Flash Talk

Flash Memory Database Systems: Challenges and Opportunities

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Magnetic Disk vs Flash SSD

Champion for 50 years

Seagate ST340016A
40GB,7200rpm

Intel X25-M Flash SSD
80GB 2.5 inch

New challengers!

Samsung FlashSSD
128 GB 2.5/1.8 inch

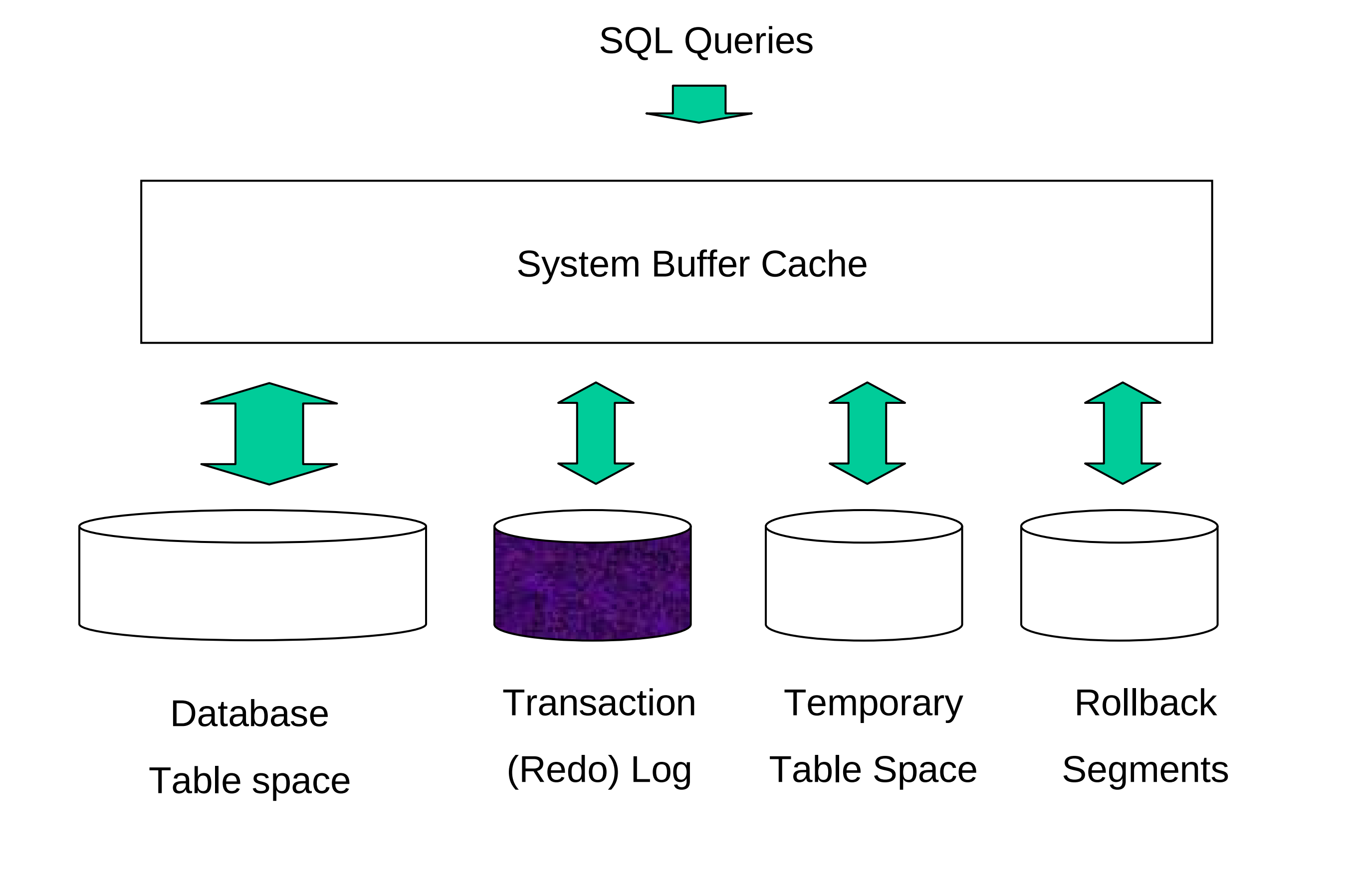
Technology Trend

- NAND flash density increases faster than Moore's law
  - Predicted *twofold annual increase* of NAND flash density until 2012 [Hwang, ProcIEEE'03]
  - purSilicon announced 2.5" Nitro SSD with 1-TB capacity (CES'09)
    - Double-stacked 128 chips (2 x 64 x 64Gb), 32-channel, 512 MB RAM, SATA-II
- Bandwidth catches up and throughput excels
  - Bandwidth in range of 200-300 MB/sec and 80-150 MB/sec for R/W
  - Throughput in range of 10k-30k and 1k-3k for R/W

Flash SSD for Databases?

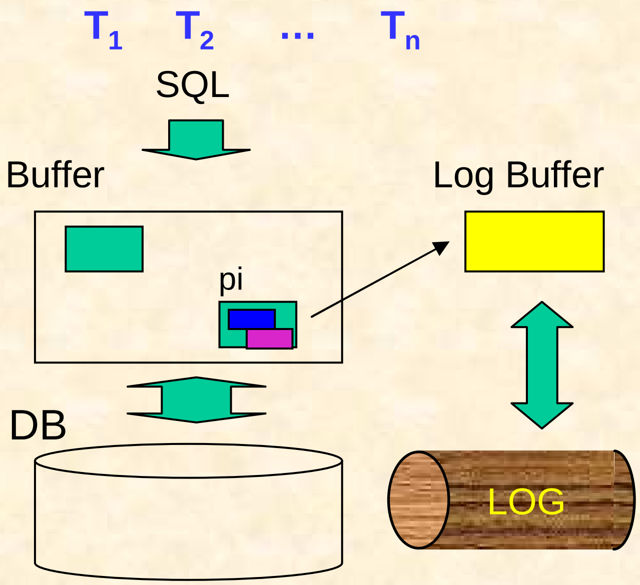
- Not inconceivable to run a full database server
  - Computing platforms with TB-scale Flash SSD
- Immediate benefit for some DB operations
  - Reduce commit-time delay by fast logging
  - Reduce read time for multi-versioned data
  - Flash-friendly I/O patterns in temp table spaces
- Still, random scattered I/O is an issue
  - Slow random writes by flash SSD can handle this?

