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THE COMPUTER AS UNIVERSAL TIME MACHINE

Time beyond and for Perception

Freezing Movement While Propelling the Still

Keeping: A Digital Time Capsule

And the clock and the calculator begat the computer. With it, a new process of manufacturing time opened a new universe. In this universe, ever-faster running clocks create time at ever-smaller intervals. The offspring of clock and calculator chops and flattens whatever it ingests into series of bits, coordinated by clocks running at speeds too fast to watch. It processes and generates patterns and streams of bits under the rules of the calculator and under the control of hyper-fast clocks. Eventually, it spits these synchronized bits out to enter the realm beyond the computer, to meet us in the time of our seeing and hearing, to print on paper or to print a prosthesis, to control chemical processes or a sewing machine, a car or the lights in a green-house – all and everything at their very own speed, on their very own scales of time.

This essay comprises two parts, *The Computer as Time Machine* and *The Digital Time Capsule*. Each one may be read independently of the other, even though both parts are conceptually related and intertwined. Neither part, nor the whole, requires more than interest in the topics addressed; no specific expertise is required, not in the arts, not in technology. And for those with specific background and expertise in one, the other, or both, this essay may add spotlights to their own considerations.

The first part, *The Computer as Time Machine*, reflects on digital technology and its relationship to human time, to human perception, and to history-making, using "time-based arts" as point of reference.

Or the other way around: The first part of the essay discusses time-based arts in its difference to still art and how the time of computer technology, the times of performance, perception and experience, the times of keeping, documenting and archiving time-based works are related.

This is generalized to address the question of how we as individuals and as institutions can keep digital data and what they represent accessible just for our own life time and maybe for one or two generations after us; keeping it in our possession and under our own control without constantly having to think about and pay for backing it up and copying it; similar to a book or a photo-album on a book-shelf, which we can pick up, read and look at and which can be forgotten in some box in the attic, and 38 or 101 years from now someone opens the box and looks at what was kept.

The second part, *The Digital Time Capsule*, proposes in more technical terms, which criteria a time-capsule for digital data has to meet and how it can be implemented today, 2020, as a low-cost equivalent to a photo-album, a vinyl record, a film, a book, or a collection of documents.

We have been implementing such a time-capsule at the Curtis R. Priem Experimental Media and Performing Arts Center (EMPAC) at Rensselaer Polytechnic Institute over the past years.

We are not aware of any other concept or implementation that meets the technical, economic and ownership criteria put forward in this essay for a digital time capsule.

Only time will tell, if the proposed and implemented concrete archival approach is successful as described and hoped for.

The more fundamental considerations explored in this essay may be seen as independent of the actual implementation of a digital time capsule.

For this essay, a few perspectives were chosen, which reflect off each other and together create a scenario of how digital technology has fundamentally changed the relationships of human time, creation, culture and tradition. Each perspective focuses on different scales of times.

There is the time of human making, perception and experience, the time of our hands, feet and mouths, the time of our senses, and the time of making sense.

Then there is the sense-making in and through art, creating one time inside another time, taking time outside of clocked time; in reciting, singing, playing, dancing and performing, in drawings, sculptures and objects, in writing and reading, in capturing and projecting movement, scenes, and colors as they change. All taking us through experience into concentrated or ablated time. Time not being the objective, but a mode as fundamental as the heartbeats that keep our bodies and minds a-changing.

Then there is the time created by digital technology, which moved the times of things and movements from their inherent time-scales to below the threshold of human perception, into the realm of unperceivable speeds and intervals inside the machine.

And there are the time-spans of individual human lives, generations, and eons. How we pass thoughts, knowledge, information and concepts from one person to the next, and from one generation to the following, took a totally new direction over just the past few decades with digital technology creating a radically new foundation for present, past and future.

What had slowly developed over millions of years in making tools that could be reused; through maybe 60 or 40 thousand years creating sculptures, drawings and paintings; then maybe starting 8000 years ago to abduct words out of the time of speaking into the time of writing and then having been written – everything created as physical objects, every material with its own inherent time beyond the time of its creation, perception and use.

The tradition of crafted objects and documents experienced a tectonic shift in the so-called Western world with the advent of mass book printing technology about 500 years ago. This revolution spread throughout Europe in only very few decades and created radically new directions for any cultural and political system it was introduced to. The technical reproductions created with metal movable types and a mechanized printing press allowed individuals to own, collect, and distribute knowledge. It broke the rule of the Christian Church, the most powerful institution that through the preceding centuries had governed the repositories of documents and the institutions of learning; had decided what was to be kept and copied; controlled the distribution of knowledge and thus laid the rule of the land – like many powerful rulers, dynasties, casts and institutions through the construction of human history by determining what was to be taken out of time to be kept and controlling who could access the kept. Now thoughts and images could be reproduced more and more independently of the ruling powers, could be smuggled, hidden, secretly studied or massively distributed to influence the readers, the people.

Education spread slowly but steadily over the next centuries, while the control over education was certainly the control over knowledge and tradition and thus people.

The thousands of years of painting, sculpting, building and writing and the 500 years of distribution and tradition in the form of replicable objects, books, photographs, films or vinyl records, took a radical turn with time-based digital technology. Due to the computer's deconstruction of physical objects and events into time-based bits, digital technology brought with it as inevitable consequence a radical change in how we keep and pass things and thoughts down through time, just for our own lifetime and from one generation to the next.

The following reflections contextualize these changes, moving from the shared time of oral tradition and performing arts, through a world in which physical objects and written documents were created and shared, could be lost and rediscovered, to the contemporary timescales of computing and data storage. For at least a few billion people, distribution and access to a seemingly endless stream of words, images, sounds, knowledge and information has shrunk to the moment of desire. But keeping, what one wants to keep – under one's own control, in one's own home, organization, institution large or small – has become next to impossible without constant care and funding. And even then, we cannot look further down the road than a decade or two. On the one hand the bits themselves, encapsulating what we want to keep, evaporate from most storage media amazingly quickly. And on the other, the cycles of obsolescence in hardware and software, driven by the economic system, are so short that even for the lifetime of an individual it is hard to keep the bits in place to restore them into the time of our perception, our seeing and hearing, whenever we want.

And finally, we may want to keep the bits – representing what we deem important – under our own control. Delegating the storage to "the Cloud", to a system and business model we have absolutely no control and say over, may be good for present-day accessibility purposes, but we don't own the physical representation of the bits in the Cloud. The Cloud takes no responsibility for data loss.

