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MySQL

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Demystified MySQL/InnoDB Performance Tuning

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Agenda

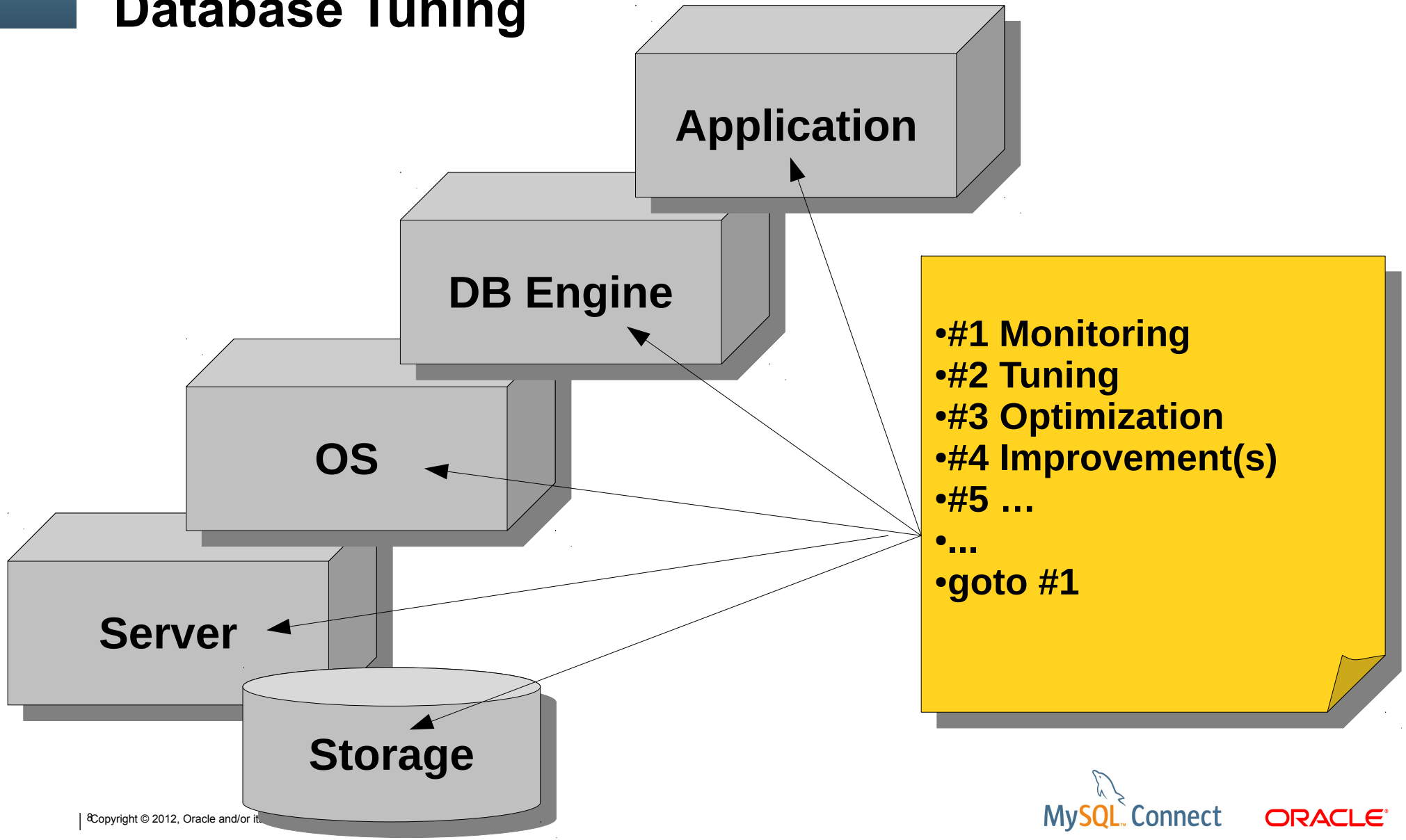
- MySQL Performance overview
- General tuning overview
- MySQL bottlenecks and solutions
- InnoDB bottlenecks and solutions
- Performance improvements made in MySQL 5.5 and 5.6
- Pending issues..
- Q & A

Preface: Too Close Look...

Preface: Less Close Look, Zoom--

Preface: Overall view, Zoom= Zoom/10

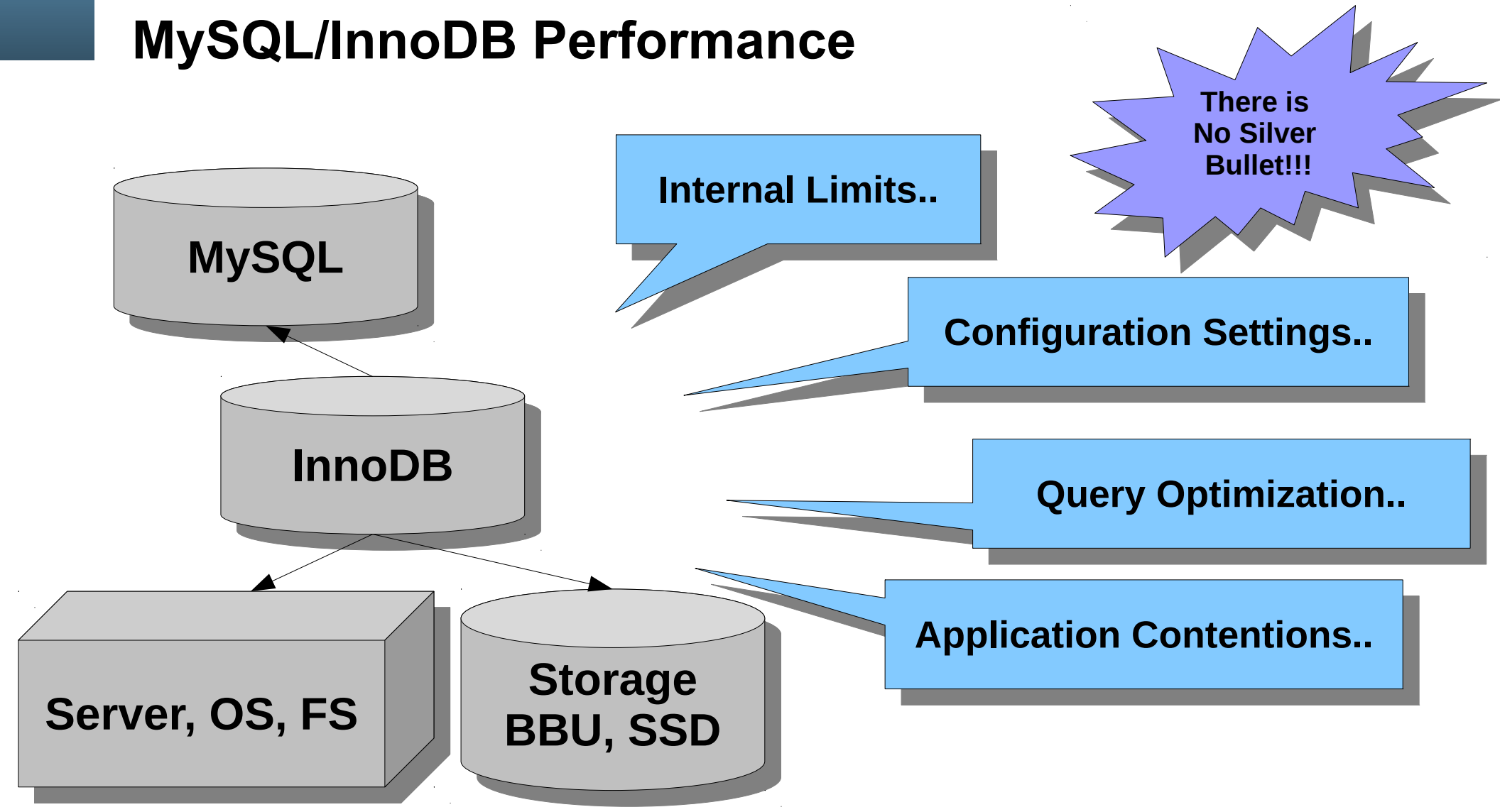
Database Tuning



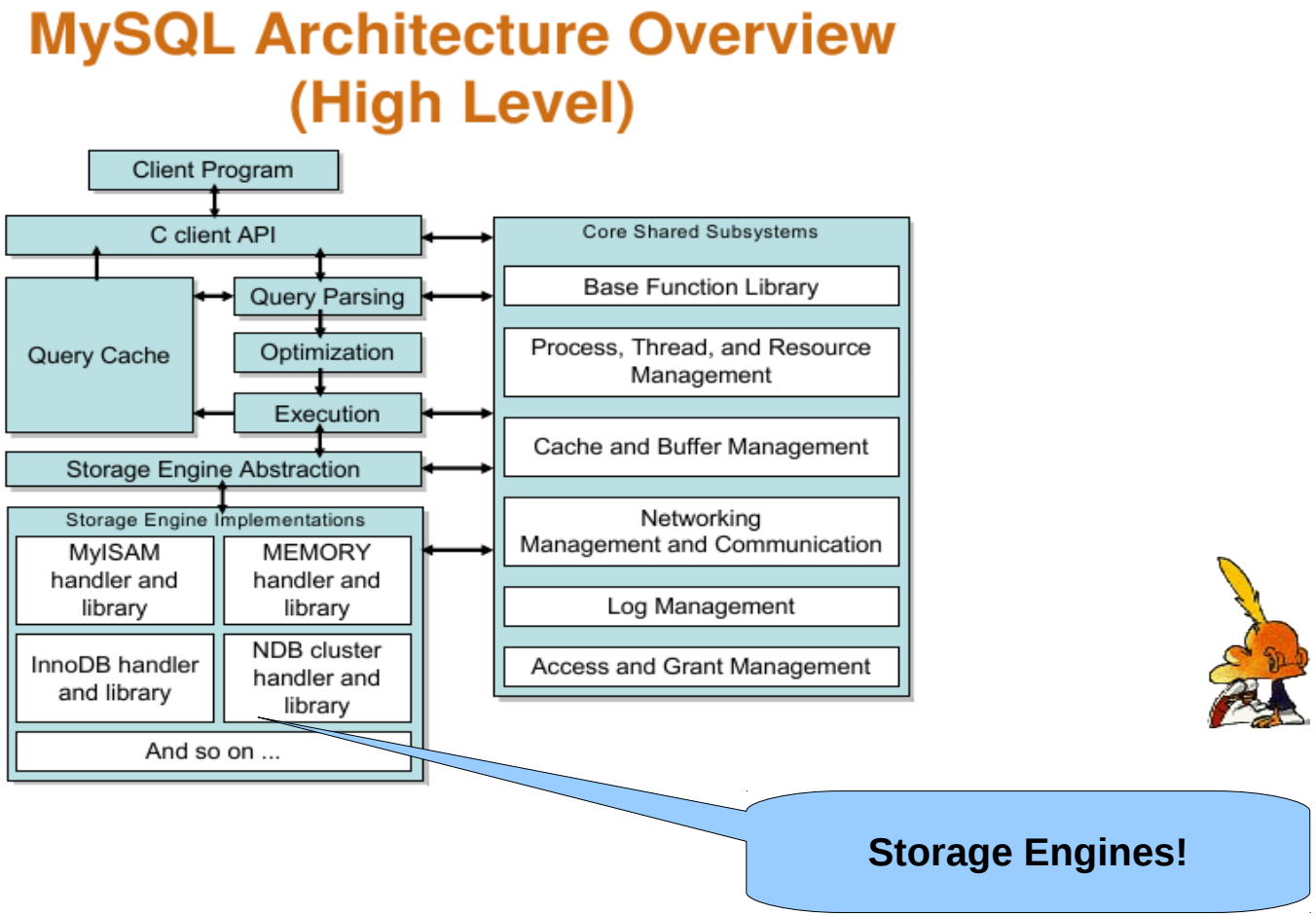
Start points for an optimal MySQL Server

- Think “Performance” from the beginning :-)
- Server:
  - Faster CPU is better! 32 cores is good enough ;-)
  - OS is important! - Linux, Solaris, etc.. (and Windows too!)
- Storage:
  - Don't use slow disks :-))
  - Having battery protected write cache helps REDO writes!
  - Having SSD drives helping random access! (index/data)
  - FS is important! - ZFS, UFS, QFS, VxFS, EXT3, EXT4, XFS, etc..
  - O_DIRECT or not O_DIRECT ;-)
- Network:
  - Don't forget!! :-) - 10Gbit is great! (faster is better)

MySQL/InnoDB Performance



MySQL Design



MySQL Design

- Multi-Threaded database
  - Fast context switch!
  - Simplified data access!
  - Concurrent access?..
  - Scalability?..

- Storage Engines
  - Initially: MyISAM only
  - Then, with InnoDB: started to match expectations of a “true RDBMS” ;-)
  - Many other engines (MEMORY, CSV, NDB, PBXT, etc.)
  - CREATE TABLE ... ENGINE=<NAME_OF_ENGINE>
  - ALTER TABLE ... ENGINE=<NAME_OF_ENGINE>
  - Did you choose a right Engine?..

