Evolution of Archival Storage (from tape to memory)

H. K. Ramapriyan

Science Systems and Applications, Inc., Lanham, MD, USA and

NASA Goddard Space Flight Center, Greenbelt, MD, USA

ABSTRACT: Over the last three decades, there has been a significant evolution in storage technologies supporting archival of remote sensing data. This section provides a brief survey of how these technologies have evolved. Three main technologies are considered – tape, hard disk and solid state disk. Their historical evolution is traced, summarizing how reductions in cost have helped being able to store larger volumes of data on faster media. The cost per GB of media is only one of the considerations in determining the best approach to archival storage. Active archives generally require faster response to user requests for data than permanent archives. The archive costs have to consider facilities and other capital costs, operations costs, software licenses, utilities costs, etc. For meeting requirements in any organization, typically a mix of technologies is needed.

1 INTRODUCTION

Over the last three decades, there has been a significant evolution in storage technologies supporting archival of remote sensing data. This section provides a brief survey of how these technologies have evolved. First, we consider the distinction between active and long-term or permanent archives.

1.1 *Active Archives*

We define active archives as facilities that store data that are in active use by the community. Typically active archives ingest raw data and/or derived digital products (hereafter simply referred to as "data") from active remote sensing missions, even though serving a user community with the stored data may proceed well beyond the life of active missions. Given the active user community, it is necessary for active archives to be responsive to the community requirements. Typically, relatively fast access is needed. Data needed to be backed up and restored promptly while the system continues to operate in a responsive manner. Support staff is needed to assist data providers in setting up mechanisms for product generation and delivery to the archive, as well as any problems that arise during production and ingest operations. Also, user services are needed to help consumers of data with answers to questions they may have about either the mechanics of obtaining the data or scientific questions about the data themselves. When the missions are active, expert consultation is generally available to user services staff from scientists associated with the mission. It is also the active archive's responsibility to prepare for permanent archive of data at the end of the active archive phase, whether the data are transferred to another organization or continue to be held at the same organization.

From a hardware standpoint, an active archive might use a tiered storage mechanism to optimize performance. Tiered storage provides access to data across a virtualized storage system (see http://en.wikipedia.org/wiki/Active_Archive.) The data migrates between several systems that use different types of media for storage. Data that are accessed more frequently and need to be provided fast would reside on more expensive media and storage systems, while other types of data would be on less expensive hardware. The migration among the systems is handled automatically. Metadata keep track of where the data are. The data are available on primary, secondary and tertiary systems, providing on-line or near-line accessibility.

1.2 *Permanent Archives*

Permanent archives store data "forever", long after the data cease to be in active use. Quick access to data may not be an essential requirement. However, it should be possible to obtain the data when needed, for example, for retrospective studies that might occur, say, 30 years after the active usage ended. The level of service to users may not be as high as it is in active archives. Experts directly involved in the missions would no longer be available for consultation. Thus one needs to depend on archived documentation, which must be complete to enable a diligent user to comprehend how the data had been generated.

Thus, from a hardware standpoint, a permanent archive may use less expensive and less responsive storage systems than an active archive. However, in both the active and permanent archives, preservation with no loss is equally important. Preservation requires:

- No loss of bits
- Discoverability and accessibility
- Readability
- Understandability
- Usability
- Reproducibility of results

From the point of view of hardware, the first and third bullets above are significant. The remaining bullets are also very important for preservation, but the actions to be taken to enable them are not within the scope of hardware solutions. Migration to newer media and reader technologies is essential to ensure no loss of bits over time and readability of data. Changes in technology over time provide less expensive and faster storage with greater capacity, enabling us to archive ever-growing volumes of data. However, they also require frequent (perhaps continuous) migrations of data to newer media.

2 STORAGE TECHNOLOGIES

There are several recent publications tracking the evolution of storage technologies and the reductions in costs per unit of archival storage over the last three decades. An interesting history of various types of computer devices including storage can be found in Computer History Museum (2015). Magnetic tapes, Hard Disk Drives and Solid State Disks/Drives are the major technologies that have been used for bulk storage. These will be discussed briefly below. It is to be noted that the names of companies and products given below only are meant to be illustrative of the technologies and capacities achieved as a part of storage technology evolution. Clearly it is beyond the scope of this section to cover all the storage products that have been made available in industry. The interested reader is encouraged to pursue the references provided here for more details.

