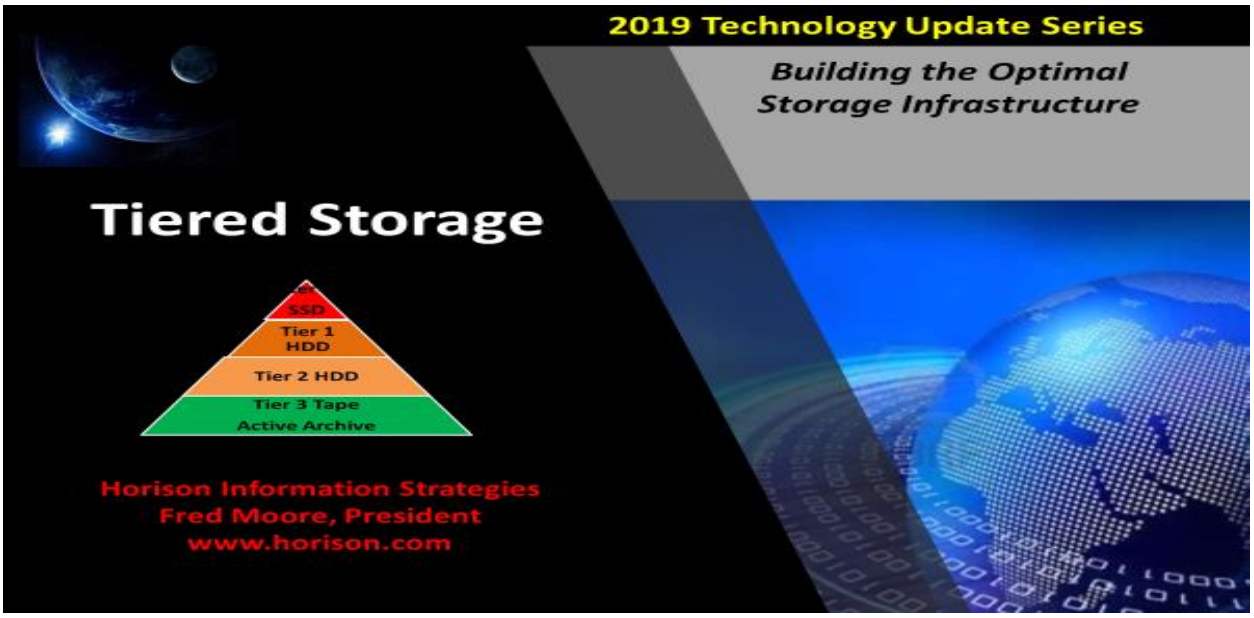
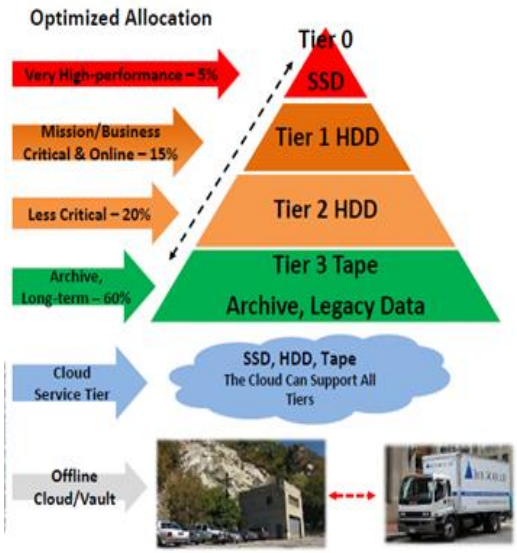


Introduction

The selection of data storage technologies has never been more robust. Today's choices range from ultra-high capacity, low cost storage at one end of the hierarchy to very high levels of performance and functionality at the other. These choices define the unique levels or tiers of today's storage hierarchy. The foundations of tiered storage had their beginnings over 30 years ago when disk, automated tape libraries and advanced policy-based data management software (HSM) combined to effectively migrate less-active data to less-expensive storage devices. At the highest level, tiered storage refers to an infrastructure capable of optimally aligning storage systems with application requirements and their required service levels. The business case for implementing tiered storage is compelling and becomes increasingly so as the storage pools get larger. Tiered storage integrates hardware and storage management software to provide a seamless operation for customers to realize the huge TCO and ROI benefits available today.