MyISAM Engine (since 1994)

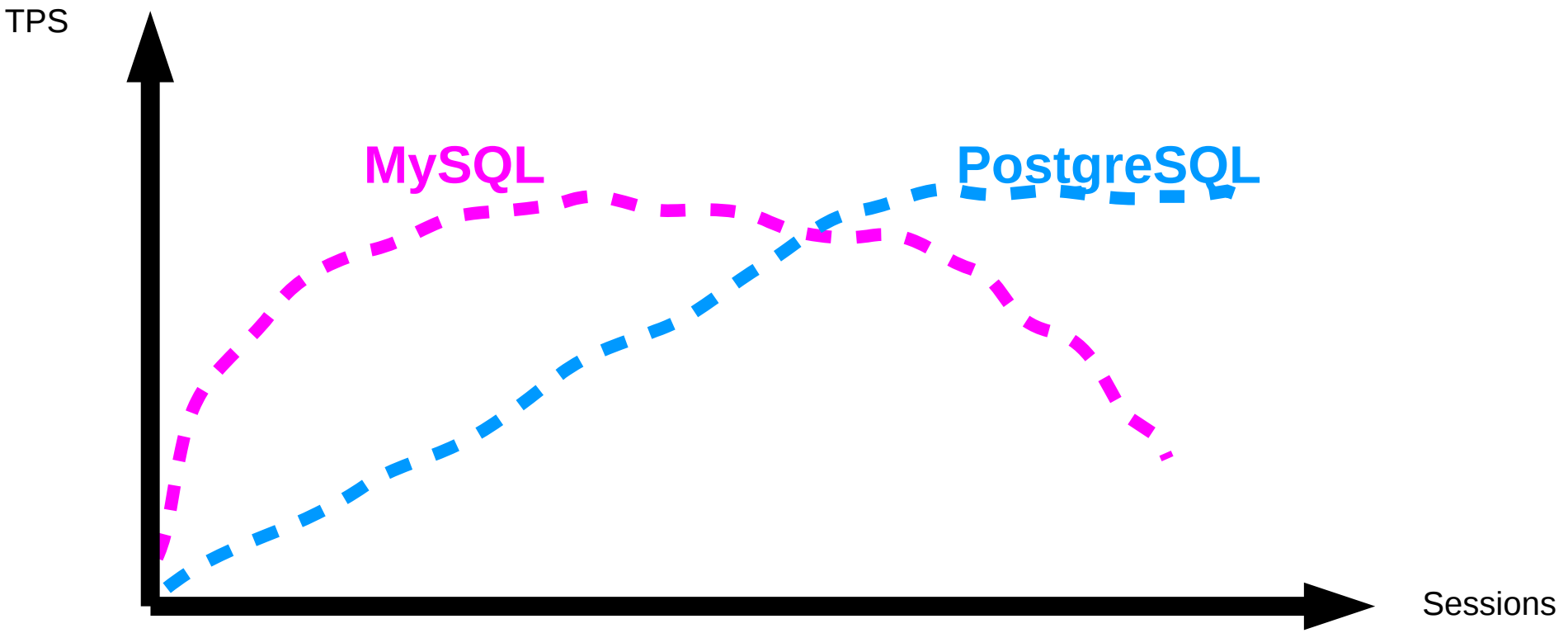
- Non-transactional! / No fast recovery! :-)
- Cache
  - Index only
  - Data => FS cache
  - mysql> flush tables;
- Single Writer @Table
  - Main bottleneck! => single writer
  - Solutions: delayed inserts, low priority
- Query plan
  - Index forcing may be necessary (hint)
- Extremely simple and lightweight

Why MySQL + MyISAM was successful?..

- Full Text search queries out-of-the-box!
- SELECT count(*) ... :-))
- Extremely SIMPLE!
  - my.conf => configuration parameters
  - mysql.server start / stop
  - Database => directory
  - Table => directory/Table.MYD, Table.MYI, Table.frm
  - $ cp Base1/Table.* /other/mysql/Base2

- Data binary compatibility! (ex: reports via NFS)
- Replication ready!
- Very FAST! (until some limit :-))
- RW workload is killing.. (but on 2CPU servers it was ok ;-))

RW benchmark: MyISAM vs PostgreSQL (in 2000)



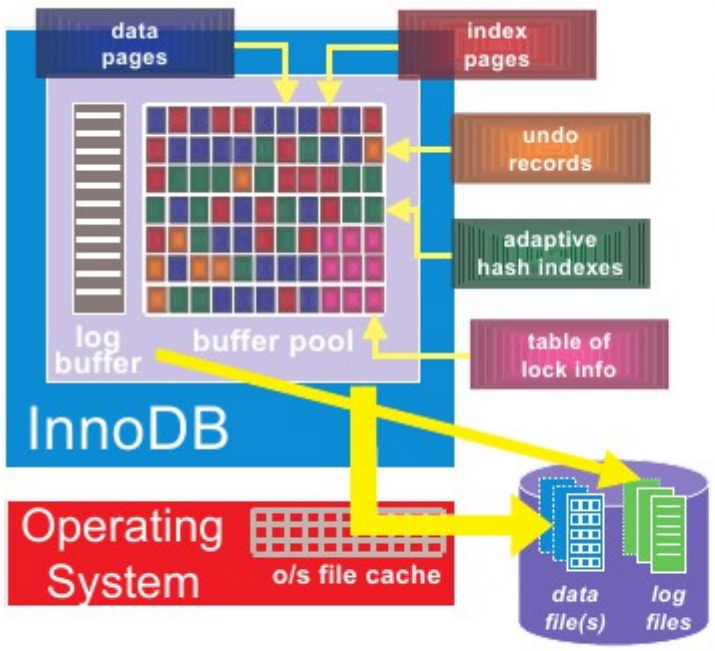
InnoDB Changing the game (since 2001)

- Row-level locking
- Index-only reads
- True transactions / UNDO
- Auto recovery
- Double write / Checksums
- Tablespaces or File-per-Table option
- Buffer pool
- Multi-threaded
- Currently the fastest transactional disk-based MySQL Storage Engine!

InnoDB Design

- All Data going via Buffer Pool
- Fuzzy Checkpoint
- Group Commit
- Log flush policy
- Threads:
  - User sessions
  - Master
  - Read Ahead
  - Page Writer
  - Log Writer

- Performance



- When data & index pages are read, they are cached for re-use, and are replaced when least-recently-used
- InnoDB on-the-fly creates adaptive hash indexes depending on query pattern (more on this later)
- On updates, row-level locking information is maintained in an efficient bit-map
- Undo info, used to reverse a transaction's changes, is cached in memory, later written to sys tblspace
- Compact representation of changes is kept in log buffer. On commit, log records are written to log file (but no buffer pool pages need to be written)
- Eventually, data, index and undo pages are flushed to data files

INNOBASE

MySQL Performance (traditionally, in the past)

- Choose the right Engine for each of your table/database
  - Read-Only / Text search => MyISAM
  - Read+Write / Transactions => InnoDB
  - Short/Small Transactions + DB fits in RAM => NDB

- Tune / Optimize your queries
- Once scalability limit is reached => go for Distributed:
  - Sharding
  - Master / Slave(s) => role-based workload
  - Any other similar :-)

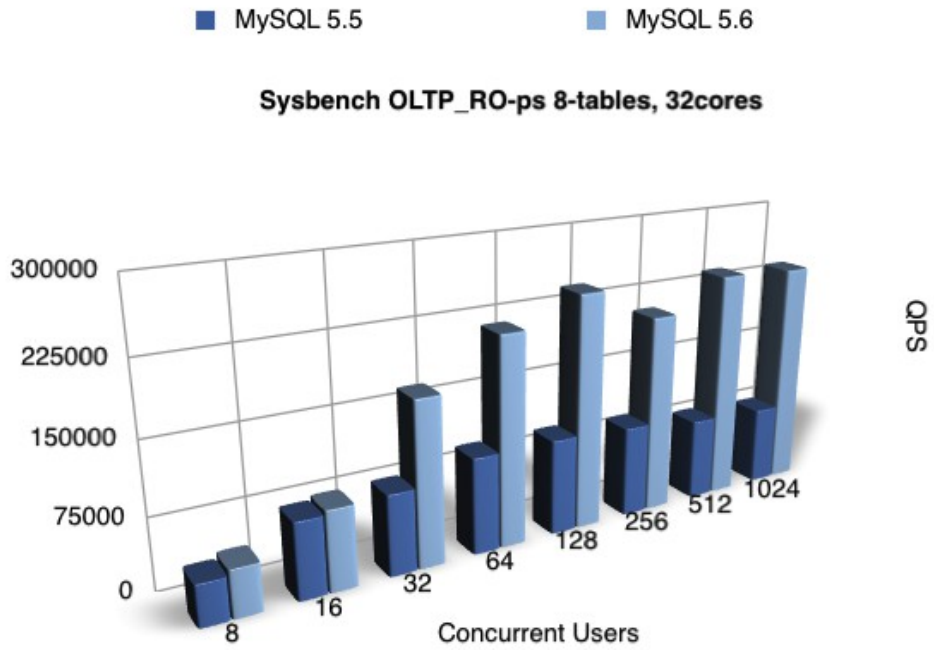
- Big Users: Google, Facebook, Amazon, (and even USA elections in 2008 ;-))..
- Scalability = Main Performance Problem!...

Things are changing constantly... :-)

- MySQL/InnoDB Scalability:
  - 2007 : up to 2CPU...
  - 2008 : up to 4CPU cores
  - 2009 : up to 16CPU cores (+Sun)
  - 2010 : up to 32CPU cores (+Oracle)
  - 2012 : up to 48CPU cores..
  - 2014 : …?? ;-)
  - NOTE: on the same HW performance is better from version to version!
- InnoDB today:
  - At least x4-8 times better performance than 2-3 years ago ;-)
  - Capable of ~~100.000~~ over 300.000 QPS(!)
  - Full Text Search (FTS) and Memcached
- Stay tuned ;-)

Sysbench OLTP_RO: MySQL 5.5 vs 5.6

- Test details:
  - All results are obtained on the same 32core Linux Server
  - Results are presented in QPS
  - Only Read + Write operations reported by Sysbench are counted
  - Each QPS number is representing the best possible performance level obtained on each MySQL version with the most optimal tuning applied..



Sysbench OLTP_RO 8-tables: MySQL 5.5 vs 5.6

- Test details:
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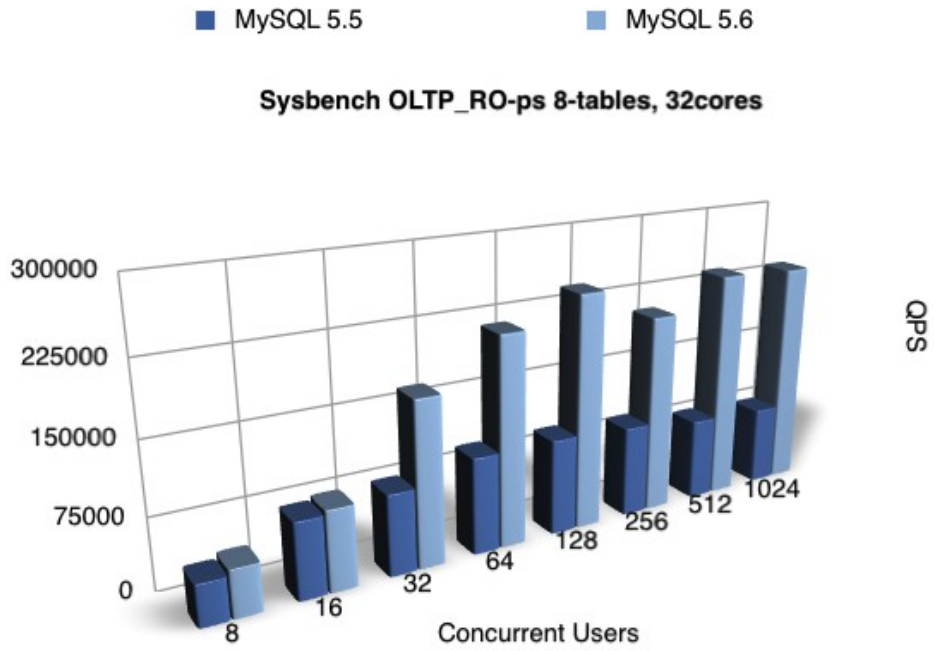

Sysbench RO Simple-Ranges: MySQL 5.5 vs 5.6

- Test details:
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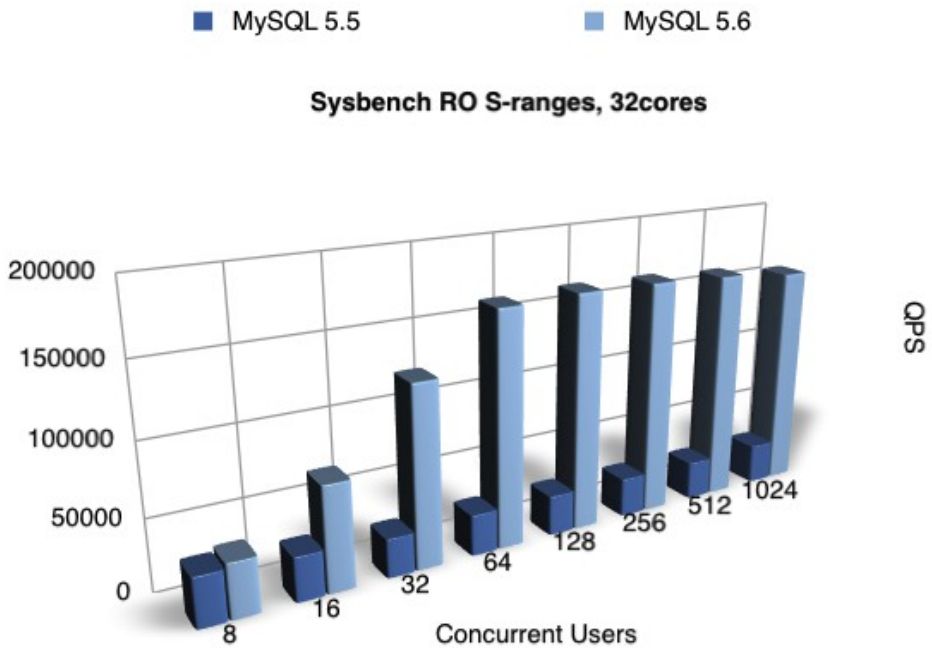

