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How Long is Long-Term? – An Update

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Abstract

At the Archiving 2011 Conference a paper was presented titled, “How Long Is Long-Term Data Storage?”, in which the author summarized the state of archival digital data storage. This paper covered causes of failure, the life expectancy of the data with the storage methods available at the time, format obsolescence, and current research into archival storage. With that paper being about 13 years old now, it is time for an update. This paper will discuss the same topics covered in the previous work, including failure, life expectancy, format obsolescence, as well as current research in all 4 of the primary data storage methods used today (hard-disk drives, solid-state drives or flash memory, optical discs, and ½” magnetic tape. It ends with a discussion of our current research on a human-readable, high-density storage medium.

Introduction

Many governmental agencies and academic, medical and business communities have a great interest in preserving records for extended periods of time. We will refer to these entities collectively as archives. Up until the computer age (starting in about 1940), these archives preserved materials that were mostly very long-lasting (over 200 years), including books, maps, audio recordings, and films. The advent of the computer age changed this dramatically. Suddenly archives were receiving “born-digital” materials (typically on magnetic tape); the data on these materials had far shorter life expectancies (LEs) than previous materials, and sometimes as short as 5 years. Ever since this transition, archives have been tasked with the challenge of finding methods (typically workflows) of preserving the information on these materials for the foreseeable future. In this paper, we review the capabilities and outlooks for the key data storage media available and emerging today, including hard-disk drives (HDDs), solid-state drives (SSDs), optical disks (ODs), magnetic tape, a new silica medium being developed by Microsoft, and DNA.

As has been discussed in numerous papers (see for example references 1, 2, 3), the world we live in has numerous factors which affect the LE of digital data on any medium. These factors include temperature, humidity, light, and in some cases voltage. We will discuss how each of these factors affects the storage media in common use today, and conclude with a proposal for a new storage medium targeted specifically at archives.

Hard-Disk Drives (HDDs)

Hard-disk drives have been around since they were first introduced by IBM in the 305 RAMAC of 1956. Since then they have grown in capacity and reduced in cost/byte by more than 7 orders of magnitude, an astounding feat. Today a 10 TB drive can be purchased for under $200.

Since the disks of an HDD cannot be removed, the LE of data on HDDs is a function of the LE of the HDD itself.. That is, if any of the sealed components of the HDD fail (including the heads, the track servos, the bearings, or the recording layer of the disks), the data are extremely difficult to recover and the HDD is generally just replaced. So while it is true that the actual data on the disks of an HDD can persist for many decades, the HDD itself cannot.

One cloud company that uses many HDDs and publicly reports on the failures of these is Backblaze (NASDAQ: BLZE). In their Q3 2023 report, they noted that the AFR (Annual Failure Rate) of over 259,000 HDDs from four different vendors, was 1.47% (over 1,900 failures in six months), and the weighted average age of their HDDs was 39.4 months, or just over 3¼ years. Clearly, HDDs are not a practical way to store data for long periods of time. Additionally, use of HDDs for direct archival (write on them and then store them) is not recommended, as their infant mortality failure rate is higher than their average failure rate [4].

Solid-State Drives (SSDs)

Solid-State Drives using flash memory have been available for a couple of decades now, starting with SanDisk’s 20 MB SSD in 1998, selling for around $1,000 [5]. Today an SSD with >10 TB can be purchased for under $200.

SSDs continue to be adopted for use in data centers, high-performance computing, personal use, and now in most laptop computers. The limited number of program/erase (P/E) cycles of flash memory is well known, and most SSDs come equipped with a wear algorithm that prevents specific memory locations from experiencing too many P/E cycles, thus prematurely wearing out some memory locations.

While the limited number of program/erase (P/E) cycles is well known and continues to be an issue in archival storage with SSDs, the relationship between the number of P/E cycles and the archival LE of the data is not well known.

The relationship between the number of read cycles and the LE of the SSD data is also an open question that is presently being investigated by this research team. However, a 2017 paper [8] reports that “2D NAND flash is suitable for digital archive: millennium memory with only one time write.” Figure 1 from this paper states, “Only 1 time write. Data-retention (DR) lifetime is over 1000 years” It should be noted that this finding presently applies only to 2D NAND flash memory. Nevertheless, this claim merits further research.

