

# Linux and H/W optimizations for MySQL

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- MySQL performance overview and improvement history
- SSD and MySQL performance
- Memory and swap space management
- File I/O
- Network
- Useful command line tools and tips

# History of MySQL performance improvements

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## ■ H/W improvements

- HDD RAID, Write Cache
- Large RAM
- SATA SSD, PCI-Express SSD
- More number of CPU cores
- Faster Network

## ■ S/W improvements

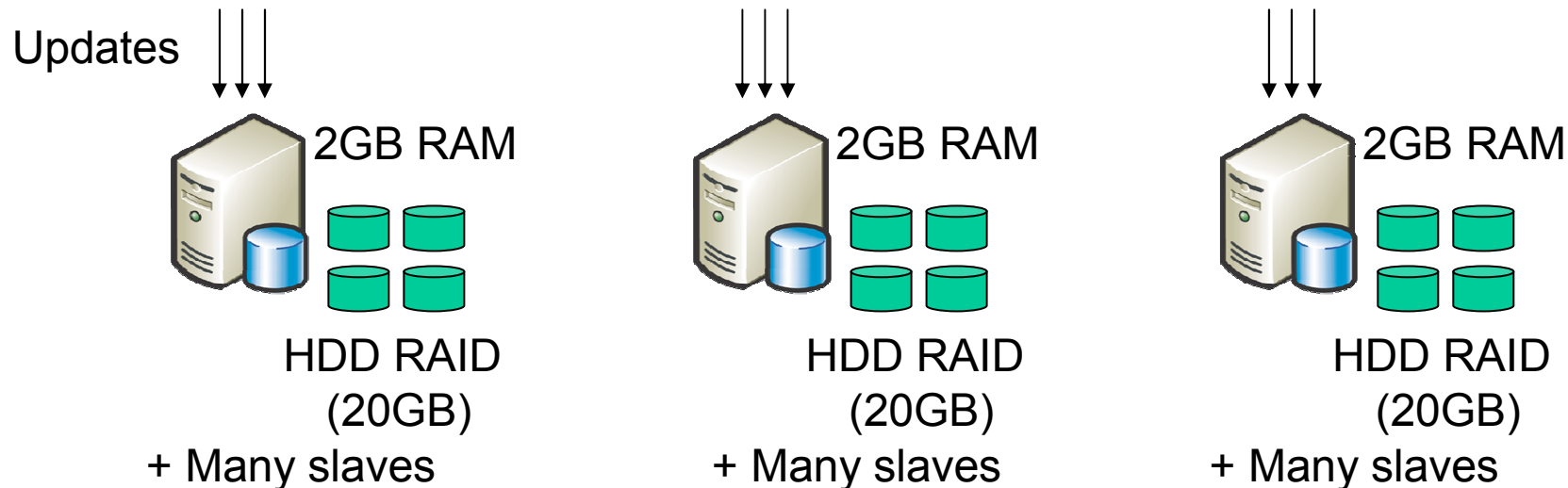
- Improved algorithm (i/o scheduling, swap control, etc)
- Much better concurrency
- Avoiding stalls
- Improved space efficiency (compression, etc)

# Per-server performance is important

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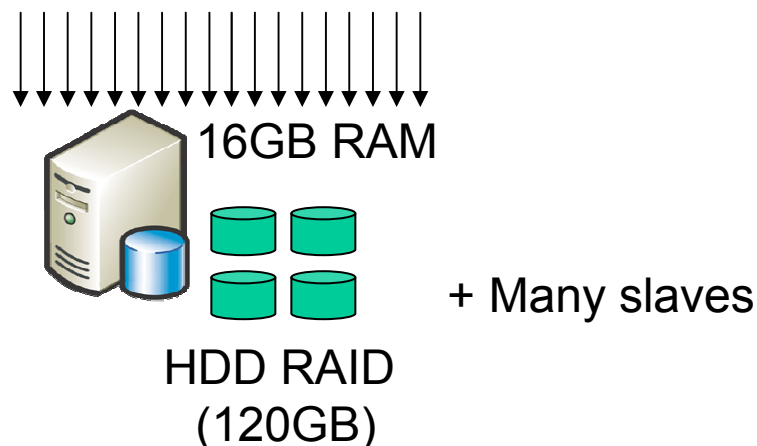
- To handle 1 million queries per second..
  - 1000 queries/sec per server : 1000 servers in total
  - 10000 queries/sec per server : 100 servers in total
- Additional 900 servers will cost 10M\$ initially, 1M\$ every year
- If you can increase per server throughput, you can reduce the total number of servers, which will decrease TCO
- Sharding is not everything

# 32bit Linux



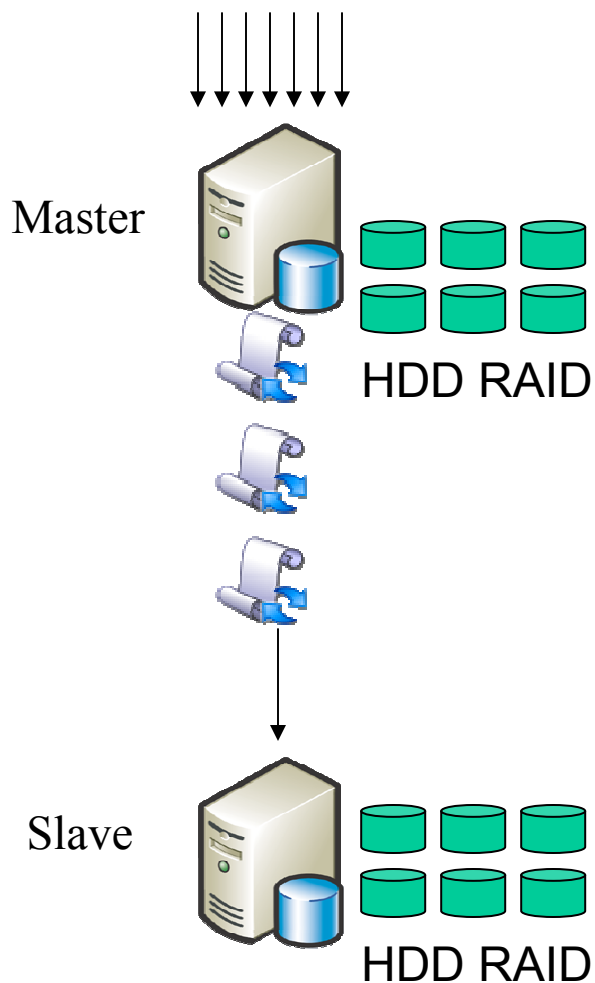
- Random disk i/o speed (IOPS) on HDD is very slow
  - 100-200/sec per drive
- Database easily became disk i/o bound, regardless of disk size
- Applications could not handle large data (i.e. 30GB+ per server)
- Lots of database servers were needed
- Per server traffic was not so high because both the number of users and data volume per server were not so high
  - Backup and restore completed in short time
- MyISAM was widely used because it's very space efficient and fast

# 64bit Linux + large RAM + BBWC



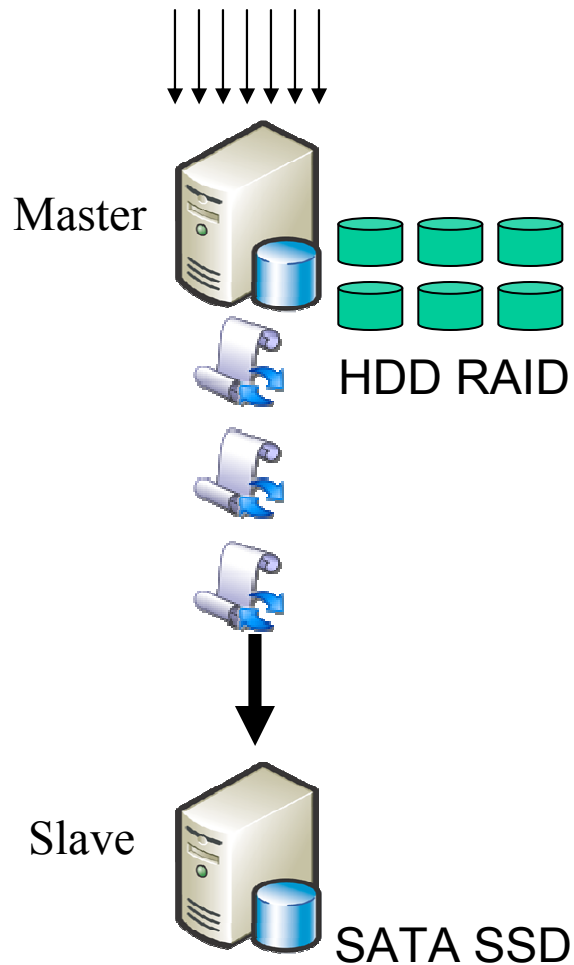
- Memory pricing went down, and 64bit Linux went mature
- It became common to deploy 16GB or more RAM on a single linux machine
- Memory hit ratio increased, much larger data could be stored
- The number of database servers decreased (consolidated)
- Per server traffic increased (the number of users per server increased)
- “Transaction commit” overheads were extremely reduced thanks to battery backed up write cache
- From database point of view,
  - InnoDB became faster than MyISAM (row level locks, etc)
  - Direct I/O became common

# Side effect caused by fast server



- After 16-32GB RAM became common, we could run many more users and data per server
  - Write traffic per server also increased
- 4-8 RAID 5/10 also became common, which improved concurrency a lot
- On 6 HDD RAID 10, single thread IOPS is around 200, 100 threads IOPS is around 1000-2000
- Good parallelism on both reads and writes on master
- On slaves, there is only one writer thread (SQL thread). No parallelism on writes
  - 6 HDD RAID10 is as slow as single HDD for writes
- Slaves became performance bottleneck earlier than master
- Serious replication delay happened (10+ minutes at peak time)

# Using SATA SSD on slaves



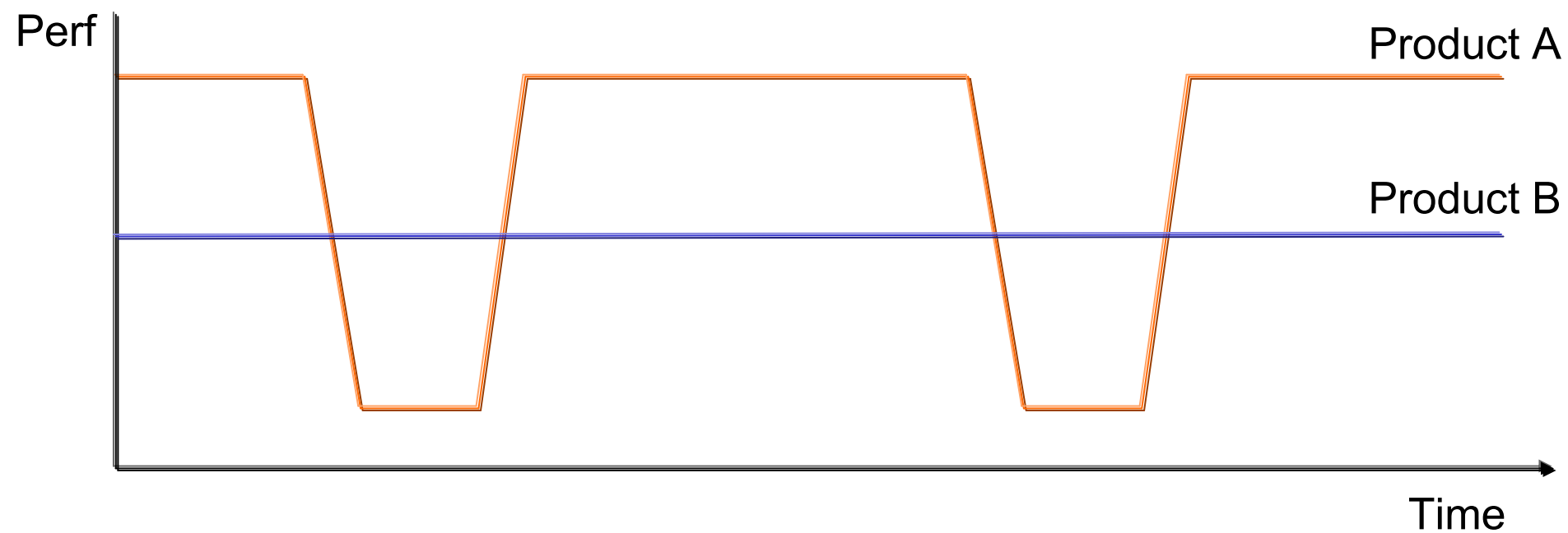
- IOPS differences between master (1000+) and slave (100+) have caused serious replication delay
- Is there any way to gain high enough IOPS from single thread?
- Read IOPS on SATA SSD is 3000+, which should be enough (15 times better than HDD)
- Just replacing HDD with SSD solved replication delay
- Overall read throughput became much better
- Using SSD on master was still risky
- Using SSD on slaves (IOPS: 100+ -> 3000+) was more effective than using on master (IOPS: 1000+ -> 3000+)
- We mainly deployed SSD on slaves
- The number of slaves could be reduced
- From MySQL point of view:
  - Good concurrency on HDD RAID has been required : InnoDB Plugin



# Concurrency improvements around MySQL

- Row level locks, not table/page level locks
  - InnoDB: Row level locks, MyISAM: Table level locks
- No Hot Giant Lock(Global Mutex)
  - Critical sections (spots that only single thread can be accessible) reduce concurrency a lot
  - InnoDB Buffer Pool, Data Dictionary, etc
  - InnoDB now scales pretty well with many CPU cores (5.1 Plugin, 5.5)
- Parallel I/O threads
  - Increasing the number of disk i/o threads
    - Front-end operations (i.e SELECT) throughput improved
  - Introducing asynchronous I/O
- Parallel background tasks
  - Dividing checkpoint thread (main thread) and purge thread (physically removing delete-marked records)
- Single-threaded replication channel (SQL Thread) is currently hot spot

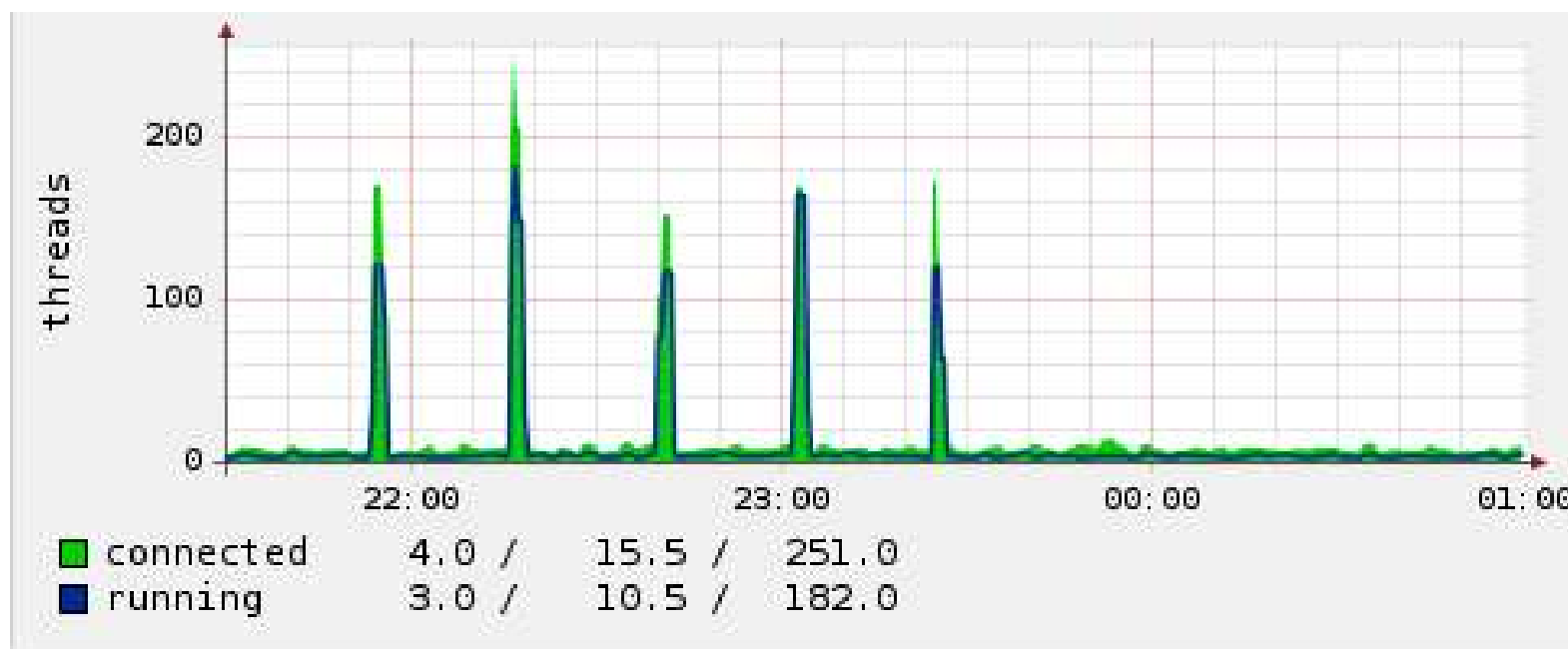
# Avoiding sudden performance drops



- Some unstable database servers suddenly drop performance in some situations
- Low performance is a problem because we can't meet customers' demands
- Through product A is better on average, product B is much more stable
- Don't trust benchmarks. Vendors' benchmarks show the best score but don't show worse numbers

# Avoiding stalls

- All clients are blocked for a short period of time (less than one second – a few seconds)
  - The number of connections grow significantly (10-100 on average, but suddenly grows to 1000+ and TOO MANY CONNECTIONS errors are thrown)
  - Increased response time



# Avoiding stalls(2)

- Mainly caused by database internal problems
  - Some of them are known issues. Follow best practices
  - Improved every day
  - Don't use too old MySQL versions (4.0/4.1, 5.0.45, etc..)
  
- Typical stalls
  - Dropping a huge table (LOCK\_open mutex)
  - Burst write (at checkpoint, at the time when redo log file free space becomes not enough)
  - pthread\_create()/clone() (called at connection establishment)
  - etc

# Handling Real-World workloads..

## ■ Company Introduction: DeNA and Mobage Platform

- One of the largest social game providers in Japan
  - Both social game platform and social games themselves
  - Subsidiary ngmoco:) in SF
- Japan localized phone, Smart Phone, and PC games
- 2-3 billion page views per day
- 25+ million users
- 1.3B\$ revenue in 2010

# RDBMS or NoSQL ?

- Is MySQL good for social games ?
  - It's good!
  - DeNA uses MySQL for data stores, memcached for caching summary/objects
  - H/W is getting fast enough for RDBMS to handle lots of workloads (Nehalem CPU, Large RAM, PCI-Express SSD)
  - Complex query, multiple columns, transaction, secondary index, online backup, monitoring, utility tools are still very helpful for social games
- Is RDBMS slow (Can't MySQL handle 1000 updates/second) ?
  - Some of our MySQL servers handle 10,000+ UPDATE statements per second
  - Highly depending on random disk i/o speed and indexing
  - Any NoSQL database can't be fast if it becomes disk i/o bound
- Schema, transaction and indexes should be more taken care

# Social Game workloads

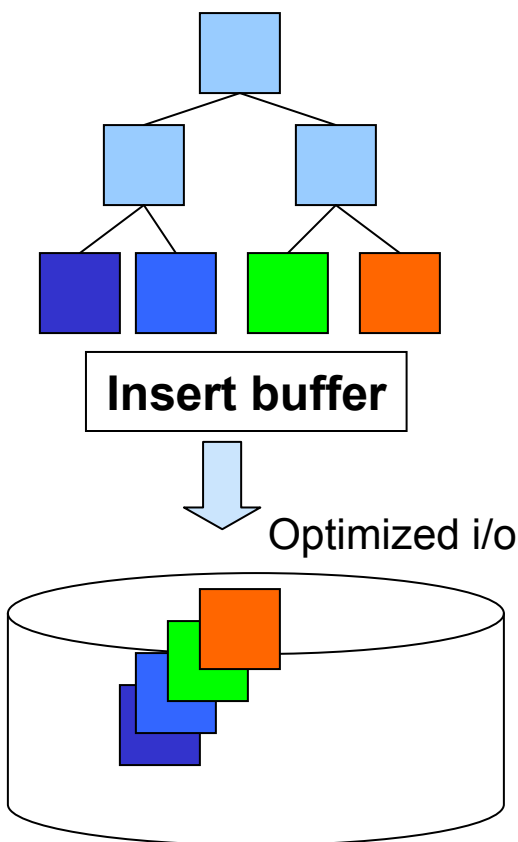
- Easily increasing millions of users in a few days
  - Database size grows rapidly
    - Especially if PK is “user\_id + xxx\_id”
    - Increasing GB/day is typical
- Load balancing reads is not difficult
  - Adding slaves or caching servers
- Load balancing writes is not trivial
  - Sharding
- Solutions depend on what kinds of tables we’re using, INSERT/UPDATE/DELETE workloads, etc

# INSERT-mostly tables

- History tables such as access logs, diary, battle history
  - INSERT and SELECT mostly
  - Table size becomes huge (easily exceeding 1TB)
  - Locality (Most of SELECT go to recent data)
  
- INSERT performance in general
  - Fast in InnoDB (Thanks to Insert Buffering. Much faster than MyISAM)
  - To modify index leaf blocks, they have to be in buffer pool
  - When index size becomes too large to fit in the buffer pool, disk reads happen
  - In-memory workloads -> disk-bound workloads
    - Suddenly suffering from serious performance slowdown
    - UPDATE/DELETE/SELECT also getting much slower
  - Any faster storage devices can not compete with in-memory workloads

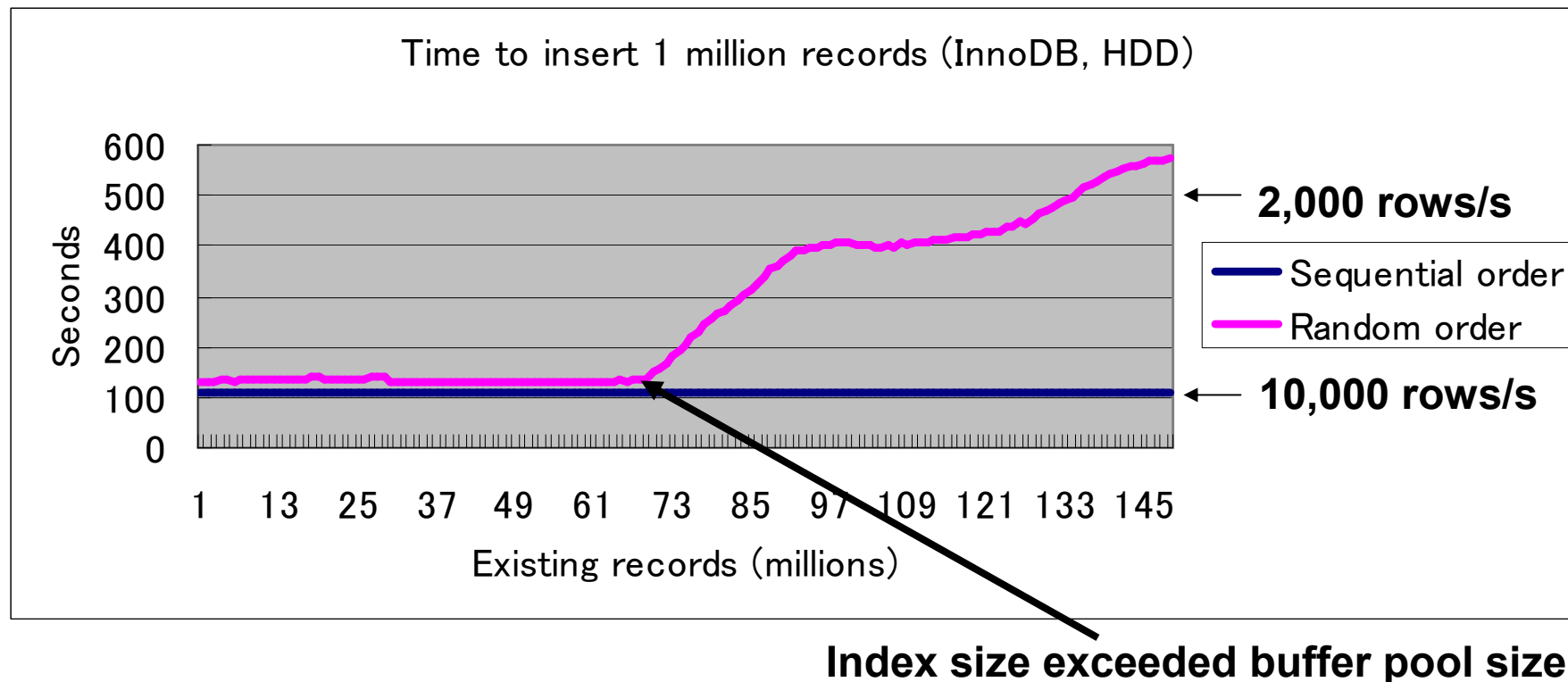


# InnoDB Feature: Insert Buffering



- If non-unique, secondary index blocks are not in memory, InnoDB inserts entries to a special buffer(“insert buffer”) to avoid random disk i/o operations
  - Insert buffer is allocated on both memory and innodb SYSTEM tablespace
- Periodically, the insert buffer is merged into the secondary index trees in the database (“merge”)
- Pros: Reducing I/O overhead
  - Reducing the number of disk i/o operations by merging i/o requests to the same block
  - Some random i/o operations can be sequential
- Cons:
  - Additional operations are added
  - Merging might take a very long time
    - when many secondary indexes must be updated and many rows have been inserted.
    - it may continue to happen after a server shutdown and restart

# INSERT gets slower

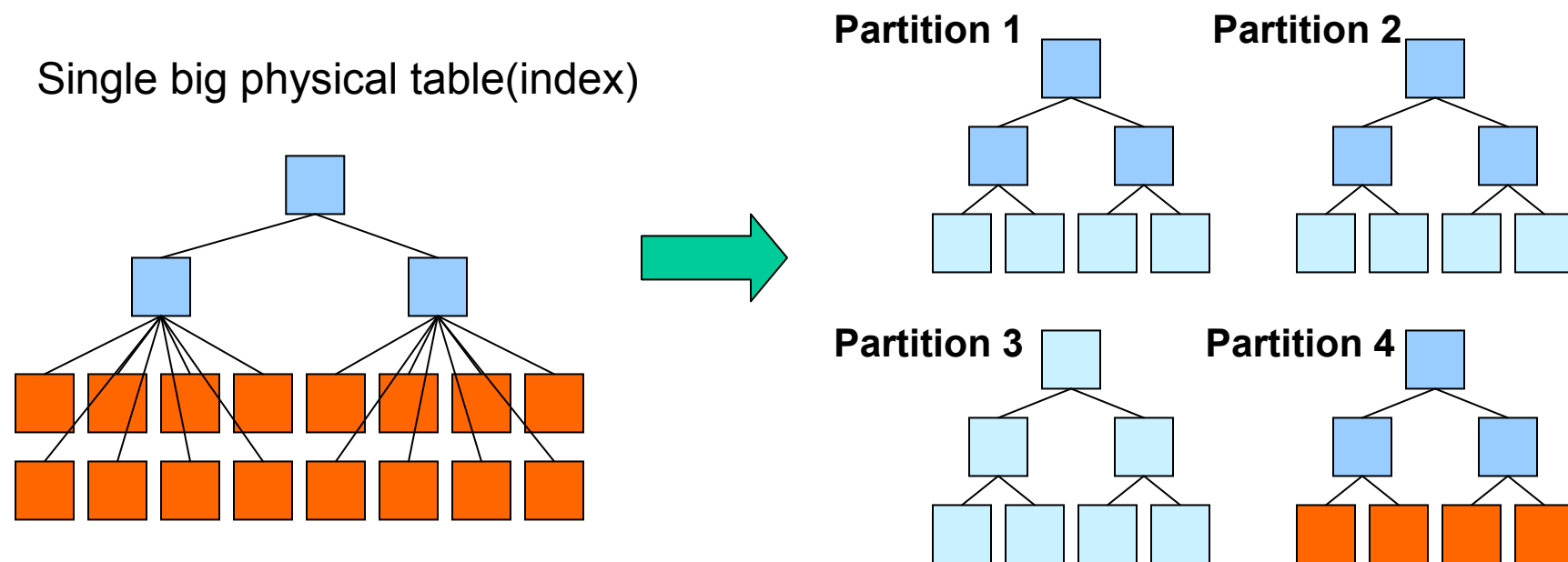


- Index size exceeded innodb buffer pool size at 73 million records for random order test
- Gradually taking more time because buffer pool hit ratio is getting worse (more random disk reads are needed)
- For sequential order inserts, insertion time did not change. No random reads/writes

# INSERT performance difference

- In-memory INSERT throughput
  - 15000+ insert/s from single thread on recent H/W
- Exceeding buffer pool, starting disk reads
  - Degrading to 2000-4000 insert/s on HDD, single thread
  - 6000-8000 insert/s on multi-threaded workloads
- Serious replication delay often happens
- Faster storage does not solve everything
  - At most 5000 insert/s on fastest SSDs such as tachIOon/FusionIO
    - InnoDB actually uses CPU resources quite a lot for disk i/o bound inserts (i.e. calculating checksum, malloc/free)
- It is important to minimize index size so that INSERT can complete in memory

# Approach to complete INSERT in memory



## ■ Range partition by datetime

- Started from MySQL 5.1
- Index size per partition becomes  $\text{total\_index\_size} / \text{number\_of\_partitions}$
- INT or TIMESTAMP enables hourly based partitions
  - TIMESTAMP does not support partition pruning
- Old partitions can be dropped by `ALTER TABLE .. DROP PARTITION`

# Approaches to complete INSERT in memory

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- Dividing tables by datetime (up to 5.0, or if your tables are too big to store on single server's disks)
- Purging or archiving older data
- Dropping indexes
- Dropping columns
- Using space efficient data types, compression
- Using large RAM
- Sharding

# UPDATE—mostly tables

## ■ Typical usage

### ● Updating users' status

- Current HP, experiences, money, number of items, friends' status, battle status, etc
- UPDATE and SELECT are most frequently executed for handling user status

## ■ UPDATE performance

### ● Need to read target record blocks and index blocks

- Fast if completed in buffer pool, otherwise massive foreground disk reads happen
- Data size does not grow significantly, depending on INSERT/DELETE

### ● Huge performance difference between storage devices

- In-memory UPDATE: 12,000/s
- HDD UPDATE: 300/s
- SATA SSD UPDATE: 1,800/s
- PCI-E SSD UPDATE: 4,000/s
- \* Single Thread
- Random reads happen in foreground, so random read speed matters a lot

## ■ SSD performance and deployment strategies for MySQL

# What do you need to consider? (H/W layer)

## ■ SSD or HDD?

## ■ Interface

- SATA/SAS or PCI-Express?, How many drives?