Sysbench OLTP_RW: MySQL 5.5 vs 5.6

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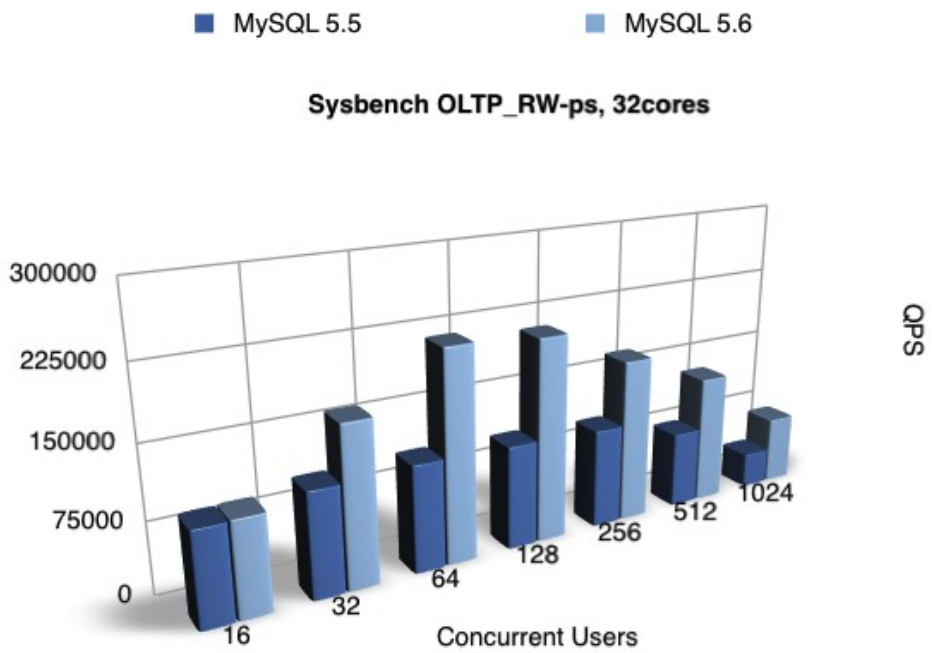


But it was not easy... Except if.. :-)

- Let's split the problems...
- MySQL + System
- MySQL Internals
- InnoDB Internals
- InnoDB and I/O

MySQL & OS : memory allocation

- Be Aware: “Default” malloc() LIB is usually not MT-concurrency oriented !!
- Concurrent memory allocation may freeze threads
- Important part of MySQL is written on C++
  - Creation of any variable calls malloc() automatically in C++ !

- Use MT-oriented solutions:
  - HOARD (was the first and most fast before)
  - Solaris: libmtmalloc, libumem
  - Linux: libtcmalloc, jemalloc
  - Force with LD_PRELOAD:

```
$ LD_PRELOAD=/usr/lib64/libjemalloc.so.1
$ export LD_PRELOAD
```

NOTE: it's a choice according your workload!

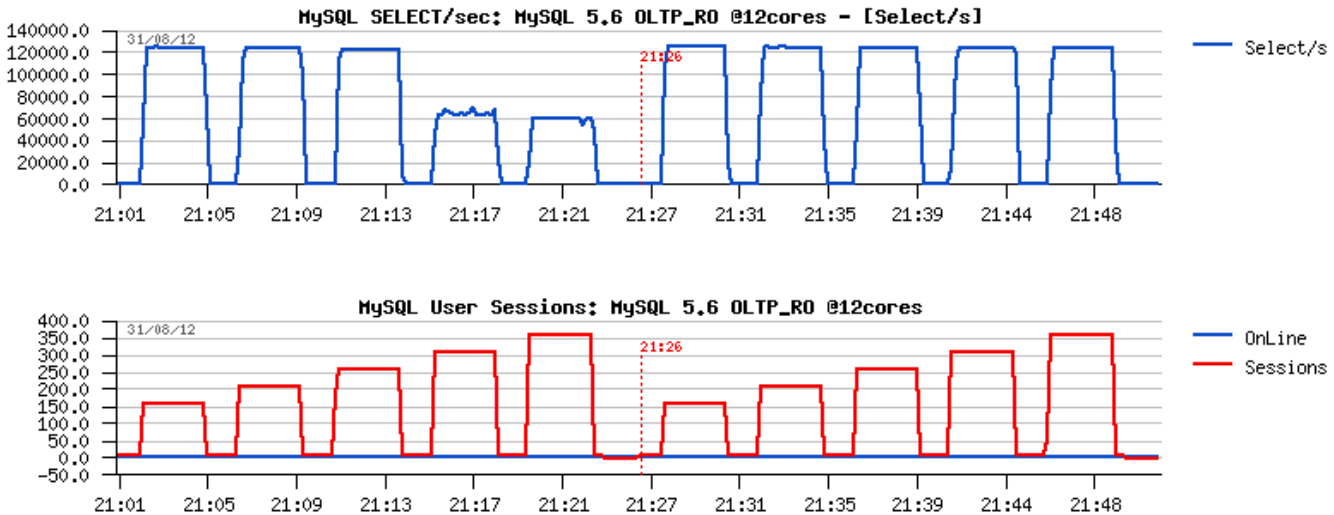
MySQL Internals : LOCK_open contention

- MySQL 5.5 and before:
  - Keep “table_open_cache” setting big enough!
  - Monitor global status for '%opened%'
  - Once this contention become the most hot – well, time to upgrade to 5.6 ;-))

- Since MySQL 5.6:
  - Fixed, part of MDL now :-)
  - But it doesn't mean “table_open_cache” can be low ;-)
  - Monitor PFS Waits!
  - Monitor “table_open_cache%” status variables!
  - Keep “table_open_cache_instances” at least bigger than 1
  - But MDL lock contention become the most hot if other contentions are gone..
  - MDL mutex lock contention => fix in progress (already a working prototype)
  - MDL rw-lock contention => more complex, planned for MySQL 5.7

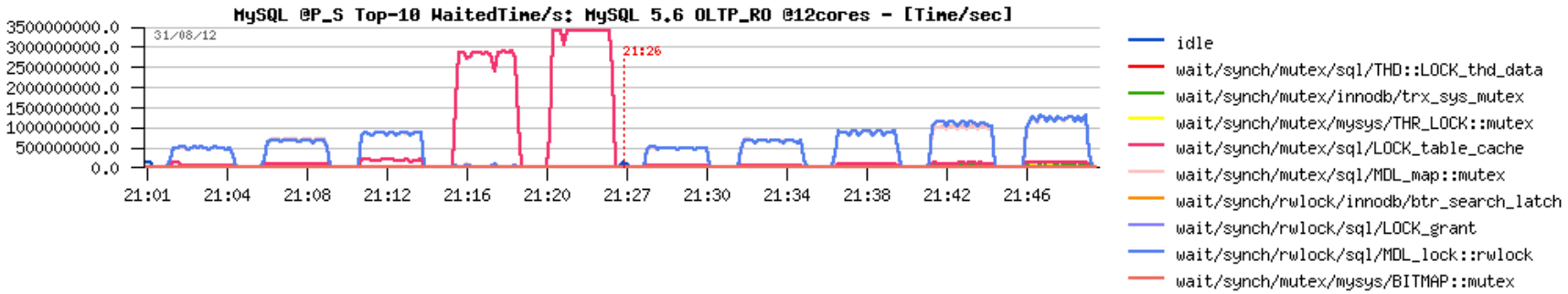
MySQL 5.6 Internals : low table_open_cache

- MySQL 5.6 :
  - Not big enough “table_open_cache” setting

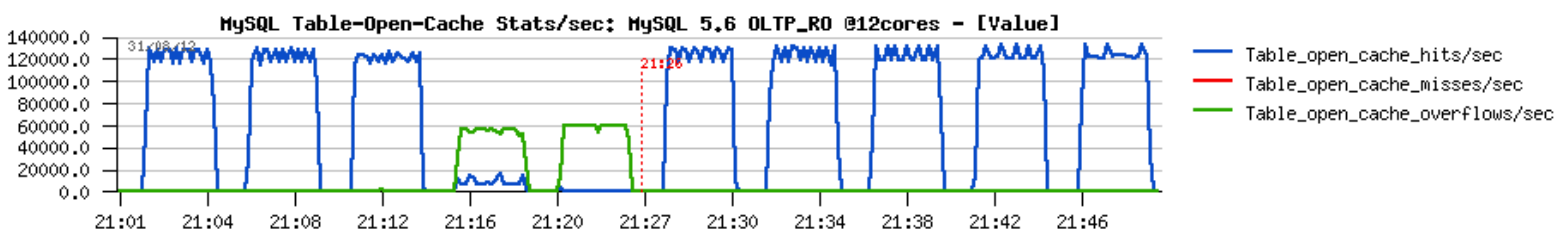


MySQL 5.6 Internals : low table_open_cache (2)

- MySQL 5.6 :
  - Not big enough “table_open_cache” setting
  - PFS Waits monitoring: LOCK_table_cache become the most hot:

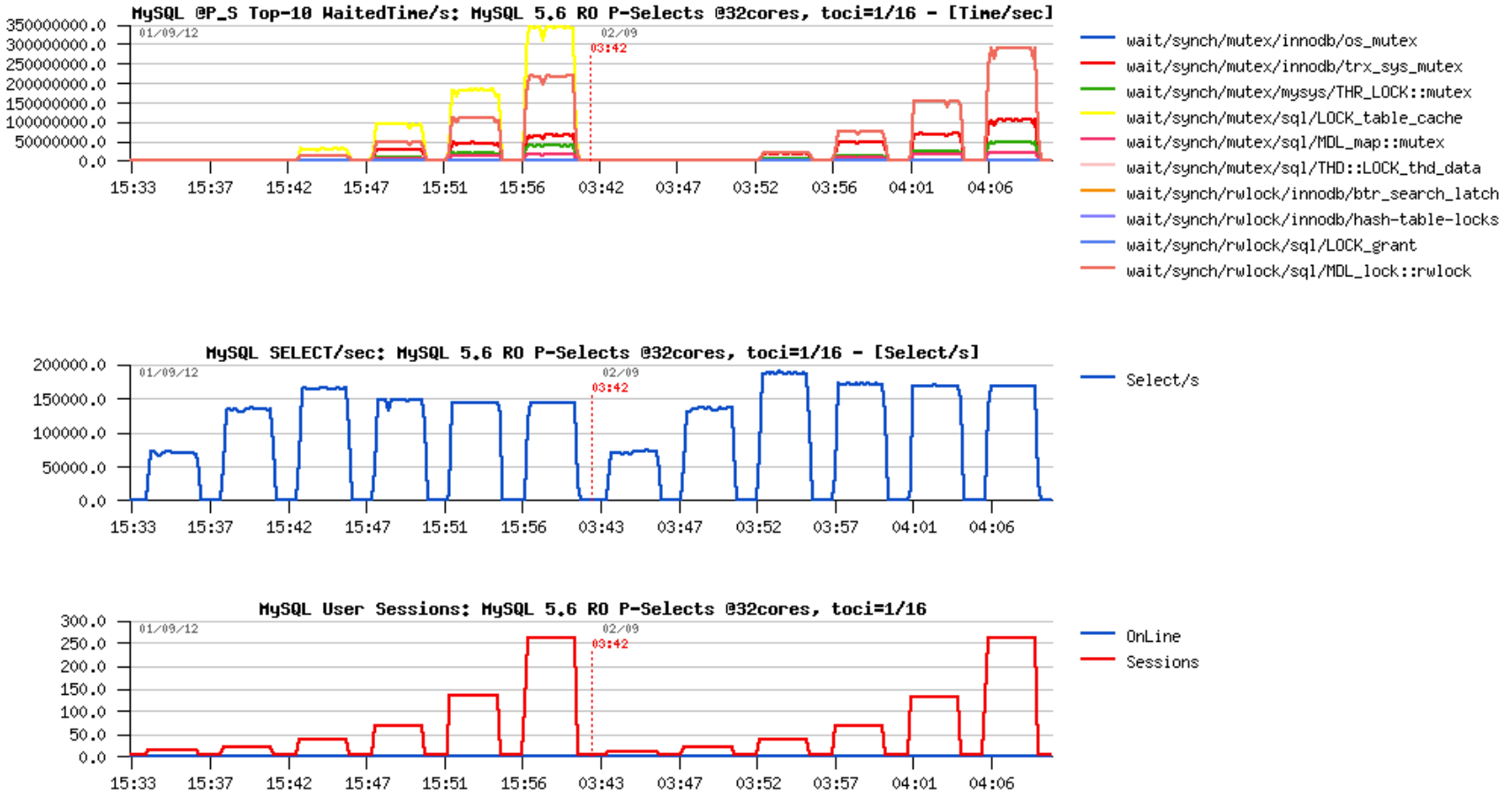


  - Table_open_cache% status:



