Beyond Block I/O: Rethinking Traditional Storage Primitives

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Agenda

- Introduction and Motivation
  - Solid State Storage (SSS) Characteristics
  - Duplicated efforts at SSS and upper layers
- Atomic-Write Primitive within FTL
- Leverage Atomic-Write in DBMS
  - Example with MySQL
- Experimental Results
- Conclusion and Future Work

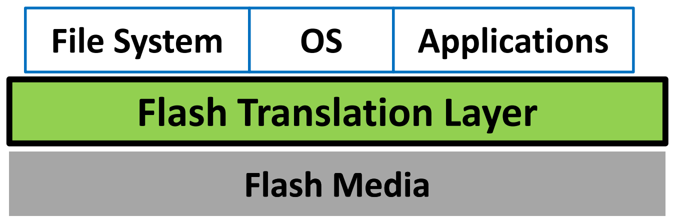
Evolution of Storage Devices

- Interface to persistent storage remains unchanged for decades
  - seek, read, write
  - Fits well with mechanical hard disks

- Solid State Storage (SSS)
  - ✓ Merits
    - Fast random access, high throughput
    - Low power consumption
    - Shock resistance, small form factor
  - Expose the same disk-based block I/O interface
  - Challenges…

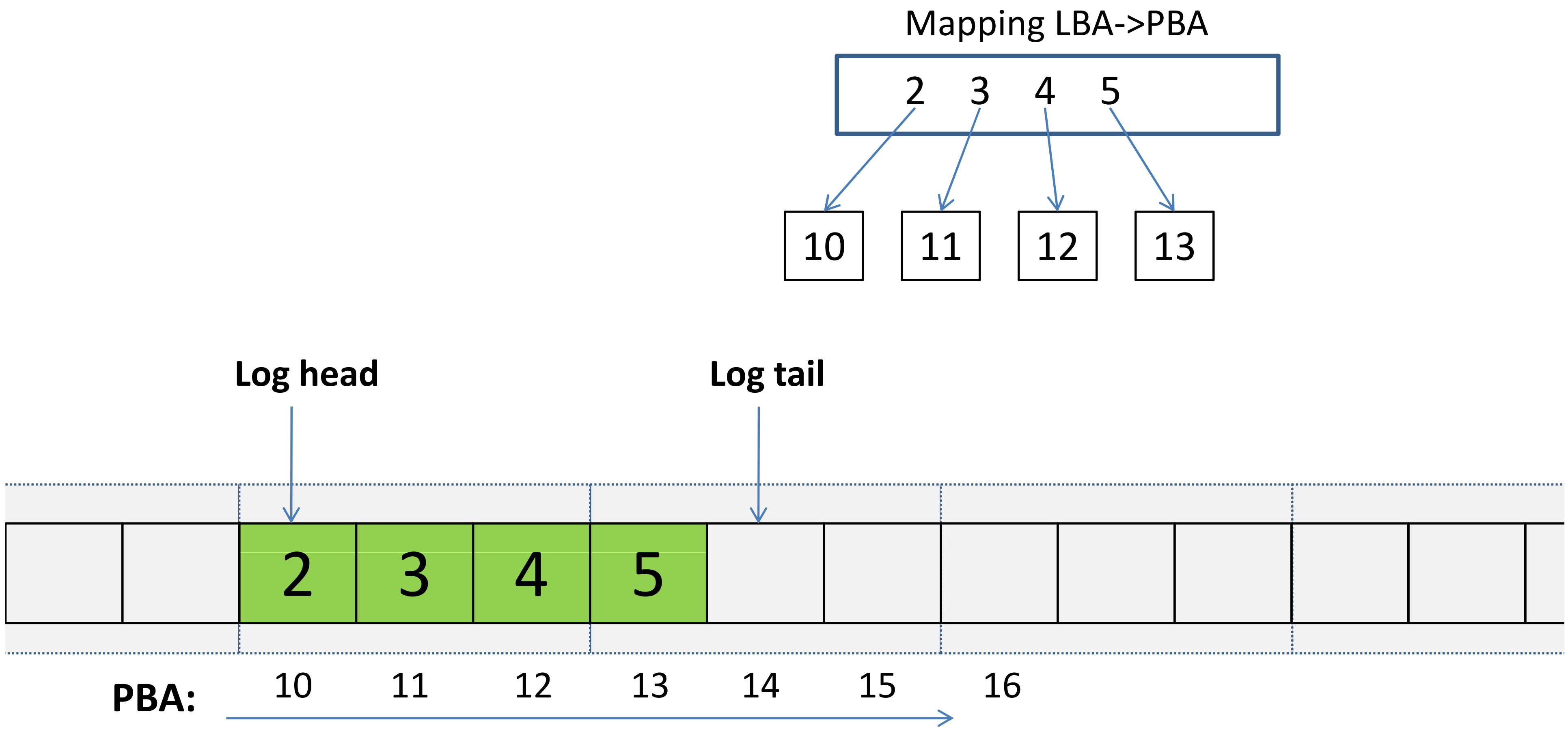
NAND-flash Based Solid State Storage (SSS)

- Pitfalls
  - ✖ Asymmetric read/write latency
    - Cannot overwrite before erasure
    - Erasure at large unit (64-256 pages), very slow (1+ ms)
  - ✖ Flash Wear-out: limited write durability
    - SLC: 30K erase/program cycles, MLC: 3K erase/program cycles

