SanDisk®

Driving IMC Computing Efficiency with Flash Extended Memory

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June 30, 2015

Forward-Looking Statements

During our meeting today we will make forward-looking statements.

Any statement that refers to expectations, projections or other characterizations of future events or circumstances is a forward-looking statement, including those relating to market growth, products and their capabilities, performance and compatibility, cost savings and other benefits to customers. Information in this presentation may also include or be based upon information from third parties, which reflects their expectations and projections as of the date of issuance.

We undertake no obligation to update these forward-looking statements, which speak only as of the date hereof.

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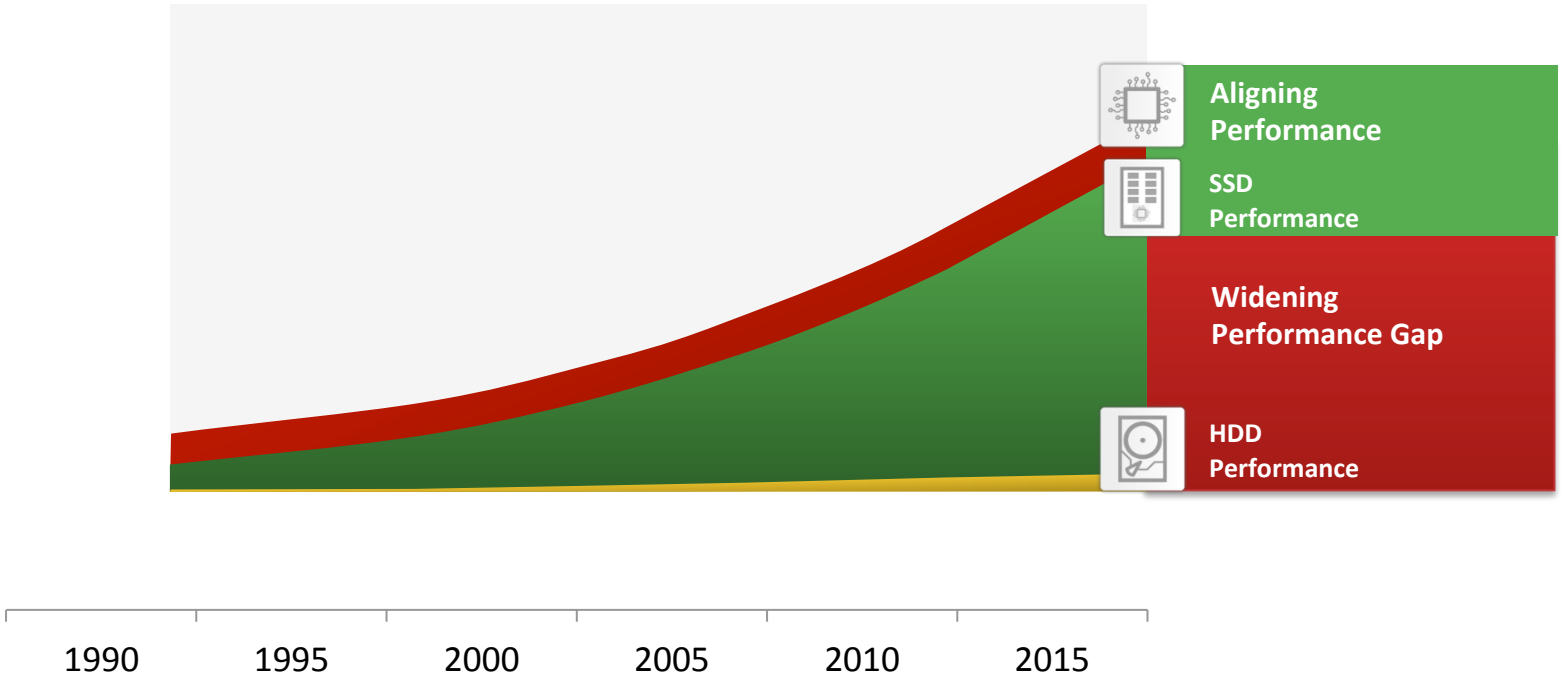
Mega Trend: Legacy Storage I/O Bottleneck

