A7
4006

# USING HYBRID DRIVES TO FACILITATE THE INDUSTRY TRANSITION FROM HARD DISK DRIVES TO SOLID STATE DRIVES

**Daniel Bednarczyk (dpb34@pitt.edu, Budny 4:00), Lawrence Kunkel (lhk3@pitt.edu, Budny 10:00)**

***Abstract*** - *The memory capacity of Hard Disk Drives (HDD) has steadily increased since their inception; unfortunately, due to the physical limitations of their moving components, the data transfer rate is significantly lower than digital methods [1]. To eliminate the setbacks of mechanical parts, engineers have developed Solid State Drives (SSD) which operate without moving components. These devices make use of a superior technology called flash memory and are able to sustain the exponential growth of the computing industry [2]. Unfortunately, manufacturing expenses and unrefined technology currently make Solid State Drives impractical for use in affordable consumer electronics. Regardless, SSDs have already become popular in applications where performance and durability take precedence over high quantities of storage.*

*If the advantages of these two technologies could be bridged, high-end processing power could be accessible to the general population on a much larger scale. To achieve this goal, engineers have developed Hybrid Drives, which blend the computational power and speed of SSDs with the cost efficiency and storage capacity of HDDs. Hybrid Drives have two separate storage spaces, one of which is a small flash memory component, the other a traditional disk [3]. To make Hybrid Drives feasible, software is being developed to determine the optimal allocation of data on each component. Considering the wide range of possibilities that Hybrid Drives create, they can serve as the catalyst for the industry transition to a sustainable new generation of data storage and computational power.*

*Key Words - Data Transfer Rate, Flash Memory, Hard Disk, Hybrid Drive, Solid State, Storage, Sustainability*

## DATA STORAGE: THE INDUSTRY DILEMMA AND HOW HYBRID DRIVES CAN MEDIATE

Even the earliest civilizations recognized the importance of recording their knowledge in a permanent format. Keeping careful records allows future generations to move forward by expanding on pre-established knowledge. By thinking ahead, human communication has evolved from etching figures in clay to the global information system in effect today. Although thousands of years have passed, the same principles still apply to modern technology.

In recent years, the computer industry has been experiencing the same developmental struggle. The rapid expansion of electronics has served as the fountainhead for unprecedented innovation and technological development, but engineers are currently facing an overwhelming dilemma. Hard Disk Drives, the current industry standard data storage medium, are failing to keep up with advancements in computer processing power. Other core components, such as the Computer Processing Unit (CPU), are failing to reach their theoretical potential when relying on HDDs. As a result, computational advancements are hindered by the restrictions of disk-based storage [2]. This inability to withstand current demands and future growth fails to provide a sustainable industry infrastructure. In this context, the term sustainability applies to technology that supports the existence and continued development of other technology. In search of a sustainable data storage successor, engineers have developed digital Solid State Drives to replace traditional memory and withstand industry demands. However, manufacturing costs and unrefined technology make them unrealistic to implement in the market [4]. In order to make the transition to Solid State Drives a reality, the industry needs a practical, intermediate device to facilitate the research and development of this technology. Parallel Distributed Computing (PDC), a professional peer reviewed journal, notes that in order to "utilize SSDs performance benefit in a cost effective way, there should be a way of integrating SSDs with HDDs, while retaining the advantages of both devices" [4]. The device to which the PDC Journal alluded has been introduced to the market and can potentially relieve the stalemate faced by the industry. Consequentially, the so-called Hybrid Drive may be the next format in a long line of data storage standards.