2.1 *Magnetic Tapes*

Magnetic tape storage technology, first patented by a German engineer, Fritz Pfleumer in 1928 (Zetta, Inc. 2015), has been evolving over time and is still in use for bulk storage applications due to its low cost, portability and unlimited off-line capacity. Magnetic tapes were used for audio recording in the 1930s and were first used for data storage by UNIVAC in 1951. In circa 1970, IBM introduced the 10.5" standard tape reels. This standard lasted for over 25 years with various lengths (1,200 feet, 2,400 feet and 3,600 feet), numbers of tracks (7 and 9), and recording densities (ranging from 200 characters per inch to 6,250 characters per inch). The Digital

Equipment Coporation's (DEC) CompacTape Cartridge replaced the 1960s tape technology and was later standardized as Digital Linear Tape (DLT). The DLT technology evolved from 92MB capacities in 1984 to 800 GB capacities in 2006 (superDLT Format). Cartridges and cassettes, consisting of tape reels what are completely enclosed in a plastic casing have come into common use since audio compact cassettes were used in home computers as inexpensive storage in the 1970s and 1980s. As of 2014, various cartridge formats are in use - Digital Data Storage (DDS), a format for storing computer data on a Digital Audio Tape (DAT), Digital Linear Tape (DLT), Linear Tape – Open (LTO). Steady increases in cartridge capacities are exemplified by the evolution of generations of LTO. LTO-1, in the year 2000, had a capacity of 100GB, while LTO-6 in 2012 had a capacity of 2.5 TB. It is anticipated that LTO-10 will have a capacity of 48 TB.

Magnetic tapes can be stored off-line or in "near-line" tape libraries. With off-line storage, a human operator needs to mount a tape on a tape drive in order to read or write data. Near-line tape libraries include a robotic device that is controlled to access and mount the tape of interest on a tape drive to permit reading and writing. The IBM 3850 mass storage system, announced in 1974, was one of the earliest examples, consisting of a number of cylindrical cartridges held in a hexagonal array of bins. Data were transferred automatically between higher-speed disk drives (on-line storage) and the cartridges. The capacity of the mass storage systems ranged from 35.3 GB to 472 GB, depending on the model. This series was discontinued in 1986. Over the past three decades, use of near-line libraries has become common. In late 1990s through mid-2000s, the NASA Earth Observing System (EOS) Data and Information System (EOSDIS) used robotic tape silos for near-line storage of most (several petabytes) of the EOS data and derived digital products in its Distributed Active Archive Centers (DAACs). The access to data from near-line storage can be significantly slower than that from on-line spinning disks. (Today, the DAACs use on-line spinning discs for most of the archive storage while using near-line capacity for back-up.) Of course, the access with near-line robotic tape silos would typically be much faster and less subject to human errors than from off-line storage requiring tape mounts by operators. As of 2014, there are near-line mass storage systems with multi-exabyte capacities (Oracle, 2015).

2.2 *Hard Disk Drives (HDD)*

A history of the evolution of hard disk storage and a detailed time line from 1956 to 2014 can be seen in Wikipedia Contributors (2014). The following is a short summary of highlights from that article. The first commercial hard drives were introduced by IBM in 1956 with a capacity of 5 million 6-bit characters. In 1965, the IBM 2341 was introduced with removable disk packs of 11 disks for a total capacity of 29 MB. In 1975, the IBM 3350 "Madrid" was brought into market, re-introducing disk drives with fixed disks. The capacity of Madrid was 317.5 Megabytes per drive, for a capcity of over 2 GB per string consisting of eight 14" disks. In 1980, Seagate Technology (then Shugart Technology) introduced the ST-506, the first 5.25 inch hard disk drive, which had a capacity of 5 MB. Also in 1980, the IBM 3380 came on the market. It was the world's first gigabyte-capacity disk drive (2.52 GB), was the size of a refrigerator, and weighed 249 kg. In 1988, PrarieTek 220 was introduced as the first 2.5 inch hard drive, which had a capacity of 20 MB and suitable for portable computers. In 1997, IBM introduced the Deskstar 16 GP "Titan" with five 3.5 inch disks with a capacity of 16.8 GB. This was significant in that it was the first commercial use of Giant Magnetoresistance heads. Also in 1997, Seagate brought into market the Medalist Pro 9140 (ST39140A) with a 9.1 GB capacity, the first hard drive with fluid bearings. There were several key developments in 2005. The first 500 GB hard drive was shipped by Hitachi GST (HGST), Serial ATA 3 Gb/sec was standardized, Seagate introduced Tunnel Magneto-Resistive Read Sensor and Thermal Spacing Control, faster Serial Attached SCSI was introduced, and Toshiba shipped the first perpendicular magnetic recording hard disk drive (1.8 inch, 40/80 GB). The years 2007 through 2011 saw a few firsts in the capacities of hard disks, starting from 1 TB (2007, HGST) to 4 TB (2011, Seagate). In 2013, HGST announced a helium-filled 6 TB hard disk drive for enterprise applications. In 2014, Seagate shipped the first 8 TB hard drives.