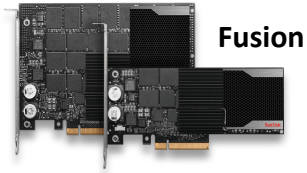


Source: StorageIOblog; Sep 2009; http://storageioblog.com/data-center-io-bottlenecks-performance-issues-and-impacts/

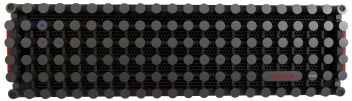
Non-Volatile Memory (NVM)

- Today: NAND Flash
  - Capacity: 100s of GB to 100s of TB per device
  - Trends: Higher capacity, lower cost/GB, lower write cycles, SLC->MLC->3BPC
  - IOPS: 100K to millions, GB/s of bandwidth
- Tomorrow: Non-Volatile Memory technologies (Phase Change Memory, MRAM, STT-RAM, etc.)
  - Potential for orders of magnitude performance improvement

SAS and SATA SSDs



Fusion ioMemory™ PCIe



InfiniFlash™ System

SanDisk ION Accelerator™

Why Do Applications Need Optimization for Flash?

- Many applications assume high latency storage (some even optimize for read/ write head positioning)
- Flash is different from disk
  - Performance, endurance, addressing
  - Getting more different over time
- Flash-focused application acceleration
  - Shifting bottlenecks (Compute to I/O to Network to Application)
  - Managed writes = greater device lifetime (wear leveling, endurance)
  - Improved system efficiency (TCO and TCA)
  - Even lower power and cooling costs

Area	Hard Disk Drives	Flash Devices
Read/Write Performance	Largely symmetrical	Heavily asymmetrical.
Sequential vs Random Performance	100x difference.	<10x difference.
Background ops	Rare	Regular
Wear out	Largely unlimited	Limited writes
IOPS	100s to 1,000s	100Ks to Millions
Latency	10s milli sec	10s-100s micro sec
Addressing	Sequence, Sector	Direct, byte addressable

Becoming "Flash Aware": SanDisk NVMFS

Non-Volatile Memory File System – Optimized for Flash and Beyond

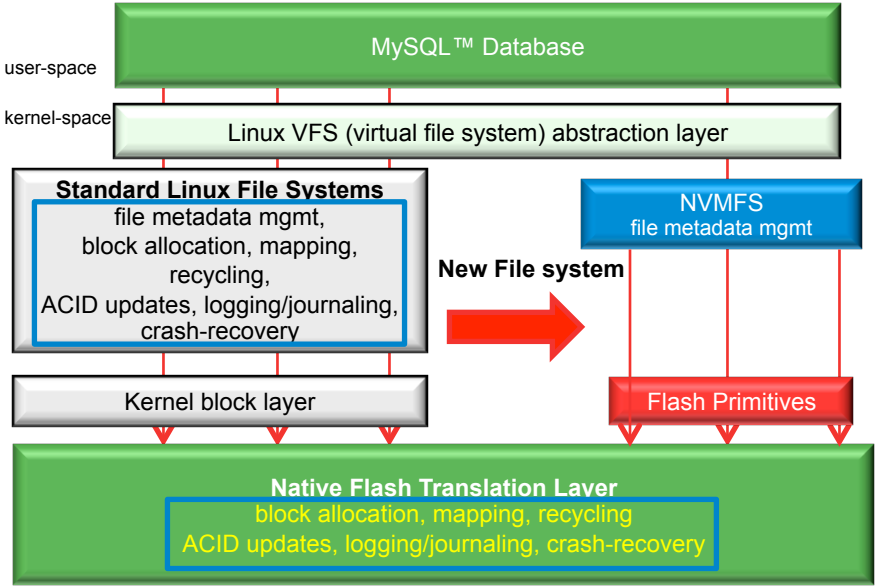
Value

- Increase life expectancy of flash devices
- Consistent low latency
- Consistent high performance

How

- Reducing MySQL™ Writes to flash
- Optimize IO Write path for flash
- Applications leverage enhanced I/O interface

