A Case for Flash Memory SSD in Enterprise Database Applications

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Magnetic Disk vs Flash SSD

Champion for 50 years

Seagate ST340016A
40GB,7200rpm

M-Tron Flash SSD
32GB 2.5 inch

New challengers!

Samsung FlashSSD
32GB 1.8 inch

Trend in Market Today

- **In mobile storage market**
  - **NAND flash memory wins over hard disk in mobile storage market**
    - **PDA, MP3, mobile phone, digital camera, ...**
  - **Due to advantages in size, weight, shock resistance, power consumption, noise …**
- **In personal computer market**
  - **Compete with hard disk in personal computer market**
    - **32GB Flash SSD: M-Tron, Samsung, SanDisk**
  - **Vendors launched new lines of personal computers with NAND flash SSD replacing hard disk**
    - **Apple, Samsung, and others**

Market Trend in Prospect

- **Price drops quickly**
  - **NAND flash is a lot cheaper than DRAM;**
    - **ASP/MB of NAND < 1/3 of ASP/MB of DRAM as of 2007.**
  - **Still much more expensive than magnetic disk.**
  - **Annual drop in ASP/MB was about 60% in 2006.**
  - **Projected annual drop in ASP/MB is about 30-40% in next 5 years. [Eli Harari@SanDisk, August 2007]**
- **Emerging Enterprise Market**
  - **NAND ASP was $10/GB in 2007. With 40% annual drop, it could be *$800/TB in 2012*.**
  - **Not inconceivable to run a full database server on a computing platform with TB-scale Flash SSD as secondary storage.**

Technology Trend in Prospect

- **NAND flash density increases faster than Moore's law**
  - **Predicted *twofold annual increase* of NAND flash density until 2012 [Hwang, ProcIEEE'03]**
  - **Toshiba hopes for 512GB SSD by the end of 2009**
    - **30 nm chip-making process, Multi-level-cell (MLC)**

- **Bandwidth catches up**
  - **Samsung MCAQE32G8APP-0XA [2006]**
    - **Sustained read 56 MB/sec, sustained write 32 MB/sec**
  - **Samsung, Mtron [Feb. 2008]**
    - **Sustained read 100~120 MB/sec, sustained write 80~90 MB/sec**
  - **Intel-Micron's 4-plane architecture + higher clock speed [Feb. 2008]**
    - **Sustained read 200 MB/sec, sustained write 100 MB/sec**
  - **Samsung MLC-based 256GB SSD with SATA-II [May 2008]**
    - **Sustained read 200 MB/sec, sustained write 160 MB/sec**

Past Trend of Disk

- From 1983 to 2003 [Patterson, CACM 47(10) 2004]
  - Capacity increased about 2500 times (0.03 GB → 73.4 GB)
  - Bandwidth improved 143.3 times (0.6 MB/s → 86 MB/s)
  - Latency improved 8.5 times (48.3 ms → 5.7 ms)

Year	1983	1990	1994	1998	2003
Product	CDC 94145-36	Seagate ST41600	Seagate ST15150	Seagate ST39102	Seagate ST373453
Capacity	0.03 GB	1.4 GB	4.3 GB	9.1 GB	73.4 GB
RPM	3600	5400	7200	10000	15000
Bandwidth (MB/sec)	0.6	4	9	24	86
Media diameter	5.25	5.25	3.5	3.0	2.5
Latency (msec)	48.3	17.1	12.7	8.8	5.7

Latency of Disk Lags

- **Trend**
  - **In the time that bandwidth doubles, latency improves by no more than a factor of 1.2 to 1.4.**
    - **Latency improves by no more than *square root* of the improvement in bandwidth.**
  - **The bandwidth-latency imbalance may be even more evident in the future.**
- **The trouble is**
  - **Latency remains important for**
    - **Interactive applications, database logging (or whenever I/O must be done synchronously)**
- **What can NAND Flash Memory do for this?**

Magnetic Disk vs NAND Flash

- **Below is what the data sheets show**

	Sustained Transfer Rate	Average Latency
Magnetic Disk	**110 MB/sec**	**8.33 msec**
NAND Flash SSD	**56 MB/sec (read) 32 MB/sec (write)**	**0.2 msec (read) 0.4 msec (write)**

- **Magnetic Disk : Seagate Barracuda 7200.10 ST3250310AS**
- **NAND Flash SSD : Samsung MCAQE32G8APP-0XA drive with K9WAG08U1A 16 Gbits SLC NAND chips**