## THE EVOLUTION OF DATA STORAGE: PAST AND PRESENT

### Origins of Computational Memory

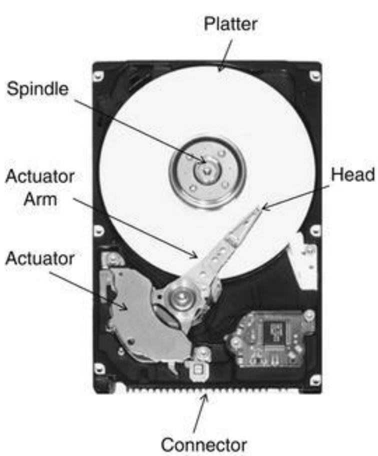
In light of the ubiquitous integration of computer technology today, it is sobering to examine its humble origins. The earliest incarnations of computers were enormous machines with less processing power than the average cell phone [5]. These machines were large, slow, loud, unreliable, and power-consuming. In spite of these setbacks, they were revolutionary and sustainable for their era. Perhaps most shocking of all, they used holes punched in cards to read and store information [1]. Less than a century later, the amount of memory available to the average cell phone dwarfs the memory on these cards. In addition to the small quantities of memory, their performance was poor and access was inconvenient [1]. The inadequate performance of these devices initiated a long series of data storage media advancements that is still continuing today.

## The Current Industry Standard: Hard Disk Drives

Following the era of punched cards, a series of inventions paved the way for the computer revolution of the late twentieth century. In 1948, the Williams Tube was introduced, which stored data by utilizing a Cathode Ray Tube [1]. However, the stored data was volatile, a term used to describe information that can only be retained while power is supplied. This development subsequently became Random Access Memory, another vital component in modern computers. Unfortunately, this type of memory did not solve the ongoing need for nonvolatile memory, so engineers developed techniques to store data on reels of magnetic tape. While the tape was a notable improvement, it still had some major flaws, namely its flimsy nature and the need to be rewound [1]. Borrowing a structural idea from vinyl records, engineers reapplied the technology behind these strips in the form of magnetic disks, which allowed for continuous operation [1]. The resulting storage medium was the Hard Disk Drive, which has, in various forms, been the industry standard medium since its inception in the mid-1950s.

This new type of drive proved to be a much more compact and practical method of storing magnetic data. Specifically, it physically writes data onto rapidly rotating magnetic disks, otherwise known as platters [6]. These disks are mounted to spindles, which allow them to spin at high rates, typically 5,400 revolutions per minute, thus creating a magnetic field [6]. While spinning, an extended arm called an actuator passes over each platter and measures the current induced by the varying strength of the magnetic field (see Figure 1).

**FIGURE 1 [6]**

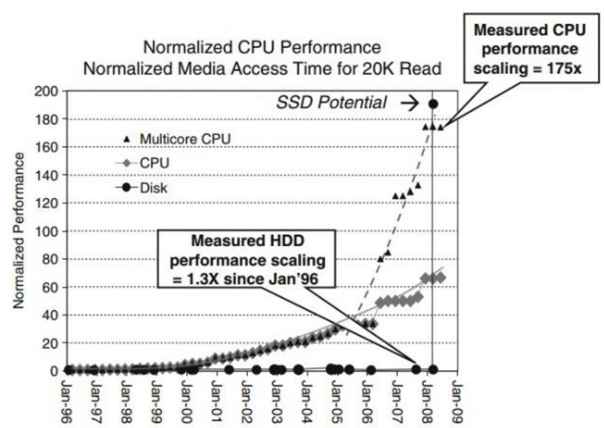



**The Basic Components of the Hard Disk Drive**

The data is stored in binary digits, otherwise known as bits, represented by either a 0 or a 1. The varying current determined by the bits acts as a logic gate which can then be read as a binary message and interpreted by the computer. Writing data to the magnetic disk is a similar process, but in reverse. Instead of measuring the current, the actuator generates its own binary current, changing the polarity of the magnetic field in each sector [6]. This process causes the data on the disk to be rewritten, establishing a new measurable arrangement of polarities. While the main components of HDDs have remained the same, each individual component has evolved to adapt to the constantly changing computer industry.

