SOFTWARE-DEFINED STORAGE DONE RIGHT

How to Succeed with a Software-Defined Storage Strategy

"SDS abstracts storage software from the underlying hardware, and to provide a common management platform and data services across an IT infrastructure composed of heterogeneous or homogeneous enterprise storage assets."
According to Gartner, by 2024 fully half of global storage capacity will be deployed as SDS[1]

Software-defined storage (SDS)–the use of software to virtualize data storage for consumers,[2] while abstracting them from the underlying hardware–has taken the enterprise IT community by storm. Growing numbers of organizations are implementing, planning for, or predicating their long-term IT strategies on replacing purpose-built storage systems with "commodity" hardware, using software to create and present virtual *storage resources*[3] to their application servers. Conventional wisdom holds that SDS has three advantages over purpose-built storage systems:

COST SAVINGS

SDS deployments can be built using "commodity" storage servers and devices at significantly lower acquisition cost than purpose-built systems

FLEXIBILITY AND SCALE

With SDS, storage capacity can expand without limit, at minimal expense and operational upheaval. In an ideal SDS deployment, storage services mimic the cloud model, with IT consumers provisioning their own storage resources from an organization-wide equipment pool, minimizing the need for costly vendor consulting services

VENDOR INDEPENDENCE

In principle, SDS deployments can consist of hardware from multiple vendors, allowing organizations to exploit cost savings, expedited delivery, and base technology innovations as they occur.

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1 "The Future of Software-Defined Storage in Data Center, Edge and Hybrid Cloud," Gartner, ID: G00354830, © 2019 https://www.commvault.com/resources/what-you-need-to-know-about-software-defined-storage-sds

2 This brief refers to individuals who administer applications that use IT services as *consumers*.

3 In this brief, the term *storage resources* refers collectively to virtualized block volumes, file systems, and object stores, as distinguished from the physical equipment and software that comprise them.

THE REST OF THE SOFTWARE-DEFINED STORAGE STORY

An SDS deployment has three essential elements:

- **Storage**, typically "commodity" hardware–generic servers containing SSDs
- A robust **network** that connects storage servers to applications
- **Software** that integrates hardware and network into an infrastructure that provides accessibility, failure tolerance, virtualization, and configuration management

Each of these poses challenges, both to the architects who define the SDS strategy and to the IT team that manages it on an on-going basis. Pure Storage products eliminate many of these challenges, smoothing the adoption path, as the following subsections describe.

HARDWARE CHALLENGES

A typical SDS architecture defines one (or a few) storage hardware configurations, often called *pods*, that can be easily integrated into an existing infrastructure. Software creates virtual storage resources (e.g., block volumes) from pod hardware and allocates them to consumers. While the prospect of lower hardware acquisition cost makes SDS attractive, other hardware-related factors also contribute to cost:

CONFIGURATION MANAGEMENT

All IT equipment, but especially storage, is characterized by 3 to 5 year product lifetimes. Deploying SDS necessarily includes managing hardware lifecycles, vendor supplies, and maintenance. Most troublesome of all are the "forklift upgrades" and data migration from hardware that's being retired to its replacements. They interrupt service to users, consume equipment and human resources, and are often plagued by operational errors.

Pure greatly reduces hardware management concerns. Evergreen™ Gold service agreements include periodic technology refresh. Coupled with the products' non-disruptive upgrade capability, they eliminate upgrade-caused data migrations. FlatAndFair service pricing protects against "surprises" in maintenance costs. And FlashForever lifetime device guarantees eliminate concerns over flash device reliability and endurance.

COMPONENT COMPATIBILITY

SDS pods are typically defined by component capabilities–device bays, network ports, amount of DRAM, storage server processing power, SSD capacities and speeds, and so forth. Pod configurations may result in artificial configuration constraints, especially where multiple vendors are involved. For example, server limitations might preclude use of the largest SSDs or fastest network interfaces and most modern protocols. Configuration constraints like these often result in greatly overprovisioning storage resources to meet the needs of demanding applications (or, to chronically underserve them).