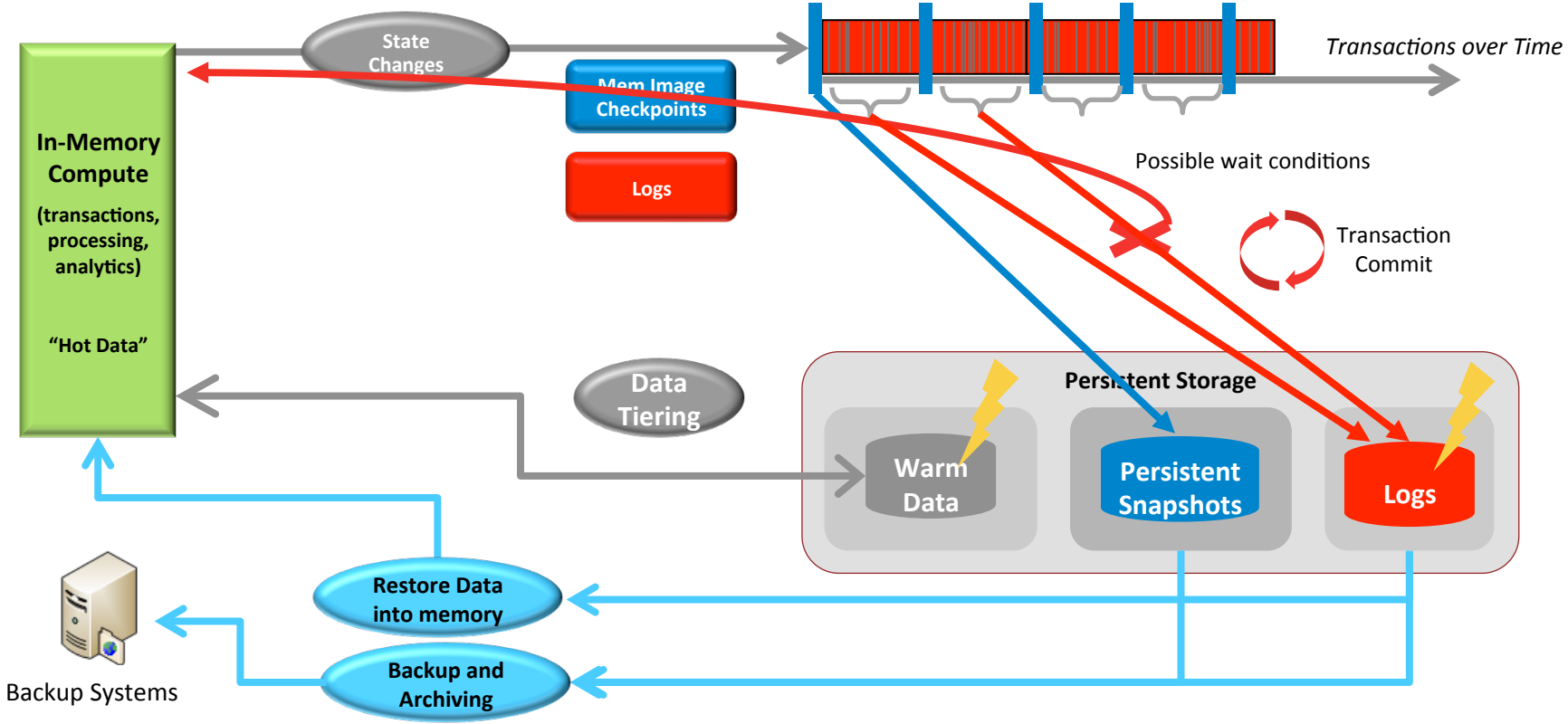
Available today!



Eliminating Duplicate Logic and Leveraging New Primitives for Optimal Flash Performance and Efficiency

In-Memory Database and Persistence

Checkpoints, Logs and Data Tiering, Oh My!



