
- Benchmark results

Question Policy

- Interrupt us if something is unclear
- Keep long generic questions to the end
- Approach me during the conference
- Write us: peter@mysql.com,

Do you use InnoDB

- How many of you ?
  - Do not use MySQL yet ?
  - Use MySQL with MyISAM tables only ?
  - Use InnoDB with other storage engines ?
  - Are Using only InnoDB or mostly InnoDB ?

InnoDB at glance

- Transactional storage engine
  - Fully ACID
  - Row level locks with multi-versioning
    - no locks for standard selects
  - Multiple isolation modes
  - Foreign Key support
  - Automatic crash recovery
    - no need for **CHECK TABLE** on power failure
  - Data clustered by **PRIMARY KEY**
- Developed by Heikki Tuuri, Innobase Oy
  - Standard part of MySQL distribution

InnoDB and MyISAM

- Transaction commit overhead
  - Simple updates outside of transaction slower than MyISAM
- Journaling and versioning overhead
  - Large data modifications are slower than MyISAM
- Significantly larger footprint than MyISAM
  - Tables can be 2-3 times larger than MyISAM
  - Memory fit is normally better with MyISAM
  - Indexes are not packed
    - May be 10 times larger than MyISAM for **VARCHAR** columns
- Clustering by **PRIMARY KEY**
  - Can be badly fragmented on random inserts
  - Slower than MyISAM for disk full table scan

InnoDB and MyISAM

- **BLOBs** stored outside of the main row, in many pages
  - Slower **BLOB** retrieval and much slower updates
- Very slow index creation (**ALTER TABLE**, **LOAD DATA**)
  - Indexes are currently built row by row
- Some features absent
  - GIS, Full Text search, RTREE indexes
- Some features present
  - Do you need transactions ? Foreign Keys ? Safety guarantees ?
- Fast recovery on crash failure
  - How long **REPAIR TABLE** will take for 1 billion of rows MyISAM table ?
- On hardware failure InnoDB recovery can be tricky

InnoDB vs MyISAM

- Much better concurrency for read-write workloads
  - Multiple users can write to the table at the same time
- Data clustered by **PRIMARY KEY**
  - Primary key lookups up to 2 times faster for disk bound case
- Larger pages (16K) – faster warm up
- Background flushing of modified pages
  - OS can help for MyISAM but not as safe and good
- Only referenced columns are retrieved
  - Faster accessed for tables with **BLOB/TEXT** columns
- Both data and Index are cached in process memory
  - MyISAM only caches Indexes
- Hash indexes built in memory for faster access

InnoDB table design

- Use short **PRIMARY KEY**
  - Primary key is part of all other indexes on table
  - Consider artificial **auto_increment PRIMARY KEY** and **UNIQUE** for original **PRIMARY KEY**
  - **INT** keys are faster than **VARCHAR/CHAR**
- **PRIMARY KEY** is most efficient for lookups
  - Reference tables by **PRIMARY KEY** when possible
- Do not update **PRIMARY KEY**
  - This will require all other keys to be modified for row
  - This often requires row relocation to other page
- Cluster your accesses by **PRIMARY KEY**
  - Inserts in PRIMARY KEY order are much faster.

InnoDB table design

- **UNIQUE** keys are more expensive than non unique
  - Insert buffering does not work
- Prefix indexes especially useful
  - No key compression as in MyISAM
- Long row reduce overhead
  - Blob reading can be skipped if not referenced
  - Vertical partition rarely makes sense
- Manual partitioning still make sense
  - ie users01, users02... users99
  - Table locks is not the problem but ALTER TABLE is

Loading data to InnoDB table

- Loading data or bulk inserts are much slower than MyISAM
- Loading should be done in **PRIMARY KEY** order
  - Sort externally if needed
  - Performance difference 100x +, faster resulting table
- **SET UNIQUE_CHECKS=0**
  - Do not check keys for uniques – uses insert buffer
    - Make sure it is really unique or mild corruption will happen
- **SET FOREIGN_KEY_CHECKS=0**
  - Improve load speed, do not depend on table order
  - No tool to verify everything is intact after loading
- Good if non-Primary keys fit in buffer pool
  - Insert buffer helps but in memory operations are still faster