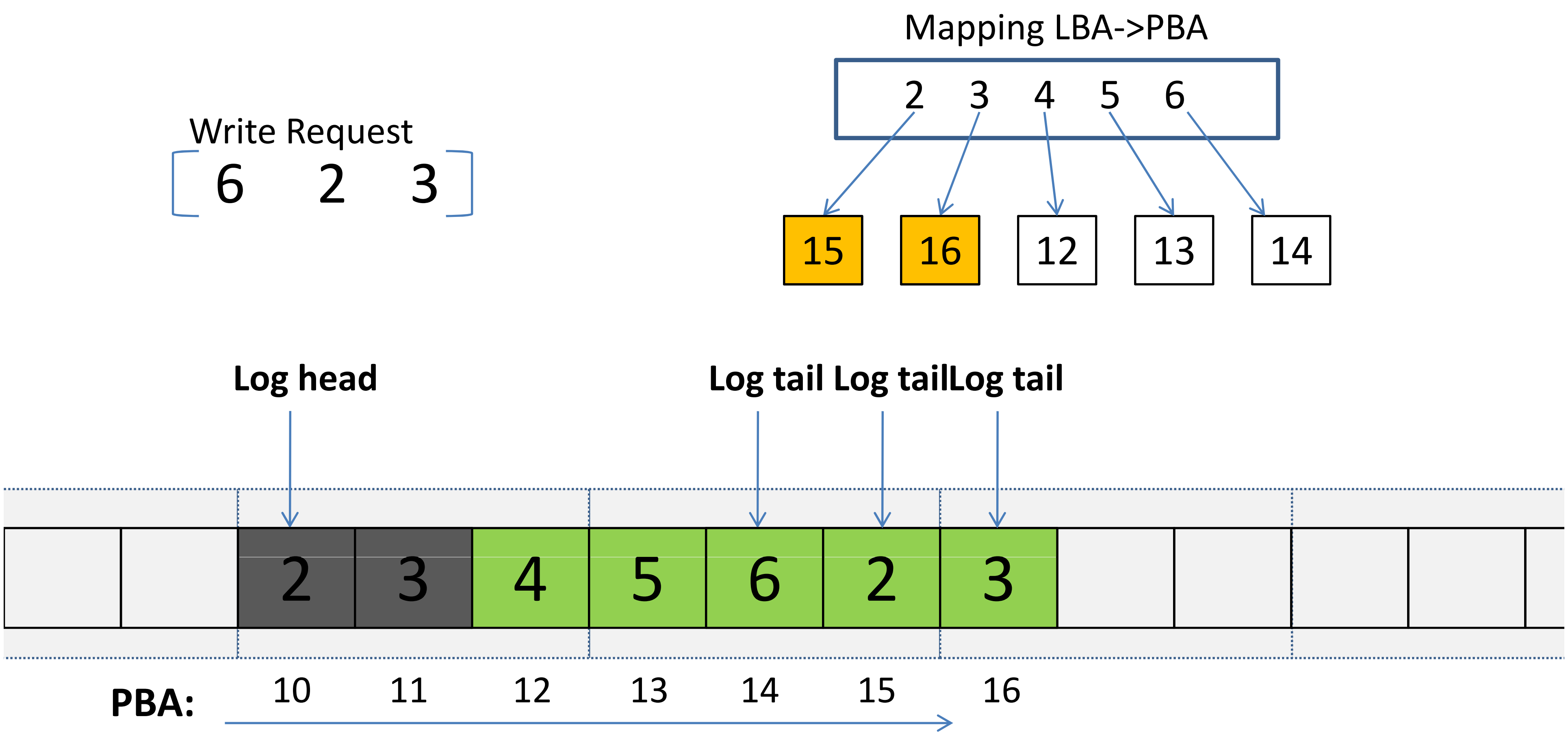


- Flash Translation Layer (FTL)
  - – Input: **Logical Block Address (LBA)**
  - – Output: **Physical Block Address (PBA)**

Log-Structured FTL



Log-Structured FTL



Log-FTL Advantages

- ✓ ***Avoid in-place update (Block Remapping)***
- ✓ ***Even wear-leveling***

Duplicated Efforts at Upper Layers and FTL

- ***Multi-Version*** at Upper Layer
  - DBMS (Transactional Log)
  - File-systems (Metadata journaling, Copy-on-Write)
  - To achieve **Write Atomicity**
    - ACID: Atomicity, Consistency, Isolation, durability

- ***Block-Remapping*** at FTL
  - Avoid **in-place update** in critical path

- **Common Thread: Multi-versions of same data**
- **Why duplicate this effort ?**

- Proposed approach:
  - **Offload Write-Atomicity guarantee to FTL**
  - **Provide Atomic-Write primitive to upper layers**

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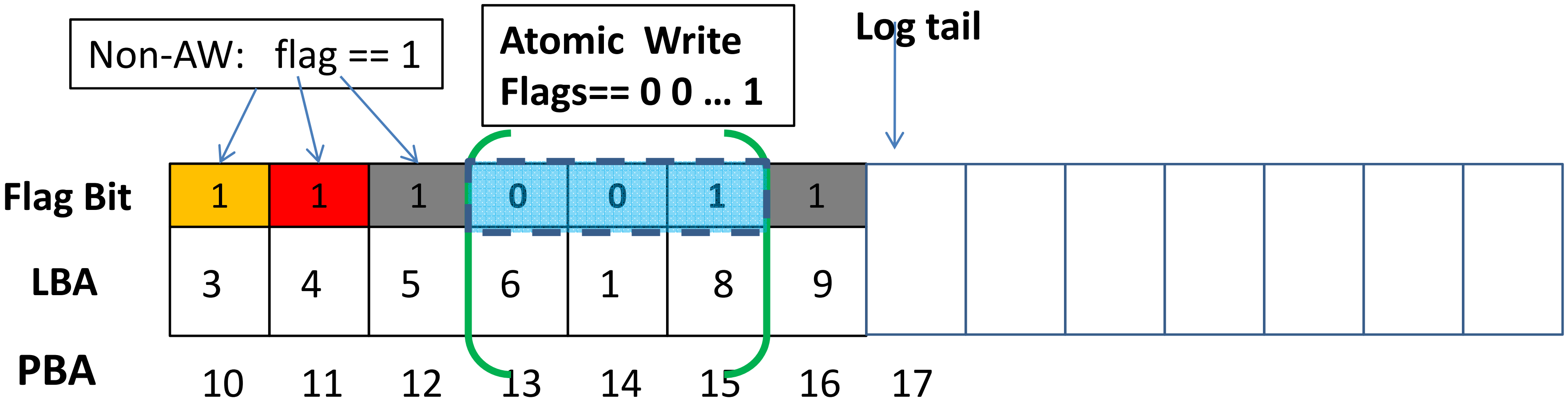
Atomic-Write: a New Block I/O Primitive

- Offload the Write-Atomicity guarantee into FTL
- Combines multi-block writes into a logical group (contiguous , non-contiguous)
- Commit the group as an atomic unit, if the compound operation succeeds
- Rollback the whole group is any individual fails