  - **Newer SSD products report much higher bandwidth for read and write**

Characteristics of NAND Flash

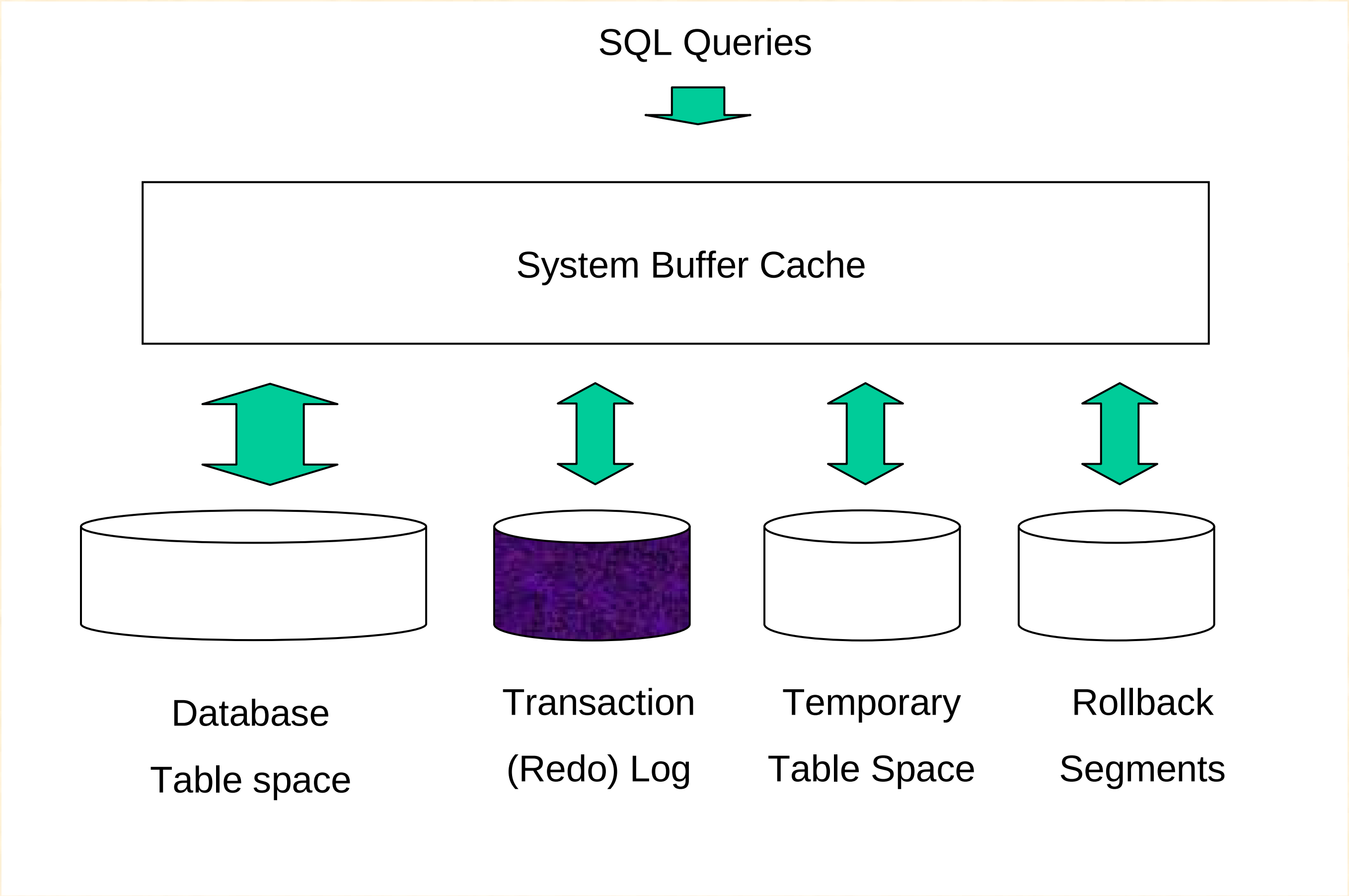
- **No mechanical latency**
  - **Flash memory is an electronic device without moving parts**
  - **Provides *uniform* random access speed without seek/rotational latency**
    - **Very low latency, independently of physical location of data**
- **Asymmetric read & write speed**
  - **Read speed is typically at least twice faster than write speed**
    - **(E.g.) Samsung 16 Gbits SLC NAND chips: 80 μsec vs 200 μsec (2 KB)**
- **No in-place update**
  - **No data item or page can be updated in place before erasing it first.**
    - **An erase unit (typically 128 KB) is much larger than a page (2 KB).**
    - **(E.g.) Samsung 16 Gbits SLC NAND chips: 1.5 msec (128 KB)**
  - ***Write (and erase) optimization* is critical**

Flash SSD for Databases?

- **Immediate benefit for some DB operations**
  - **Reduce commit-time delay by fast logging**
  - **Reduce read time for multi-versioned data**

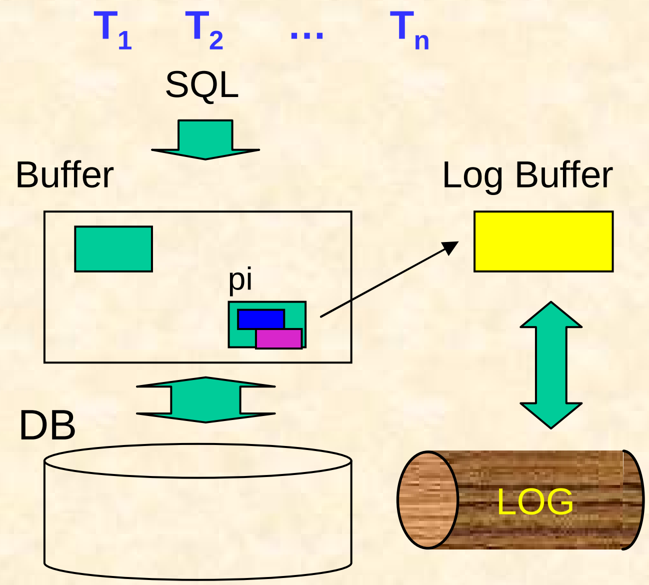
- **Still, many concerns to be addressed**
  - **Random scattered I/O is very common in OLTP**
    - **Slow random writes by flash SSD can handle this?**
  - ***Flash-aware design of DBMS?***
  - ***Flash-friendly algorithms?***
  - ***Flash-friendly implementation?***

Transactional Log



Commit-time Delay by Logging

- **Write Ahead Log (WAL)**
  - **A committing transaction *force-writes* its log records**
  - **Makes it hard to hide latency**
  - **With a separate disk for logging**
    - **No seek delay, but …**
    - ***Half a revolution of spindle* on average**
    - **4.2 msec (7200RPM), 2.0 msec (15k RPM)**
  - **With a Flash SSD: about 0.4 msec**