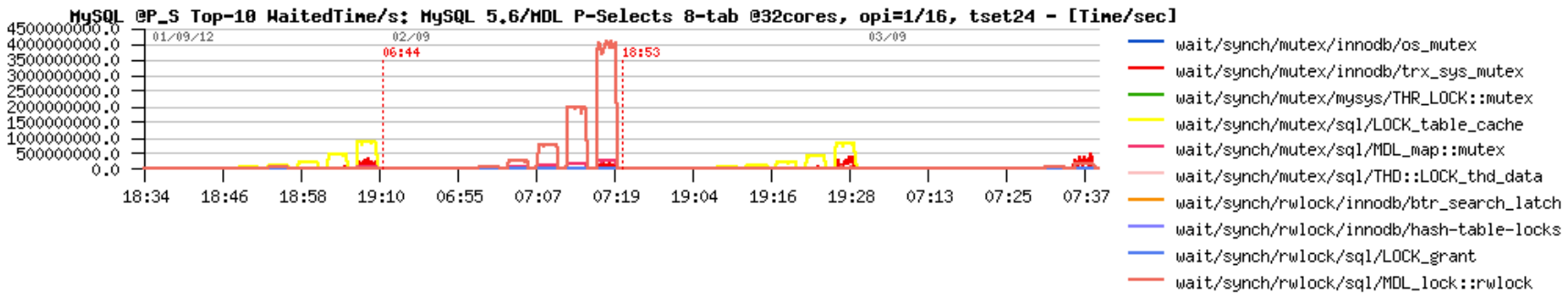
MySQL 5.6 Internals : table_open_cache_instances

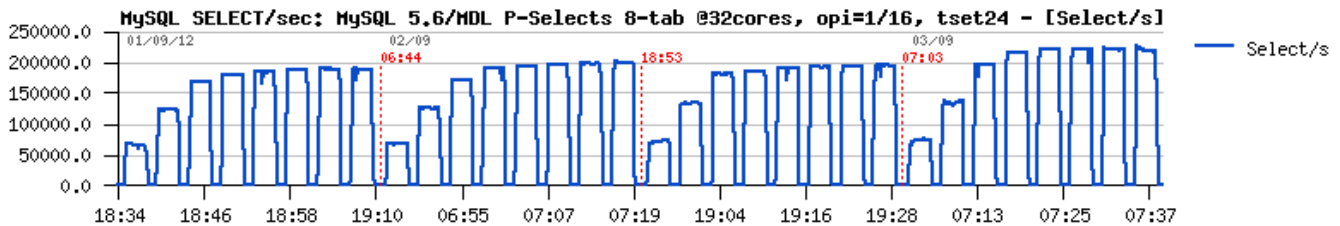
- MySQL 5.6 :
  - When LOCK_table_cache wait is on top, the gain is usually well visible:

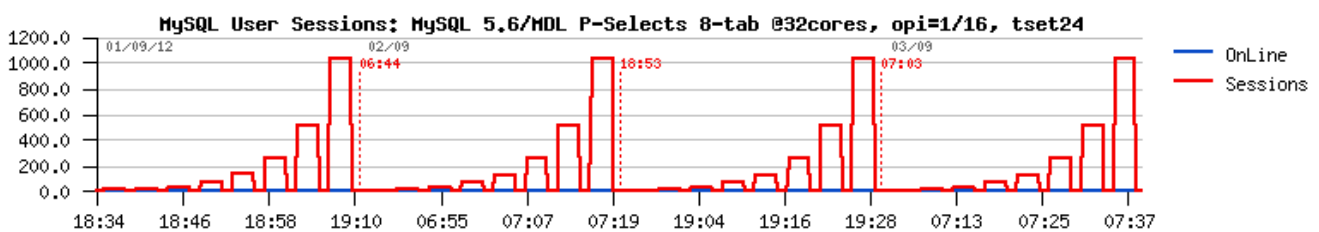


MySQL 5.6 Internals : MDL contention

- MDL lock involved on <u>every</u> table for every query, fix in progress..
  - Test: 5.6 opi=1, 5.6 opi=16, 5.6-mdl-fix opi=1, 5.6-mdl-fix opi=16

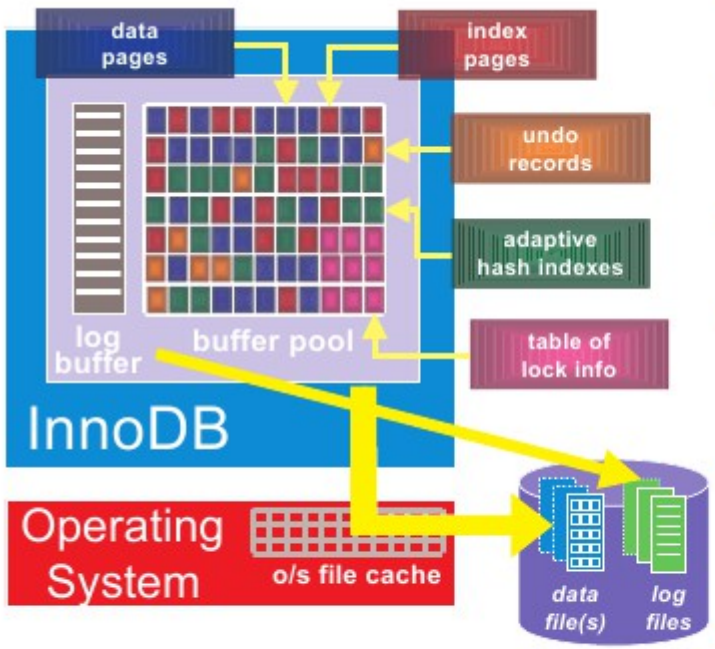






InnoDB : sources of performance issues

- Buffer Pool
- Internal locks
- Concurrency
- IO capacity
- Purge
- Flushing
- etc...



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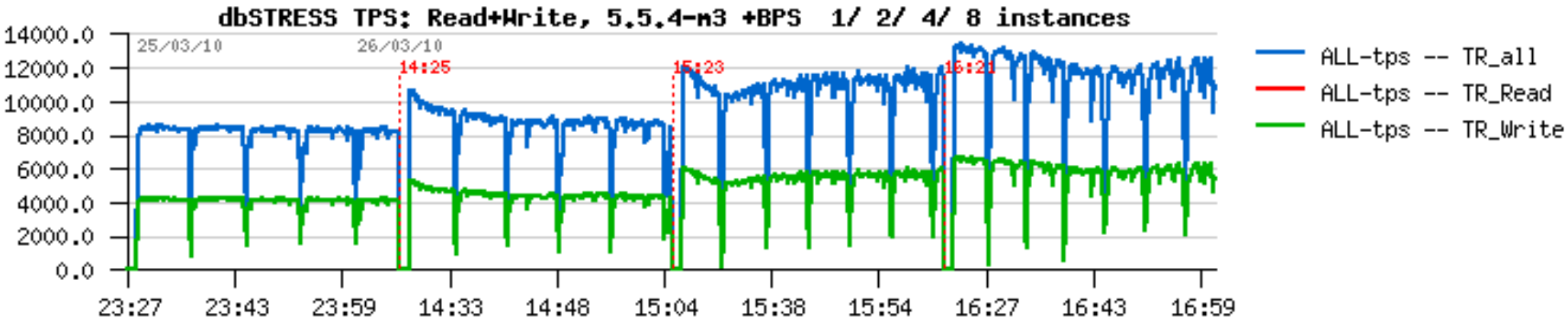
INNOBASE

InnoDB : Buffer Pool instances

- Before 5.5.4:
  - even all your data pages are seating in the Buffer Pool there was still a contention on the Buffer Pool mutex.. - so, needs a split!
  - was the main showstopper for all the following improvement in 5.5 !
- Split via hash table:
  - ok, but may require a huge hash table, hit hash table code scalability limits..
- Multiple buffer instances :
  - scales better, open door for new features!
- NOTE :
  - in 5.5 contention still depends on the data/page distribution within a Buffer Pool (as in Oracle RDBMS too)
  - In 5.6 hashing is added to the pages, so the impact is less dramatic + more stable performance

InnoDB : Buffer Pool instances in MySQL 5.5

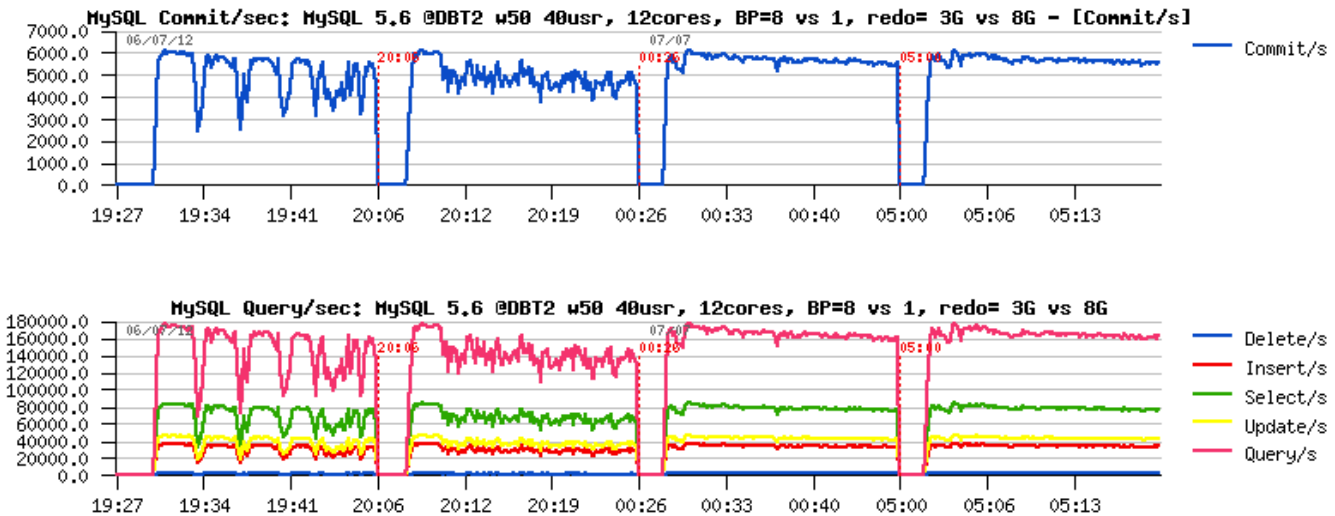
- RW Workload
  - innodb_buffer_pool_instances= 1/ 2/ 4/ 8



InnoDB : Buffer Pool instances in MySQL 5.6

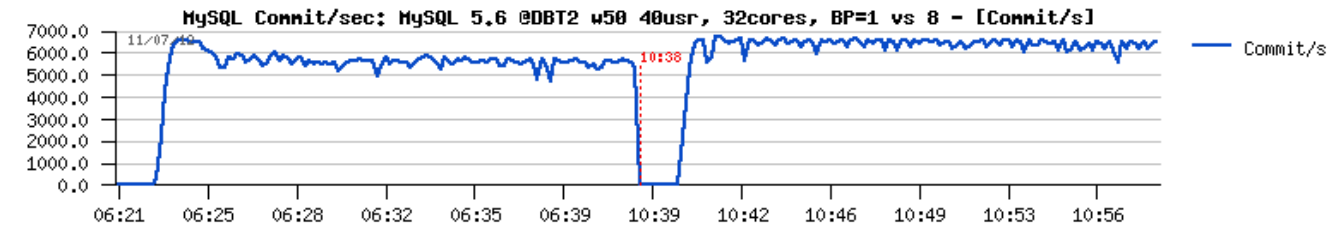
- DBT2 (heavy RW) Workload
  - innodb_buffer_pool_instances= 1/ 8
  - Problem: sync flushing...
  - Solutions: bigger REDO, faster storage, tuned Adaptive Flushing

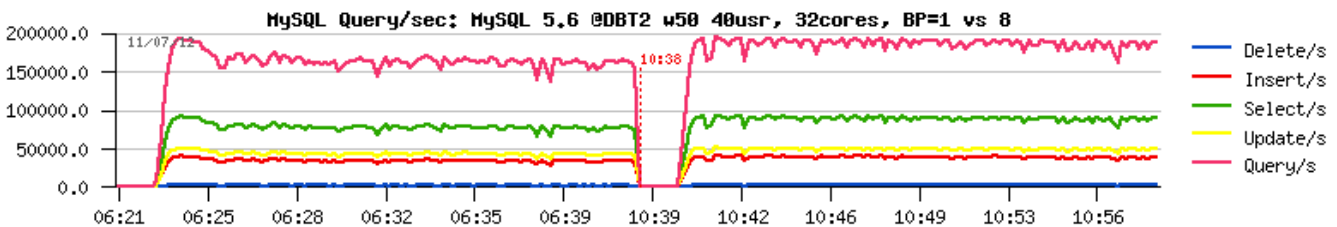
- Bigger REDO:



InnoDB : Buffer Pool instances in MySQL 5.6 (2)

- DBT2 (heavy RW) Workload
  - innodb_buffer_pool_instances= 1/ 8
  - Same REDO, just faster storage:



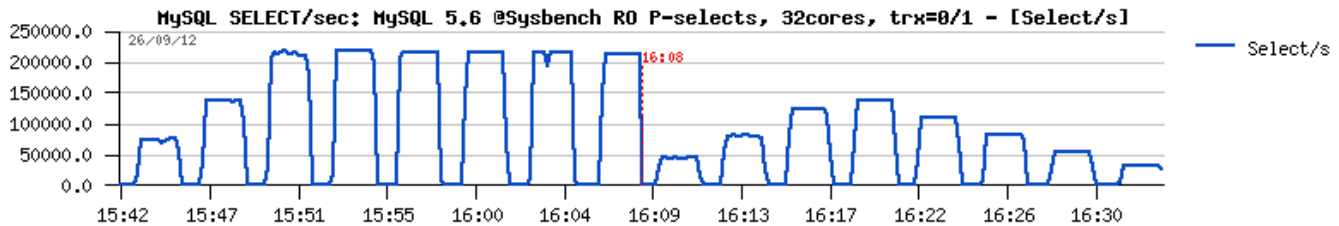


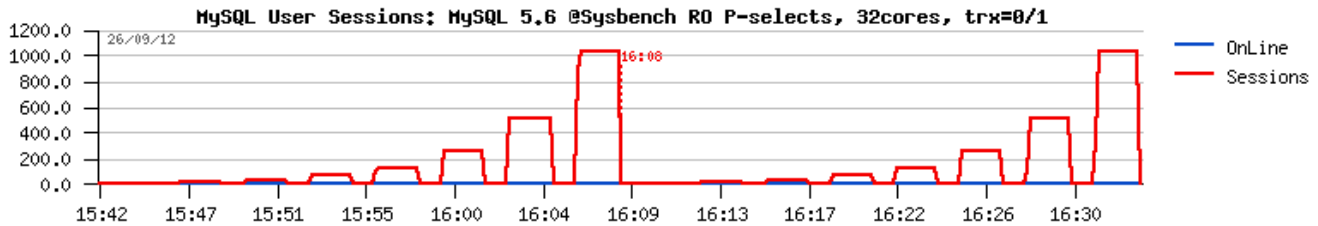
InnoDB : Internal locks

- MySQL 5.5 :
  - kernel_mutex: the most hot, blocking factor in most of workloads (RO & RW)
  - btr_search_latch RW-lock: used by AHI, can be avoided by switching AHI off
  - Index lock: blocking writes and purge(!), contention can be reduced by using partitions (but not always applicable)..
- MySQL 5.6 :
  - split of kernel_mutex !!
  - other mutex contentions became more hot, finally reducing overall performance..
  - trx_sys mutex became a showstopper for any further improvement..
  - trx_sys is mainly used by every transaction, even RO workload.. hm..
- RO transactions(!) :
  - explicit START TRANSACTION read only
  - or having AUTOCOMMIT=1 and not involving any start transaction / begin/commit

InnoDB : Read-Only Transactions in MySQL 5.6

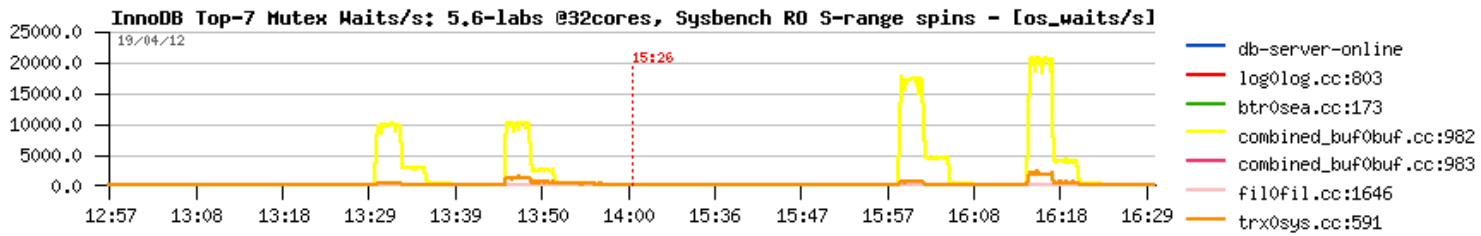
- Sysbench POINT-SELECTs RO Workload
  - Concurrent user sessions: 1, 2, 4 .. 1024
  - Using of transactions in sysbench = 0 / 1

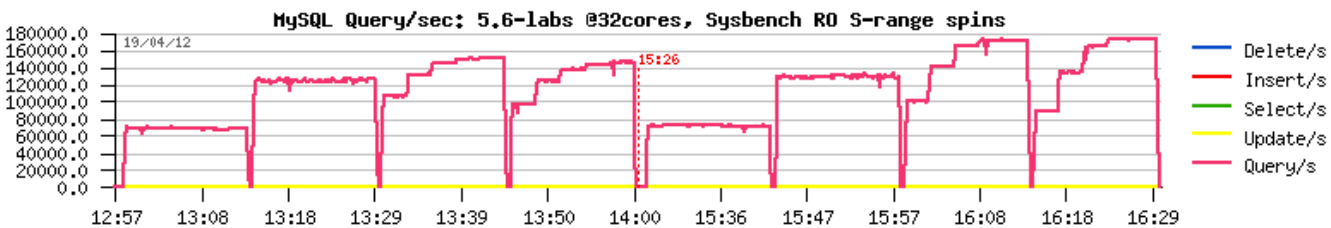




InnoDB : trx_sys mutex contention with more CPUs

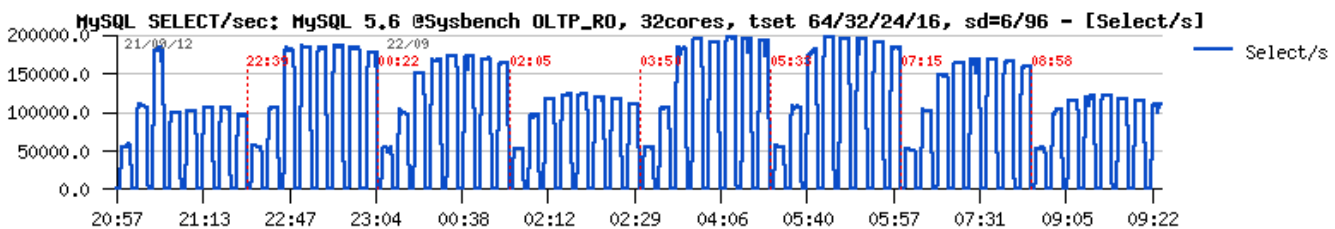
- Sysbench RO Workloads
  - With more CPU cores contention become more hot
  - Bind of mysqld to less cores helps, but the goal is to get benefit from more cores ;-)
  - Using innodb_thread_concurrency is not helping here anymore..
  - So, **innodb_spin_wait_delay** is entering in the game:

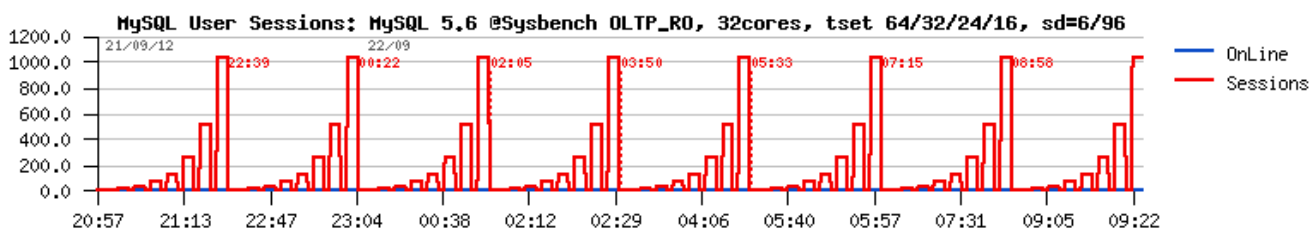




InnoDB : adapting innodb_spin_wait_delay

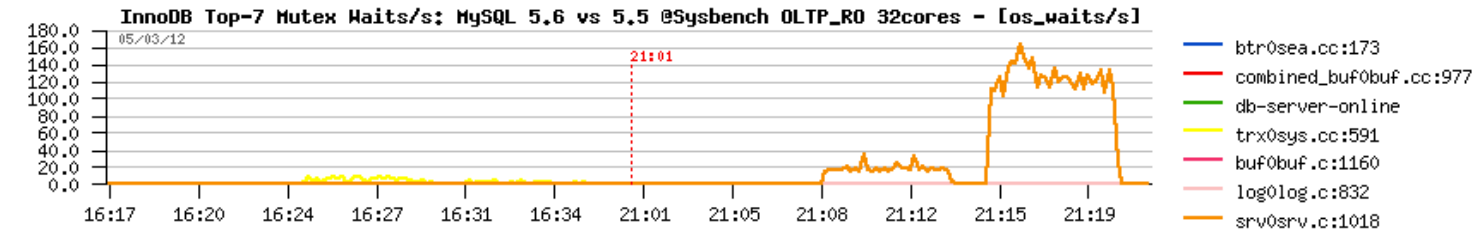
- RO or RW Workloads
  - NOTE: bigger innodb_spin_wait_delay is simply increasing the max random delay that user thread may sleep within a spin loop in wait for lock..
  - Ideally should be auto-adaptive.. while the same tuning works for 5.5 as well ;-)
  - General rule: default is 6, may need an increase with more cores
  - Test: 32-bi-threadi/ 32/ 24/ 16cores, spin delay = 6 / 96 :

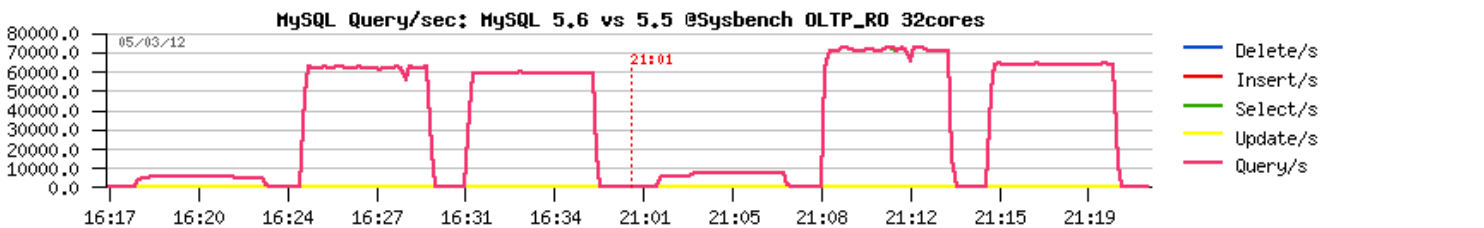




InnoDB : false sharing of cache-line = true killer

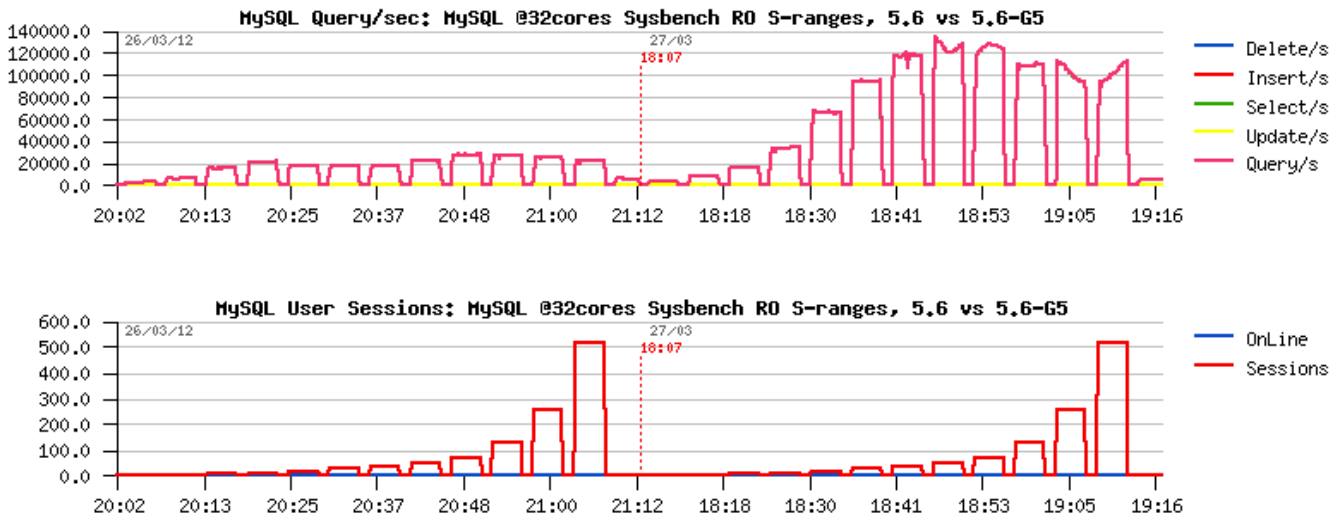
- RO or RW Workloads
  - Same symptoms in 5.5 & 5.6 : no QPS improvement between 16 and 32 user sessions:





InnoDB : false sharing of cache-line fixed!

- RO or RW Workloads
  - “G5” patch! :-)
  - x2 times better on Sysbench OLTP_RO, and x6 times on SIMPLE-Ranges!
  - NOTE: unfortunately the fix is not applicable on 5.5..