Atomic-Write (1): Flag Bit in Block Header

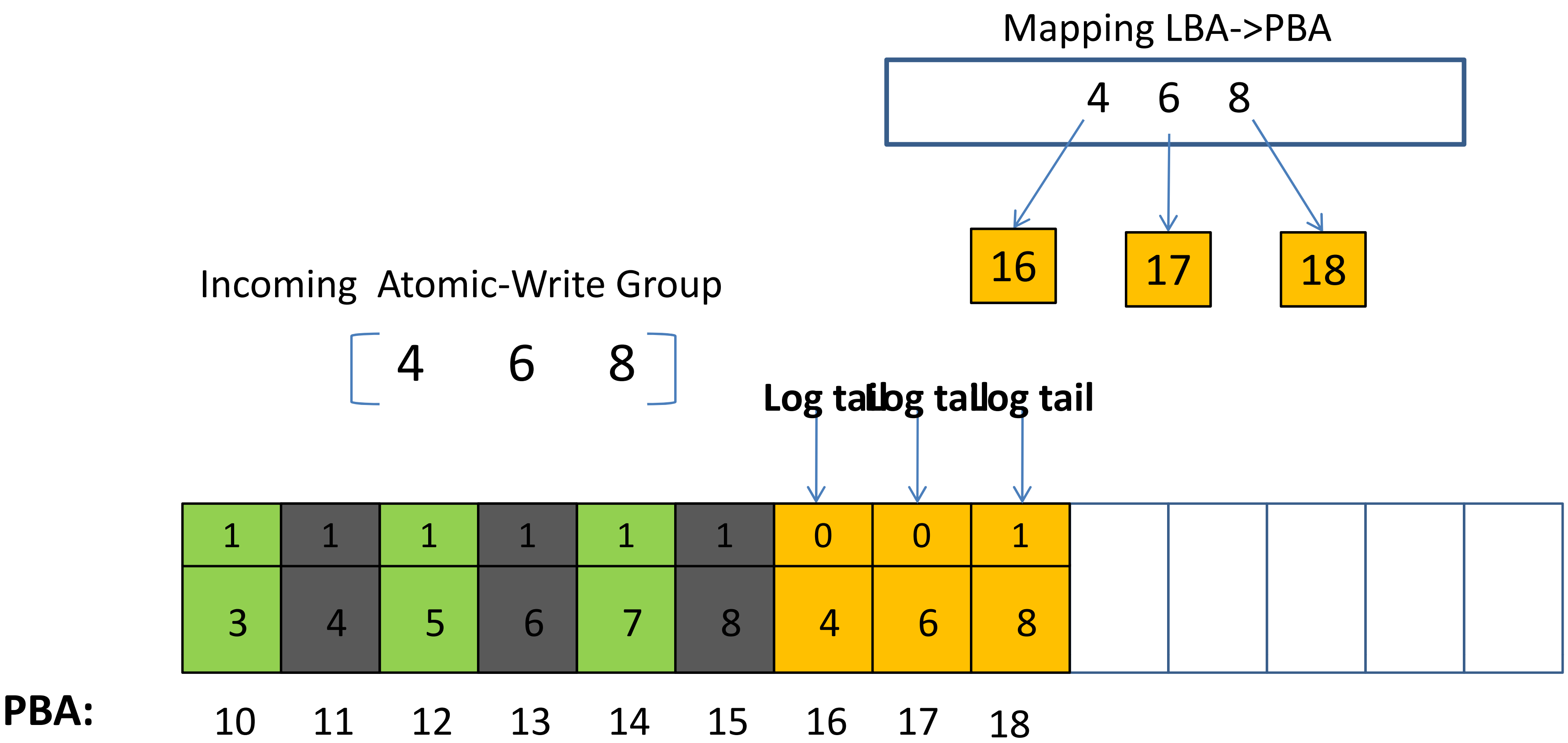
- One Flag Bit per block header
  - ➢ Identify blocks belonging to the same atomic-group



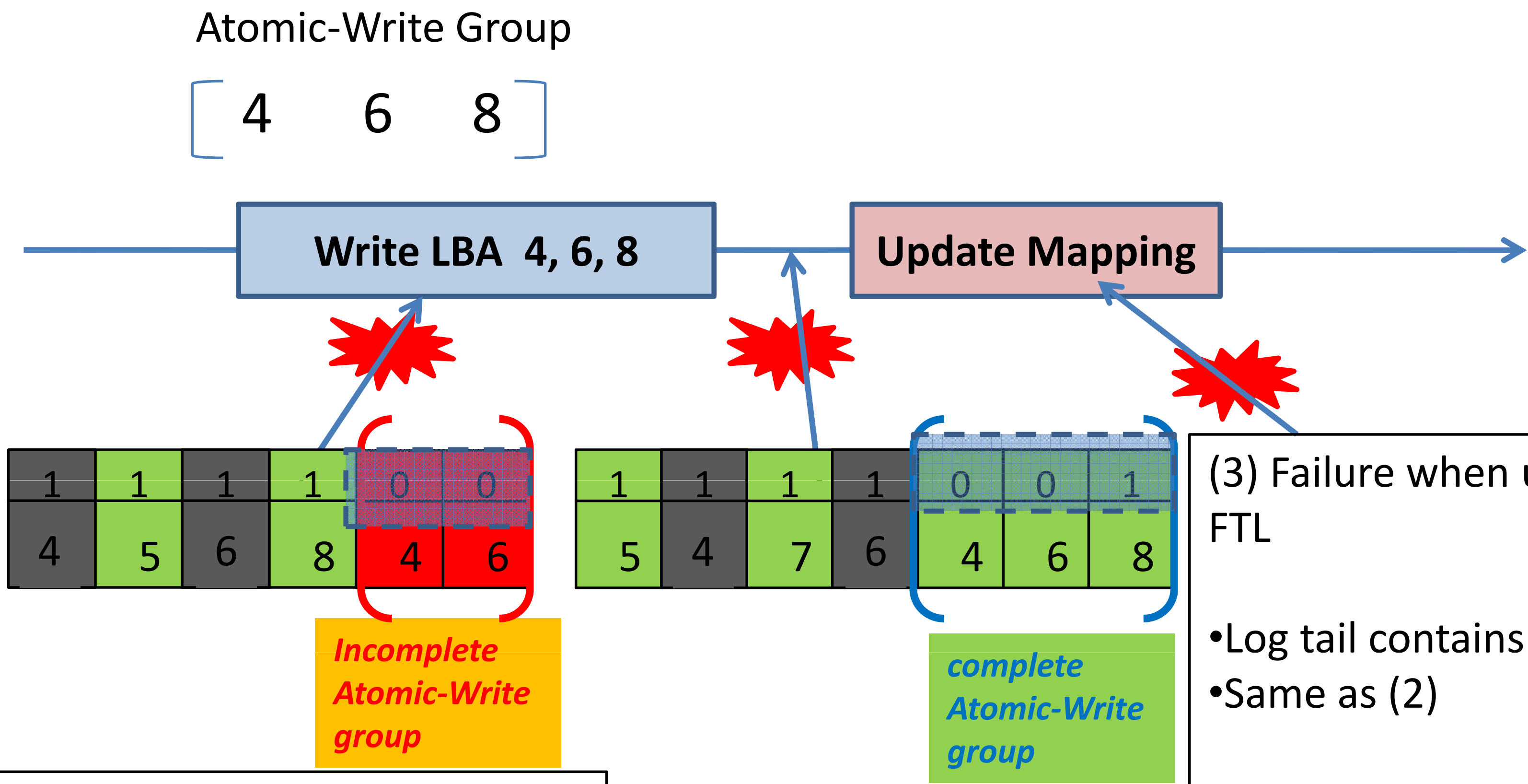
- Don’t allow Non-AW to interleave with Atomic-Write