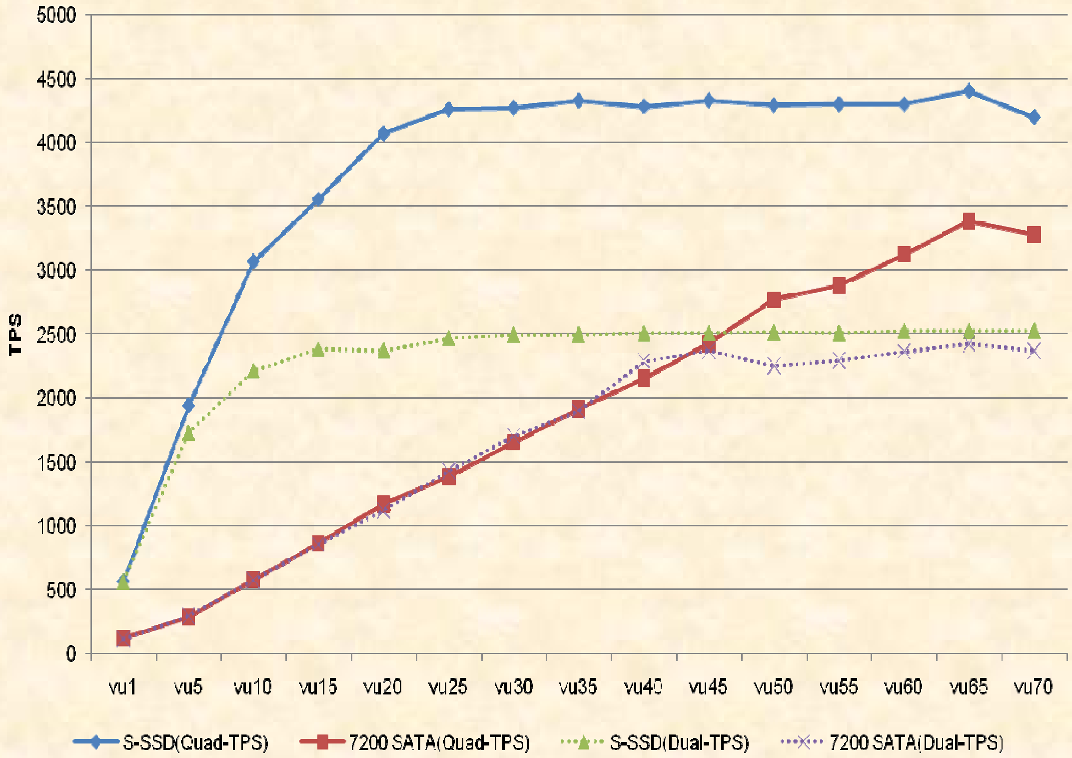


- **Commit-time delay remains to be a significant overhead**
  - **Group-commit helps but the delay doesn't go away altogether.**
- **How much commit-time delay?**
  - **On average, 8.1 msec (HDD) vs 1.3 msec (SDD) : *6-fold reduction***
    - **TPC-B benchmark with 20 concurrent users.**