Pure's systems are engineered with carefully matched storage, processing, and network components. For example, the FlashArray line includes both capacity-optimized FlashArray//C and performance-optimized FlashArray//X and //XL systems with wide ranges of physical capacity that eliminate overprovisioning for I/O-intensive applications.
As Direct Flash Module (DFM) capacities grow, as processors become more powerful, and as network speeds increase, Pure does the engineering to ensure that systems that utilize new component technologies fully exploit them.

UTILIZATION

Hardware cost is based on physical capacity, but the storage resources made available to users must be protected against faults while delivering adequate performance, which can influence cost. For example, an SDS architecture that only supports mirroring nearly doubles (or triples, for two-fault protection) the cost of the capacity presented to consumers.

Overprovisioning–"hidden" flash that conventional SSDs use to manage data internally and to extend endurance–puts them at an inherent disadvantage relative to directly addressable flash modules. As much as 15% of the flash in a conventional SSD must be paid for, packaged, and powered, but is not part of the capacity available for consumers.

At up to 48TB each, the Direct Flash Modules (DFMs) used in FlashArray and FlashBlade systems offer the highest storage density available. Pure's RAID-based architecture provides two-fault protection in each of a FlashArray's write groups (10 or 20 DFMs) at 12%-25% overhead (vs. 100% or 200% for mirroring. For many types of data, the systems' built-in deduplication and compression store more data in less physical flash.

ENVIRONMENT

The hardware in an SDS deployment has a decisive effect on operating cost. Physical storage density determines both "real estate" (e.g., number of equipment racks) and power and cooling cost, but the relevant metrics for SDS are the cost of capacity delivered to users, some of whom require massive capacity; others of whom prioritize high performance. Usable TB per watt and per cubic meter of data center space have a strong effect on the hardware component of SDS operating costs.

DFMs' high physical storage density coupled with efficient flash-specific RAID data protection and data reduction mean more usable terabytes per rack and per watt then solutions built on commodity servers and SSDs.
Pure Storage has over a decade of experience in making flash enterprise-capable and was the first to overcome the issues inherent in low-cost QLC flash. Today, the Pure product line includes QLC-based systems optimized for high capacity as well as TLC-based ones that deliver the highest performance.

NETWORK CHALLENGES

An ideal SDS deployment operates as a kind of "in-house cloud," with storage consumers acquiring virtual resources on demand from a common hardware pool. This mode of operation needs a storage network capable of connecting physical storage to application servers flexibly, securely, and with the required performance and reliability. In a deployment with dozens of storage servers, thousands of SSDs, and constantly changing consumer demands, keeping consumers connected to their storage resources is a challenge.

With the Pure Fusion distributed control plane, hosts use virtual network addresses to communicate with their storage resources. This allows fleet administrators to easily add to and redeploy an infrastructure's hardware and to relocate consumers' virtual storage resources transparently while they are in use.

SOFTWARE CHALLENGES

Software is the most complex element of SDS, with challenges on multiple levels:

SCALE

All hardware has limits–SSD capacity, server device bays, processor cores, DRAM, and so forth. SDS deployments typically scale beyond the capacity of a single pod by using software to *federate* (loosely integrate) multiple pods.

Pure Fusion integrates an organization's Pure systems, wherever they are located, into a unified infrastructure in which IT teams manage hardware and software and users acquire and relinquish virtual storage resources in a cloud-like "storage as code" model.
The Pure Fusion control plane consists of Pure1 applications that IT teams and consumers use to specify desired outcomes, and software agents within managed systems produce them. This architecture provides a highly available control plane without user-provided management servers, along with individual systems' ability to continue operating if cloud connectivity is lost. There is no practical limit to the size of an infrastructure.