The costs of hard disk drives from 1980 to present are summarized by M. Komorowski (2009 & 2014). Figure 1 is adopted from his articles. Note the logarithmic scale in the figure. It shows that the cost per gigabyte has dropped from $700K in 1981 to between $0.03 and $0.06 in 2014. Komorowski shows a regression model indicating doubling of storage capacity per unit cost every 14 months. Other examples of such cost trends are compiled by Smith (2014) and McCallum (2014).

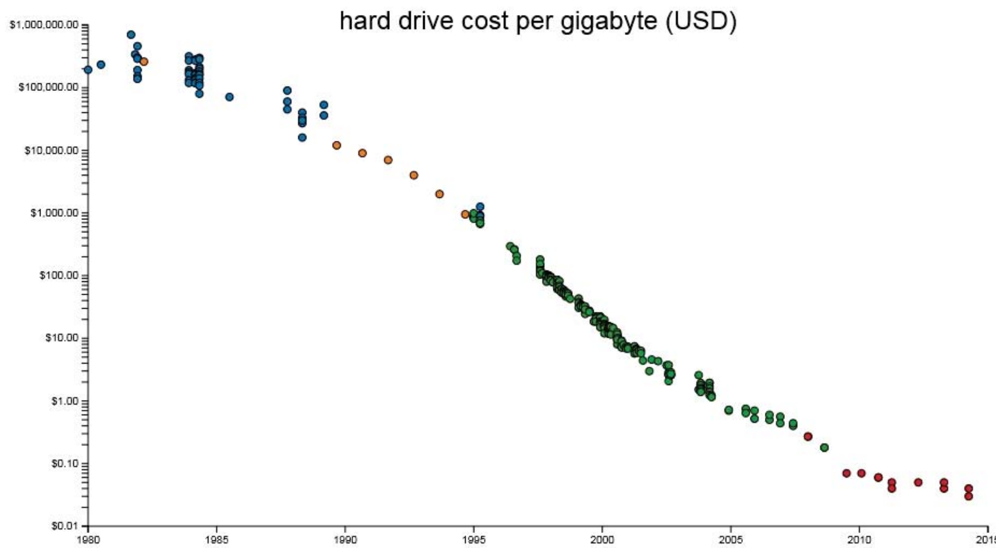

Figure 1. Hard Drive Costs per Gigabyte - 1980 to 2014. (Credit M. Komorowski).

2.3 *Solid-State Drives or Solid-State Disks (SSD)*

Devices called Solid-State Drives or Solid-State Disks (SSD) are neither drives nor disks. They are storage devices like HDDs, but use integrated circuit assembles for persistent storage of data. They also use electronic interfaces that are compatible with Hard Disk Drives (HDDs), but provide significantly higher input/output performance. SSDs differ from HDDs, floppy disks or tape drives in that they do not have any moving components and thus are resistant to physical shocks and run silently. Most SSDs use NAND-based flash memory, which can retain data without constant need for electric power. For faster access, Random Access Memory (RAM) SSDs can be used, but they require some source of electric power to retain data. (See Wikipedia Contributors, 2015b).