## ■ RAID

- H/W RAID, S/W RAID or JBOD?

## ■ Network

- Is 100Mbps or 1Gbps enough?

## ■ Memory

- Is 2GB RAM + PCI-E SSD faster than 64GB RAM + 8HDDs?

## ■ CPU

- Nehalem, Opteron or older Xeon?



# What do you need to consider?

## ■ Redundancy

- RAID
- DRBD (network mirroring)
- Semi-Sync MySQL Replication
- Async MySQL Replication

## ■ Filesystem

- ext3, xfs, raw device ?

## ■ File location

- Data file, Redo log file, etc

## ■ SSD specific issues

- Write performance deterioration
- Write endurance

# Why SSD? IOPS!

- IOPS: Number of (random) disk i/o operations per second
- Almost all database operations require random access
  - Selecting records by index scan
  - Updating records
  - Deleting records
  - Modifying indexes
- Regular SAS HDD : 200 iops per drive (disk seek & rotation is slow)
- SSD : 2,000+ (writes) / 5,000+ (reads) per drive
  - highly depending on SSDs and device drivers

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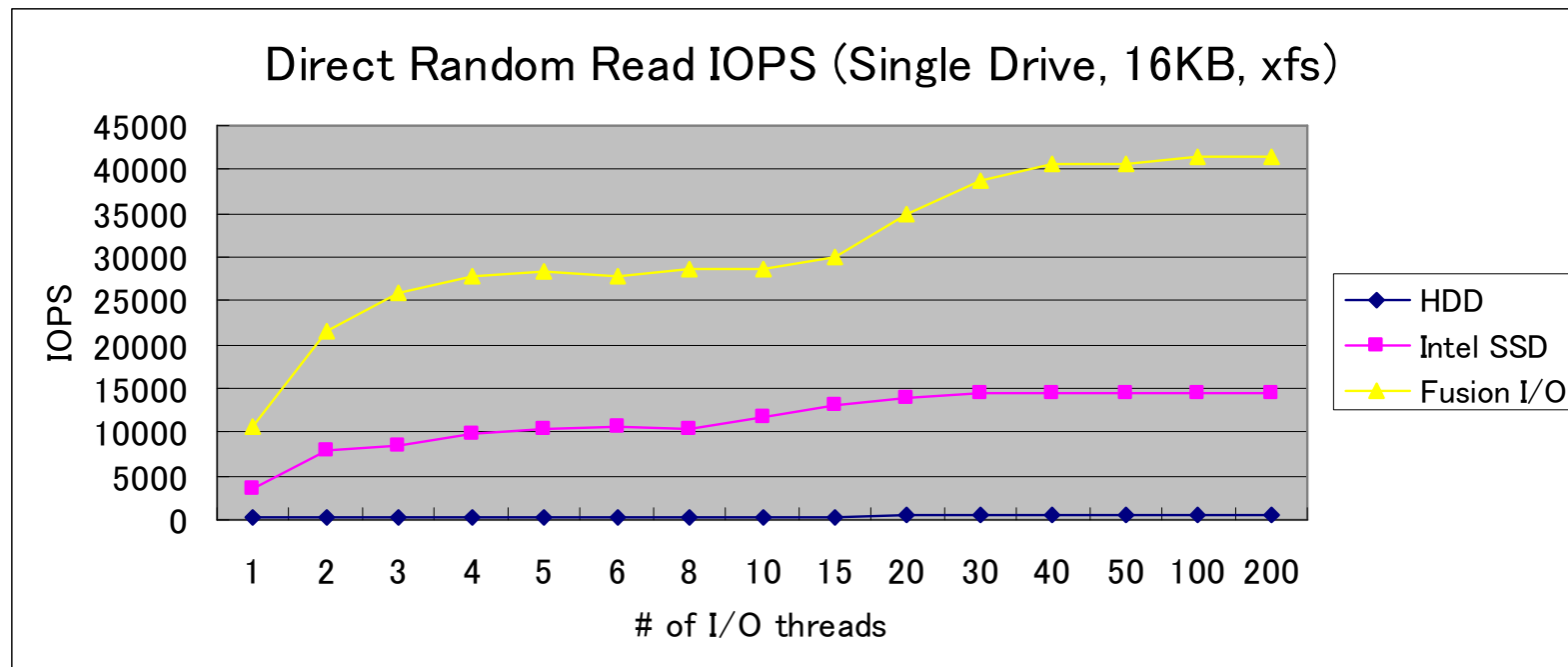
## ■ Basic Performance on SSD/HDD

- Random Reads
- Random Writes
- Sequential Reads
- Sequential Writes
- fsync() speed
- Filesystem difference
- IOPS and I/O unit size
- SLC vs MLC
- # of interfaces/drives
- Opteron vs Nehalem

## ■ MySQL Deployments for benchmarks

## ■ MySQL Deployments for real workloads

# Random Read benchmark



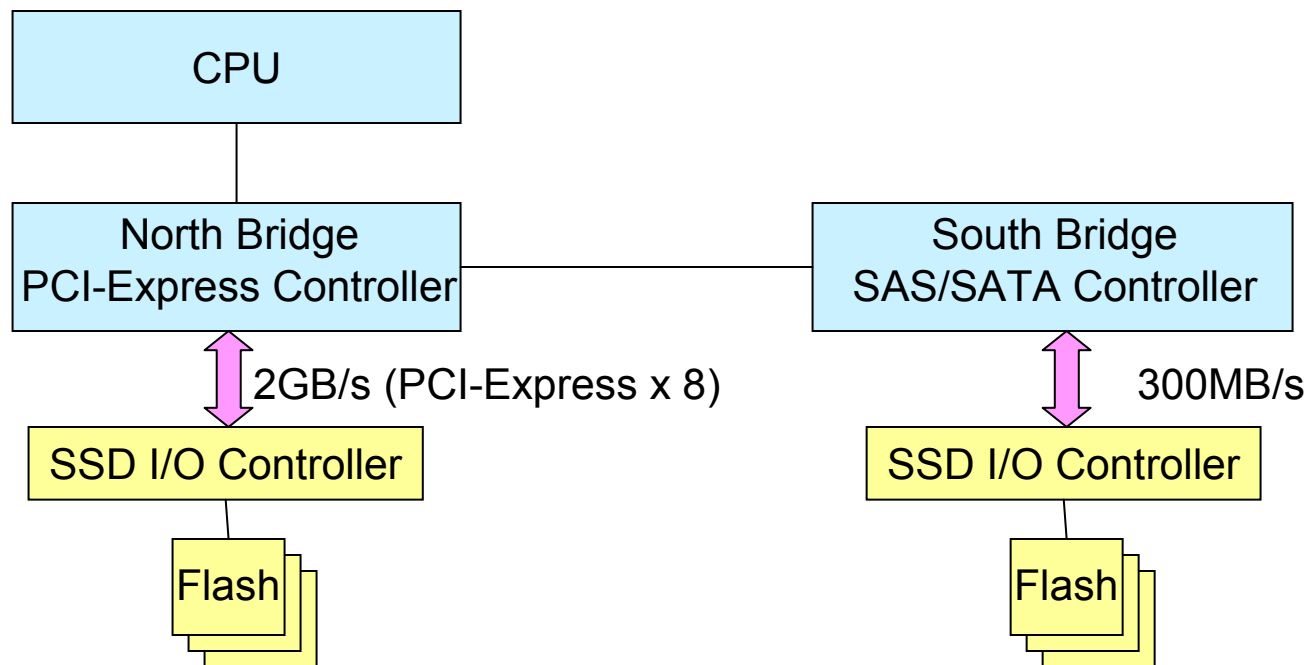
- HDD: 196 reads/s at 1 i/o thread, 443 reads/s at 100 i/o threads
- Intel : 3508 reads/s at 1 i/o thread, 14538 reads/s at 100 i/o threads
- Fusion I/O : 10526 reads/s at 1 i/o thread, 41379 reads/s at 100 i/o threads
- Single thread throughput on Intel is 16x better than on HDD, Fusion is 25x better
- SSD's concurrency (4x) is much better than HDD's (2.2x)
- Very strong reason to use SSD

# High Concurrency



- Single SSD drive has multiple NAND Flash Memory chips (i.e. 40 x 4GB Flash Memory = 160GB)
- Highly depending on I/O controller and Applications
  - Single threaded application can not gain concurrency advantage

# PCI-Express SSD



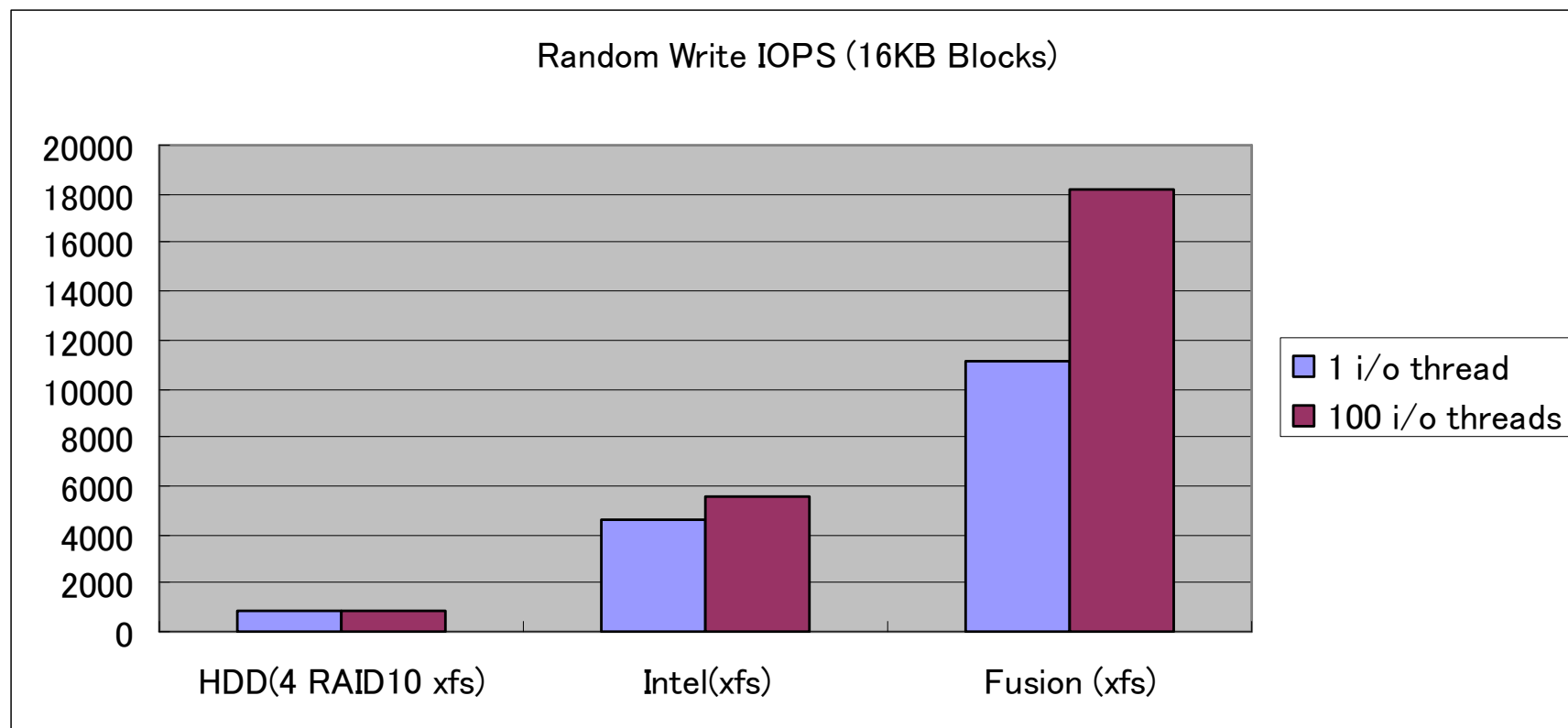
## ■ Advantage

- PCI-Express is much faster interface than SAS/SATA

## ■ (current) Disadvantages

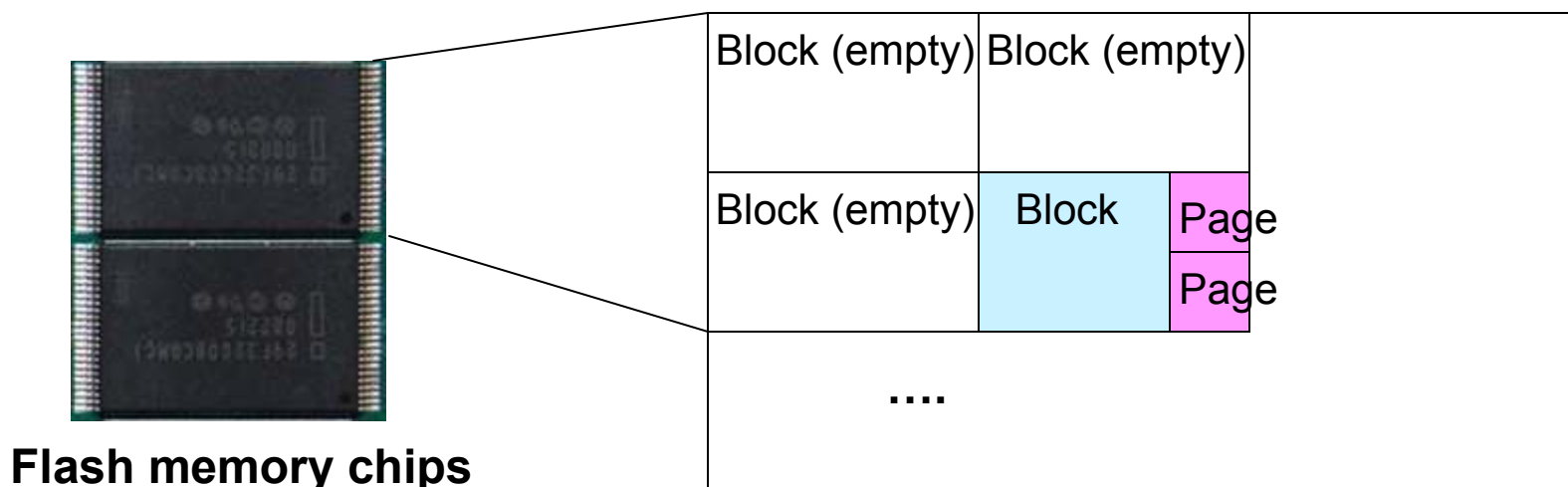
- Most motherboards have limited # of PCI-E slots
- No hot swap mechanism

# Write performance on SSD



- Very strong reason to use SSD
- But wait.. Can we get a high write throughput \*everytime\*?
  - Not always.. Let's check how data is written to Flash Memory

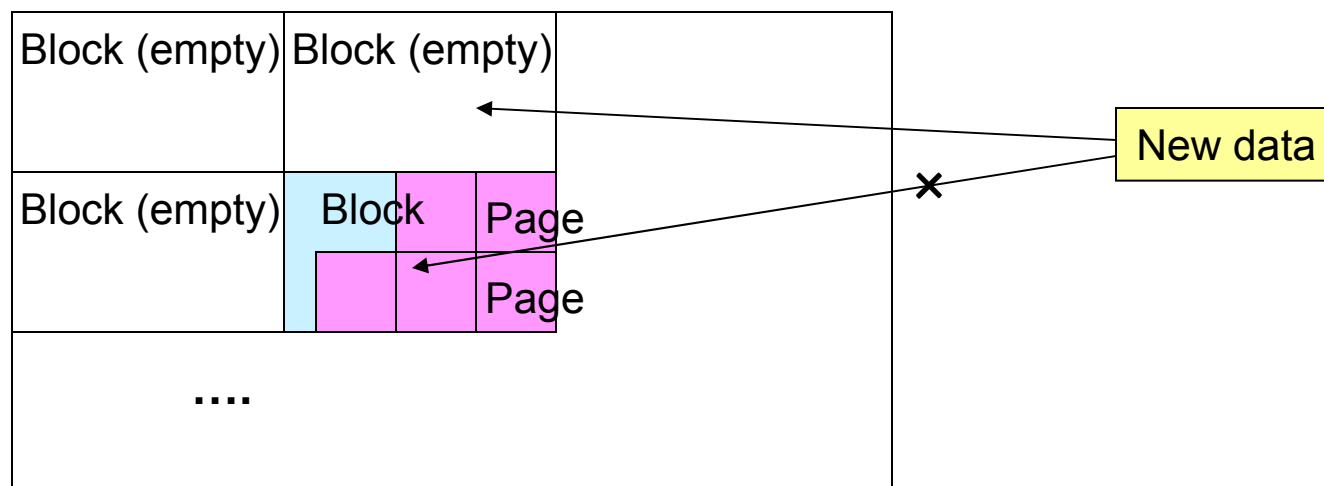
# Understanding how data is written to SSD (1)



- Single SSD drive consists of many flash memory chips (i.e. 2GB)
- A flash memory chip internally consists of many blocks (i.e. 512KB)
- A block internally consists of many pages (i.e. 4KB)
- It is *\*not\** possible to overwrite to a non-empty block
  - Reading from pages is possible
  - Writing to pages in an empty block is possible
  - Appending is possible
  - Overwriting to pages in a non-empty block is *\*not\** possible

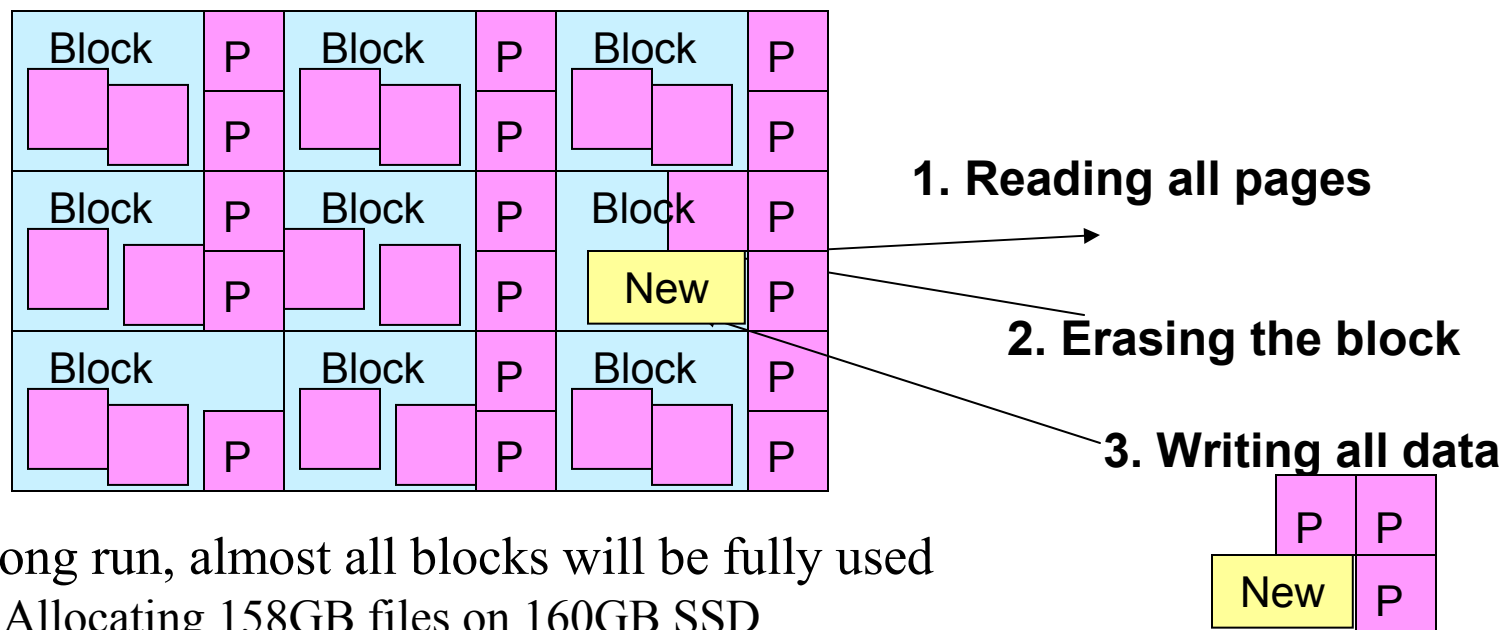


# Understanding how data is written to SSD (2)



- Overwriting to a non-empty block is not possible
- Writing new data to an empty block instead
- Writing to a non-empty block is fast (~200 microseconds)
- Even though applications write to same positions in same files (i.e. InnoDB Log File), written pages/blocks are distributed (Wear-Leveling)

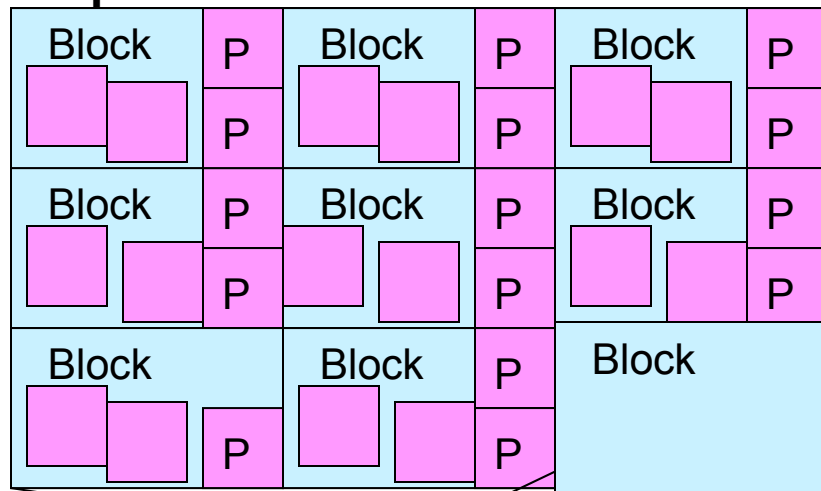
# Understanding how data is written to SSD (3)



- In the long run, almost all blocks will be fully used
  - i.e. Allocating 158GB files on 160GB SSD
- New empty block must be allocated on writes
- Basic steps to write new data:
  - 1. Reading all pages from a block
  - 2. ERASE the block
  - 3. Writing all data w/ new data into the block
- ERASE is very expensive operation (takes a few milliseconds)
- At this stage, write performance becomes very slow because of massive ERASE operations

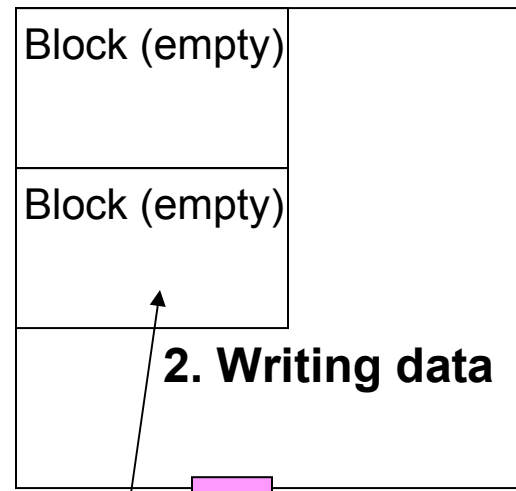
# Reserved Space

## Data Space



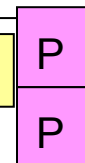
1. Reading pages

## Reserved Space



2. Writing data

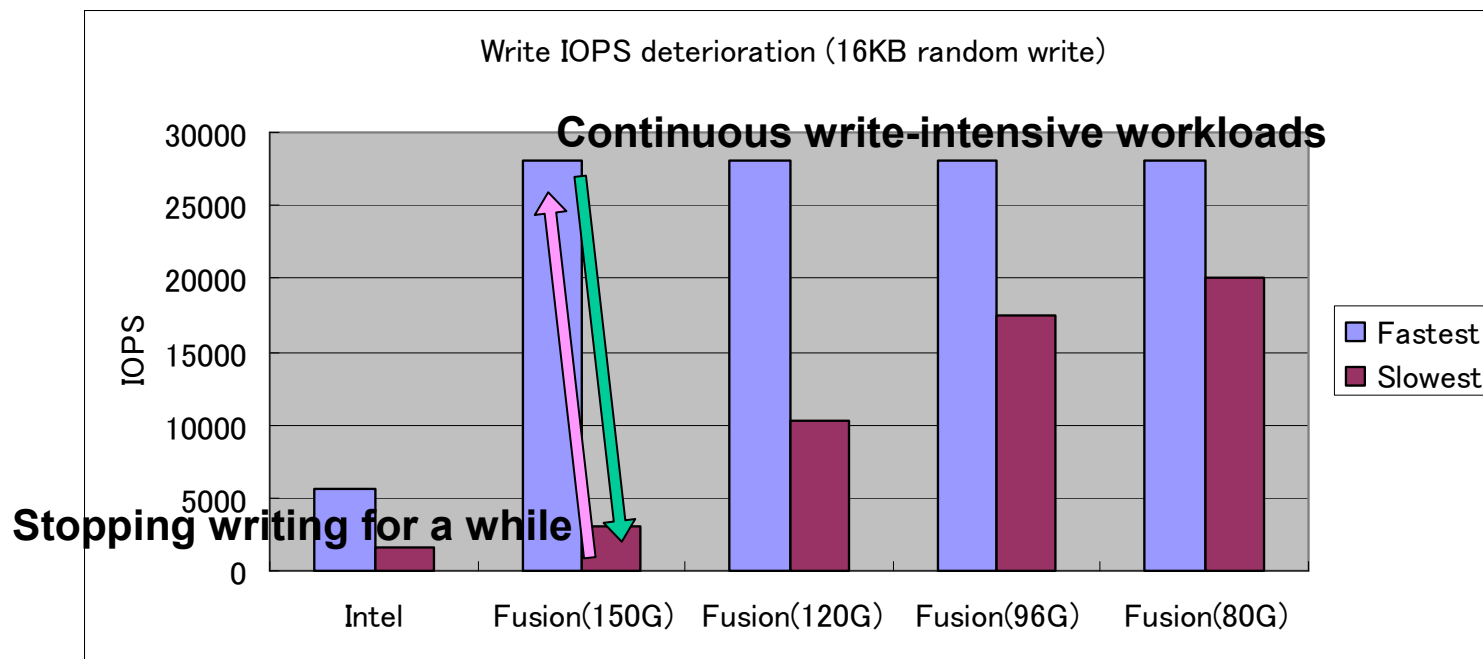
New data



## Background jobs ERASE unused blocks

- To keep high enough write performance, SSDs have a feature of “reserved space”
- Data size visible to applications is limited to the size of data space
  - i.e. 160GB SSD, 120GB data space, 40GB reserved space
- Fusion I/O has a functionality to change reserved space size
  - # fio-format -s 96G /dev/fct0