STORAGE SERVICES

SDS presents block volumes, file systems, and/or object stores to consumers. Its software constructs these from the underlying hardware, meeting user requirements for performance, data protection, and co-location or separation of resources. Virtualization typically includes data protection in the form of mirroring, RAID, cross-system replication, and performance management by cross-device striping and data placement. If SDS software doesn't standardize and automate the creation and placement of virtual resources, IT teams must negotiate service level agreements with (often unqualified) consumers and configure volumes, file systems, or object stores on a per-case basis.

Pure's systems are inherently thin-provisioned–they do not pre-allocate physical storage—and when hosts write data, they automatically place it optimally based on systems' internal state, evaluated in real time. This architecture greatly simplifies virtual resource creation. For example, administrators define FlashArray volumes by specifying a name and a capacity–there are no data placement, protection, or other user-specifiable attributes.

For disaster protection, FlashArrays offer three options for remote replication, each with a different balance of currency of replicated data vs. resource consumption.

SECURITY

The larger an IT user community, the more pressing are its security needs. SDS should provide reliable data access to authorized consumers and deny access to unauthorized ones, and should protect data from misappropriation, both while it is "at rest" (stored) and "in motion" (traversing the network).

SDS software should include robust user authentication, both for administration of the infrastructure and for consumers who create and manage their own virtual resources.

Increasingly, applications are encrypting and decrypting data "at its source," so that only they have access to unencrypted data.[4] Many older applications, however, do not encrypt data, making it incumbent upon the SDS to protect it against misappropriation.

In addition to local password or public-private key pair credentialing, Pure's systems integrate with customers' LDAP and AD systems to authenticate administrators for local management. Access to Pure1 (and Pure Fusion) is controlled by recognized identity management authorities, provided either by the customer or by Pure Storage.

Pure's systems encrypt all data (and the metadata that describes and locates it) before writing it to NVRAM or on flash. Encryption is "always on"—there is no way to disable it.

USER INTERFACE

An SDS deployment should provide "self-service" consumer access with well-defined virtual resource options presented in a user-friendly way. It must isolate consumers from each other and provide monitoring capabilities so that consumers can verify that their SLAs are met.

Pure Fusion separates infrastructure management and storage consumer roles. IT teams define common *templates* for service offerings, and consumers use them to create virtual resources. Hosts use virtual addresses to communicate with their storage resources, which allows IT teams to relocate them transparently while in use, for example to utilize newly-added equipment or to rebalance load across the infrastructure. A *tenant* concept isolates major parts of an organization from each other. Tenants create and manage *tenant spaces* that separate individual applications' storage resources from one another.

[4] Data encrypted at its source is essentially irreducible, so there is little to be gained by deduplicating or compressing it at the storage system level.

As a component of Pure1, Pure Fusion makes all the monitoring, workload analysis, and AI-based Meta forward planning available to storage administrators and consumers through a common web interface. Its API-centric design makes it easy to integrate services with data center automation software or customer-developed scripting tools.

THE BOTTOM LINE ON CHALLENGES

While SDS may improve an IT team's operational flexibility, an architecture based on commodity hardware and third-party software necessarily entails compromises that may profoundly affect the cost, performance, reliability, and longevity of the architecture.

TOTAL COST OF OWNERSHIP (TCO)

TCO over a 3 to 5 year lifetime includes both acquisition and operating cost, as well as the cost of managing diverse hardware and software and the hidden cost of opportunities lost to the organization due to constraints imposed by commodity components.

INTEGRATION RESPONSIBILITIES

Even with an SDS architecture that includes "turnkey" software from an ISV, an organization that deploys SDS takes on responsibility for integrating the selected hardware, network, and software into a smooth-running infrastructure that meets the organization's storage needs.

IMPACT ON THE ORGANIZATION

Arguably, the main impact of SDS lies not in storage cost savings, but in IT operational efficiency and the resulting effectiveness in serving the organization. Consumers experiencing long waits for storage resources, infrastructure failures that cause application outages, SLAs not met due to load imbalances, and similar issues all represent costs, not only to IT operations, but also to the organization as a whole.