Atomic-Write (2): Deferred Mapping Table Update

- Defer mapping table update
  - ➢Not expose partial state to readers



Atomic-Write (3): Failure Recovery



(3) Failure when updating FTL

- Log tail contains "1" flag bit
- Same as (2)

(1) Failure during writing:

- Scan backwards, discard blocks with "0" flag bits
- Rollback the partial blocks to previous version

(2) Failure after writing

- Scan the log from beginning, rebuild the FTL mapping

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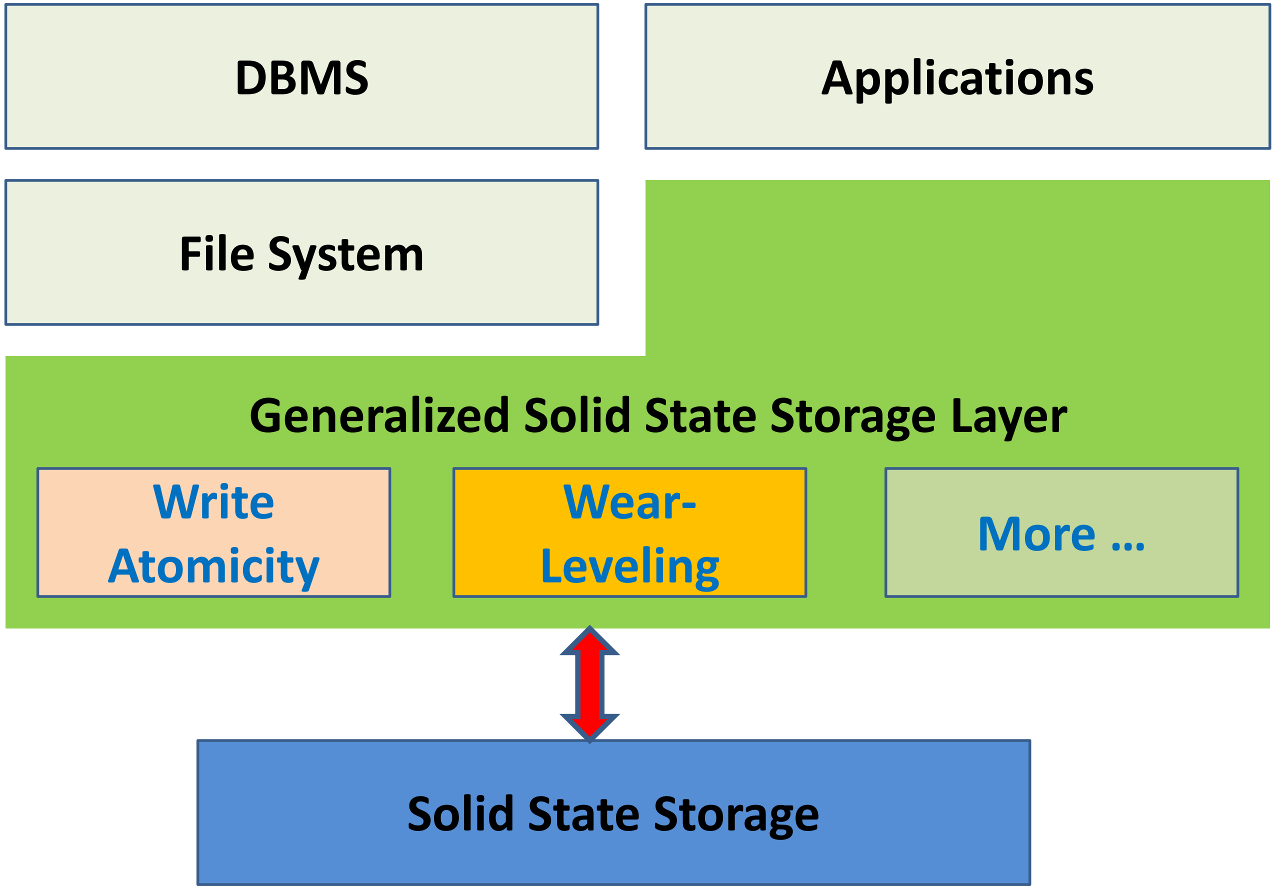
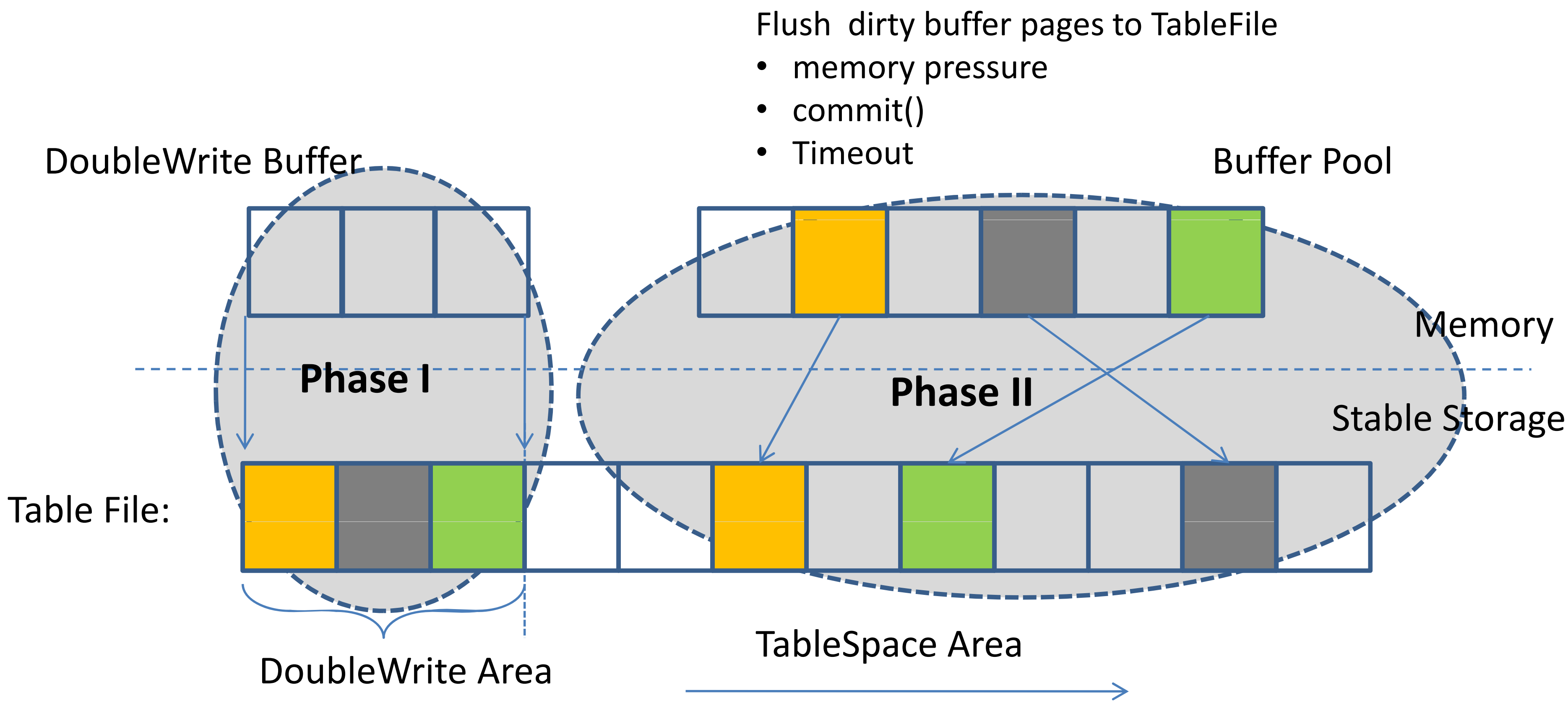
Proposed Storage Stack