Loading data to InnoDB

- Parallel load is better done in different tables
  - Increased fragmentation may happen with same table.
- Parallel load makes sense in two cases
  - You have enough memory to cache both tables
  - You're disk bound in any case and have many disks
- Adjust InnoDB server settings for initial import
  - If your database size is much larger than memory
  - **innodb_buffer_pool_size** up to 90% of memory
  - **innodb_log_file_size** to **innodb_buffer_pool_size**
    - Note you can't just change the option, check manual
- Load in chunks (ie by 10000 rows)
  - Rolling back failed large import transaction may take days

InnoDB BLOB/TEXT support

- First 512 bytes of BLOB are always stored with row
  - So you can have prefix indexes on BLOB/TEXT
  - 8000 bytes row size applies to this prefix
    - If you have 20 blob fields you may fail on insert
    - Watch for upgrades to utf8 as data size increases
- Remaining stored in its own file segment
  - Allocated page by page up to 32 pages, by 64 pages after
    - Serious size overhead may happen – 33 pages blob will take 96
    - BLOB can be significantly fragmented by 16K chunks
      - Depends on workload a lot. Frequently chunks are larger.
- On update new BLOB is allocated in new place
  - Opposite to how row data is treated
- Single **BLOB/TEXT** with data in XML may be faster

Optimal transaction size

- Size of transaction is often partially in your control
  - Web application – one transaction per page load or one per "module" ?
- Too small transaction
  - Expensive transaction commit overhead
- Too large transaction
  - Undo space growing (and may need to be flushed to disk)
  - Excessive locking, larger chance of deadlocks
  - Binary log cache overflow
- SELECTs only - fastest outside of transaction
  - but watch for data consistency
- Medium transactions offer best performance

Number of connections

- Easy to control in some applications
  - Java connections pooling
- Harder in LAMP applications but possible
  - ie Using FastCGI for PHP processing
- If not connections, limit number of active heavy queries.
  - **SELECT GET_LOCK("mycomplexquery01");**
- Depending on load optimal number is different
  - CPU/disk bound ?
  - Query complexity ? Application processing delay ?
  - Read/write ratio ?
- After certain point performance drops significantly
  - If this happened server may never recover by itself

Number of Connections

- **innodb_thread_concurrency** – protection from too many active threads
  - Try setting to (num_cpus+num_disks)*(2..4)
  - Try setting to 1000 to disable and see if OS does the job
- Too many threads busts CPU cache efficiency
- Too many threads may randomize disk IO
- Too many threads cause more locks and latches conflicts
- Too many threads result in context switching waste
- Need many threads to load CPUs and disks fully
- Transaction group commit starts to work
  - Committing several transactions with single log write

Caching

- If queries are well designed, memory is most common bottleneck
- InnoDB is much better with its own cache than OS cache
  - All your memory should be accessible by MySQL
  - Look at 64Bit Platform if you have more than 4G RAM
- InnoDB has 16K pages for index and data
  - Fast warm up (data fetched in large chunks)
  - Limited number of "random" rows can be cached at the time
- Moving frequently accessed data to separate table may be good solution
  - Horizontal partitioning, ie "news" and "topnews" tables

Transaction isolation

- Default (**REPEATABLE-READ**) is fast enough
  - Repeatable read results, even no phantoms
  - **SELECT FOR UPDATE/LOCK IN SHARE MODE** will bypass versioning!
- **READ-COMMITED** allows to save a bit on undo space
- **READ-UNCOMMITED** – access to the transaction result as it goes
  - You can see how you long transaction is progressing
- **SERIALIZABLE** – set locks on reads
  - More deadlock prone
  - Worse concurrency
  - Waste memory for locks