Emergence of Flash Extended Memory

Decoupling of the physical infrastructure (memory) from the management and utilization of that infrastructure through a software interface

Flash Extended Memory

Memory Addressable and I/O Addressable

Storage Device Technologies:

Memory

Persistent Memory

"Flash as Memory"

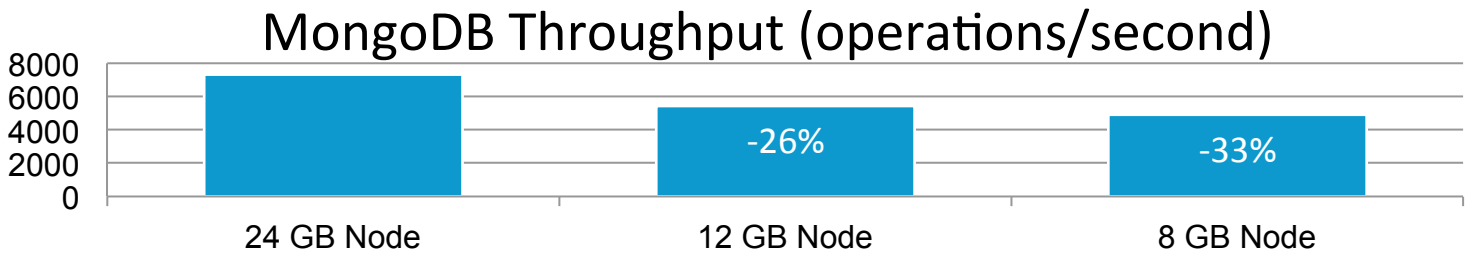
Flash Devices

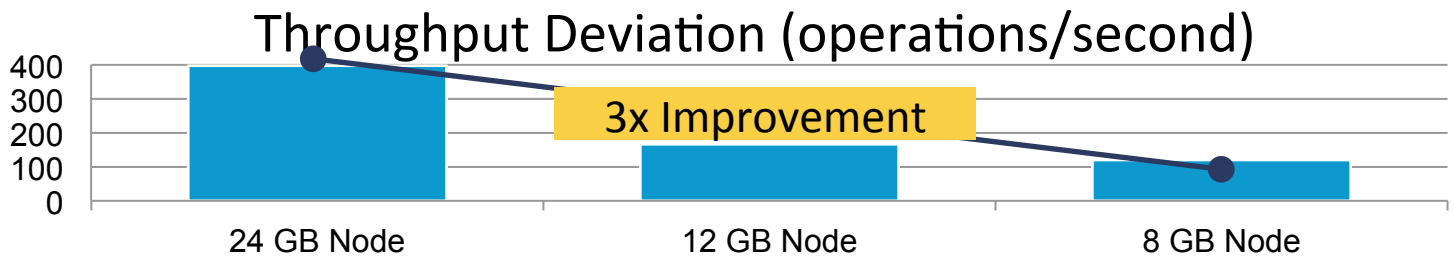
"Flash as Disk"

HDDs

Traditional Block I/O

Flash Extended Memory Example: MongoDB – Lowering TCO through transparent DRAM/Flash tiering