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**

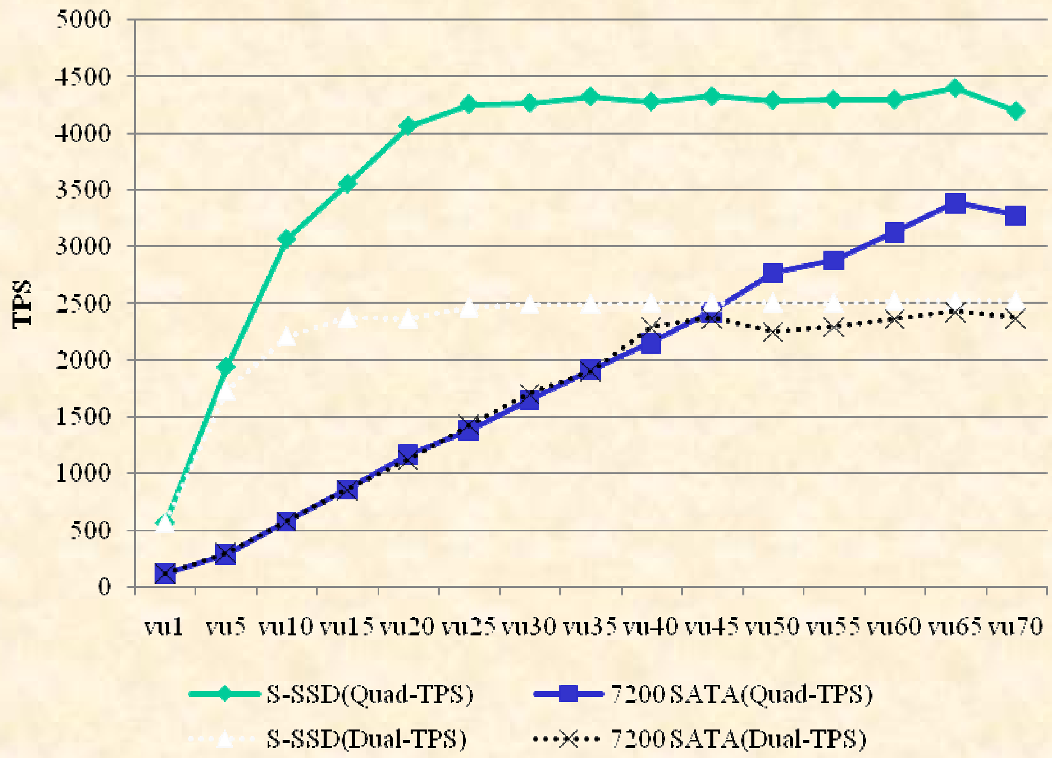


- Commit-time delay remains to be a significant overhead
  - **Group-commit helps but the delay doesn't go away altogether.**
- How much commit-time delay?
  - **On average, 8.2 msec (HDD) vs 1.3 msec (SDD) : *6-fold reduction***
    - **TPC-B benchmark with 20 concurrent users.**

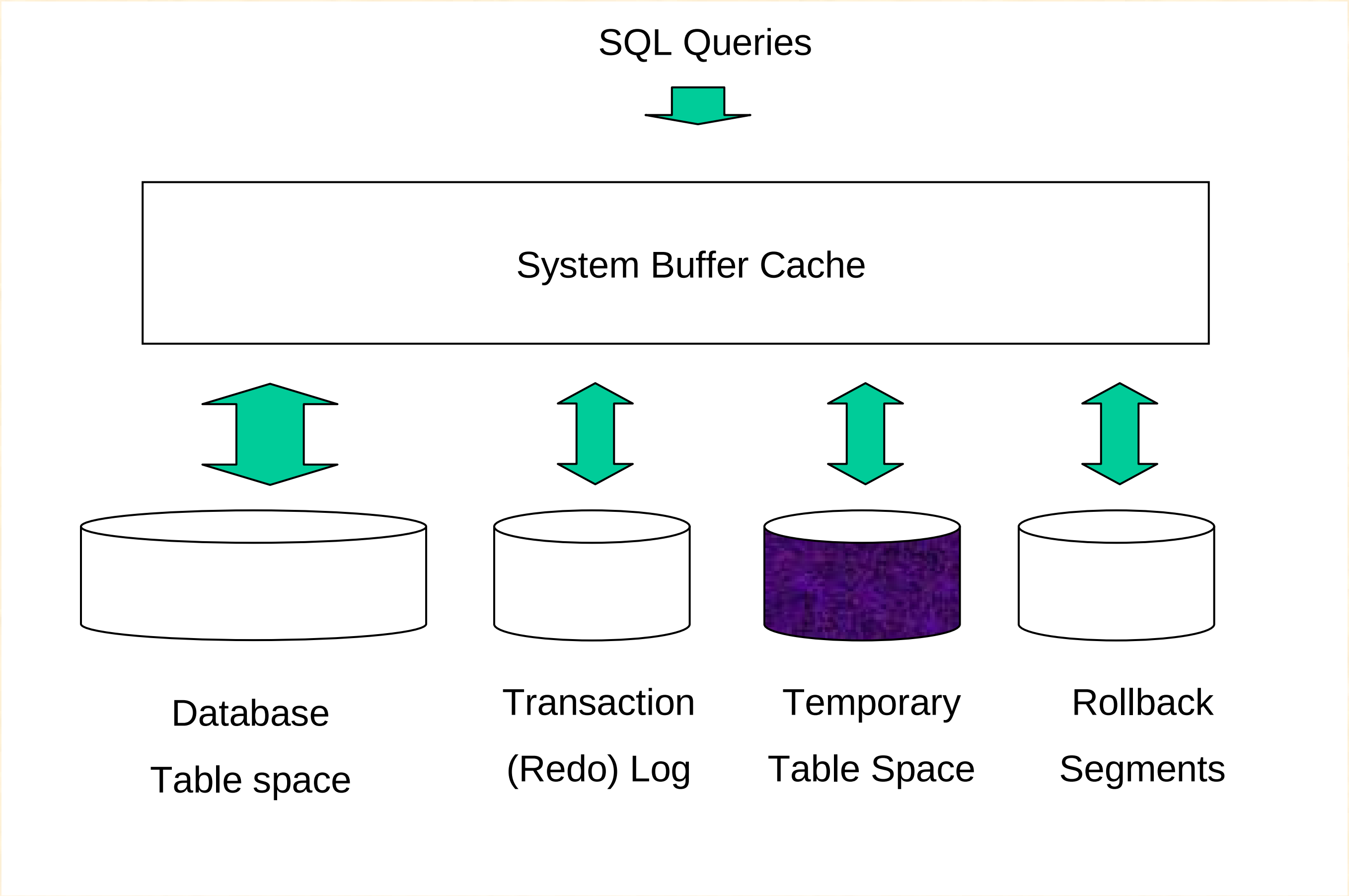
HDD vs SSD for Logging

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

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



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?