PROLOG II

There was always a clear difference between the arts that moved in and through time with gestures and sound, and the arts that created objects like drawings or sculptures. One was gone as soon as it entered our perception, and the other remained within reach, touch and sight over a human life-time, or – as it turned out – through generations, centuries and millennia. The oral tradition, the teaching by an older person and learning by a younger one in "real time" was the foundation for passing practice and knowledge from generation to generation; this process always included shifts, variations, and embellishments as a fundamental part of the tradition, loss and new inventions being inherent to this process. Drawings and paintings froze a movement, sounds could not be captured, but words could be taken out of time.

As writing once allowed us to write poems and stories down, to elaborate them out of the time of reciting and telling, music notation evolved as well. The oldest discovered examples of music notation stem from around 3,500 years ago, just about 5,000 years later than the oldest found object with written words. Different cultures developed different ways to notate rhythms and melodic contours. In the 9th century a development started in the western part of Europe, which – as many musical notations – began as a mnemonic system, documenting how words were to be sung. This freezing out of time went into a different direction in the following centuries, when the notation was not capturing "the old" and preserving tradition, but rather it was used in a prescriptive way: it communicated to musicians what and how to play what was put down in writing. This notation moved out of the religious realm and, in Western music, underwent constant change through to the mid-20th century. Composition developed, the construction of music out of "real time". Not anymore were changes and inventions bound to the time of playing, but composers predicted how things they wrote down would sound when performed by musicians. The construction of temporal elements outside of time of playing allowed a speculative underpinning of the compositional process. Intellectual and philosophical aspects could be developed and integrated with the composition finding their way into the time of the sounding piece. As had happened with writing language, the notation allowed a local preservation and archive and the distribution of the notated, which allowed performances in other places; all that then exploding with book printing used for music notation and then subsequently with the colonization of the world by the European powers. As musical notation captured more and more details of what and how to play, it was closely intertwined with the change of music over the centuries in Europe, or as Western culture liked to put it, with the "evolution" or "progression" of music.

Over hundreds of years the European culture accumulated experience and knowledge of constructing time-based events outside the time of the eventual performance. A symbolic notation is placed on an imagined time-line that runs from, usually, left to right across a two-dimensional piece of paper. The placement on this horizontal abstract time-line notates the progression from one symbol to the next. On the vertical axis of the page, simultaneity is coordinated, what sounds together at a given point in time. With the continuous addition of symbols to denote how to play something, and more and more complex relationships on the time-line for when to play something, one of the most complex graphical systems developed – far beyond any scientific and mathematical graphs, having "frozen time" on an "x-axis" (before the explicit introduction of this axis to the sciences), though with the major difference that the musical notation was prescriptive-compositional versus the descriptive-analytical goal in science.

This process of taking time out of the construction of the time-based art of music did not find a counterpart in dance and theater until technology allowed the capture of movement. No comparable extensive system for dance was developed, theater used the written word, and both started to document aspects of their work through engravings, which could be printed along with descriptions.

The canons of the traditional performing arts – dance, theater, and music – then expanded and cross-bred through the electrical and electronic technologies of the 19th and 20th century, with film, video, live-electronic performance, performance art, electronic art, new media art, interactive and web art, forming the panoply of time-based arts.

Our relationship to time – how we move in and through it, how history is created through large organizations of power, and how we experience art as a substance of life – may be viewed through the lens of the new time that digital technology manufactured and which it, in the literal sense of the words, incorporates and embodies. The following essay focuses on how the universal time-machine turns fleeting what has been still for our perception and interaction, and how it holds the fleeting around us by capturing it at speeds way faster than the threshold of our perception for change.

PROLOG III

Due to the computer's deconstruction of physical objects and events into bits and their synchronization at ever-higher clock speeds, the arrival of digital technology brought with it the inevitable consequence of a radical change in how we pass things and thoughts down through time. The following reflections contextualize these changes, moving from the shared time of oral tradition and performing arts through a world in which physical objects and written documents were created, shared, lost and rediscovered, to the contemporary timescales of computing and data storage.

Over the past few decades, the cycles of preservation, obsolescence, disappearance, copying, moving, and maintaining these bits have shortened to a fraction of a human generation, and have floated the control over what and how cultural traditions are conveyed back towards powerful entities, whose thrust is needed to propel and maintain the digitized memories. The role the Church once played about 1000 years ago as the controlling body in the era of Europe's first universities is now being taken over by multinational companies through data collection, data mining, and structured accessibility. The revolution of book printing, which allowed individuals to own, collect, and distribute knowledge and which has been essential for the past 500 years, is now being expanded through digital documents that make "everything" accessible "everywhere." However, the infrastructures and business models that are needed to keep the bits "alive" and accessible have now reverted to put the control over resources that hold knowledge and memory across generations back to superstructures beyond individual reach, in the literal sense out of the hands of readers; one might say leading back to the Western medieval ages, with the data companies as the resurrected power of The Church.

The difference in our relationship to the time of a piece of paper, a book, a vinyl record, a photograph or film, and conversely to the time of digital technology, marks a radical change in how we, as individuals, communities, small and large institutions, and even as national and supranational entities, shape our identities and construct continuity for our personal life span as well as for societies and cultures as a whole.

You may hold this text in your hands as part of the book it was originally published in. You will close the book and may put it on a shelf and forget it. If it is safe from fire and water, you can be sure that the printer's ink will still be on this page when you open it in 10 or 20 years. But if you place digital storage media, such as a thumb drive, on the shelf next to this book, and a decade or two later you want to look at the photographs you stored on it and you are fortunate enough to still have a device you can connect it to, the data and with it your pictures may very well have vanished.

This essay ends with the description of a Digital Time Capsule in the context of the evaporating time of digital technology. We researched, developed and implemented a time capsule, which may enable us to keep our personal or institutional digital documents, words, numbers, pictures, sounds, and moving images under our own control, for our lifetime and beyond, at very low cost, and without the continuous need for air conditioning, electricity, and data maintenance.

