TOTENPASS

The new paradigm in the permanent storage of precious digital data

By ROY SEBAG

Introduction: the problem; our solution.

"The world's most valuable resource is no longer oil, but data."[1] Both personal and collective data, which conserves the unique qualitative diversity of human culture, are considered to be precious. In the analogue world, archives, libraries and museums serve as a repository for our collective knowledge, for our shared experiences, and for the human *esprit*, consciously safeguarding physical heirlooms for posterity. Like a prehistoric artefact encased in amber, a near perfect state of preservation helps to enlighten our bygone past. When data is rightfully preserved, future generations are empowered with the ability to excavate that data, to study it, and to learn from the past in order to prepare for the future. In light of the importance of data preservation in an era of supernumerary personal and collective content, I will put forth the following arguments:

> *i. Precious digital data is not being well preserved. Moreover, this data is increasingly centralized on a handful of enterprise clouds in physical locations that are inaccessible to the owners of that data.*
>
> *ii. This leaves individual citizens, private corporations and government agencies exposed to both counterparty risk and degradation of their precious data with the passage of time.*
>
> *iii. This relatively new trend in the centralization and consolidation of data stands in stark contrast to nearly 500 years of recent human history, during which information was generally spread outwards, becoming decentralized and leading to unprecedented liberty, prosperity and peace.*
>
> *iv. Because of (i)-(iii), a market opportunity has emerged which must be addressed by the invention of an energy-efficient and permanent data storage technology.*

I will ultimately propose a new technology which has been developed by embracing the unique properties of the element Gold (Au) along with recent advances in light refraction. This technology allows for the permanent storage of precious digital data, thereby eliminating any future dependence on the internet and the vast amounts of energy required presently to store content. By consequence, this technology will empower both individuals and corporations to decentralize, preserve and fully control their precious digital data once and forever.

[1] https://www.economist.com/leaders/2017/05/06/the-worlds-most-valuable-resource-is-no-longer-oil-but-data

I. An overview of the current state of digital data.

Digital data is measured in various units, beginning with the *Bit*—the lowest value unit within the Binary Base-2 numeral system powering the present day digital computation paradigm. A Bit can either be a 0 or a 1. A *Gigabyte* represents 8,589,934,592 Bits. A *Zettabyte*, is one trillion Gigabytes. According to the International Data Corporation (IDC), the current global stock of data is estimated to grow from 33 Zettabytes in 2018 to 175 Zettabytes by 2025[2].

To help illustrate the scale of this global, cumulative "stock" of digital data, consider that if one was able to store the entire 175 Zettabytes humanity will create by 2025 on DVDs, that stack of DVDs would reach to the moon over 23 times or circle the Earth 222 times. If one tried to download this amount of digital data using a cutting edge 25 mbps broadband connection, it would take 1.8 billion years to do so.

Every day, over 5 billion individuals interact with digital data. By 2025, that figure will rise to 6 billion, which is to say 75% of the world's projected population. By then, the average person will interact with digital data at least once every 18 seconds, or 4,909 times per day through a collective 150 billion connected devices. This truly awesome rate of human cooperation has transformed how people live and work and has been enabled by the convergence of several important trends over the last two decades:

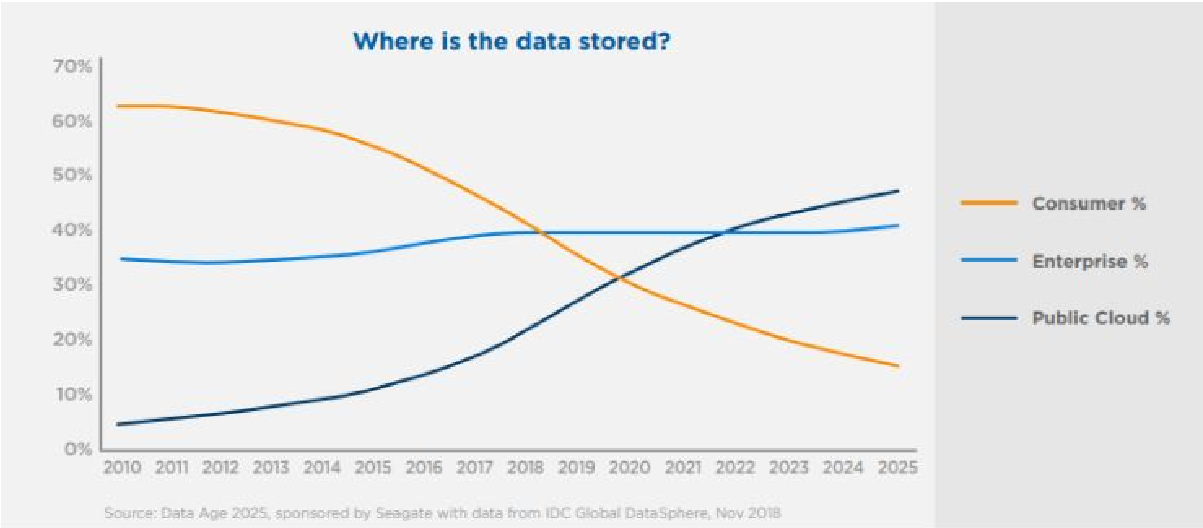
- **Internet Adoption -** The number of internet users reached 4.02 billion in 2018, up from just 76.5 million in 1998.[3] This figure represents 53% of the estimated global population.
- **Proliferation of Smartphones and Mobile Connected Devices -** At the end of 2018, there were 8.48 billion unique mobile devices connected to the internet.[4]
- **Broadband Adoption -** Internet access speeds have increased with the majority of active internet connections now being classified as 3G or better (76% of the world's population).[5]
- **Trust in Cloud Networks and Software as a Service (SaaS)-** Higher internet speeds have enabled advances in technology architectures that have, in turn, resulted in a shift from on-premise to cloud-based computing. Trust in cloud networks has made possible the delivery of software-as-a-service (SaaS).
- **Shift to Cloud Networks Results in Economies of Scale -** Important applications can now be delivered cost effectively and securely to customers over the internet without the need to purchase supporting hardware or pay for ongoing maintenance. As a result, the Cloud and SaaS industries have witnessed astronomical growth, with Gartner Inc. expecting total cloud spending to increase from $130 billion worldwide in 2013 to $206 billion in 2019.[6]
- **Remote Workflows -** Forrester Research, Inc. (Forrester) estimates that 29% of the global workforce in 2018 used three or more devices, worked from multiple locations, and accessed several applications. Increasingly, applications such as Slack, Asana, and Trello, are being used to augment the physical office setting. Even the physical office is being disrupted by

[2] https://www.seagate.com/files/www-content/our-story/trends/files/idc-seagate-dataage-whitepaper.pdf
[3] https://wearesocial.com/blog/2018/01/global-digital-report-2018
[4] Ibid.
[5] https://www.itu.int/dms_pub/itu-s/opb/pol/s-pol-broadband.18-2017-pdf-e.pdf p-11
[6]https://www.gartner.com/en/newsroom/press-releases/2018-09-12-gartner-forecasts-worldwide-public-cloud-revenue-to-grow-17-percent-in-2019

shared-workspace concepts such as WeWork where employees may come and go or work from various locations throughout the year while remaining connected.