When the first commercial Hard Disk Drive was released in 1956, it was about the size of two refrigerators and weighed more than a ton [5]. In spite of its bulk, it could only store about 5 MBs of data [5]. For perspective, this is roughly equivalent to the size of a single digital music file [5]. This comparison clearly illustrates the ongoing tradeoff between physical size and memory capacity, a trend that has been consistent for more than half a century. Fortunately, the cost per unit storage has steadily decreased as the technology has matured, allowing HDDs to become a sustainable medium during the rapid expansion of the electronics industry. Although HDDs offer a substantial amount of memory capacity, their mechanical parts restrict the speed at which data can be read and written [6]. Furthermore, the speed of computer software has increased exponentially since HDDs were first introduced half a century ago. Springer Microelectronics, a subsidiary of industry leader Springer Publishing Company, reports that, “since 1996, CPU computing and processing performance of mobile and desktop systems has grown a remarkable thirty times whereas the performance of Hard Disk Drives has managed to grow around 30% over the same period” [6]. As a result, many modern computers can process information faster than HDDs are able to read it, which results in a bottleneck for the applications of computer software. In other words, this speed limitation prevents processors from reaching their full operating potential. There has been a great disparity between the growth of CPU power and Hard Disk Drive read/write speed (see Figure 2).

**FIGURE 2 [6]**



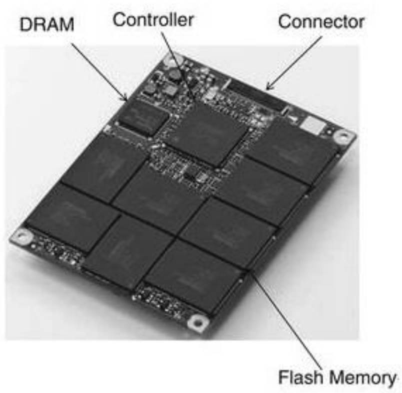

**The Performance Growth of HDDs vs SSDs**

In order to combat the restrictions of moving parts and create a sustainable technology, engineers have developed new methods of storing data that make use of fully digital systems, otherwise known as flash memory.

### Recent Developments: Flash Memory

Digital data storage has many considerable benefits over traditional methods because it lacks the moving parts that hinder Hard Disk Drives. Accordingly, secondary storage devices that make use of flash memory are called Solid State Drives (SSD), a name which refers to their motionless structure, which actually consists of few physical parts (see Figure 3).

**FIGURE 3 [6]**




**The Basic Components of the Solid State Drive**

Flash memory stores data using a series of semiconductor logic gates made of tiny transistors [6]. Each transistor acts as a switch which represents a binary digit; these are the same bits that are stored in the magnetic field of a Hard Disk Drive. By default, each transistor is in the "off" position and represents a 0. If a given transistor receives a current, it switches to the "on" position and represents a 1 [6]. The computer is able to read these drives by determining the position of each transistor. The computer recognizes these signals as binary code and is able to interpret them for the user.

The arrangement of the transistors in the circuit determines how the information is read. The transistors are either wired in series or parallel; these configurations are called NAND and NOR, respectively [6]. Each type uses a different logic pattern to represent data. Due to their structure, NOR drives are used almost exclusively in read-only devices, while NAND drives are used in everyday read/write applications [6]. In either case, SSDs are able to access all of their embedded information simultaneously; as a result, the access time is much quicker than for mechanical methods.

Because Solid State Drives do not require any moving parts, they are not restricted by the physical limitations of Hard Disk Drives. This freedom allows them to provide satisfactory performance to other core computer components that rely on data storage. Of particular note, SSDs are able to support the processing power of modern CPUs which are fundamental to a sustainable computing environment [1]. However, the cost per unit memory and limited lifespan of Solid State Drives hinders their growth. The technology is, as of yet, still impractical for use in consumer electronics with considerable memory requirements. Because of these obstacles, SSDs have not been able to reach the same level of acceptance as traditional memory, despite their numerous advantages [1]. Both technologies have unique advantages and disadvantages, but neither one is able to bear the weight of current industry demands.

