Hard Disk Drives (HDDs) vs. Solid State Drives (SSDs)

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Abstract—**This paper sets out to explain the differences between Hard Disk Drives and Solid State Drives. While the history of HDDs is long and rich, SSDs have been on rise due to their rich benefits. Without doubt, each technology has its own benefits in terms of their applications. This paper also includes some metrics surrounding the price, performance, and capacity of each. Will SSDs lead to the extinction of HDDs? These are questions that only time will tell.**

I. INTRODUCTION

The I/O subsystem provides the mechanism for communication between the CPU and the outside world (I/O devices). When considering one of the design factors it is evident that storage plays a monumental role in the overall execution time of the system. In the beginning of time there were not many options available, now there are several hard drives to store the data on your laptops and PCs. Solid state and hard disk drives are the top two options presently available, with hard disks being phased out wherever possible. Due to its compelling price/performance characteristics, NAND Flash memory is now expanding its reach into the once-exclusive domain of hard disk drives and DRAM in the form of Solid State Drives (SSDs). As CPU performance has scaled through faster cores and multi-core architectures, hard disk drive (HDD) performance has stalled due to limitations in increasing the rotational speed of the magnetic media. This paper will set out to cover the history, technology, and performance of both technologies.

II. HISTORY

2019 marks the 63th commemoration of the respected Hard Disk Drive (HDD). While new PCs progressively swing to Solid State Disks (SSDs) for fundamental stockpiling, HDDs remain the winner of minimal effort, high-limit information stockpiling. That is a main motivation behind why regardless we use them in our Storage Pods. How about we take a turn the wayback Machine and investigate the historical backdrop of hard drives. We should likewise consider what the future may hold for HDD.

RAMAC which stands for "Random Access Method of Accounting and Control" is the first commercial hard disk drive-based computer IBM made. Its storage system was called the IBM 350. RAMAC was as big as the size of two refrigerators and it required an entire room to operate and inside were stacked with 50 24-inch platters.

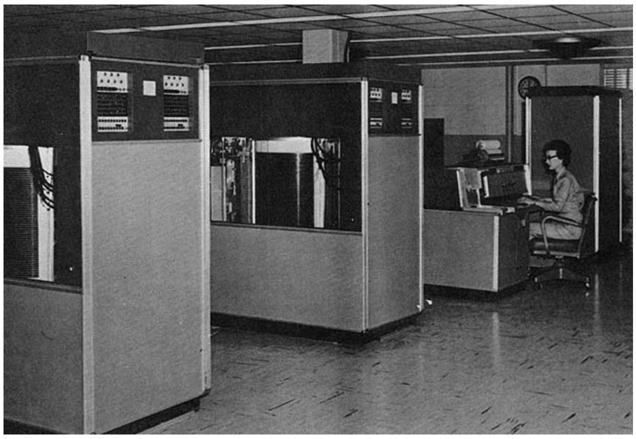

Figure 1: First Hard Disk Drive

For that, RAMAC customers ended up with less than 5 MB. IBM's marketing people didn't want to make RAMAC store any more data than that. They had no idea how to convince customers they'd need more storage than that. IBM customers paid over $3,200 for the privilege of accessing and storing that information a month that is equivalent to almost $30,000 per month in 2019.

Sixty some years ago the cost of the data storage was about $640 per megabyte, per month. At IBM's 1956 rates for storage, a new iPhone 10 would cost you about $20.5 million a month. These days you can fit 2 TB onto a SD card which is the measure of a postage stamp, yet 50 years back, it was an altogether different story. IBM kept on refining early hard disk drive but systems were still enormous and massive.

By early/mid 1960s, IBM's clients were eager for more storage limit, yet they just didn't have the space to continue installing refrigerator-sized storage devices. So the people at IBM camp up the idea of Removable storage.

In 1962 IBM introduced 1311 Disk Storage Drive, which let IBM's mainframe customers expand their storage capacity as much as they needed or could afford. IBM shrank the size of the disks to half, from 24 inches in diameter down to 14 inches. The 9-pound disk packs fit into a device about the size of a modern washing machine. Each pack could hold about 2 MB.