# Write performance deterioration



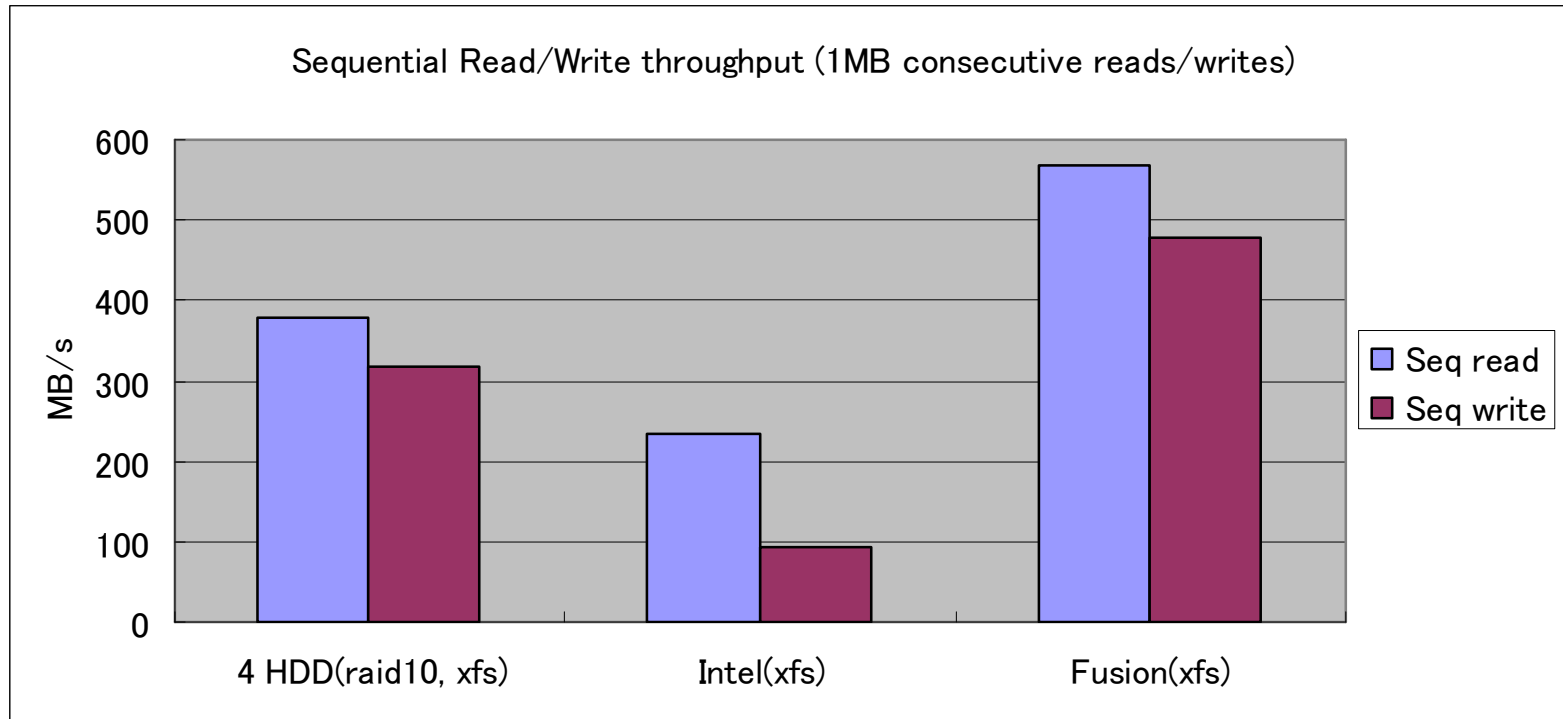
- At the beginning, write IOPS was close to “Fastest” line
- When massive writes happened, write IOPS gradually deteriorated toward “Slowest” line (because massive ERASE happened)
- Increasing reserved space improves steady-state write throughput
- Write IOPS recovered to “Fastest” when stopping writes for a long time (Many blocks were ERASEd by background job)
- Highly depending on Flash memory and I/O controller (TRIM support, ERASE scheduling, etc)

# Mitigating write performance deterioration

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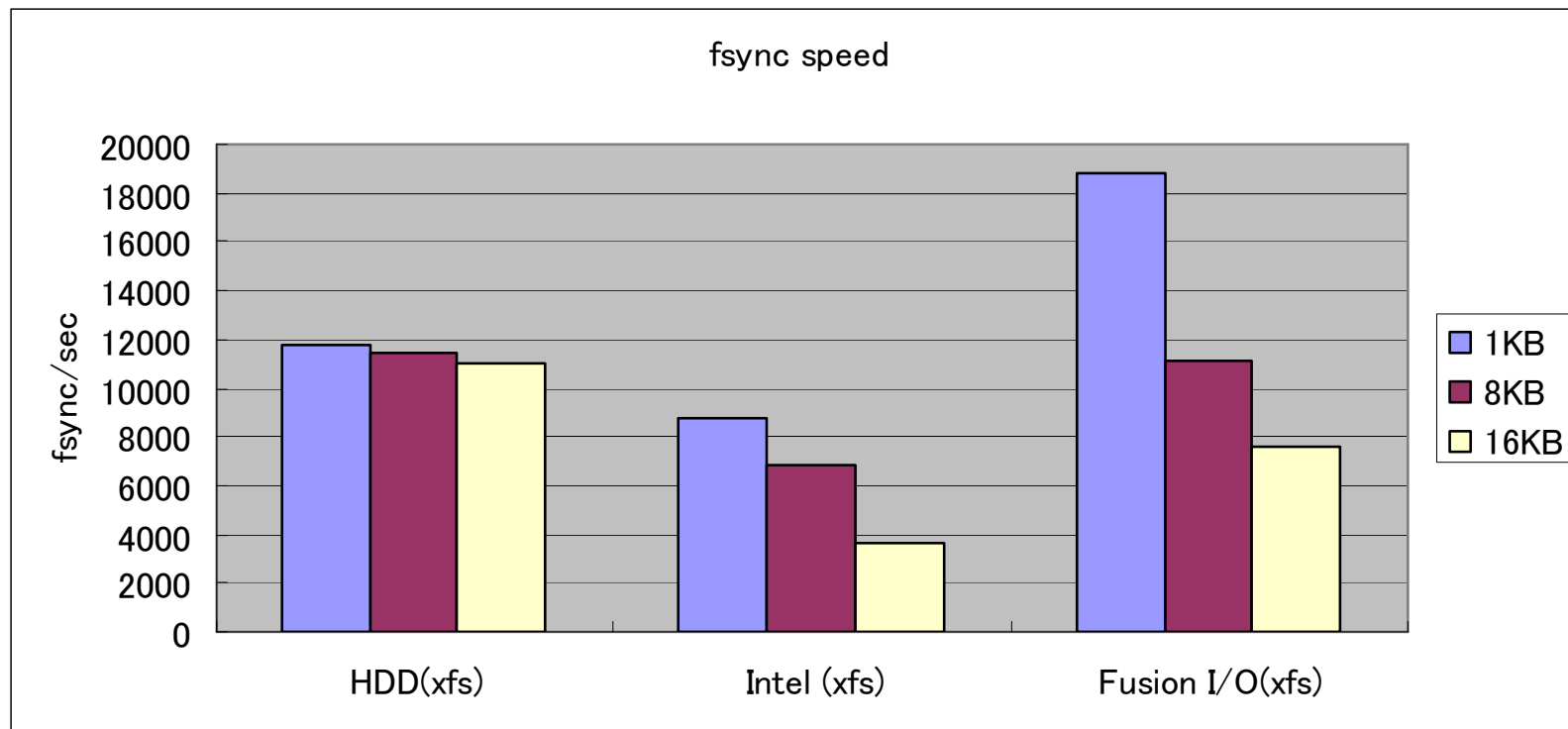
- Allocating more reserved space
  - Per space pricing increases. This is not always acceptable
- Using tachIOon
  - tachIOon is highly optimized for keeping write performance higher
- Using Software RAID0
  - Write traffic is distributed to multiple drives. You can gain high enough write throughput even though additional reserved space is not allocated

# Sequential I/O



- Typical scenario: Full table scan (read), logging/journaling (write)
- SSD outperforms HDD for sequential reads, but less significant
- HDD (4 RAID10) is fast enough for sequential i/o
- Data transfer size by sequential writes tends to be huge, so you need to care about write deterioration on SSD
- No strong reason to use SSD for sequential writes

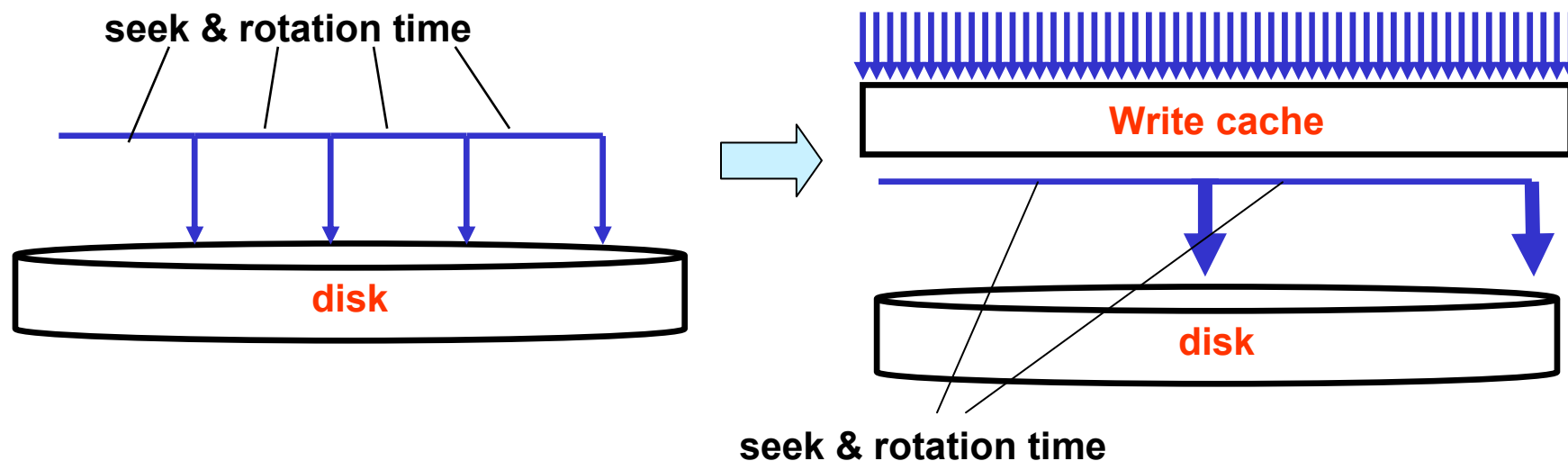
# fsync() speed



- 10,000+ fsync/sec is fine in most cases
- Fusion I/O was CPU bound (%system), not I/O bound (%iowait).

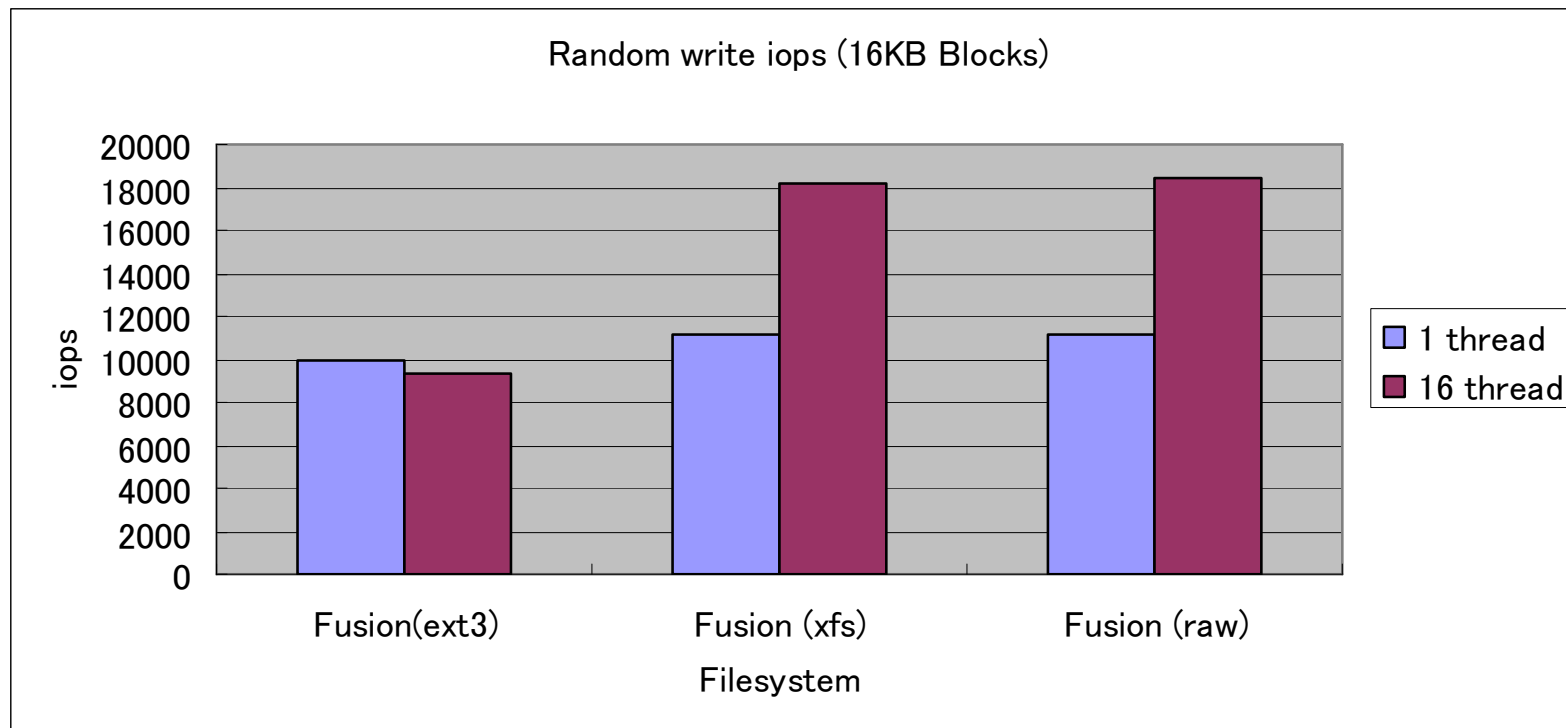
# HDD is fast for sequential writes / fsync

- Best Practice: Writes can be boosted by using BBWC/FBWC (Battery Backed up Write Cache), especially for REDO Logs (because it's sequentially written)
- No strong reason to use SSDs here



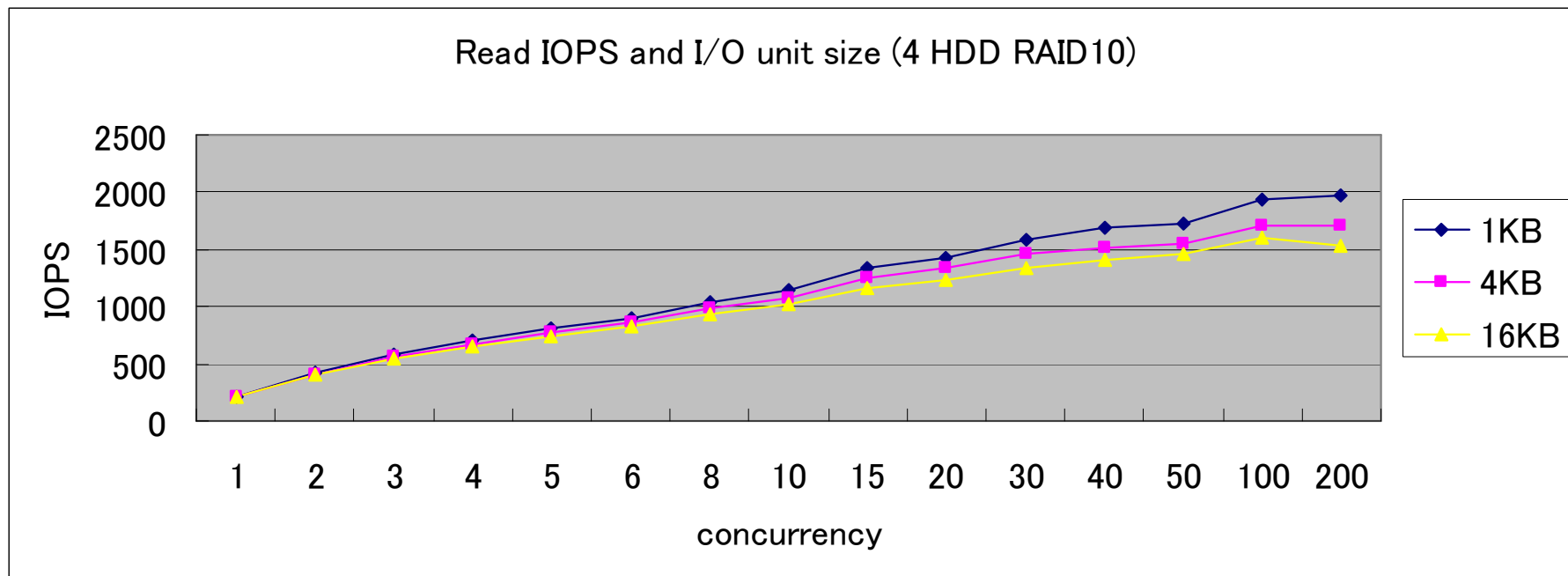


# Filesystem matters



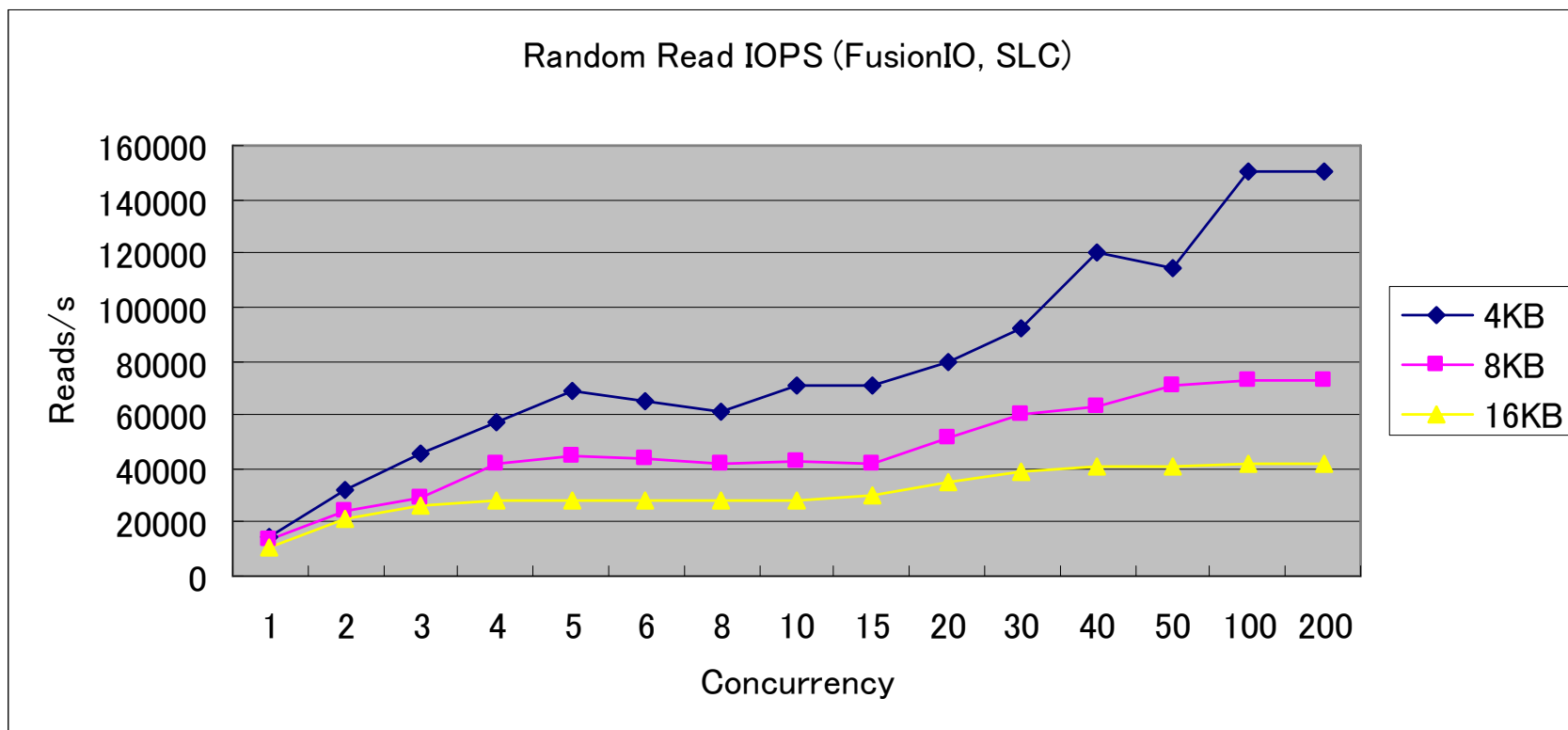
- On xfs, multiple threads can write to the same file if opened with `O_DIRECT`, but can not on ext\*
- Good concurrency on xfs, close to raw device
- ext3 is less optimized for Fusion I/O

# Changing I/O unit size



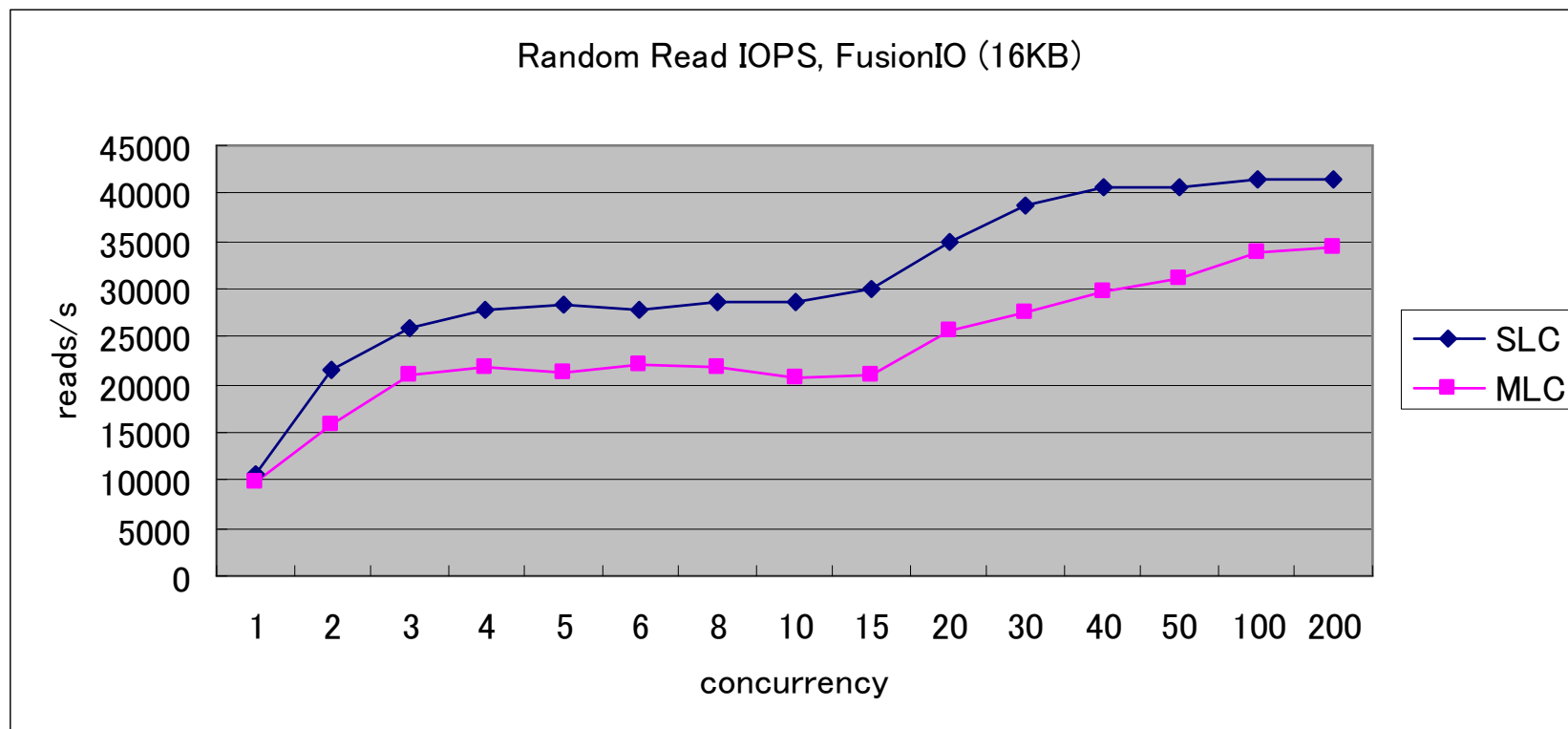
- On HDD, maximum 22% performance difference was found between 1KB and 16KB
- No big difference when concurrency < 10