## A COMPARATIVE ANALYSIS: TRADITIONAL AND FLASH MEMORY

### Processing Speed

The foremost reason for the development of flash memory has been to overcome the speed restrictions of disk-based memory. As previously stated, modern software is capable of outperforming even the best HDDs on the market today. On average, Hard Disk Drives can transfer data at a rate of 200 megabytes per second (MB/s); comparatively, Solid States typically reach speeds of about 500 MB/s [6]. In the world of computational power, this is an astronomical difference. Furthermore, Solid State Drives benefit from miniscule access latency, a term used to describe the time between initiation of a command and the actual retrieval of data. The PDC Journal observes that because "SSDs do not generate mechanical overhead, such as seek time or rotational delay, to locate the desired data, it is possible to deploy exceptionally high I/O" [4]. In other words, the location of data on the drive does not impact the transfer rates of Solid State Drives, but dramatically impacts Hard Disk Drives. Additionally, HDDs are suspect to data fragmentation, which means that related groups of data can be spread across the entire disk [4]. The more dissipated the data is, the longer the read time. Conversely, all of the data on flash memory can be read simultaneously, minimizing latency time. Another time-saving feature of Solid State Drives is their near-instantaneous start-up time [4]. While the boot time of SSDs is limited only by the speed of flowing electrons, HDDs must accelerate their disks to operational speed before beginning data transfer, meaning that time is wasted spinning the platters. Each of these latencies add up quickly, making operation inconvenient for the user.

### User-Friendliness

In addition to the speed enhancements, the non-moving structure of SSDs allows for a more user-friendly product. HDDs can only read information when the disk is spinning, creating the familiar 'whirring' noise often associated with these devices; conversely, SSDs are silent during operation [6]. The rapid rotation of the disks also generates large amounts of heat due to friction, this creates the need for increased cooling inside the computer casing [1]. Solid States do not require fans for cooling, and are therefore unobtrusive.

Another factor that makes SSDs a more consumer-friendly product is their lightweight structure. The semiconductor parts of SSDs do not weigh nearly as much as their HDD counterparts, which consist mostly of metallic materials. These factors combined lead to a large difference in weight, leaving HDDs the heavier of the two.

In addition to their lightweight structure, they are also smaller in size. Both drives use the same standard 3.5 inch enclosure for compatibility reasons, but Solid State Drives do not occupy the entire encasement [6]. Springer Microelectronics notes that "an SSD actually does not have to come packaged in a HDD form factor. The NAND Flash memory components and SSD controller can be soldered onto a printed circuit board. These small form factors enable thin, lightweight portable devices such as ultrathin laptops and tablets" [6]. Smaller drives means smaller consumer products; however, even small products must be able withstand daily wear and tear.

## Physical Reliability

Springer Microelectronics continues to state that, "while HDDs are the most common secondary storage devices, their high power consumption and low shock resistance limit them as an ideal mobile storage solution" [6]. Consumer electronics must be able to provide reliable energy while being resistant to physical abuse. Despite the lightweight form factors of SSDs, they are surprisingly more durable than HDDs. Once again, their static frame leads to numerous advantages. Because they do not have any fragile disks, SSDs are more resistant to shock and trauma than Hard Disk Drives [6]. In addition to physical ruggedness, Solid State Drives are also resistant to magnetic fields, a benefit that HDDs do not possess. Flash memory uses semiconductors to store data instead of a magnetic field, therefore eliminating the threat of electromagnetic disturbances.

Although the short-term reliability benefits of flash memory are ideal, the overall lifespan can be shortened by semiconductor degradation. Each time data is saved to a Solid State Drive, the semiconductor gates are rearranged. There is a limited number of times that any given transistor can be switched before there is a deterioration in performance and reliability [6]. By comparison, the magnetic field in Hard Disk Drives can be written and rewritten an infinite number of times without any noticeable reduction in performance.

Once individual transistors exhaust their maximum number of write cycles, they may become fixated in the "off" position, reducing the total amount of storage capacity or causing stored data to become corrupt. Tech Directions observes that "SSDs may well endure for ten years or more under normal use" [7]. Regardless, performance degradation poses serious problems for the computing industry. This concern has been noticed by many leaders in the computer hardware industry, such as SanDisk affiliate Pliant Technology Incorporated. Specifically, they recognize that, "high performance computing environments require consistent performance over time and across a wide range of workloads" [8]. To counteract the effects of SSD degradation, engineers are developing combative algorithms to make use of a technique called wear leveling.