On the other hand, surprisingly the journey of SSDs development began in 1950s. During this time, it had two similar technologies; card capacity read-only store and magnetic core memory.

Late 1970s and early 1980s came as a major historical changes to SDDs. SSDs experienced a major wave of implementation in the early Cray, IBM and Amdahl supercomputer's semiconductor memory. However, due to their high prices, people rarely used them. The vast majority of instruments created at the time contained an electrically alterable ROM.

Figure 2: Solid State Technology

By early 2000s Samsung, SanDisk and others brought to market flash SSDs that acted as drop-in replacements for hard disk drives. SSDs have gotten faster, smaller and more plentiful. Now most PCs, Macs and smartphones all include flash storage of all shapes and sizes and will continue to move in that direction and for that reason SSDs provide better performance, better power efficiency.

III. ARCHITECTURE

Hard disk drives have been the main form of persistent data storage systems for decades and the development of these I/O device is still ongoing. It is worth understanding the details of the disk operation for several reasons.

Let's start by first understanding the interface to a disk drive. Each drive consists of a large amount of sectors, each of which can be read or written. These sectors are numbered from 0 to n on a disk. Another way to think of these sectors is as the address space of the drive.

Now we can begin to move into the geometry of a modern disk drive. Starting with the platter, a circular hard surface on which data is stored persistently by making magnetic changes to it. It is possible that a disk has several platters with each side being referred to as a surface. It is the coating magnetic layers on these platters that allows for the drive to persistently store bits even when the drive is powered off. These platters are bound together around the spindle, which is connected to a motor that spins the platter around at a constant rate. The rate in rotation is typically measured in rotations per minute (RPM) where values usually lie between 7200 RPM to 15000 RPM range. Data is encoded on each surface in concentric circles of sectors; we call one such concentric circle a track. A single service can contain many thousands of tracks, tightly packed together, with hundreds of tracks fitting into the width of a human hair!

In order to be able to read and write from the surface, an additional mechanism is needed to allow us to either sense the magnetic patterns on the disk or induce a charge in them. This process is accomplished by the disk ahead, where there is once per surface. The disk head is attached to a single disk arm, which move across the surface to position the head over the desired track.

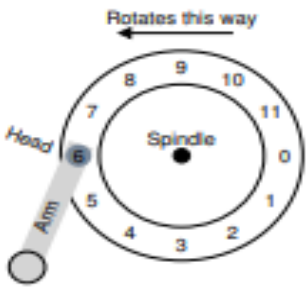

Figure 3: A Single Track Plus A Head

We can understand how disks work by examining a model one track at a time. Assume we have one track, this track has 12 sectors, each of which is 512 bytes in size and addressed therefore by the number 0 through 11. The single platter we have here rotates around the spindle, to which a motor is attached. Of course, the track by itself isn't too interesting; we want to be able to read or write those sectors, and thus we need a disk head, attached to a disk arm, as we now see. In the figure above, the disk head, attached to the end of the arm, is positioned over sector 6, and the surface is rotating counter-clockwise.

Now using our one track disk as an example, let's now see how a request would be processed. In our simple disk it would just wait for the desired sector to rotate under the disk head. In a modern drive this is seen as a monumental component in the I/O service time, also known as rotational delay. In this example, if the full rotational delay is R, the disk has to incur a rotational delay of about R2 to wait for 0 to come under the read/write head (if we start at 6).

Figure 5: Three Tracks Plus A Head (Right: With Seek)

It is super unrealistic for a disk to have a single track, modern disks usually deal in the millions. Let's now consider a disk surface with three tracks, each track containing several sectors. To understand how the drive might access a given sector, we now trace what would happen on a request to a distant sector. To service this read, the drive has to first move the disk arm to the correct track (in this case, the outermost one), in a process known as a seek. Seeks, along with rotations, are one of the most costly disk operations.

After the seek, the disk arm has been positioned over the proper track and the platter has been rotated. When the correct sector has been reached the final phase of I/O will take place. This step is known as the transfer, where data is either read from or written to the surface. At this point is when we have a completion timeline of the I/O operation(s): first a seek, then waiting for the rotational delay, and finally the transfer.