# Changing I/O unit size on FusionIO



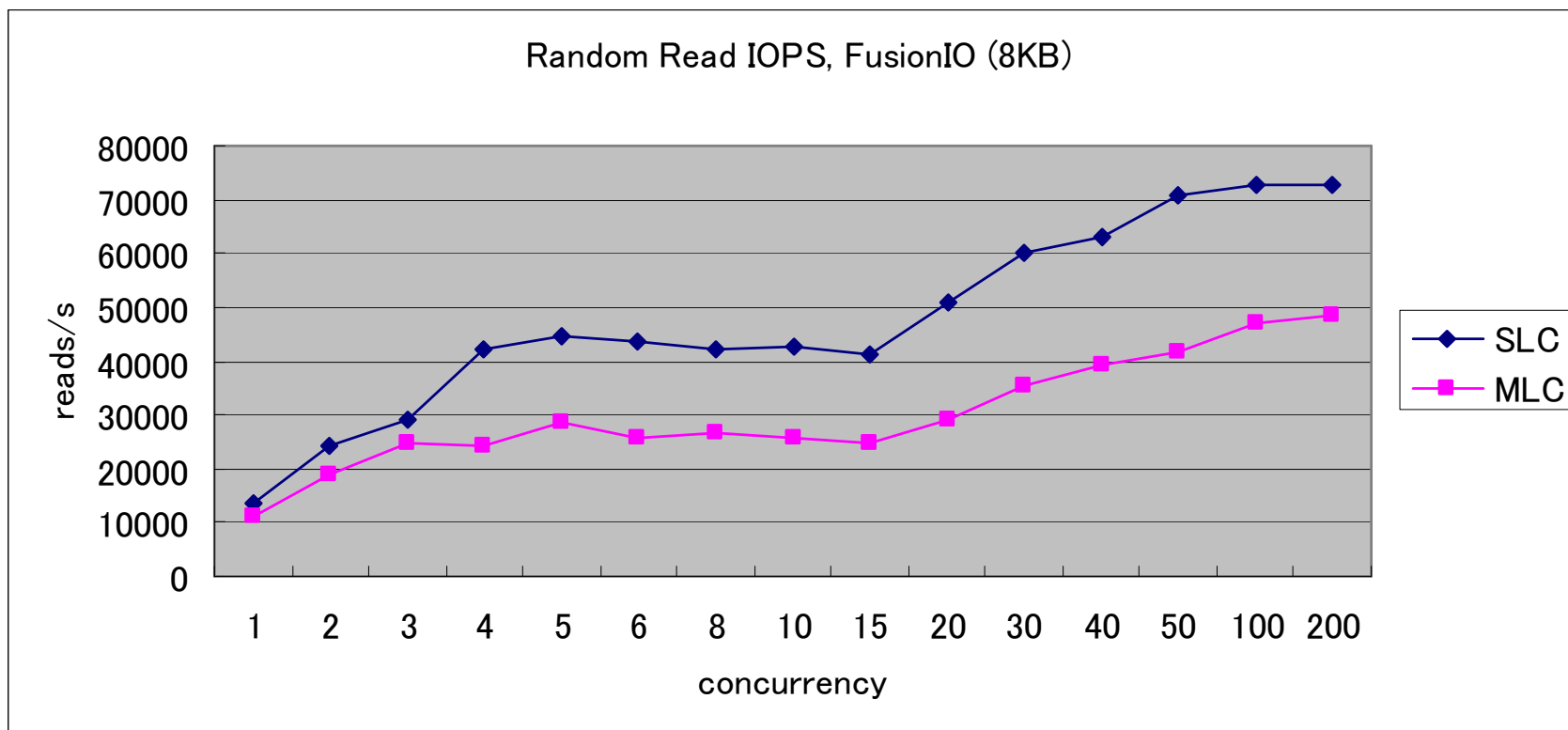
- Huge difference
- On SSDs, not only IOPS, but also I/O transfer size matters
- It's worth considering that Storage Engines support “configurable block size” functionality

# SLC vs MLC (16KB)



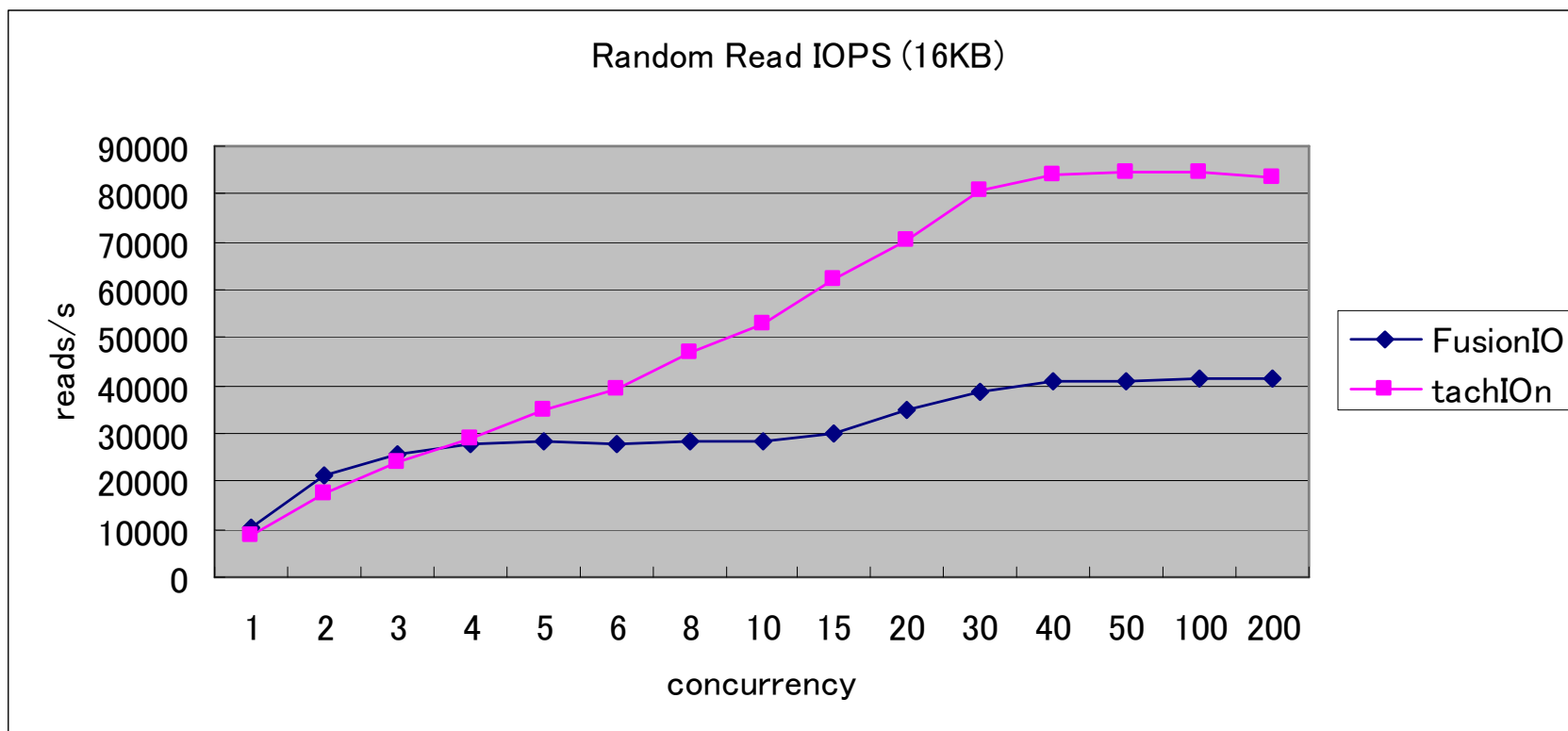
■ 8-40% better throughput on SLC

# SLC vs MLC (8KB)



- 25-75% better throughput on SLC
- Random I/O benchmarks should be done carefully (SLC or MLC, I/O unit size, etc..)

# tachIO on vs FusionIO (SLC)



- tachIO on performs very well, especially when concurrency is high enough

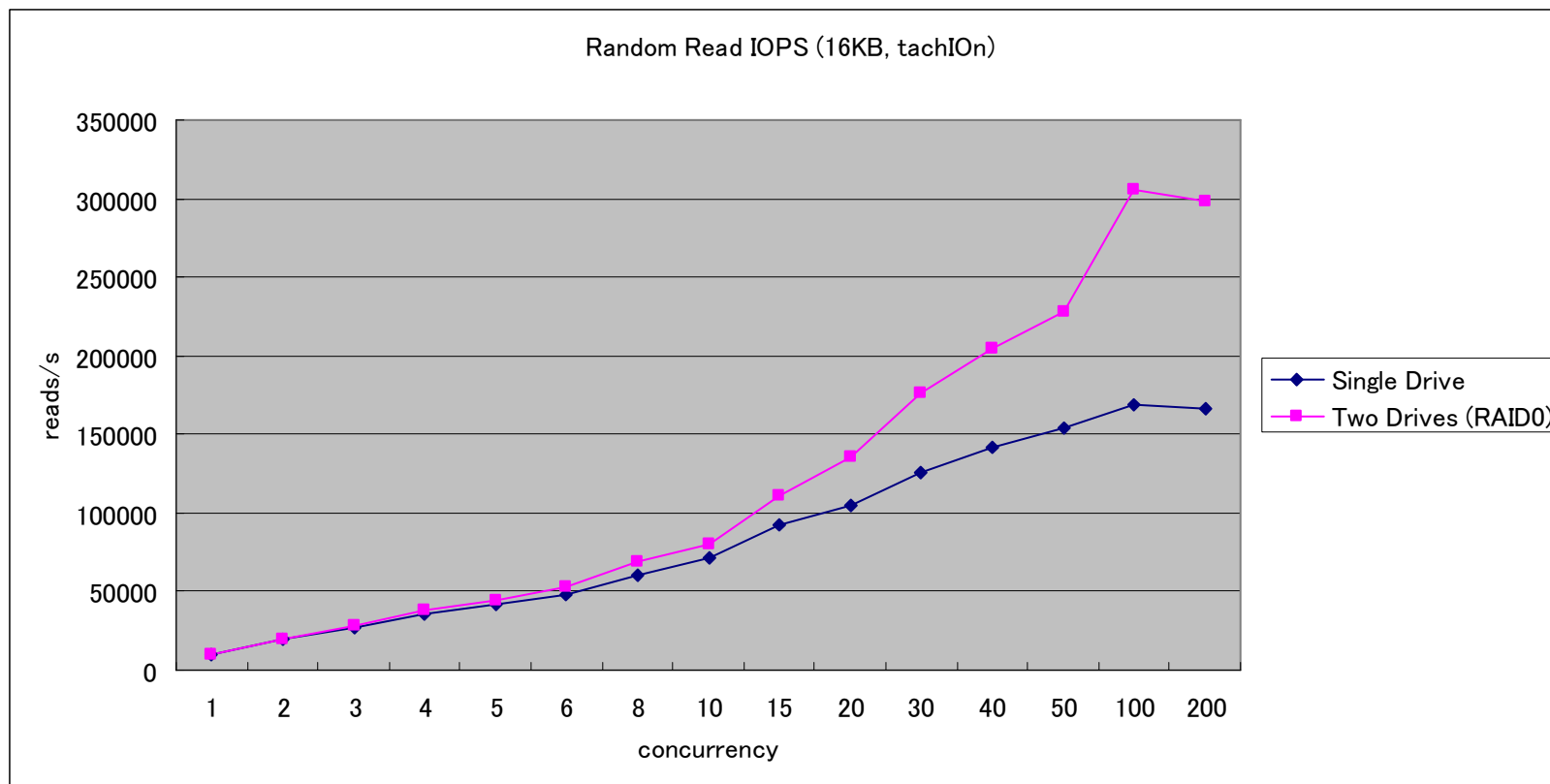
# PCI-Express interface and CPU util

```
# cat /proc/interrupts | grep PCI
83:      ... PCI-MSI    vgcinit
202:      ... PCI-MSI-X  eth2-0
210:      ... PCI-MSI-X  eth2-1
218:      ... PCI-MSI-X  eth2-2
226:      ... PCI-MSI-X  eth2-3
234:      ... PCI-MSI-X  eth2-4
```

```
# mpstat -P ALL 1
CPU    %user   %nice   %sys %iowait    %irq   %soft  %idle  intr/s
all      0.45     0.00    7.75  26.69    1.65    0.00   63.45  40046.40
  0      1.00     0.00   12.60  86.40    0.00    0.00    0.00   1000.20
  1      1.00     0.00   13.63  85.37    0.00    0.00    0.00    0.00
  2      0.40     0.00    4.80  26.80    0.00    0.00   68.00    0.00
  3      0.00     0.00    0.00   0.00   79.20    0.00   20.80 39033.20 ...
```

- %irq (Hardware interrupts) was bottleneck
- Only one IRQ port was allocated per single PCI-E SSD drive
- By using multiple drives the number of IRQ ports increases

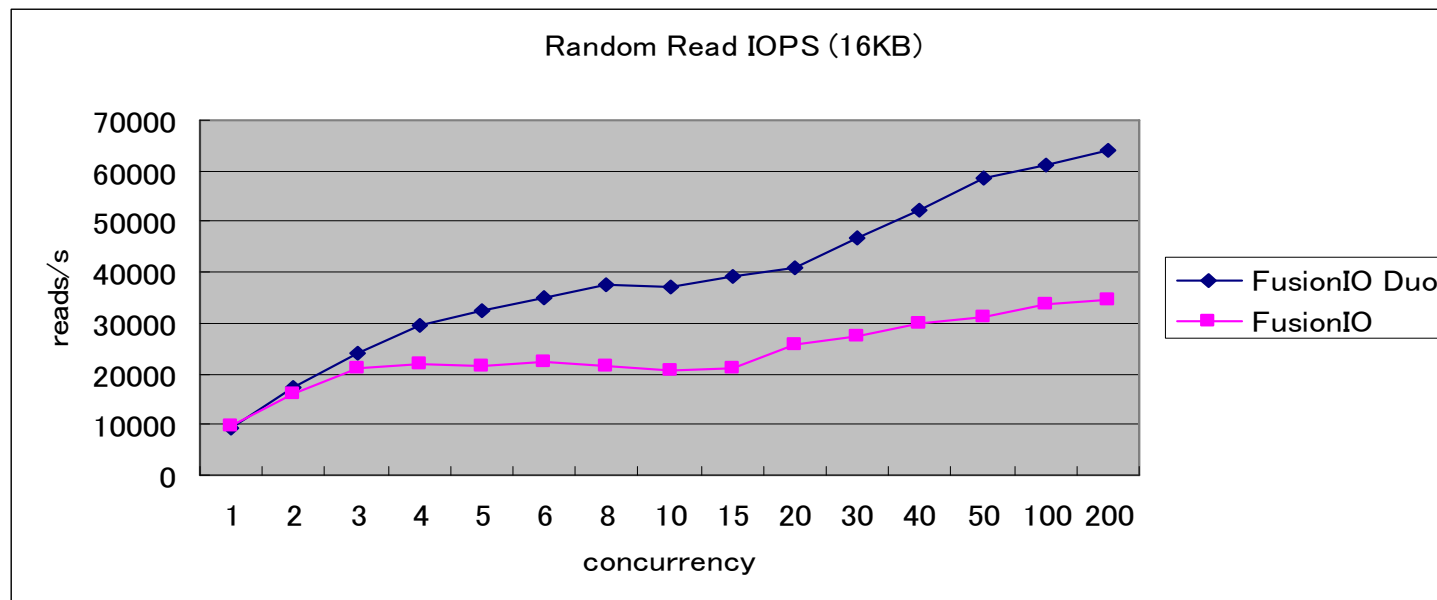
# # of interfaces (tachIOon SLC)



- Two drives result in nearly two times better throughput, if enough read i/o is coming
- When the number of clients was small (not enough i/o requests were coming), %irq was not so high, so using two drives was not so much helpful
- The number of slots are limited on most motherboards

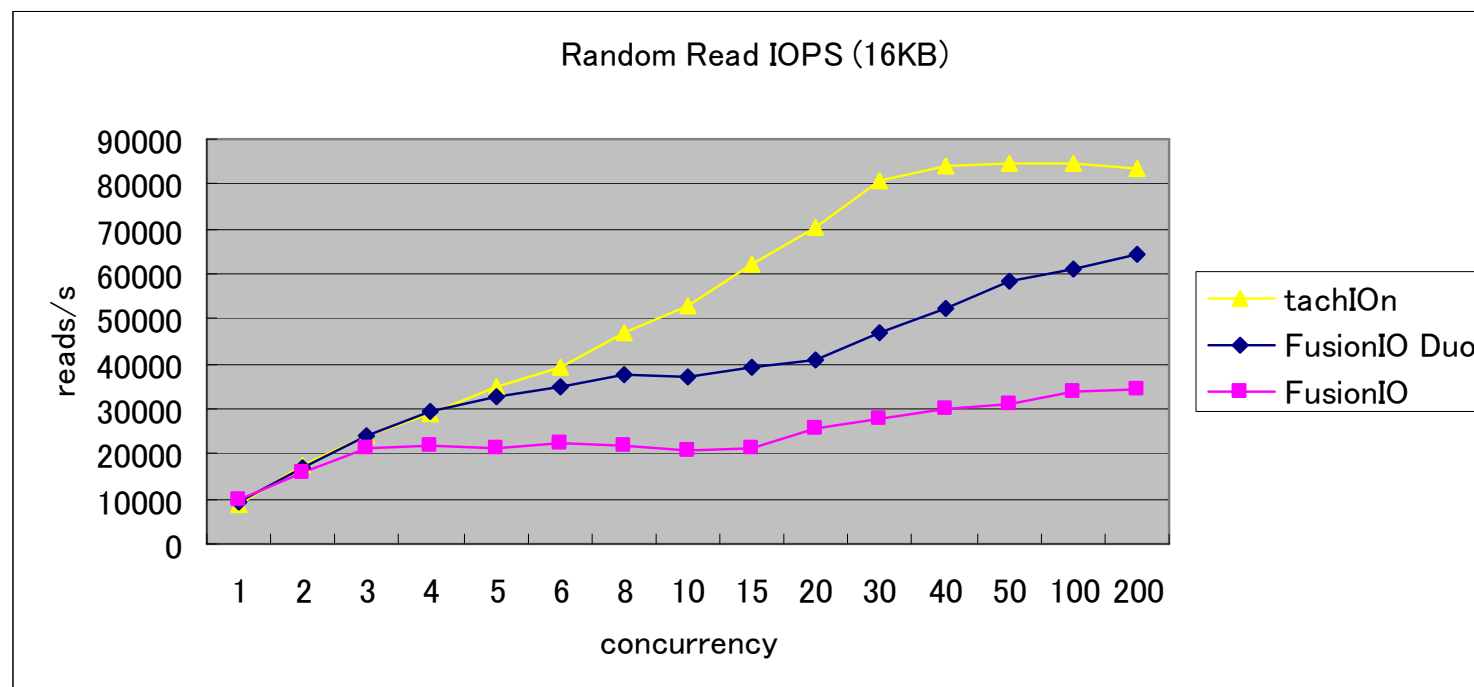


# # of interfaces (FusionIO MLC)



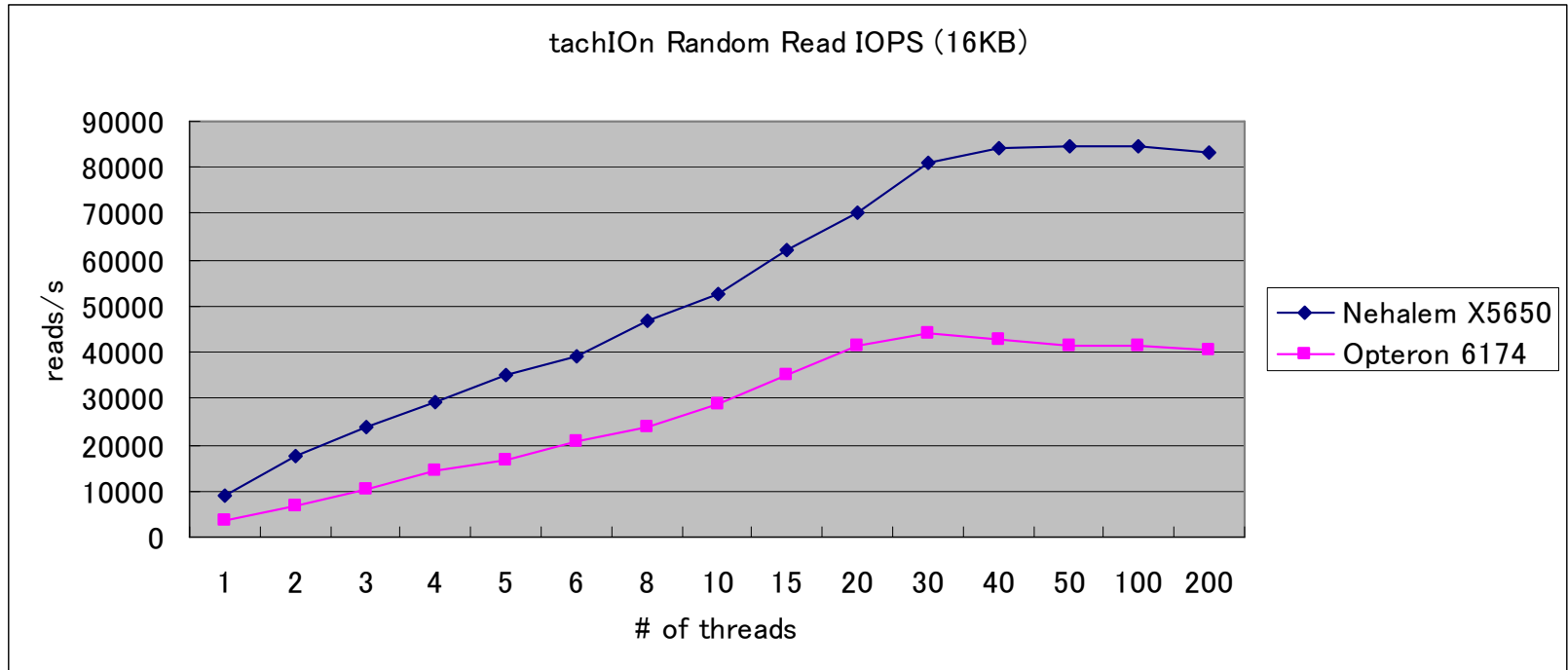
- FusionIO Duo internally has two drives per single PCI-Express connector
  - Two IRQ ports can be used, which greatly increases throughput
- A couple of restrictions
  - FusionIO Duo has two device files (/dev/fioa, /dev/fiob). Single large native filesystem can not be created
  - FusionIO Duo has physical(height/length) and electrical restrictions
    - Only one Duo drive can be installed on HP DL360 (two PCI-E ports) physically
    - On some servers, without an optional power cable, maximum performance can not be gained

# tachIOon(SLC) vs FusionIO Duo(MLC)



■ Fusion IO Duo performs good enough, considering it's MLC

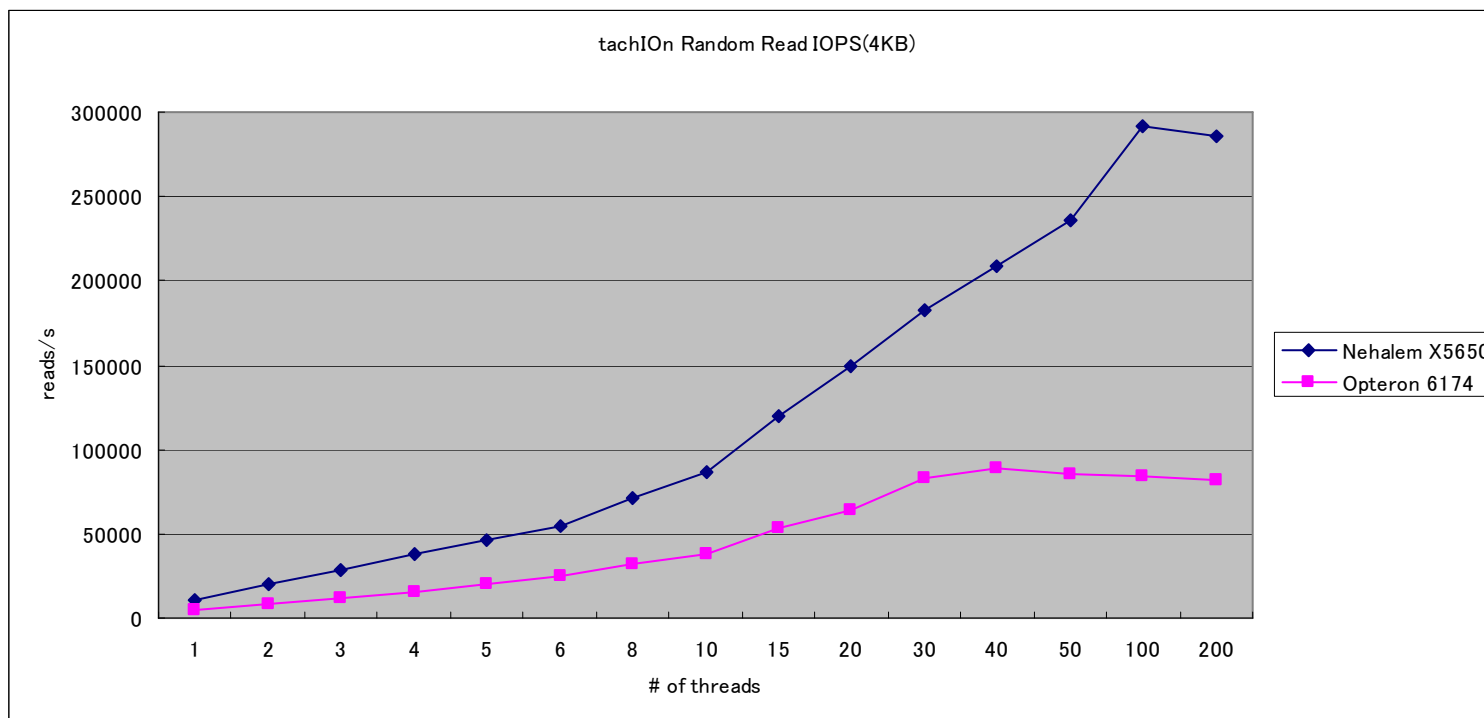
# Opteron vs Nehalem(tachIOon)



## ■ 2 times performance difference

- Single thread IOPS is bad
- Latency difference between PCI-E and CPU seems quite high

# Opteron vs Nehalem(tachIOon)



## ■ 2-4 times performance difference

- In both cases %irq was 100% used
- Handling Hardware Interrupts requires high CPU clock speed

# How about using SSD as L2 Cache?

## ■ Using SSD as L2Cache

- Interesting approach, as long as SSD is costly and capacity is limited
- Transparent from applications

## ■ Recent lineups

- ZFS L2ARC
  - Part of ZFS filesystem
- Facebook FlashCache
  - Working as Linux Kernel module
- FusionIO DirectCache
  - Working between OS and FusionIO. Depending on FusionIO drives
- Oracle Smart Flash Cache
  - L2 cache of Oracle Database. Depending on Oracle database