A time-line of the evolution of SSD's from 1976 to 2014 is given by Zsolt Kerekes (2015). The following is a brief summary of its highlights. In 1976, Dataram brought into market an SSD called BULK CORE. It emulated hard disks and had a capacity of 2 MB. In 1978, 1 GB of RAM SSD would have cost $1M. Texas Memory Systems introduced a 16 KB RAM SSD for accelerating field seismic data acquisition for oil companies. In 1982, SemiDisk Systems shipped SSD accelerators for the Personal Computer market, initially with a capacity of 512KB and later with a capacity of 2 MB. In 1990, NEC introduced 5.25" SCSI SSDs that used RAM technology and backed up with internal batteries. By 1996, with ATTO Technology's introduction of SiliconDisk II, the RAM SSD capacities had gone up to 1.6 GB with a throughput of 80 MB/s and 22,000 input/output operations per second (IOPS). In 1999, BiTMICRO introduced a flash SSD with a capacity of 18GB. By the end of 1999, there were at least 11 manufacturers of SSDs. In November 2000, BiTMICROS launched the first hot-swappable 3.5" SCSI SSD. In 2001, Winchester Systems introduced FlashSSD as an option in its OpenRAID Storage Area Network products for use on a small percentage of "hot files" that account for a majority of disk access requests. FlashSSD provided consistent performance of 12K IOPS and 40 MB/s throughput. Also in 2001, Texas Memory Systems began promoting its RamSan-210, a RAM SSD with 32GB capacity, 100K IOPS and 20 microsecond access times. In 2003, SSDs with a capacity of 1 TB became commercially available. In 2005, M-Systems announced that the industry's highest capacity 2.5" Serial Advance technology Attachment (SATA) SSD with 128 GB storage capacity was available. Also, Texas Memory Systems launched SSDs with a 4Gb/s Fiber Channel interface offering up to 128-gigabytes capacity and 500,000 random IOPS performance. In 2006, 1.8" 32GB flash SSDs from Samsung hit the market. In 2008, the number of Original Equipment Manufacturers (OEMs) of SSDs reached 100. In 2010, Texas Memory Systems announced the availability of the RamSan-630 SSD with 4 to 10TB capacity, 500,000 IOPS, and 8GB/s bandwidth. Foremay announced its 2TB 3.5" and 1TB 2.5" SATA flash SSDs with read/write speeds of up to 200MB/s. Fusion-io set speed records of achieving 1 million IOPS and 6.2 GB/s bandwidth, and offered capacity up to 5.7 TB. In late 2011, BiTMICRO announced a new generation of enterprise SSD controllers that could deliver up to 400K IOPS and a capacity of 5TB for availability in the first half of 2012. In 2012, HGST demonstrated the first 12Gb/s Serial Attached SCSI SSD in industry. In 2013, Micron announced a new model of hot swappable 2.5” Peripheral Component Interconnect Express (PCIe) SSDs with up to 1.4TB multi-level cell (MLC) capacity, which could deliver 750K IOPS. Samsung entered the entry into the 2.5” PCIe SSD market with its NVMe SSD which had up to 1.6 TB capacity, read throughput of 3 GB/s and up to 740K IOPS. IN 2014, Samsung provided a comparison of speeds of 2.5” SSDs using SAS and PCIe technologies and showed that its PCIe SSDs were 3 times faster than the SAS SSDs. SanDisk started sampling 2.5” 4 TB SAS SSDs. Skyera launched its 136 TB, 1U (i.e., 1.75” high) rack-mounted SSD called the SkyHawk FS.

A comparison of average prices per gigabyte of HDD and SSD over the period 1996 through 2012 is shown in Figure 2 (from Royal Pingdom 2011). The cost of hard disks and drives has dropped significantly over the past three decades, making their use feasible for petabyte scale data archives. Where high throughput performance is a requirement, Solid State Disks (SSDs) are being used in recent years. SSDs are significantly more expensive than HDD’s as shown in Figure 2. However, the cost differential between HDD and SSD has been dropping significantly over the years. Cost of SSD per GB was 120 times that of HDD in 2007, while in 2011 the same ratio was 32. In 2014, this ratio had dropped to about 25. Vendor advertisements in January 2015 showed a ratio of 8 to 10. It is difficult to predict whether the two costs will become comparable in the future. See Baxter (2014) for a comparison of HDD and SSD and a discussion of pros and cons.).