Tiered Storage – A Closer Look Inside the Storage Tiers

A tiered storage environment consists of two or more kinds of storage technologies, delineated by differences in four primary attributes: price, performance, capacity and functionality. As storage pools grow, automated tiered storage becomes the optimal storage architecture since 1) manual data movement is very time consuming 2) the amount of digital data is continually increasing and 3) limited staff resources leave storage administrators stretched too thin. To implement a tiered storage strategy from a technology perspective, the de-facto standard four-tiered hierarchy model of storage tiers 0, 1, 2, and 3 presents the optimal choice. The cloud and offline data vault storage options represent services using the four tiers.



Leading storage suppliers offer a complete tiered storage portfolio including high-performance SSDs (Solid State Disk), RAID arrays and automated tape libraries. A few vendors' tiered offerings still consist of a "disk only" strategy and the disks used are similar, varying mainly in RPM speeds and price. This approach is costly and forces archival, lower activity data to reside on continually spinning disks. The benefits of tiered storage are greatest when the tape tier (tier 3) is used as it has a significantly lower price and TCO compared to other solutions. The distinctions between tiered storage and HSM software often blur, but the eventual rise of HSM tools enabled automation of the tedious manual process of storage tiering. This resulted in making the primary goal of driving lower activity and long-term data to lower cost tiers common practice. To achieve the functionality and benefits of tiered storage, hardware and intelligent software combine to provide the capabilities to implement user-defined policies which automatically assign and re-locate data depending on frequency of use and the available types of storage media. Future technology developments project continued advancements for all storage technology capabilities. A more intelligent and advanced software management approach will soon be required to address what lies ahead. Look for artificial intelligence to enhance these efforts.

The Tiered Storage chart below serves as a model to describe the key attributes of the four de-facto standard storage tiers.

Inside the Storage Tiers				
Storage Tier	**Tier 0** 	**Tier 1** 	**Tier 2** 	**Tier 3** 
Amount of Data in Each Tier (optimal ranges)	5%	15%	20%	60%
Primary Technology	NVM (DRAM, 3D-Flash SSD, PCM, 3D-Xpoint)	Enterprise disk arrays	Midrange disk arrays	Tape libraries, offsite data vaults, cloud services
Nominal Access Time	1-10 µ	5-10 ms	5-10 ms	25-121 sec
Typical File Access	Random	Random	Random	Sequential
Data Classification Category	I/O intensive, response-time critical, OLTP ultra high-performance	Mission-critical, OLTP, revenue generating applications	Vital, sensitive, business important applications	Archives, fixed content, big data, reference data, govt. regs, very high data rates
Relative Price Index*	~15x	~6x	~4x	~1x
Data Recovery	Mirrored, replication	Mirrored, replication	Scheduled backups	Local and remote backup
Reliability (BER)	$1x10^{17}$	$1x10^{16}$	$1x10^{15}$	$1x10^{19}$
Media Life	3-5 years	4-5 years	4-5 years	>30 years
Power Consumption per GB	Medium	Highest	High	**Lowest**

***Prices are relative and vary based on a variety of factors. See specific vendor for current quotes.**

Tier 0: High-performance storage - Tier 0 is used for extremely high performance, high IOPs data that needs to be captured, analyzed and retrieved at the highest possible speed. Flash memory technology is firmly established as the solution of choice for tier 0, primarily using higher density 3D-Flash memory. The emergence of NVM (Non-Volatile Memory) and Phase Change Memory (PCM) technologies such as 3D - XPoint, are expected to soon join tier 0 solutions as the future roadmap for NVM solutions is robust. The arrival of Non-Volatile Memory express (NVMe), a specification that allows SSDs to make more effective use of a high-speed PCIe bus in a server, has provided a huge boost for further increasing performance for solid state products. Tier 0 solutions offer the highest levels of IOPs and are the most expensive tier on a $/GB basis. Given the inherent variability with latency intrinsic to the cloud, tier 0 is only viable when used on premises or when provided by a cloud provider to an application running in that cloud environment.