By creating a perspective on fields as diverse as digital technology, time-based arts, digital preservation and cultural tradition, any expert may clearly see the shortcomings of this essay in their own fields of expertise. The goal of the text is not to take a position of "right or wrong" as guideline for criteria. Rather, my goal in putting these words on paper and in electronic form is to illuminate theoretical perspectives and concrete consequences arising from my expeditions in digital technology and the time-based arts through concrete projects; ranging from initializing new art works, creating production environments at the intersection of the physical and the digital realms, and developing archives for that which is only time-based. And all this fueled by spirited discussions with colleagues in the arts and in technology.

The Computer as Time Machine

The computer is very different from most other tools we have created. Besides the computer, there are two other devices that stand similarly aside from other tools: the clock and the calculator. The digital computer stems from the intercourse of a clock and a calculator.

Almost all (or maybe all) other tools have the sole purpose of changing matter, the state of matter, or its consistency – putting matter together like with glue, fusing it, baking it in a bread machine, dissolving it when using nail polish remover, creating other objects, changing their shape or position, moving and transporting things or us, extending life or terminating life, putting ink on paper, or blowing up a dam. A hammer can destroy a vase or drive a nail into the wall. A physics or chemistry lab fuses and splits matter. Fabric keeps water, cold wind, or blazing sun away from our skin. The metabolism of living bodies can be changed and pain can be relieved. We can get drunk and drive a car. There is a goal inherent in the design of all these tools; they have the specific goal to change matter from one state to another.

At the same time, most tools can be used against their "original" purpose. A piano can be used to keep a heavy door from slamming shut instead of striking strings to push air molecules back and forth and make sounds. A book can raise the height of a computer monitor. Nuclear reaction can be used to destroy life as well as to turn water into steam and drive a turbine, which in turn generates electricity that can then drive computer chips.

The clock, the calculator, and the computer are tools of a different kind. The operations that make them tick and click are not geared to shape other matter directly. The keys of an old cash register, the spring driving the hands of a clock, and the transistors on a computer chip are certainly all material, but the material change within these tools do not have direct and unmediated effects in the world of things, however small or gargantuan. They just sit there and execute their movements, totally "useless" if not perceived by people interested in their states or connected to tools of the first kind effecting changes in matter.

If a hammer is used to shatter a vase, this is indeed a change in the state of matter. But if a clock, a calculator, or a computer is activated, their change of state needs to be interpreted by a human being, who draws conclusions from what they present to us or who connects them to other specific tools.
A clock – be it a mechanical, electric, electronic, incense, or water clock – is void of meaning. Its change of state – the hands running in a circle, updated digital displays, or shortening of the incense stick – needs to be interpreted by us. It can be connected to a bomb to make it go off at a certain time, but making the connection to an exploding device is the actual interpretation and how the clock is "put to work." A clock makes time present in both an abstract and a physical way, detached from sun, moon, and heartbeats as indicators of intervals of time, while simultaneously creating a representation of what was discarded – turning passing time into a tool for power.

Likewise, a calculator is meaningless in the movements resulting from its buttons being pushed. A calculator does not care about whether it adds eggs, haystacks, molecules, weight, or time measured by a clock. It is constructed to obey certain rules seen as meaningful by us. Its function is always the same but the outcome is abstract, literally detached from its functioning and from the items it is used to get a handle on. Its outcome still needs to be put in some connection to the physical world, with dollars, chickens or eggs, time or distance, constants or variables.

As such, the calculator is the great partner of the clock. It discards the physical properties of things and makes things manageable out of time. It makes things become part of our human concepts of abstraction, making the world of things and systems literally "calculable."

In other words, the output of the calculator still needs to be mapped to something else, be it material things the numbers stand for, or abstractions (like in mathematics, economics, or musical composition). Only through this step of interpretation, of connecting its output with something else, does the calculator become a useful tool, a tool of power over something. Otherwise its functioning is meaningless.

We have these two physical devices, which are abstracting from time and matter, while at the same time making time and matter quantifiable. As their output needs to be reconnected to other things and thoughts, such output is freely assignable and can be interpreted independent from the input. I can add egg by egg by egg by egg, and take the output as proof of being the most successful chicken farmer, or as proof that I should switch to growing more crops to stay in business as a farmer. I can add cups of running water over a number of rotations of a clock and determine that we have a drought twice as bad as last year's. The functioning of clock and calculator are independent from the input, and the output is void without any – logical or arbitrary – connection to something outside of these machines, in the realm of other tools, of matter or things, of human thought and action.

The clock and the calculator were a match made for each other and they begot the electronic digital computer. This computer inherited the properties of its ancestors, being ignorant of its input and being void without output into the world of things, matter, and perception, without interpretation of what it puts forward. The process inside a computer needs to be connected to the physical world; it needs to be converted for our senses to perceive what it did; it needs to be connected to other tools that shape physical matter. We cannot verify what a computer does unless its operations are made tangible, visible, or audible, unless what it triggers in the world of matter becomes sooner or later again tangible to our senses.

The clock was devised to bring passing time into the realm of matter, eating away at a stick of incense, making sand flow in an hour glass, making hands move or digits change. The clock was devised to chop up cycles of experience such as sunrise and sunset, to govern those living in those cycles, thus governing nature and other humans. The clock is a tool for governing as well as a tool for planning future actions. The clock started out as a device to create repeatable and quantifiable chunks of time that could be mapped to our senses of perception, which in turn would govern our own actions as the chunks of time could be correlated to experience. The clock is abstracted from whatever time might be. Or rather, it actually created time in correspondence with the governing cultural, economic, political, and scientific frames of reference. And it made the passing of whatever it created as time tangible and quantifiable beyond the sequence of now, before, and after.

With the electric and electronic clock, time could be chopped into ever smaller chunks, divisions of divisions, which are smaller than we can perceive and have a "sense of." Only from the beginning time and the end time of an event can we determine "what time" has passed, down to the shortest interval on which a clock might be based.

Clocks govern the processing inside a computer at very high speeds. It is no longer a matter of fingertips punching the keys of a calculator. We are not able to trace the functioning of computer chips in a directly perceivable way. Instead we have to deduce from its output if it functions correctly, or we have to stop the machine to determine its current state and what might have gone wrong.

The clock originally allowed us to construct time in the realm of visual perception. With the clocks needed for computers to function at ever-higher speeds, time has been pushed again out of perception.