II. The "Great Drain": increasing centralization of data in the Cloud leaves citizens, corporations and governments with fewer choices for permanent storage of precious digital data.

We have illustrated how an increasing volume of digital data is being created at an unprecedentedly fast pace. We will now demonstrate how the multifarious nature of the funnels which feed this explosion in digital data results in a gravitational draining of the data towards cloud-based storage rather than storage on physical devices. By 2025, the IDC predicts that nearly 90% of the world's stored data stock will reside in public cloud environments (both consumer and enterprise), leaving only 15% in the hands of private citizens. This compares to 60% in 2010. This relatively new trend seems to be marching forward with great momentum and with no visible end in sight.



It is my belief that not enough individuals, corporate leaders, and public officials are questioning how this accelerating trend towards centralized, cloud-based data storage may impact our civilization's ability to preserve the genuinely precious data which sits at the heart of the human experience. Our collective knowledge is becoming increasingly centralized by a handful of publicly-traded technology companies, who commingle and co-locate the data according to whatever changing laws, circumstances and profit-driven motivations they may be incentivized to seek with each passing quarter.

In the parlance of the financial world, data is being centrally deposited and *fractionally reserved* rather than being *fully reserved* in the bonafide custody of the individual citizen who owns the data. This increases counterparty risk and poses a serious threat to the integrity of data ownership through time.

Put yet another way, one can reasonably argue that the supercycle which began with the Gutenberg printing press, leading towards an effervescent flow of information which lasted five hundred years and enlightened billions of citizens around the world, is now being reversed. For this reason, I have named this trend the "*Great Drain*": our most individual human experiences and knowledge leak from our physical, personal custody towards an ostensibly safer and more accessible, albeit *centrally controlled* and *physically remote* repository. In many cases, the data we rely upon every day may be physically residing on a hard drive thousands of miles away from us. Moreover, any content on these hard drives is, for all intents and purposes, fully accessible to any actor who can physically access them. While I comprehend that this societal transformation has been catalyzed by a spirit of good intentions (such as improved accessibility, increased potential quantity of storage and long-term resilience), one cannot doubt that this transformation demarcates a significant change in the dynamics of how our most precious knowledge and experiences are stored. A reasonable thinker may even meditate on the eventual repercussions that could emanate from what is undoubtedly an increase of entropy within the human repository of knowledge. To quote Aesop: *a bird in the hand is worth two in the bush*.

The relative nascency of these centralized, cloud-based storage technologies leaves us ill equipped to know whether the present paradigm of digital data storage, which includes best-practices for backup and storage, are even capable of preserving precious physical documents such as a family tree, family photographs, an intergenerational recipe book, or an important letter any better than lead pencils inscribing symbols on bleached pulps of wood — also known as paper. Moreover, it is too soon to know if the dominant cloud-digital data providers are being honest with their customers about their ability to preserve this data over long periods of time.

Again, it is abundantly clear that the majority of Zettabytes of digital data being created are of the non-precious kind which help to power actions and pass on ephemeral information, but which ultimately are to be discarded as trash. As this metabolism takes place, the digital data is ultimately stored in silos where it is effectively going through a slow but certain process of decomposition. Decomposition by design is fine in and of itself and even serves an important generative role in the computational ecosystem. In nature, things grow up and they die back down.

But what of the *precious* digital data? Can one really argue that this seemingly unstoppable trend does not make it more difficult to isolate and store our most valued bits of data; the data which has *qualitative value?* Internet memes may come and go, but a cherished family photograph should be forever. If we return to the natural world, there are non-metabolic forms of energy to which we ascribe intrinsic value; these manifestations of toil become stores of value which we prize. Assets such as artwork, property, jewelry and other heirlooms are kept and preserved through time because they have a special subjective meaning which we cherish and desire to pass on. This is our one and only defense against the relentless march of time: a moment, a memory, a special occasion will soon flee into the powerless past. In the realm of digital data and information, there are precious bits that should never be discarded, such as important corporate secrets, intellectual property, surveys, engineering plans, architectural drawings, financial statements, family videos, archives, *et cetera.* One can think of myriad forms of precious data that require a permanent home — a safe place to withstand the winds of entropy, from theft, to fires, to cyber hacks, to changing laws and regulations.

If we are to look to the world of private corporations, we know that as of December 2018 there are trillions of dollars of audited, intangible assets on the balance sheets of private, public, and governmental corporations.[7] This intellectual property, patents, goodwill and other non-corporeal

[7] https://brandfinance.com/images/upload/gift_report_2017_bf_version_high_res_version.pdf

assets are essentially stored in the form of bits and bytes on some physical storage medium somewhere in the world. A particularly great example of this one segment of the market would be a company like Allergan (NYSE: AGN), which has an enterprise value of $81 Billion while carrying disclosed intangible assets of $78 Billion.[8] For a company like Allergan, protecting its most precious data is critical to its future (and solvency), for the company is dependent on that data being preserved, not only from intrusion, data leaks, or cyber attacks, but, as I will show, from something as seemingly innocuous as *natural degradation*, also known as *bit rot.*

Trillions of dollars of corporate-owned precious data pale in comparison to the value of privately-owned precious data — a written work, a video recording of a birth or a wedding, or a special recipe passed down for hundreds of years. There is no question that the sea change in both the centralization of digital data and the phenomenon of human experiences being increasingly created and stored as digital data ultimately means that more of our heirloom-quality moments are to be stored as digital bits on a computer.

Over the next century, as billions of people around the world and millions of corporations will increasingly find themselves caught in the midst of a forced transition into the Cloud which they are effectively powerless to stop, they will find themselves in the same predicament and without a clear choice: *how can we store precious bits of data once, permanently?*

III. Energy efficiency and immutability: the potential to innovate the material for precious data storage.

As I have shown thus far, a convergence of secular trends in technology have resulted in the creation of unprecedented amounts of digital data. While not all digital data is important and can be discarded, an increasing stock of precious digital data is suboptimally being preserved by remote means, potentially undermining the relationship between the owner and their data. As I have further shown, people have always had, and will continue to have, a desire to preserve this precious digital data for economic, social and even metaphysical reasons.

The global Purpose-Built Backup Appliance (PBBA) market accounted for $4.52 billion in global revenues in 2017 and is expected to reach $22.80 billion in revenues by 2026, growing at a CAGR of 19.7% during the forecast period.[9] The PBBA market is essentially comprised of enterprise, physical and software solutions provided by companies such as IBM, Microsoft, Dell, Oracle, Iron Mountain, CommVault, Arcserve, Symantec, NetAPP, Hitachi, HP, and others. While the PBBA market is healthy and compounding at an admirable rate, it does not comprehensively define the market opportunity because this segment of the market excludes companies such as DropBox, WeTransfer, and Zoolz, which many consumers and businesses increasingly rely upon to backup their most precious data. Dropbox, for example, reported $1.4 billion in revenue in 2018 from 12.7 million paying customers residing in 180 countries. Moreover, the PBBA market research completely excludes the market for consumer data storage devices such as Hard Disk Drives (HDD), Solid State Drive (SSD), Memory Cards, USB Flash Drive, and Optical Disks. Together, this consumer market is worth an additional $18.8 billion per annum by 2025 and is dominated by companies such as Seagate, Western Digital, Toshiba, Samsung, Sony, Transcend, Verbatim, PNY, Kingston, and Corsair.