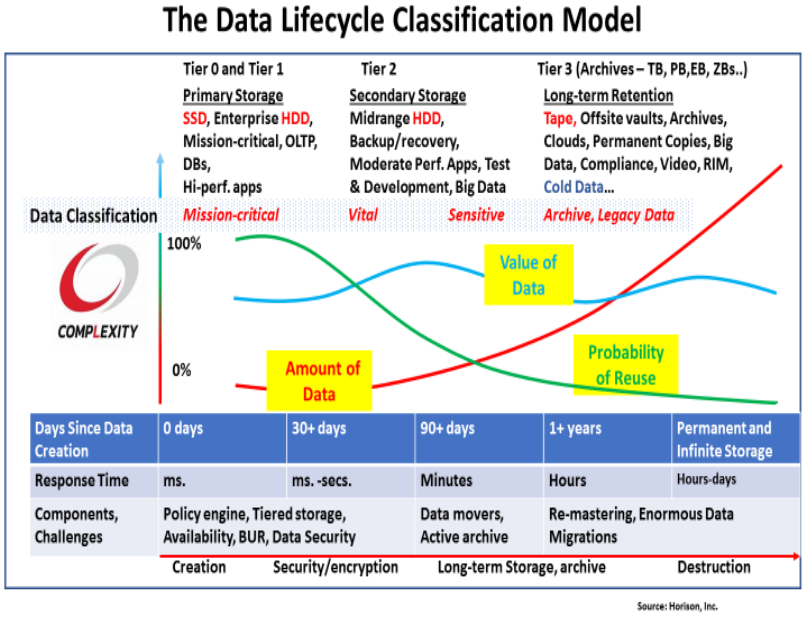
Tier 1: Primary storage - Tier 1 mission critical data uses the enterprise-class disk systems and uses high performance, high availability with near-zero downtime and fast RTOs (Recovery Time Objectives) to support customer-facing and revenue-generating applications. When fully featured, these systems can carry a premium $/GB price, however this is often justified because the lower performance or less reliable disk systems could directly impact customer satisfaction, business revenues and corporate viability. Mission critical data is often stored on solutions such as mirrored disk or double-parity RAID. Looking ahead, disk drives are faced with minimal performance improvements and substantial challenges for increasing capacity though HAMR and MAMR developments should help. Even though many tier 1 applications will stay on spinning disk, enterprises are often choosing high-performance workloads using NVMe and SSDs as these tier 0 products quickly encroach on the disk market.

Tier 2: Secondary storage - This tier includes midrange disk storage normally used with less criticality and at lower price points than tier 1 disk. Tier 2 supports a broad range of major business applications including low-activity databases, backup, email, file systems and Enterprise Resource Planning (ERP). Tier 2 solutions must securely store active business data where sub-second response is not necessarily a requirement, but reasonably fast response still is needed. Choosing the optimal tier 2 technology is normally a balance between cost, performance and availability.

Tier 3: Archive, long-term storage - Tier 3 storage represents the fastest growing segment of the storage industry at nearly 60% compounded annually. For many companies, all their digital data from 10 years ago can fit on one or two cartridges today! As most data ages, access activity drops off rapidly and the data reaches archival (cold) status. Archival data can have significant untapped value that is waiting to be analyzed yet must be protected and kept for prolonged, if not infinite periods of time. Tape is presently the most cost-effective destination and the primary choice for archival data given it has the lowest price per gigabyte and TCO of any storage option. Future roadmaps indicate tape has the greatest potential for capacity and data rate improvement. Tape has much faster data transfer rates (throughput) than disk making it a good solution for recovery of large files and DR applications. Tape provides WORM (Write-Once-Read-Many) and encryption capabilities enabling a secure storage medium for compliance, legal and any types of valuable files. The Tape Air Gap adds significant protection against cybercrime. Tier 3 tape is green storage and has the lowest energy consumption per GB of any tier enabling the goal that **"data that isn't accessed shouldn't consume energy"** become a reality.