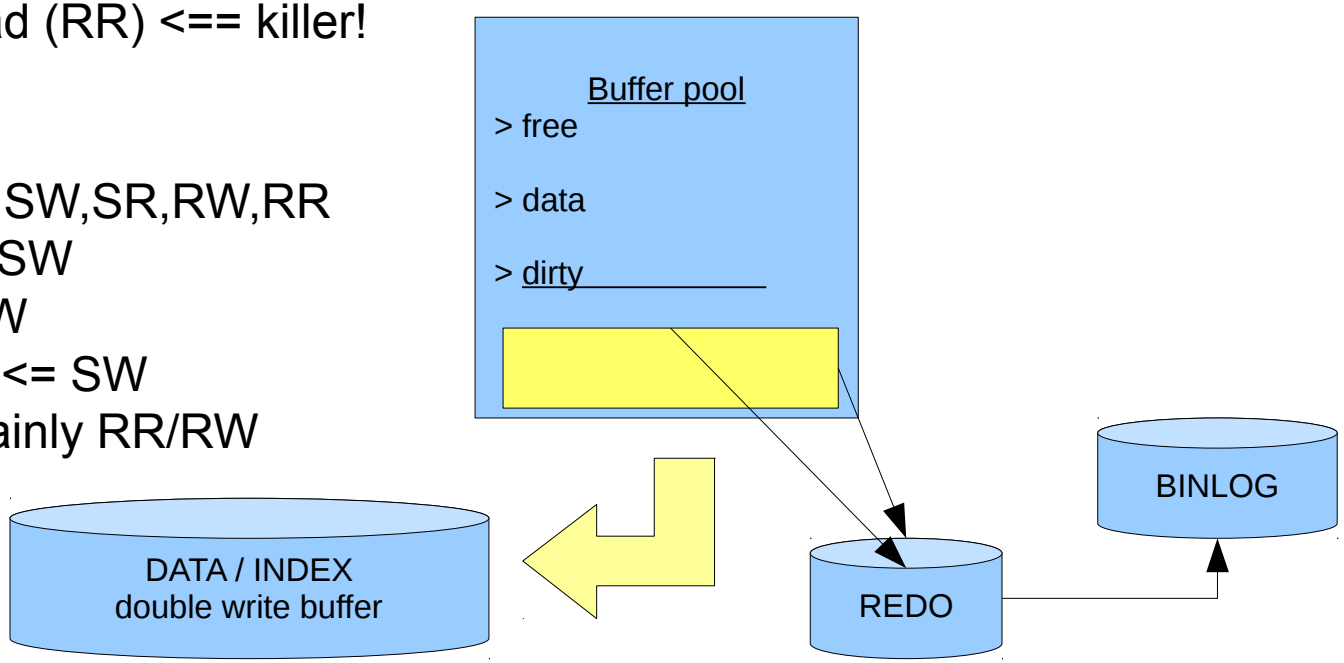
InnoDB : I/O level design

- Initially:
  - limited to 100 writes/sec...
  - 1 Read-Ahead thread
  - 1 Page-Write thread
  - 1 RSB
- Since MySQL 5.5 :
  - I/O capacity option!
  - Multiple Read helper and Write helper threads, + AIO support on Linux
  - x10-x100 faster recovery
  - Adaptive Flushing
  - Purge Thread
  - 128 RSB (+configurable!)
- Since MySQL 5.6 :
  - Several Purge threads, Page cleaner thread, improved Adaptive Flushing, over 4GB REDO logs, more...

InnoDB : I/O operations nature

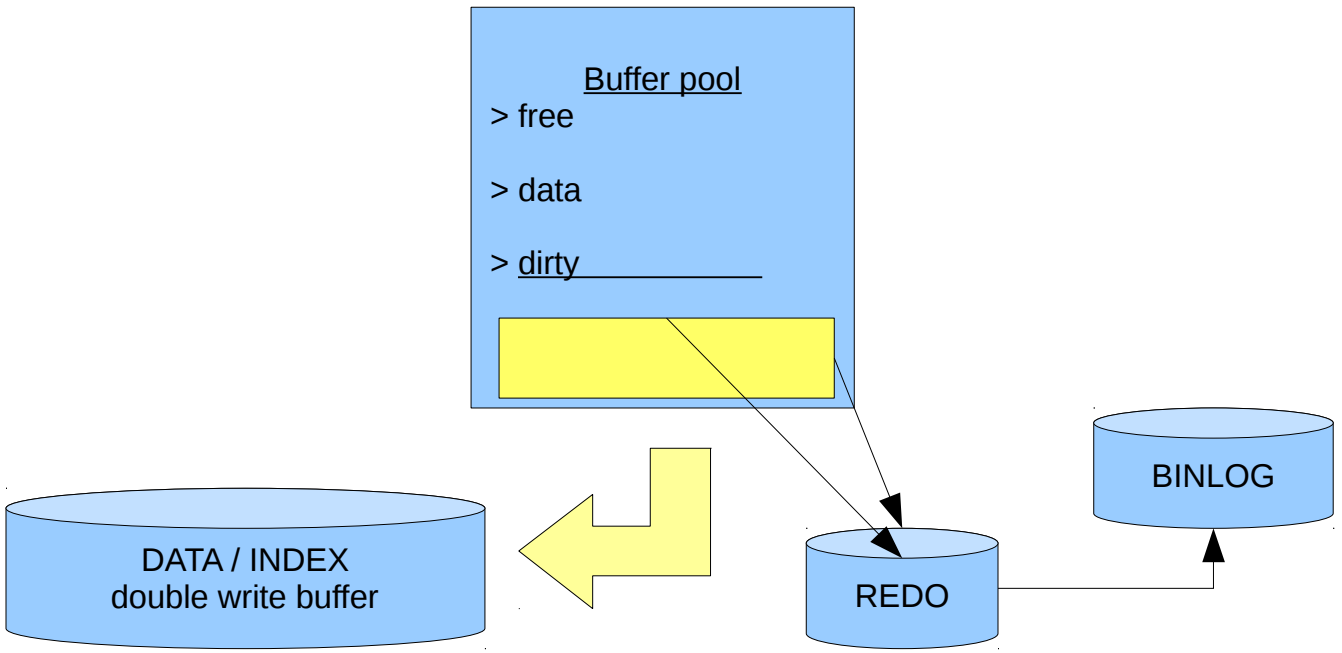
- Keep in mind the nature of I/O operation!
  - Sequential Write (SW)
  - Sequential Read (SR)
  - Random Write (RW)
  - Random Read (RR) <== killer!

- InnoDB
  - Data files <= SW,SR,RW,RR
  - Redo log <= SW
  - Bin log <= SW
  - Double write <= SW
  - UNDO <= mainly RR/RW



InnoDB : mix of I/O operations impact

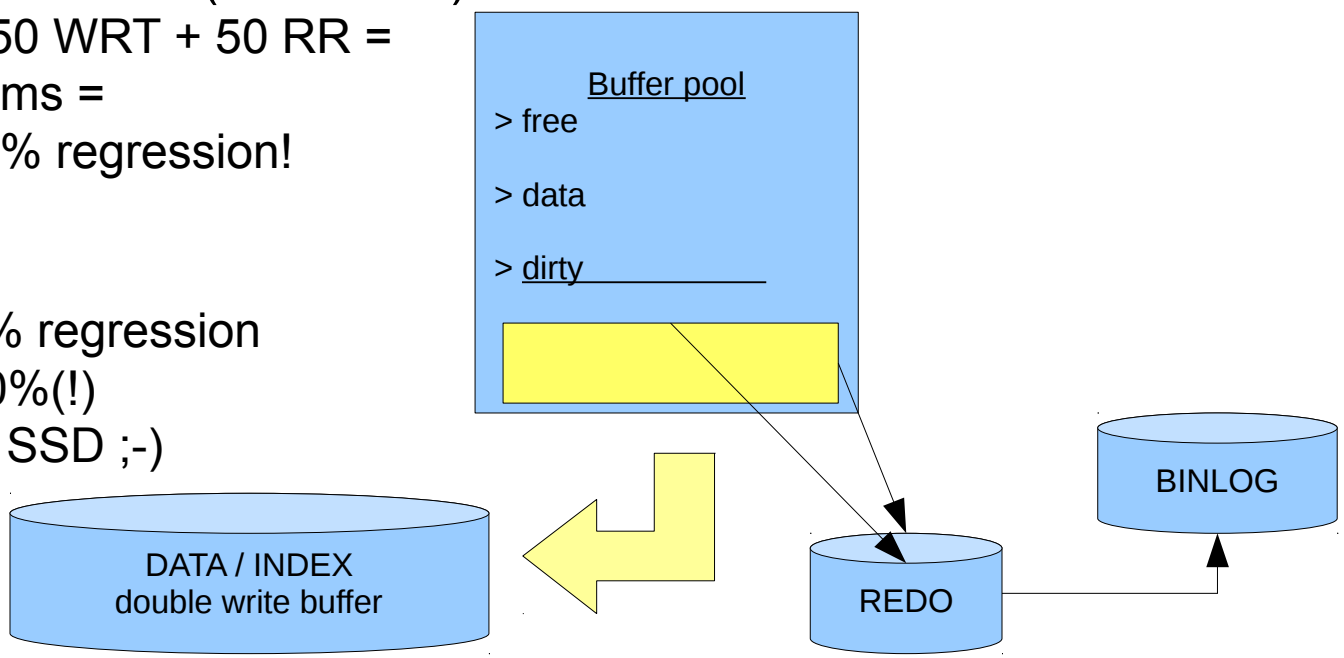
- For ex: you're doing 1000 writes/sec
- Now, 5% of your I/O operations become random read.. <= any % regression?



InnoDB : mix of I/O operations impact on HDD

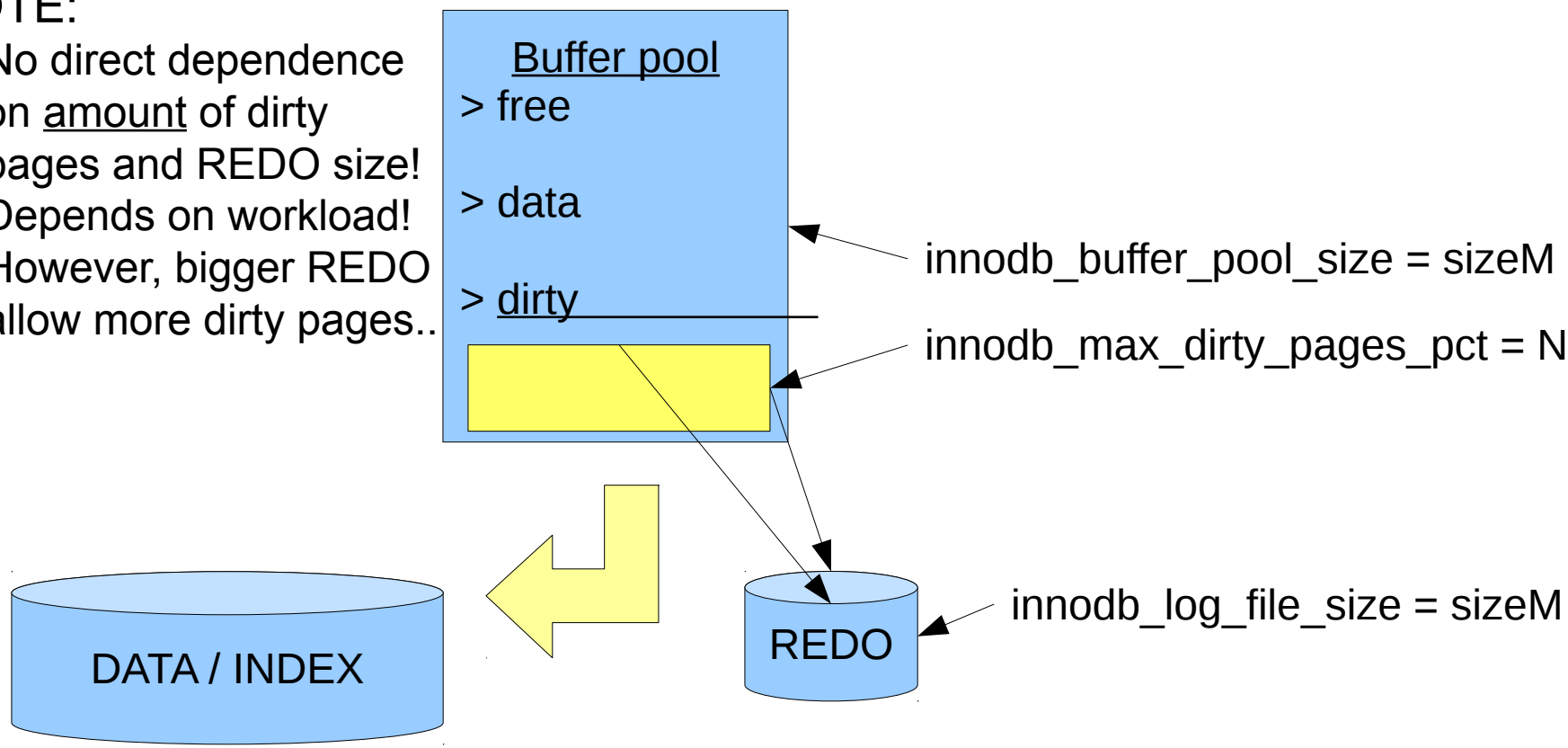
- For ex: you're doing 1000 writes/sec
- Now, 5% of your I/O operations become random read.. <= any % regression?
- So, before 1000 I/O = 1000ms
- Since 5% become RR (5ms each) :
  - 1000 I/O = 950 WRT + 50 RR =
  - 950ms + 250ms =
  - 1200ms = 20% regression!