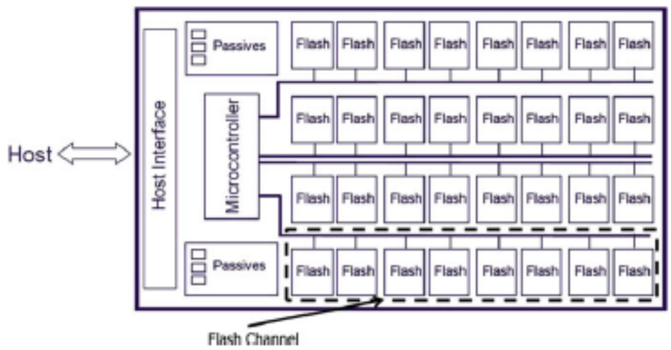

Figure 4: Block diagram of a SSD

Let’s now move to the architecture of Solid State drive. SSD is a complete, small system where every component is soldered on a PCB and is independently packaged. Flash cards, USB flash drives are examples of this technology which many of us have been using for years. These examples of electronic systems are based on non-volatile memories.

A solid state disk, as shown in the figure above has memories, a controller, and some other components we won't mention here. The fundamental component at play here is the non-volatile memory deployed here. Flash chips are designed to store one or more bits in a single transistor. These flash chips are organized into banks or planes which consist of a large number of cells. These banks are accessed in two different size units, a block (e.g., 128KB-256KB) or a page (e.g., 4KB). It is important to understand the differences between blocks and pages; it turns out this distinction is critical for flash operations such as reading and writing, and even more so for the overall performance of the device.

Flash chips support three low-level operations: Read, Erase, and program.

Read (a page): A client of the flash chip can read any page, simply by specifying the read command and appropriate page number to the device.

Erase (a block): Before writing to a page within a flash, the nature of the device requires that you first erase the entire block the page lies within.

Program (a page): Once a block has been erased the program command can be used to change some of the 1’s within the page to 0’s, and write desired contents of a page to the flash.

Please see an example of states transition after various erase and program operations within a 4-page block:

		iiii	*Initial: pages in block are invalid (i)*
Erase()	→	EEEE	*State of pages in block set to erased (E)*
Program(0)	→	VEEE	*Program page 0; state set to valid (V)*
Program(0)	→	**error**	*Cannot re-program page after programming*
Program(1)	→	VVEE	*Program page 1*
Erase()	→	EEEE	*Contents erased; all pages programmable*

Figure 6: State transitions in SSD

In summary reading a page is much easier than writing a page. Flash chips do this quite well, and quickly; in terms of performance, they offer the potential to greatly exceed the random read performance of modern disk drives, which are slow due to mechanical seek and rotation costs.

Writing a page is much trickier because the entire block must first be erased, and then the desired page programmed. This is an expensive operations and can take frequent repetitions of this program/erase cycle. When designing a storage system with flash, the performance and reliability of writing is a central focus.

IV. Comparison

Now it’s time to do some comparisons and determine which might be best for your individual needs, which one should you go for? The information below illustrates the comparison of SSD and HDD with their respective advantages.

Power Draw / Battery Life
SSD - Less power draw, averages 2 – 3 watts, resulting in 30+ minute battery boost
HDD - More power draw, averages 6 – 7 watts and therefore uses more battery

Cost
SSD - Expensive, roughly $0.20 per gigabyte (based on buying a 1TB drive)
HDD - Only around $0.03 per gigabyte, very cheap (buying a 4TB model)

Capacity
SSD - Typically not larger than 1TB for notebook size drives; 4TB max for desktops
HDD - Typically around 500GB and 2TB maximum for notebook size drives; 10TB max for desktops

Operating System Boot Time
SSD - Around 10-13 seconds average bootup time
HDD - Around 30-40 seconds average bootup time

Noise
SSD - There are no moving parts and as such no sound
HDD - Audible clicks and spinning can be heard

Vibration
SSD - No vibration as there are no moving parts
HDD - The spinning of the platters can sometimes result in vibration

Heat Produced
SSD - Lower power draw and no moving parts so little heat is produced
HDD - HDD doesn't produce much heat, but it will have a measurable amount more heat than an SSD due to moving parts and higher power draw

Failure Rate
SSD - Mean time between failure rate of 2.0 million hours
HDD - Mean time between failure rate of 1.5 million hours

Encryption
SSD - Full Disk Encryption (FDE) Supported on some models
HDD - Full Disk Encryption (FDE) Supported on some models

Magnetism Affected?
SSD - An SSD is safe from any effects of magnetism
HDD - Magnets can erase data

As we can see from the result above, SSD clearly has more advantages over HDD. But it doesn't make HDD useless and inefficient because it all depends on individuals' needs and most importantly the variance of costs between the two and you might have to consider following rules to figure out which might be the right choice for your needs.