Data Classification – Understanding and Learning Your Data Access and I/O Patterns

Most digital data begin life on disk and then migrates through the tiers based on a variety of user-defined policies as it ages. In practice, data is classified into four general categories and these categories are mapped to the storage tier best fitting those characteristics. Understanding and quantifying the I/O characteristics and access patterns of applications has long been a tedious and often extremely difficult task. However, with an understanding of the degree of activity and access pattern, you can tailor the storage solution to the application. This could mean improved performance to match the SLA's of the application and a more cost-effective storage solution.



Learning about or characterizing data access patterns, while extremely important, is not enough. The characteristics of the storage itself, both hardware and software, must be understood as well. Knowing the likely I/O patterns of an application would then allow the I/O performance requirements to be estimated therefore enabling an enterprise to choose the optimal storage solution.

Align Your Data with the Optimal Tier

Tiered storage can be managed at a much lower cost and more efficiently than a single-tiered architecture by deploying advanced tools that move, migrate, and respond to changing lifecycle needs of the data or application. Three consistently observable storage profiles (see Data Lifecycle Classification Model chart above) have evolved that help understand data behavior over its lifecycle:

1) **the probability of reuse** of most data declines as the data ages
2) **the value of data** to a business can change over time based on a variety of circumstances
3) **the amount of data** is increasing as it ages since more data is being kept for much longer periods of time than ever before pushing older and less active data into tier 3 status

It is for these reasons that managing and protecting data throughout its lifetime has become a most critical storage management task. With or without sophisticated tools, most organizations should be able to identify their most important applications and have a clear understanding of their value to the success of the business. This process of matching data and devices can then assign data to the optimal tier. In practice, however, tiered storage implementations have often been limited due to:

1) Lack of automated data classification and limited deployment of migration tools
2) Lack of support for heterogeneous server and/or storage environments

A Closer Look at Data Classification

Data classification assigns data to the optimal storage tier. If data classification software and tools are not readily available, the template model below can serve as a simple starting point to begin the classification process by mapping the required data characteristics for a given file or application to the optimal tier.

When classifying data, ask yourself:

- How fast (the performance requirement) do I need to access the data?
- How long do I need to retain data?
- How soon do I need the data back if lost, damaged or inaccessible?
- How secure does it need to be?
- What regulatory requirements need to be adhered to?

There are four major data classes, but several sub-classes can be defined to meet specific needs.

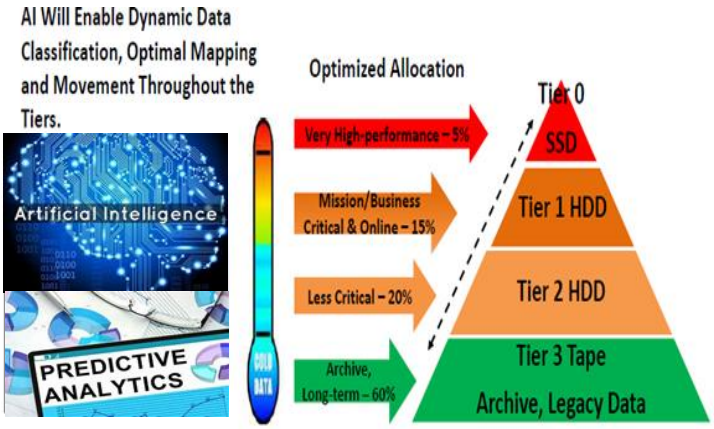
Data Class	Description
	**Very High-Performance** Ideally, mission-critical data resides on highly functional, highly available, and costlier enterprise class disk arrays and SSDs requiring multiple replication or backup copies that can be stored at geographically separate locations. Mission critical data is IOPs intensive and includes a variety of response time critical applications and databases that normally have significant business or societal value. This data typically resides on tier 0 SSD or tier 1 high-performance disk and no more than 20% of all data is considered "very high-performance" at any given time.
	**Mission Critical data** defines the most important revenue generating business processes, customer facing applications. Social security and credit card numbers are in this category. Losing access to mission-critical data means a rapid loss of revenue, potential loss of customers and can place the survival of the business, or society, at risk in a relatively short period of time. Mission critical data normally resides on tier 0 or tier 1 storage systems based on the performance requirements.
	**Business Critical** (or less critical data) typically resides on tier 1 or tier 2 disk arrays. The difference between mission critical and business critical lies in the major adverse impact and the real possibilities of loss of life, serious injury and/or financial loss. This decision totally depends on the consequences for both the business and customer when this service is interrupted. If the system goes down for a few hours or a day or so, it's not the end of the world. The data is usually available elsewhere, or businesses can continue to do their job sufficiently without it for a while. Within a couple of days however, to manage and accelerate their business, they will need the application and data back up and running