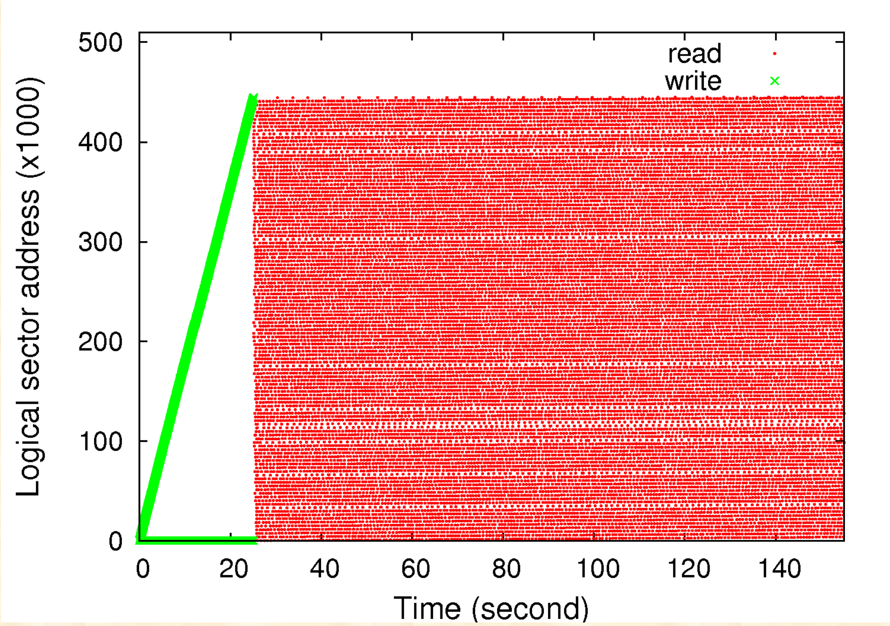
External Sort: I/O Pattern

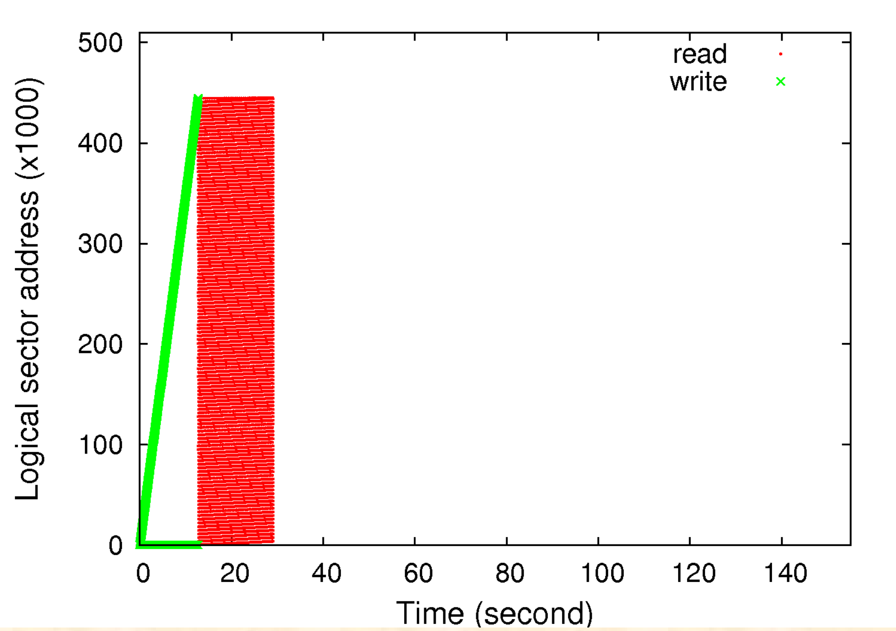
- External Sort algorithm runs in two phases
  - **Sorted run generation**
    - **Partitioned to chunks, sorted separately and, saved in sorted runs**
    - **Read sequentially from table space, written sequentially into temp space**
  - **Merging sorted runs**
    - **Read randomly from temp space,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

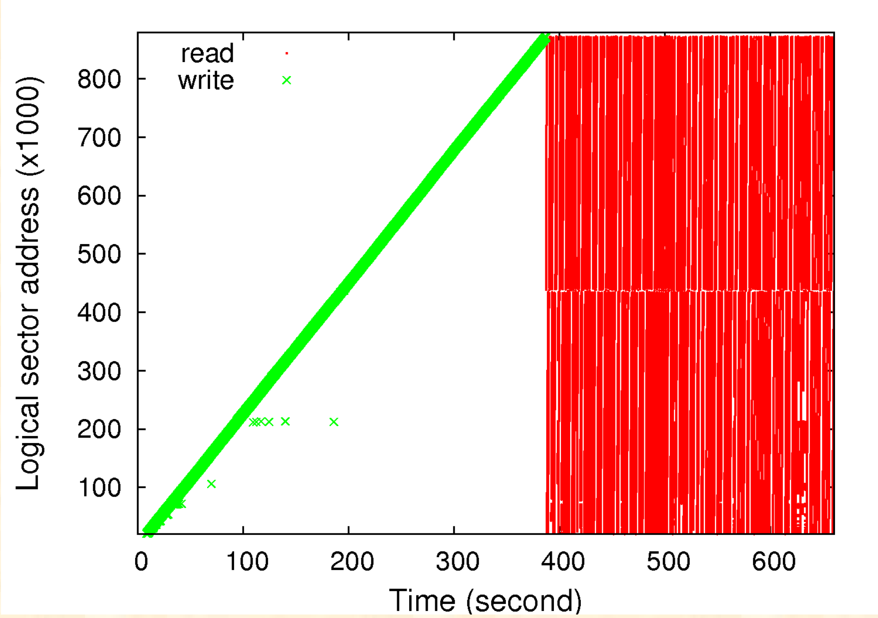
- HDD vs SSD as a medium for a temp table space
  - **Sort a table of 2 M tuples (200 MB), with 2 MB buffer cache**
- SSD is good at *sequential write + random read*
  - **Almost an order of magnitude reduction in merge times**