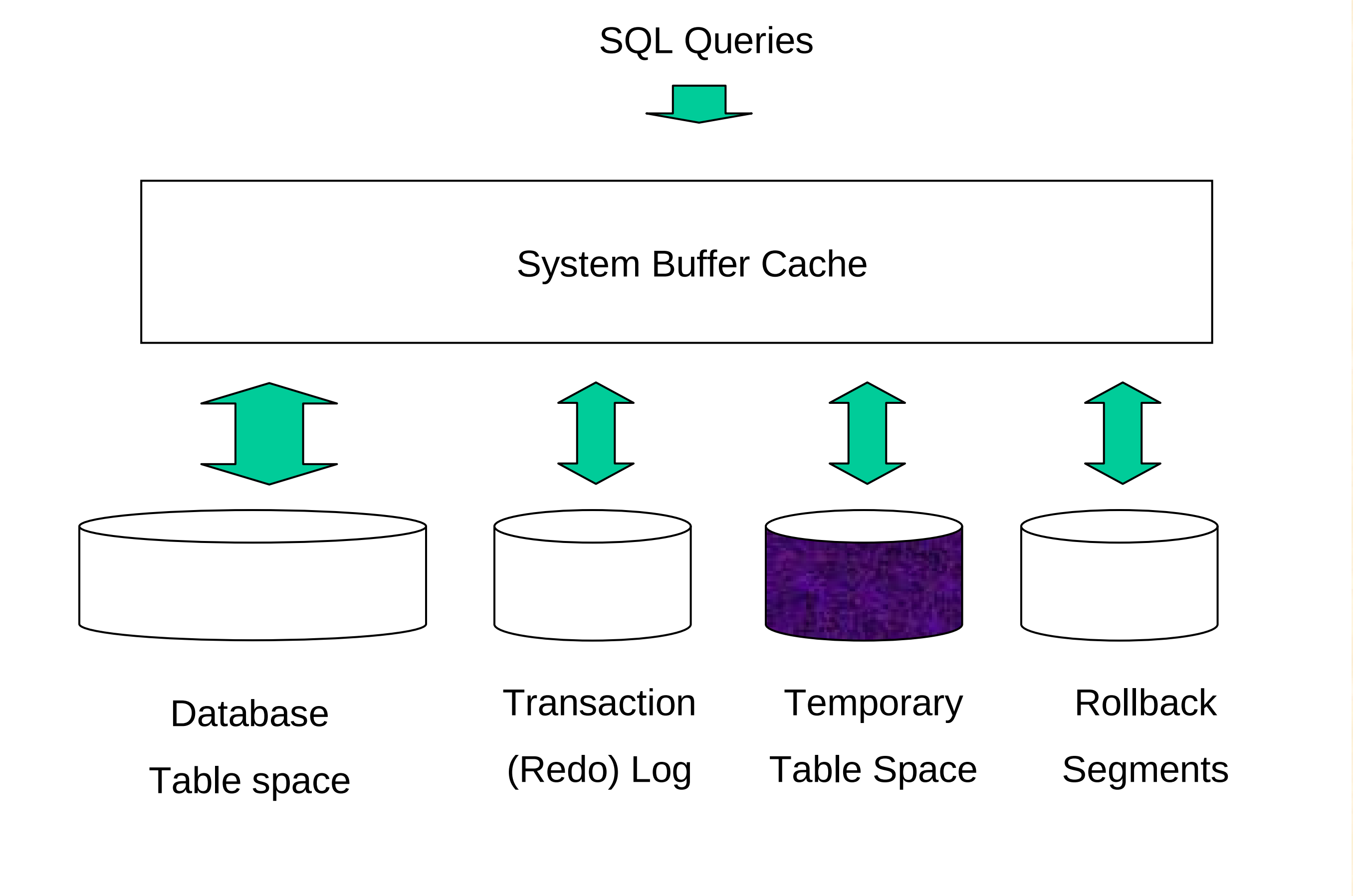
HDD vs SSD for Logging

- With SSD for log
  - **CPU better utilized**
    - **By shortening commit-time, and serving more active transactions.**
  - **Leads to higher TPS**

- Exaggerated by caching entire DB in memory
- TPC-B to stress-test logging
  - **Transaction commit rate higher than TPC-C**



Temporary Table Space



Temp Data and Query Time

- Query processing often generates temp data
  - Sorts, joins, index creation, etc.
  - Typically bulky, performed in foreground; Direct impact on query processing time
- Typically stored in separate storage devices
- Ask the same question
  - What happens if SSD replaces HDD for temporary table spaces?

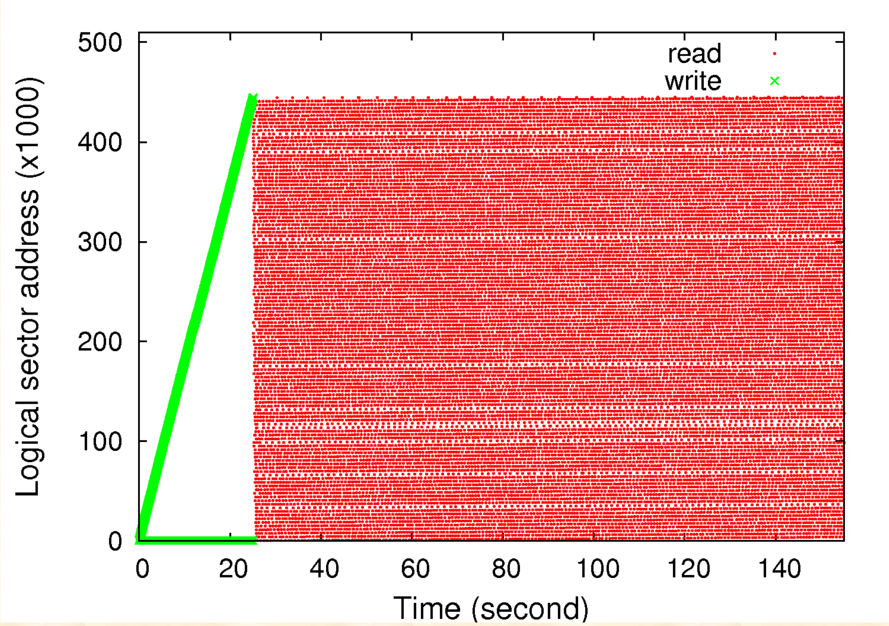
External Sort: I/O Pattern

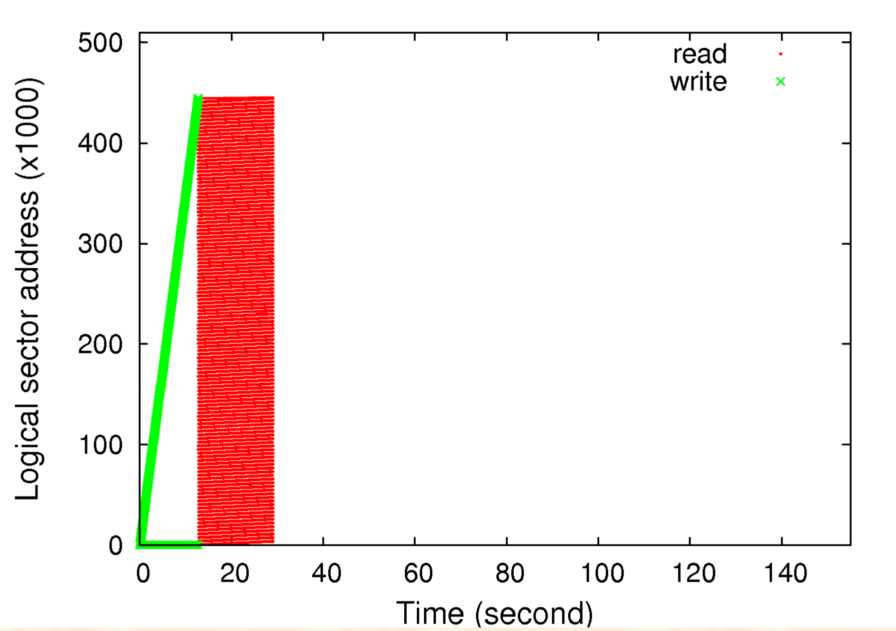
- External Sort algorithm runs in two phases
  - **Sorted run generation**
    - **Partitioned to chunks, sorted separately and, saved in sorted runs**
    - **Read sequentially from table space, <u>written sequentially into temp space</u>**
  - **Merging sorted runs**
    - **<u>Read randomly from temp space</u>, written sequentially into table space**