The idea behind wear leveling is that transistors have a finite number of erasures. To minimize the number of times that data is erased, the memory controller ensures that unused cells are written to before overwriting currently used cells. The peer reviewed SIGOPS Operating Systems journal highlights this process: "during write allocation, the class of the current write disk is compared to the desired class of storage for the buffer being allocated. If these do not match, a new current write disk is chosen" [3]. This procedure dramatically reduces the number of times that any given transistor is erased, therefore increasing the overall lifespan of the drive.

## Environmental Impact

Because no parts are required to physically move, Solid State Drives require less energy and therefore consume less power than Hard Disk Drives. One of the greatest challenges in modern engineering is developing devices that give efficient performance with little impact on available resources, encouraging the ideals of sustainability [9]. By the nature of electronic devices, they become outdated quickly. The end result is usually a large amount of waste leftover from discarding the previous generation of devices. Many companies, like Best Buy and Staples, have recently initiated recycling programs to reuse parts from electronic devices, therefore reducing waste and the impact of production [9]. The transition from HDDs to Hybrid Drives would abandon countless HDDs, but many parts can be recycled because they share several core components with Hybrid Drives. These pieces are returned to manufacturers and used for the next generation of devices, reducing wasted material. By reducing the negative aspects of innovation and development, programs like these help create a more sustainable world, allowing progress to thrive.

## Manufacturing Cost

Another major restriction to the development of SSDs is their high cost per unit memory. Flash memory averages \$3.00 per gigabyte, which is about ten times greater than the average of Hard Disk Drives, which is only thirty cents per gigabyte [4]. This difference in cost is possibly the greatest reason that Hard Disk Drives continue to maintain their position as the industry standard. Tech Directions predicts that, "as with just about all relatively new digital technologies, SSDs come with a price premium, but that premium is bound to decline over time” [7]. The high cost of Solid State Drives currently makes them unsustainable because they would raise the cost of personal computers, making them less accessible to the average consumer. To compare, the price of Hard Disk Drives continued to fall for many years after they were first introduced; it is likely that Solid State Drives will follow the same pattern as the technology is refined making them more sustainable over time.

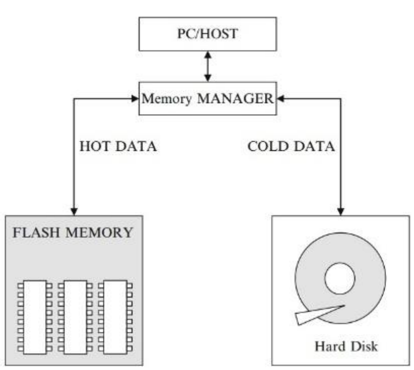
## ENGINEERING A SOLUTION: HYBRID DRIVES

If the advantages of these two technologies could be bridged, flash memory could be accessible to the general population on a much larger scale. Springer Microelectronics predicts that this increased market for Solid State Drives would mean “new opportunities in enterprise and client computing applications” [6]. To make these innovations possible, engineers have developed Hybrid Drives, which blend the computational power and speed of SSDs with the cost efficiency and storage capacity of HDDs.

### Device Hardware

Hybrid Drives are essentially an HDD and SSD alongside one another, acting as a single drive. The hardware for each individual component is basically the same as each independent drive (see Figure 4 on page 5). The quality of Hybrid Drives that makes them so groundbreaking is the way in which the two separate drives are united. Even though there are actually multiple drives inside the hardware, the computer recognizes them as a single memory bank, though it has simultaneous access to each drive.

**FIGURE 4 [6]**




**The Physical Arrangement of Hybrid Drives**

Not only does the Hybrid Drive benefit from the individual advantages of each component, it gains additional strength from their union. Once again, Springer Microelectronics notes that “we further improve performance by allowing concurrent access across the two types of storage devices” [2]. This added feature of multitasking increases the computer’s ability to transfer data. This advantage can be further increased when used in conjunction with specialized software.