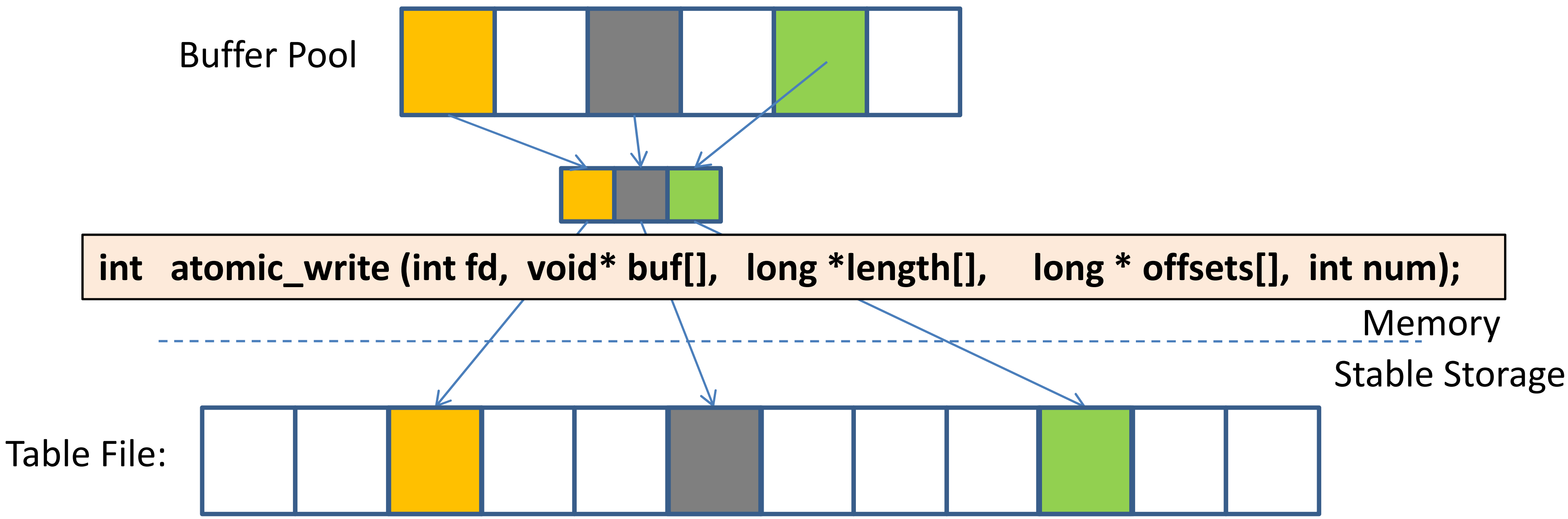
➔**Example: Leverage Atomic-Write in DBMS (MySQL)**

DoubleWrite with MySQL InnoDB Storage Engine



- **Every data page is written twice !**
  - **Impact the performance**
  - ***Double amount of writes to Flash media***
    halve device's lifespan

MySQL InnoDB: Atomic-Write



- ✓ **Reduce the data written by half**
  Double the effective wear-out life
- ✓ **Simplify the upper layer design**
- ✓ **Better performance**
- ✓ **Guarantee the same level of data integrity as DoubleWrite**

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Experiment Setup

- Fusion-io 320GB MLC NAND-flash based device
- Atomic-Write implemented in a research branch of v2.1 Fusion-io driver
- MySQL 5.1.49 InnoDB (extended with Atomic-Write)
  - 2 machines connected with 1 GigE
  - Both Trans. log and table-file stored on solid state

Processor	Xeon X3210 @ 2.13GHz
DRAM	8GB DDR2 667MHz, 4X2GB
Boot Device	250GB SATA-II 3.0Gb/s
DB Storage Device	Fusion-io ioDrive 320GB PCIe 1.0 4x Lanes
OS	Ubuntu 9.10 , Linux Kernel 2.6.33

Micro Benchmark

- Different Write Mechanisms:
  - ***Synchronous***: write() + fsync()
  - ***Asynchronous***: libaio
  - ***Atomic-Write***
- Different write patterns:
  - Sequential
  - Strided
  - Random
- Buffer strategies
  - Buffered_IO: OS page cache
  - Direct_IO: bypasses OS page cache

I/O Microbenchmark: Latency

Write Latency ***(Lower is Better)***

(64 blocks, 512B each)

		Latency (us)		
Write Pattern	**Buffering**	**Write Strategy**		
		Sync	**Async**	**A-Write**
Random	Buffered	4042	1112	**NA**
	DirectIO	**3542**	**851**	**671**
Strided	Buffered	4006	1146	**NA**
	DirectIO	**3447**	**857**	**669**
Sequential	Buffered	3955	330	**NA**
	DirectIO	**3402**	**898**	**685**

- Atomic-Write : all blocks in one compound write
- Synchronous Write: write ( ) + fsync( )
- Asynchronous Write: Linux libaio