- **Dominant I/O patterns are *sequential write* followed by *random read***
  - **No-in-place-update limitation is avoided.**
  - **These are *flash-friendly* I/O patterns!!**

External Sort: Performance

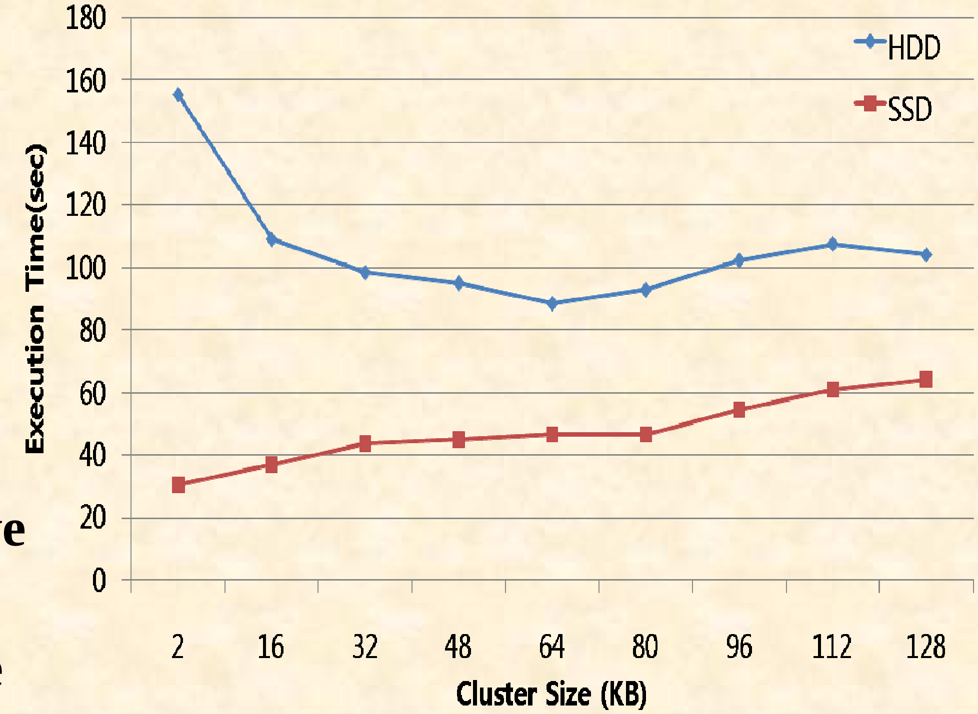
- HDD vs SSD as a medium for a temp table space
  - Sort a table of 2 M tuples (200 MB), with 2 MB buffer cache
- SSD is good at *sequential write + random read*
  - Almost an order of magnitude reduction in merge times





One Less Tuning Knob?

- **Cluster sizes for Sorting?**
- **With a larger cluster**
  - **Disk bandwidth improves (*by hiding latency*)**
  - **The amount of I/O may also increase due to *reduced fan-in* for merging sorted runs**
- **Flash SSD is**
  - ***With low latency,* not as sensitive to the cluster size**
  - **2KB page was the best with the max fan-in**

