SNIA
Solid State Storage Initiative

Two May Be Better Than One: Why Hard Disk Drives and Flash Belong Together

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The Solid State Storage Initiative

About SNIA

The Storage Networking Industry Association (SNIA) is a not-for-profit global organization made up of some 400-member companies and 7,000 individuals spanning virtually the entire storage industry. SNIA's mission is to lead the storage industry worldwide in developing and promoting standards, technologies, and educational services to empower organizations in the management of information. To this end, SNIA is uniquely committed to delivering standards, education, and services that will propel open storage networking solutions into the broader market. For additional information, visit the SNIA web site at http://www.snia.org.

Introduction

Some analysts and press have predicted that solid state drives (SSD) will take over the mass storage role traditionally filled by hard disk drives (HDD) for computer applications. But despite these optimistic predictions, the adoption rate of full computers with SSD rather than HDD is very slow. This is because many computer users need a fair amount of digital storage, which can be expensive using Flash memory alone.

The difference in price per GB of Flash memory vs. hard disk drives does not appear to be closing any time soon, yet higher resolution content in computers may drive storage demand even higher for many users. As a consequence, we project that the percentage of computers that only contain SSD will remain much less than those with HDD for years to come.

However, there is a golden opportunity to use Flash memory to increase the performance of computers that still contain HDD. While the storage capacity of hard disk drives has increased considerably over the years, the write and read data rates have increased much more slowly. Currently the performance of HDDs is considerably less than DRAM and as a consequence there may be an opportunity for a new caching (and buffering) layer in today's computers with a memory/storage technology that can fill this performance gap. Flash memory appears to fit the bill of such an intermediate caching and buffering technology, and unlike DRAM, it is nonvolatile as well. Computer users would love to get the performance of Flash memory and the low storage costs of HDDs together. Combining Flash memory with HDDs in computer architectures could provide a way to fill this user need and drive the use of much more Flash memory in computers than as simply an HDD replacement.

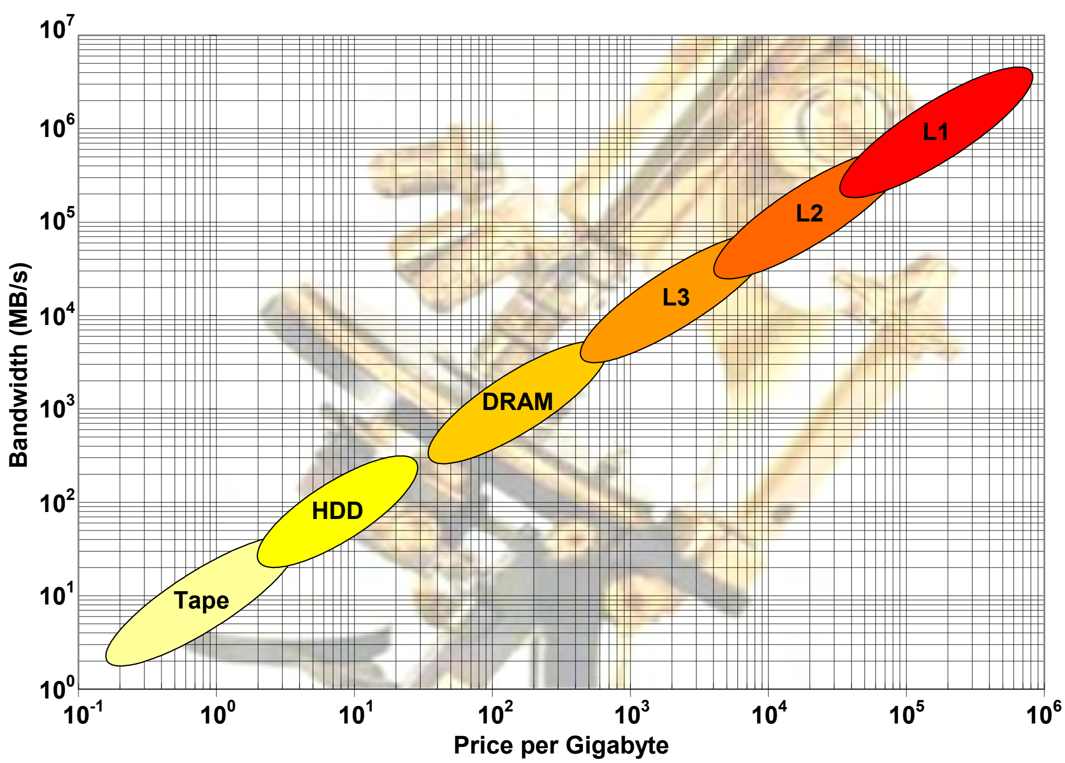
This white paper will explore the need for a caching and buffering technology between DRAM and HDDs and why Flash memory can be used to fill this need. We will go on to look at various ways that Flash and HDDs can be combined in a computer storage hierarchy. These technologies to combine Flash memory and HDDs include hybrid HDDs, Flash on the computer motherboard, and a combination of Flash and HDD storage devices in the same computer – paired storage systems.