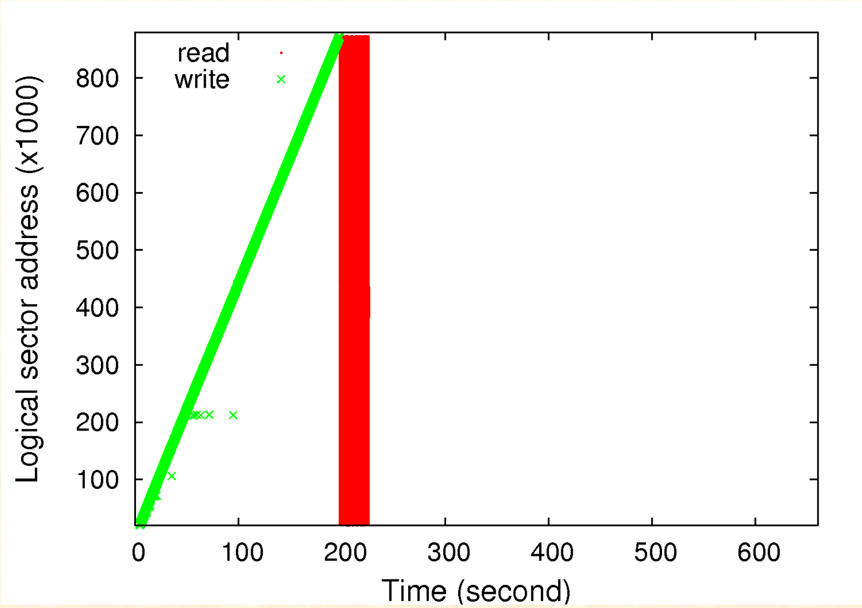




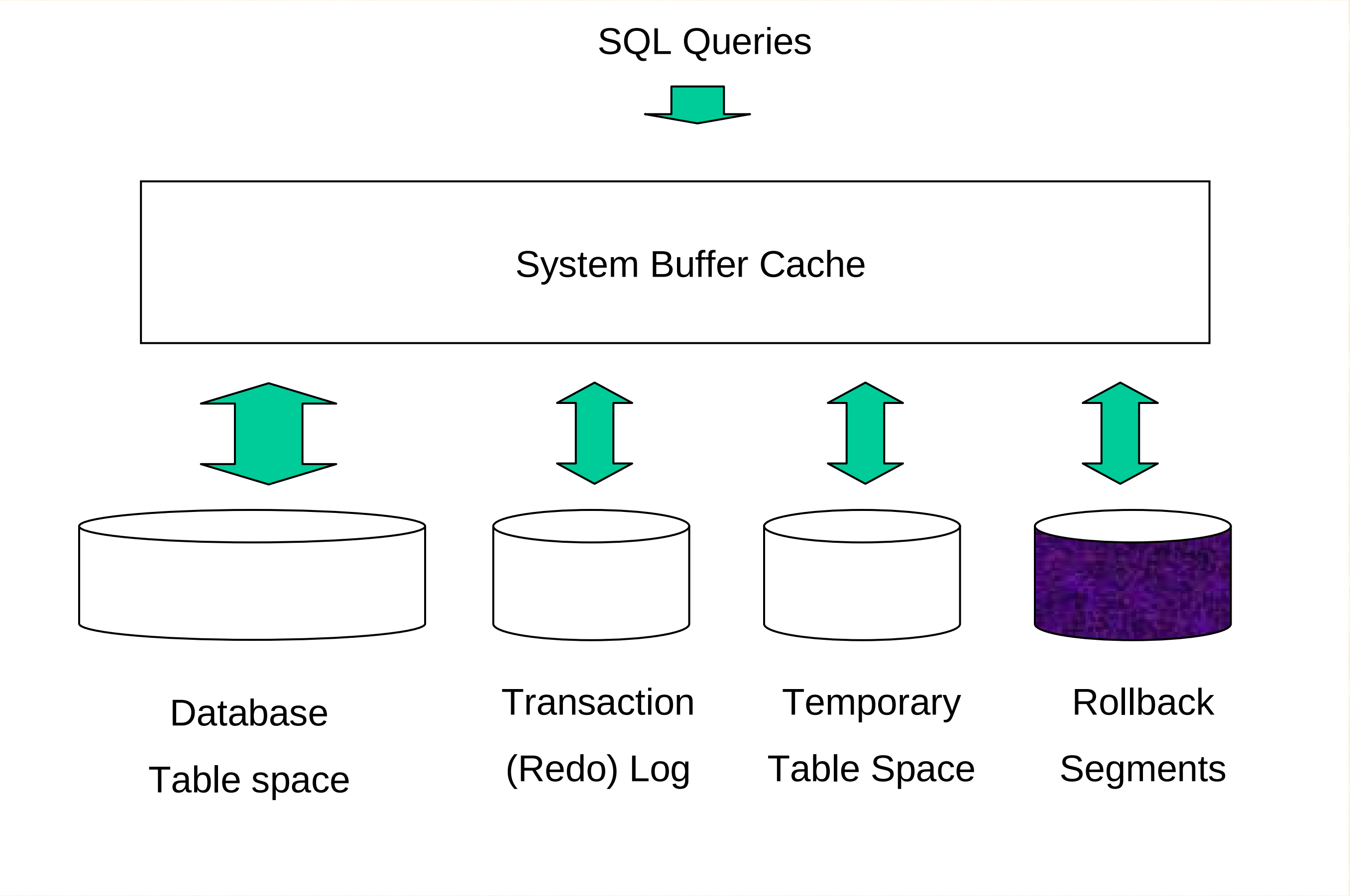
Hash Join: Performance

- 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

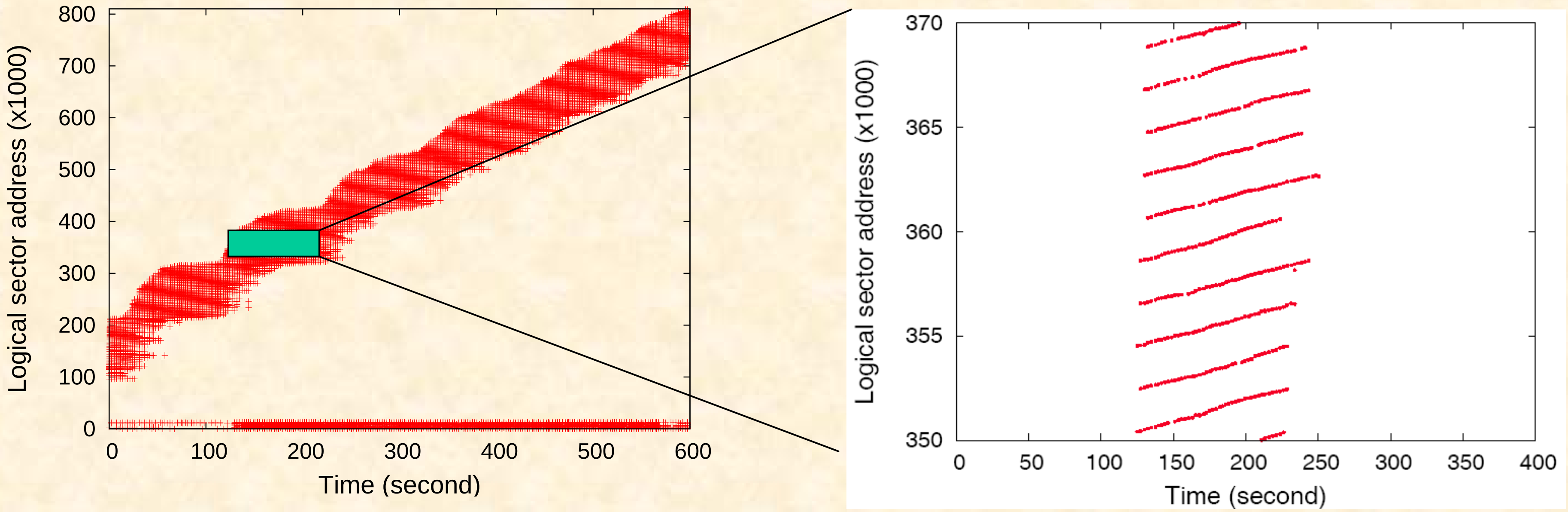


MVCC Rollback Segments

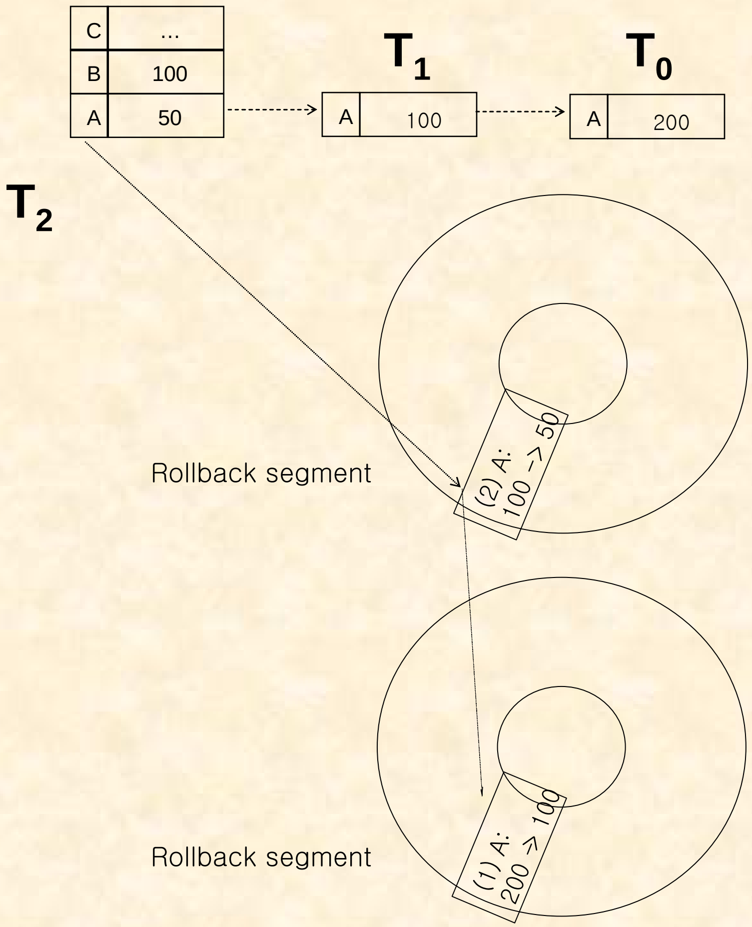
- **Multi-version Concurrency Control (MVCC)**
  - **Alternative to traditional Lock-based CC**
  - **Support read consistency and snapshot isolation**
  - **Oracle, PostgresSQL, Sybase, SQL Server 2005, MySQL**
- **Rollback Segments**
  - **Each transaction is assigned to a rollback segment**
  - **When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