The 2011 version of this update paper cited a 2008 paper that stated, “the MTTDL for a Flash SSD (solid-state drive) is approximately 13 years.” (MTTDL = Mean Time to Data Loss). Our further research into this topic has not produced any changes to this estimate.

Optical Disks (ODs)

The 2011 version of this update paper provided an excellent summary of the LE of optical discs, separating them into the physically distinct categories of stamped and recordable ODs. Stamped ODs were shown to have an LE of approximately 1,500 years, but these are impractical for low volumes and so are not an option for archival storage. Recordable ODs, with the exception of the M-Disc, had LEs of 1-25 years, depending on several factors. The M-Disc had an LE of over 1,000 years due to the use of an inorganic recording layer and a special write strategy.

Because both sales and the use of ODs have dramatically decreased since the 2011 paper was published, the authors of this paper have been under the impression that little development work has been underway in this area. However, a recent development entitled "Very Big Disc™" as been announced. The University of Shanghai for Science and Technology has announced a capacity of 200 TB on a single optical disc the same diameter and thickness as CDs, DVDs, and BDs. It uses 100 recording layers separated by only 1µm. They have estimated the LE of the data to be between 50 and1. 100 years. They have yet to develop a fast and affordable drive for reading the discs [9].

2.

Magnetic Tape

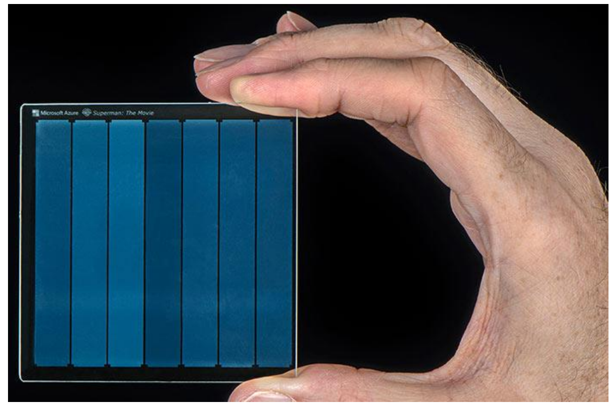
Published less than a month before this paper's3. submission, Bharat Bhushan of Ohio State University, overviewed the "Current status and outlook of magnetic data4. storage devices" [14], stating that magnetic tape drives remain dominant for archival storage and backup because of their high volumetric density and low cost per TB. Although previously projected to last upwards of 50 years, the current consumer LE5. for Linear Tape-Open (LTO) tapes are around 30 years [15]6. when stored between 15 and 25 °C (59 to 77 °F) with the7. traditional workflow of being rotated every 5-7 years as reported to one of the authors when attending the Archiving conference several years ago.

After a study, the Council on Library and1. Information Resources has claimed after a study [16] that the theoretical LE of Magnetic audio tape reaches 100 years under2. ideal storage conditions. Audio tape, however, is not indicative of overall digital data, and given deal storage conditions (as3. described above), the estimated Mean Swaps Between Failures remain at 100,000 cartridge load/unload cycles and the Mean Time Between Failures is 250,000 power-on hours @ 100% duty cycle. There is no indication that on average LTO tapes last longer than the estimated 30-year lifespan.

Other Archival Storage Options: Project Silica

Starting about 7 years ago, Microsoft began developing a storage technology they dubbed Project Silica [10]. It is targeted specifically at the archival community, and has many1. promising features. These include:

2.



:Figure 1: A quartz slide used in the Microsoft Project Silica [11].

1. A highly durable medium (quartz) that is well known to be extremely durable over time, humidity and temperature. It is also inexpensive.
2. Once written to, the media is essentially impervious to EMF (ElectroMagnetic Fields), including an EMP (ElectroMagnetic Pulse).
3. Very high density storage; presently announced at 7 TB in a square glass platter approximately the size of a DVD.
4. Volumetric recording (using voxels) to record in hundreds of layers on each platter.
5. Femto-second lasers write to the quartz media, and polarization-sensitive microscopy with regular light is used to read the data. Thus, readback hardware cannot accidentally overwrite.
6. Write throughputs comparable to current archival systems.
7. Full readback-after-write verification.
8. Very high scalability.

Since no technology is perfect, the drawbacks these authors see in this system include:
1. The "crabbing" shuttles are highly mechanical, which means that they will experience failures.
2. Readback of the recorded data is highly dependent on the specialized recording system; it is not human-readable.
3. Quartz is brittle and often shatters when dropped.

