FlashSoft™ Software from SanDisk®: Accelerating Virtual Infrastructures

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January 16, 2013
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Executive Summary

Higher I/O requirements from Tier 1 mission critical applications and the rapid growth of high density virtualized infrastructures place greater I/O demands on storage than ever before. This increase in I/O requests can make it more difficult to meet SLAs with existing storage in datacenters. As a virtual infrastructure’s virtual machine and application densities rise it is more difficult to keep up with growing I/O request demands. This can force a rise in CAPEX and OPEX spending on servers and storage.

Many IT organizations have invested in solid-state storage technology to help handle this increased I/O demand. Solid state technology has been very helpful in handling the higher I/O request demand both on the host side and the backend storage by relieving the storage subsystem from handling frequently used data, or “hot blocks.” But performance improvements can only go so far without caching engine intelligence to use solid-state storage in the most efficient way. For virtualized infrastructures, handling I/O traffic through solid-state storage not only improves performance and latency but it also allows improved virtual machine density. The full benefits of improved performance and increased density with solid-state storage cannot be realized without some kind of efficient intelligence to manage I/O traffic.

Host side caching engines intelligently utilize Solid State Devices (SSDs) to maximize application performance and virtual machine density. Utilizing SSDs gives business applications high-speed data access to minimize application latency. This goes a long way to keeping SLAs met, especially in virtualized infrastructures.

SanDisk has introduced new technology for an enterprise software caching engine that supports the higher demand of I/O requests from mission critical applications and virtualized infrastructures by using intelligent software to get the most performance out of SSDs. FlashSoft software can deliver higher I/O performance by taking advantage of solid-state storage intelligently. The following sections will discuss the economics, the important critical elements for caching engines and discuss how SanDisk’s FlashSoft meets these requirements for VMware infrastructures.

*Note: In this document, the term Solid State Device (SSD) refers to any solid state storage that has a volume or thick-provisioned VMFS file presented to VMware vSphere as capacity that can be used for cache. Physical SSDs can be attached either host side like a PCIe flash card or externally like a cache appliance.
Economics

Server and desktop virtualization have brought efficiency to many IT operations. However, a common and growing concern in today’s IT departments is server sprawl as virtualized infrastructures grow. Increasing virtual machine density can save CAPEX and OPEX but sustaining performance for SLAs can be a challenge. IT organizations must optimize the virtualized datacenter to control CAPEX and OPEX spending while still meeting operational and business needs and the ever-growing demand for quick data access.

Server and desktop virtualization can create intense storage workloads with a limited number of connections to the storage infrastructure. Servicing the I/O performance requirements of application SLAs is the most frequent issue found in virtualized infrastructures. Caching appliances have entered the market to more efficiently raise virtual machine densities and address storage bottlenecks. However, these appliances can still be expensive, even though solid-state storage prices have declined.

Increased Virtual Machine Density

Virtualization has added complexity to today’s datacenter infrastructures. Even though VMware® vSphere® is a very efficient hypervisor and provides special features and APIs used by storage vendors to address storage performance issues, virtualization complexity can still make it difficult to meet response time requirements because of the added overhead. Intelligent caching engines coupled with SSDs can help reduce latency by intelligently accessing high-speed storage with access times in the microseconds, instead of HDDs with response times in milliseconds. This will shorten the data path for application I/O requests and therefore lower I/O latency.
Critical Elements

There are a number of design elements for caching engines that are critical to handling the frequently used data responsible for the high I/O volumes produced in virtualized environments. Virtualized infrastructures produce highly concentrated workloads, causing higher demands on the backend storage. As a result, the way that I/O requests are handled and managed has to change to meet these demands and keep up with current SLAs.

Types of Caching Engines

Today there are four major types of software intelligent caching engines:

- **Agent in the Guest OS of a Virtual Machine** – To manage the resources needed for each virtual machine, an agent is installed on every virtual machine supported on a physical host. Caching operations happen in the guest OS of a virtual machine. This is not a practical caching approach for virtualized desktops, and agent software must be available for every OS version that can be run in a VM. For VMware vSphere features like vMotion and Storage vMotion, software agents in VMs require extra steps to flush the cache before moving a virtual machine, and centralized management and security can be more of a challenge. While guest-resident caching engines may provide greater granularity of the Guest OS I/O profile, scalability can be a concern, particularly for larger enterprise environments with hundreds or thousands of virtual machines.

- **Virtual Acceleration Appliance** – This software is deployed as a virtual machine appliance in a host with SSD resources, where it determines what data gets cached to a presented SSD virtual volume from all virtual machines residing on the host. The caching operations are transparent to virtual machines and their guest OS, for which there is no agent required. Since there are no guest OS dependencies these appliances usually support most Windows and Linux server versions. However, this caching engine’s performance is limited by the connectivity between the virtual machine appliance and the other virtual machines. Also, it is subject to the same performance issues as any virtual machine.