Locking Reads

- Locking reads bypass versioning
  - You can't lock the row which does not exist any more
- Locking read requires access to the row
  - Covering index will not benefit
    - index on all columns referenced in select for the table
    - **EXPLAIN** will not show it!
  - **SELECT ... LOCK IN SHARE MODE** can be much slower than non-locking **SELECT**
- Locking reads may help prevent deadlocks
  - Using **FOR UPDATE** when reading rows, to be updated in the dame transaction
- Locking reads may lead deadlocks, lock waits
  - If used unwisely

Fighting Deadlocks, Lock waits

- Deadlocks hurt performance
  - You need to restart transaction and redo it over
- Row lock waits increase response time.
- Handle deadlocks and timeouts
  - It is hard to guaranty they will never happen for most apps
- Control number of connections you have
- Lock data in the same order in all transactions
- Do not lock data when possible.
- Lock data you will need to lock anyway in the begin of transactions
  - Use **SELECT FOR UPDATE** fetching rows you'll update

Fighting Deadlocks

- Rows which are not affected may be locked
  - **UPDATE tbl SET status=1 WHERE name like "%s00me%"**
    - All rows in the table will be locked.
  - InnoDB locks the row when it reads it, if it did not match **WHERE** clause on MySQL level it is not unlocked
  - Make sure you use index whenever possible
  - Statement chopping may help if you do not have index
    - **UPDATE tbl SET status=1 WHERE name like "%s00me%" and id between 10000 and 19999;**
- Next-key locks – will not allow to insert just before/after the row in index order
  - Needed to avoid phantom rows
  - **innodb_locks_unsafe_for_binlog** to disable next-key locks

InnoDB Server Settings

- **innodb_buffer_pool_size –** InnoDB data and index cache size
  - Set 70-80% of memory for dedicated MySQL/Innodb boxes
  - Much more efficient than OS cache especially for write loads
- **innodb_buffer_pool_awe_mem_mb**
  - Windows only AWE "extended" buffer pool
  - Allows to address over 4G of ram on 32bit boxes
  - Much better to use true 64bit platforms these days
- **innodb_additional_mem_pool_size –** Caching dictionary and other internal structures
  - Normally 8-16MB is enough,
  - Requirements growth with number of tables and connections
  - If size is not enough allocation from conventional memory happens
  - Setting it more than needed is just waste of memory

InnoDB server settings

- **innodb_autoextend_increment –** growth chunk for "autoextend" tablespace
  - Default value is 8 (MB) is normally OK
  - Larger value help in intensive growths, reduce file system fragmentation
- **innodb_fast_shutdown –** Should Innodb shutdown fast or with full cleanup
  - Default value (ON) should be good for most cases
  - Fast shutdown does not increase startup time
  - Insert buffer merge can be just done during normal operation on restart
- **innodb_file_io_threads –** number of threads to use for IO helpers
  - Only works on Windows. Unix/Linux has fixed 4 threads
  - More threads may help with more IO devices
  - 4 threads means one thread of each type (read, write, insert_buffer,log)

Innodb_File_Per_table

- **innodb_file_per_table –** create each table in its own file/tablespace
  - Option only affects new tables.
    - You can switch it back to create some tables using system tablespace
  - Data and all indexes are stored in the same single file
  - System tablespace is used for undo records
  - You can't move .ibd file between directories or servers
  - Helpful to manually balance IO between IO devices
  - Helpful for binary backup on per table basics
  - Helpful against per inode IO kernel locks in some OS
  - May have larger update overhead
    - fsync() needed for each file, flushing doublewrite buffer

Innodb_data_file_path

- Specifies one or several files for system tablespace
  - **ibdata1:2G;ibdata2:10M:autoextend:max:500M**
  - Files are logically concatenated, filled from the first one
    - No IO balancing between files of any sort
- Single file allows to save on fsync() calls
- Multiple files help in case of poor kernel locking
  - limited effect as no control where tables are stored
- You can use Raw partitions for Data files with Innodb
  - **/dev/hdd1:5Graw;/dev/hdd2:2Graw**
    - **"newraw"** first time to set up tablespace
  - Logs have to remain in files
  - Very limited performance improvement, especially when DIRECT IO is used.