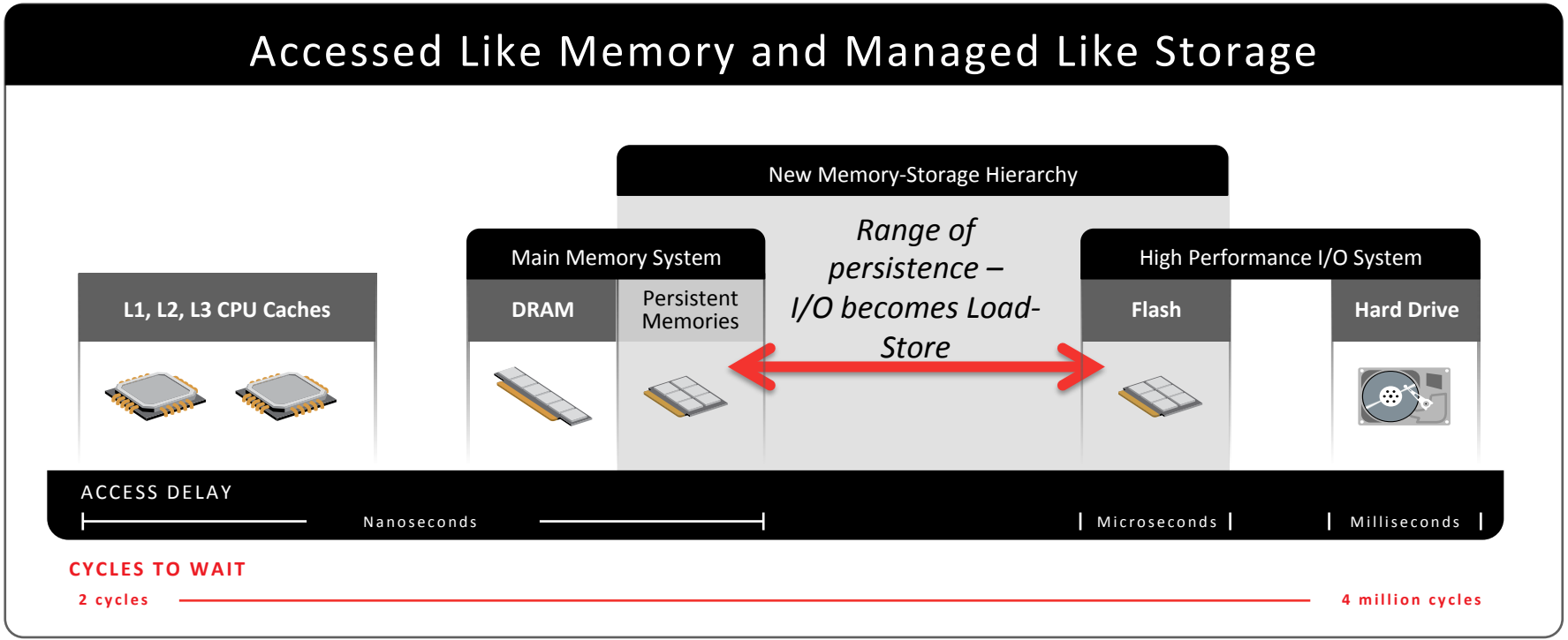


YCSB Workload A

DRAM reductions of 2x and 3x yield 26% and 33% throughput degradations respectively. Throughput predictability actually improves with less DRAM. Latency shows similar trend.