I/O Microbenchmark: Bandwidth

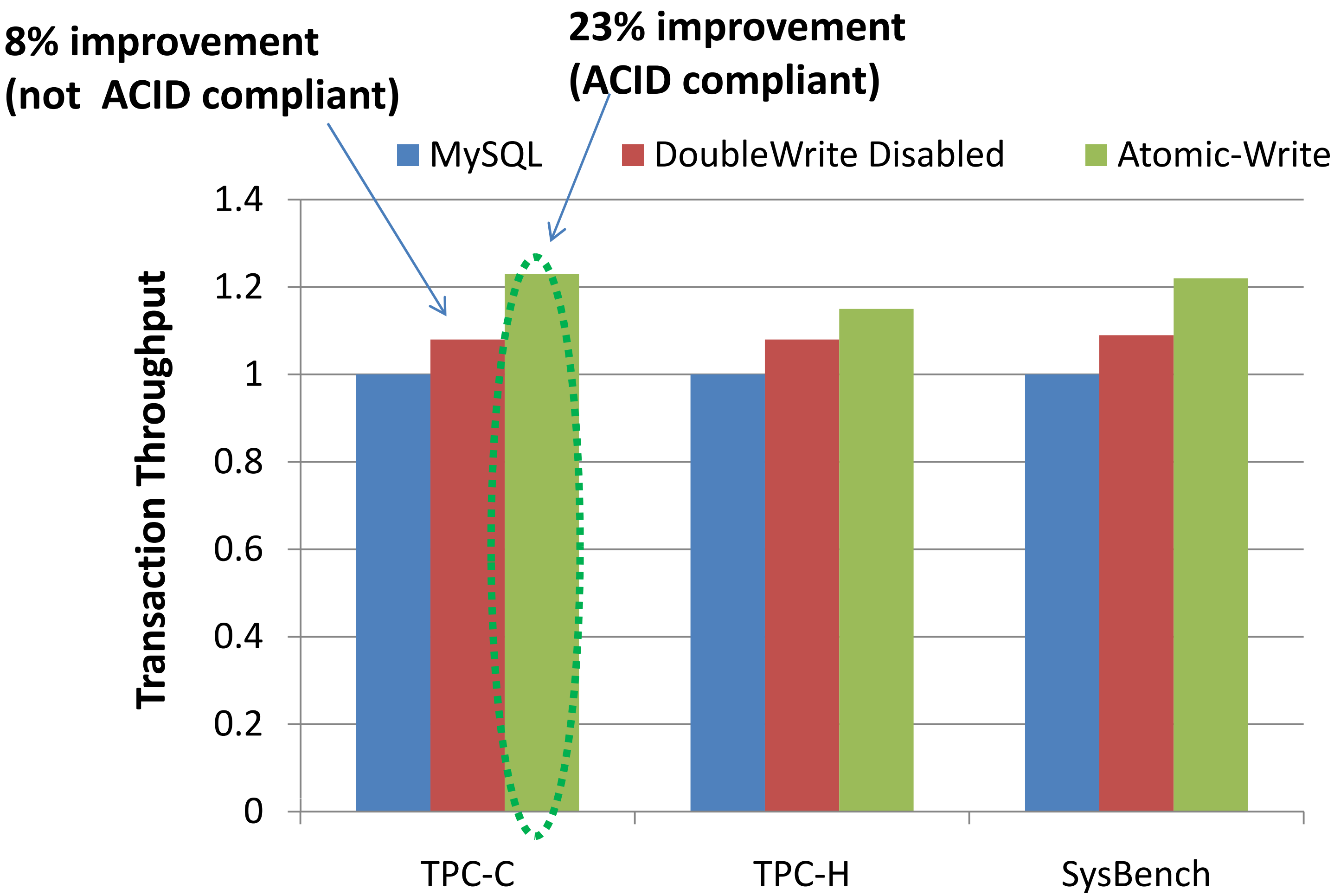
Write Bandwidth ***(Higher is Better)***

(64 blocks, 16KB each)

		Bandwidth (MB/s)		
Write Pattern	**Buffering**	**Write Strategies**		
		Sync	**Async**	**A-Write**
Random	Buffered	302	301	**NA**
	DirectIO	**212**	**505**	**513**
Strided	Buffered	306	300	**NA**
	DirectIO	**217**	**503**	**513**
Sequential	Buffered	308	304	**NA**
	DirectIO	**213**	**507**	**514**

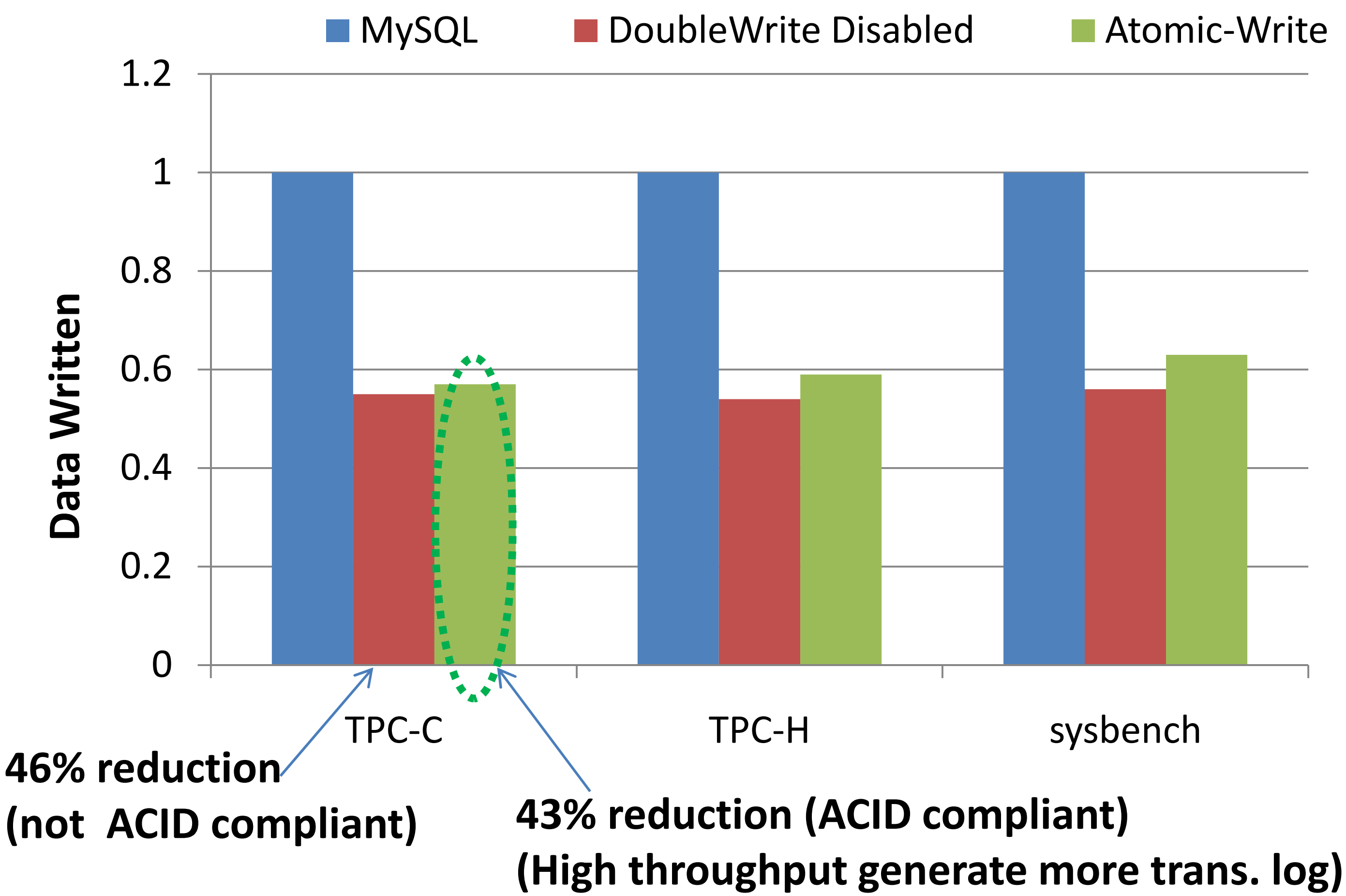
- Atomic-Write : all blocks in one compound write
- Synchronous Write: write ( ) + fsync( )
- Asynchronous Write: Linux libaio