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[8] Ibid.
[9] https://www.researchandmarkets.com/research/d5m849/22_8_bn?w=12

Through these various market segments, I have presented sufficient evidence that consumers and businesses are spending over $40 billion a year on the storage, backup, and protection of their precious data. This provides sufficient proof that an industry is developing around the archival, backup, protection and storage of precious data in lock-step with the trends in data centralization and digitization. Ultimately, the $40 billion annual market I have presented, along with any other economic demand for precious data storage, is addressed via two specific technologies: (i) *Cloud-based data backup and storage services*, and (ii) *physical storage cards, disks, tapes and drives.*

Through the use of Cloud-based backup and storage services, physical backup storage products, or a combination thereof, it might appear that some of my earlier concerns have been addressed. One might argue, for example, that even though much of the data is stored on the Cloud, the relatively smaller amounts of precious data can always be treated with extra care by IT departments and CTOs. Private citizens can rely on Dropbox and WeTransfer so long as they pay a subscription — as long as they do so, the service providers shall be obligated to protect their data. Moreover, the more ardent private citizens or corporate IT professionals can backup data on physical storage devices. A combination would achieve a more decentralized state of storage and improve accessibility. These would be the dogmatic responses to my concerns thus far; such responses arise from an implicit trust and belief that the present paradigm sufficiently addresses any negative consequences arising from the "*Great Drain*."

To understand why such positions are flawed, we must return to the capital importance that data preservation be energy-efficient in order to gain immutability: any form of preservation involves a tangible cost in the form of *expended energy* in order to withstand the forces of *entropy* through time. Digital data, like any building or machine, is not exempt from this natural law of requiring energy in order to fight decay.

The EROI (energy return on investment) of storing digital data is an extremely important component in this equation and is predicated entirely on the *duration* of preservation. Within the current paradigm of data storage, the longer one wishes to store data, the more energy will be required. The question we seek to address is whether this EROI can be optimised and whether material science may play a role in such optimisation.

To build Chartres cathedral requires a tremendous amount of energy, in the form of natural materials and labour, but the famed church has lasted for a millennia; by contrast, modern buildings made quickly and cheaply are built not to last, but to serve an imminent purpose of convenience and profit. The former is built once and lasts, serving its purpose as a church unto generations; in this way, it is *more energy-efficient* than the latter, which, once built, requires constant repair, renovation and updating. Stone is naturally more resilient than wood; likewise, is there a better physical medium available for the storage of data? I propose that, indeed, we should strive to employ the most *energy-efficient* material to store our precious digital data as measured on a *long-term basis*; moreover, said measurement must include all the energy required to transition from one form factor to another. In other words, due to the effects of the Great Drain, we must consider whether certain data necessitates a greater upfront investment in energy to preserve sustainably and thus more energy efficiently.

Unfortunately, the issues plaguing the current data storage paradigm extend beyond merely energy efficiency. There is another issue — *immutability* — which is perhaps even more concerning. In the next few sections, we will engage in a more rigorous inquiry in order to understand precisely *what* digital data is, *why* it is always exposed to degradation and *how* modern storage and backup paradigms have not sufficiently addressed an impending crisis in both the permanent loss of data as well as declining physical accessibility to precious content.

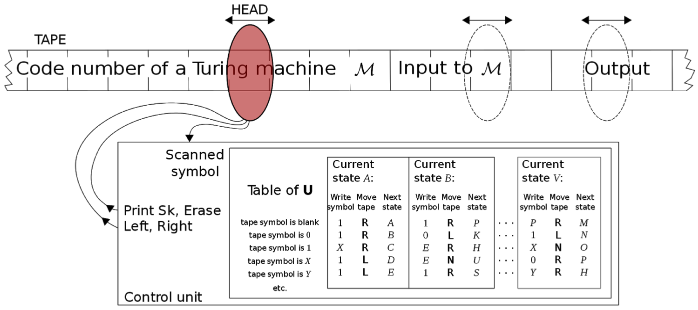
In short, I will argue that the present paradigm for the backup and storage of precious data fails not only due to the suboptimal energy efficiency dynamics but also due to an inherent reality concerning immutability. Again, it is my position that, when compared to the current paradigm, a higher standard of energy efficiency and immutability was met in the recent past with innovations as antiquated as the physical printed book, document or record.

IV. Binary data: the gulf between the computer and the human experience which it seeks to reproduce.

It is important to understand the foundational difference between digital data within the realm of computation and the sense-data of human experience to derive meaning and knowledge. Typing an email on a keyboard, listening to classical music on a computer with audio speakers, or watching a video through the employ of our perceptual visual system is ultimately a virtualized phenomena predicated on the computation of binary bits. Conversely, our human experience in nature is an entirely different phenomena, which computational scientists often call “analogue.” The counter-examples would be writing a letter by hand, listening to a symphony performed by an orchestra or watching a live performance of a play. This analogue human experience is qualitative and irreducible, while the phenomenon of computation is an abstraction which is always reducible to a mathematical-geometrical point.

Most of the digital data we interact with every day has been carefully synthesised into a range of phenomenological experiences which stimulate a limited range of our sense perceptions, but the data itself always exists as *binary*, a base 2 numeral system invented by Leibniz in 1689. It is from a binary foundation that Alan M. Turing invented computation as presented in his 1936 paper [“On Computable Numbers, With an Application to the Entscheidungsproblem”].

Here, Turing put forward the theoretical framework for the Universal Turing Machine, also known as a computer. What Turing discovered is that from a purely mathematical perspective, a machine could be constructed which could calculate any set of numbers by employing *binary code* (so long as certain conditions were met):



“If an a-machine prints two kinds of symbols, of which the first kind (called figures) consists entirely of 0 and 1 (the others being called

symbols of the second kind), then the machine will be called a computing machine. If the machine is supplied with a blank tape and set in motion, starting from the correct initial ra-configuration, the subsequence of the symbols printed by it which are of the first kind will be called the sequence computed by the machine. The real number whose expression as a binary decimal is obtained by prefacing this sequence by a decimal point is called the number computed by the machine."[10]

What Turing shows is that, if we have a rather long runway of tape, mimicking the phenomena of human memory, a machine can, through the employ of binary symbols, print symbols on the tape, read the symbols which were printed, and then, based on the input value read, move either forwards or backwards through the tape in order to take the next action. Through the introduction of a set of certain rules of logic, this system can begin to set more complex rules of action which can, with the advantage of faster speeds and greater sources of power, abstract, recall and virtualize any phenomena of sound or vision. While in the world of ordinary experience it would appear to be a disability to wake up one day and merely rely on two-dimensional vision and sound, somehow, in the world of computation, humans are happily willing to condense their range of perceptions for the sake of expediency.