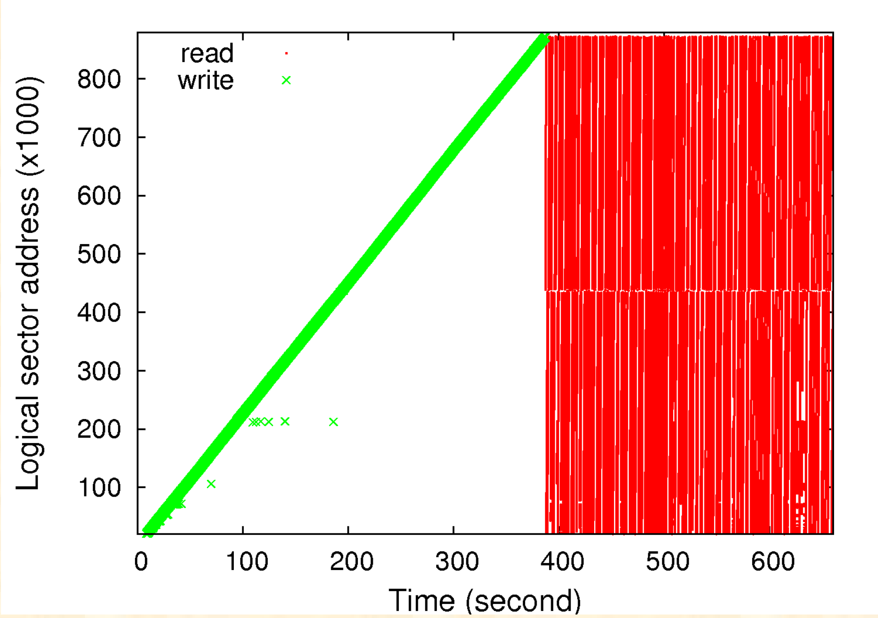


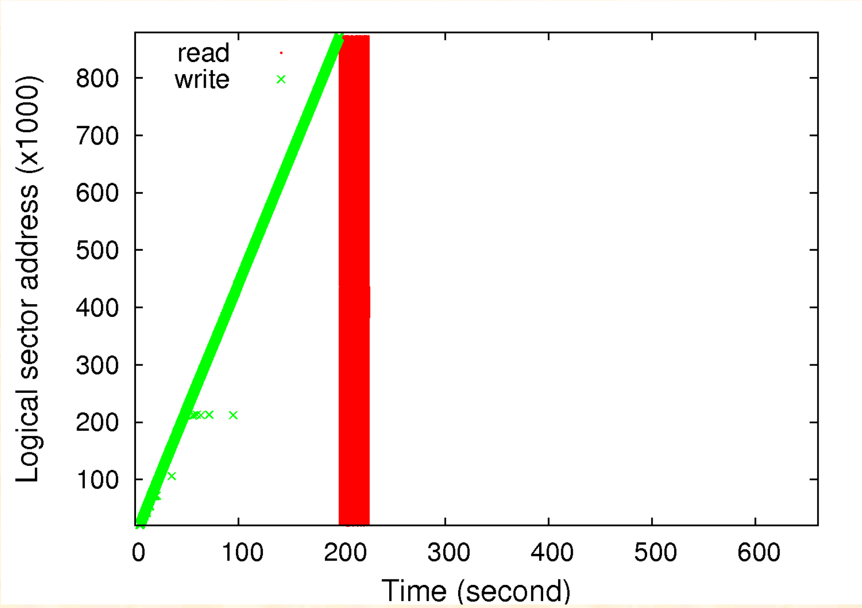
Hash-Sort Duality a Myth?

- **The I/O pattern of hashing is said to be**
  - ***random write*** **(for writing hash buckets) +** ***sequential read*** **(for probing hash buckets)**
  - **As opposed to sort (*****sequential write*** **+** ***random read)***
- **If it's the case, hashing is *<u>not</u>*** ***flash-friendly*****.**
  - **Re-implement hashing to make it flash-friendly?**
  - **It appears already done by some vendors.**
    - **The observed I/O pattern was quite similar to that of sort (*****sequential write + random read*****)**

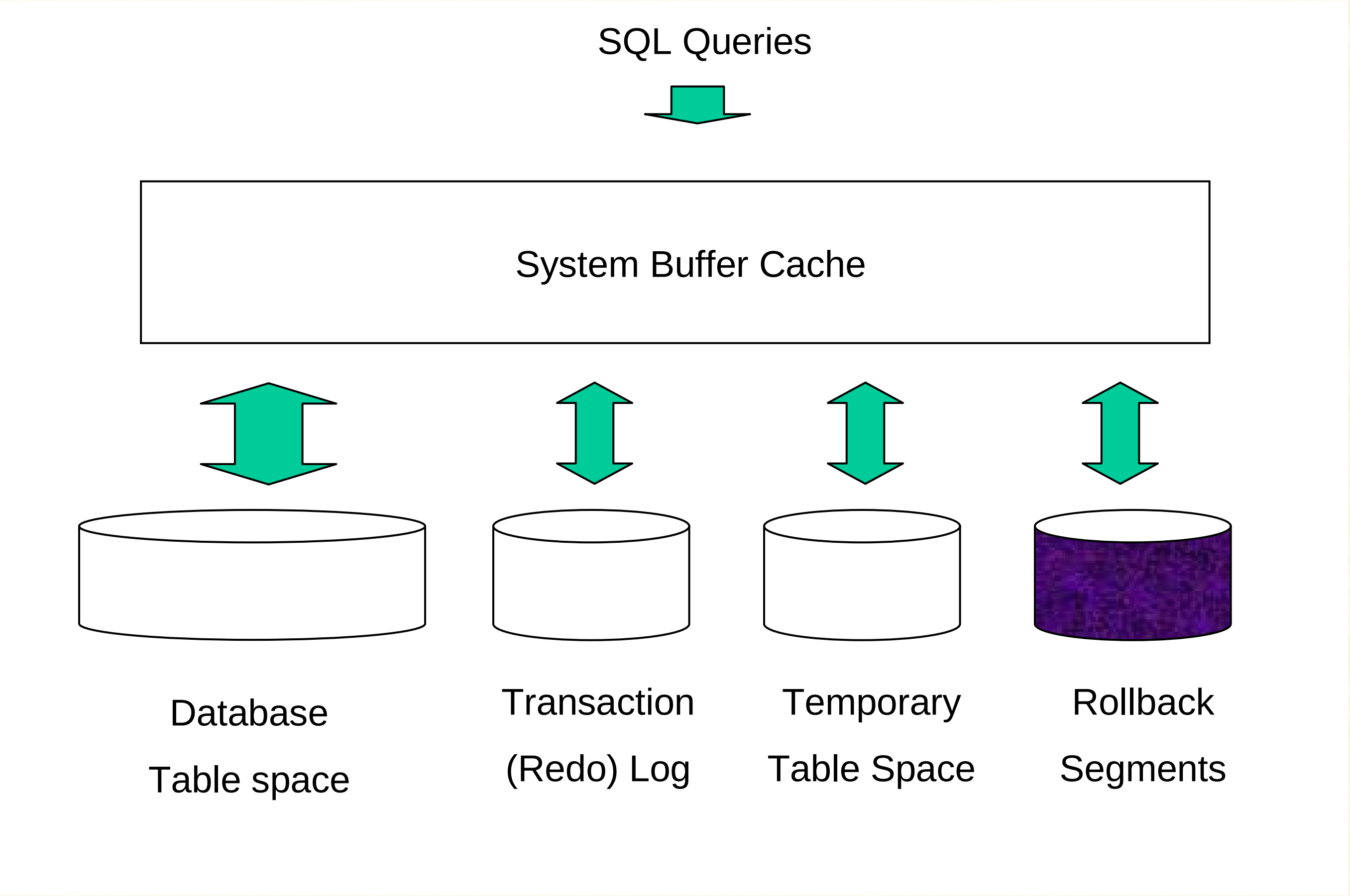
Hash Join: Performance

- **HDD vs SSD as a medium for a temp table space**
  - **Hash-join two tables of 2 M tuples (200 MB) each, with 2 MB buffer cache**
  - **About 3-fold reduction in join time**