The computer is a time machine because it functions only based on "clocks," on synchronicity and a-synchronicity, the flows inside its guts being tightly regimented by If and Then interwoven with Now and Next. It can only run; it cannot stop. Even when it stops, it is running. This is like Alice in Wonderland meeting the Red Queen, who says one has to run very fast to stay in one place. Once the computer clocks stop, the machine is "dead." Its output, though, has to be presented for our senses at a speed that we can perceive. We have to display output on screens that pretend as if the letters of a text are not moving; we convert bits to sound at a speed perceivable by our ears; we can control cranes and rockets and nanoscale instruments and the flow of electrons. But only an output slowed down for the bandwidth of our senses allows us to verify that the functioning of the computer meets our intentions, creating meaning out of the processes inside the computer. Only a change in matter that we can observe, sense, and experience allows us to control the machine and assign meaning to it (which is also true when brain-computer interfaces are implanted directly in human neural systems, bypassing our sensory organs as physical connections to the world around us.)

Equally on the input side: The speed of our body and mind is the determining factor when programming the computer for processes far beyond our perception. The ever-smaller chunks of time, through which the machine can acquire changes of matter from the physical world outside of its own framework and far beyond our perception, depend on our verification through an output we can perceive, interpret, or use to govern other tools of the first kind.

Input and output of the time-machine computer are only connected by its internal processing, hardware, and software. We design, build, and program this connection between input and output to the degree our senses and mind allow us to be in charge of what happens inside the box, accessible to us only through the doors of our perception and subsequent actions and reactions.

In all other tools, the design of the tool, what it is to be used for, and the resulting deformation of matter are intrinsically linked and fall into that one moment when we use the tool. In clocks, calculators, and electronic digital computers, we have separated "input" and "output." It is absolutely up to us at any given moment to determine how we connect the input and output of a computer. We can acquire data from pictures and turn them into sound; we can detect changes in air pressure and use them to move lights across a stage; we can use data acquired from the sun and have a robot spray-paint a car based on that data. Anything can be mapped onto anything else, as long as we scale the input and the output according to the task.

Because of its complexity and its seemingly universal versatility, this time machine came at a price. It came at the price that its mode of operation became paradigmatic for the interpretation of our world. This is evident for instance in expressions like "the brain is a computer," "neural network computing," or "the bomb with artificial intelligence ethics." And it came at the price that the two opposite time-scales deeply linked in this one machine created a new economic and cultural time of its own dimensions, directly influencing and shaping human life, communication, and history: one being the nano-sliced, unperceivable, and ever-accelerating time grid of its internal operations, and the other being a function on the economic macro scale of changes to the machine through the spiral of hardware and software iterations with their implicit rate of obsolescence.

The computer as time machine abstracts the captured and ingested materials from their original time and puts them under the regimen of its own time of bits and operations. Since these bits can be reproduced seemingly without change and can be reconstituted for the world outside of its operations, it is propagated as the solution to hold “all information forever,” the eternal archive for human thoughts, activities, and history, including the arts.

These three levels of time that computers underlie and create – the time and logic they operate in and on, the time of their technological changes, and the time they are assigned as part of human history – are contradictory to each other and can most likely not be reconciled as they are all rooted in the economic system. It does not seem to be appreciated how the computer is inherently bound to the economic system. For example, it might be inconceivable that a machine like this would have risen to its current dominance in an egalitarian society where everyone’s needs are covered. A hammer and a gun can be used in any economic and political system, but that might not be true for computers. Paradise and computers are exclusive of each other.

Time Based Arts

Time-based arts are created through the conjunction of time and space, when a spectator’s time is shaped by the time the art takes to unfold. Of course, still – i.e. static – art exists in space and time, however, it does not move perceivably for our human senses. We shape the time of our encounter with the artwork. We walk around a sculpture, along a temple frieze, or past a line of umbrellas across the hills of California. We move our legs, head and eyes to experience what is there. The artwork does not itself move. We have to move ourselves to move the “still.” I read a poem or a novel and take the still letters back into the time of my reading, maybe silently moving my lips.

There is a dance, a theater or music performance, a film or an interactive installation. It moves through time, through repetitions or jumps, cuts or fades, and we are moved along as long as we are with it, as long as we give our time to follow its time; us and it are shaping where and how the two strands of time meet in the shared space.

Between 2001 and 2008, the Curtis R. Priem Experimental Media and Performing Arts Center (EMPAC) at Rensselaer was specifically designed, built, and equipped for time-based arts. The term “time-based arts” has snuck into more common use relatively recently, over the decades before and after the turn of the 21st century. At EMPAC, the plural form time-based arts – as opposed to the singular time-based art – is used with an all-encompassing scope, embracing any artwork that moves on a timeline, that uses time as “material,” or as an explicit constituent: dance, media art, theater, music, film, performance art, video, interactive art, spoken words, Internet art, generative art… The question of how this term came about can be cast in a narrative that sheds light on the current situation of arts practice and experience, on institutional power, and art(s) theory and criticism.

When someone talks about art (singular), they usually mean the fine arts or, more generally, visual art. Up to the acceptance of film (the non-still, moving image) within exhibition contexts, visual art was “still art” (not to be confused with the “still life” as a genre of paintings). It hung on a wall, was supported by a pedestal, or was painted on a ceiling. Once film departed from its origins as animated décor for a theater stage and became a medium for artists, time entered the visual arts. Up to that point in the early 20th century, time was only a constituent part of the performing arts, of music, dance, spoken word, and theater. Certainly "moving parts" had been integrated into the stagecraft for theatrical performance, and clockmakers had created self-playing carillons, music boxes, and mechanical singing nightingales, but the clear division between fine/visual arts and performing arts had been in place for millennia throughout different cultures.

That relationship changed in the 20th century not only with the moving image but also as at the same time visual artists began working with choreographers and composers as equal partners, and the raucous, industrialized, war-driven times in Western culture made visual artists enter time in different ways. Painters froze not only the blur of movement on canvas but, for instance, in 1912, Marcel Duchamp overlaid the movements of a nude descending a staircase within the single frame of a painting. Artists created sculptures that did not show only one captured moment of a movement but rather several snapshots frozen in one block of material. In the second decade of the 20th century, the Italian Futurists established their movement, and the painter Luigi Russolo wrote his manifesto L'Arte dei Rumori (The Art of Noises), built his own noise instruments and performed on them. In the same decade, the Dadaists formed as a group embracing visual, literary, and sound art.