Transaction Throughput



- Buffer Pool : Database = 1 : 10
- DB workload: TPC-C (DBT2) , TPC-H (DBT3) , SysBench

Data Written to SSS



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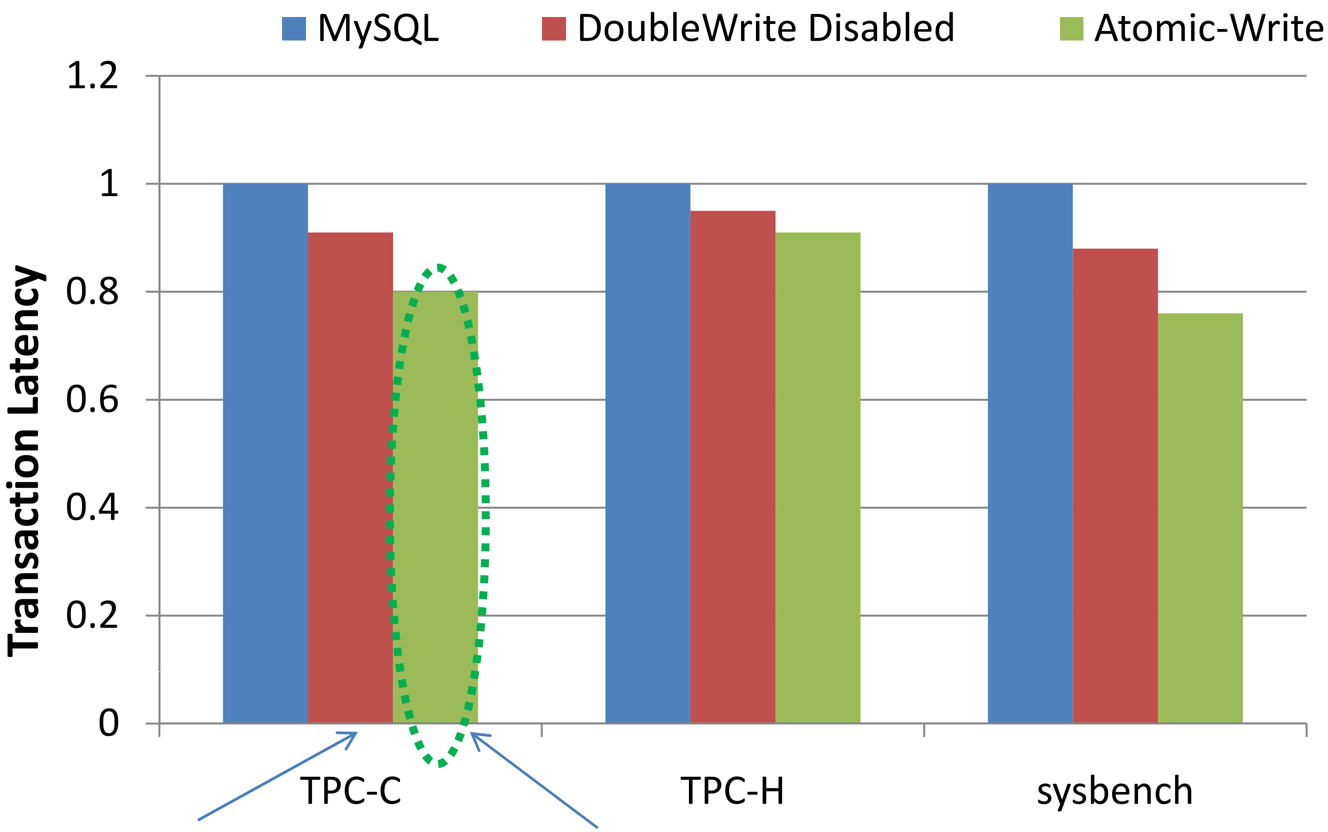
Transaction Latency