The Pure Storage approach to SDS minimizes TCO, eliminates the need for the customer to integrate the storage infrastructure, and with the API-driven self-service provisioning model, delivers a cloud-like "storage as code" experience to an organization's storage consumers.

PURE AND SOFTWARE-DEFINED STORAGE

In a sense, the very first FlashArrays that Pure Storage shipped were software-defined storage, albeit on a small scale by today's standards. Designed to minimize cost, they used general-purpose servers, "consumer-grade" SSDs, and commodity HBAs and NICs obtained from various vendors. What made them into enterprise-ready arrays was the Purity//FA software that integrated components into full-function, high-performing, reliable systems that presented virtual *volumes* to consumers. Purity//FA did the "hard stuff"—data reduction to make flash affordable, flash-friendly data layout and RAID to maximize SSD endurance and protect against failures, transparent failover to protect against controller and network failures, and eventually, snapshots and replication to protect data against human error and disasters.

FlashArray's advantages were sufficiently compelling to gain Pure a foothold in a mature market space already occupied by large, well-entrenched incumbent vendors. As the company became increasingly successful, however, two things became obvious:

- Commodity components have limitations that prevent systems built from them from reaching the full potential of the underlying technologies
- Customers want to manage their storage as a whole, not by each individual array.

COMMODITY HARDWARE SHORTCOMINGS

MEDIA

The limitations of commodity components first became apparent with SSDs.

Of necessity, SSDs contain *flash translation layer* (FTL) firmware that dynamically maps the sector addresses they export to internal data locations and does "housekeeping" such as *garbage collection* (recovering space occupied by overwritten data) and intra-device wear leveling. FTLs constantly relocate stored data, causing *write amplification* (internal writes exceed external ones) which detracts from device performance. Each SSD model maps data differently, so Purity//FA needed custom *flash personality layer* (FPL) software to optimize for each supported SSD type.

Write amplification also reduces a device's endurance, so vendors compensate, partly with FTL wear leveling, but more importantly by *overprovisioning*–building in more flash than advertised device capacity and distributing internal writes across an entire device. Overprovisioning increases endurance but the hidden "extra" flash increases cost.

FTL complexity, write amplification, and the inherent cost of overprovisioning meant that commodity SSDs were never going to deliver the full potential of any given generation of flash in an enterprise storage system context. Moreover, the inherent limitations of the technology–low endurance, unpredictable write performance, and high raw error rates–got worse with each new generation. Fourth generation *QLC* flash was a watershed, with specifications well below enterprise-storage acceptability without engineering innovations to overcome its shortcomings.

CONTROLLERS

Similarly, commodity servers had inherent limitations as array controllers. Dual controllers were necessary, primarily for redundancy, but also to provide additional host I/O paths. Two controllers meant two servers, each in a separate rack-mounted chassis, and each with dedicated I/O cards and cabling for intercommunication (early FlashArrays used Infiniband).

Commodity hardware had other limitations as well. Consumer SSDs are single-ported, so they needed custom hardware to communicate with both controllers. SSDs had to be mounted in separate rack-mounted “shelves,” meaning more sheet metal and cables and less system reliability. NVRAMs occupied storage shelf bays, reducing shelf capacity and sharing bandwidth with SSDs…the list went on. The company understood from its earliest days that it could build significantly better products if it controlled their hardware underpinnings.

OPTIMIZING HARDWARE

CONTROLLERS

Pure first attacked commodity controller issues. In 2015, after a year-long development, the first FlashArray//M systems with Pure Storage-designed controllers and chassis shipped. The 3U-high system chassis contained two custom controller mainboards interconnected by PCIe bridges, I/O card slots for host connections, redundant power supplies and cooling fans, and bays for four NVRAMs and 20 SSDs. The chassis midplane provided Internal connections, so base systems needed only six cables for power and host connection, eliminating a source of unreliability. Expansion shelves provided additional capacity if needed.