In addition, we will explore other technologies that utilize Flash memory combined with other storage devices, as well as software that may help in creating paired storage and hybrid storage systems. We will finish by describing how combined storage architectures in computers that use Flash memory and HDDs together could become the dominant computer storage architecture. This would create a great new demand for Flash memory to fill these important storage niches. As a consequence, Flash memory will become a valuable enabling technology in all computer systems.The data for our analyses is excerpted from a much more detailed report written by Coughlin Associates and Objective Analysis[i].

Meeting the Need of Higher Performance

Processors and network speeds have increased considerably over the last few decades, and although storage capacity increases for HDD have ramped at a similar or even faster rate, the speed with which the data on an HDD can be accessed has not increased nearly as quickly. DRAM and other semiconductor memory device data access speeds have increased at a faster rate than HDDs, leaving a gap in the memory/storage capacity performance hierarchy as shown in Figure 1[ii].

Figure 1: A gap in the memory/storage hierarchy

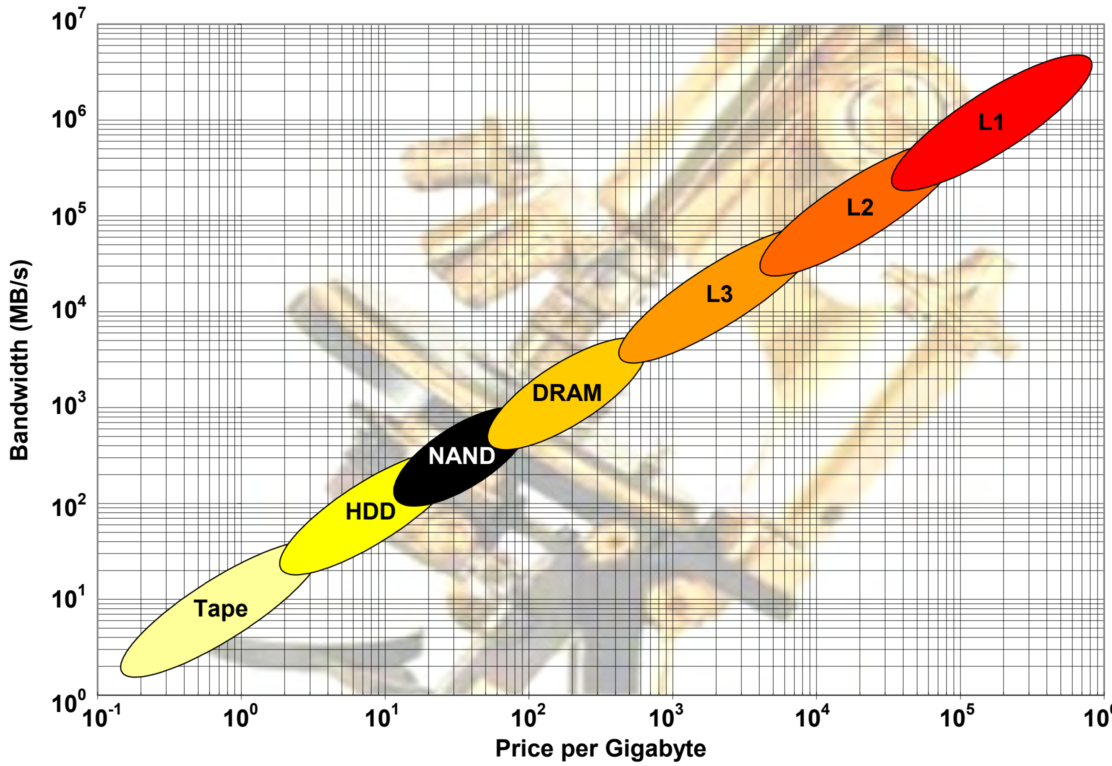


In this figure L1, L2, and L3 are cache memories (Levels 1-3) within or closely associated with a microprocessor chip. These cache memories generally use Static Random Access Memory (SRAM) technology. These different levels of cache memory are the fastest memory technologies used in modern computers. Somewhat slower than the cache memories is Dynamic Random Access Memory (DRAM). DRAM is slower than the SRAM used in cache memories but less expensive on a per bit basis. Below

DRAM in the graph above lie HDDs and then magnetic tape. These are non-volatile storage technologies using electromechanical access systems that are much slower but much less costly than DRAM. The gap in read and write performance between DRAM and HDDs has widened in the last few years, leaving an opportunity for a new intermediate memory/storage technology between HDDs and DRAM.

As suggested in Figure 2, NAND Flash memory can fill the performance gap between HDDs and DRAM.

Figure 2: NAND Flash memory can fill the gap in the memory/storage hierarchy



By filling the gap in performance between HDDs and DRAM, NAND Flash memory can provide a lower cost way than DRAM to boost performance using a given amount of storage capacity. Also, Flash memory provides non-volatile memory and thus could be used for long term data storage. For these reasons, NAND Flash will see an increasing use as cache and buffer memory or as an element in a paired storage configuration. Thus Flash memory and HDDs can be combined in a single storage system (a hybrid storage device) as a new storage/memory layer on the motherboard of a computer or as separate storage devices in a computer system. We will look at each of these ways to combine Flash memory and HDDs in the following sections.