- So far:
  - 5% RR = 20% regression
  - 10% RR = 40%(!)
  - so, love your SSD ;-)



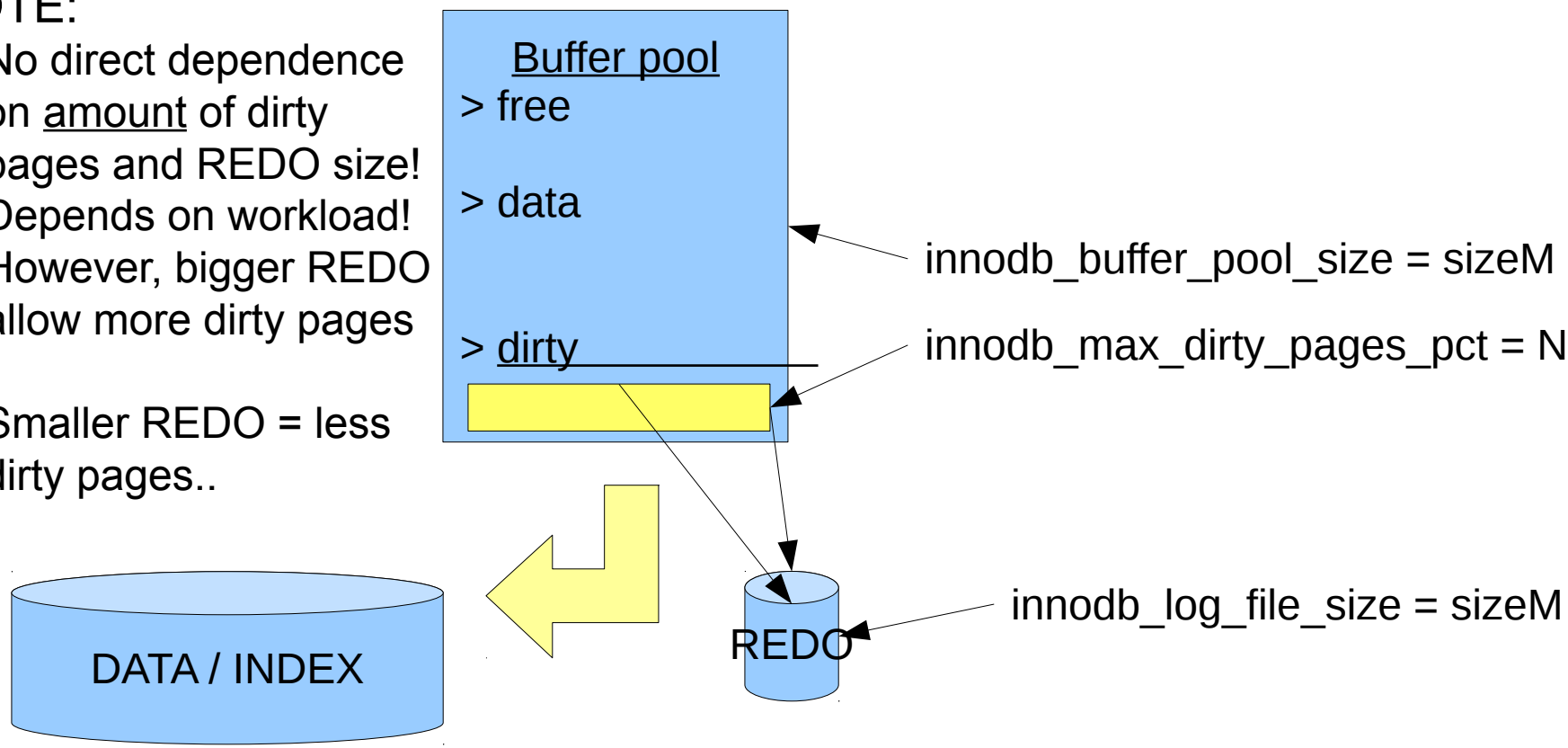
InnoDB : Dirty pages

- Direct dependence on REDO log size
- NOTE:
  - No direct dependence on amount of dirty pages and REDO size!
  - Depends on workload!
  - However, bigger REDO allow more dirty pages..



InnoDB : Dirty pages

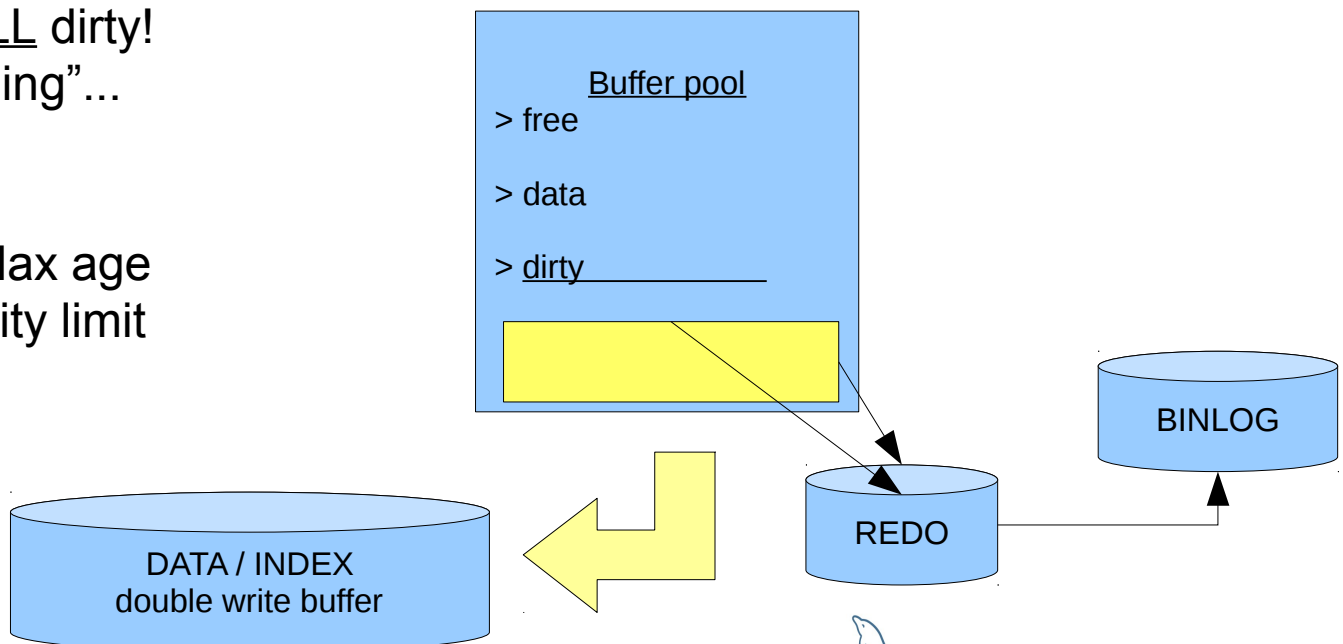
- Direct dependence on REDO log size
- NOTE:
  - No direct dependence on amount of dirty pages and REDO size!
  - Depends on workload!
  - However, bigger REDO allow more dirty pages
  - Smaller REDO = less dirty pages..



InnoDB : REDO log constraints

- REDO log constraints: (Always monitor Checkpoint Age!!!)
  - Cyclic, need free space
  - Checkpoint age: diff between the current LSN in REDO and the oldest dirty page LSN
  - Checkpoint age cannot out-pass the max checkpoint age (redo log size)
  - If Checkpoint age >= 7/8 of Max age => Flush ALL dirty!
    => AKA “furious flushing”...

- Adaptive Flushing:
  - Keep REDO under Max age
  - Respecting IO capacity limit



InnoDB : Adaptive Flushing

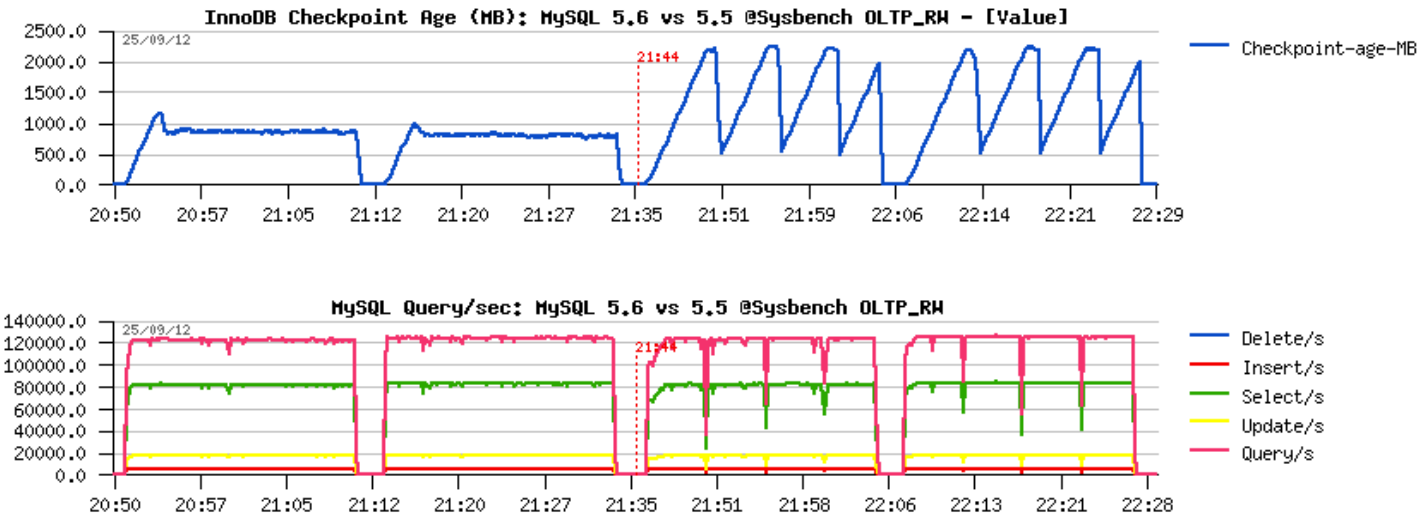
- MySQL 5.5:
  - Estimation based
  - Sometimes works ;-)

- MySQL 5.6 :
  - Based on REDO write rate + I/O capacity Max
  - Involving batch flushing with N pages to flush (progressive, depending on REDO %free) + page age limit (according REDO rate)

  - Tuning:
    - innodb_io_capacity
    - innofb_io_capacity_max
    - Both are dynamic!
    - Monitor Checkpoint Age..

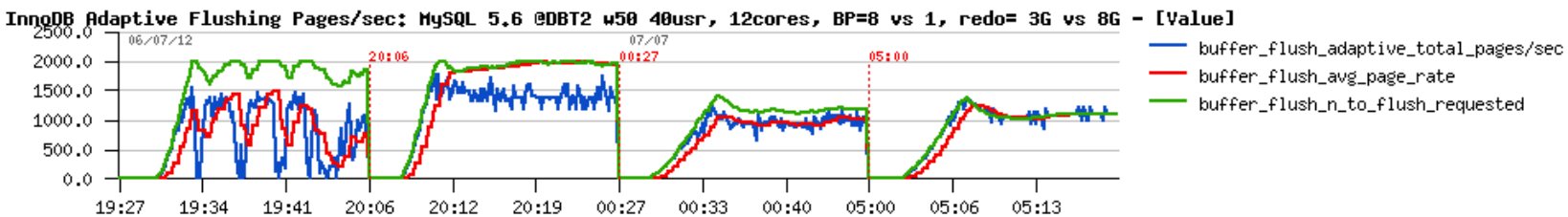
InnoDB : Adaptive Flushing in 5.5 vs 5.6

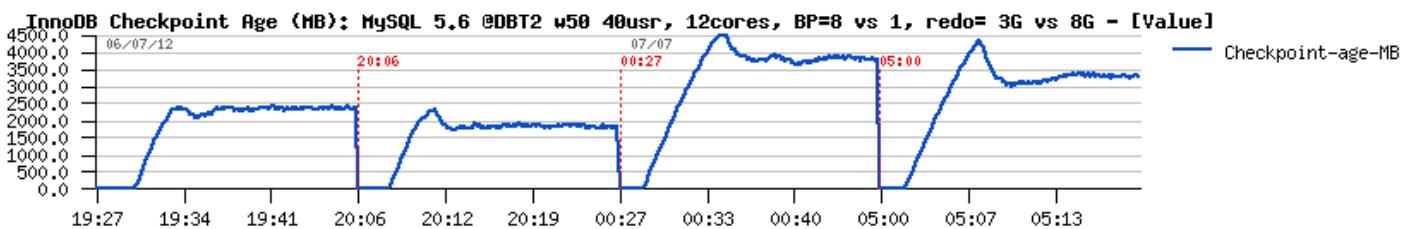
- OLTP_RW Workload:
  - Same IO capacity
  - Different logic..