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**

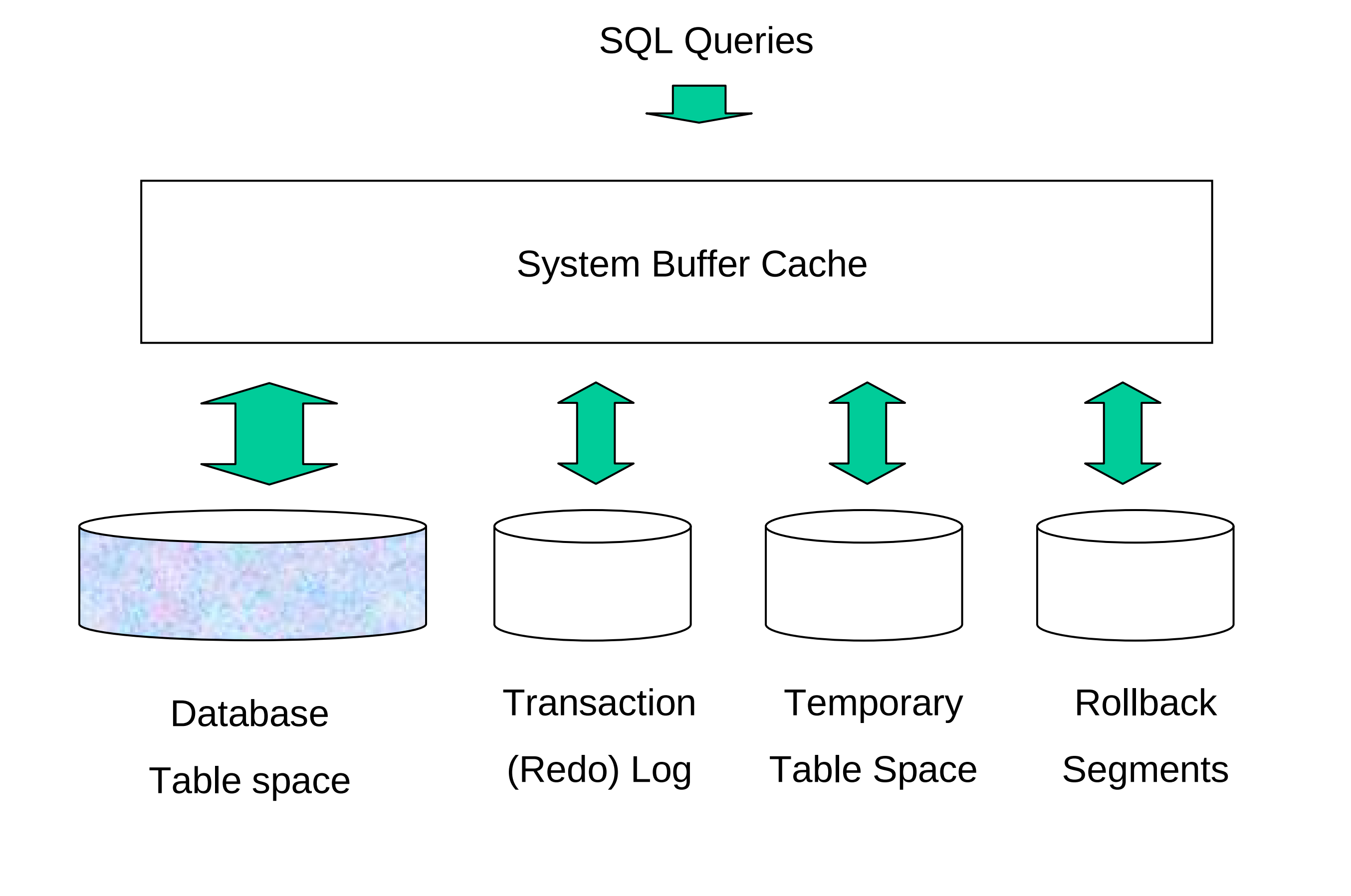


MVCC Read Performance



- 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 (wholesale supplier queries)
  - **Exhibit little locality and sequentiality**
    - **Mix of small/medium/large read-write, read-only (join)**
  - **Highly skewed**
    - **84% (75%) of accesses to 20% of tuples (pages)**
- 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* and *Asymmetric read/write speeds***

Industry Response

- Common in Enterprise Class SSDs
  - Multi-channel, inter-command parallelism
    - Thruput than bandwidth, write-followed-by-read pattern
  - Command queuing (SATA-II NCQ)
  - Large RAM Buffer (with super-capacitor backup)
    - Even up to 1 MB per GB
    - Write-back caching, controller data (mapping, wear leveling)
- Samsung EC SSD Prototype
  - Fat provisioning (up to ~20% of capacity)
- Intel X-25M/E
  - Claims a very low (~1.1) write amplification factor

Impressive Improvement

- **Samsung EC SSD**
  - **10x/100x higher R/W IOPS than early prototypes**
  - **20x/8x higher R/W IOPS than a 15k-RPM disk**
  - **1.4x~2x higher transaction rate than RAID0 (eight 15k-RPM disks) for R/W TPC-C workload**
- **Intel X-25M**
  - **Bandwidth: 240/80 (MB/sec) for R/W**
  - **Throughput: 20000/1200 (IOPS) for R/W**

Still, Not There Yet …

- **Write still lags behind**
  - $IOPS_{Disk} < IOPS_{SSD\text{-}Write} << IOPS_{SSD\text{-}Read}$
  - $IOPS_{SSD\text{-}Read} / IOPS_{SSD\text{-}Write} = 4 \sim 17$

Prototype/Product	EC SSD	X-25M	15k-RPM Disk
Read (IOPS)	**10500**	**20000**	**450**
Write (IOPS)	**2500**	**1200**	**450**

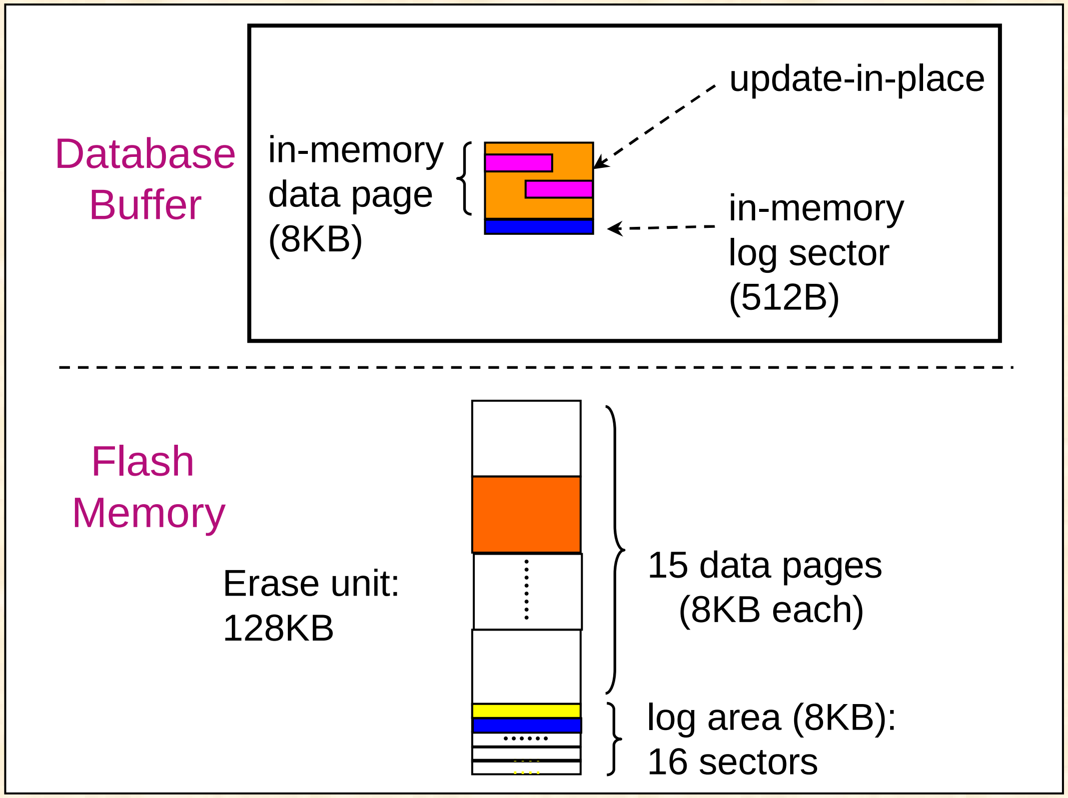
In-Page Logging (IPL)