innodb_flush_log_at_trx_commit

- Tune InnoDB log flush behavior on transaction commit
  - InnoDB always flushes log to disk about 1/sec in background
  - Value 0 - no log flushing on transaction commit
    - Use when performance is paramount
    - Transaction loss possible when MySQL server crashes
  - Value 2 – log is not flushed to the disk, but to OS cache
    - Usually just a bit slower compared to value 0
    - Transaction loss only when OS/Hardware crashes
    - Similar to MyISAM guarantees at some extent
  - Value 1 (default) - fully ACID, log flushed to disk on commit
    - Use for applications when no transaction loss can be allowed
    - Use RAID Battery write back cache for performance
    - Make sure OS does proper flush to disk or may be worthless
- With any value tables are not corrupted in case of crash

innodb_flush_method

- Specifies a way InnoDB uses to ensure data made it to the disk
  - **fsync** (default). Both data and log files are flushed by fsync
    - Good for data files as multiple writes followed by single fsync() allows OS to optimize disk IO
  - **O_SYNC** fsync() is used for data files but log file is just opened with O_SYNC flag
    - Try it. Some OS are faster with fsync(), others with O_SYNC for single writes.
  - **O_DIRECT** (Linux) – use direct IO to bypass OS cache
    - Eliminates double buffering and extra copying
    - Sync data writes happen request by request
    - May be faster or slower depending on workload and kernel
    - Normally good choice for RAID with writeback cache

innodb_force_recovery

- Activate Special InnoDB data recovery more
  - Only change when recovering your data, switch back when done
- Start with lower values, continue increasing if Innodb still asserts
  - Higher values increase chance of incomplete data recovered
- Avoid side load on the server when using this option
  - Innodb will block updates for safety anyway
- Read manual carefully before using
  - http://dev.mysql.com/doc/mysql/en/forcing-recovery.html

innodb_lock_wait_timeout

- Timeout waiting for InnoDB row locks
  - Innodb will abort, roll back transaction waiting too long
- Low values may increase number of timeout errors
- High values may stall your users for very long time
  - It is better to return “try again” to Web user when return nothing for minutes
- Value is global, can't be set without restarting server
  - setting on per session basics will make a lot of sense
    - Yes Heikki, this is a hint :)
- Avoid long transaction when possible
- For long transaction (ie batch jobs) think what transactions it could be locking
- Use non-blocking reads when possible

innodb_locks_unsafe_for_binlog

- Relaxes InnoDB locking
  - Disables “next-key” locking
  - In MySQL 5.0 makes update/delete to only lock rows selected for update
- This option is named so because using it may break replication
  - Will be fixed when row level replication is implemented
- Phantom rows will appear in REPEATABLE-READ mode
  - READ-COMMITED remains without changes
- Limited number of users use this option
- Use when nothing else helps

InnoDB Logging options

- **innodb_log_buffer_size –** buffer for log IO
  - Buffer is flushed on transaction commit or once per second, do not set it to high. 8MB usually enough. 64MB tops.
- **innodb_log_files_in_group –** number of log files
  - Default of 2 is normally good
- **innodb_log_file_size –** size of each of these files
  - Large size faster. Small files more buffer pool flushes
    - page has to be flushed from buffer pool before information about modification is overwritten in log file
  - Larger size increase “redo” recovery time
    - Roll back of uncommitted transaction is faster with large logs
  - Set value which you can afford based on your recovery time up to size of buffer pool.

InnoDB Server Options

- **innodb_max_dirty_pages_pct** – maximum percent of pages in buffer pool Innodb can have dirty
  - Some clean pages are needed to avoid page read stalls
  - Large values typically offer better performance
  - Innodb start do aggressive once it is reached.
  - Lowering value close to 0 makes sense before shutdown
    - makes clean shutdown fast even with large buffer pool
- **innodb_open_files -** number of .ibd files innodb can keep open
  - Only used if you use **innodb_file_per_table**
  - Keep large enough to avoid frequent file reopens
  - No simple way to identify number of reopens of .idb files, or number of them currently open.

innodb_thread_concurrency

- Sets maximum number of threads can be executing Inside InnoDB kernel
  - Mainly needed when OS makes threads to thrash
  - May significantly improve performance
  - Too low value can significantly decrease performance
    - 10ms sleep before starting wait.
  - Worth to try 1000 to disable queueing
    - Shows best performance results on some workload
  - Reasonable values 2..4*(NumCPU+NumDisks)
  - Group commit works better with higher values
  - Resource consumption (ie additional_mem_pool usage) grows as this value is increased.

