A Memory-Efficient Persistent Key-Value Store on eNVM SSDs

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Abstract
Emerging fast byte-addressable non-volatile memory (eNVM) technologies such as ReRAM and 3D Xpoint are projected to offer two orders of magnitude higher performance than flash. However, the existing solid-state drive (SSD) architecture optimizes for flash characteristics and is not adequate to exploit the full potential of eNVMs due to architectural and I/O interface (e.g., PCIe, SATA) limitations. To improve the storage performance and reduce the host main memory requirement for KVS, we propose a novel SSD architecture that extends the semantic of SSD with the KVS features and implements indexing capability inside SSD. It has in-storage processing engine that implements key-value operations such as get, put and delete to efficiently operate on KV datasets. The proposed system introduces a compute channel interface to offload key-value operations down to the SSD that significantly reduces the operating system, file system and other software overhead. This SSD achieves 4.96 Mops/sec get and 3.44 Mops/sec put operations and shows better scalability with increasing number of key-value pairs as compared to flash-based NVMe (flash-NVMe) and DRAM-based NVMe (DRAM-NVMe) devices. With decreasing DRAM size by 75%, its performance decreases gradually, achieving speedup of 3.23x as compared to DRAM-NVMe. This SSD significantly improves performance and reduces memory by exploiting the fine grain parallelism within a controller and keeping data movement local to effectively utilize eNVM bandwidth and eliminating the superfluous data movement between the host and the SSD.

Introduction
• Key-value store is a fundamental building block for many enterprise applications
  – Social Networks
  – Online shopping
  – Inline storage deduplication
• Key-value store
  – Supports simple operations: Get, Put and Delete
  – Preferred over traditional relational DBs for its superior scalability, performance and simplicity
  – Often implemented through an in-memory index structure which points to key-value pairs in storage
  – Popular management solution for large volume of records
• Emerging NVM technologies are very promising
  – Byte-addressable
  – High density
  – Low standby power
  – DRAM-like performance

Challenges
• The existing SSD architecture optimizes for flash characteristics and is not adequate to exploit the full potential of emerging NVM technologies due to architectural and I/O interface (e.g., PCIe, SATA) limitations
• The main memory size imposes a challenging problem in scalability and performance of key-value stores due to relatively slow growth of DRAM capacity as compared to rapidly growing key-value datasets
• Key-value store has random accesses to the storage and the existing memory/storage hierarchy is not adequate for this type of application
  – Cache miss, TLB flush
  – Poor host CPU utilizations
  – Large DRAM usage for caching and metadata management

Results

Conclusion
• Propose a memory-efficient key-value store for next-generation SSDs
• Extended semantic of SSD with key-value store features
• Significantly reduced the host CPU and DRAM usage for key-value data processing
• Demonstrated in a prototype storage system with adequate software and hardware support

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