- Some academics believe
  - Improving SSD alone cannot do the job

- Key Ideas of the IPL Approach
  - Changes written to *log* instead of updating them in place
    - Avoid frequent write and erase operations
  - Log records are *co-located* with data pages
    - No need to write them sequentially to a separate log region
    - Read current data more efficiently than sequential logging
  - DBMS buffer and storage managers work together

Design of the IPL

- **Logging on Per-Page basis in both Memory and Flash**

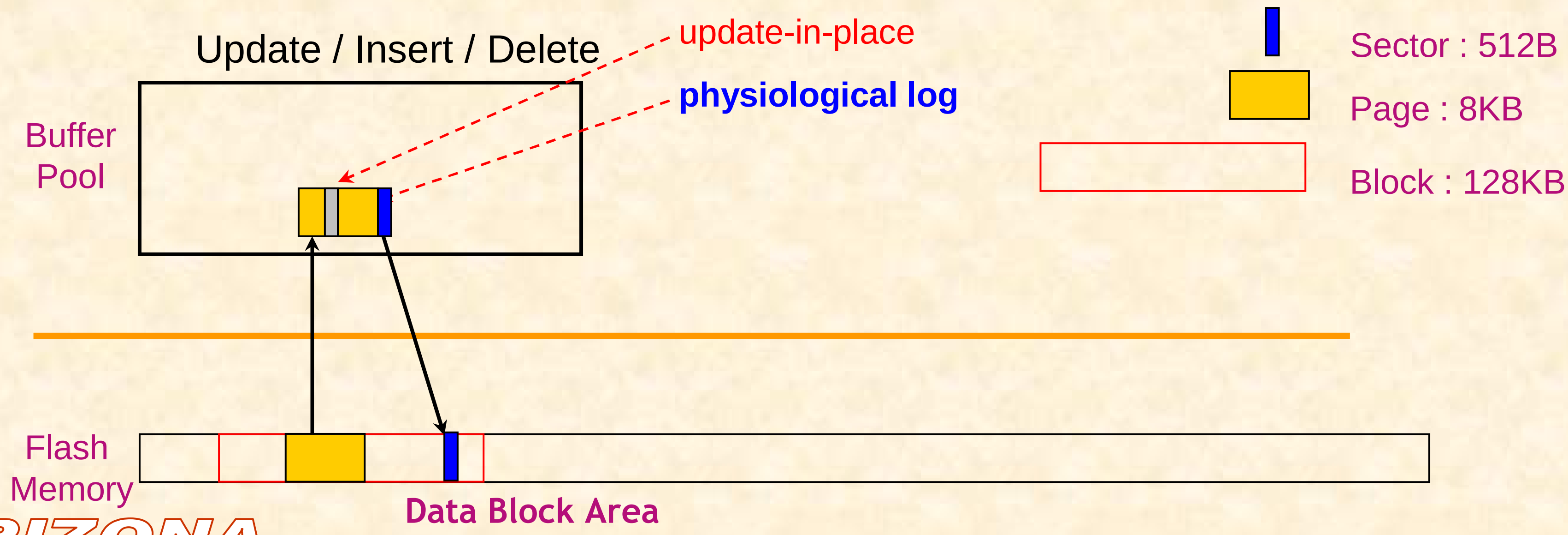


The log area is shared by all the data pages in an erase unit

- An ***In-memory log sector*** can be associated with a buffer frame in memory
  - Allocated on demand when a page becomes dirty
- An ***In-flash log segment*** is allocated in each erase unit