Hardware for InnoDB

- Identify if you have CPU bound or disk bound workload
  - Measure CPU consumption during benchmark
- Attempt to fit database (or working set) in memory first
  - No IO system can beat memory in access performance
  - Investment in IO subsystem a lot when this can't be done
- Get Hardware RAID write back cache if you have many small transactions
  - Increase transaction rate without sacrificing durability
- RAID10 is best choice. RAID5 is very slow on writes
- Use large (256K-1M RAID stripe size)
- Get 64bit CPU so all memory can be addressed
  - Opterons, Xeons with EM64T is good choice

OS for InnoDB

- OS should have reliable synchronous disk IO
  - So much data was lost due to broken fsync()
- Good thread library is critical
- DIRECT IO support (bypass OS cache)
- Good Virtual memory subsystem
  - So no swapping even with large buffer Pool
- Current top popular choices: Linux, Solaris, Windows
- Get 64bit OS if you have 64bit CPU
- Use “deadline” scheduler in 2.6 Linux Kernel
- Use journaling file system
  - Avoid long file system check on dirty restart.

DIKU Research

- Partnership between Copenhagen University and MySQL AB, focused on MySQL performance research and improvement
- Implemented Native Asynchronous IO support for Linux
  - To be included in MySQL standard release soon
- Implemented Priority IO support for Innodb and Kernel
  - Increase performance by optimal loading of IO system
- MySQL Cache efficiency research
- IO pattern research Instrumentation
- Christoffer Hall-Frederiksen, visiting conference
  - Talk to him if you're interested in details

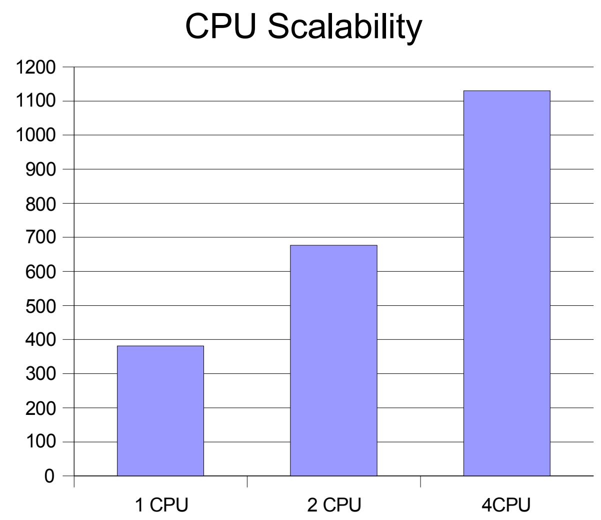
Benchmarks

- Using SysBench benchmark tool
  - http://www.sourceforge.net/projects/sysbench
  - Developed for testing MySQL scalability on OLTP workloads
  - Easy to set up, a lot of options to adjust workload
- Different data access distributions
  - Uniform – all rows have same probability to be accessed
  - Special - highly skewed distribution, typical in real world
- No full detail disclosure due to time constrains
- Results in Transactions/sec - larger numbers better.
- Will be checking:
  - CPU scalability, Number of connections, Data size, Page sizes, File Systems, Kernel Versions

MySQL/InnoDB CPU Scalability

- Sun V40z / 4x 2390MHZ Opteron / Solaris 10/ 8GB RAM
- Read/Write, Special distribution, 1mil rows, 16 threads
- Similar scalability on Linux