InnoDB : tuning Adaptive Flushing in 5.6

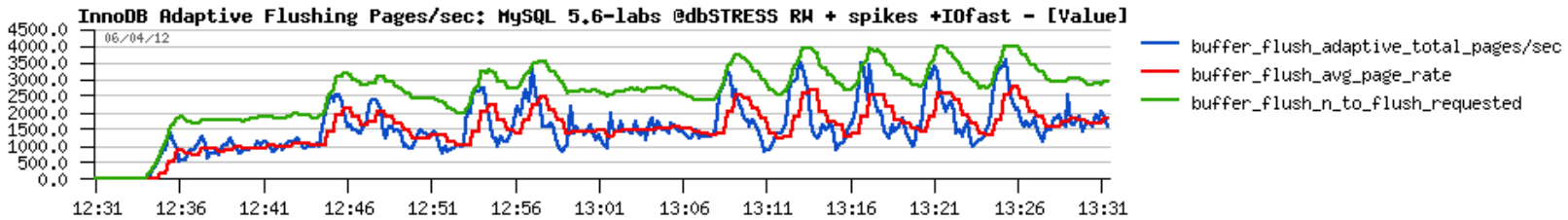
- Monitoring:
  - Flush adaptive pages/sec
  - Pages requested to flush
  - Flush AVG page rate

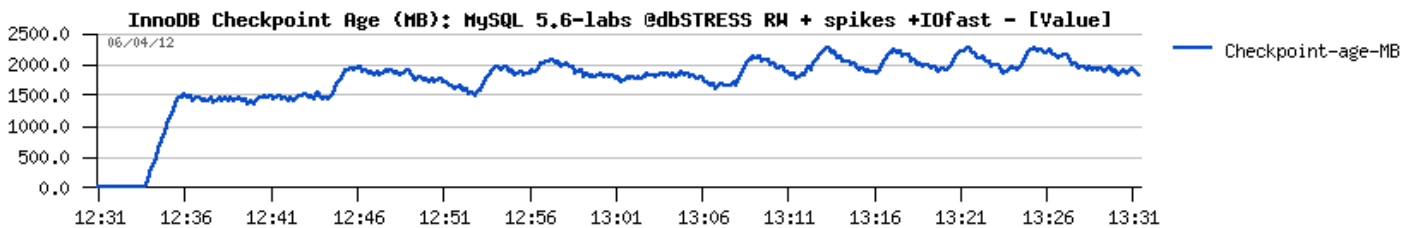


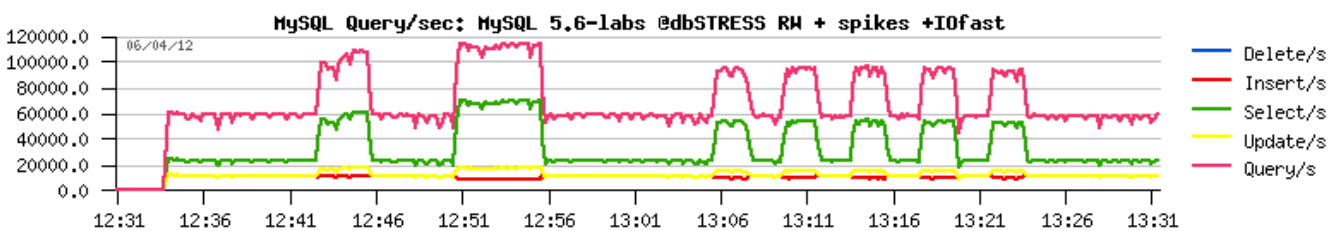


InnoDB : Resisting to activity spikes in 5.6

- dbSTRESS RW Workload + RW spikes:





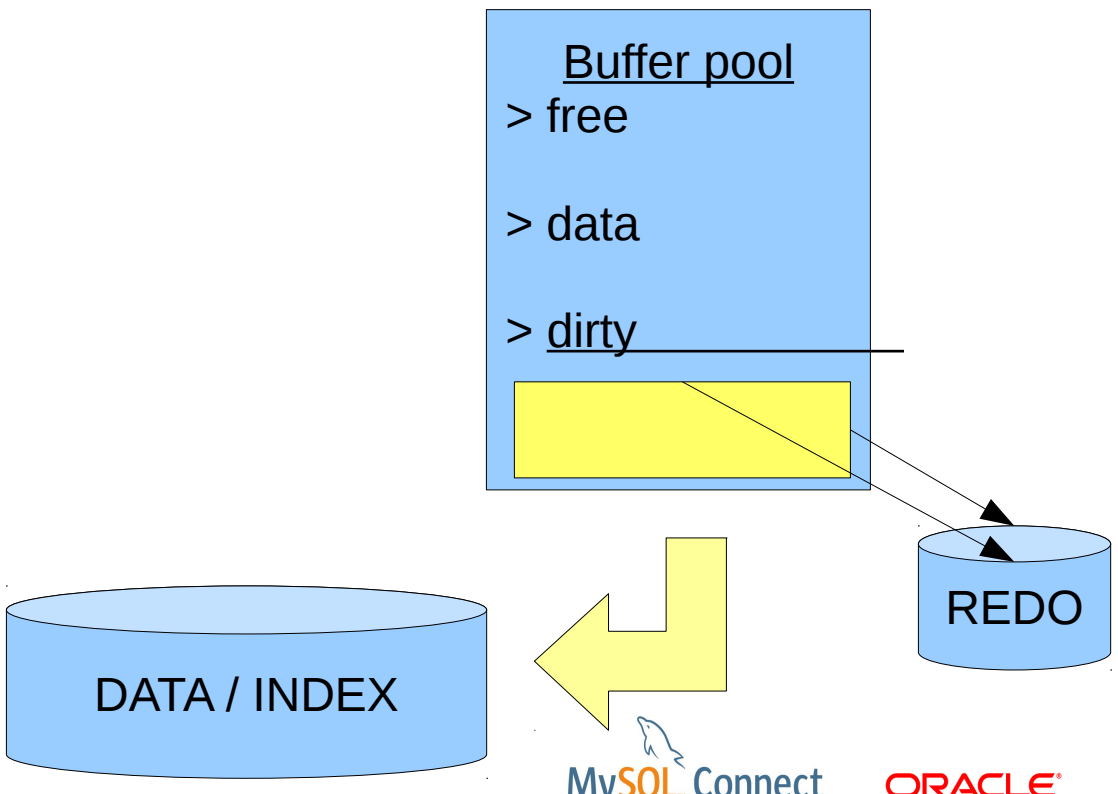


InnoDB : Why Purge Thread?..

- Reading source code:

Master Thread

```
loop: //Main loop
...
if( dirty pct > limit)
  flush_batch( 100% IO);
...
do {
  pages= trx_purge();
  if( 1sec passed )  flush_log();
} while (pages);
...
goto loop;
```



InnoDB : Purge Thread is the must!

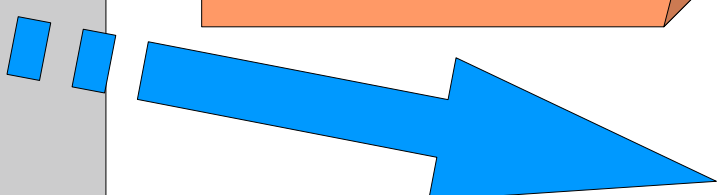
- Improved code:

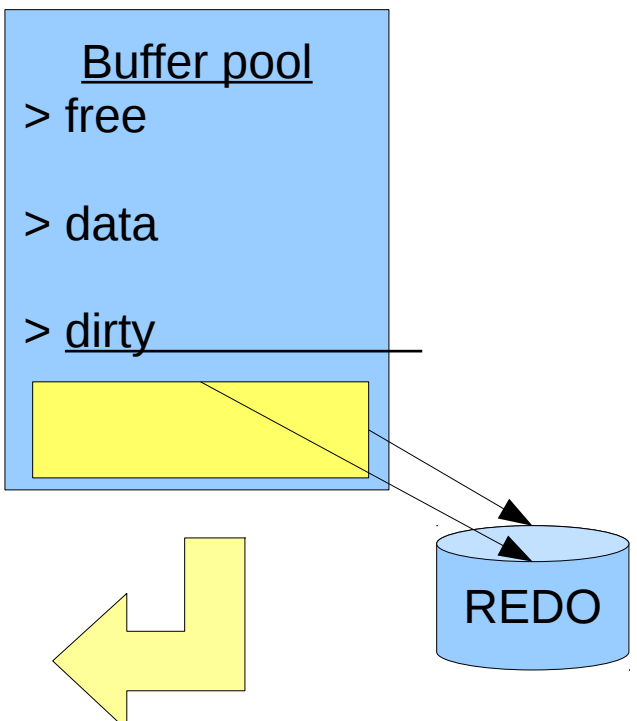
Master Thread

```
loop: //Main loop
...
sleep( 1 );
...
if( dirty pct > limit)
  flush_batch( 100% IO);
...
 flush_log();
...
goto loop;
```

Purge Thread

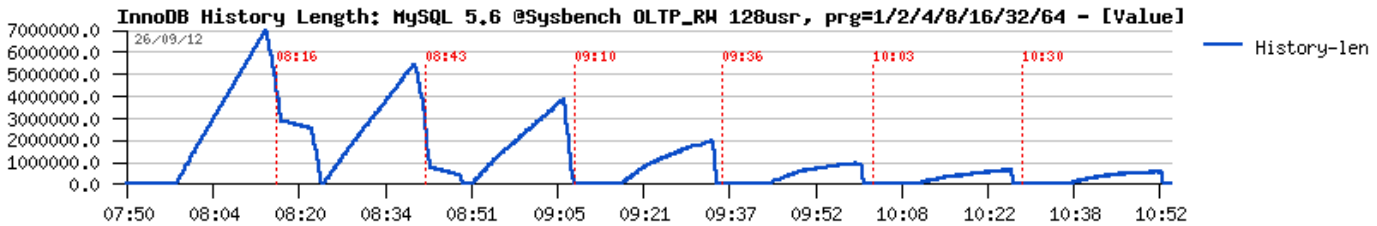
```
loop:
sleep( ... );
do {  pages=
     trx_purge();
} while (pages);
goto loop;
```

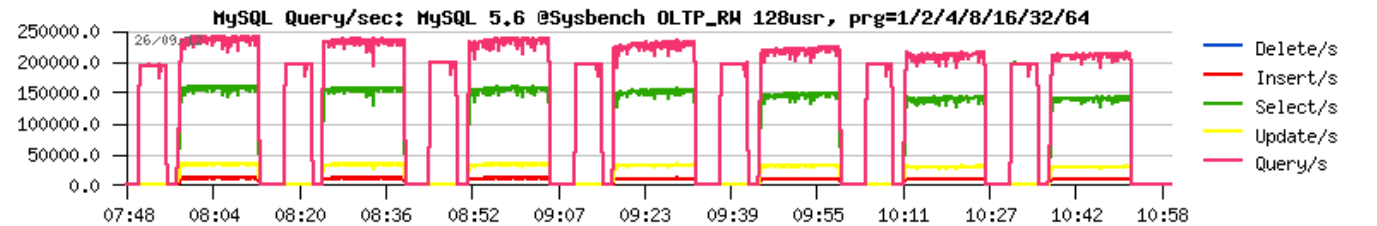




InnoDB : Purge improvement in 5.6

- Several Purge Threads :
  - NOTE: activation is auto-magical (I'm serious ;-))

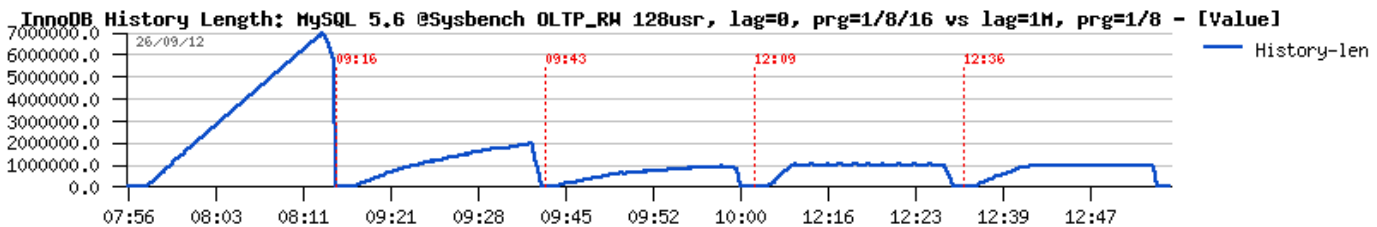


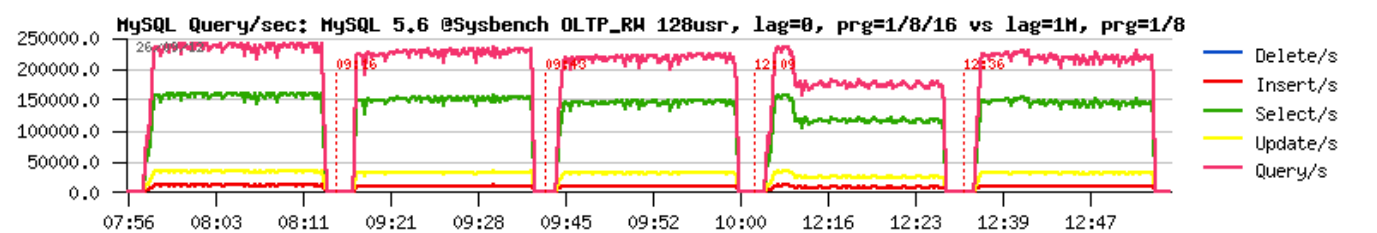


InnoDB : Purge improvement in 5.6

- Fixed max purge lag code!
  - innodb_max_purge_lag
  - innodb_max_purge_lag_delay <= configurable!

- Setting innodb_max_purge_lag=1M:





InnoDB : Other performance issues

- RW limitations:
  - Index lock..
  - Flushing limits..
  - Do we really using 100% of available I/O capacity?..
  - Work continues ;-)

- dbSTRESS workload :
  - Some mysterious contentions..
  - More in depth analyzing required..

MySQL Monitoring

- SQL> status;
- SQL> show global status;
- SQL> show processlist;
- SQL> show engine innodb status \G
- SQL> show engine innodb mutex ;
- INFORMATION_SCHEMA
- PERFORMANCE_SCHEMA !! <= let you surprise by “ps_helper” !!
- InnoDB METRICS TABLE !!
- etc..

MySQL Monitoring Tools

- MySQL Enterprise Monitoring!
- Cacti, etc.
- dim_STAT (http://dimitrik.free.fr)
  - All System load stats (CPU, I/O, Network, RAM, Processes,...)
  - Manly for Solaris & Linux, but any other UNIX too :-)
  - Add-Ons for Oracle, MySQL, PostgreSQL, Java, etc.
  - MySQL Add-Ons:
    - mysqlSTAT : all available data from “show status”
    - mysqlLOAD : compact data, multi-host monitoring oriented
    - mysqlWAITS : top wait events from Performance SCHEMA
    - InnodbSTAT : most important data from “show innodb status”
    - innodbMUTEX : monitoring InnoDB mutex waits
    - innodbMETRICS : all counters from the METRICS table
  - And any other you want to add! :-)

THANK YOU !!!

- All details about presented materials you may find on:
  - http://dimitrik.free.fr - dim_STAT, Benchmark Reports
  - http://dimitrik.free.fr/blog - Articles about MySQL Performance