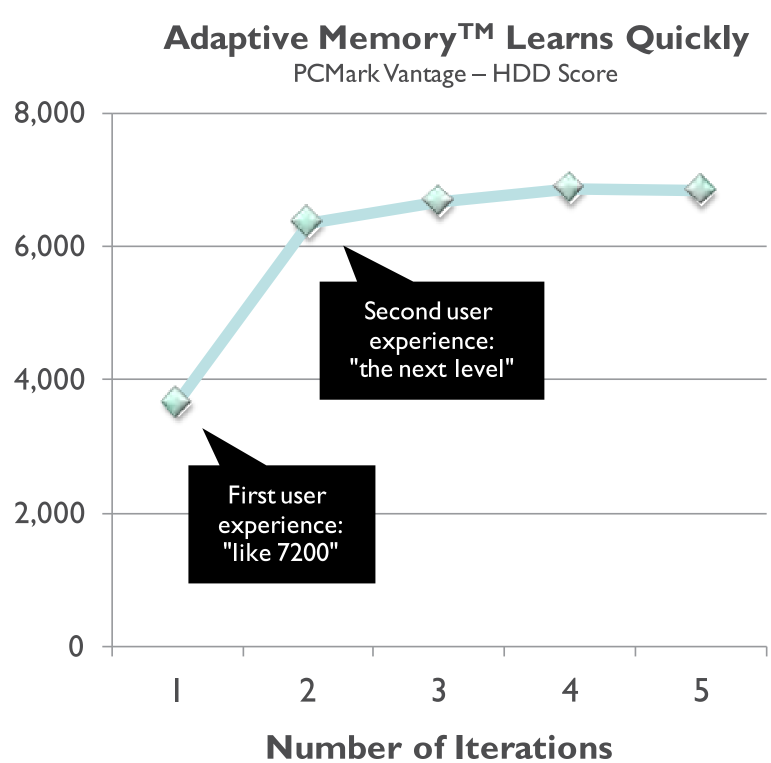
Hybrid Storage Devices

In early 2007, Seagate, Hitachi, Samsung, and Toshiba created a Hybrid Storage Alliance that promoted HDDs with some Flash memory. This early hybrid drive was intended to work with Windows operating systems to use Flash memory for write and read caching (this Windows support was known as Ready-Drive). Unfortunately, this early effort was tied to anticipated Windows support for Flash functions that never materialized.

In 2010 Seagate introduced a new generation of hybrid Flash and HDD storage (Momentus XT) that they called the "solid state hybrid drive." This product currently contains 4 GB of Flash memory on the HDD circuit board. The Flash memory is used to store frequently accessed content using an adaptive memory algorithm. The Seagate solid state hybrid drive does not depend on the operating system for its operation.

Seagate's adaptive memory algorithm monitors data access transactions and maintains frequently accessed data on the Flash memory. This adaptive memory algorithm dramatically improves storage access to content that is accessed