FlashArray//M quadrupled storage density, more than doubled I/O performance, greatly improved reliability by reducing component counts, and made a range of performance and capacity options possible with different CPU and DRAM configurations. It was the starting point of an on-going path of steady increases in FlashArray storage density, performance, and reliability that would not have been possible with commodity components.

MEDIA

In 2017, Pure introduced *Direct Flash Modules* (DFMs), another in-house design that replaces commodity SSDs in today’s FlashArrays. As the name implies, DFMs directly expose flash to controllers, eliminating overprovisioning and the complexity and performance drag of FTL firmware. With visibility to individual flash pages, Purity//FA performs FTL-equivalent functions on an array-wide basis, optimizing scheduling and housekeeping across all devices rather than within each one. DFMs offer significantly higher density, performance, reliability, and endurance than SSDs. Moreover, the in-house module design allows Pure to incorporate flash technology innovations quickly–the company was first in the industry to offer capacity-optimized arrays based on QLC flash with enterprise reliability and full Purity//FA data services. Today, with 48TB DFMs, a FlashArray//C can host up to 1.88PB of physical QLC flash,[5] providing by far the highest raw capacity density available anywhere.

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[5] 7.3PB of usable capacity with typical data reduction (calculated based on installed base data reported to Pure1).

Pure's evolution from commodity components to custom hardware holds a lesson for SDS architects. While early FlashArray models built from commodity components demonstrated that enterprise-class systems *could* be built from commodity components, it was the evolution to custom-designed components specifically engineered to interoperate with each other that allowed the company to create today's high-density, high-performing arrays and offer them in flexible configurations. Today, Pure customers can configure the exact combination of high performance FlashArray//XL, FlashArray//X, and cost-effective FlashArray//C models in a range of capacities to meet virtually any combination of data storage needs.

EVERGREEN

Periodic equipment refresh is a key consideration for SDS deployments intended to last many years. Understanding and controlling the hardware that goes into its systems has enabled Pure to offer the unique Evergreen® program that extends the lives of customers' systems to a decade or more without "forklift" upgrades or massive data migrations. With Evergreen, storage is data centric–Pure's service agreements provide for periodic controller refresh and DFM replacement as necessary, but arrays stay in service and data remains continuously accessible to applications throughout the systems' lifetimes.

PURE FUSION: THE "GLUE"

With the introduction of Pure Fusion,[6] Pure has demonstrated a commitment to software-defined storage as described in the Gartner Group citation on page 1. Pure Fusion is a distributed SDS infrastructure, initially supporting on-premises iSCSI-connected FlashArrays and Cloud Block Store instances, but designed to eventually encompass others of the company's products. Its API-centric *storage-as-code* model provides consumers with a cloud-like self-service experience. For IT operations teams, it elevates storage management from the array level to an organization's entire "fleet" of Pure Storage systems.

Pure Fusion embodies the key SDS properties:

HARDWARE ORGANIZATION

Pure Fusion organizes systems into user-defined (conceptually geographic) *regions*, each subdivided into *availability zones* (effectively scale-out clusters of arrays). Consumers (application managers) create virtual storage resources (today, disk-like volumes) within an availability zone, but have no awareness of the array they occupy. This enables IT operations teams to transparently relocate storage resources within a zone to balance load or to accommodate changes in the zone's hardware complement.

[6] Described in technical brief TB-210401, available to authorized users of the Pure Storage knowledge base at https://support.purestorage.com.

NETWORKING

Pure Fusion presents storage resources to consumers via virtual network addresses. This enables it control host connections and to relocate resources between arrays while they are in use. Relocation is transparent to consumers' applications.