The last 70 years of human history can, perhaps, be described as the advent of a religious practice which emanated from Turing's paper, resulting in the massive investment and build-up of modular systems of computation which have become faster, more complex, and now consume nearly one fifth of our total electricity production.[11] The consequence is that computers and computational data have not only augmented and aided our human experiences, but, in many aspects of life, they have played a key role in both creating and occupying our human experience.

For most people today, it may come as a surprise that there even exists a line of separation between the human phenomena of sense perception in nature and that of perceiving a virtual experience computed from binary. To return to our earlier examples: pause for a moment to consider the qualitative experience of being at the opera (the colors, the sounds, the lingering taste of supper, the palpable feeling in the air), to the experience of listening and viewing an opera being played as a video streamed on Youtube, virtualized through an LED screen, and condensed into audio speakers. Or, consider the act of writing a letter on a piece of paper using a lead pencil or a mercury ink pen versus the act of typing a key which results in the same letters visualized into a word processing software, which can then be stored as a digital data document that can be printed on a piece of paper. Most people today, especially those members of the Millenial, Gen-X or Gen-Z generations, may even go beyond and argue that the two pieces of paper — the one written by hand and the one printed from a computer — are one in the same.

In truth, they can never be the same. The written page was never a binary number, it was conjured from the mysterious mechanism of our mind and, in that present moment of contemplation, acted out on the page through the body. When reading the letter, we can understand the symbols through the mystery of consciousness. There is no requirement for a computational intermediary: only mind and body. In other words, there is no requirement for the meaning of the symbols to be condensed into binary. We have no way of knowing how it all works, nor can ever reduce the phenomena from our

[10]*ON COMPUTABLE NUMBERS, WITH AN APPLICATION TO THE ENTSCHEIDUNGSPROBLEM Proceedings of the London Mathematical Society*, Volume s2-42, Issue 1, 1937, Pages 230–265

[11]https://www.theguardian.com/environment/2017/dec/11/tsunami-of-data-could-consume-fifth-global-electricity-by-2025

vision of the symbols to a specific point of memory where the symbols are stored in our brain. While there are boundless attempts by academic theoreticians to state that this "hard problem of consciousness" has been resolved as "settled science" through the latest current of theories and beliefs, all attempt to do so by neuroscientists, philosophers, physicists and psychologists always leads to an infinite regress of unanswerable questions.

On the other hand, the printed page came to life from its starting point in the mind through the detour of its state as a binary number. The moment our fingers touched the keyboard, specifically reducible and identifiable bits of binary were printed onto a computer memory. Even though the computer has virtualized those binary codes back through a screen which mimics the written page, where our human sense of vision can read the symbols as letters and words, the computer itself is working within the far distant world of binary. When we choose to print the document, it is binary code which is being sent to a printer, computing the binary into symbols which are printed on paper. While our mind's mechanism of memory may be capable of comprehending the meaning of the words printed on the paper no different than the symbols we write on paper, there is an unequivocal distinction: there is indeed an extra step which required extra energy. This intermediary has been introduced by way of the computer and the corresponding digital medium of the data.

Herein lies the problem, it is not the human meaning of the words which is being stored by the computer in digital data — instead, it is *binary*. When the printed sheet of paper disappears or is destroyed, the binary data is what remains. It must then be once again converted, through the use of the intermediary computer and a printer, into something a human can derive meaning from.

This philosophical grounding is important and will help to advance our inquiry towards a clearer understanding of the challenges inherent in digital data storage. So long as human information is increasingly being created and stored as digital data within computer memory, that human information risks being essentially lost forever while it remains in its digital storage form; that is because, from the outset, the experience has been condensed into machine readable binary. Moreover, it matters not whether the digital data may be understood by us through the employ of a translation system — a Rosetta Stone if you will. One cannot escape the mere fact that unilaterally transforming all residue of human activity into purely digital data increases the entropy within the human repository of knowledge.

As I have shown, there are important distinctions between our human experiences and the computational paradigm with regards to how information and meaning is derived. Within computers, digital data is stored as binary numbers, either as a "1" or as a "0". These reducible points have no meaning to us unless they are sufficiently computed, translated and reified into visual symbols or auditory sounds. Alas, this introduces another issue: *in order to maintain the digital data as binary, we must constantly allocate and expend energy to preserve the information within the digital data which we value, that which is precious.*

V. How computers store digital data: the risks involved in the computer storage paradigm.

The mathematical foundations set by Turing for computation and computational memory are elegantly simple in their design, yet quite clever. As I have previously shown, the Binary system can have one of two states: a "1" or "0", an "On" or "Off", a "Yes" or "No", etc. There are seemingly endless potential symbolic representations which may emanate from just two relative states. Ultimately, what this binary activity represents is a corporeal phenomena in the form of a "positive" charge or a "negative" charge emanating from an electron which is physically changing states. This physical action powers the computational process and the storage of digital data within digital storage media.

The digits 1 and 0 have come to be the preferred symbol employed, and so from this point onwards, I, too, shall employ them. Bits of data grouped into 8 units have become known as "Bytes".

The thing to always remember is that while Bits and Bytes may appear to be digital, the electrons which they represent and which give them life must be physically generated and stored within physical mediums somewhere, everywhere, all the time. Some of these bits and bytes are metabolic, powering the machine's mainframe, integrated circuits, and central processing unit (CPU). Such is the case for the CPU Cache or Random Access Memory (RAM) where bits and bytes flow through at the speed of light (300,000 km/s) and can be read and written simultaneously. Other bits and bytes serve longer-term purposes, such as storing files or backing up the computer's activity. This data always requires a longer time to be processed and read by the CPU depending on the type of storage device, the physical location and position of the bits and bytes and the speed of the processor.

All digital data, be it in the Cache, RAM, or longer-term storage is merely a binary state stored, that is to say *memorized on a micro scale*—1's and 0's occupying billions upon billions of micro edifices. Like a micro hostel, these bits can come, go, or stay according to the instructions they receive. These micro hostels can be divided into rooms where only one Bit can fit at any given time, these rooms are known as *memory cells* and each cell has a uniquely identifiable address.

Due to the apparently infinite possible combinations of Binary "1"s and "0"s, computers can, with the aid of densely-packed memory cells and human input, abstract any sound or image, store it, and then virtualize it back into something we understand.

A brief history of digital data storage (computer memory) media
Since the advent of the computer, several technologies have been invented for the storage of digital data. Below is a list of historic and existing digital data storage technologies that advanced beyond the theoretical phase to become actively employed in real world applications. The list includes the type of technology, the year it was invented, and the potential storage capacity.