repeatedly. Figure 3 shows the sort of learning performance improvement observed with Seagate's solid state hybrid drive using PCMark Vantage as a bench marking method[iii]. A 50% performance improvement is seen between the first and second iteration of data access. The performance improvements for additional data access grow very small; most of the improvement is seen by the second access.

Figure 3: Seagate hybrid drive adaptive memory performance improvement with access frequency



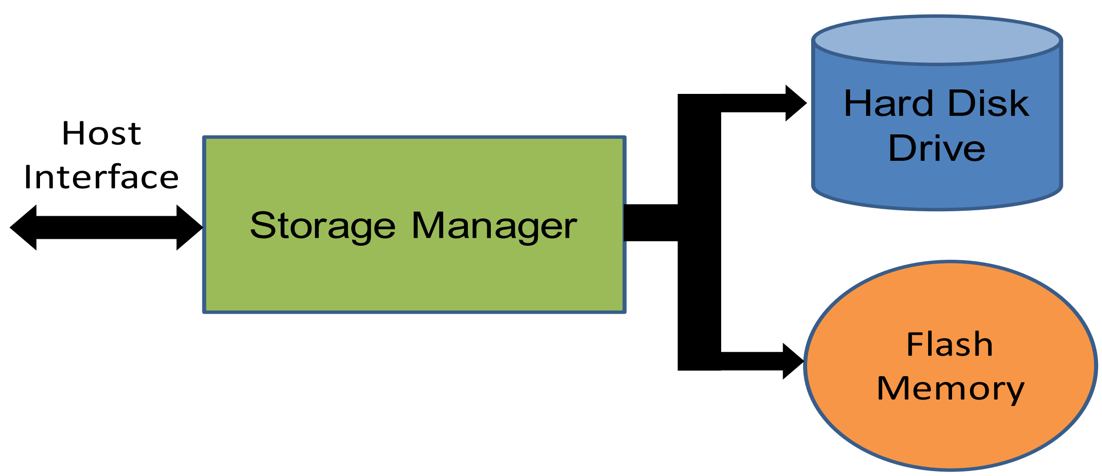
Flash Memory on a Computer Motherboard

Computer motherboards contain the processor chip and perhaps some associated high performance SRAM memory. In addition they contain the DRAM main memory. In the last few years there have been a few proposals to add Flash memory to the computer motherboard for a non-volatile memory layer to the motherboard memory/storage architecture. The motherboard Flash memory could be inserted into the motherboard with an ONFI module or DIMMs similar to those currently used for DRAM, allowing memory replacement when faster or larger memory becomes available.