### Accompanying Software

The hardware would not be nearly as useful without integrating it with special software. The fundamental idea behind Hybrid Drives is that they are able to increase productivity substantially through the inclusion of just a small amount of flash memory adjoined to the disk memory. This performance optimization is made possible by software which places data in specific locations based on frequency of access. Springer Microelectronics cites an algorithm that “determines which device to place data on in order to take advantage of their desirable characteristics while trying to overcome some of their undesirable characteristics” [2]. Because of the mindful distribution of data, the overall access time is greatly reduced.

According to Intel, their Smart Response Technology, a special data allocation software, boasts three times faster access to crucial applications and files by distributing data for optimal performance [10]. They continue to explain that high-value, multi-purpose data takes precedence over background tasks when determining whether to place it on the flash or Hard Disk portion [10]. Valuable data, including operating systems and frequently accessed files, are placed on the flash memory. Utilizing this simple data placement algorithm, “hot” files are booted significantly faster, while “cold” files boot at the same speeds they would normally. This process, along with the ability to simultaneously use both drives, nets an overall increase in load speeds.

## THE ULTIMATE GOAL: POTENTIAL APPLICATIONS OF SSDS AND HOW HYBRIDS CAN MAKE THEM POSSIBLE

If flash memory could be refined, its potential benefits would be deeply felt across the computing industry. The applications of such technology are far-reaching and groundbreaking. Unfortunately, as previously stated, the technology is not quite ready to handle the demands of the computing industry. Solid State Drives are too expensive to be sustainable on the consumer market, but Hard Disk Drives can no longer keep up with the processing power of modern CPUs. Consequently, something must be done to facilitate the development of flash memory. Springer Microelectronics claims that “the real issue at hand is the need for storage technology that can match the exponential ramp in processor performance over the past two decades” [6]. This is the role that the Hybrid Drive can play in assisting the computer industry; it can act as the catalyst for this industry transition. Hybrid Drives are the best way to provide a worthy intermediary memory drive while flash memory is prepared for widespread implementation. When the technology is ready, the applications will be felt in all corners of the computing infrastructure.

### High-Performance Computing

Highly technical and mathematically intensive fields, where wasted time can have huge consequences, require highly accurate calculations done as quickly as possible. Just to name a few fields, “fluid dynamics, seismic tomography, aerospace design, climate simulation, and biological modelling” all require high-end processing power [6]. This heavy computational number crunching is achieved through clusters of high performance computers. In addition to high level computations, medical and military applications need lightning fast processing power because every second counts. These fields require the fastest technology because even small delays can add up quickly [6]. The integration of flash memory could eliminate the restraint that HDDs have on this line of work, allowing the computers to perform calculations at their maximum potential.

Other fields require the storage of massive files, such as computer aided drafting and population modelling. These files take far too long to load from an HDD but an SSD large enough to hold them is very costly [6]. These models require a great deal of processing power and often require the most cutting edge technology available. When transferring files of this magnitude, flash memory can allow for much greater performance. However, the technology must be further developed before it can be integrated into such delicate and demanding systems.

### High Bandwidth Web Services

Following the rapid decline of home media and video rental stores, online streaming services have assumed the position as the primary outlet for renting movies and listening to music. These services require high amounts of bandwidth and data transfer per second. In addition, high definition video has recently increased in popularity, meaning that the amount of data that needs to be transferred is increasing as well. Springer Microelectronics notes that “fast and reliable video streams are necessary to provide a satisfactory customer experience.” [6]. Online streaming services need to take advantage of flash memory in order to accommodate the high processing demands of their services and unpredictable behavior of their users. In fact, “response times increase exponentially as the number of user requests increases. In addition, these user requests are not usually constant or predictable and the servers have to be able to manage spikes in demand” [6]. Only Solid States have the potential to process such high volumes of unpredictable data.