Source: Based on internal testing by SanDisk; Nov 2014

Storage Memory Convergence: Rethinking the Memory Hierarchy

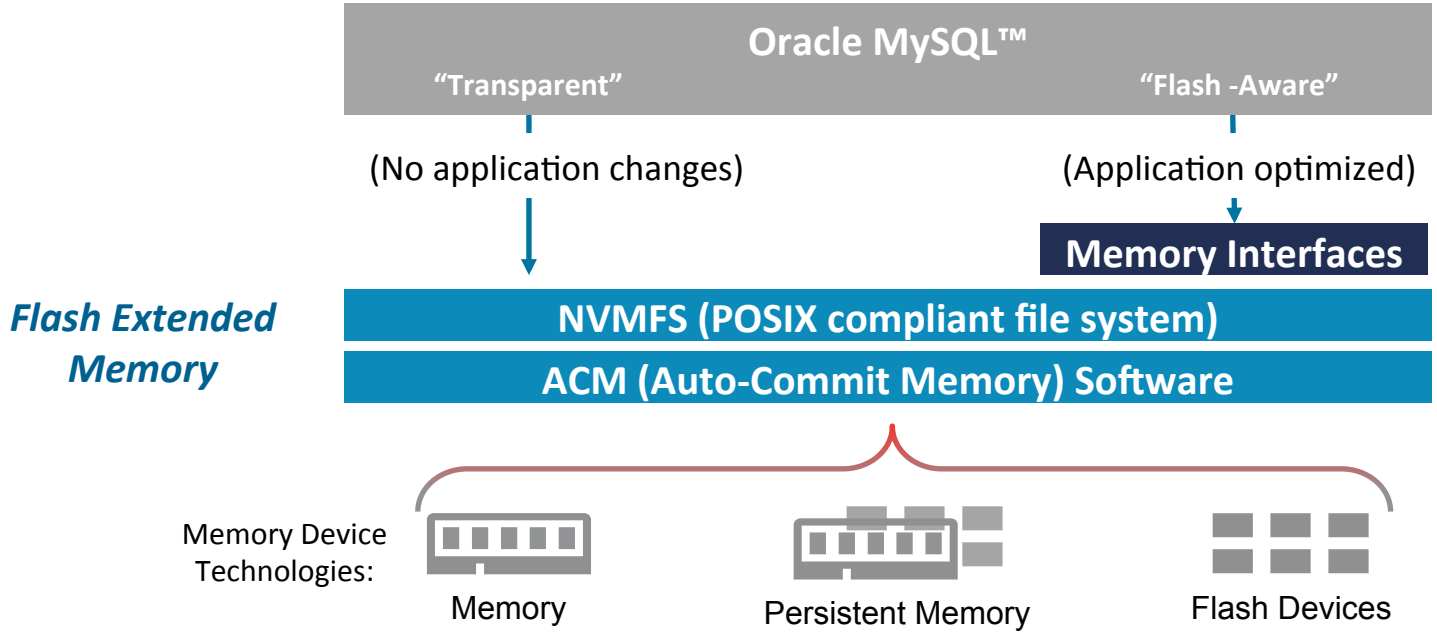


Implications for Applications

- Extremely low latency transaction commits
  - 10-100us reduced to <1us
- Accelerate logs, indexes etc.
- Convergence of in-memory and disk approaches
  - New data structures to optimize directly for memory access
- Rich variety of programming models
  - Traditional I/O will still be available
  - Mmap directly to persistent memory is alternative model: use pointer operations to manipulate persistent data
  - SNIA Non-Volatile Memory Programming TWG – standardize mmap for persistent memory
- New challenges
  - CPU cache management
  - Atomicity?

Technology Preview: Database Acceleration Through Flash Extended Memory

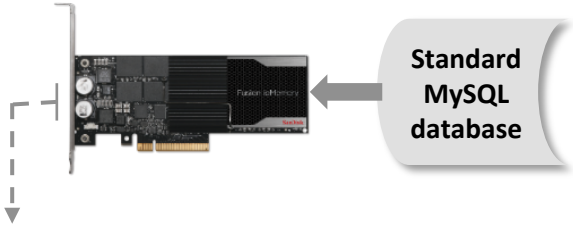
- A “transparent” Software Defined Memory layer can provide accelerated I/O over a “baseline” unaware interface
- But “flash-aware” applications can optimize that acceleration



Technology Preview Example Configuration

"Baseline"

Fusion ioMemory™ PCIe-based flash

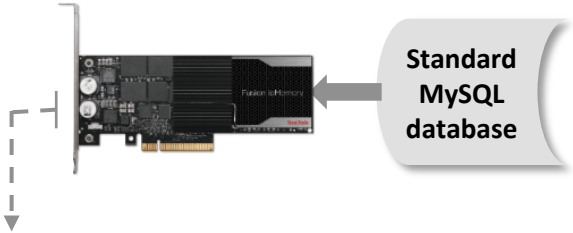


Standard Flash Acceleration

HP ProLiant DL380 Gen8

"Transparent"

Fusion ioMemory™ and persistent memory with NVMFS

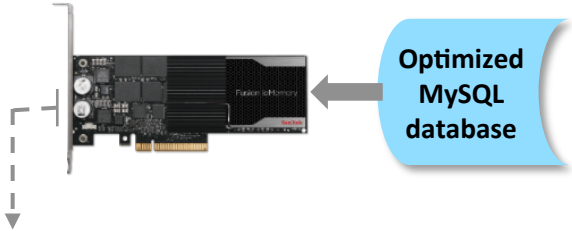


NVMFS and ACM

HP ProLiant DL380 Gen8

"Flash Aware"