Rollback Segments

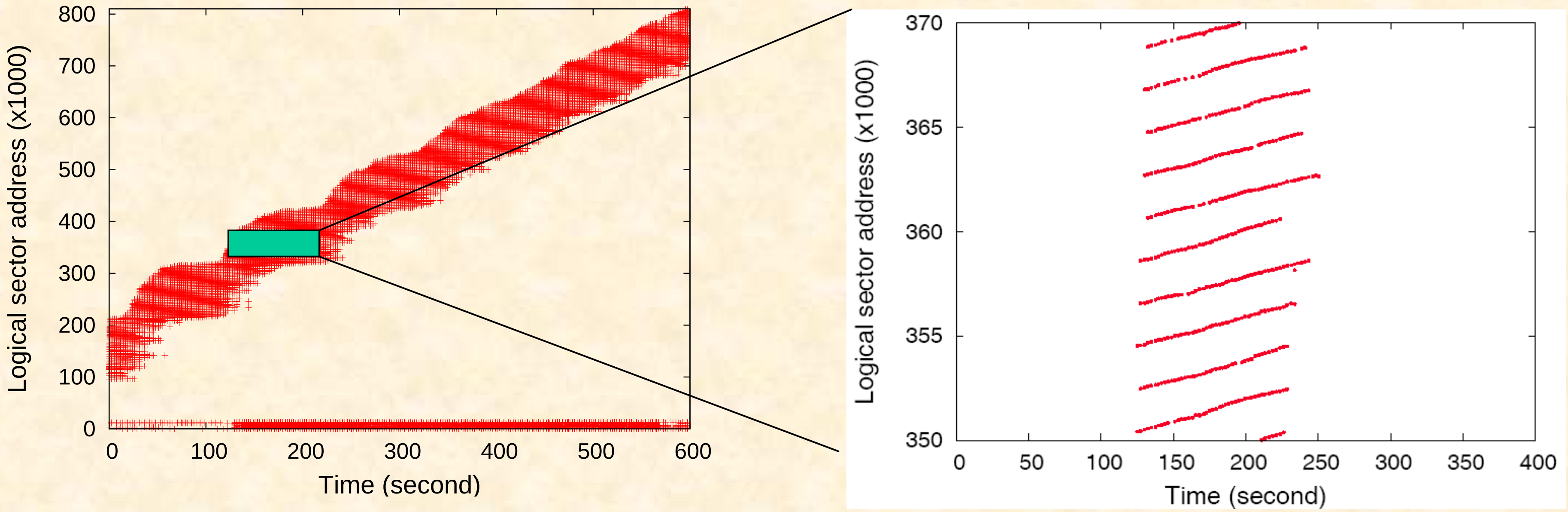


MVCC Rollback Segments

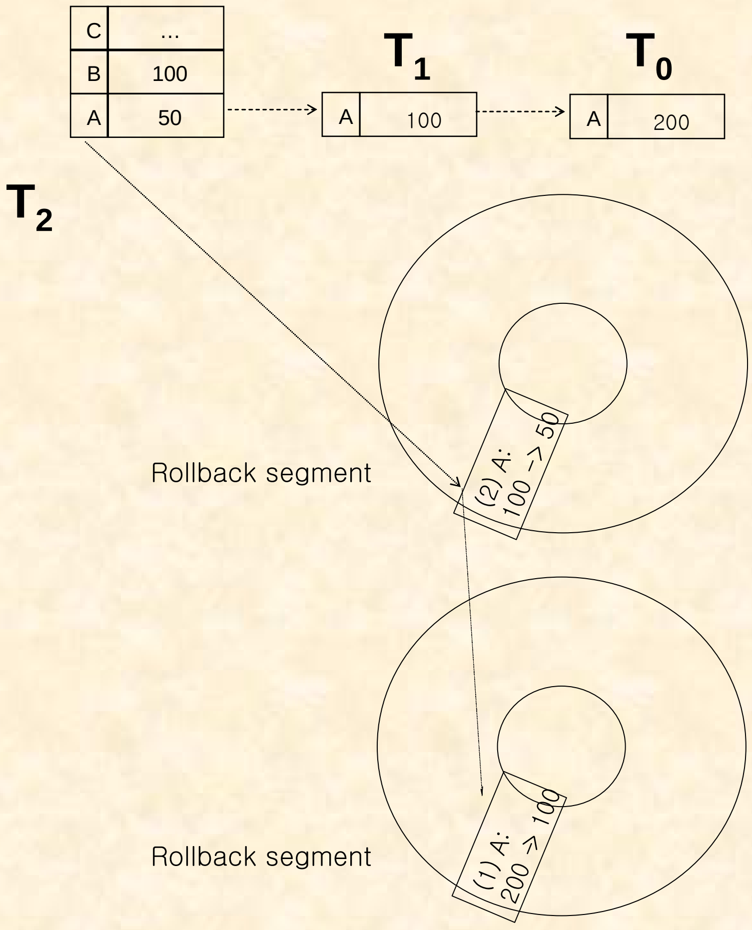
- **Multi-version Concurrency Control (MVCC)**
  - **Alternative to traditional Lock-based CC**
  - **Support read consistency and snapshot isolation**
  - **Oracle, PostgresSQL, Sybase, SQL Server 2005, MySQL**
- **Rollback Segments**
  - **When updating an object, its current value is recorded in the rollback segment**
  - **To fetch the correct version of an object, check whether it has been updated by other transactions**
  - **Each transaction is assigned to a rollback segment; old images of data are written to the rollback segment sequentially (in *append-only* fashion).**