They performed in cabaret clubs and used pub tables as their stage in a way that found a continuity in performance art after the Second World War. The painter Paul Klee developed graphical notations of musical compositions. His visual arts colleagues of the German Bauhaus entered the theatrical realm in the 1920s with costumes, choreographies, and mechanically driven stage shows. Musical instrument builders used electricity to build new instruments. Rhythm in time entered the visual arts as artists created kinetic sculptures and used film to compose abstract moving images with visual rhythms. Sounds were layered by capturing the sound of an instrument on a record, playing the recorded music back, and then playing another layer live, while recording the combined result to a new record. Sounds recorded on the light tracks of film could be edited and spliced "out of time" on the film (which had no images, but only the sound track) to bring then the collage back into the time of hearing. A new relationship to time moved through the arts and made the boundaries between still and moving, between visual and performing arts permeable.

In a nut shell: most major trajectories for visual artists to propel their works from static to moving were initialized in Western civilization before the Second World War – driven by mechanization and industrialization, technology and electricity, economic and social upheavals. The killing, destruction, and dehumanization of the First World War went hand-in-hand with accelerated technological development, leading to the Second World War with its unprecedented killing and technological development, while suppressing and interrupting the cultural energies stemming from the preceding decades of the century. The great economic, technological, and research jolt that went through the Western world over the two decades following the Second World War, under the umbrella of the Cold War, which was yet fed by hot proxy wars of the super powers in non-European countries, accelerated "Western" visual artists to integrate time in many different ways. They picked up the threads from the first half of the century. Classical visual arts media became accelerated as for example in action painting, where time and result collapsed in one, like in the performing arts. They broke out of the stasis of museums and galleries through performance art, and adopted time-based technologies, integrated light sources and slides and video synthesizers. Commoditized film, audio, and video technology came into reach as personal production media. And, as soon as they could put their hands on computers, artists used them first in the enclaves of research labs and universities until digital technology became a commodity as well. In short, artists coming from the visual domain integrated time as "material," as "medium of media," entering the areas previously regarded as the domain of performing arts.

At the same time, during this period after the Second World War, performing artists in dance, theater, and music integrated the same time-based technologies used by their visual arts colleagues: tape, film, video, synthesizers, and computer technology.

Coming from the performing arts, I might say that, on the one hand, visual artists integrating time had to learn to catch up with hundreds of years of experience with time in the performing arts, and that, on the other hand, they brought an unburdened freshness to break up old and established patterns formed over hundreds of years in Western performing arts. "Beginning" and "End" were no longer the defined bookends of time-based works, and the audience could come and go during a performance without the expectation established in Western culture over the previous 100 or 200 years of continuous attendance "from beginning to end." Rhythm could be used in the most rigid traditional or pseudo-ritualistic way, or sonic movements just ebbed and flowed. Very, very long events were staged, becoming known as "durational performances". Interestingly, a precursor to such durational performance, the composition Vexations created in the early 1890s by the French composer Eric Satie, received its first interpretation only in early 1960s in New York through a performance that lasted 18 hours. The time was ripe.

And finally, finally: computer technology became a commodity in the late 1980s, integrating all time-based media in one box – moving or still images, sound, text and image generators, light, movement and interaction, arbitrarily connectable, mappable, mashable, and distributable in their digital abstraction. The ultimate time machine had arrived and became accessible at the cost of a used car. Capturing time-based sound and movement, creating time-based events through algorithms, processing and cross-processing anything that could meet our human senses, the computer inhaled it all through the abstract processes of a symbolic machine, and exhaled it back into the world of our sensory perception, so we could see, hear, and interact.

The traditional performing arts and their historians had no problem integrating into their frame of reference all the new time-based potential that digital technology provided. These were just new instruments added to the repertoire of moving in time. But the theorists and museums of the visual arts were confronted with all these new technologies that came so quickly after the moving images of film and video had found their place in museums. New words and categories needed to be found to place all this in the canon of art history. New museum infrastructure had to be put in place ad hoc and serviced. New museum designs could (!) have integrated the architectural, technical, and acoustic capabilities needed to present these time-based works adequately. And approaches to preserving these works were sought as if they were traditional works of "still art."

The performing arts institutions on the other side struggled to integrate and operate the new technology, which artists required for their works, with their traditional technical infrastructure. Expensive video projectors were needed to enable projections large and bright enough for an auditorium while competing with stage lighting. The cooling fans of video projectors created a noise floor permeating the audience. Dozens of loudspeakers distributed and flown throughout a venue were required. Sensor technology entered performances as well as interactive technology driven by performers and audiences. Computer networks flexible enough to connect "anything with anything" in a performance environment were needed as a backbone, and the computer technology had to be robust enough for repeated performances, which started and ended at a traditionally defined time. If something went wrong, the performing arts lacked the option of hanging an "Out of Order" sign on the door, as often appears in front of interactive installations in museums.

Since the mid-20th century, visual art curators, critics, and educational departments in museums expanded their programs to incorporate film, video art, media art, interactive art, web art, and other categories of time-based visual art, attempting to tame passing time as a medium into their institutional and theoretical frameworks. They were now confronted with a conundrum that dance, music, and theater had been working with for hundreds of years:

There is no way to capture in a holistic way the experience of an audience and the performers in the moment of a performance. Any documentation – be it a multi-camera shoot with surround sound, a full-surround camera capture, still photography, or a written report, sketches, diagrams, or musical notation – always has a specific angle and perspective, which is not the same as a person attending the event, as a member of the social setting, or as a performer with true spatial perception in viewing and hearing. Once the performance is over, it is gone in its entirety. The documentation is not a reproduction. Space-time as part of our human life cannot be reproduced; it can only be documented, remembered, and newly interpreted. The documentation may help us imagine how it might have been, with our experience, expertise, and fantasy filling in all that the documentation could not capture.

Still art waits patiently in its place to be visited or rediscovered, it waits for the time a visitor brings to it. And it meets a visitor in the time-frame the viewer determines. The performing arts are bound to be interpreted anew, to be performed, and if a work is desired to be brought back into time, it will by necessity come back into time in always different ways, independent of it resting on static notation, descriptions, texts, and sketches, or on moving-image-and-sound documentation, however complete. The time of such events needs to be dry-frozen. The work has to be taken out of time, and, by adding time back again, a different interpretation is created.