- **User mode of the hypervisor kernel** - This solution is software that can be used with most host side SSDs, existing or new. This code is at the user level of the hypervisor and is transparent to virtual machines, the hypervisor and the backend storage. This software works above the file level, so it does not operate at the VMFS level and cannot be used with file-based caching appliances or NFS data stores. This software is usually managed through the hypervisor’s system management console (i.e. vCenter for VMware vSphere).

- **Kernel mode of the hypervisor kernel** - This software also can be used with most SSDs. It can be managed through a hypervisor system management console and is transparent to virtual machines, the hypervisor and backend storage as well. Implementing the software to work
below the file system within the kernel of the hypervisor gives more flexibility in supporting new and evolving hypervisor features. Operating below the file system level enables the software to work with networked file-based caching appliances and NFS datastores, and provides granularity at the VMDK level, so administrators can precisely target virtual disk volumes and workloads for acceleration. This hypervisor-resident caching engine integrated directly in the I/O path is becoming highly desirable.

Each of these caching engine approaches used appropriately, offers higher performance and virtual machine density. The engines working at the kernel level can offer more transparency to the hypervisor for advanced features, such as VMware’s Storage vMotion and Storage DRS.

**Caching on Flash Memory vs. DRAM**

Caching read operations to very fast memory (dynamic RAM) that is persistent (protected from power loss) is a common caching technique for increasing database and application responsiveness. Caching techniques can also be implemented on solid state flash technology to address storage I/O latency. However, there are a few different architectural points in using dynamic RAM vs. solid state devices:

- Intelligently deciding what data to keep in cache and for how long are architecture-dependent design considerations. A cache based on DRAM is typically designed for a specific database or application, while a storage cache is designed for the storage driver stack and storage volumes of the operating system.
- Buffer cache designs for dynamic RAM efficiently handle metadata management, garbage collection, etc., at moderate volumes. However, in a buffer cache these operations are easily overwhelmed when the capacity is much larger (TBs), which is commonly found with SSDs. This means that caching engines for SSDs require a different architecture to manage capacities that are orders of magnitudes larger than the traditional buffer cache designs for dynamic RAM.
- When handling mixed workloads the cache should maintain write data for access as read cache for a dynamic period of time in addition to supporting protected writes. Some applications reference data immediately after writing and require a cache that can accommodate rapid access without sacrificing high reference count read operations as well. Caching engines using SSDs must be able to use solid state storage as a read cache in conjunction with protected writes.

**Higher Performance and Lower Response Time**

Solid-state storage has microsecond response time, which is an order of magnitude faster than rotating media with response times in the milliseconds. Additionally, when used as a cache, solid-state storage can be implemented in the compute environment, avoiding external latency that might increase I/O request response times. Simply throwing solid-state storage hardware at a performance problem does
not always remove storage performance bottlenecks. It is not enough to install SSDs to gain optimal additional performance. Solid-state technology needs to be accessed and managed intelligently in order to truly maximize performance. The efficient use of SSDs through intelligent software, with no need for a guest OS agent, and sitting below the file system for a high level of transparency improves performance and scalability for virtual machines and their applications, while supporting essential hypervisor features and preserving compatibility with servers and storage systems.

**Increased Density and Scalability**

Server and desktop consolidation through the use of virtualization technology is a key priority for IT organizations seeking to lower their datacenter footprint and to save CAPEX and OPEX. Virtual machine density, the number of virtual machines per physical server, is a common metric used by IT departments today to measure their effectiveness of density and scalability. This metric is also used as a rule of thumb when planning for a new or growing virtual infrastructure.

IT administrators are always looking at new ways to increase virtual machine densities, whether by buying a bigger or faster physical server or detailed capacity planning on virtual machine placement. Additionally, other techniques, like better systems management or resource over-subscription, have also been used. In addition, some have found that adding solid-state storage may be beneficial to increase virtual machine density at a lower cost. This may help in adding a few more virtual machines, but to triple or quadruple the number of virtual machines; intelligent use of solid state storage through a caching engine is required to achieve much higher density and scalability.