MVCC Write Pattern

- **Write requests from TPC-C workload**
  - **Concurrent transactions generate multiple streams of append-only traffic in parallel (apart by approximately 1 MB)**
  - **HDD moves disk arm very frequently**
  - **SSD has no negative effect from no in-place update limitation**

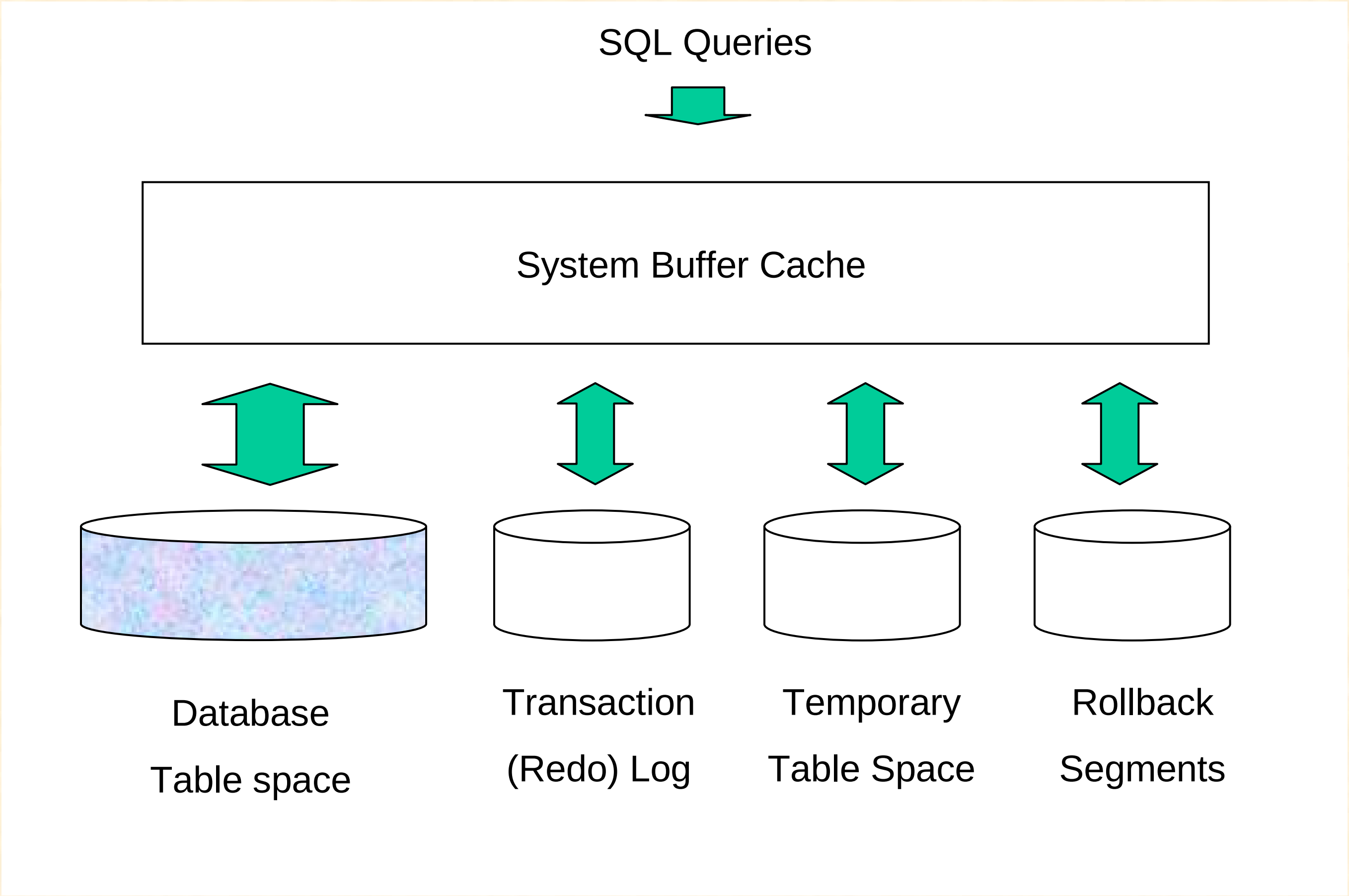


MVCC Read Performance



- **To support MV read consistency, I/O activities will increase**
  - **A long chain of old versions may have to be traversed for each access to a frequently updated object**
- **Read requests are scattered randomly**
  - **Old versions of an object may be stored in several rollback segments**
  - **With SSD, *10-fold read time reduction* was not surprising**

Database Table Space



Workload in Table Space

- **TPC-C workload**
  - **Exhibit little locality and sequentiality**
    - **Mix of small/medium/large read-write, read-only (join)**
  - **Highly skewed**
    - **~80% of accesses to 20% of tuples**
- **Write caching not as effective as read caching**
  - **Physical read/write ratio is much lower that logical read/write ratio**
- **All bad news for flash memory SSD**
  - **Due to the *No-in-place-update* limitation**
  - ***In-Page Logging (IPL)* approach [SIGMOD'07]**

ARIZONA

Concluding Remarks

- Clear and present evidences that Flash memory SSD can co-exist or even replace Magnetic Disk
  - Even now for logging, rollback segments and temp table spaces
  - Write optimization needed for database table spaces
- Flash-Aware DBMS Design is a must!
  - Flash-friendly algorithms, flash-friendly implementations
  - Need fresh new look at almost everything: Buffer management, B-trees, Sorting and Hashing, Self-Tuning, File Systems, etc.