Even the most capable media technology, as it evolved from the 19th century until today, cannot capture and reproduce the time-based event an audience experiences in the full complexity that meets our senses, our gaze, focus, and interest in the moment of its "execution." There are only two exceptions: audio and the moving image. If we listen to a recording of sound with headphones, we are very close to the event and we can recreate an impression of what was captured live, albeit without the visual and potential social environment. And film or video, when used as the originating medium for an artwork (not for documentation), can be reproduced for our perception as it was created, provided that the media used – film, video tape, or digital formats – themselves "stood up to time" (a very telling expression).

Many technologies have been developed over the past 70 years that tackle the desire to capture events as we experience them in the moment of their happening, to extract time out of events, to dry-freeze time, and to reconstitute the captured events by infusing time back again for the full experience. But 3D films are flat, and 360-degree immersive environments often imply "to sacrifice the suspension of disbelief." This almost triple negation indicates that digitally created immersion demands the viewer to accept the projected media as identical with a non-projected environment – "yeah, almost, though... yes we know, not quite there yet."

Time-based Arts and Computer Technology

As soon as a new technology comes about, which can be used in any shape or form by artists, they use it right away. The oldest example we have today is a flute from some 40,000 years ago, made of a bird bone with holes drilled into it. This immediate artistic adoption and adaption has been especially true with the explosion of technology in Western culture during the centuries since the Renaissance. With the universal time-based machine, the computer, at hand, it was immediately embraced as a tool for the arts, both still and time-based. In the mid 1950s Lejaren Hiller and Leonard Isaacson programmed the first algorithms to create music scores to be played by acoustic instruments and, by the end of that decade, music and moving images were generated with computing technology. In the first half of the 1960s, computer-generated graphic art started to get printed on plotters, and interactive music systems using computer technology entered the stage in 1970 with the GROOVE system developed by Max Mathews and F. Richard Moore.

The input to a computer, like sound, light, or force, and its subsequent digital processing, is dissociated from the eventual output for our sensory perception. Input, internal process, and output can be connected in any arbitrary way computer logic and technology provides. These connections can be made independent of "media" and "meaning." This has, as consequence, that in time-based arts all digitally connected time-based media and devices can be driven, generated, or controlled independent of their origin or their "meaning." The creation of "meaning" results from the new digital connections set inside the computer, based only on the underlying logic of the computer. Light can be controlled by tactile interfaces or by sound; movement can be captured and drive images; a theater rigging system can be controlled by brain waves. Any data captured or generated can be mapped and connected to any other media or to any device that has an interface to the digital domain.

Now that "all media" can be used, manipulated (literally "by hand"), automated, processed, and generated by one time-based box (which now costs a fraction of what film and video technologies, video and sound synthesizers, or the clunky electric controls of mechanical devices formerly did), the merging of media is limited only by one's own desire to learn about digital processes.

Previous categories assigned to artists and their works have had to give way. New taxonomies have been continually developed by historians and theorists to respond to the fluidity of artists' productions that use the time machine. And artists contribute greatly to this process of theoretical interpretation of their work, creating categories, and establishing a place for their works in the notebooks of history.

As noted previously, the crossing of the visual arts into the domain of time evolved over the 20th century, but now the digital means of production for "all media" have become accessible to whoever wants to use them in whichever way (within the restrictions of digital technology and its connectivity to the physical world). As a consequence, physical performance spaces designed and equipped with the technology necessary to present these works are needed to make them part of an experience shared between artists and audiences, visitors, spectators, participants. This is where the institutional struggle arose and still arises.

Institutions rooted in the traditional performing arts of music, dance, and theater rely on scripts, notations, interpretations, staging and productions – between what has been handed down from the past and new interpretations. It has always been understood that there was not "one way" to perform a specific work of performing arts but that the performers always engaged in an act of interpretation. Specific to each moment in its cultural, philosophical, scientific, political, and technological shaping, and specifically different between the areas of music, dance, and theater, there are different degrees to which original instructions or documents of a work are related to a new performance. Changing, editing, and shortening the scripts and texts that underlie theatrical works has been a common approach over centuries. Changing notated details in a musical composition has been frowned upon more and more only over the past 200 years, though adapting, "stealing," or arranging a piece of music for instruments other than the original continue to be done, with digital sampling, remixing and mashing up adding over the past 35 years a new layer of appropriation. Changing previous chorographical concepts or creating a new choreography for existing music, be it written for a ballet or otherwise, is customary. Different approaches have been developed over the centuries to radically transform a work, by cutting it up, rewriting it, mixing it with other sources, putting new words to an existing song or piece of music, or changing the dramaturgy. The idea of reconstructing "the original," "how it was meant," and how it was performed at the time of inception is, historically speaking, a relatively recent direction and has become more prevalent with the invention of photography and sound and moving-image recordings, in conjunction with changes in theoretical and political perspectives, approaches to history, and with new research methods applied to historic sources.

Musicians understand that Western musical notation does not give exact and detailed instructions for how the music was played and sounded at the time it was composed, even as composers notated more and more details. Also the tools, the instruments, changed. For example, the strings on violins changed from gut to steel as the size of performance spaces increased, and pianos and wind instruments, like flutes and oboes, changed quite radically under the influence of advances in precision mechanics during the first half of the 19th century. These changes affected the “tone color” of older works as they were performed on these new instruments and facilitated also new “virtuosic” playing techniques. Even the by most audiences unidentifiable musical characteristics in Western music, the tuning systems, have changed radically over the past 300 years. Notation in the dance community is still variable and does not have a unified code for communicating a choreography. Only since the availability of technologies capable of capturing sounds and visual movement have certain aspects of these works been possible to re-render with the inclusion of more precise details from past performances.

Having institutionalized the accumulation and presentation of still art, museums tackled the new curatorial, archival, and presentation requirements of reproducible time-based media, like film and video, as they became part of the visual art canon. Eventually black cubes needed to be put up “inside the white cube,” the accepted standard for the design of museums in the 20th century, especially for “modern art.” With the introduction of lights, projections, and video monitors into art works, daylight and light reflections from walls needed to be blocked. Integrated electronic technologies pushed museums further into the abyss of moving time, facing the questions of how to present, store, maintain, and preserve such works. Could fluorescent light bulbs be replaced or should spares be stored? What about cathode ray picture tubes as used in old TV sets, which were part of an installation? The answer to what constituted an “original” and appropriate conservation method changed as technology-based time and obsolescence entered the realm of the still.