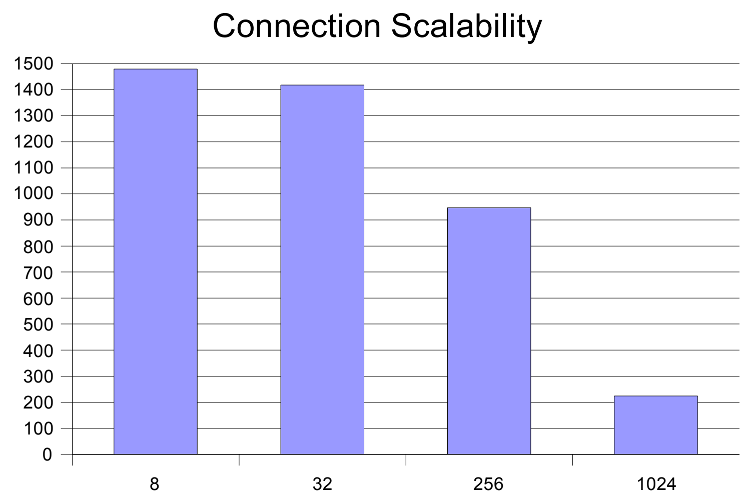
CPUs	Trans/sec	Ratio
1	382	
2	677	1.77
4	1130	2.96



Connections Scalability

- Sun V40z / 4x 2390MHZ Opteron / Solaris 10/ 8GB RAM
- 1m rows, Special, Read Only, 4CPU
- Read Only workload has even larger regression

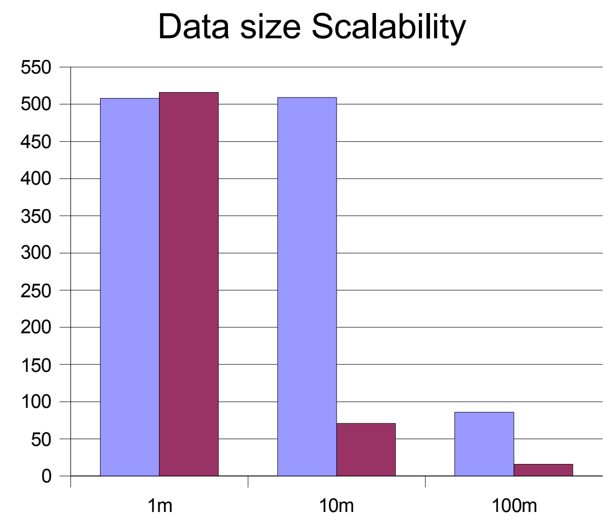
Connections	Trans/sec	Ratio
8	1479	
32	1418	0.96
256	947	0.64
1024	224	0.15



Data size Scalability

- 4*Xeon 2.0Ghz HT, 4GB RAM, 8 drives RAID10 (SATA)
- Benchmarks with 1,10,100m rows on EXT3, 32 threads
- Special and Uniform distributions, Read Write
- Data access pattern role is often underestimated

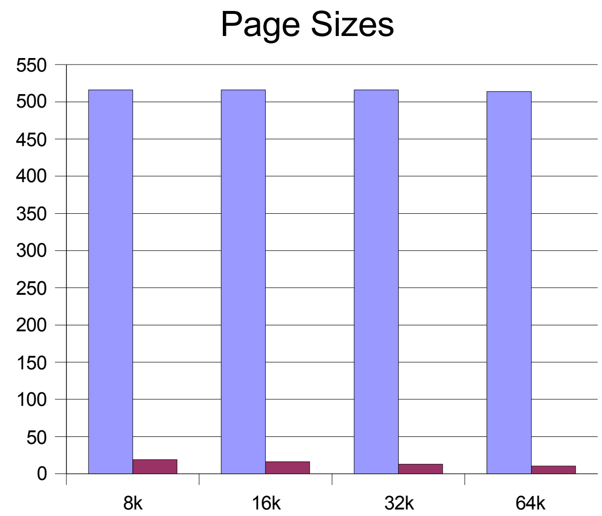
Rows	Special	Uniform
1m	508	516
10m	509	71
100m	86	16