An HDD might be the right choice if:

- You need lots of storage capacity, up to 10TB
- Don't want to spend much money
- Don't care too much about how fast a computer boots up or opens programs - then get a hard drive (HDD)

An SSD might be the right choice if:

- You are willing to pay for faster performance
- Don't mind limited storage capacity or can work around that (though consumer SSD now go up to 4TB and enterprise run as high as 60TB)

HDDs are yet still a popular choice for some buyers, they choose HDD as the storage in their new PC just because it is a lot less expensive However, more and more user desire top computing performance and are opting for an SSD inside their new setup or as an upgrade to their current one for their computers and phones.

V. PERFORMANCE

Recently the solid state drive (SSD) has started to gain more prominence over traditional hard disk drive (HDD). According to the dell research lab, The capacity of HDDs has increased 40% annually, their random input/output (I/O) performance has increased only 2% annually, which means HDDs may not deliver the standard that some of today's enterprise, web, cloud, and virtualized applications that require which is both high capacity and performance. HDDs may not deliver a cost-effective storage solution, even with their significant drop in cost per GB and this is where SSDs has the upper hand because it offers exceptionally high performance for business needs.

It was observed that during research that across various models SSD outperformed HDD almost every time. Generally, the File I/O speed and File Copy/Write speed were the focal points.

	SSD	HDD
File Opening Speed	Generally above 200 MB/s and up to 550 MB/s for cutting edge drives	The range can be anywhere from 50 – 120MB / s
File Copy/Write Speed	Up to 30% faster than HDD	Slower than SSD

In a similar study done by Dell research lab, Dell set up eleven application I/O workload profiles for both SSD and HDD. For each profile, Dell used the IOmeter application to simulate the workload and measure the corresponding I/O. The analysis was done with the IOmeter 2006 version, which has more randomized data content than the 2008 version.

The Table below illustrate that SSDs offer significant benefits for specific workloads. However, if your workloads do not require high performance, or have a higher than 10% write duty cycle and are not suitable for stacking then an investment in SSDs may not be cost-effective. While your system may perform well, it could be over-provisioned and under-utilized for what the applications can leverage.

Application	Block Size in Bytes	Read/ Write Percentage	Random/Sequential Percentage	I/O Performance Metric*
Web File Server	4KB, 8KB, 64KB	95%/5%	75%/25%	IOPS
Database Online Transaction Processing (OLTP)	8KB	70%/30%	100%/0%	IOPS
Exchange Email	4KB	67%/33%	100%/0%	IOPS
OS Drive	8KB	70%/30%	100%/0%	IOPS
Decision Support Systems (DSS)	1MB	100%/0%	100%/0%	IOPS
File Server	8KB	90%/10%	75%/25%	IOPS
Video on Demand	512KB	100%/0%	100%/0%	IOPS
Web Server Logging	8KB	0%/100%	0%/100%	MBPS
SQL Server Logging	64KB	0%/100%	0%/100%	MBPS
OS Paging	64KB	90%/10%	0%/100%	MBPS
Media Streaming	64KB	98%/2%	0%/100%	MBPS

VI. CONCLUSION

It is now evident that storage plays a monumental role in the overall execution time of any system. There are some many options currently available, whether it be a HDD, SSD, or even a hybrid of the two! So which of the two is the better choice? To be completely honest there is no straightforward answer to this question. Each buyer has different needs that have to be evaluated based on their needs, preferences, and budget. Even though the price of SSDs has been falling, the price per gigabyte advantage is still strongly with HDDs. Yet, if performance and fast bootup is your primary consideration and money is secondary, then SSD is the way to go.

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