### Compact Mobile Devices

Currently, the industry standard size for memory drives is 2.5 inches for personal laptops. As a result, the drive is often one of the largest components of the physical computer, restricting the space available inside the casing. Solid State Drive manufacturers have adopted the 2.5 inch standard for the sake of compatibility with Hard Disk Drive form factors; however, they do not require the entire space [1]. Taking note of this potential, Springer Microelectronics notes that “due to its compelling size and performance characteristics, flash memory is now expanding its reach into the once-exclusive domain of hard disk drives in the form of Solid State Drives” [6]. If Solid State Drives continue to grow and become the industry standard, they could shrink the size of computer hardware because they provide greater flexibility in terms of physical dimensions. In addition to their small size, they require less energy to operate and therefore can extend battery life [6]. This makes them ideal for integration in mobile electronics, where size and battery life are crucial.

### Consumer Availability

Each of the aforementioned applications have a single goal in common: increased large-scale consumer availability. Though Solid State technology currently exists, the goal that many proponents of Hybrid Drives have in mind is greater accessibility to technology that is currently only available to a limited market and at a very high cost. If Hybrid Drives were to become the industry standard, the public would soon experience noticeably faster computers for little additional cost. During this time, the SSD could be further improved until such a time when it alone is ready to become a sustainable industry standard. At that time, computers would once again experience a perceptible speed increase, continuing the tradition of technical innovation and exploration. The goal in mind here, and in the broad scope of engineering, is to bring the best technology to as many people as possible.

Of course, these claims pose the question of when to expect practical Solid State technology. History has shown many times that computer speed increases much faster than many other concurrent technologies. For example, Intel co-founder Gordon Moore once observed that the number of transistors contained in electronics nearly doubles every eighteen months [11]. This observation was coined Moore’s Law and has been surprisingly accurate since its original statement in 1965 [11]. If technological growth continues to expand at such an alarming rate, it will not be long before Solid States are ready to be an independent medium. After all, flash memory has only existed for about twenty years, only a third of the time that HDDs have been around. Given another few years, it is likely that we will see SSDs in more places and in greater numbers.

**Daniel Bednarczyk**
**Larry Kunkel**

## HYBRID DRIVES IN A SUSTAINABLE INDUSTRY INFRASTUCTURE

Improved data storage clearly has great potential to revolutionize many different fields. In the past few decades, technology has become an integral part of many fields that previously had no affiliation with computers. In fact, the consumer market is at the point where technology allows near-seamless integration of unrelated parts of life, creating an improved user experience [9]. The benefits of this social change are especially noticed in the areas of communication and consumer accessibility to personalized technology. As this technology plays a greater role in our lives, it becomes an inseparable part of our identity. Children are introduced to computers at a very young age, both as an educational tool and as a field of scientific exploration [9] In time, observers will notice that people grow alongside the technology, simultaneously maturing and playing a role in the other's development. This reflection has profound implications: the continued development of mankind is reliant on the development of technology. Furthermore, mankind must embrace and support the development of new technology in order to sustain itself and expand its outreach.

Because of the need to continue technological development, these fields need devices that are able to provide a sustainable foundation for new ideas and innovation. As previously explored, Hard Disk Drives are creating a widespread bottleneck for the performance of software in all fields that rely on computational power. Unwarranted attachment to restrictive devices does not embrace the ideals of sustainability, which govern the direction of quality engineering [9]. In order to continually improve upon the past and follow the tradition established by the great innovators of our world, we must seek ways in which to overcome the restrictions of our current technology. In the field of data storage, Solid State Drives show the most promise as far as sheer performance is concerned, but they are not yet fully sustainable. Because of their high production cost and limited lifespan, they do not meet all of the requirements of a sustainable device. If they were to be implemented prematurely, they would surely fail commercially [9]. The industry is at a stalemate; HDDs are not sustainable because of their performance and SSDs are not sustainable because of their cost. A solution has finally arrived: the Hybrid Drive.

It will likely take a few more years to perfect the technology behind flash memory, but Hard Disk Drives are incapable of carrying the weight of the computing industry in the meantime. It is in this respect that Hybrid Drives provide a sustainable answer; they can allow mankind to continue innovating instead of waiting for the development of one specific technology. Because so many fields depend on data storage, any delay in its development will affect other industries. However, there is a promising future for these fields once the new technology has been implemented.