Digital Storage Medium	**Year Invented**	**Storage Capacity**
Machine Readable Paper Punch Cards	1725	7.2 Megabytes per 1 A4 Paper
Semiconductor (AC/DC Converter)	1874	Gigabits
Magnetic Tape (Digital)	1951	185 Terabytes
Magnetic Disk (Hard-Disk Drive)	1954	16 Terabytes[12]

[12] https://petapixel.com/2015/08/15/samsung-16tb-ssd-is-the-worlds-largest-hard-drive/

Magnetic Disk (Floppy)	1967	~1.5 Megabytes
Solid State Drive	1980	100 Terabytes
Optical CD/CD-ROM	1982	847 Megabytes
Optical DVD	1995	17.08 Gigabytes
Optical Blu-Ray Disk	2002	128 Gigabytes
Optical Magneto Disk (MiniDisc)	1985	9.1 Gigabytes
Solid State Storage (SD)	1999	2 Terabyte
Solid State Storage (USB Flash)	2000	1 Terabyte

This list of technologies shows how machine readable digital storage mediums have evolved from the paper punch cards of the 18th century to the USB Flash drive of the 21st. It is important to recognize that all of these technologies are essentially micro-edifices with trillions upon trillions of physical memory cells which can store bits of 1s and 0s.

And while each of these technologies may differ, all employ some mechanism to both read and write the digital data onto the memory cells. Some of these devices are *immutable*, which is to say the data can only be written once though it can be read multiple times. Other devices are *mutable*, which is to say that data can be written and rewritten many times.

As we shall now see, both mutable and immutable digital storage media suffer from data degradation which fundamentally restricts their lifecycle and energy efficiency which consequently undermines their utility in permanently storing digital data.

Data degradation (bit rot) and the lifecycle of various digital storage media

As we find in most natural phenomena, even computed digital data, it seems, decays and rots through time. This entropic aspect inherent in all digital data is little discussed yet the effects of this corrupted data are real and quite alarming. Herewith a visual example of a digital image undergoing Bit Rot. The series of images from left to right have just single bits changed in each resulting in a significantly altered image:

0 bits flipped | 1 bit flipped | 2 bits flipped | 3 bits flipped

Data degradation results from the gradual decay of the physical medium over the course of years or longer. In my research, I have found that beyond the material science being employed, an important factor contributing towards "bit rot" is the mutability of these technologies. Just as a machine withers which each use, the prevalent data storage technologies will see an increase in entropy with each read/write cycle.

All digital storage media from flash memory to paper punch cards suffer from this phenomena. What we find is that a combination of the material being used to construct the storage media coupled with the number of read/write cycles will always result in a shelf-life which isn't necessarily objective and therefore somewhat unpredictable. This, in turn, fundamentally restricts the ability to store digital data over long periods of time (say the human lifecycle) and reduces the energy efficiency of the storage media.

Let us review each kind of digital storage media technology to recognize how data degradation arises through time.

- Solid-state media, such as EPROMs, flash memory and other solid-state drives (SSD), store data using electrical charges, which can slowly leak away due to imperfect insulation. The chip itself is not affected by this, so reprogramming it once per decade or so prevents decay. An undamaged copy of the master data is required for the reprogramming; by the time reprogramming is attempted, the master data may be lost. The memory cells used in flash drives do eventually wear out, but this is typically caused by the number of times data is written to the memory — as opposed to the physical age of the drive itself. Depending on the type and manufacturer's specifications, a flash drive may have 10,000 to a million data-write cycles before it begins to give error messages when used.[13] In other words, solid state drives do fail even in spite of having no mechanical parts.
- Magnetic media, such as hard disk drives, floppy disks and magnetic tapes, may experience data decay as bits lose their magnetic orientation[14]. Periodic refreshing by rewriting the data can alleviate this problem. In warm or humid conditions these media, especially those poorly protected against ambient air, are prone to the physical decomposition of the storage medium. The average lifetime of a stationary hard drive today is around 5–10 years[15] (depending on the type and manufacturer) which rapidly declines if the drive is subject to strong variations in temperature, humidity and motion. Since a majority of people today own laptops and external hard drives, which get dragged around quite a bit, a realistic lifetime for a hard drive

[13] https://gadgetwise.blogs.nytimes.com/2011/07/19/qa-the-lifespan-of-a-flash-drive/?_r=0

[14] Totenpass co-founder Bruce Ha was recently invited by the Library of Congress to discuss archival technology solutions. During that meeting he discovered that the LoC, which predominantly uses LTO magnetic storage technology for their backup needs, had made the decision to outsource their archival activity to AWS. The AWS rep who happened to be at the same meeting was approached by Bruce and asked how AWS intended to backup the digital data and the rep responded "with LTO". This anecdote characterises the circular logic and increasing systemic risk which is growing within our public institutions who have been tasked with the responsibility to preserve our knowledge and culture.

[15] https://en.wikipedia.org/wiki/Data_degradation

is around 3 – 5 years. This is an extremely short time to reliably store precious data, and consequently requires earnest upkeep on the part of the individual.

- Optical media, such as CD-R, DVD-R and BD-R, may experience data decay from the breakdown of the storage medium. This can be mitigated by storing discs in a dark, cool, low humidity location. "Archival quality" discs made from Gold and precious metals are available with an extended lifetime which manufacturers claim to be as high as 100 years. While these appear to be the best existing solution on the market, it is important to recognize that these Gold DVD media are still not especially resilient due to their composition of polymer. For example, a little moisture or heat can lead to breakdown of the polymer resulting in total loss of the digital data if just one bit is impaired. These DVD media can be scratched, they can be burned in a fire, and, owing to their read/write cycles, they will eventually diminish and degenerate through time.
- Paper media, such as punched cards and punched tape, may literally rot and have diminishing utility with each read/write cycle.

As has been made clear, tangible degradation takes place in all existing digital storage media technologies. This degradation is caused not due to any specific technology but as a result of the type of materials the storage media is physically constructed from, the amount of moving parts, or the amount of read/write cycles. No technology on the market today seems to be immune to the natural phenomena of *bit rot*.

Within the range of digital storage media technologies, it is clear that immutable mediums employing precious metals such as Archival Gold and M-Disc DVD's have the longest life cycles. Alas, even these mediums suffer from degradation due to read cycles, scratching, or a natural disaster such as a fire.

Summary of digital storage media by lifespan, bit rot, exposure to fire and water

Storage Media	**Estimated Lifespan**	**Data Degradation (Bit Rot)**	**Immunity to Home Fire (1,100 F)**	**Immunity to Water**
Blu-Ray	2-5 Years	Yes	No	No
Hard Disk Drives [16]	3-5 Years	Yes	No	No
CD-Rom[17]	5-10 Years	Yes	No	No
DVD[18]	5-10 Years	Yes	No	No
Magnetic Tapes	10 Years	Yes	No	No
Solid State Storage	10 Years	Yes	No	No
Floppy Disk	20 Years	Yes	No	No
Archival Gold	100 Years	Yes	No	No

[16] Ibid.
[17]https://www.npr.org/sections/alltechconsidered/2014/08/18/340716269/how-long-do-cds-last-it-depends-but-definitely-not-forever
[18] https://blog.storagecraft.com/data-storage-lifespan/

(DVD)[19]				

It is truly concerning to consider that not one of the existing digital storage media technologies is immune to fire or water and all digital storage technologies on the market today will suffer from data degradation (some in as little as 5 years).