Fusion ioMemory™ and persistent memory with NVMFS

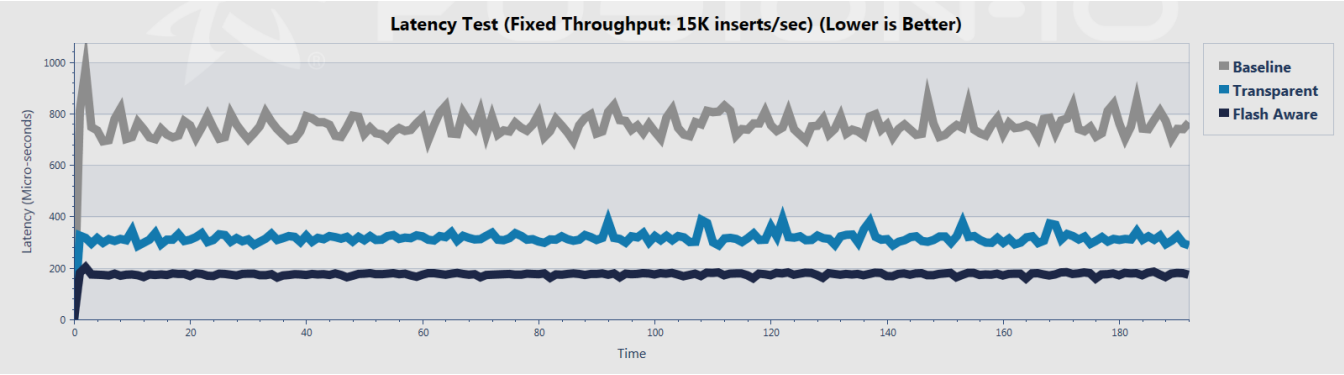


NVMFS and ACM

HP ProLiant DL380 Gen8

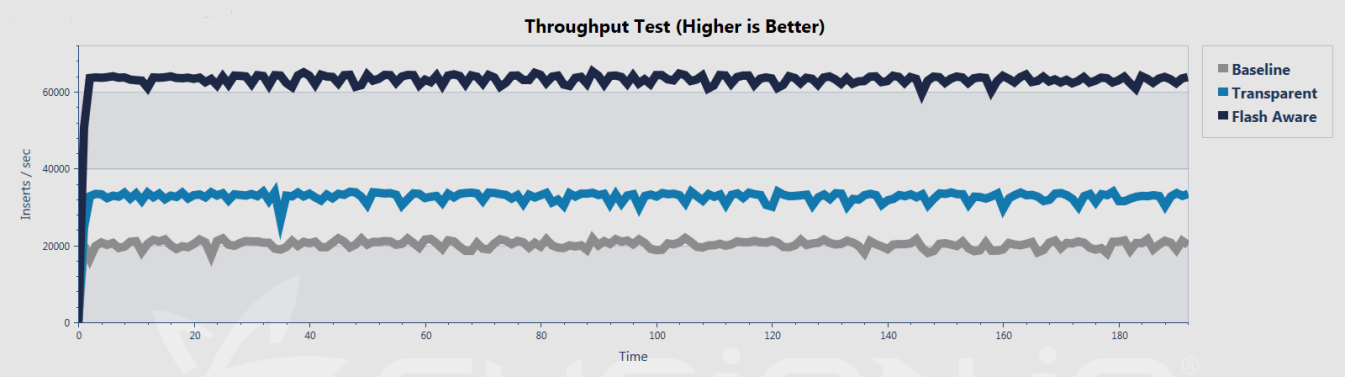
Flash Extended Memory Enabled

Performance Results



Latency (lower is better)

Throughput (higher is better)