	**Archival** data presently represents over 60 % of all data stored making it the largest and fastest growing data classification segment. Setting the right data retention policies is a necessity for archival data and in particular for governance and legal compliance. At best, many businesses are fulfilling their industry's compliance and regulatory requirements, but not yet looking deeper into the strategic value of their stored information. Lost, corrupted or damaged archival data can be reconstructed with minimal effort, and acceptable recovery times can range from hours to days. The primary technology for archival data is automated tape libraries used in local, cloud and remote locations. Tier 3 archival data represents the prime growth opportunity for cloud providers.

Data Classification is Targeted for Help from Artificial Intelligence (AI)

If data is the new currency, then storage is the new bank. IT staffs are under increasing strain as the volume and complexity of managing daily workloads defy the traditional approach of simply adding more drives when capacity is maxed out. Furthermore, data will have to be analyzed, tagged (metadata), processed and subjected to other processes in order to effectively support analytics and the real-time applications that drive productivity. Organizations will need to dynamically migrate, replicate and mirror data across increasingly complex and geographically dispersed tiered storage infrastructures, which can only be accomplished through an intelligent software stack or a virtual army of storage managers, the latter of which is highly unlikely. From 2011-2020, data is expected to grow ~50 times while the number of trained IT professionals is projected to grow just ~1.5 times. The challenge is undeniable and new tools will be required.

Fortunately, storage and data management are both critical areas that are poised to get a dose of intelligence – meaning AI (Artificial Intelligence). Artificial intelligence is the theory and development of computer systems able to perform tasks that normally require human intelligence, such as visual perception, speech recognition, decision-making, and translation between languages.



Managers can harvest lots of data about storage systems and applications using today's storage instrumentation and tools. Creating actionable changes from that data (and metadata) however is surpassing the scope of user-defined policies. As storage pools reach PB and EB levels it will become virtually impossible to manage data without a significant boost from advanced predictive analysis, machine learning and AI tools. Imagine a data center where incident alerts arrive several minutes before problems even begin — you would actually have the capability to avert bottlenecks and deliver a more seamless experience to your customers. AI manages data through its lifecycle by gathering large amounts of information about how the data is used such as: Who access it? How often is it accessed? What kind

of file is it? What type of data does it contain? As this information is gathered, learning algorithms can start to create predictive models describing how the data is most likely to be used in the future. The storage industry is getting anxious and is primed for AI tools, but they won't suddenly appear - rather they will evolve and improve their capabilities over time.

Economic Considerations for a Tiered Storage Implementation

The example below compares the initial acquisition cost of 1 PB of storage for a tiered storage implementation. The ASPs (average selling price) are calculated from 2020 projections for each tier and serve as an example. Businesses can input their own respective storage cost metrics or use actual price quotes from your storage vendor(s) to determine costs for a specific tier. The average amount of data in each tier uses the industry averages from the Tiered Storage chart described earlier.

Total capacity	**Ex: 1 PB**			
Storage Tiers	**Tier 0 (SSD)**	**Tiers 1&2 (disk)**	**Tier 3 (tape)**	**Total**
ASP/TB by tier (2020 est. price)	$175.00	$38.00	$5.50	_____
Total PB price per tier if all data on each tier	$175,000	$38,000	$5,500	_____
Optimal data allocation % by tier	5% (50 TB)	35% (350 TB)	60% (600 TB)	1 PB
Total optimal price 2 tiers (disk tiers only)	0%	100% $38,000	0%	100% $38,000
Total optimal price 3 tiers (SSD, disk and tape)	5% $8,750	35% $13,300	60% $3,300	100% $25,350

For 1 PB of storage, the acquisition price of a two-tiered disk only tiered implementation is 1.5 times more expensive at $38,000 compared to an active three-tiered implementation using tape for tier 3 archival data costing $25,350. The more inactive disk data that can move to tape, the greater the cost savings over an "all disk" approach. Keep in mind that the real cost (TCO) of storage comes from operating the solution over several years as these expenses all quickly dwarf the upfront costs to purchase and deploy. In any case, the larger the storage pool, the greater the benefits of tiered storage become.