As I have previously argued, when it comes to our precious data, the more they move around, the greater the increase in entropy, which is to say *the potential for the information to be lost*. Equally important when it comes to storing data, the shorter the lifespan of the digital storage medium, the greater the energy being required over time.

The present paradigm may be sufficient for metabolic digital data but it leaves much to be desired when it comes to precious digital data. Anyone who simply wants to preserve a meaningful human experience or valuable knowledge is forced to play a game of lustrum frogger where every few years digital data is transitioned from one physical drive to another. As with moving from one home to another, each move increases the risk that some things may get left behind.

At this point, more trusting personalities may argue that, with Cloud solutions, the user bears no risk for these physical transitions as the provider is ultimately responsible per the customer agreement. This argument reminds me a lot of the same arguments we heard from bankers, regulators and institutional investors about the resilience of the global banking system before the events of 2008 unfolded.

My response would be that the facts and information which I have provided show that it is not enough to merely trust the Cloud provider. No matter how trustworthy they may be, there is an inherent risk that, given enough time, and given enough backup cycles, precious bits of data entrusted to the existing digital data storage paradigm will be lost forever. What we learned in 2008, and what humans always learn the hard way, is that tail-risks accruing upon a flimsy foundation will eventually result in violent reversions. This is the natural order of things.

It is my strong opinion that even well meaning enterprise Cloud providers are taking on an inordinate amount of reputational, financial and regulatory risk with the digital data they are storing. Companies such as Google, Amazon, IBM, Microsoft, Oracle and DropBox are falsely representing their ability to preserve digital data permanently and effortlessly, pricing their services on that representation. In the best case, physically backing up every bit of data forever would be far costlier than what they are charging, and, in the worst case, the act of backing data will result in losses of bits via degradation or other forms of entropy.

Cognitive dissonance on the part of consumers, governments, and corporations is compounding this risk by deferring the act of custody and security thereby contributing to this unsustainable rate of centralization. In so doing, citizens are willingly taking part in a historic consolidation of human knowledge and experience into centralized repositories which are neither permanent nor immune from fire, water damage, or other natural disasters.

[19] Archival Gold DVD's or iterations of these technologies such as the M-Disc utilize thin layers of precious metals such as gold or silver which are sandwiched between substrates of carbon polymer.

Putting aside the need to constantly backup and transfer files from one digital storage media to another, at this stage of the paper, it should be clear that the existing digital data storage paradigm wastes a tremendous amount of energy in comparison to historic, non-digital media such as a pen and paper or a book printed on Gutenberg's Printing Press 500 years ago.

In a word, the existing digital storage paradigm is insufficient for the storage of precious data. A solution is required that can reverse this trend or at the least provide a choice to those who wish to protect the sum of human knowledge and experience from this increased rate of entropy.

VI. Non-digital means of storing information, knowledge and human experience.

As the previous section has shown, our modern commitment to the computational paradigm, together with an ostensibly endless demand for data storage, has mesmerized society into expending far more energy than necessary in order to preserve our precious human experiences. But could these experiences be better stored via non-digital means?

Adding yet another layer of complexity to this puzzle is the insight which this section shall elucidate, namely that neither binary as a numeral system, nor computers as an electrically-powered apparatus for calculations, have a monopoly as powerful tools to store human experience.

A deeper inquiry shows there are far more efficient ways to condense and preserve a human experience into something physical which can be recalled in the future. Here are some examples:

- ***DNA -*** Deoxyribonucleic Acid is, contrary to what most people assume it to be, an informational storage medium using three dimensions rather than the two employed in binary. Simply put, DNA is a more efficient way to store mathematical information, for it is more dense. The structure was postulated first to make sense of various biological theories (*The Central Dogma*)[20] but its efficacy in condensing mathematical values in 3-d has made it a potent tool for storing binary digital data upon which, as I have shown, all computation is based. Using various compression theories and algorithms, academics have been able to model as much as 1.28 Petabytes of digital binary on a gram of DNA. Now, it is important to restrain any excitement over these results with a dose of humility. While all of this makes sense mathematically, there is at present no concrete way to actually achieve this. However, this exercise in storing digital data by incorporating more than 2 dimensions (as opposed to binary) is a critical clue in understanding the technology which I will soon present.

- ***Abacus -*** For over 4,000 years, virtually every human civilization has employed the Abacus (and its Japanese counterpart the *Soroban*) as the primary tool for calculation. The Computer 1.0 is so simple yet so powerful. It can add, subtract, and even multiply abstract numbers.[21] The abacus is essentially a physical medium which helps us store information which we can then recall in the future. This is a data storage technology that does not rely on binary, electricity or Turing computation.

[20] https://en.wikipedia.org/wiki/Central_dogma_of_molecular_biology
[21] https://www.ee.ryerson.ca/~elf/abacus/abacus-contest.html

- ***Braille* -** Braille is a reading and writing system comprised of raised dots which can be embossed onto paper or metal. In braille, each cell is divided into 6 potential dots which can be raised or flat. Variations of each cell correspond to specific letters within the Latin alphabet. The result is a system where human meaning, in the form of words and information, can be physically inscribed onto a solid state storage media. There is no need for a computer to process the braille into a visual sensation. Like a book, meaning can be derived through the mechanics of human consciousness by merely reading the braille or by incorporating the knowledge understood within braille within the natural world.

- ***Morse Code* -** Similarly to Braille, Morse code abstracts electromagnetic sounds into distinctly recognizable points of varying auditory length. Using an initial key which maps sounds to alphanumeric symbols, morse code operators were able to communicate long messages carrying human meaning across vast geographic locations. Morse code powered the entire telegraphy revolution of the late 19th and early 20th century. In Morse code, we see a system for communicating human meaning which does not require computation. A human can merely listen to the sound and understand the underlying information.

- ***Magnetic Tape (Analogue)/ Wire Recording* -** In my research, one of the most interesting phenomena I have learned about has been that electromagnetic fields can quite literally store auditory sounds onto a metal. This should not be confused with the modern Hard Disk or Magnetic Tape systems which use this same phenomena to store binary code. The distinction here is an important one. Wire and magnetic tape systems work without the need for a computer to process information into something humans derive meaning from. An electromagnetic head can simply write electrical energy, transduced from audio sound vibrations, onto a metal steel wire, or a ferro-oxide tape. When the tape or wire are run back through the same electromagnetic field, the sound vibration is played. This extremely efficient technology was the primary mode of recording meaningful information for nearly a hundred years.