These authors believe that this archival system has tremendous potential if future readability can be assured.

Other Archival Storage Options: DNA

Research on storing data with DNA began several decades ago, and it has recently been shown to have tremendous potential [11]. :Positive and negative characteristics of this type of storage include the following:
1. Immense density. The entire contents of the US Library of Congress could fit in the size of a poppy seed – 6,000 times over [12].
2. Long storage lifetime. Estimates range from hundreds to thousands of years, depending on storage conditions. [13]

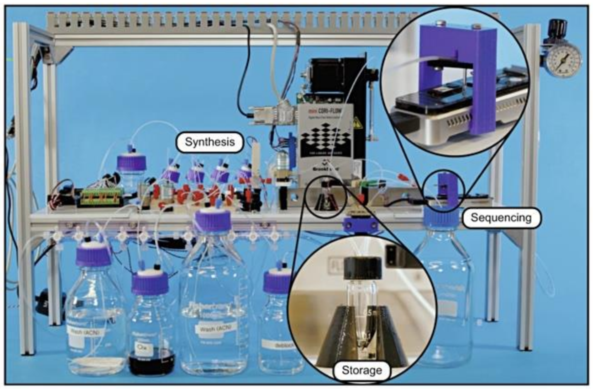


Figure 2: DNA storage is still a benchtop chemical process. [12]

3. 3. Very slow write times. Reference 12 indicates that, “Appending a single base to DNA takes about one second.”
4. 4. Very slow read times. Reference 13 indicates that, “This process requires approximately ten hours from sample preparation to data readout.”
5. 5. Encoding computer data into DNA base pairs (on the write end) and decoding back (on the read end) is somewhat compute-intensive.
6. 6. High cost. Though this barrier has been reduced over time, there is not yet any “Moore’s Law” equivalent in the DNA domain.
7. 7. The sample must be protected from deoxyribonucleases (DNases), which are ubiquitous and will cleave the DNA if they encounter it.
8. 8. No major breakthroughs are on the horizon, but development continues, as it has for decades.
9.

Other Archival Storage Options: Project Nano Libris

Human readability is a very important attribute of archival materials; current examples of media that exhibit human readability include books, maps, and other printed materials; microfilm and microfiche; and many works of art (especially sculptures). In an extension of microfilm and microfiche, what if we could use current nano-writing technologies to write onto a long-lasting substrate? What might the potential of this medium be?

Our current research (provisional patent filed) in this area includes the following features:

1. Writing with an e-beam, ion beam, AFM or ATM tip, or other extremely-high resolution writing device, onto:
2. Standard ½” mylar tape.
3. Use of a new material that replaces the magnetic recording layer on the tape, where this material will have extremely long life, and be writable as in #1 above.
4. At a character size of 100 x 75 nm, the capacity of an LTO tape of 960 meters long would be roughly 1.536 x 10^{15} characters. The standard volume in the US Library of Congress (LoC) contains 375,000 characters, so simple math shows that this technology has the potential to store about 4.1 billion typical volumes, or the entire contents of all 176,000,000 volumes of the LoC on a single LTO tape cartridge, more than 20 times over. This would include room for the index and any necessary metadata about each volume.
5. This technology would store data in human-readable form, requiring only high magnification for it to be read in the centuries to come.
6. Using the halftone process developed for black & white newspapers many decades ago, this technology can also be used to store monochromatic images in human-readable form.

Conclusion

The 2011 version of this paper contained a summary table, which we would like to update for the conclusion of this paper. The media in this table exhibit a wide range of LEs. Of the media listed below, only one (Project Nano Libris) is human-readable.

Media	LE of Data	Change Since 2011	Human Readable
LTO-8 magnetic tape	15-30 years	Down somewhat	No
Magnetic hard-disk drives (HDDs)	1-5 years	Down somewhat	No
Flash drives & solid-state drives (SSDs), normal use	10-12 years	Unchanged	No
Flash drives & SSDs write once (BYU)	1,000 years	Dramatic improveme nt	No
Recordable optical disks, standard	1-25 years	Unchanged	No
M-disc (re-cordable)	1,000 years	Unchanged	No
Project Silica (Microsoft)	100,000 years	New technology	No
Project Nano Libris (BYU)	1,000 years	New technology	Yes

Table 1: Life expectancy for data stored on media in this paper.

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