The motherboard Flash memory can be used for write caching and for read caching, similar to the operations that were to be performed by the original hybrid HDDs. Intel introduced a motherboard Flash memory technology in 2007 that it called "Robson Technology" or "Turbo Memory." This early implementation ran into issues due to lack of support for management of the Flash and HDD memory in the dominant computer operating system. In 2009 Intel re-introduced the concept (calling it Braidwood) with the stated intent to roll this technology out in computers in 2010. The Braidwood approach combined NAND Flash on the computer motherboard with chipset and firmware control of the NAND use. Intel withheld introduction of Braidwood in 2010 for reasons that they did not disclose.

Central to the operation of any hybrid or paired storage computer architecture is management to determine which data is to be kept on the HDD and which data will be kept on the Flash memory. Figure 4 shows a storage management controller that determines what data should be stored on each memory device. This storage management function must balance the needs of data access, power savings opportunities, and data security.

Figure 4: Control of data placement on an HDD and Flash memory device in a hybrid or Paired Storage environment



Paired storage computers using Flash memory and HDDs

We have now explored hybrid storage devices that incorporate Flash memory into HDDs, as well as the addition of Flash memory to the computer motherboard. Now let's see how separate Flash memory storage devices can be used together with an HDD in a computer to achieve high performance and low cost storage. Where these separate storage devices are independent memory/storage systems, we call the resulting computer a paired storage system. The easiest example of such a paired storage configuration would put both an SSD using Flash memory into a computer along with a hard disk drive. The SSD contains an independent memory controller and can be a mass storage system in its own right. A trade-off between system storage access performance and storage capacity cost can be achieved by putting the most frequently accessed content (such as an operating system and user applications) on the SSD and the less frequently accessed data (such as user data) on the HDD. Because the content on the SSD is limited to this frequently-accessed data, its size can be considerably less than that of the HDD used in the paired storage system.

Note that a Flash memory device does not have to conform to the form factor that the electromechanical components in a hard disk drive require. Because it is basically a group of chips, an SSD used in a paired storage computer could be on a small circuit board such as an mSATA device or even in a single BGA chip package. Thus adding an SSD into a paired storage configuration does not need to increase the size of the computer. This can be particularly important for mobile computers where size is critical.

The table in Figure 5 can be used to estimate how much storage capacity would be required for an SSD used in a paired storage computer.

Figure 5: Control of data placement on a HDD and Flash memory device in a hybrid or paired storage configuration

	Dual-Drive		Single-Drive
	C: SSD	D: HDD	C: SSD
Microsoft Windows* 7 64-bit (Ultimate)	13.5		13.5
Page file	4GB (4GB DRAM)		4GB (4GB DRAM)
Hiberfile	3.2GB (4GB DRAM)		3.2GB (4GB DRAM)
Updates	1.5 – 6		1.5 - 6
Drivers	0.2		0.2
Office* 2007	0.9	0.9	1.8
Adobe Photoshop*	1.3	1.0	2.3
iTunes*	0.8		0.8
Total Disk Space used	25.4–29.9 GB	1.9 GB	27.3-31.8 GB

In this example the SSD contains the operating system and frequently used applications software while the HDD contains user data and less frequently used applications. Some additional storage capacity beyond that required for the operating system and applications will be required if the system designer wants to include write caching or read caching using the SSD for power savings and performance improvements for frequently accessed user content. It appears that a 32 GB SSD might be enough to provide the desired performance improvements in today's standard PC.