InnoDB Page sizes

- 4*Xeon 2.0Ghz HT, 4GB RAM, 8 drives RAID10 (SATA)
- 8k,16k, 32k, 64k page sizes on EXT3, 32 threads
- 1m and 100m row workloads, RW, Uniform
- MySQL Server recompilation needed to change page size
  - Only 16K officially supported

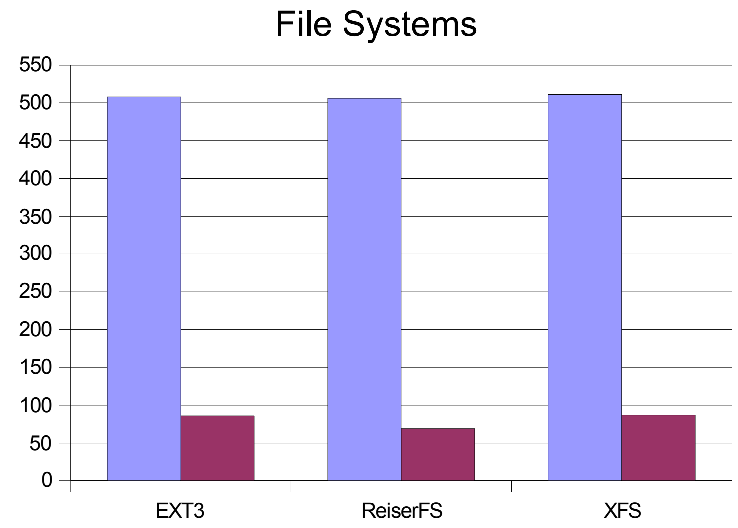
Page size	1m	100m
8k	516	19
16k	516	16.1
32k	516	12.8
64k	514	10.5



File Systems

- 4*Xeon 2.0Ghz HT, 4GB RAM, 8 drives RAID10 (SATA)
- RH AS 4.0 kernel, elevator=deadline
- Read/Write, Special distribution

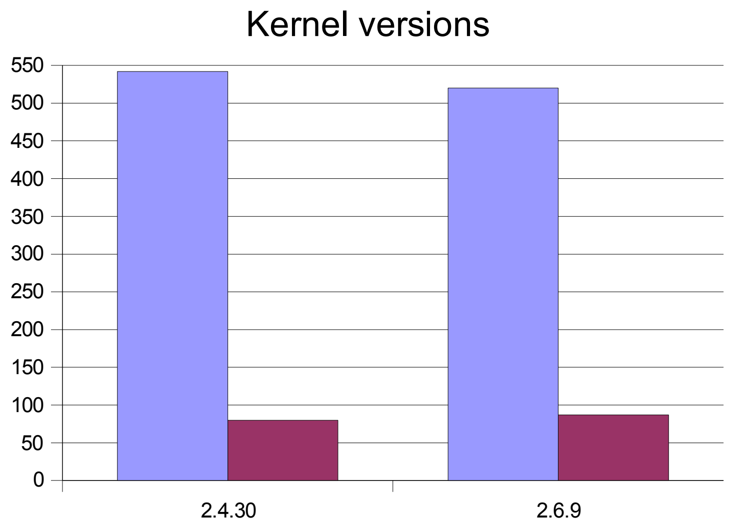
File Systems	1m	100m
EXT3	508	86
ReiserFS	506	69
XFS	511	87



Linux Kernel versions

- 4*Xeon 2.0Ghz HT, 4GB RAM, 8 drives RAID10 (SATA)
- Read/Write, Special distribution, EXT3
- 2.4.30 vs 2.6.9, elevator=deadline "vanilla" versions.

File Systems	1m	100m
kernel 2.4.30	542	80
kernel 2.6.9	520	87



Resources

- MySQL Online Manual – great source for Information
  - http://dev.mysql.com/doc/mysql/en/index.html
- SysBench - Benchmark and Stress Test tool
  - http://sourceforge.net/projects/sysbench
- MySQL Benchmarks mailing list
  - benchmarks@lists.mysql.com
- Write us your questions if you forgot to ask
  - peter@mysql.com tobias@mysql.com
  - Feel free to grab on the conference to discuss your problems