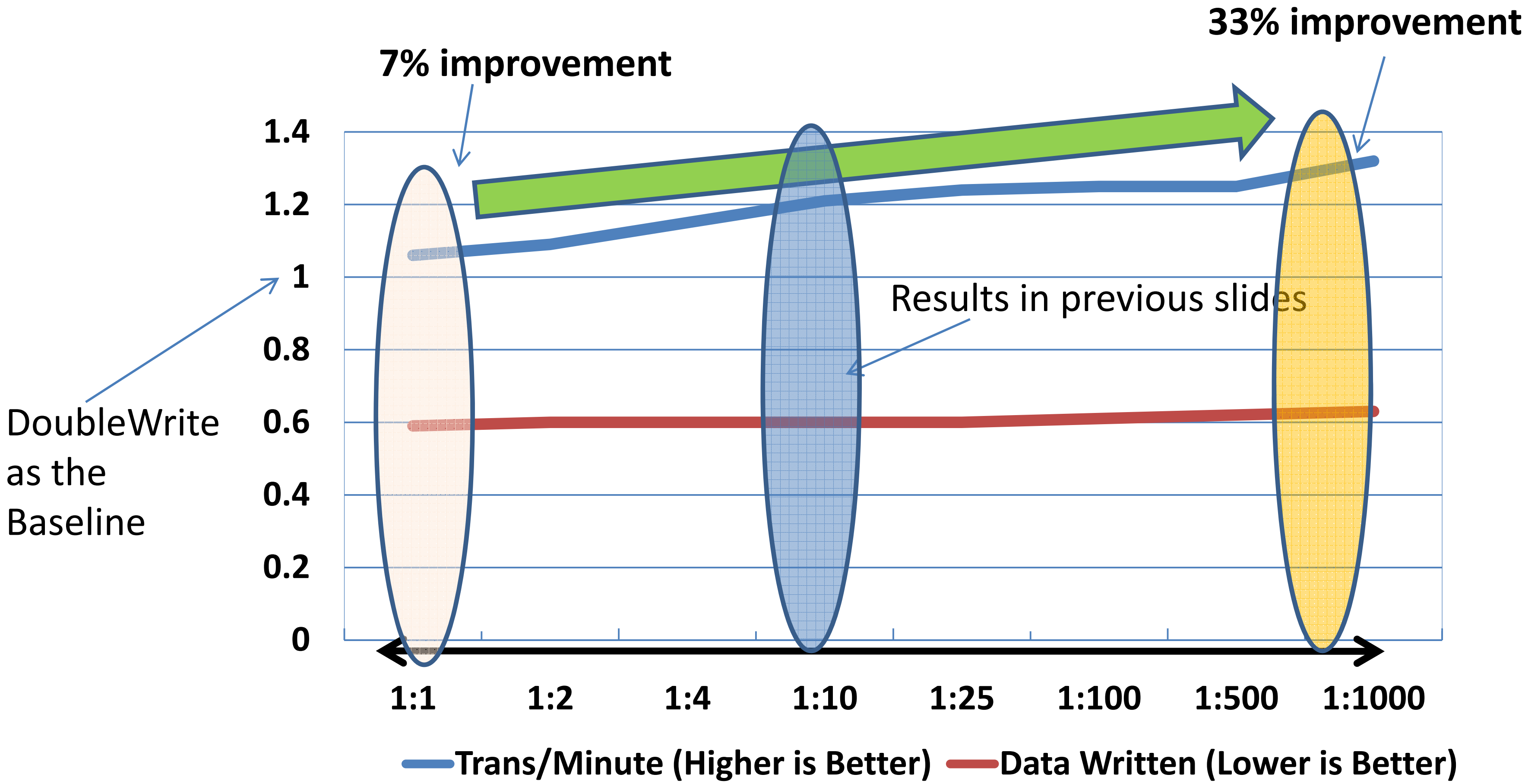


9% improvement (not ACID compliant)

20% improvement (ACID compliant)

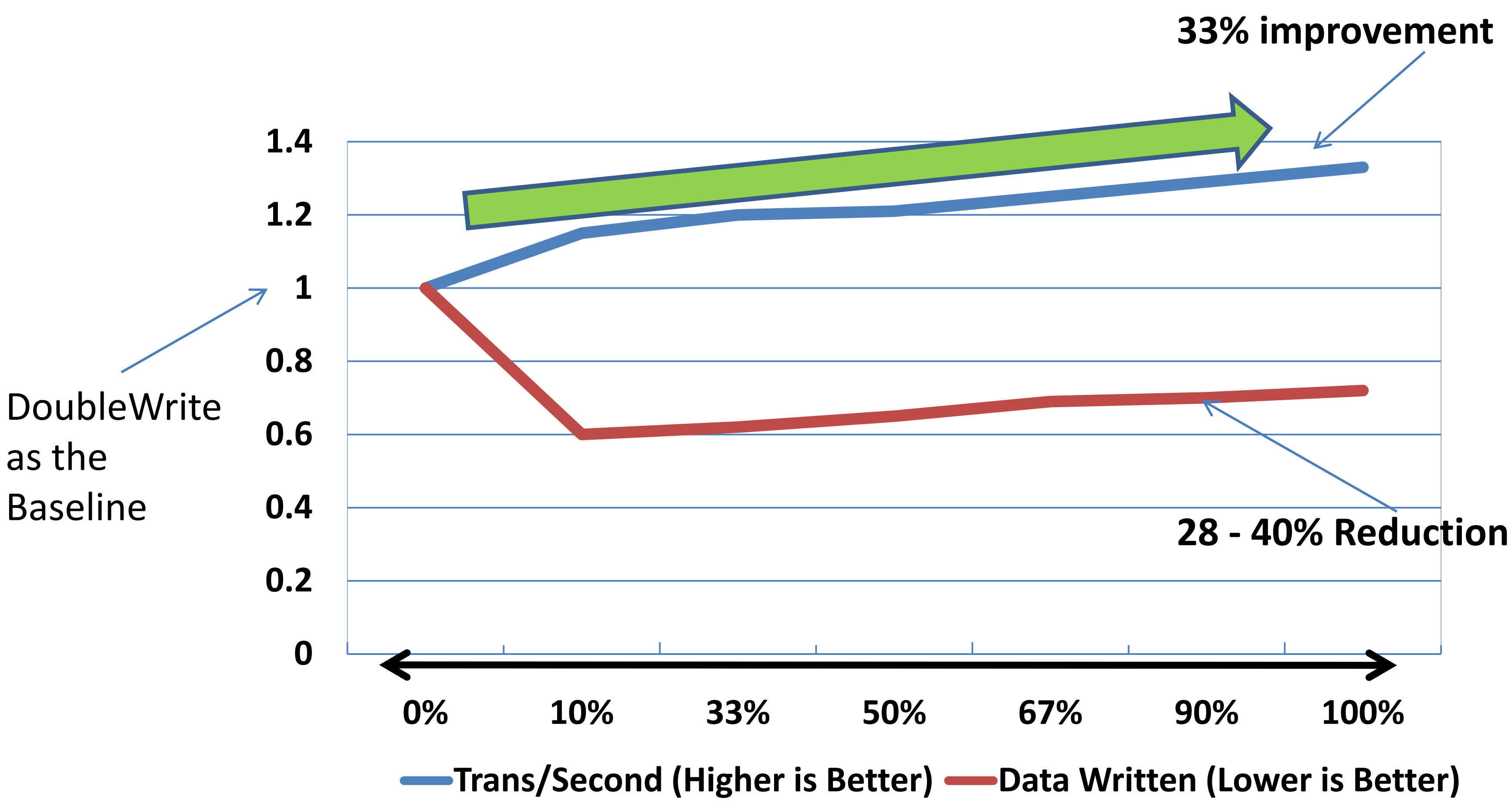
- Buffer Pool : Database = 1 : 10
- DB workload: TPC-C (DBT2) , TPC-H (DBT3) , SysBench

DB-buffer-pool size : DB on-disk size



- DB workload: TPC-C (DBT2)
- Vary Buffer Pool : Database size
- Atomic-Write vs. DoubleWrite

DB Records Update Ratio



- DB workload: SysBench
- Vary Update ratio in total workload
- Atomic-Write vs. DoubleWrite

Conclusions

- Solid State Storage opens opportunities for higher order primitives in storage interfaces

- Atomic-Write: allows multi-block write operations to be completed as an atomic unit

- Benefit upper layers with ACID requirements
  - OS, Filesystem, DBMS, applications
  - Reduced complexity
  - Improved performance
  - Improved device durability

Future Work

- Work with Linux kernel maintainers to integrate atomic-write in a non-proprietary way

- To support multiple outstanding atomic-write groups
  - Full transactional support

- Explore other higher order I/O primitives

Thank You!