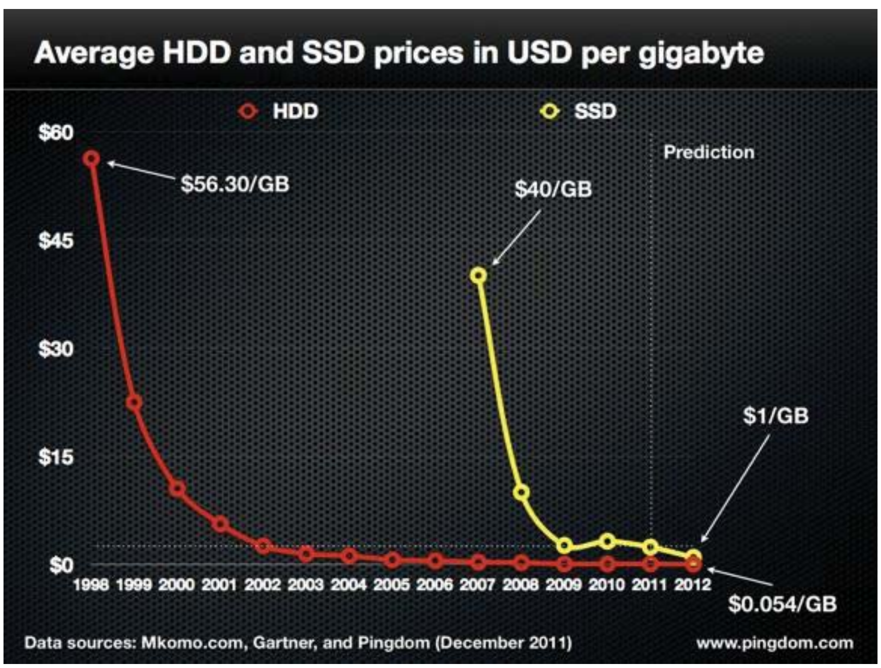

Figure 2. Comparison of Cost of Hard Disk Drives and Solid State Drives (Credit: Royal Pingdom)

3 CASE STUDY – NASA'S EOSDIS

NASA's Earth Observing System Data and Information System (EOSDIS) is a large system with 12 Distributed Active Archive Centers across the United States. EOSDIS manages most of NASA's Earth science data from satellite missions, aircraft investigations, field campaigns and other sources. At the end of 2014, EOSDIS archived approximately 10 PB of data. The EOSDIS Core System (ECS) provides common "core" hardware and software capabilities to three DAACs – the Atmospheric Science Data Center at NASA Langley Research Center, Hampton, Virginia, the Land Processes DAAC at USGS EROS in Sioux Falls, South Dakota, and the National Snow and Ice Data Center at the University of Colorado in Boulder, Colorado. For purposes of illustration, the storage technologies employed in the ECS archives are discussed below. The ECS has been in operation since late 1999 and has been supporting archiving and distribution of the EOS satellite missions. It has evolved from near-line tape-based robotic archives to on-line disk-based archives. Behnke et al (2005) describe the technology changes since the beginning of the ECS design in 1995 through 2005. Initially, all of the data were stored in robotic tape silos, with on-line disk storage being used to cache the data. As the cost of disk storage decreased, it became feasible to provide some of the data on-line. The concept of "data pools" was introduced in 2001 (Moore and Lowe, 2002). Data Pools were large (tens of TB) caches of popular datasets that could be directly downloaded by users, thus reducing the latency in meeting user requests. With further reductions in disk costs, most of the data are now held on-line. This also helps in providing other on-line services to users such as subsetting, reprojection, visualization, etc. upon request. Regarding the utilization of disk and tape technologies for back-ups of archives at all the EOSDIS DAACs, the following observations can be made. There is an equal mix of tape and disk based on product count. Disk is a popular medium for smaller volume products and tape for larger volume products. Transition from tape to disk based backup has been driven by reduced disk costs; improved restore input/output speeds from disk; and lower error rates in stored disks. A small number of products are backed up on CD/DVD/Blu Ray (optical media). The DAACs have automated systems to manage ingest, archiving and back-up of data. In particular, the back-up system used at the three DAACs mentioned above that have the EOSDIS Core System is a tiered storage management system using StorNext. This provides seamless access to data held on disk and tape media. The data are ingested on to a set of archive disks. They are then copied from the archive disk to tape for a complete back-up. Copies to tape are determined by a set of configurable policies and generally occur after a set period of time, a data volume threshold is reached for specified datasets, or when an archive disk reaches a capacity threshold.