Performance art (not to be confused with the performing arts) blew up the static white cubes and their lobby spaces by introducing performative time into the visual arts. Now, it was not only the technical time of film, video, and installations, but the human time of doing and moving – of heartbeats – that resisted reproduction and maintenance. The time of the performing arts, along with their modes of operation, infrastructure and economic frameworks, entered with performance art an institution that had been established to keep objects out of time. The introduction of time could not any longer support the paradigm of a market-driven accumulative value for individual works as established for still art. As time-based works of art in the form of film, media, and video installations did not smoothly fit the well-protected conditions of the market for still art, performance art moved the market conditions even closer to the performing arts. Preserving and re-staging works of time-based visual art demanded different approaches of conservation. Performed art could only be valued in the form of a composer’s or writer’s manuscript (unless the drawings, sketches, or photographs of the performance could be subsumed under still art and its related economics). The cultural, societal, and economic position of art museums has changed through letting time into their walls. This time bomb suggests that an exchange with the performing arts is and continues to be beneficial on many levels.

Museums, as buildings for still art, were, and are still, challenged by the introduction of time-based technology, with the computer enabling artists to feed eyes and ears “out of one box.” Not only are sounds now bleeding through museum galleries from one work to the next, and technical teams are necessary to install works and keep them up and running, but the fundamental paradigm of the museum holding still art has been challenged by the introduction of time and ever-changing technology. The constant change in hardware and software, operating systems and programs, of network protocols, media formats, and data storage have put works of time-based arts under the conditions of the economics of time-based performing arts, which indeed is very different from the higher end market for still art.

> A performance, or time-based event in general, does not accumulate value over time, it cannot be used as long-term investment by just having it stored away and waiting for time to pass and "the market" increasing its value. The return on investment in time-based arts is transactional in direct relationship to each individual human's moment and time spent with the work, as the work moves through its own time with the time of the individuals watching, listening, and interacting. Ticket prices to museums do not influence the value of the still art displayed. Ticket prices, cost for prepackaged media, or fees charged for time-based experiences are solely dependent on the very moment of desire of audience members or participants to share time with what will meet their senses, and the financial calculation and market analysis of the artist, presenter, producer or distributor.

Digital technology is based on ever-smaller subdivisions of time and reciprocally accelerated-processing speed, which are below the threshold of resolution needed to coordinate or control humans in their temporal flow of perception, action, and interaction. Time is not any longer only a measure relative to change in mass and space, or a measure of labor in the trade of human-life time against material goods; time has become an inextricable material of a product. Time embedded in digital technology is as important to digital technology as are the physical substrates of a chip, the soldering of connections, or the electric plug. Time below the threshold of human perception has become a manufactured product and can be used as such like any other product in the economic system. The computer's ever-finer slices of time have become the enablers of communication, processing, control, and document storage, serving the perceivable, physical world at human scale. Their synchronization at very high speeds is absolutely needed to execute the logic computers are based on. The deliberate or enforced innovation and obsolescence of digital hardware, software, environments, and data formats is enabled through the manufacturing of time below the threshold of our perception.

Of course, the traditional performing arts were also confronted with changing technology, especially in the realm of music since the 1950s, the time when live-electronic technology became part of contemporary works. Parallel to film and video, music also has a tradition of "fixed media," where either the whole sounding piece is produced and saved on media storage, or where an electronically produced part is played back with the performance of live instruments. These fixed-media works raise the same questions about storage as film and analog video: How can the media itself be stored and how long does the specific storage medium retain the stored? Works with live electronics though, where instrumental or electronic sounds were created, played, or processed in real time during a performance, have had the issue of changing technology since their very beginnings. When technical instruments and devices became obsolete, the works could not be performed anymore. Only for a few works by "famous composers," the configuration of the analog technology and how it was used in a work was documented and, in some cases, ported to the digital domain so the works could still be performed in the then-current digital environment to which it was ported. With the advent of digital technology and its real-time use during a performance, the dilemma widened. Now, even within five or ten years, the original combination of hardware, operating systems, and programs may have become obsolete and, if possible, would need to be resurrected. In only the rarest of all cases, a composer or an institution has invested in the transfer of a work into the next generation of technology. If this did or does not happen, the only leftovers are the notated score (if used), diagrams and descriptions of the technology, possibly some computer programs either in digital format or as print-outs, and the audio recording of a performance. And, in the case of improvisations, only the audio recording would give an impression of what the piece was or might have been. The fleeting time of musical performance has been met by the new fleeting time of technological instruments, which change and disappear at a much faster rate than the acoustical instruments of past centuries.

Extracting Time and Reinjecting Time

A chiseled inscription, a hand-written note, a book, or a painting are, for our senses, standing still in time. They can be looked at without the aid of any technology and are thus independent of changes in technology. Time nibbles away at their substrate. Sun, rain, and wind can weather stone and wood. Documents and objects can be destroyed by fire and floods, but humans had found a way to communicate across generations. What was to be inscribed on monuments, outlasting human generations, was determined by those in power or by those of means who commissioned such memorials. Writing on wood and clay tablets allowed for communication across days, years, decades and, unimaginable at the time, millennia. As education in reading and writing spread, there was a change in what was deemed to be, in the literal sense, noteworthy. In the medieval ages of Europe, the rule over knowledge was exerted by the church, through their libraries and their control over universities, as well as over the workforce of monks who could produce manually written copies of manuscripts. With book printing and the cultural and political change during what we call the Renaissance era – which in turn was based on the rediscovery of classical Greek and Latin documents by their intellectual elite – wider education and access to mechanically copied books became available, bypassing schools, universities, and libraries, and undermining those who ruled the distribution of and access to documents, especially now that documents in the commonly spoken languages could be massively distributed. With lithography and offset printing, the mass distribution of media, which allowed asynchronous communication between author and reader, reached the pinnacle of accessibility without any technical support needed by the reader. A box with books could be forgotten in an attic, could be rediscovered after a few centuries, and had the potential to still be read. In other words: depending on the substrate used to communicate across times, a very high density of words could be packed into a very small object. A library could contain more volumes than the owner could ever read in his (yes, mostly his) lifetime.