- ***Wax Strip Cylinder Recorde*r -** Invented by Alexander Graham Bell in 1886, this ingenious system converts the vibration of sound through an enlarged transducing brass cylinder. When audio vibrations enter the cylinder they are transduced by a sharp stylus which engraves the sound vibrations onto a sheet of beeswax. This link shows one of these systems being used. To hear the sound played back, the system is run in reverse. The engravings on the beeswax result in vibrations which our auditory system instantly recognizes as sound.

- ***Hieroglyph* -** Dating back to 3,000 BCE, hieroglyphs are logographic scripts which denote characters or phonetic sounds. While academic schools differ on the actual meaning behind hieroglyphs, the condensing of human meaning by way of engraving physical characters into stone or 24 karat gold is yet another example of a way to store information, knowledge and experience in non-binary storage mediums over extended periods of time. These scrolls engraved on pure gold are known by historians as a totenpass. Indeed, these totenpasses have been essential in preserving the knowledge of our past.

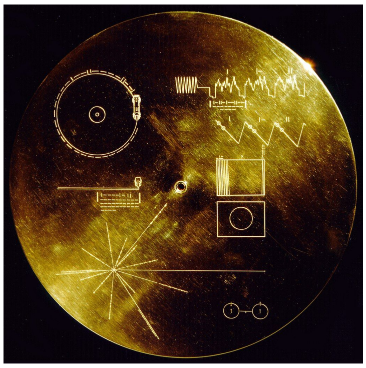
- ***Index Cards* -** Index cards, as well as the card catalogues comprised of a file cabinet of index cards, are another interesting yet simple invention which condense and store human meaning and knowledge. For at least 400 years, humans have been organizing important information into small index cards which could be re-arranged easily. Index cards allow us to compress human meaning into a format that is more easily preserved and accessible without the requirement for energy, computation, or binary.

To think that only binary code can store human experiences, knowledge and meaning is to accept the current paradigm without any understanding of the myriad alternatives of non-digital storage. What must be done by a rigorous thinker is to revert back to the original axiom and to consider alternate ones. In this section of the paper, I have shown that there are other natural phenomena which help us to store human experiences, and which have successfully done so before the advent of the Turing machine. This contrarian perspective will allow us to consider alternate materials and approaches towards storing the digital binary data that is increasingly assuming control of our most precious human experiences and knowledge.

The key to understanding both the opportunity and challenge in front of us is to recognize the following: *yes*, every digital data file begins as binary, and *yes*, only the computer can understand binary; *and yet, despite this challenge there exist non-computational approaches to condense machine-readable binary into a physical and permanent storage medium.* We allude to a storage technology, constructed of immutable materials, the purpose of which is to restore the direct relationship between individuals and their data such that a computational intermediary is no longer required.

VII. Achieving immutability and energy efficiency through time: the importance of gold and precious metals.

The first insight which should be clear at this point is that gold can play a serious role here. I have already shown that the best digital data storage media on the market today (in terms of lifespan) is the gold DVD technology which is viewed as the best-practice method for the archival, backup and preservation of digital data.



Indeed, when a NASA committee chaired by Carl Sagan was tasked with creating a time capsule to store humanity's greatest experiences in space, the committee chose to engrave information onto a gold record which was sent upon the Voyager 1 Probe in 1977.[22]

And as I have also shown, Egyptian hieroglyphs engraved into 24 karat gold, or the scene of the Crucifixion etched into the Cross of Lothair, are not only clearly visible today, but look and feel exactly the same way they did those many years ago. What we find is that the same qualities which make gold so special in nature, which have led towards its ascent as premier money, premier artistic media and premier jewelry, also make gold the premier method to *store data* — digital or otherwise — when *permanency and energy efficiency through time* are the primary objectives.

[22] https://en.wikipedia.org/wiki/Voyager_Golden_Record

The natural chemical inertness of gold means that it is completely immune to entropy and ensures that no gold object will ever oxidize or degenerate in any way. In this sense, gold would solve at least one problem: the problem of material degradation. And as I have shown, the longer the digital data may be stored in one medium — not having to be copied over in a risky game of frogger — the more energy-efficient that medium will be. Only a miniscule amount of gold is used in Archival Gold DVDs, which significantly improves their immutability through time relative to other digital storage media. But, what if more gold were used? How about a solid piece of gold? And what of other precious metals? Could platinum and palladium perhaps play a role?

And what of information density? Could gold's exemplary natural attributes also play a role in condensing more data than other digital storage media technologies? If that were to be the case, it would surely introduce a high EROI method to store digital information. And what of the problem of centralization? As you may recall in the earlier sections of this paper, the *Great Drain* is resulting in more information being centralized. Could gold not somehow empower billions of people who want to easily store their precious data once and forever in the palm of their hands?

What is required is an immutable solid-state innovation that would permit precious metals to densely preserve digital bits of data while remaining both human and machine-readable; a technology to store precious bits of digital data *permanently, once and forever*. Such a solution, as has been demonstrated through our inquiry thus far, would not only be demanded as an economic good but would also command a large premium from individuals, corporations and governmental agencies for the peace of mind it introduces.

In the remaining sections of this paper, I will outline a new technology that solves the issues inherent to the present paradigm for precious digital data storage by combining the unique qualities of precious metals — primarily Gold — with recent advances in light diffraction, in order to store digital data in human readable non-binary formats.

VIII. Totenpass: the new paradigm in the permanent storage of precious digital data.

The Totenpass is a permanent digital storage drive constructed from solid gold and nickel that requires no energy and has no movable parts. Digital data is written onto the drive by way of a proprietary light-diffraction process which imprints images, documents and other files that can be stored as either human readable, without the aid of computers, or machine readable, with the employ of a smartphone. A Totenpass can permanently store up to 2 Gigabytes of human and machine readable data, thereby ending any future dependence on energy, the Cloud, or the internet.

Analogue and digital storage on the same drive

The Totenpass provides users with the flexibility to preserve data as both digital and analogue information. For the storage of digital data, the Totenpass relies on the coherence properties of laser light. Using the collimated light and a proprietary imprinting technique, light is made to diffract resulting in patterns written into multiple dimensions of the gold surface. This multi-dimensional data density is more efficient than a binary type system which characterizes the existing digital storage paradigm. The second technique employs a domain transformation that converts spatial information into a secondary domain which compresses that information on a photonic level.

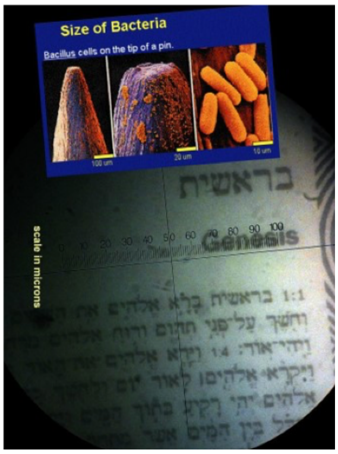
For analogue storage, the diffractive patterns are arranged with billions of diffractive bits to form pixels that comprise the formats familiar to our human experience such as visual documents and photos.

The unique elegance of the Totenpass information storage architecture lay in its capability to achieve both digital as well as analog storage density on the same surface. Like a futuristic Rosetta Stone, both machine and human languages can be used to decipher any information recorded onto the gold.