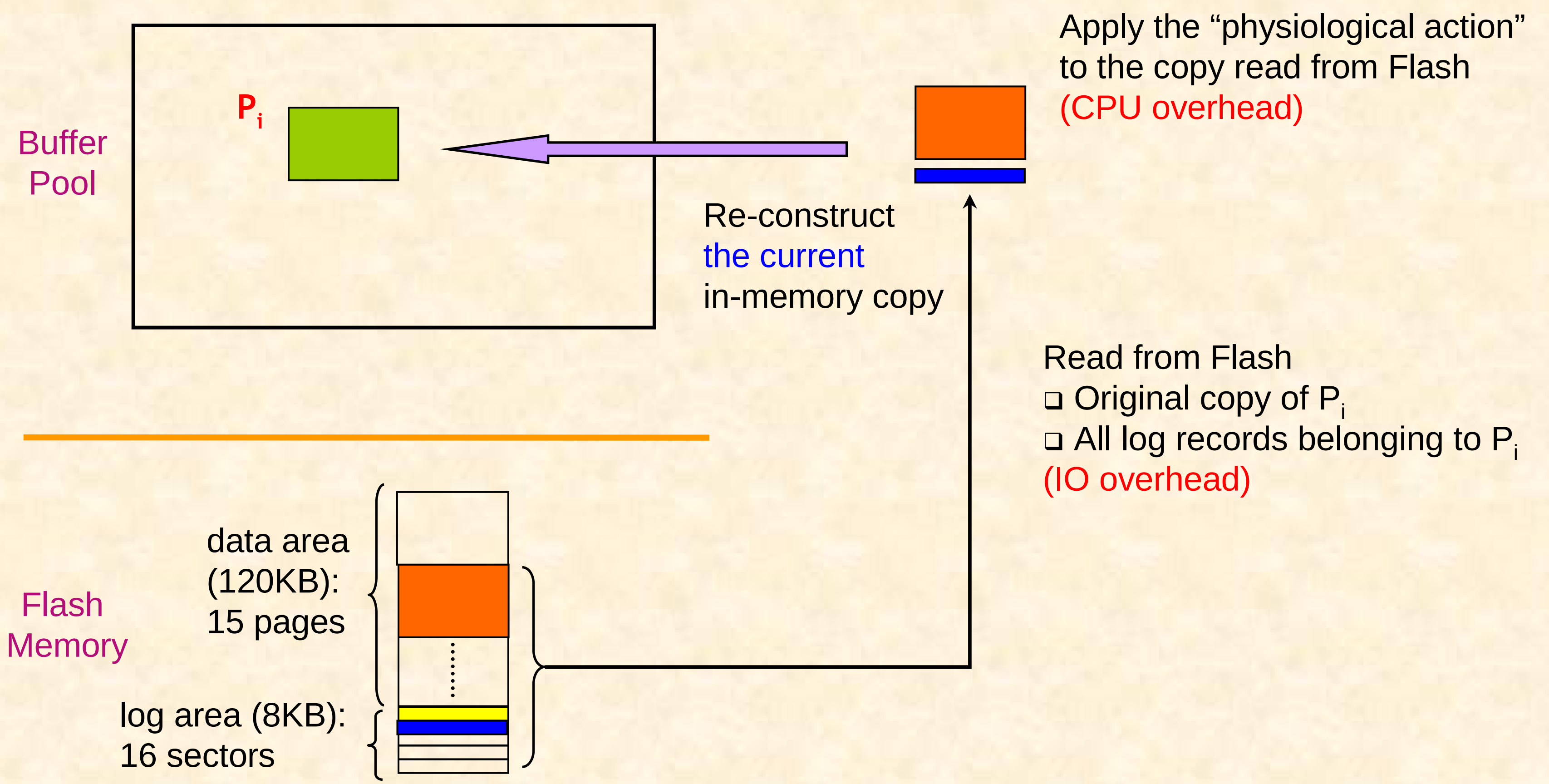
IPL Write

- Data pages in memory
  - Updated in place, and
  - Physiological log records written to its in-memory log sector
- In-memory log sector is written to the in-flash log segment, when
  - Data page is evicted from the buffer pool, or
  - The log sector becomes full
- When a dirty page is evicted, the content is *not written* to flash memory
  - The previous version remains intact
- Data pages and their log records are physically co-located in the same erase unit



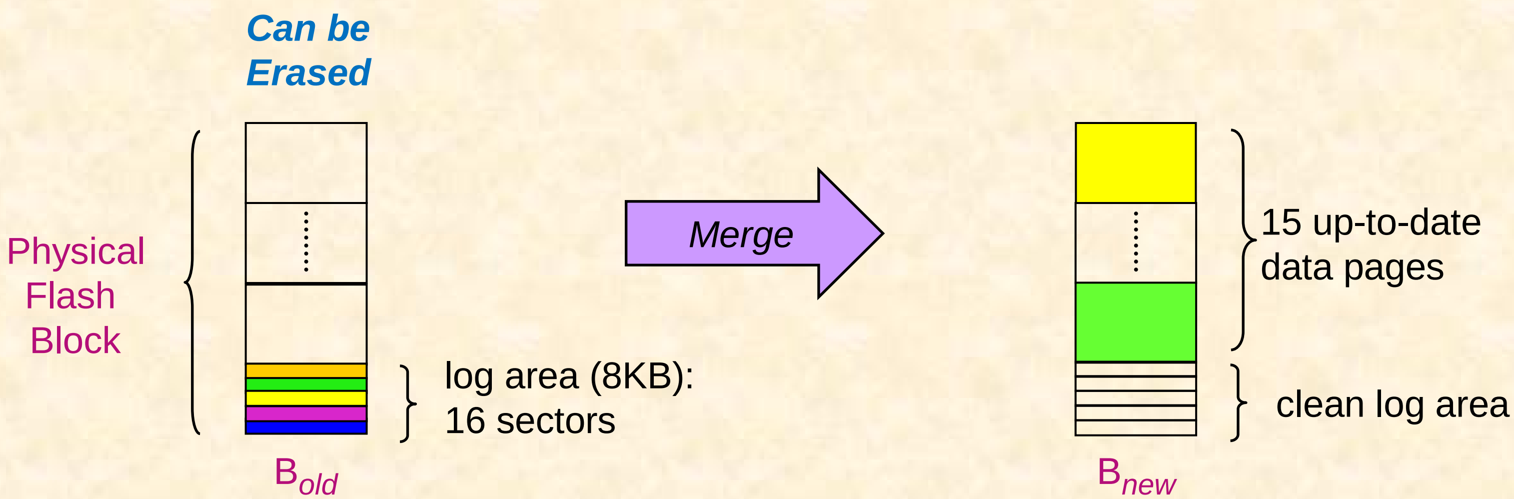
IPL Read

- **When a page is read from flash, the current version is computed on the fly**



IPL Merge

- **When all free log sectors in an erase unit are consumed**
  - **Log records are applied to the corresponding data pages**
  - **The current data pages are copied into a new erase unit**
    - **Consumes, erases, and releases only one erase unit**



Evaluation of IPL

- IPL simulation with TPC-C workload
  - Average length of a log record: 20 ~ 50 Bytes
    - A single log sector can absorb more than 10 updates
  - An order of magnitude improvement in write time
- TPC-C *Write* frequencies are highly skewed
  - Blocks containing hot pages consume log sectors quickly, causing frequent erase operations
  - Trade space for improved write performance
    - Use a larger log segment in blocks for less frequent merges
- *Zero* (or *negative*) write amplification possible

Concluding Remarks

- **Flash Memory SSD will stay here …**
  - **Co-exist or even replace Magnetic Disk**
  - **Significant performance boost for enterprise systems**
  - **Cost recovery from energy savings in large-scale TPC-C systems, data centers, HEC systems, etc.**
- ***Flash-Aware DBMS Design***
  - **Need fresh new look at almost everything: Buffer management, B-trees, Sorting and Hashing, Self-Tuning, File Systems, etc.**
- ***DBMS-Aware SSD Architecture (?)***
  - **Address mapping, channel parallelism, command queuing, etc.**

Questions

For more information about *Bongki*'s work,

www.cs.arizona.edu/~bkmoon