4 CONCLUSION

This section provides a discussion of three main technologies for archival storage and traces their historical evolution, summarizing how reductions in cost have helped being able to store larger volumes of data on faster media. The cost per GB of media is only one of the considerations in determining the best approach to archival storage. Active archives generally require faster response to user requests for data than permanent archives. The archive costs have to consider facilities and other capital costs, operations costs, software licenses, utilities costs, etc. An example of such an analysis by the San Diego Supercomputer Center is given in Moore et al. (2014) They demonstrate that the annual operating cost per TB of storage at their facility is a factor of three less for tape than for disk storage. However, for meeting requirements in any organization, typically a mix of technologies is needed. There has been a very significant change over the past 30 years in the capabilities that active archives can provide for their users. One could not have imagined 30 years ago that scientists using remote sensing data would today have most of the data available to them on-line and be able to "work from anywhere". Several technological advances have contributed to this change, including evolution of archival storage discussed in this section as well as inexpensive storage available for users' laptop or desktop computers and faster performance of networks. While it is difficult to predict the technological environment of 30 years into the future, it can be expected that SSD's will become sufficiently inexpensive to support major archival operations and help with much faster access to data from users all over the world.

ACKNOWLEDGEMENTS

This section was supported by National Aeronautics and Space Administration (NASA) under contract number NNG12HP08C with Science Systems and Applications, Inc. The author gratefully acknowledges encouragement, support and review comments by Ms. Jeanne Behnke of the Earth Science Data and Information System Project at NASA's Goddard Space Flight Center, Greenbelt, MD. He also thanks Mr. Chris Doescher of the United States Geological Survey's USGS-Earth Resources Observation and Science (EROS) Center for discussions on storage systems at the Land Processes Distributed Active Archive Center and back-up approaches.

REFERENCES

Baxter, A. 2014, "SSD vs HDD", http://www.storagereview.com/ssd_vs_hdd. Retrieved on January 26, 2015.

Behnke, J. et al 2005, "EOSDIS Petabyte Archives: Tenth Anniversary", Proceedings of the 22nd IEEE / 13th NASA Goddard Conference on Mass Storage Systems and Technologies (MSST'05).

Computer History Museum, 2015, "Memory and Storage", http://www.computerhistory.org/revolution/memory-storage/8/intro. Retrieved on January 26, 2015.

Kerekes, Z. 2015, "Charting the Rise of the Solid State Disk Market", http://www.storagesearch.com/chartingtheriseofssds.html. Retrieved on January 26, 2015.

Komorowski, M. 2009, "A History of Storage Cost", updated September 8, 2009, http://www.mkomo.com/cost-per-gigabyte. Retrieved on January 26, 2015.

Komorowski, M. 2014, "A History of Storage Cost (update)", updated March 8, 2014, http://www.mkomo.com/cost-per-gigabyte-update. Retrieved on January 26, 2015.

McCallum J. C. 2014, "Disk Drive Prices (1955-2014)", http://www.jcmit.com/diskprice.htm, last update September 14, 2014. Retrieved on January 26, 2015.

Moore, M., and Lowe, D. "Providing rapid access to EOS data via Data Pools", Proceedings of SPIE, Earth Observing Systems VII, Seattle, WA, July 7-10, 2002.

Moore, R. L. et al, "Disk and Tape Storage Cost Models", http://users.sdsc.edu/~mcdonald/content/papers/dt_cost.pdf. Retrieved on January 26, 2015.

Oracle, 2015, http://www.oracle.com/us/products/servers-storage/storage/tape-storage/sl8500-modular-library-system/overview/index.html. Retrieved on January 26, 2015.

Royal Pingdom 2011, "Would you pay $7,260 for a 3 TB drive? Charting HDD and SSD prices over time", December 19th, 2011, http://royal.pingdom.com/2011/12/19/would-you-pay-7260-for-a-3-tb-drive-charting-hdd-and-ssd-prices-over-time/. Retrieved on January 26, 2015.

Smith, I. 2014, "Cost of Hard Drive Storage Space" last update April 3, 2014, http://ns1758.ca/winch/winchest.html. Retrieved on January 26, 2015.

Wikipedia contributors 2014, "History of hard disk drives," *Wikipedia, The Free Encyclopedia,* http://en.wikipedia.org/w/index.php?title=History_of_hard_disk_drives&oldid=644810953, Last modified December 29, 2014. Retrieved on January 26, 2015.

Wikipedia contributors 2015a, "Active Archive", *Wikipedia, The Free Encyclopedia,* http://en.wikipedia.org/wiki/Active_Archive. Retrieved on January 20, 2015.

Wikipedia contributors 2015b, "Solid-state drive", *Wikipedia, The Free Encyclopedia,* http://en.wikipedia.org/wiki/Solid-state_drive, last modified on 22 January 2015, at 09:27. Retrieved on January 26, 2015.

Zetta, Inc. 2015, http://www.zetta.net/history-of-computer-storage/. Retrieved on January 26, 2015.