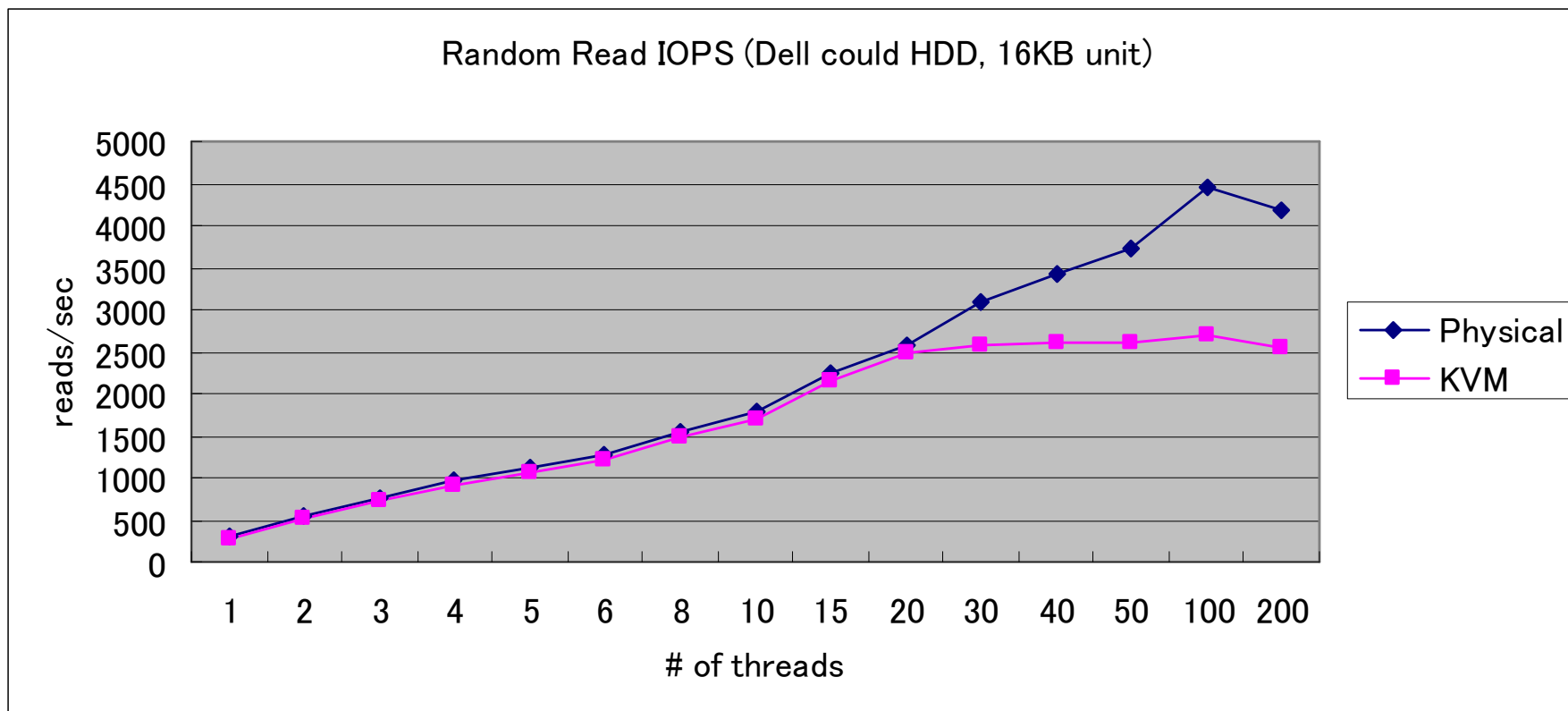
## ■ Issues

- Performance is not good (FlashCache)
  - Overheads on Linux Kernel seem huge
  - Even though data is 100% on SSD, random read iops dropped 40%, random write iops dropped 75% on FusionIO (tested with CentOS5.5)
  - Less performance drops on Intel X25-E
- In practice it's Single Point of Failure
  - It's not just a cache. We expect SSD-level performance. If it's broken, the system will go down.
- Total write volume grows significantly. L2Cache needs to be written when reading from HDD

# Virtualization?

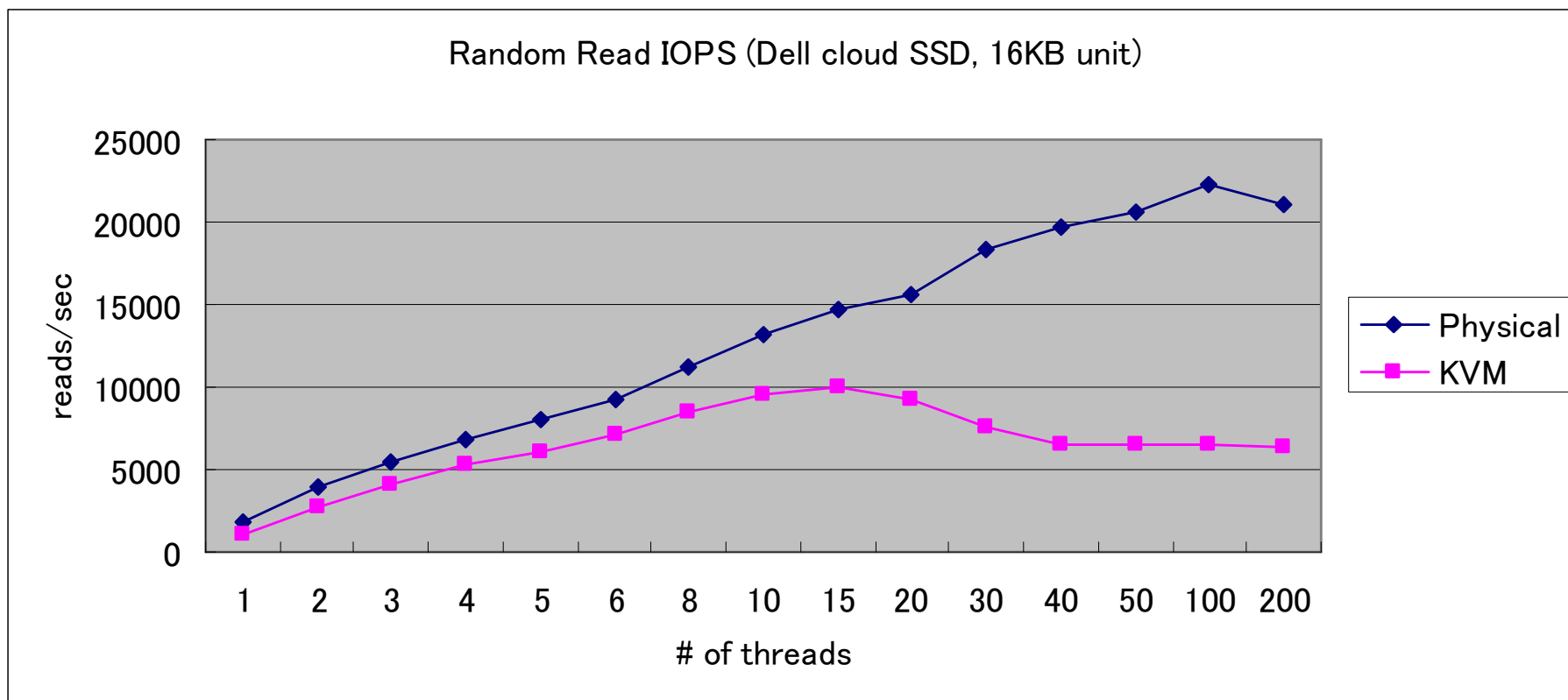
- Currently performance drops are serious (on faster drives)
  - Got only 1/30 throughput when tested with Ubuntu 10.4 + KVM + FusionIO
- When tested with HDD, performance drops were not so serious
- Not many case studies about running FusionIO/tachIO on virtualization environments
- It's better to run multiple MySQL instances on single OS

# Virtualization benchmarks (HDD)



■ Not so bad on HDD

# Virtualization benchmarks (SATA SSD)



■ Difference becomes huge when using SSD



# MySQL Deployment Practices on SSD

## ■ What will happen if ...

- Replacing HDD with Intel SSD (SATA)
- Replacing HDD with Fusion I/O (PCI-E)
- Moving log files and ibdata to HDD
- Not using Nehalem
- MySQL 5.5 or 5.1

## ■ DBT-2 benchmarks (write intensive)

- 200 Warehouses (20GB – 25GB hot data)
- Fusion I/O: SLC, 96GB data space, 64GB reserved space

# HDD vs Intel SSD vs Fusion I/O

	HDD	Intel	Fusion I/O
Buffer pool 1G	1125.44	5709.06	15122.75

NOTPM: Number of Transactions per minute

- Fusion I/O is a PCI-E based SSD
- PCI-E is much faster than SAS/SATA
- 14x improvement compared to 4HDDs

# Which should we spend money, RAM or SSD?

	HDD	Intel	Fusion I/O
Buffer pool 1G	1125.44	5709.06	15122.75
Buffer pool 2G	1863.19		
Buffer pool 5G	4385.18		
Buffer pool 30G (Caching all hot data)	36784.76		

- Increasing RAM (buffer pool size) reduces random disk reads
  - Because more data are cached in the buffer pool
- If all data are cached, only disk writes (both random and sequential) happen
- Disk writes happen asynchronously, so application queries can be much faster
- Large enough RAM + HDD outperforms too small RAM + SSD

# Which should we spend money, RAM or SSD?

	HDD	Intel	Fusion I/O
Buffer pool 1G	1125.44	5709.06	15122.75
Buffer pool 2G	1863.19	7536.55	20096.33
Buffer pool 5G	4385.18	12892.56	30846.34
Buffer pool 30G (Caching all hot data)	36784.76	-	57441.64

- It is not always possible to cache all hot data
- Fusion I/O + good amount of memory (5GB) was pretty good
- Basic rule can be:
  - If you can cache all active data, large enough RAM + HDD
  - If you can't, or if you need extremely high throughput, spend on both RAM and SSD

# MySQL file location

- SSD is extremely good at random reads
- SSD is very good at random writes
- HDD is good enough at sequential reads/writes
- No strong reason to use SSD for sequential writes
  
- Random I/O oriented:
  - Data Files (\*.ibd)
    - Sequential reads if doing full table scan
  - Undo Log, Insert Buffer (ibdata)
    - UNDO tablespace (small in most cases, except for running long-running batch)
    - On-disk insert buffer space (small in most cases, except that InnoDB can not catch up with updating indexes)
  
- Sequential Write oriented:
  - Doublewrite Buffer (ibdata0)
    - Write volume is equal to \*.ibd files. Huge
  - Binary log (mysql-bin.XXXXXXX)
  - Redo log (ib\_logfile)
  - Backup files

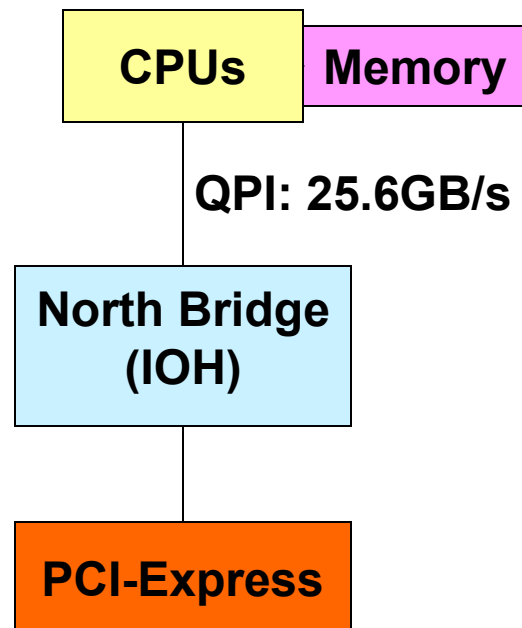
# Moving sequentially written files into HDD

	Fusion I/O	Fusion I/O + HDD	Up
Buffer pool 1G	15122.75 (us=25%, wa=15%)	19295.94 (us=32%, wa=10%)	+28%
Buffer pool 2G	20096.33 (us=30%, wa=12.5%)	25627.49 (us=36%, wa=8%)	+28%
Buffer pool 5G	30846.34 (us=39%, wa=10%)	39435.25 (us=49%, wa=6%)	+28%
Buffer pool 30G	57441.64 (us=70%, wa=3.5%)	66053.68 (us=77%, wa=1%)	+15%

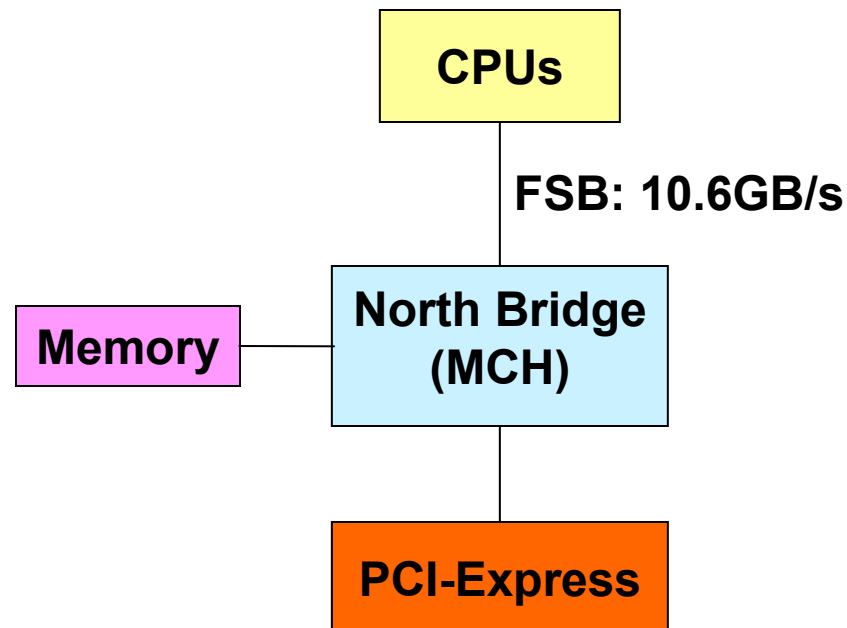
- Moving ibdata, ib\_logfile, (+binary logs) into HDD
- High impact on performance
  - Write volume to SSD becomes half because doublewrite area is allocated in HDD
  - %iowait was significantly reduced
  - Write volume on SSD is less than half

# Does CPU matter?

## Nehalem



## Older Xeon



### ■ Nehalem has two big advantages

1. Memory is directly attached to CPU : Faster for in-memory workloads
2. Interface speed between CPU and North Bridge is 2.5x higher, and interface traffics do not conflict with CPU<->Memory workloads  
Faster for disk i/o workloads when using PCI-Express SSDs

## Harpertown X5470 (older Xeon) vs Nehalem X5570 (HDD)

HDD	Harpertown X5470, 3.33GHz	Nehalem(X5570, 2.93GHz)	Up
Buffer pool 1G	1135.37 (us=1%)	1125.44 (us=1%)	-1%
Buffer pool 2G	1922.23 (us=2%)	1863.19 (us=2%)	-3%
Buffer pool 5G	4176.51 (us=7%)	4385.18(us=7%)	+5%
Buffer pool 30G	30903.4 (us=40%)	36784.76 (us=40%)	+19%

us: userland CPU utilization

- CPU difference matters on CPU bound workloads



# Harpertown X5470 vs Nehalem X5570 (Fusion)

Fusion I/O+HDD	Harpertown X5470, 3.33GHz	Nehalem(X5570, 2.93GHz)	Up
Buffer pool 1G	13534.06 (user=35%)	19295.94 (user=32%)	+43%
Buffer pool 2G	19026.64 (user=40%)	25627.49 (user=37%)	+35%
Buffer pool 5G	30058.48 (user=50%)	39435.25 (user=50%)	+31%
Buffer pool 30G	52582.71 (user=76%)	66053.68 (user=76%)	+26%

- TPM difference was much higher than HDD
- For disk i/o bound workloads (buffer pool 1G/2G), CPU utilizations on Nehalem were smaller, but TPM were much higher
  - Verified that Nehalem is much more efficient for PCI-E workloads
- Benefit from high interface speed between CPU and PCI-Express
- Fusion I/O fits with Nehalem much better than with traditional CPUs

# Intel SSDs with a traditional H/W raid controller

	Single raw Intel	Four RAID5 Intel	Down
Buffer pool 1G	5709.06	2975.04	-48%
Buffer pool 2G	7536.55	4763.60	-37%
Buffer pool 5G	12892.56	11739.27	-9%

- Raw SSD drives performed much better than using a traditional H/W raid controller
  - Even on RAID10 performance was worse than single raw drive
  - H/W Raid controller seemed serious bottleneck
  - Make sure SSD drives have write cache and capacitor itself (Intel X25-V/M/E doesn't have capacitor)
- Use JBOD + write cache + capacitor
  - Intel 320 SSD supports capacitor

# Enable HyperThreading

Fusion I/O + HDD	HT OFF (8)	HT ON (16)	Up
Buffer pool 1G	19295.94	20785.42	+7.7%
Buffer pool 2G	25627.49	28438.00	+11%
Buffer pool 5G	39435.25	45785.12	+16%
Buffer pool 30G	66053.68	81412.23	+23%

- InnoDB Plugin and 5.1 scales well with 16-24 CPU cores
- HT is more effective on SSD environments because loads are more CPU bound

# MySQL 5.5

Fusion I/O + HDD	MySQL5.1	MySQL5.5	Up
Buffer pool 1G	19295.94	24019.32	+24%
Buffer pool 2G	25627.49	32325.76	+26%
Buffer pool 5G	39435.25	47296.12	+20
Buffer pool 30G	66053.68	67253.45	+1.8%

- Got 20-26% improvements for disk i/o bound workloads on Fusion I/O
  - Both CPU %user and %iowait were improved
    - %user: 36% (5.5.2) to 44% (5.5.4) when buf pool = 2g
    - %iowait: 8% (5.5.2) to 5.5% (5.5.4) when buf pool = 2g, but iops was 20% higher
  - Could handle a lot more concurrent i/o requests in 5.5 !
  - No big difference was found on 4 HDDs
    - Works very well on faster storages such as Fusion I/O, lots of disks

# Where can PCI-Express SSD be used?

## ■ Deploying on master?

- If PCI-E SSD is used on master, replication delay will happen again
  - 10,000IOPS from single thread, 40,000+ IOPS from 100 threads
- 10,000IOPS from 100 threads can be achieved from SATA SSD
- Parallel SQL threads should be implemented in MySQL

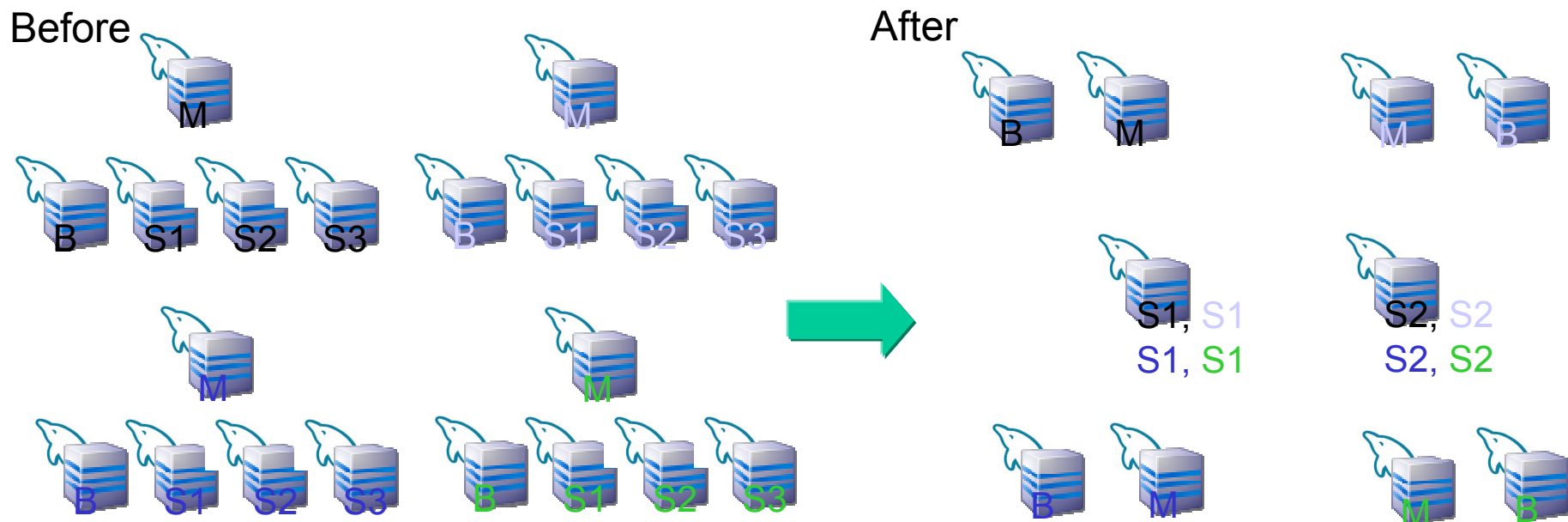
## ■ Deploying on slave?

- If using HDD on master, SATA SSD should be enough to handle workloads
  - PCI-Express SSD is much more expensive than SATA SSD
- How about running multiple MySQL instances on single server?
  - Virtualization is not fast
  - Running multiple MySQL instances on single OS is more reasonable

## ■ Does PCI-E SSD have enough storage capacity to run multiple instances?

- On HDD environments, typically only 100-200GB of database data can be stored because of slow random IOPS on HDD
- FusionIO SLC: 320GB Duo + 160GB = 480GB
- FusionIO MLC: 1280GB Duo + 640GB = 1920GB (or using ioDrive Octal)
- tachIO on SLC: 800GB x 2 = 1600GB

# Running multiple slaves on single box



## ■ Running multiple slaves on a single PCI-E slave

- Master and Backup Server are still HDD based
- Consolidating multiple slaves
- Since slave's SQL thread is single threaded, you can gain better concurrency by running multiple instances
- The number of instances is mainly restricted by capacity

# Our environment

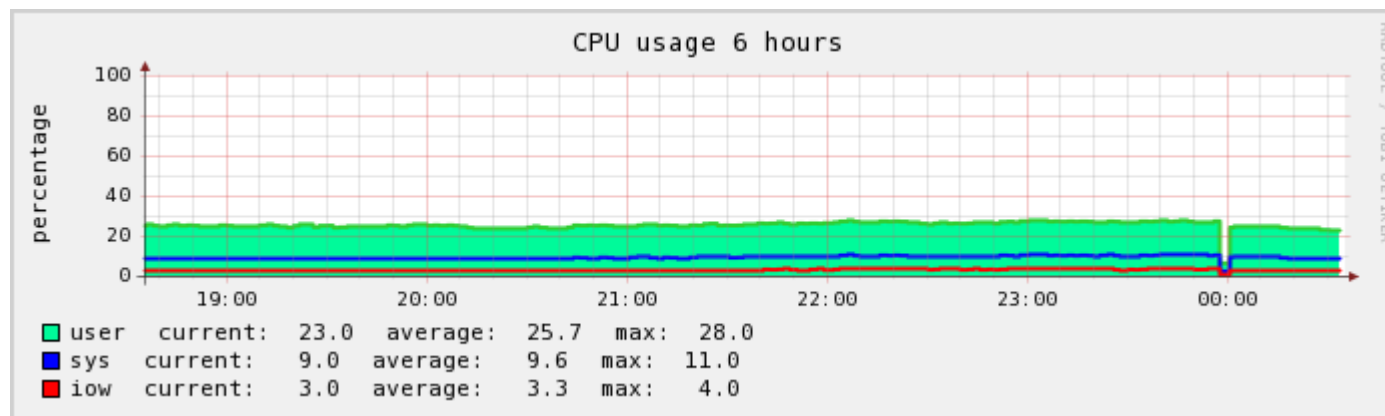
- Machine
  - HP DL360G7 (1U), or Dell R610
- PCI-E SSD
  - FusionIO MLC (640-1280GB Duo + 320-640GB )
  - tachIO on SLC (800GB x 2) -> MLC
- CPU
  - Two sockets, Nehalem 6-core per socket, HT enabled
    - 24 logical CPU cores are visible
    - Four socket machine is too expensive
- RAM
  - 60GB or more
- Network
  - Broadcom BCM5709, Four ports
  - Bonding x 2
  - Two physical IP addresses, 6-12 (=instances) virtual IP addresses
- HDD
  - 4-8 SAS RAID1+0
  - For backups, redo logs, relay logs, (optionally) doublewrite buffer

# Statistics

- Consolidating 7 instances on FusionIO (640GB MLC Duo + 320GB MLC)
  - Let half of SELECT queries go to these slaves
  - 6GB innodb\_buffer\_pool\_size
- Peak QPS (total of 7 instances)
  - 61683.7 query/s
  - 37939.1 select/s
  - 7861.1 update/s
  - 1105 insert/s
  - 1843 delete/s
  - 3143.5 begin/s
- CPU Utilization
  - %user 27.3%, %sys 11%(%soft 4%), %iowait 4%
  - C.f. SATA SSD: %user 4%, %sys 1%, %iowait 1%
- Buffer pool hit ratio
  - 99.4%
  - SATA SSD : 99.8%
- No replication delay
- No significant (100+ms) response time delay caused by SSD



# CPU loads



22:10:57	CPU	%user	%nice	%sys	%iowait	%irq	%soft	%steal	%idle	intr/s
22:11:57	all	27.13	0.00	6.58	4.06	0.14	3.70	0.00	58.40	56589.95
...										
22:11:57	23	30.85	0.00	7.43	0.90	1.65	49.78	0.00	9.38	44031.82

- CPU utilization was high, but should be able to handle more
  - %user 27.3%, %sys 11%(%soft 4%), %iowait 4%
  - Reached storage capacity limit (960GB). Using 1920GB MLC should be fine to handle more instances
- Network will be the first bottleneck
  - Recv: 14.6MB/s, Send: 28.7MB/s
  - CentOS5 + bonding is not good for network requests handling (only single CPU core can handle requests)
  - Using four or more network cables, then building two or more bond interfaces should scale

# Things to consider

- Allocating different IP addresses or port numbers
  - Administration tools are also affected
  - We allocated different IP addresses because some of existing tools depend on “port=3306”
  - ip addr
  - bind-address=“virtual ip address” in my.cnf
- Creating separated directories and files
  - Socket files, data directories, InnoDB files, binary log files etc should be stored on different location each other
- Storing some files on HDD, others on SSD
  - Binary logs, Relay logs, Redo logs, error/slow logs, ibdata0 (files where doublewrite buffer is written), backup files on HDD
  - Others on SSD

# taskset

```
# taskset -pc 0,12,2,14 `cat /var/lib/mysql/mysqld1.pid`  
# taskset -pc 1,13,3,15 `cat /var/lib/mysql/mysqld2.pid`  
# taskset -pc 5,17,7,19 `cat /var/lib/mysql/mysqld3.pid`  
# taskset -pc 8,20,10,22 `cat /var/lib/mysql/mysqld4.pid`  
# taskset -pc 9,21,11,23 `cat /var/lib/mysql/mysqld5.pid`  
# taskset -pc 4,16,6,18 `cat /var/lib/mysql/mysqld6.pid`  
# taskset -pc 8,20,10,22 `cat /var/lib/mysql/mysqld7.pid`
```

- MySQL server currently does not scale well with 24 logical CPU cores
- When running 6+ instances on 24 cores, the number of utilized CPU cores should be limited per instance
- Check `/proc/cpuinfo` output
- Use same physical id (socket id) for the same instance
- Within the same physical id, use same core id (physical core) for the same instance

# Application Design

- Bottleneck shifts from storage to CPU/Network
  - Massively executed SQL statements should be migrated to NoSQL / HandlerSocket /etc
  
- Separating tables
  - History tables (only recent data is accessed) fit with HDD because most of active data fit in memory
  - Rarely accessed tables can also be stored on HDD
  - Other tables on SSD

# Making MySQL better

---

- Parallel SQL threads
- Pool of threads
- 8KB/4KB InnoDB Blocks
- Minimized performance stalls
- No hot global/large mutex
  - LINEAR HASH partitions on large tables helps
    - Index mutex is allocated per partition

# Future improvements from DBA perspective

- One master, one backup/slave and one DR slave
  - Single slave should be enough from performance perspective
- Differential recovery (no full restore) on crash
  - Restoring 800GB data file takes hours in total
- MySQL should be better for crashes
  - Master should flush transactional data to disks at commit
    - `sync-binlog=1, innodb_flush_log_at_trx_commit=1`
    - Right now performance is poor
  - Semi-sync replication (GA in 5.5)
  - Crash-safe binary logs (binlog checksum)
  - Relay log execution status should be stored on InnoDB tables, not on file(`relay-log.info`) (in 5.6?)
    - Relay log status can be consistent