SOFTWARE

Pure Fusion *control planes* are hybrids of cloud-based application software that interacts with *agents* located in managed arrays. IT teams manage the infrastructure and consumers their own storage resources via the Pure1 user interface, but Pure Fusion is REST API-centric. Its every function is invoked via the same APIs called when Pure1 users issue CLI or GUI commands. With this design, it is easy to manage a Pure Fusion via IT automation software and/or user-developed scripts. In general, the APIs express desired states (e.g., new virtual resource templates or new volumes) which the Pure Fusion cloud and agent components cooperate to produce. APIs are asynchronous, so they do not block invoking software, and are idempotent, so no rollback is required if calls fail.

Pure Fusion provides a separate Pure-managed private cloud for each participating customer; there are no customer-provided management servers. The private clouds are integrated with Pure1™, so users have access to the monitoring, alerting, support case management, and AI-based forward planning capabilities (based on over a decade of input from installed systems) that make FlashArray users the world's best-informed, best-supported, and most self-sufficient storage consumers.

WELL-DEFINED ROLES

Pure Fusion makes a clear distinction between storage provider (IT operations) and consumer (typically divisional or departmental) roles and assigns specific functions to each. Providers manage hardware and networking for the infrastructure and define virtual resource templates for consumer use. Tenant administrators manage *tenant spaces* for each of their applications. Tenant space administrators create and relinquish virtual storage resources for use by their application managers. The self-service model abstracts the storage resources that applications use from the equipment used to instantiate them.

PURE STORAGE, PURE1, SDS, AND ESG

With Pure1, and now Pure Fusion, Pure Storage has committed to a long-term software-defined storage strategy. The company has developed world-leading products that Pure Fusion integrates to forge a customer's "fleet" of arrays into a scalable, flexible, organization-wide storage infrastructure defined and managed by customer-accessible APIs:

- The cloud-based implementation means there is no realistic limit to scale and no need for customer-provided control plane servers
- The API-centric design means that users can integrate a Pure SDS deployment with any commercial or internally developed data center automation tools

- The clear separation of roles and the abstraction of virtual resources from the hardware that instantiates them enables a self-service model similar to that offered in public clouds for an organization's consumers of on-premises storage.

Most importantly, Pure Fusion deployments are underpinned by field-proven products with best-in-class volumetric efficiency, data reduction, six "nines" of demonstrated availability, and Evergreen investment protection. An SDS deployment based on Pure Storage products provides:

LOW TCO

High density storage, efficient use of flash (including QLC), and flexible configuration options keep direct costs to a minimum. The same factors minimize on-going operating costs like data center space, power consumption, and cooling. For data that contains redundancy,[7] FlashArrays further reduce physical storage consumption by deduplication and compression, stripping out redundancy before storing it.

The ability to relocate virtual storage resources while they are in use promotes further efficiency by enabling providers to optimize equipment utilization without impacting consumers' IT operations.

As evidenced by the company's recently released inaugural Environment, Sustainability, and Governance (ESG) Report,[8] Pure Storage leads the industry in environmentally friendliness of its products today and intends to continue to do so in the future.

"IT JUST WORKS" OPERATION

For over a decade, Pure has done the system engineering and quality control to both optimize its systems as they evolve and integrate them into a scalable infrastructure, no matter where in an organization they are located–system engineering and quality control that would be an IT staff responsibility in an SDS deployment constructed from components provided by different vendors. With Pure Fusion, storage providers manage the infrastructure and consumers use a self-service portal to self-manage their own virtual storage resources.

Today Pure Fusion delivers SDS for FlashArray; the company anticipates that in the future more of its products will fall within the Pure Fusion framework. Organizations considering adoption of a software-defined storage strategy would do well to seriously evaluate how Pure Storage products integrated by Pure Fusion stack up against any other SDS architecture, especially those assembled from commodity components, in terms of capability, flexibility, performance, reliability, simplicity, longevity, and most importantly, TCO.

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[7] For example, text or tabular data not encrypted at its point of origin (FlashArrays encrypt all data prior to staging and storing it). In general, pre-encrypted data, digital images, and media streams are not significantly reducible.

[8] Available publicly on the worldwide web at ESG report.

Software-Defined Storage that Works

Simplifying the modern data experience at scale