**Other Critical Elements**

- **Transparency** - Installation should be lightweight and quick to deploy. In addition, the installation should be transparent to business applications, virtual machines, the hypervisor and any backend storage. Caching engines should be able to not only accelerate performance and increase virtual machine density but they should optimize traffic going to any backend storage.
- **SSD support** - Support for all major host side solid state storage devices is important and existing solid-state storage can be utilized. It is an added benefit if external caching appliances can also be utilized.
- **Multi-Platform Independence** – Caching engines that have support for multiple hypervisors and native physical operating systems make using these engines more flexible in mixed datacenters.
- **Cluster Support** – In this case, a cluster is two or more ESXi servers on two or more physical servers that share a set of resources (or resource pool), like storage. Clustering also centralizes management and enables VMware vSphere features like HA, DRS and vMotion. Since the average virtualized enterprise environment is clustered, having cluster support is critical to accelerate performance and scalability within the cluster.
• **Minimal Server Resources Used** – Minimizing server resource overhead is a key contributing factor for the scalability of the caching engine. This ensures that valuable server resource cycles are not used to manage caching, but are instead available for virtual machine and mission critical application performance.

**The FlashSoft Software Solution**

**How does FlashSoft work?**

The FlashSoft caching engine is intelligent software that operates at the kernel level and installs as a file level filter within the VMware vSphere kernel, below the file system. FlashSoft identifies the I/O belonging to an accelerated virtual storage device, without any disruption to the original handle information for VMFS or NFS datastores. FlashSoft algorithms further identify the I/O belonging to “hot data” blocks, to service those I/O requests from the SSD.

FlashSoft uses a minimal amount of system resources to operate. It uses <3% CPU utilization, has a 140MB main memory footprint, and the metadata cache dynamically grows and shrinks as needed. A circular buffer with a variable block size is used to minimize the amount of metadata needed. This, in turn, reduces data fragmentation and has no need for garbage collection. FlashSoft helps manage wear leveling which helps extend the life of SSDs, and will track, monitor and predict end of life for SSDs used.

FlashSoft works transparently to the backend storage, the hypervisor, the virtual machine, and their business applications. With VMware vSphere 5.x, the software does not modify the VM kernel and works transparently with existing SSDs and back end storage with no firmware modifications.

**How FlashSoft Handles I/O**

FlashSoft works with persistent SSD media to make sure reads and writes are protected in case of power loss or failure. The software is designed to deliver I/O acceleration with the assurance of data integrity.

Caching software like FlashSoft, uses algorithms to identify frequently used data (“hot blocks”) and places and manages that data on a high-performance SSD. Most real world application workloads have on average <3-5% of their dataset considered as hot blocks. Virtualized infrastructures handling multiple applications have a higher average at <10%. Though it is rare, there are a few extreme cases where as much as 40% of the dataset is considered frequently used data. Each I/O is handled appropriately depending on the write mode and the type of read. Reads that get cached (read hits) are managed and handled with FlashSoft and are directly sent to and from SSDs.
FlashSoft currently does not support write-back for VMware. It does currently support write-through mode, where writes are simultaneously being written to the cache and back end storage. This can optimize writes to the back end storage.

**FlashSoft Software for vSphere Advantages**

**Multi-Level Metadata Management**

Multi-Level Metadata Management is a patented feature by SanDisk to manage the large amounts of metadata required by large terabyte-scale solid-state cache. Traditional methods of maintaining metadata in main memory can create a sizable footprint in memory, taking resources from virtual machines and business applications. Multi-Level Metadata Management writes all metadata pages to persistent solid state storage and swaps the currently required metadata pages into a “metadata cache” in main memory. This ensures a small metadata footprint in main memory, only 140MB, regardless of the size of the cache or the number of virtual machines supported. The FlashSoft caching engine uses a circular buffer cache design that supports blocks of variable size, and it coalesces operations to optimize performance. In this case cache coherency is important and FlashSoft has a lightweight metadata model to ensure no metadata is lost or overwritten before a metadata page is transferred to persistent solid state storage. This type of high performance design is what allows for hundreds of virtual machines to be supported on a single host.

The availability of the metadata in the persistent solid state storage also enables recovery of the cache in milliseconds upon a restart of the server, hypervisor or individual VM. FlashSoft uses metadata snapshots in times of recovery. In a needed recovery the most recent metadata snapshot in cache is read first, then reads subsequent transactions and completes the recovery in milliseconds. In addition for VMware vSphere clusters these metadata snapshots also help to ensure cache coherency across clustered caches.

**VMware vSphere Cluster Support**

FlashSoft is architected to support VMware vSphere clustering. An accelerated ESXi server can be clustered with a non-accelerated ESXi server, as in the case of a HA only configuration. Common clustering features, like VMware vSphere’s DRS, Storage DRS, vMotion and Storage vMotion, are supported.

**SSD Support and Performance**

Even though FlashSoft has been developed by SanDisk, this software supports all the major host side SSD vendors including LSI, Intel, STEC, Virident, Fusion-io, OCZ, Samsung and their own enterprise SanDisk SSDs. Host side SSDs give caching engines, like FlashSoft, a shorter application I/O path to the storage as shown in Figure 1 earlier. This offers lower latency, higher performance and higher virtual
machine density than external SAN or networked solutions. In VMware vSphere virtual infrastructures storage has been the limiting factor in the performance of the infrastructure. With lower latencies, more application transactions can complete, more work can get done, and resources like CPU and memory that would otherwise be idle can be more fully utilized. Removing storage bottlenecks in virtual infrastructures will not only increase the performance of that infrastructure but will also allow for increased virtual machine density.