# Conclusion for choosing H/W

## ■ Disks

- PCI-E SSDs (i.e. FusionIO, tachIOon) perform very well
- SAS/SATA SSDs with capacitor (i.e. Intel 320)
- Carefully research RAID controller. Many controllers do not scale with SSD drives
- Keep enough reserved space, use tachIOon, or use RAID0 if you need to handle massive write traffics
- HDD is good at sequential writes

## ■ Use Nahalem CPU

- Especially when using PCI-Express SSDs

# Conclusion for database deployments

- Put sequentially written files on HDD
  - ibdata, ib\_logfile, binary log files
  - HDD is fast enough for sequential writes
  - Write performance deterioration can be mitigated
  - Life expectancy of SSD will be longer
- Put randomly accessed files on SSD
  - \*ibd files, index files(MYI), data files(MYD)
  - SSD is 10x -100x faster for random reads than HDD
- Archive less active tables/records to HDD
  - SSD is still much expensive than HDD
- Use 5.1 InnoDB Plugin or 5.5
  - Higher scalability & concurrency matters on faster storage



# What will happen in the real database world?

- These are just my thoughts..
- Less demand for NoSQL
  - Isn't it enough for many applications just to replace HDD with Fusion I/O?
  - Importance on functionality will be relatively stronger
- Stronger demand for Virtualization
  - Single server will have enough capacity to run two or more mysqld instances
  - Right now performance is poor. Running multiple instances is a good workaround
- I/O volume matters
  - Not just IOPS
  - Configurable block size, disabling doublewrite, etc
- Concurrency matters
  - Single SSD scales as well as 8-16 HDDs
  - Concurrent ALTER TABLE, parallel query

## ■ Memory and Swap Space Management

# Random Access Memory

- RAM access speed is much faster than HDD/SSD
  - RAM: -60ns
    - 100,000 queries per second is not impossible
  - HDD: -5ms
  - SSD: 100-500us
- 16-100+GB RAM is now pretty common
- \*hot application data\* should be cached in memory
- Minimizing hot application data size is important
  - Use compact data types (SMALLINT instead of VARCHAR/BIGINT, TIMESTAMP instead of DATETIME, etc)
  - Do not create unnecessary indexes
  - Delete records or move to archived tables, to keep hot tables smaller

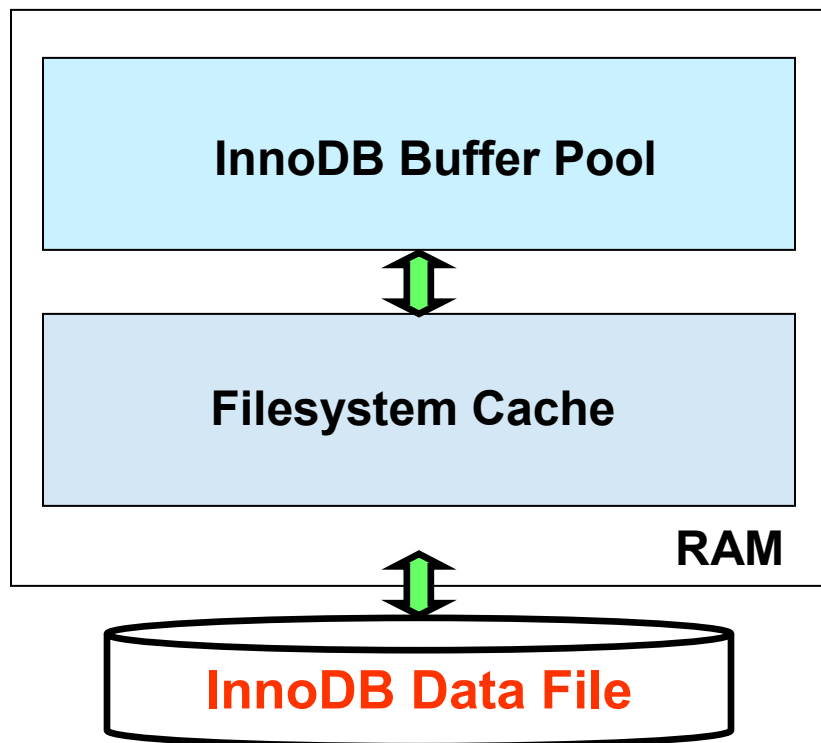
# Cache hot application data in memory

DBT-2 (W200)	Transactions per Minute	%user	%iowait
Buffer pool 1G	1125.44	2%	30%
Buffer pool 2G	1863.19	3%	28%
Buffer pool 5G	4385.18	5.5%	33%
Buffer pool 30G (All data in cache)	36784.76	36%	8%

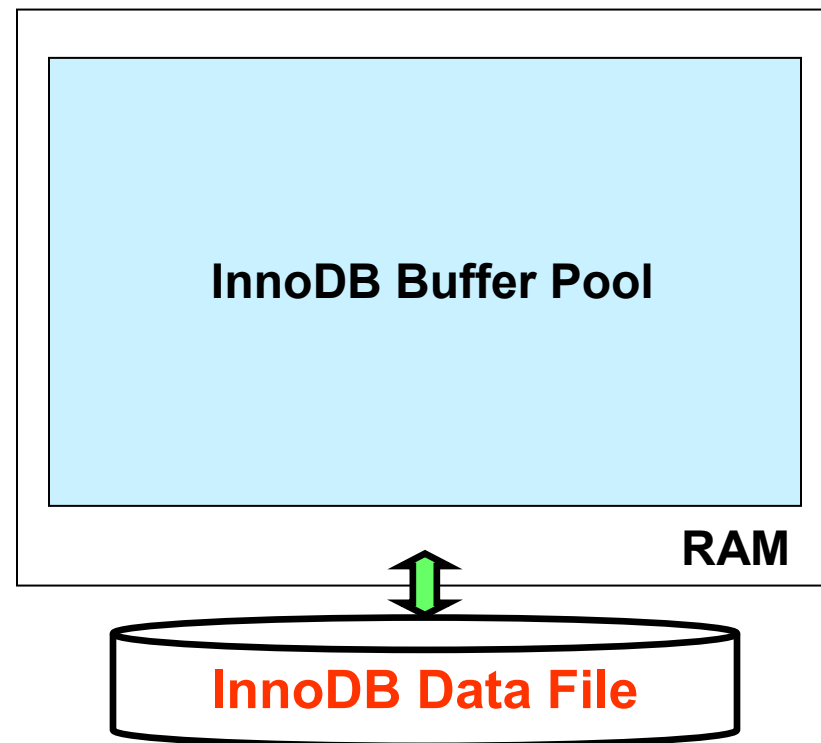
- DBT-2 benchmark (write intensive)
- 20-25GB hot data (200 warehouses, running 1 hour)
- RAM size affects everything. Not only for SELECT, but also for INSERT/UPDATE/DELETE
  - INSERT: Random reads/writes happen when inserting into indexes in random order
  - UPDATE/DELETE: Random reads/writes happen when modifying records

# Use Direct I/O

## Buffered I/O



## Direct I/O



- Direct I/O is important to fully utilize Memory
- `innodb_flush_method=O_DIRECT`
- Alignment: File i/o unit must be a factor of 512 bytes
  - Can't use `O_DIRECT` for InnoDB Log File, Binary Log File, MyISAM, PostgreSQL data files, etc

# Do not allocate too much memory

```
user$ top
```

```
Mem: 32967008k total, 32808696k used, 158312k free, 10240k buffers
```

```
Swap: 35650896k total, 4749460k used, 30901436k free, 819840k cached
```

PID	USER	PR	NI	VIRT	RES	SHR	S	%CPU	%MEM	TIME+	COMMAND
-----	------	----	----	------	-----	-----	---	------	------	-------	---------

5231	mysql	25	0	35.0g	30g	324	S	0.0	71.8	7:46.50	mysqld
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## ■ What happens if no free memory space is available?

- Reducing filesystem cache to allocate memory space
- Swapping process(es) to allocate memory space

## ■ Swap is bad

- Process spaces are written to disk (swap out)
- Disk reads happen when accessing on-disk process spaces (swap in)
- Massive random disk reads and writes will happen

# What if setting swap size to zero?

- By setting swap size to zero, swap doesn't happen anymore. But..
  - Very dangerous
- When neither RAM nor swap space is available, OOM killer is invoked. OOM Killer may kill any process to allocate memory space
- The most memory-consuming process (mysqld) will be killed at first
  - It's abort shutdown. Crash recovery takes place at restart
  - Priority is determined by ORDER BY /proc/<PID>/oom\_score DESC
  - Normally mysqld has the highest score
    - Depending on VMsize, CPU time, running time, etc
- It often takes very long time (minutes to hours) for OOM Killer to kill processes
  - We can't do anything until enough memory space is available

# Do not set swap=zero

```
top - 01:01:29 up 5:53, 3 users, load average: 0.66, 0.17, 0.06
Tasks: 170 total, 3 running, 167 sleeping, 0 stopped, 0 zombie
Cpu(s): 0.0%us, 24.9%sy, 0.0%ni, 75.0%id, 0.2%wa, 0.0%hi, 0.0%si, 0.0%st
Mem: 32967008k total, 32815800k used, 151208k free, 8448k buffers
Swap: 0k total, 0k used, 0k free, 376880k cached
```

PID	USER	PR	NI	VIRT	RES	SHR	S	%CPU	%MEM	TIME+	COMMAND
26988	mysql	25	0	30g	30g	1452	R	98.5	97.7	0:42.18	mysqld

- If no memory space is available, OOM killer will be invoked
- Some CPU cores consume 100% system resources
  - 24.9% (average) = 1 / 4 core use 100% cpu resource in this case
  - Terminal freezed (SSH connections can't be established)
- Swap is bad, but OOM killer is much worse than swap



# What if stopping OOM Killer?

- If `/proc/<PID>/oom_adj` is set to `-17`, OOM Killer won't kill the process
  - Setting `-17` to `sshd` is a good practice so that we can continue remote login
  - `# echo -17 > /proc/<pid of sshd>/oom_adj`
- But don't set `-17` to `mysqld`
  - If over-memory-consuming process is not killed, Linux can't have any available memory space
  - We can't do anything for a long long time.. -> Long downtime

# Swap space management

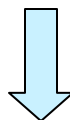
- Swap space is needed to stabilize systems
  - But we don't want mysqld swapped out
  
- What consumes memory?
  - RDBMS
    - Mainly process space is used (innodb\_buffer\_pool, key\_buffer, sort\_buffer, etc)
    - Sometimes filesystem cache is used (InnoDB Log Files, binary/relay log files, MyISAM files, etc)
  - Administration (backup, etc)
    - Mainly filesystem cache is used
  
- We want to keep mysqld in RAM, rather than allocating large filesystem cache

# Be careful about backup operations

Mem: 32967008k total, 28947472k used, 4019536k free, 152520k buffers

Swap: 35650896k total, 0k used, 35650896k free, 197824k cached

PID	USER	PR	NI	VIRT	RES	SHR	S	%CPU	%MEM	TIME+	COMMAND
5231	mysql	25	0	27.0g	27g	288	S	0.0	92.6	7:40.88	mysqld



**Copying 8GB datafile**

Mem: 32967008k total, 32808696k used, 158312k free, 10240k buffers

Swap: 35650896k total, 4749460k used, 30901436k free, 8819840k cached

PID	USER	PR	NI	VIRT	RES	SHR	S	%CPU	%MEM	TIME+	COMMAND
5231	mysql	25	0	27.0g	22g	324	S	0.0	71.8	7:46.50	mysqld

■ Copying large files often causes swap

# vm.swappiness = 0

Mem: 32967008k total, 28947472k used, 4019536k free, 152520k buffers

Swap: 35650896k total, 0k used, 35650896k free, 197824k cached

PID	USER	PR	NI	VIRT	RES	SHR	S	%CPU	%MEM	TIME+	COMMAND
5231	mysql	25	0	27.0g	27g	288	S	0.0	91.3	7:55.88	mysqld



**Copying 8GB of datafile**

Mem: 32967008k total, 32783668k used, 183340k free, 3940k buffers

Swap: 35650896k total, **216k used**, 35650680k free, **4117432k cached**

PID	USER	PR	NI	VIRT	RES	SHR	S	%CPU	%MEM	TIME+	COMMAND
5231	mysql	25	0	27.0g	27g	288	S	0.0	80.6	8:01.44	mysqld

- Set vm.swappiness=0 in /etc/sysctl.conf
  - Default is 60
- When physical RAM was fully consumed, Linux kernel reduces filesystem cache with high priority (lower swappiness increases priority)
- After no file system cache is available, swapping starts
  - OOM killer won't be invoked if large enough swap space is allocated. It's safer

# But swap happens even though swappiness==0

## ■ 32GB RAM box, CentOS5 (2.6.18.128)

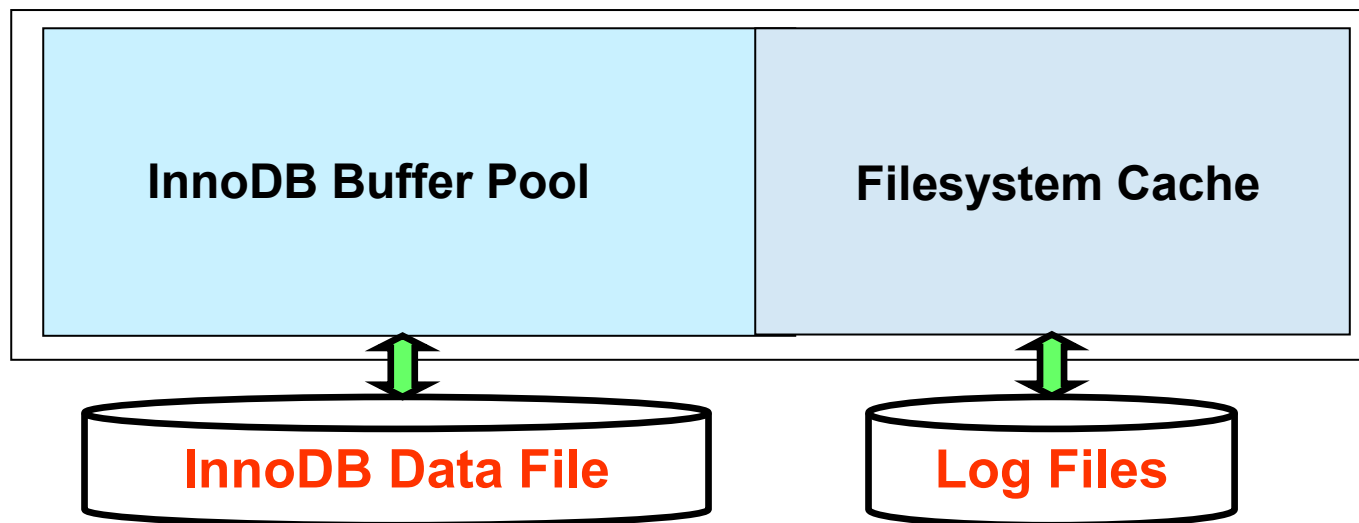
- innodb\_buffer\_pool\_size = 26GB
- mysqld other than innodb\_buf\_pool\_size: approx 3GB

## ■ Kernel space : approx 1GB

```
top - 11:54:51 up 7 days, 15:17, 1 user, load average: 0.21, 0.14, 0.10
Tasks: 251 total, 1 running, 250 sleeping, 0 stopped, 0 zombie
Cpu(s): 0.5%us, 0.2%sy, 0.0%ni, 98.9%id, 0.3%wa, 0.0%hi, 0.1%si, 0.0%st
Mem: 32818368k total, 31154696k used, 1663672k free, 125048k buffers
Swap: 4184924k total, 1292756k used, 2892168k free, 2716380k cached
```

PID	USER	PR	NI	VIRT	RES	SHR	S	%CPU	%MEM	TIME+	COMMAND
6999	mysql	15	0	28.4g	26g	5444	S	9.3	85.2	210:52.67	mysqld

# Swap caused by log files



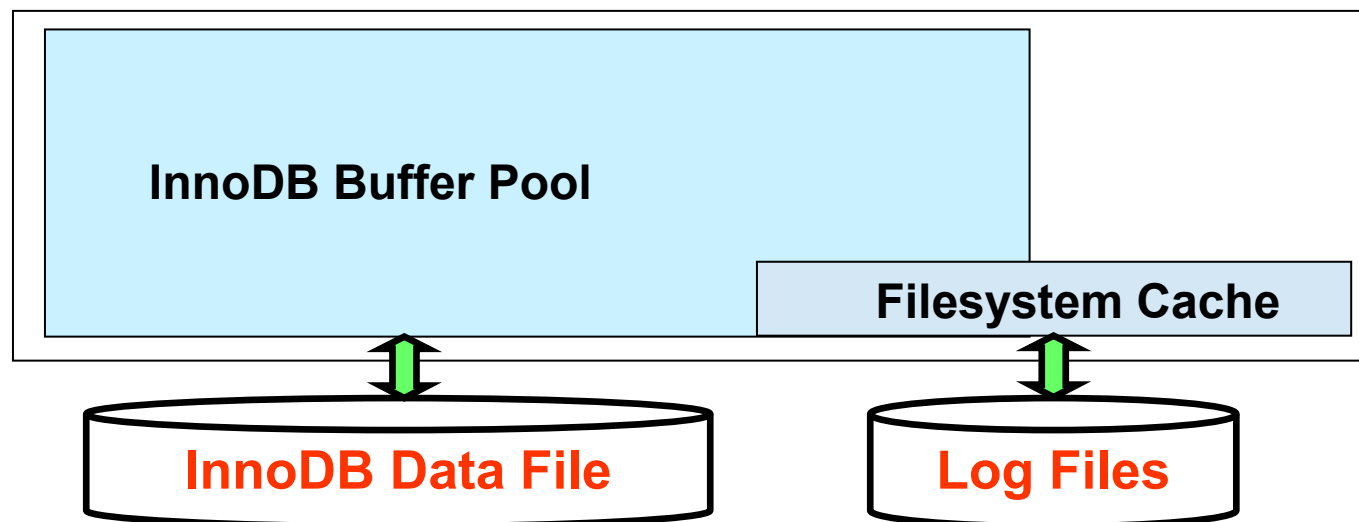
- Swap happened even though filesystem cache was not wiped out
- InnoDB log file size : 3GB in total
  - It's common in InnoDB Plugin because crash recovery becomes much faster
- Binary logs (or relay logs)

# Swap bug on Linux

- A known issue of Linux Kernel
  - Fixed in 2.6.28: Merged on RHEL6
  - [https://bugzilla.redhat.com/show\\_bug.cgi?id=160033](https://bugzilla.redhat.com/show_bug.cgi?id=160033)
  - When will CentOS 6 be released?
- Before the bug was fixed:
  - $\text{swap\_tendency} = \text{mapped\_ratio} / 2 + \text{distress} + \text{sc->swappiness}$ ;
  - If  $\text{swap\_tendency} > 100$ , swap happens regardless of filesystem cache
    - This might happen if distress is high enough, even though  $\text{swappiness} == 0$
- When distress becomes high?
  - Writing to InnoDB log files, binary log files, relay log files
  - On recent MySQL this issue becomes even more serious because `innodb_log_file_size` can be bigger
    - Slow crash recovery bug has been fixed in InnoDB Plugin, so using 3-4GB inodb log file becomes common
- What workarounds can be available in RHEL5?
  - Decrease `innodb_buffer_pool_size` or `innodb_log_file_size`?
    - I don't like the solution
  - Unmap InnoDB log files and binary/relay log files from file system cache

# Tool: unmap\_mysql\_logs

- [https://github.com/yoshinorim/unmap\\_mysql\\_logs](https://github.com/yoshinorim/unmap_mysql_logs)
  - Perl based command line tool
    - Depending on Inline::C CPAN module
- Unmapping the below files from filesystem cache
  - InnoDB Log Files: All files
  - Binary log files, Relay log files:
    - Current (hot) binlog/relay log: All except the latest (tail) 10% of the file
    - Because the tail of the current files are read by Binlog Dump thread or SQL thread: needs to be cached
    - Others: all





# Performance effect

Mem: 32825116k total, 32728924k used, **96192k free**, 246360k buffers  
Swap: 4186072k total, **118764k used**, 4067308k free, **2803088k cached**

PID	USER	PR	NI	VIRT	RES	SHR	S	%CPU	%MEM	TIME+	COMMAND
30814	mysql	15	0	28.8g	27g	5644	S	81.1	89.4	158198:37	mysqld



Mem: 32825116k total, 30061632k used, **2763484k free**, 247420k buffers  
Swap: 4186072k total, **118764k used**, 4067308k free, **143372k cached**

PID	USER	PR	NI	VIRT	RES	SHR	S	%CPU	%MEM	TIME+	COMMAND
30814	mysql	15	0	28.8g	27g	5644	S	76.1	89.4	158200:59	mysqld

- Filesystem cache was reduced, free memory space was increased
- No swapping has happened anymore
- Regularly invoke the script
  - Every 10 minutes from cron

# Memory allocator

- mysqld uses malloc()/mmap() for memory allocation
- Faster and more concurrent memory allocator such as tcmalloc can be used
  - Install Google Perftools (tcmalloc is included)
    - # yum install libunwind
    - # cd google-perftools-x.y ; ./configure --enable-frame-pointers; make; make install
  - export LD\_PRELOAD=/usr/local/lib/tcmalloc\_minimal.so; mysqld\_safe &
- InnoDB internally uses its own memory allocator
  - Can be changed in InnoDB Plugin
    - If Innodb\_use\_sys\_malloc = 1(default 1), InnoDB uses OS memory allocator
    - tcmalloc can be used by setting LD\_PRELOAD

# Memory allocator would matter for CPU bound workloads

	Default allocator	tcmalloc_minimal	%user	up
Buffer pool 1G	1125.44	1131.04	2%	+0.50%
Buffer pool 2G	1863.19	1881.47	3%	+0.98%
Buffer pool 5G	4385.18	4460.50	5.5%	+1.2%
Buffer pool 30G	36784.76	38400.30	36%	+4.4%

- DBT-2 benchmark (write intensive)
- 20-25GB hot data (200 warehouses, running 1 hour)

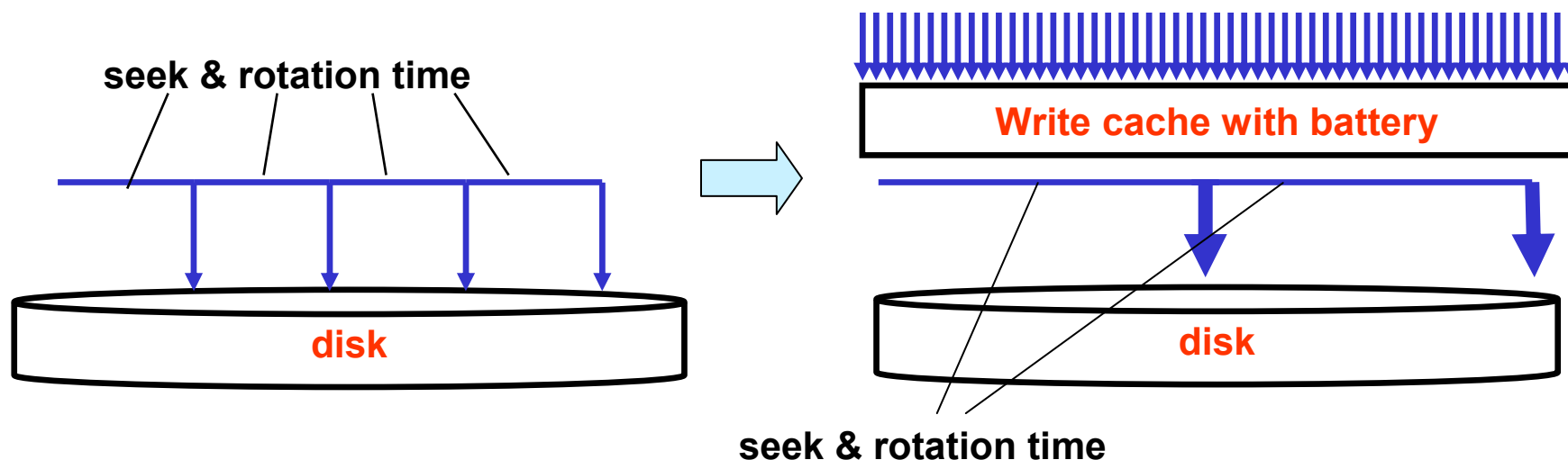
# Be careful about per-session memory

- Do not allocate much more memory than needed (especially for per-session memory)
- Allocating 2MB takes much longer time than allocating 128KB
  - Linux malloc() internally calls brk() if size <= 512KB, else calling mmap()
- In some cases too high per-session memory allocation causes negative performance impacts
  - `SELECT * FROM huge_myisam_table LIMIT 1;`
  - `SET read_buffer_size = 256*1024; (256KB)`
    - -> 0.68 second to run 10,000 times
  - `SET read_buffer_size = 2048*1024; (2MB)`
    - -> 18.81 seconds to run 10,000 times
- In many cases MySQL does not allocate per-session memory than needed. But be careful about some extreme cases (like above: MyISAM+LIMIT+FullScan)

## ■ File I/O

# File I/O and synchronous writes

- RDBMS calls `fsync()` many times (per transaction commit, checkpoints, etc)
- Make sure to use Battery Backed up Write Cache (BBWC) on raid cards
  - 10,000+ `fsync()` per second, without BBWC less than 200 on HDD
  - Disable write cache on disks for safety reasons
- Do not set “write barrier” on filesystems (enabled by default in some cases)
  - Write-through to disks even though BBWC is enabled (very slow)
  - ext3: `mount -o barrier=0` (needed for some distros such as SuSe Linux)
  - xfs: `mount -o nobarrier`
  - drbd: `no-disk-barrier` in `drbd.conf`



# BBWC and “Auto Learn” Issues

- Battery needs to be discharged and recharged every specific periods
  - “Auto Learn”
  - Disabling write cache (entering write through), recharging battery
    - Takes 1 Hour or even more
  - Sudden performance drops happen
    - iowait suddenly increases a lot
  - Automated auto learn
    - Default behavior
    - It is serious if happened at peak time
  - Manual auto learn (in many cases officially not supported)
    - Manually discharge and recharge on off-peak loads
    - If you forget to execute for a long time (i.e. 8 months), battery will be broken
- Expected behavior on Dell servers (not a bug)
  - LSI RAID Controllers with BBWC
  - Approximately every 90 days
    - “Event Description: BBU disabled; changing WB virtual disks to WT”

# FBWC

---

- Flash Back Write Cache

- Using NOR flash memory and capacitor instead of battery

- No “Auto Learn” issue

- HP adopts FBWC on recent lineups (DL360G7)



# Overwriting or Appending?

- Some files are overwritten (fixed file size), others are appended (increasing file size)
  - Overwritten: InnoDB Logfile
  - Appended: Binary Logfile
- Appending + fsync() is much slower than overwriting + fsync()
  - Additional file space needs to be allocated & file metadata needs to be flushed per fsync()
  - 10,000+ fsync/sec for overwriting, 3,000 or less fsync/sec for appending
    - Appending speed highly depends on filesystems
    - Copy-on-write filesystems such as Solaris ZFS is fast enough for appending (7,000+)
  - Be careful when using sync-binlog=1 for binary logs
    - Consider using ZFS
    - Check “preallocating binlog” worklog: WL#4925
  - Do not extend files too frequently
    - innodb-autoextend-increment = 20 (default 8)