Within the next few years, 32 GB SSDs will be available at a cost of less than $30, making computers with this performance improvement only a bit more expensive than HDD-only based computers. The management of what data to put on the SSD and the HDD can be manual or automatic. In the manual approach a user puts the operating system and applications on the SSD manually. In an automated management system a driver or other software dynamically allocates operating system components, applications, frequently accessed files, etc. to the SSD to maximize performance. Studies by IBM have shown that with optimal placement of data on SSDs and HDDs in a paired storage computer (using an automated management system), 80% of the performance improvement of an SSD-only based computer can be achieved (and at much lower cost)[iv].

Other Paired Storage and Hybrid Approaches

Several controller and software/firmware companies have shown support for paired storage computers. Among these companies are Marvell, LSI, NVELO, and several others. Support for paired storage management with proper optimization of what is on the SSD and what is kept on the HDD is required to get the best combination of low cost and high performance.

There are other interesting combinations of Flash memory with storage devices that deserve attention. Hitachi-LG Data Storage has announced an optical disc drive (ODD) that includes Flash memory in a hybrid Flash/ODD configuration. The Flash memory acts as a cache for the content read out of the optical disc player. The data is loaded onto the Flash memory and read from it. It is attractive to use Flash as cache rather than DRAM because larger storage capacity is available for a given cost, plus the Flash memory is non-volatile. Reading data from the Flash memory allows power savings vs. playing the content directly from the optical disc, an important factor for mobile players and laptop computers.

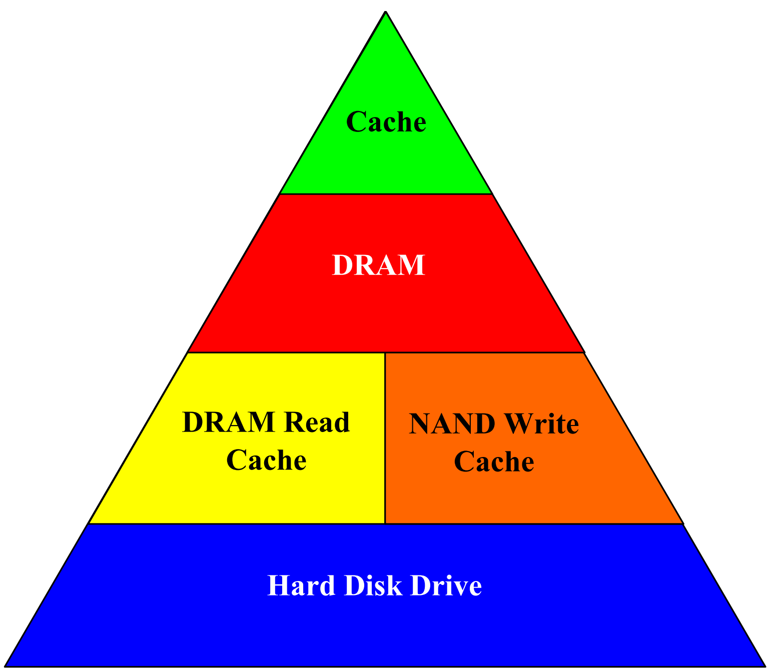
Enterprise data center managers and many high-end server and storage OEMs began to understand the benefit of adding a NAND layer to their storage hierarchy a few years ago. In these systems it is now relatively common to find one or more SSDs buffering data from an array of standard HDDs. These SSDs fill a need that had previously been addressed using high-speed RAID or striping techniques built around a number of enterprise HDDs. Such systems were a costly means of accelerating storage performance, but they enabled storage speeds that otherwise could not be achieved. Today many of these high-speed arrays have been replaced with a single SSD at a fraction of the cost of the high speed array.

Conclusions

We expect that the performance gains of hybrid storage systems and paired storage computers will drive the inclusion of Flash memory in most computers over the next few years. Rather than displacing HDDs, Flash memory will allow customers to keep their low cost HDD storage while enjoying performance enhancements that approach those of a pure SSD-based computer. The required modicum of Flash memory will be inexpensive enough to afford users these benefits without requiring a significant price premium.