Caching Engines Shorten the Data Path and Increase Performance

![Caching Engines Shorten the Data Path and Increase Performance](image)

The data path in a virtual infrastructure, from the application in a guest OS in a virtual machine to the backend storage, has many opportunities to increase latency and decrease performance, especially for frequently used data. Shortening the data path for an I/O request will lower I/O latency for a business application, and directing the I/O to high-speed storage, such as solid-state storage, can greatly lower the risk of violating response time requirements.

For performance purposes, the default parameters are optimal for most use cases. If needed, SanDisk support professionals can tune the caching engine parameters for special storage and SSD requirements, and/or specific application I/O performance requirements.
FlashSoft Installation and Management for VMware vSphere

FlashSoft can be installed on individual vSphere hosts, in a VMware vSphere Cluster, or in a VDI infrastructure for acceleration and/or increased virtual machine density. The amount of resources used by the caching engine (CPU and memory) does not increase with the number of virtual machines, and acceleration is implemented at a per-VMDK granularity. All accelerated VMDKs dynamically share the solid-state cache with no explicit SSD allocation. If multiple SSDs are being used, it is recommended that a native vSphere 5.x LVM be used to combine the devices into a one logical solid-state device. An important feature of FlashSoft is it accelerates both SAN and NAS datastores.

FlashSoft is administered via a vCenter plug-in to navigate and control the software, for example to select specific extents for acceleration. Updates are transparent to the cluster and can be performed on a per-server basis without requiring a cluster reboot. FlashSoft does not have to be installed on all servers in a cluster, only on those servers that require help with I/O latencies. Additionally, FlashSoft works transparently with VMware vSphere features such as HA, vMotion, Storage vMotion, snapshots, etc. Snapshots and clones are accelerated individually and no caching redundancy occurs when multiple clones are shared by the same base VMDK. For VDI, keeping a gold master in SSD during a boot storm will greatly accelerate the handling of many users attempting to log into their virtual machines at the same time.

Performance and Density

Tier 1 Application Performance

For OLTP applications on database engines like Oracle, DB2, or MySQL, SanDisk is seeing anywhere from 3x to 5x performance gains after introducing FlashSoft software and SSDs to the configuration. In addition there was a 6x increase in SQL batch requests per second. Performance test details are in the report titled “FlashSoft™ for VMware® vSphere® Application Performance Test.” For other I/O intensive applications related to analytics, business intelligence (BI) or other user custom I/O intensive applications there can be even higher performance gains.
Virtual Machine Density

The ability to increase virtual machine density is a good way to help keep down CAPEX and OPEX spending and cut down on physical server sprawl in virtual infrastructures without having to purchase larger servers. Meeting the highly active to extreme I/O demands of virtual infrastructures storage performance is key to the success of satisfying SLAs. The ability to handle much higher I/O workloads provides an opportunity to fully utilize other resources (CPU, memory and network) that may be underutilized due to storage bottlenecks. FlashSoft software with SSDs has demonstrated a >3x higher virtual Machine density than using traditional hard disk drive (HDD) only solutions. The test environment described below used a mixed virtual infrastructure workload of web, mail, application, database and infrastructure server applications and equaled one tile, similar to what you see with SPECvirt.

Figure 3 – Increased commercial ordering system by 4x
Summary

SanDisk has chosen a good direction with the FlashSoft architecture by choosing to operate at the kernel level under the file system, ensuring flexibility. Their choice to not put an agent in the guest operating system has made it easier and more efficient to work in a VMware vSphere cluster with the advanced vSphere features. Upon installation FlashSoft does not plug-in to the hypervisor and has no need for it’s own management server or an additional management console outside of working integrated with VMware vCenter. SanDisk designed FlashSoft with data coherency as a top priority.

Caching engines can help improve performance and scalability by reducing I/O latency. Since I/O performance and latency is the number one concern in virtualized infrastructures, caching engines like FlashSoft software can relieve those common I/O bottlenecks that are often found in virtual computing environments. Handling I/O more efficiently allows applications to get greater utilization out of other system resources, like CPU, memory and network without being gated by the amount of I/O that can be processed. This helps increase application performance and virtual machine density. A virtualized infrastructure is only going to perform as fast as its slowest component. FlashSoft alleviates a virtual infrastructure’s I/O subsystem from being the slowest part of the infrastructure. For many organizations, this level of increased performance may be sufficient to migrate business-critical applications to virtual computing environments.
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