# Quick file i/o health check

- Checking FBWC/BBWC is enabled, and write barrier is disabled
  - Overwriting + fsync() test
    - Run mysqlslap insert(InnoDB, single-threaded, innodb\_flush\_log\_at\_trx\_commit=1), check qps is over 1,000
    - \$ mysqlslap --concurrency=1 --iterations=1 --engine=innodb ¥  
--auto-generate-sql --auto-generate-sql-load-type=write ¥  
--number-of-queries=100000

# Buffered and asynchronous writes

- Some file i/o operations are not direct i/o, not synchronous
  - file copy, MyISAM, mysqldump, innodb\_flush\_log\_at\_trx\_commit=2, etc
- Dirty pages in filesystem cache needs to be flushed to disks in the end
  - pdflush takes care of it, maximum 8 threads
- When? -> highly depending on vm.dirty\_background\_ratio and vm.dirty\_ratio
  - Flushing dirty pages starts in background after reaching dirty\_background\_ratio \* RAM (Default is 10%, 10% of 64GB is 6.4GB)
  - Forced flush starts after reaching dirty\_ratio \* RAM (Default is 40%)
- Forced, and burst dirty page flushing is problematic
  - All buffered write operations become synchronous, which hugely increase latency
- Do flush dirty pages aggressively
  - Execute sync; while doing massive write operations
  - Reduce vm.dirty\_background\_ratio
  - Upgrade to 2.6.32 or higher
    - pdflush threads are allocated per device. Flushing to slow devices won't block other pdflush threads

# Filesystem – ext3

- By far the most widely used filesystem
- But not always the best
- Deleting large files takes long time
  - Internally has to do a lot of random disk i/o (slow on HDD)
  - In MySQL, if it takes long time to DROP table, all client threads will be blocked to open/close tables (by LOCK\_open mutex)
  - Be careful when using MyISAM, InnoDB with innodb\_file\_per\_table, PBXT, etc
- Writing to a file is serialized
  - Serialized by “i-mutex”, allocated per i-node
  - Sometimes it is faster to allocate many files instead of single huge file
  - Less optimized for faster storage (like PCI-Express SSD)
- Use “dir\_index” to speed up searching files
- Use barrier=0 to disable write-through

# Tip: fast large file remove

## ■ Creating hard links

- `ln /data/mysql/db1/huge_table.ibd /var/tmp/huge_table.ibd.link`
- `DROP TABLE huge_table;`
- `rm -f /var/tmp/huge_table.ibd.link`
- Physical file remove doesn't happen because ref count is not zero
- When removing the hard link, physical file remove happens because at that time ref count is zero
- Physical remove operation causes massive random disk i/o, but at this stage this doesn't take MySQL mutex so it won't block MySQL operations
  - But `iowait` increases so don't run `rm` command when load is high

# Filesystem – xfs/ext2

## ■ xfs

- Fast for dropping files
- Concurrent writes to a file is possible when using O\_DIRECT
- Not officially supported in current RHEL (Supported in SuSE)
- Disable write barrier by setting “nobarrier”

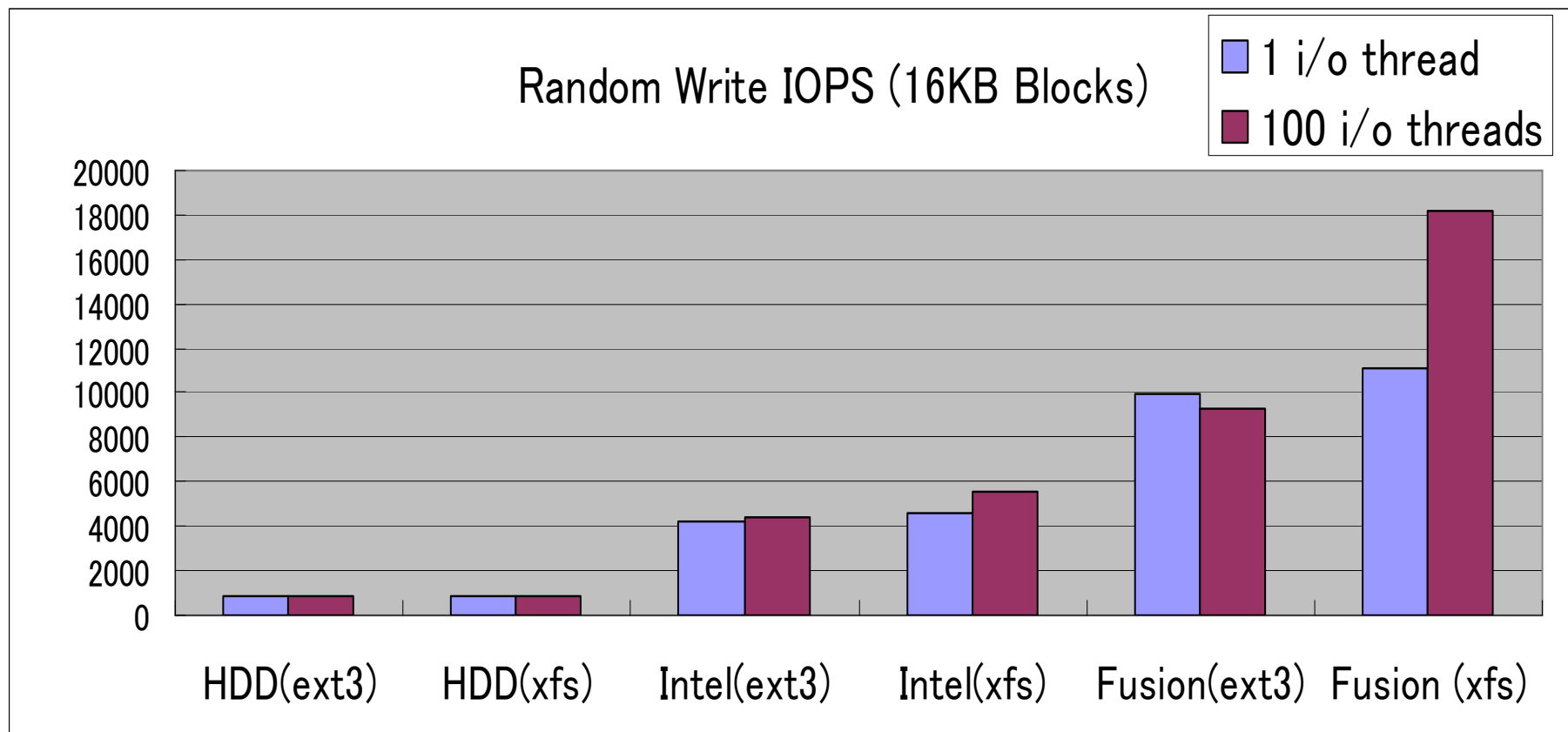
## ■ ext2

- Faster for writes because ext2 doesn't support journaling
- It takes very long time for fsck
- On active-active redundancy environment (i.e. MySQL Replication),  
in some cases ext2 is used to gain performance

## ■ Btrfs (under development)

- Copy-on-write filesystem
- Supporting transactions (no half-block updates)
- Snapshot backup with no overhead

# Concurrent write matters on fast storage



■ Negligible on HDD (4 SAS RAID1)

■ 1.8 times difference on Fusion I/O

# I/O scheduler

- Note: RDBMS (especially InnoDB) also schedules I/O requests so theoretically Linux I/O scheduler is not needed
- Linux has I/O schedulers
  - to efficiently handle lots of I/O requests
  - “I/O scheduler type” and “Queue Size” matters
- Types of I/O schedulers (introduced in 2.6.10: RHEL5)
  - noop: Sorting incoming i/o requests by logical block address, that's all
  - deadline: Prioritize read (sync) requests rather than write requests (async) to some extent (to avoid “write-starving-reads” problem)
  - cfq(default): Fairly scheduling i/o requests per i/o thread
  - anticipatory: Removed in 2.6.33 (bad scheduler. Don't use it)
- Default is cfq, but noop / deadline is better in many cases
  - `# echo noop > /sys/block/sdX/queue/scheduler`



# cfq madness

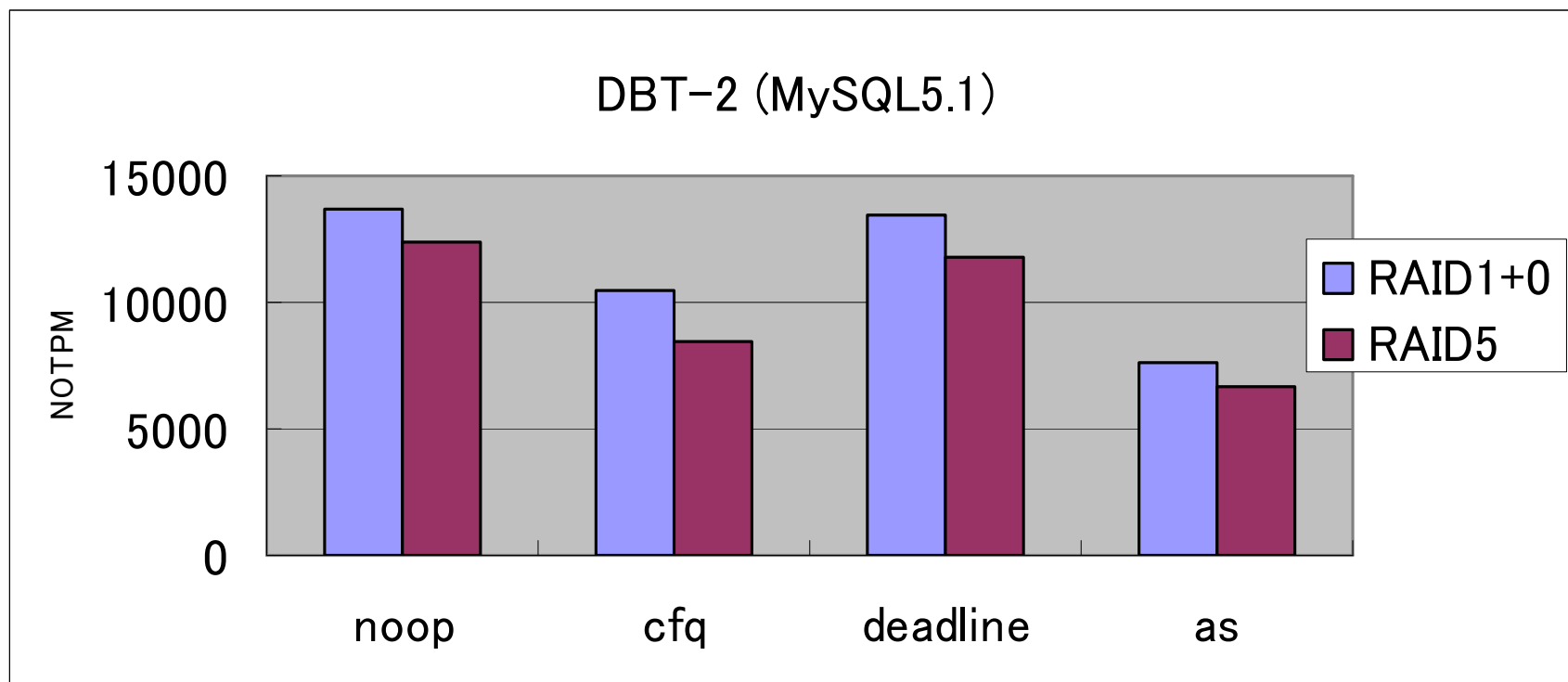
Running two benchmark programs concurrently

1. Multi-threaded random disk reads (Simulating RDBMS reads)
2. Single-threaded overwriting + fsync() (Simulating redo log writes)

Random Read i/o threads	write+fsync() ) running	Scheduler	reads/sec from iostat	writes/sec from iostat
1	No	noop/deadline	260	0
		cfq	260	0
100	No	noop/deadline	2100	0
		cfq	2100	0
1	Yes	noop/deadline	212	14480
		cfq	248	246
100	Yes	noop/deadline	1915	12084
		cfq	2084	0

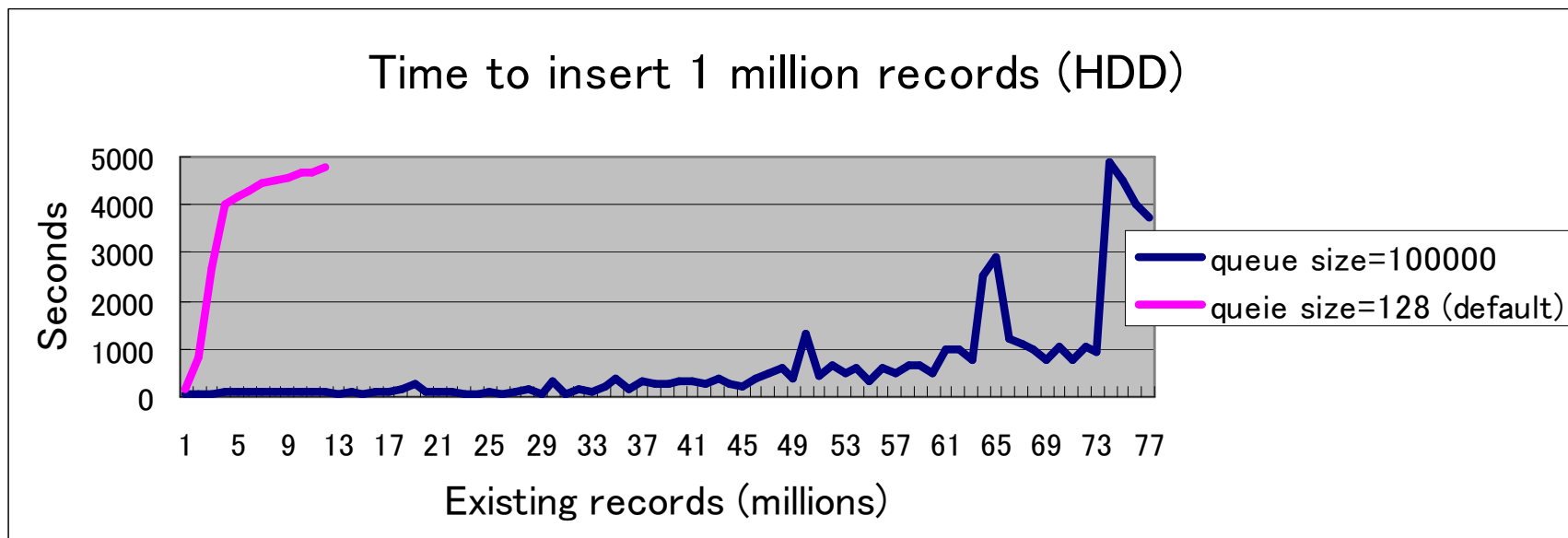
- In RDBMS, write IOPS is often very high because HDD + write cache can handle thousands of transaction commits per second (write+fsync)
- Write iops was adjusted to per-thread read iops in cfq, which reduced total iops significantly

# Changing I/O scheduler (InnoDB)



- Sun Fire X4150 (4 HDDs, H/W RAID controller+BBWC)
- RHEL5.3 (2.6.18-128)
- Built-in InnoDB 5.1

# Changing I/O scheduler queue size (MyISAM)



- Queue size = N
  - Sorting N outstanding I/O requests to optimize disk seeks
- MyISAM does not optimize I/O requests internally
  - Highly depending on OS and storage
  - When inserting into indexes, massive random disk writes/reads happen
- Increasing I/O queue size reduces disk seek overheads
  - `# echo 100000 > /sys/block/sdX/queue/nr_requests`
- No impact in InnoDB
  - Many RDBMS including InnoDB internally sort I/O requests

## ■ Network

# Fighting against network bottlenecks

## ■ Latency

- 100Mbit Ethernet: 3000 us
  - Around 35,000qps from 100 memcached clients
  - Not good if you use SSD
  - Easily reaches 100Mbps bandwidth when copying large files
- 1Gbit Ethernet: 400us
  - Around 250,000qps from 100 memcached clients
  - 100,000qps is not impossible in MySQL
- Latency is not so amazing at 10Gbit Ethernet
  - Check Dolphin Supersockets, etc

## ■ Single CPU core might be bottleneck

- Older Linux kernels (including CentOS5) do not scale with CPU cores for network requests handling
  - Use latest kernels (RHEL6 etc) when this becomes really issue

# Tx/Rx multiqueue

```
# cat /proc/interrupts | grep PCI
202:      ... PCI-MSI-X   eth2-0
210:      ... PCI-MSI-X   eth2-1
218:      ... PCI-MSI-X   eth2-2
226:      ... PCI-MSI-X   eth2-3
234:      ... PCI-MSI-X   eth2-4
```

- Network requests can be distributed between CPU cores
- Some NICs and drivers work multiqueue on older kernels, but don't work when bonding is enabled
- Check `/proc/interrupts`
- Check `%irq` and `%soft` from `mpstat`
  - Single CPU core might occupy 100% `%soft`
- Use latest kernels (RHEL6 etc) when this becomes really issue

# Be careful about bandwidth

- Between servers, racks, switches
- Be careful when sending large data
  - Setting up OS from PXE server
  - Sending large backup file
  - Restoring large data and initializing replication
- Do not use 100Mbps networks
  - Network switch, Network Cards, Cables
- When setting up new replication slave, the master sends large binlog events to slaves, which easily occupies 100Mbps traffics
  - START/STOP SLAVE IO\_THREADS; repeatedly
  - Manually send binlogs by scp with upper limits, then apply events by mysqlbinlog and mysql

# Remote datacenter

---

- RTT (round trip time) from Tokyo to West coast easily exceeds 200 ms
- MySQL Replication for Disaster Recovery purpose
  - I/O thread delays  $RTT/2$ 
    - Time to send binary log from master to slave
    - Not bad (ping delays RTT)
    - Lots of binary log events can be sent at once
  - Do not use semi-synchronous replication here
    - Every commit takes RTT for send/recv. Only few transactions can be handled per second



# Waiting three seconds for SYN

- Establishing network connections is expensive
  - Client: Sending TCP SYN
  - Server: Sending TCP SYN+ACK
  - Client: Sending TCP ACK
  
- If client fails to receive SYN+ACK packet, it waits for three seconds, then sending SYN again
  - This happens quite a lot of times on high traffic environments
  - Not limited to MySQL
  - Increasing backlog helps, but problems still exist
    - `echo 8192 > /proc/sys/net/ipv4/tcp_max_syn_backlog`
    - `back_log` in `my.cnf`
  
- Using persistent connections / connection pooling is the fundamental solution

# Flows to establish N/W connections

## Client

1. Sending SYN,  
Changing state to SYN\_SENT

6. Receiving SYN+ACK

7. Generating ACK

8. Sending ACK

■ If a packet is lost or dropped between 1 and 6, the client re-sends a packet again

- But the client waits three seconds to resend, which sacrifices response times

## Server

2. Receiving SYN

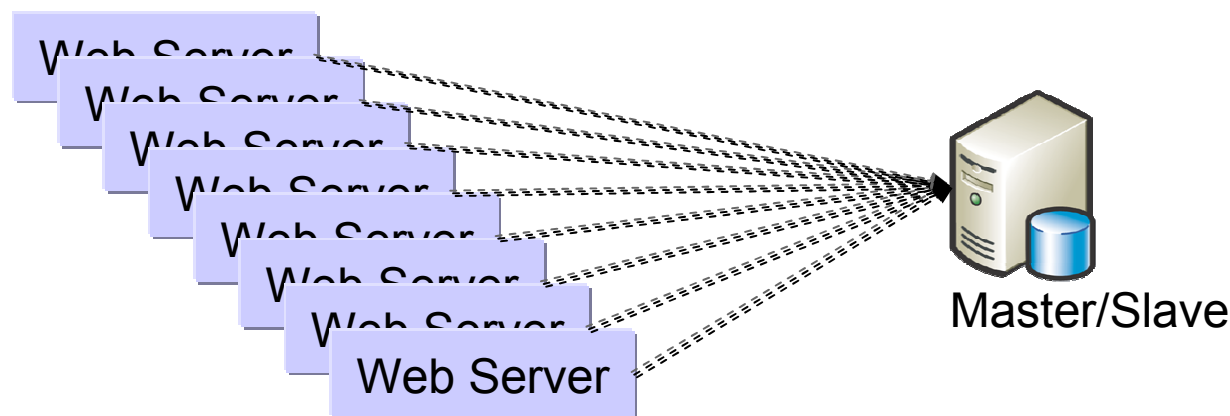
3. Checking conditions (i.e. back\_log)  
If it doesn't meet criteria, dropping it

4. Generating SYN+ACK,  
Changing state to SYN\_RECV

5. Sending SYN+ACK

9. Receiving ACK,  
Changing state to ESTABLISHED

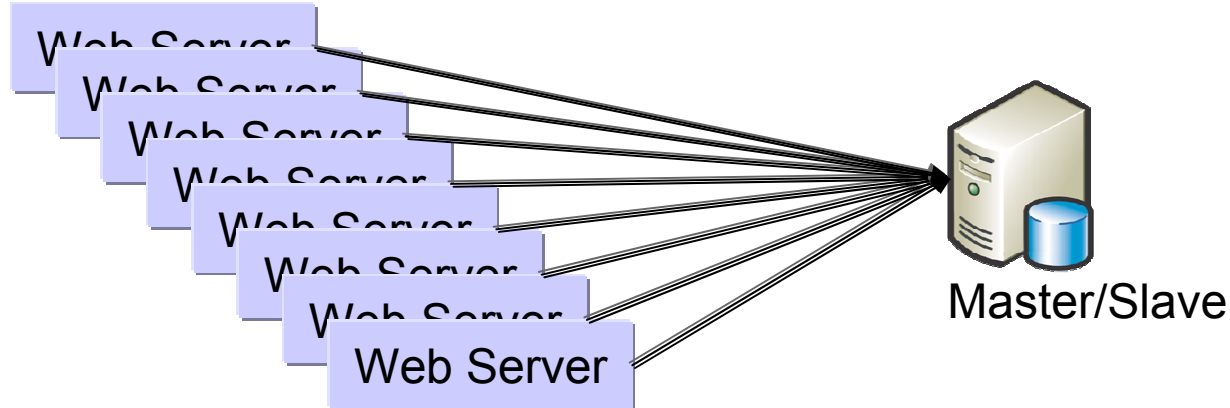
# Database connections



## ■ Non-Persistent connections are majority

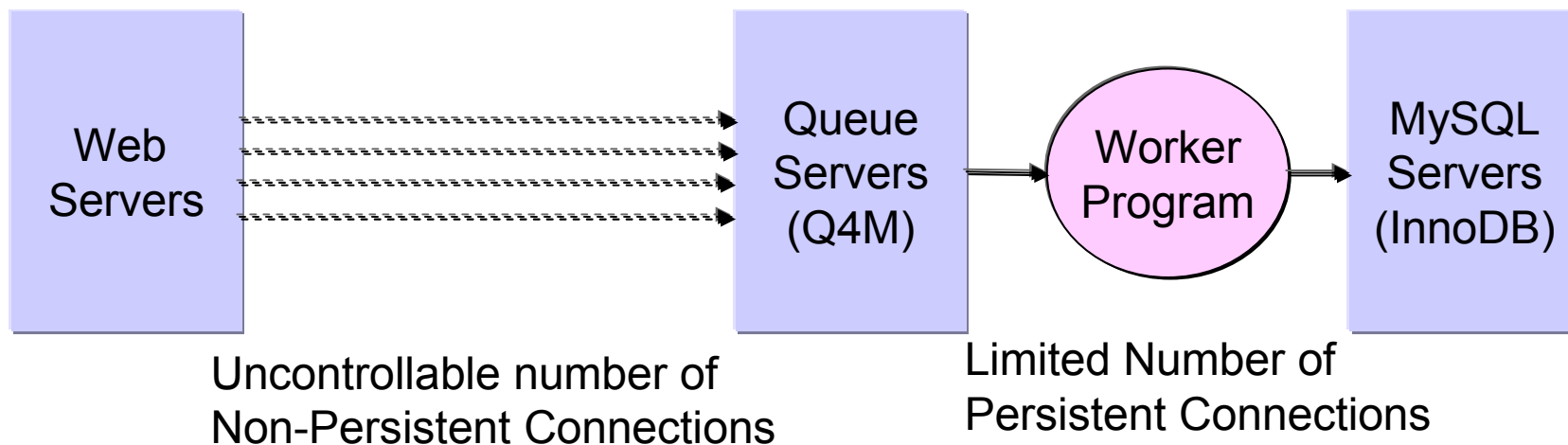
- Right now it's not so much issue
  - Establishing / terminating network connections is not relatively costly compared to disk access overheads
  - Waiting 3 seconds for TCP SYN retry is frequent problem
- Overheads will not be negligible when bottleneck shifts to CPU/Network
  - Expensive network accesses (SYN-> SYN+ACK -> ACK, initialization SQL statements (SET xxx), etc)

# Persistent Connections



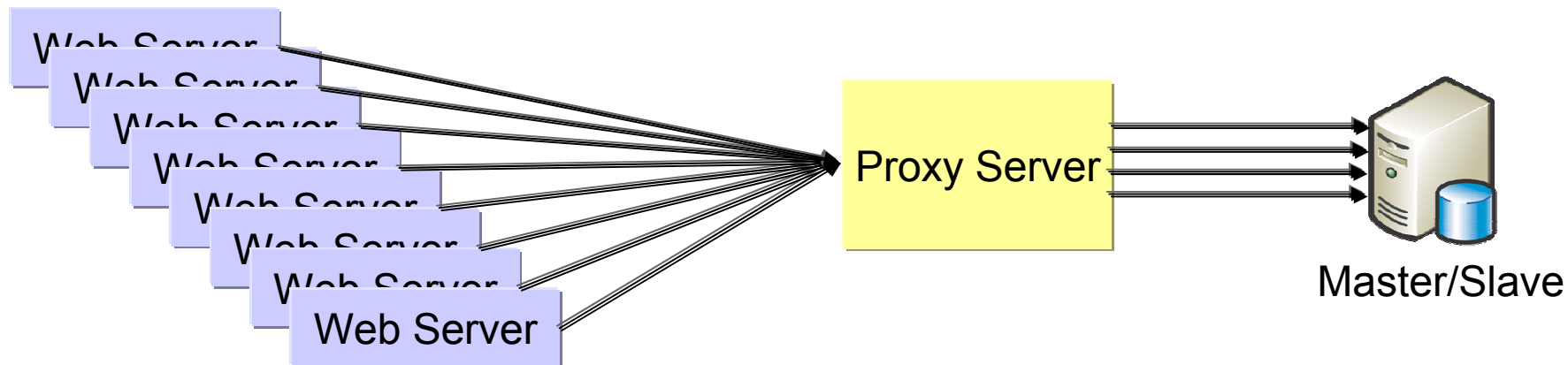
- Keeping connections established permanently
- No connection/disconnection overheads
- The number of connections equals to
  - “The number of Web Servers” x “Connections per process”
  - Easily reaches 10000 connections
  - max-connections my.cnf has to be increased
- It's effective as long as the number of web servers is small...
- It doesn't work when the number of web servers becomes large
  - Performance doesn't drop even though there are thousands of idle connections
  - But RAM space is consumed
  - If mysqld stalls for a short period of time (0.5-1 second), suddenly 1000+ clients execute queries at the same time
  - Very serious problems such as OOM might happen