More Data is on the Way…

Even as CIOs struggle with the exploding growth of disk farms, which are devouring IT budgets and overcrowding data centers, many continue to maintain expensive tier 1 or tier 2 disks often half full of data which has little or no activity for years. Organizations are keeping as much as 40% of their inactive data on their most expensive infrastructure. Unstructured data (unsearchable data) makes up roughly 80% or more of enterprise data and is growing at the rate of 55% and 65% per year. Storing redundant data can only add to the problem. Obviously, few data centers can afford to sustain this kind of inefficiency. Data will be generated in ever greater volumes from the rise of cloud computing, the

unknown scope and magnitude of the Internet of Things (IoT), mobility, surveillance, social media and analytics - all key reasons why overall data storage volumes are expected continue to (at least) double every two years. The IoT, coupled with the arrival of 5G networks that are ~20x faster than 4G, promises to generate floods of data points that may number in the billions and trillions. How much new incremental data will the IoT create? Where and for how long will the IoT data be stored?

Typical Applications for Each Data Class	
Very High Performance	High performance databases, operating system files, indices, logs, roll files, directories, system catalogues, HPC and scientific applications, real-time analytics, simulation, OLTP, reservation systems, database acceleration, artificial intelligence and machine learning, augmented reality, any data that demands the highest levels of I/O performance (IOPs)
Mission Critical Data	Mission critical databases, navigational systems for a spacecraft, reservation systems, ATM, point-of-sales, virtual machines, police, military and national security systems, online banking systems, railway/aircraft/transportation operating and control systems, electric grid, energy and power systems, nuclear reactor controls
Business Critical	Business-critical applications, web servers and applications, data protection – backup, recovery data, security systems, surveillance, image capture and retrieval, application development and test, select transactional workloads, data warehousing, ERP, big data and reference data, mobile devices, edge devices, BC/DR
Archival	All long-term data retention, archive and backup, big data that is yet to be analyzed, compliance data, GDPR, medical records, photos and images, e-mail history, unstructured file data, scientific, video, movies, audio, documents, collaboration, social media history, archive cloud applications, video surveillance and security system history and archives, off-site media storage, remote data vaults, BC/DR
Archival Storage Futures…	Automated Tiered Storage for SSD, HDD and Tape (AI and advanced software) Intelligent Active Archive – Pre-staging (AI), Integrated Tape, Disk and SSD Advanced LTFS partitioning and Recommended Access Order (RAO) for faster tape access

Conclusion

An effective tiered storage strategy has to balance storage costs, data lifecycle management practices, storage technology priorities and data access speeds. Each storage tier has its own unique capabilities and benefits. The best choice to address the waves of data that lie ahead is to take of advantage of a multi-tier storage system that automatically migrates your data to the most cost-efficient (TCO) tiers of storage. Whether that's high-performance SSDs, primary storage, tape or the cloud—your organization can most cost-effectively store its data based on various policy requirements.

Why wait? As storage systems grow larger, the ability for a full-time administrator to manage, monitor and maintain a petabyte-scale storage system becomes increasingly limited while the challenges for effective storage management will only get larger. A new culture of data-driven decision-making in the name of machine learning and AI is just emerging across all industries including storage management, replacing guesswork and approximations. AI has great expectations and is poised to make a heavy impact on the overwhelming storage management task that society will demand in the future. Enable your systems can take advantage of the different storage tiers so if the performance or availability needs of an application change, you can scale and won't need to re-architect. That way the IT community can finally deliver on the long-awaited promise to “have the right data - in the right place - at the right time”. For some enterprises building a tiered storage strategy may still be optional, but it won’t be for much longer. The time to build the foundation for tiered storage has arrived.

End of report.