While all files initially written onto the Totenpass originate as digital binary files from a computer or smartphone, the diffractive process results in those files coming to life as patterns of light diffraction on the surface of the Totenpass. For example: textual files including spreadsheets and powerpoints, photographs, images, documents and even audio files may be etched directly onto the surface of the Totenpass such that a human could recall the meaning of the information by mechanisms of consciousness: visual, auditory and tactile.

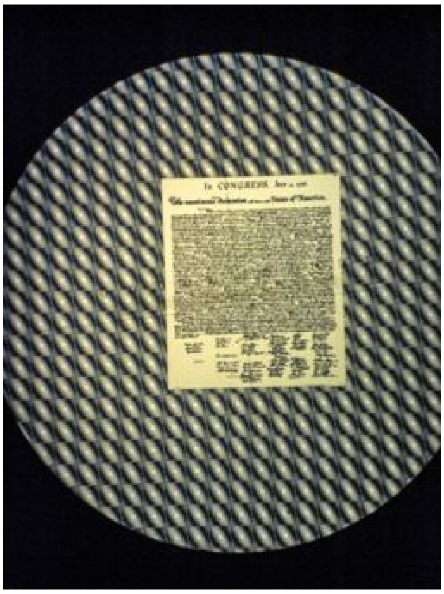
Proprietary Technology

The technology powering the Totenpass is a proprietary laser optics writing process which has been developed over the past three years. This allows for the engraving of digital information onto solid gold using a highly focused 405 nm wavelength creating feature sizes of 125nm or 1/1000th of a human hair. That is to say that each character in a document would be written onto the drive at the same scale of a bacterium.



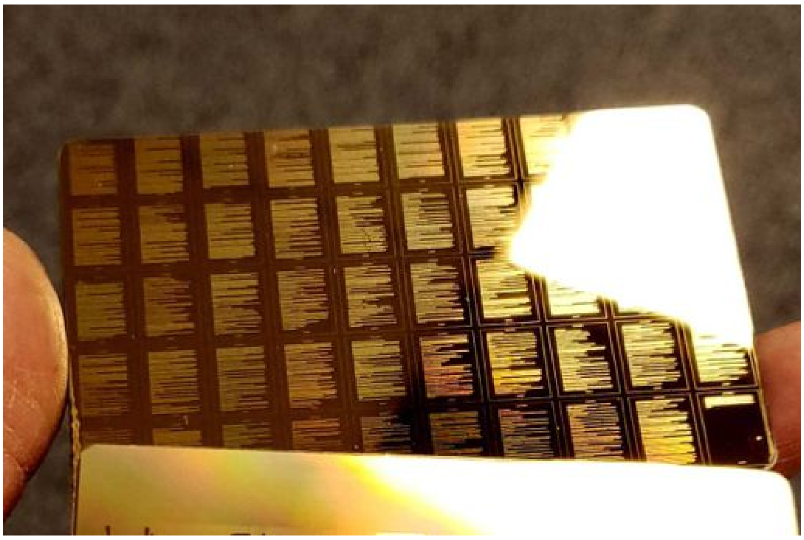
Hebrew Bible printed on a Totenpass with each character size equivalent to a bacterium.

Totenpass technology prints over 10 billion pixels at a resolution of 25,000 dots per inch at a speed of 1,000 pages per minute making it the fastest analog nano printing technology in the world.



1mm Declaration of Independence on a Totenpass

The Totenpasses writing technology requires advanced super parallel computing to break down user uploaded data into a 10.5 GigaPixel image which in turn modulate the 405 nm laser and etch the data onto the gold substrate. In comparison, Photoshop, the most advanced image handling software, can only handle a maximum of 900 MegaPixel bitmap images.



Alice in Wonderland by Lewis Caroll on a standard sized Totenpass

Bespoke options and customization — no two Totenpass are the same

The utility of the Totenpass is not just limited to the physical drive technology but also in the read/write software we have designed. The software allows users to create their Totenpass in a few easy steps. This optionality includes but is not limited to: the size of drive, storage resolution (analogue), and the ability to visually arrange the files on a surface template (analogue) before creating the drive.

This is important as for some, Totenpass may be used for just one photograph easily readable by a human eye, while others may choose to fit an entire family photo album of 50,000 photos, requiring the Totenpass app to read back or convert the information back into digital files again in the future.

To read a file from a Totenpass, all that is required is the Totenpass app and any modern smartphone. There is no identity tied to a Totenpass and no login is required to access the digital data stored on the card.

- Every Totenpass card is bespoke, crafted upon order, and has a small surface area for an owner's initials.
- No moving parts and no energy is required to store data. Due to the natural properties of Gold (Au), the Totenpass becomes the most efficient way to store precious digital data.
- 100% decentralized — precious data is physically preserved on the actual metal rather than on any server.
- 1-2 GB Storage Capacity - (such as a book, spreadsheet, or a photograph) can be visibly read by humans depending on the resolution, by a magnifying glass, or for the higher resolutions by the Totenpass app which will also automatically render certain files back into their various states (analog to digital).
- Permanent — digital data is transformed into a light-diffractive pattern that is physically imprinted onto gold. No degradation or Bit Rot ever.
- Disaster proof — The Totenpass will survive fires, earthquakes, and an EMP attack. It is also fully resistant to any radiation in outer space. The combination of Gold and Nickel results in both a hard and resilient drive and can fit into any wallet.
- ⅓ of the original drive cost is associated with the intrinsic metal value meaning the actual precious metal may appreciate in value over time.

Drive Costs

Rather than accounts, users create bespoke physical drives which come in two sizes:

Standard ($50) - The standard size is 54mm x 85mm, the size of a modern credit card, easily fitting in your wallet or pocket. This size has an analog storage capacity of 1 GB.

Large ($100) - The large size is 71mm x 143mm, the size of an iphone, easily fitting in your pocket. This size has an analog storage capacity of 2 GB.

The Totenpass user experience interface is beautiful, simple, and login free thus being privacy oriented.

IX. Conclusion - Totenpass is a disruptive technology that provides a solution for the growing need to preserve society’s precious digital data.

Totenpass aims to help people preserve their most precious digital data. An answer to the Great Drain, providing *choice* in an era marked by declining choices for storing human knowledge and experiences.

If we are successful, we believe that universities, governments, museums, libraries, industry, as well as individuals, will view this technology as the new standard for archiving, data protection and storage. We believe authors, artists, and thinkers will embrace the Totenpass as the primary method for protecting their intellectual property. Young, old, poor and rich will appreciate once again the opportunity to have direct control of their most precious data, from a family photograph to the physical recording of a will, title, or deed. Climate change activists will appreciate our contribution to lower carbon emissions by re-orienting the future towards a more sustainable path with nature, storing digital data with no further energy requirements. Privacy activists and advocates will see this as a historic rebalancing of power with regards to regaining control of personal data.

By solving these important problems, Totenpass has the potential to provide an important solution for the preservation of society's precious digital data.