Within the next few years it is likely that all computers will contain Flash memory as a recognized part of the computer storage hierarchy. Figure 6 shows what this computer memory/storage hierarchy could look like with higher cost per GB as one goes up the pyramid and lower cost as one descends. Although some computers may use only SSDs for mass memory – eliminating the use of an HDD altogether – it is likely that the majority will combine Flash memory with HDDs. The growth of hybrid and paired storage computers will drive the use of Flash memory in computers and likely cause a synergistic growth in both HDD and Flash memory demand, similar to that observed in consumer electronic storage applications [v].

Figure 6: Computer storage hierarchy including Flash memory



i **HDDs and Flash Memory, A Marriage of Convenience**, Tom Coughlin and Jim Handy, available from Coughlin Associates (www.tomcoughlin.com) or Objective Analysis (www.Objective-Analysis.com).

ii **Are Hybrid Drives Finally Coming of Age?**, Jim Handy, Objective Analysis, 2010.

iii Seagate Momentus XT Introduction Presentation, May 2010.

iv **Unleashing The Value of Solid-State Drives for DB2 Workloads**, IBM Data Management Magazine, Issue 1, 2010, Volume 15, No. 1,

v **Flash and HDDs: Symbiosis or Survival of the Fittest?**, T. Coughlin, J. Handy, R. Hoyt, White paper published in 2009 (available at http://www.tomcoughlin.com/techpapers.htm)

About the Authors

Tom Coughlin, President, Coughlin Associates, is a widely respected storage analyst and consultant. He has over 30 years in the data storage industry with multiple engineering and management positions at high profile companies. Tom is a frequent presenter at trade shows and technical conferences and an organizer of several industry events.

Dr. Coughlin has many publications and six patents to his credit. Tom is also the author of Digital Storage in Consumer Electronics: The Essential Guide, which was published by Newnes Press in 2008. Coughlin Associates provides market and technology analysis (including regular reports on digital storage technologies and applications such as professional media and entertainment, consumer electronics, and a newsletter). His company, Coughlin Associates, also provides consulting services.

Tom is active with SMPTE, IDEMA, SNIA, the IEEE Magnetics Society, IEEE Consumer Electronics Society, and other professional organizations. Tom is the founder and organizer of the Annual Storage Visions Conference (www.storagevisions.com) and a partner to the annual Consumer Electronics Show, as well as the Creative Storage Conference. Tom is also the chairman of the annual Flash Memory Summit. He is a Leader in the Gerson Lehrman Group Councils of Advisors and a member of the Consultants Network of Silicon Valley (CNSV). For more information go to www.tomcoughlin.com. Coughlin Associates can be contacted at 408-978-8184 or by email at tom@tomcoughlin.com.

Jim Handy, a widely recognized semiconductor analyst, comes to Objective Analysis with over 30 years in the electronics industry, including 14 years as an industry analyst for Dataquest (now Gartner) and Semico Research. His background includes marketing and design positions at market-leading suppliers such as Intel, National Semiconductor, and Infineon.

A frequent presenter at trade shows, Mr. Handy is known for his widespread industry presence and volume of publication. He has written hundreds of articles for trade journals, Dataquest, Semico, and others and is frequently interviewed and quoted in the electronics trade press and other media. Jim has served as the Senior Program Advisor for the Flash Memory Summit for the past four years and is a member of the SNIA Solid State Storage Initiative.

Mr. Handy has a strong technical leaning, with a Bachelor's degree in Electrical Engineering from Georgia Tech, and is a patent holder in the field of cache memory design. He is the author of The Cache Memory Book (Harcourt Brace, 1993), the leading reference in the field. Handy also holds an MBA degree from the University of Phoenix. He has performed rigorous technical analysis on the economics of memory manufacturing and sales, discrediting some widely held theories while unveiling other true motivators of market behavior.

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