# Use persistent connections properly



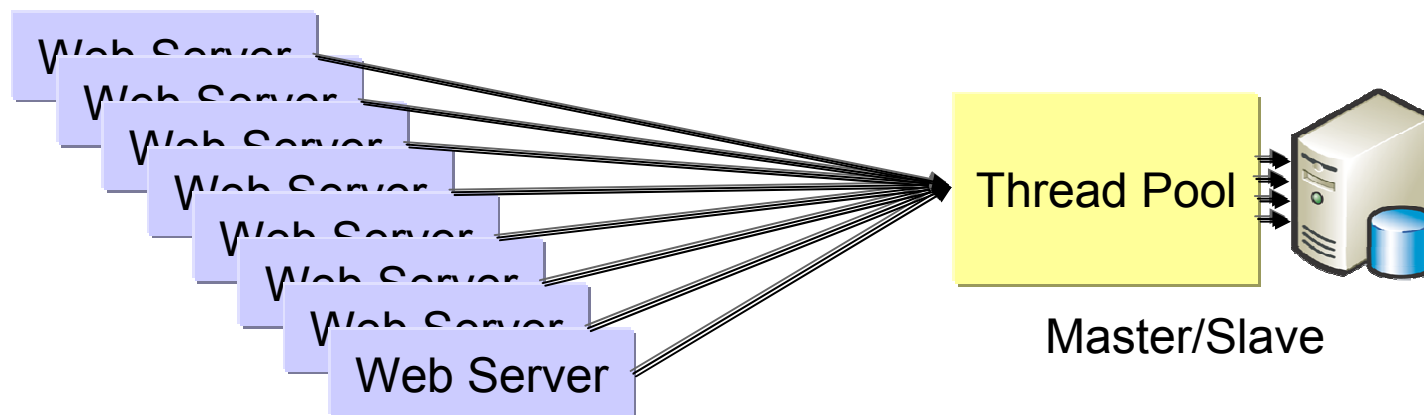
- If the number of connections can be controlled, persistent connection helps a lot
- Before using persistent connections between queue servers and MySQL servers, very often the number of connections was suddenly increased, which caused some errors (1023 error, deadlock error, etc)

# Proxy-based connection pooling



- Web servers establish persistent connections to a proxy server, and Proxy server establishes limited number of persistent connections to MySQL
- Similar to Java EE
- Proxy server is a lightweight network server
  - It's not serious even though the number of connections reach 10,000
- The number of connections at MySQL is limited, so memory usage is ok, but..
  - Proxy server has to receive/send massive network requests
  - Response time increases
  - Need High Availability architecture for Proxy

# Thread pooling within MySQL



- For stability reasons, the number of threads within mysqld should be limited
- Adding proxy servers costs more, especially when database servers become faster
- It is better that mysqld accepts thousands of connections but running limited number of threads internally: Pool of threads
- MySQL has thread pool plugin interface

# Useful commands and tools

- iostat
- mpstat
- dstat
- oprofile
- gdb
- pmp (Poor Man's Profiler)
- gcore



# iostat

- Showing detailed I/O statistics per device
- Very important tool because in most cases RDBMS becomes I/O bound
- `iostat -x`
- Check r/s, w/s, svctm, %util
  - IOPS is much more important than transfer size
- Always  $\%util = (r/s + w/s) * svctm$  (hard coded in the iostat source file)

```
# iostat -xm 10
avg-cpu:  %user %nice %system %iowait %steal %idle
           21.16  0.00   6.14   29.77   0.00  42.93
Device:  rqm/s wrqm/s   r/s   w/s rMB/s wMB/s avgrq-sz avgqu-sz await  svctm %util
sdb      2.60  389.01 283.12 47.35  4.86   2.19   43.67    4.89  14.76   3.02 99.83
```

$$(283.12 + 47.35) * 3.02(\text{ms}) / 1000 = 0.9980 = 100\% \text{ util}$$

# iostat example (DBT-2)

```
# iostat -xm 10
avg-cpu: %user %nice %system %iowait %steal %idle
          21.16  0.00   6.14  29.77   0.00 42.93
Device: rqm/s wrqm/s  r/s   w/s  rMB/s wMB/s avgrq-sz avgqu-sz await svctm %util
sdb      2.60 389.01 283.12 47.35  4.86  2.19   43.67    4.89 14.76  3.02 99.83
```

$$(283.12 + 47.35) * 3.02(\text{ms}) / 1000 = 0.9980 = 100\% \text{ util}$$

```
# iostat -xm 10
avg-cpu: %user %nice %system %iowait %steal %idle
          40.03  0.00  16.51  16.52   0.00 26.94
Device: rrqm/s wrqm/s  r/s   w/s  rMB/s wMB/s avgrq-sz avgqu-sz await svctm %util
sdb      6.39 368.53 543.06 490.41  6.71  3.90   21.02    3.29  3.20  0.90 92.66
```

$$(543.06 + 490.41) * 0.90(\text{ms}) / 1000 = 0.9301 = 93\% \text{ util}$$

- Sometimes throughput gets higher even though %util reaches 100%
  - Write cache, Command Queuing, etc
- In both cases %util is almost 100%, but r/s and w/s are far different
- Do not trust %util too much
- Check svctm rather than %util
  - If your storage can handle 1000 IOPS, svctm should be less than 1.00 (ms) so you can send alerts if svctm is higher than 1.00 for a couple of minutes

# mpstat

- Per CPU core statistics
- vmstat displays average statistics
- It's very common that only one of CPU cores consumes 100% CPU resources
  - The rest CPU cores are idle
  - Especially applies to batch jobs
- If you check only vmstat/top/iostat/sar you will not notice single threaded bottleneck
- You can also check network bottlenecks (%irq, %soft) from mpstat
  - vmstat counts them as %idle

# vmstat and mpstat

```
# vmstat 1
```

```
...
```

procs		memory				swap		io		system		cpu				
r	b	swpd	free	buff	cache	si	so	bi	bo	in	cs	us	sy	id	wa	st
0	1	2096472	1645132	18648	19292	0	0	4848	0	1223	517	0	0	88	12	0
0	1	2096472	1645132	18648	19292	0	0	4176	0	1287	623	0	0	87	12	0
0	1	2096472	1645132	18648	19292	0	0	4320	0	1202	470	0	0	88	12	0
0	1	2096472	1645132	18648	19292	0	0	3872	0	1289	627	0	0	87	12	0

```
# mpstat -P ALL 1
```

```
...
```

Time	CPU	%user	%nice	%sys	%iowait	%irq	%soft	%steal	%idle	intr/s
11:04:37 AM	all	0.00	0.00	0.12	12.33	0.00	0.00	0.00	87.55	1201.98
11:04:38 AM	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	990.10
11:04:38 AM	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00
11:04:38 AM	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00
11:04:38 AM	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00
11:04:38 AM	4	0.99	0.00	0.99	98.02	0.00	0.00	0.00	0.00	206.93
11:04:38 AM	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00
11:04:38 AM	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	4.95
11:04:38 AM	7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00

■ vmstat displays average statistics.  $12\% * 8 \text{ (average)} = 100\% * 1 + 0\% * 7$

# Typical mpstat output

## ■ Replication Slave

- %idle on a single CPU core becomes 0-10%
  - Mostly used for %user, %system, %iowait, %soft

## ■ Bulk loading/inserting on InnoDB

- %idle on a single CPU core becomes 0-10%
  - Mostly used for %user, and %iowait

# dstat

```
# dstat
```

----total-cpu-usage----						-dsk/total-		-net/total-		---paging--		---system--	
usr	sys	idl	wai	hiq	siq	read	writ	recv	send	in	out	int	csw
3	1	95	0	0	0	2096k	13M	1437k	2096k	0	0	5644	11k
3	2	95	0	0	0	1752k	4096k	1555k	2372k	0	0	6015	11k
3	1	95	0	0	0	4640k	12M	1689k	2659k	0	0	6092	12k
2	1	96	0	0	0	1616k	5352k	1590k	2493k	0	0	5593	10k
3	1	96	0	0	0	1968k	6960k	1558k	2400k	0	0	5663	10k

```
# dstat -N bond0
```

----total-cpu-usage----						-dsk/total-		-net/bond0-		---paging--		---system--	
usr	sys	idl	wai	hiq	siq	read	writ	recv	send	in	out	int	csw
2	1	95	1	0	0	2416k	5112k	782k	1196k	0	0	5815	11k
3	1	95	0	0	0	3376k	15M	792k	1213k	0	0	5632	11k
3	2	95	0	0	0	2120k	3264k	793k	1229k	0	0	5707	11k
2	1	96	0	0	0	1920k	3560k	788k	1193k	0	0	5856	11k
2	1	96	0	0	0	1872k	13M	770k	1112k	0	0	5463	10k

- yum install dstat
- Similar UI as vmstat, but it also shows network statistics
- Disk and Net total is incorrect, if you use RAID/bonding (double counted)
  - Filter by disk/interface name that you want to trace
- “mtstat” additionally supports mysql status outputs
  - <https://launchpad.net/mtstat>

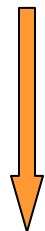
# Oprofile

- Profiling CPU usage from running processes
- You can easily identify which functions consume CPU resources
- Supporting both user space and system space profiling
- Mainly used by database-internal developers
- If specific functions consume most of resources, applications might be re-designed to skip calling them
- Not useful to check low-CPU activities
  - I/O bound, mutex waits, etc
- How to use
  - `opcontrol --start (--no-vmlinux)`
  - benchmarking
  - `opcontrol --dump`
  - `opcontrol --shutdown`
  - `opreport -l /usr/local/bin/mysqld`

# Oprofile example

```
# oprofile -l /usr/local/bin/mysqld
```

samples	%	symbol name
83003	8.8858	<code>String::copy(char const*, unsigned int, charset_info_st*, charset_info_st*, unsigned int*)</code>
79125	8.4706	<code>MYSQLparse(void*)</code>
68253	7.3067	<code>my_wc_mb_latin1</code>
55410	5.9318	<code>my_pthread_fastmutex_lock</code>
34677	3.7123	<code>my_utf8_uni</code>
18359	1.9654	<code>MYSQLlex(void*, void*)</code>
12044	1.2894	<code>_ZL15get_hash_symbolPKcjb</code>
11425	1.2231	<code>_ZL20make_join_statisticsP4JOINP10TABLE_LISTP4ItemP16st_dynamic_array</code>



- You can see quite a lot of CPU resources were spent for character conversions (latin1 <-> utf8)
- Disabling character code conversions on application side will improve performance

samples	%	symbol name
83107	10.6202	<code>MYSQLparse(void*)</code>
68680	8.7765	<code>my_pthread_fastmutex_lock</code>
20469	2.6157	<code>MYSQLlex(void*, void*)</code>
13083	1.6719	<code>_ZL15get_hash_symbolPKcjb</code>
12148	1.5524	<code>JOIN::optimize()</code>
11529	1.4733	<code>_ZL20make_join_statisticsP4JOINP10TABLE_LISTP4ItemP16st_dynamic_array</code>



# Checking stalls

- Database servers sometimes suffer from performance stalls
  - Not responding anything for 1-2 seconds
- In many cases it's database internal issue
  - Holding global mutex and doing expensive i/o
  - Buffer pool, redo log preflush, rollback segments (InnoDB mutex)
  - pthread\_create()/clone() (LOCK\_thread\_count mutex)
  - Opening/closing tables (LOCK\_open mutex)
- Collecting statistics
  - Per-minute statistics (i.e. vmstat 60) is not helpful. Collect per-second statistics

# Checking stalls by gdb or pmp

- Debugging tool
- gdb has a functionality to take thread stack dumps from a running process
- Useful to identify where and why mysqld hangs up, slows down, etc
  - But you have to read MySQL source code
- During taking stack dumps, all threads are stopped
- Debugging symbol is required on the target program

# gdb case study

```
mysql> SELECT query_time, start_time, sql_text  
-> FROM mysql.slow_log WHERE start_time  
-> BETWEEN '2010-02-05 23:00:00' AND '2010-02-05 01:00:00'  
-> ORDER BY query_time DESC LIMIT 10;
```

query_time	start_time	sql_text
00:00:11	2010-02-05 23:09:55	begin
00:00:09	2010-02-05 23:09:55	Prepare
00:00:08	2010-02-05 23:09:55	Prepare
00:00:08	2010-02-05 23:09:55	Init DB
00:00:08	2010-02-05 23:09:55	Init DB
00:00:07	2010-02-05 23:09:55	Prepare
00:00:07	2010-02-05 23:09:55	Init DB
00:00:07	2010-02-05 23:09:55	Init DB
00:00:07	2010-02-05 23:09:55	Init DB
00:00:06	2010-02-05 23:09:55	Prepare

10 rows in set (0.02 sec)

- Suddenly all queries were not responding for 1-10 seconds
- Checking slow query log
- All queries are simple enough, it's strange to take 10 seconds
- CPU util (%us, %sy) were almost zero
- SHOW GLOBAL STATUS, SHOW FULL PROCESSLIST were not helpful

# Taking thread dumps with gdb

```
gdbtrace() {  
...  
    PID=`cat /var/lib/mysql/mysql.pid`  
    STACKDUMP=/tmp/stackdump.$$  
    echo 'thread apply all bt' >  
$STACKDUMP  
    echo 'detach' >> $STACKDUMP  
    echo 'quit' >> $STACKDUMP  
    gdb --batch --pid=$PID -x $STACKDUMP  
}  
  
while loop  
do  
    CONN=`netstat -an | grep 3306 | grep  
ESTABLISHED | wc | awk '{print $1}'`  
    if [ $CONN -gt 100 ]; then  
        gdbtrace()  
    done  
    sleep 3  
done
```

- Attaching running mysqld, then taking a thread dump
- Taking dumps every 3 seconds
- Attaching & Dumping with gdb is expensive so invoke only when exceptional scenario (i.e. conn > threshold) happens
- Check if the same LWPs are waiting at the same place

# Stack Trace

```
.....
Thread 73 (Thread 0x46c1d950 (LWP 28494)):
#0  0x00007ffda5474384 in __lll_lock_wait () from /lib/libpthread.so.0
#1  0x00007ffda546fc5c in _L_lock_1054 () from /lib/libpthread.so.0
#2  0x00007ffda546fb30 in pthread_mutex_lock () from /lib/libpthread.so.0
#3  0x0000000000a0f67d in my_pthread_fastmutex_lock (mp=0xf46d30) at
thr_mutex.c:487
#4  0x000000000060cbe4 in dispatch_command (command=16018736, thd=0x80,
packet=0x65 <Address 0x65 out of bounds>, packet_length=4294967295)
at sql_parse.cc:969
#5  0x000000000060cb56 in do_command (thd=0xf46d30) at sql_parse.cc:854
#6  0x0000000000607f0c in handle_one_connection (arg=0xf46d30) at
sql_connect.cc:1127
#7  0x00007ffda546dfc7 in start_thread () from /lib/libpthread.so.0
#8  0x00007ffda46305ad in clone () from /lib/libc.so.6
#9  0x0000000000000000 in ?? ()
```

- Many threads were waiting at `pthread_mutex_lock()`, called from `sql_parse.cc:969`

# Reading sql\_parse.cc:969

```
953 bool dispatch_command(enum enum_server_command command, THD *thd,
954                        char* packet, uint packet_length)
955 {
956     NET *net= &thd->net;
957     bool error= 0;
958     DEBUG_ENTER("dispatch_command");
959     DEBUG_PRINT("info", ("packet: ' %*.s' ; command: %d", packet_length,
packet, command));
960
961     thd->command=command;
962     /*
963         Commands which always take a long time are logged into
964         the slow log only if opt_log_slow_admin_statements is set.
965     */
966     thd->enable_slow_log= TRUE;
967     thd->lex->sql_command= SQLCOM_END; /* to avoid confusing VIEW
detectors */
968     thd->set_time();
969     VOID(pthread_mutex_lock(&LOCK_thread_count));
```

# Who locked LOCK\_thread\_count for seconds?

```
Thread 1 (Thread 0x7ffda58936e0 (LWP 15380)):  
#0  0x00007ffda4630571 in clone () from /lib/libc.so.6  
#1  0x00007ffda546d396 in do_clone () from /lib/libpthread.so.0  
#2  0x00007ffda546db48 in pthread_create@@GLIBC_2.2.5 () from  
/lib/libpthread.so.0  
#3  0x0000000000600a66 in create_thread_to_handle_connection (thd=0x3d0f00)  
    at mysqld.cc:4811  
#4  0x00000000005ff65a in handle_connections_sockets (arg=0x3d0f00) at  
mysqld.cc:5134  
#5  0x00000000005fe6fd in main (argc=4001536, argv=0x4578c260) at  
mysqld.cc:4471  
#0  0x00007ffda4630571 in clone () from /lib/libc.so.6
```

- gdb stack dumps were taken every 3 seconds
- In all cases, Thread 1 (LWP 15380) was stopped at the same point
- clone() (called by pthread\_create()) seemed to take a long time

# Reading mysqld.cc:4811

```
4795 void create_thread_to_handle_connection(THD *thd)
4796 {
4797     if (cached_thread_count > wake_thread)
4798     {
4799         /* Get thread from cache */
4800         thread_cache.append(thd);
4801         wake_thread++;
4802         pthread_cond_signal(&COND_thread_cache);
4803     }
4804     else
4805     {
4811         if ((error=pthread_create(&thd->real_id,&connection_attrib,
4812                                   handle_one_connection,
4813                                   (void*) thd)))
4839     }
4840     (void) pthread_mutex_unlock(&LOCK_thread_count);
```

- pthread\_create is called under critical section (LOCK\_thread\_count is released after that)
- If cached\_thread\_count > wake\_thread, pthread\_create is not called
- Increasing thread\_cache\_size will fix the problem!



# Poor Man's Profiler

- A simple shell script (wrapper script) to summarize thread call stacks
  - Using gdb thread dump functionality
- Useful for identifying why MySQL stalls
- <http://poormansprofiler.org/>

```
#!/bin/bash
nsamples=1
sleeptime=0
pid=$(pidof mysqld)
for x in $(seq 1 $nsamples)
do
  gdb -ex "set pagination 0" -ex "thread apply all bt" -batch -p $pid
  sleep $sleeptime
done | ¥
awk '
BEGIN { s = ""; }
/Thread/ { print s; s = ""; }
/^¥#/ { if (s != "") { s = s ", " $4 } else { s = $4 } }
END { print s }' | ¥
sort | uniq -c | sort -r -n -k 1,1
```

# pmp output example

```
291 pthread_cond_wait@@GLIBC_2.3.2, one_thread_per_connection_end, handle_one_connection
  57 read, my_real_read, my_net_read, do_command, handle_one_connection, start_thread
  26
pthread_cond_wait@@GLIBC_2.3.2, os_event_wait_low, os_aio_simulated_handle, fil_aio_wait, io_handler_
thread, start_thread
  3 pthread_cond_wait@@GLIBC_2.3.2, os_event_wait_low, srv_purge_worker_thread
  1 select, os_thread_sleep, srv_purge_thread
  1 select, os_thread_sleep, srv_master_thread
  1 select, os_thread_sleep, srv_lock_timeout_and_monitor_thread
  1 select, os_thread_sleep, srv_error_monitor_thread
  1 select, handle_connections_sockets, main, select
  1 read, vio_read_buff, my_real_read, my_net_read, cli_safe_read, handle_slave_io
  1
pthread_cond_wait@@GLIBC_2.3.2, os_event_wait_low, sync_array_wait_event, rw_lock_s_lock_spin, buf_pa
ge_get_gen, btr_cur_search_to_nth_level, row_search_for_mysql, ha_innodb::index_read, handler::index_
read_idx_map, join_read_const, join_read_const_table, make_join_statistics, JOIN::optimize, mysql_sele
ct, handle_select, execute_sqlcom_select, mysql_execute_command, mysql_parse, dispatch_command, do_comm
and, handle_one_connection
```

# Disadvantages of gdb/pmp

- All threads are stopped while taking thread dumps
- The more the number of threads, the more time it takes
  - It might take 5 seconds if 1000 threads are running
  - 5 seconds stall is not acceptable in many cases
  - It is not recommended taking thread dumps on master when lots of threads are running
  - Be careful if you set high `thread_cache_size`

# gcore

- Dumping core file
- Dumping core file takes time, and blocks all threads during dump
  - Might take 1 hour when VIRT is 50GB+
  - Not useful on running systems, but can be used on a non-serving slave
- If you have a program with DWARF symbols, target (running) process does not need symbols
  - You can run stripped mysqld on production, as long as you have debug-built mysqld

# Case study

## Problem:

- mysqld on one of slaves used much more CPU resources than other slaves, and frequently replication delay happened
- the mysqld used 50GB+ VIRT on 24G box. (other slaves used 20G VIRT)

top - 20:39:14 up 360 days, 17:56, 1 user, load average: 1.26, 1.29, 1.32

Tasks: 125 total, 2 running, 123 sleeping, 0 stopped, 0 zombie

Cpu(s): 10.8% us, 0.8% sy, 0.0% ni, 87.2% id, 0.7% wa, 0.0% hi, 0.5% si

Mem: **24680588k total**, 24609132k used, 71456k free, 99260k buffers

Swap: 4192956k total, 160744k used, 4032212k free, 4026256k cached

PID	USER	PR	NI	VIRT	RES	SHR	S	%CPU	%MEM	TIME+	COMMAND
11706	mysql	16	0	<b>50.5g</b>	19g	5168	R	90.9	81.4	247117:59	mysqld
19253	root	16	0	6172	1164	852	R	0.3	0.0	0:00.03	top

# From mysql status

Slave\_open\_temp\_tables was extremely high.

Slave_open_temp_tables	15927	
------------------------	-------	--

But we don't use tmp tables right now.

Previously developers created tmp tables, but in theory SQL thread should have closed them.

SQL thread internally checks all its tmp tables whether it can be closed or not, per each SQL statement.

Parsing 15927 tmp tables per statement was very expensive and it should be the reason that caused replication delay.

I wanted to know what tables were opened, but MySQL command line tools do not provide ways to identify them.

Time to analyze core file !

# Core file analysis example

```
# Install debuginfo mysqld if not installed (don't need to run debugged mysqld)
# ulimit -c unlimited
# gdb -p $(pidof mysqld)
(gdb) gcore core (Takes long time..)
(gdb) detach
```

```
# gdb /usr/lib/debug/usr/sbin/mysqld.debug /data/mysql/core.11706
```

```
(gdb) p active_mi->rli->save_temporary_tables->s->table_name
```

```
$1 = {str = 0x31da400c3e "claimed_guids", length = 13}
```

```
(gdb) p $a->file->stats
```

```
$16 = {data_file_length = 1044496, max_data_file_length = 5592400,
index_file_length = 1044496, max_index_file_length = 0, delete_length = 0,
auto_increment_value = 0, records = 1, deleted = 0, mean_rec_length = 8,
create_time = 0, check_time = 0, update_time = 0, block_size = 0}
```

- Tmp tables are MEMORY engine so 1044496 + 1044496 bytes (2MB) were used per table.
- Table name was “claimed\_guids”

# Dumping slave's tmp tables info

```
define print_all_tmp_tables
set $a= active_mi->rli->save_temporary_tables
set $b= slave_open_tmp_tables
while ($i < $b)
  p $a->alias
  p $a->file->stats
  set $a= $a->next
  set $i=$i+1
end
end

set pagination 0
set $i=0
print_all_tmp_tables
detach
quit
```

```
# gdb /usr/lib/debug/usr/sbin/mysqld.debug /data/mysql/core.11706 -x above_script
```

List length was 15927 (same as slave\_open\_tmp\_tables), all tables were the same name, used same size (2MB)

$15927 * 2\text{MB} = 31\text{GB}$

This should be the reason why VIRT was 30+ GB larger than other slaves.  
Rebooting the slave should be fine because they are tmp tables.



# Capturing MySQL packets

- Capturing MySQL packets is useful to trace slow queries / transactions / connection requests.
  - Modifying applications MySQL settings is not needed
    - Starting from 5.1, you can dynamically enable/disable slow/general query logs
  
- libpcap
  - library to capture network packets
  - Most of network capturing tools including tcpdump rely on libpcap
  - Packet loss often happens

# tcpdump + mk-query-digest

1) [root#] tcpdump -i bond0 port 3306 -s 65535 -x -n -q -tttt -c 10000 > tcpdump.out

```
2) $ mk-query-digest --type=tcpdump --report-format=query_report tcpdump.out
# Query 1: 951.34 QPS, 1.56x concurrency, ID 0x6D23B63A5DA67F5D at byte ...
# Attribute  pct  total   min    max   avg   95%  stddev  median
# =====
# Count      22   1837
# Exec time   40    3s    0  207ms   2ms   8ms   6ms   236us
...
SELECT * FROM user WHERE user_id = 100;
# Query 2: 1.06k QPS, 0.69x concurrency, ID 0x2EB286C018F2DE27 at byte ...
...
```

- mk-query-digest has a functionality to parse tcpdump outputs
  - It can trace how long each query takes, and it can summarize and sort by total execution time
- No need to modify my.cnf settings
- Queries that take less than 1 second can be captured
  - Very helpful in MySQL 5.0 or earlier

# MySlowTranCapture

```
[mysql-server]# myslowtrancapture -i eth0
```

Monitoring eth0 interface..

Listening port 3306..

Transactions that take more than 4000  
milliseconds..

From 192.168.0.1:24441

2011/01/07 09:12:17.258307 ->

begin

2011/01/07 09:12:17.258354 <-

GOT\_OK

2011/01/07 09:12:17.264797 ->

select \* from diary where diary\_id=100 for  
update

2011/01/07 09:12:17.265087 <-

GOT\_RES

2011/01/07 09:13:01.232620 ->

update diary set diary\_date=now() where  
diary\_id=100

2011/01/07 09:13:01.232960 <-

GOT\_OK

2011/01/07 09:13:17.360993 ->

commit

From 192.168.0.2:24442

2011/01/07 09:12:20.969288 ->

begin

2011/01/07 09:12:20.969483 <-

GOT\_OK

2011/01/07 09:12:20.977699 ->

update diary set diary\_date=now() where  
diary\_id=100

2011/01/07 09:13:11.300935 <-

GOT\_ERR:Lock wait timeout exceeded; try  
restarting transaction

2011/01/07 09:13:13.136967 ->

rollback

- <https://github.com/yoshinorim/MySlowTranCapture>
- A tool to print “transactions” that take more than N milliseconds
- Held locks are not released until COMMIT/ROLLBACK is executed

## ■ Summary

# SSD

---

## ■ SATA SSD

- Much more cost effective than spending on RAM only
- H/W RAID Controller + SATA SSD won't perform great
- Capacitor + SSD should be great. Check Intel 320

## ■ PCI-Express SSD

- Check FusionIO and tachIO
- Expensive, but MLC might be affordable
- Master handles traffics greatly, but slave servers can not catch up due to single threaded replication channel
- Consider running multiple instances on a slave server

# RAM

- Allocate swap space (approx half of RAM size)
- Set `vm.swappiness = 0` and use `O_DIRECT`
  - Restart linux if kernel panic happens
    - `kernel.panic_on_oops = 1`
    - `kernel.panic = 1`
- Use linux kernel 2.6.28+, or frequently unmap logs from filesystem cache
- Do not allocate too much memory per session
- Do not use persistent connections if you can't control maximum number of MySQL internal threads

# File I/O

- Set `/sys/block/sdX/queue/scheduler = deadline` or `noop`
- Filesystem Tuning
  - `relatime` (`noatime`)
  - `ext3`: `tune2fs -O dir_index -c -1 -i 0`
  - `xfs`: `nobarrier`
  - Make sure write cache with battery/flash is enabled
- Others
  - Make sure to allocate separate database partitions (`/var/lib/mysql`, `/tmp`) from root partition (`/`)
    - When database size becomes full, it should not affect Linux kernels
  - `/etc/security/limits.conf`
    - `soft nofile 8192`
    - `hard nofile 8192`

# CPU, Network, Virtualization

---

- These need to be considered more, especially when you deploy SSD
- HyperThreading should be enabled. Now MySQL scales well with many logical CPU cores
- Utilize Tx/Rx multiqueue. Latest kernel (including RHEL6) handles better
- I prefer running multiple MySQL instances on a single OS than running multiple VMs