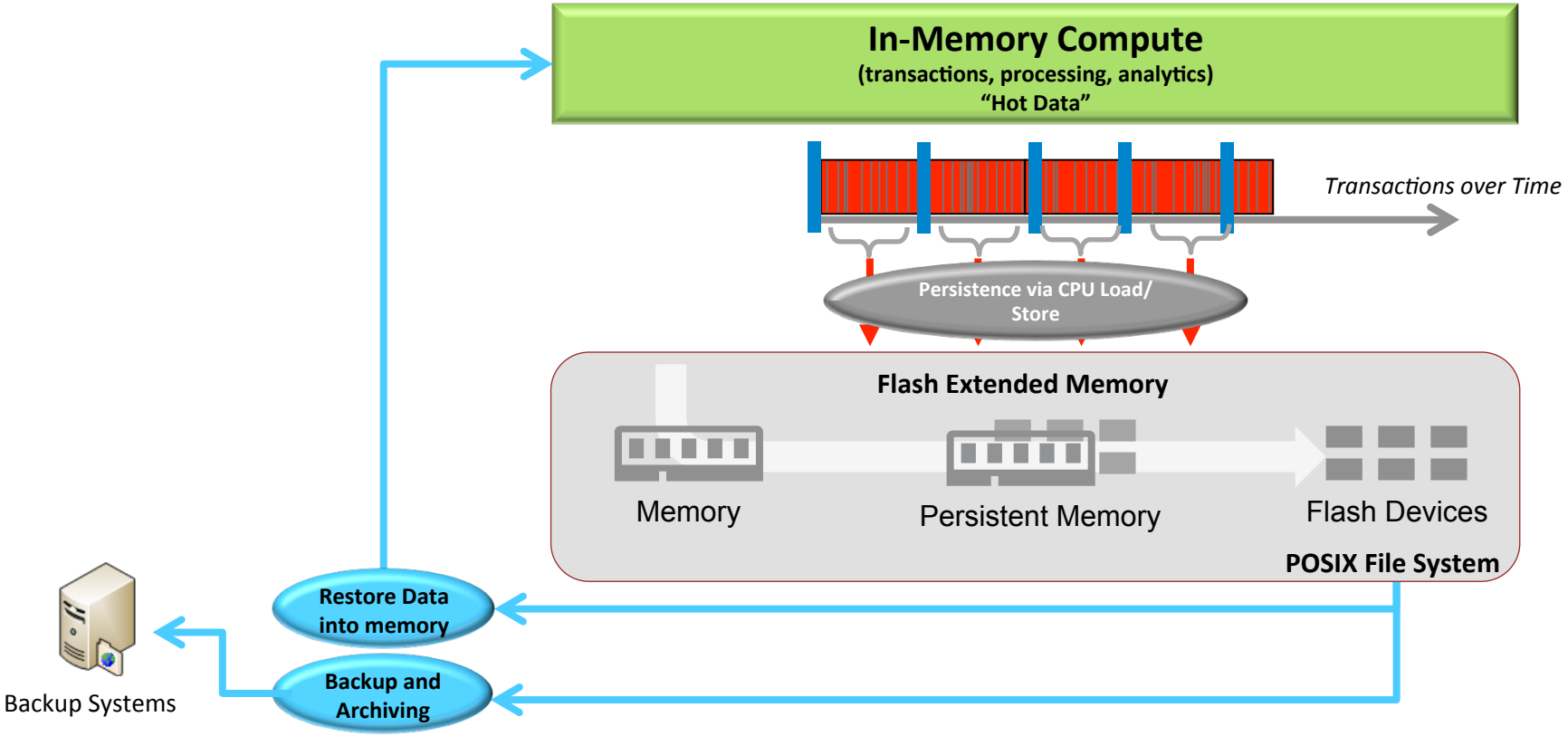
Source: Based on internal testing by SanDisk; Nov 2014

Advantages & Benefits

- Improve "Baseline" MySQL throughput performance by roughly **60%** via "Transparent" acceleration (no software mods)
- Optimize MySQL throughput performance by over **3x** with "Flash Aware" acceleration (modified software)
- Improve "Baseline" MySQL latency by roughly **2.3x** (Transparent) and optimized latency by more than **4x** (Flash Aware)
- Uses "Flash-as-Memory" byte-addressable architecture and interface
- Seamless deployment – add ioMemory and NVMFS/ACM software to Linux
- Increase performance and capacity in flexible configurations

Source: Based on internal testing by SanDisk; Nov 2014

In-Memory Computing – New Approach to I/O



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