## A LOOK AT THE FUTURE OF DATA STORAGE TECHNOLOGY

The past century has seen a number of technological developments that pushed the boundaries of computing power. Hard Disk Drives ruled the industry for half a century and Solid State Drives show promise as a worthy successor. It seems likely that Solid State technology will continue to grow for many years. In fact, Springer Microelectronic predicts that, "driven by the proliferation of thin and light mobile devices and the need for near-instantaneous accessing and sharing of content through the cloud, SSDs are expected to become a permanent fixture in the computing infrastructure" [6]. Although neither SSDs nor HDDs can bear the weight of the industry as it stands, if the advantages of these two technologies could be bridged, high-end processing power could be accessible to the general population on a much larger scale. In order to achieve this goal, engineers have developed Hybrid Drives, which blend the computational power and speed of SSDs with the cost efficiency and storage capacity of HDDs.

Because flash memory is expensive and traditional memory is comparatively slow, the next logical step is to combine the advantages of these two technologies in the Hybrid Drive. Because Solid State Drives still need some time to reach perfection, the investment into hybrid technology will be worthwhile. Considering the possibilities that Hybrid Drives can generate, they will serve as the catalyst for the industry transition to the next generation of data storage and computational power.

## REFERENCES

[1] T. Chow, S. Piramanayagam. (2011, September). "Developments in Data Storage: Materials Perspective." *Wiley-IEEE*. (Print Book).

[2] N. Fisher, Z. He, M. McCarthy. (2012, January). "A Hybrid Filesystem for Hard Disk Drives in Tandem with Flash Memory." *Springer*. (Journal Article).

[3] J. Strunk. (2012, December). "Hybrid Aggregates: Combining SSDs and HDDs in a Single Storage Pool." *ACM SIGOPS Operating Systems Review*. (Journal Article).

[4] J. No. (2012, December). "NAND Flash Memory-Based Hybrid File System for High I/O Performance." *Journal of Parallel and Distributed Computing.* (Journal Article).

[5] "IBM 305 RAMAC." (1956, September). (Accessed 2014, March 3). *IBM Hardware Archives.* (Database).

[6] K. Eshghi, A. Marelli, R. Micheloni. (2013). *Inside Solid State Drives*. New York, NY: Springer. (Print Book).

[7] R. Goldsborough. (2013, October 1). "Understanding Solid State Drives." *Tech Directions*. (Journal Article).

[8] H. Mehling. (2009, September 30). "SSD Makers Wrestle with Performance Degradation." *Enterprise Storage.* (Article).

[9] Brown, Alan S. (2011) "Sustainability: ASME's Third Annual Survey Finds That Engineers Are Still Trying To

Understand How Sustainability Fits Into Their Workflow." *Mechanical Engineering-CIME* (Journal Article).
[10] "Intel Smart Response Technology." (2011). *Intel Corporate Website*. (Online Article).
[11] "Moore's Law." (2004). "The Thames & Hudson Dictionary of Design Since 1900." *London: Thames & Hudson.* Credo. (Reference).

## ADDITIONAL SOURCES

M. Chiappetta. (2012, May). "Set up Intel's Smart Response SSD Caching: Use the Technology to Enhance your PC's Performance." *IDG Consumer & SMB, Inc*. (Journal Article).
"Seagate Delivers World's Fastest Hard Drive for Laptop Computers; Solid State Hybrid Drive Offers Solid State Performance with the Capacity and Value of Hard Disk Drives." (2012, May 24). *Business Wire*. (Article).

## ACKNOWLEDGEMENTS

We would like to thank the following for their contributions and support of this conference paper: Family and friends, our co-chair Samantha Small, our session chair Greg Wunderley, our writing Instructor John Calvasina, Dr. Dan Budny, Beth Newborg, our Resident Assistant Dominic Stokes, and everyone else for their continued support and dedication.