All this has changed with the introduction of mechanisms and clocks into the communication process, which extract time from the captured material and require that the extracted time be infused again into the stored information in order to make it perceivable by us. Extracting and reconstituting time requires the exact same time machine for these two processes; otherwise there is nothing to be brought to our attention. The record player has to play back the frozen image of sound waves on the disk at the same speed with which it had been recorded. The film projector has to project the same number of frames per second that the camera captured and froze out of time.

With the time machine computer now also taking over the storage not only of time-based media, but also of still media (like books and still images), we have potentially reentered an era close to that of the Western medieval or Renaissance ages. It took thousands of years to turn oral tradition into written tradition, which existed independent of the memory and life span of an individual, and it took centuries for the post-Roman Europe to wrangle the copying process out of the hands of the church and subsequent secular institutions of power. This development culminated in the Xerox machine and its forerunners, a most radical invention allowing individuals to produce small runs of physical copies for distribution – an invention not to be underestimated in its political power for subversion and civil disobedience, similar to social media today.

But with the wide spread of magnetic storage technology for sound, video, digitized documents and data in general in the second half of the 20th century, it only took a few decades to fall back into the need for continuously created identical copies of original information, since the magnetic storage on tape and disks lasted only a fraction of the longevity achieved by printing on paper, vinyl records, or film. The instant access and worldwide distribution of digital data as a fundamental business resource resulted in vast, continuously supported cloning and back-up strategies to keep the data from getting physically corrupted and disappearing.

So, today, it is as it was in the time before the invention of book printing, when oral tradition became captured out of time in individual manuscripts, and it was a matter of corporate, ecclesiastical, or worldly powers and funding that created physical copies of such manuscripts. Now continuous funding is needed for the copying and maintenance of digital data, which holds the dry-frozen representation of what is to be communicated, and which needs the reinfusion of time through the computer to be accessed. Just creating a one-time “archive” of, for instance, digitized books, photographs, films, or audio, will not yield the same permanence of a collection of “analog” media in their specific physical forms.

Even though the technology became a commodity, the time machine, its encoding, its data retention, and the peripheral technologies change so quickly that we are again dependent on big institutions to ensure the preservation of experience, thought, and knowledge, with companies having replaced the church and monarchs, along with governments, public institutions, and universities. As digital technology brought forth the potential for and implementation of mass distribution and accessibility to oceans of “information” in the immediate now, it powerfully reinstated at the same time the seemingly overcome old hierarchical power structures that govern the selection of what is to be kept, and the longevity and tradition of knowledge.

To reiterate, the internal working of the computer is dependent on clocks slicing time into ever-smaller segments. Even still media are parsed by the computer, transformed for its internal working, and then absolutely dependent on its time-based functioning. The stillness of a written text or a picture needs the exact process that turned it into a digital format to return it to a form our eyes can perceive, whether by creating a static object again through printing or by creating a seemingly still representation on a computer monitor. These internal processes of a computer depend on its hardware, its software and encoding formats, the input/output (I/O) devices, and the actual storage of the data that the still information was turned into through digitization.

With still information, like text and images, there are two main issues literally at hand and in sight: On the one side, there is the time machine and its inner marriage of time-based and logical operations, and, on the other, the storage of the captured and frozen data out-of-time. The data is the transubstantiation of what is directly perceivable to our senses into the time-sliced bits and pieces inside the machine, which need to be put back together by the time machine in order to be perceivable by our senses as standing still.

The rapid change of the time machine's technology and components is determined by increases in the processing speed of the internal time slices and the synchronization of these internal operations in relation to the ever-increasing amount of data. The longevity of the stored information, on the other hand, depends in a very material sense on the substrate used to store the data, and thus underlies a very different scale of time, which is outside of the time scales at which the machine operates. Both temporalities are fully intertwined and demand constant attention and care to be kept in-sync across the widely differing time scales, supported by the absolutely necessary funding for labor and continuously changing technical infrastructure.

One is not without the other; the time scales of the processes internal to the computer and the time scales of data storage outside the machine are co-dependent. The digitized document cannot be made perceivable for us if the core time machine and its programs changed to be incompatible with data stored previously under a different configuration of hard and software. The same is true if the data stored outside the time machine, the bits and pieces to be put back together through the time machine, have been corrupted on the material substrate to which they were stored. In both cases, the time machine cannot ingest the data and infuse the time again into a document to make it appear for us in the temporal and spatial domain of our senses.

The crucial point is that the technology, in its combination of hardware and software, changes several times over the lifetime of an individual, and such change is absolutely out of the control of an individual who uses it as their main repository for documents, photos, music, films, poems, tax returns, or scientific papers. At the same time, the diverse storage media, which hold the digital abstraction of the previous still media, undergo a temporal process of material deterioration. Imagine a printed book losing the printer's ink over less than a decade. The digital information stored on mass storage media, like hard disks, solid-state memory, or optical discs, needs to be checked and copied diligently throughout an individual human's lifetime. If one or the other side, the computer system or the stored data, becomes invisibly out of sync with the other, then there is nothing to be viewed, accessed, or kept.

Still media before the introduction of the computer had only been threatened by slow processes or sudden catastrophic events, but digitized and digital media are shorter "lived," needing to be turned over, checked, copied, or transformed several times over one generation of human life. Grown-ups will not be able to see pictures of themselves as children, or of their grandparents, unless their parents take care to copy, protect, transfer, or print them. "The cloud" is no solution unless we suppose that the companies who govern, own, and operate it will be as eternal as the church in the medieval times of Europe, both determining explicitly and implicitly what is to be kept and what is not. No individual, organization, university, museum, or library has control over "the cloud." Now, as several hundred years ago, it is again a matter of economic power controlling data, information, content, knowledge, and tradition, thus people.

We have gained the instant accessibility and world-wide distribution of what can be packed into digital information at the price of having lost the control over our very own collection and tradition, unless we take on the lifelong task to maintain the data encoding of what we cherish. Even if an institution commands enough funds to constantly monitor, copy, and update their archive through humans or robots, we have no experience with what the situation will be 50 years from now and what will happen if an institution runs out of funds to check, copy, and port the data, if it cannot pay the utility bill for air conditioning, update hardware and software, or if it has to shut down the tunnels dug deep into the mountains for their repository. Fundamentally, this is a very different situation than in the era when still media were kept in still archives, which had the potential to remain stable unless faced with fire, water, or censorship. These still media, accessible without technical aids, could be hidden, forgotten and rediscovered.

Almost everyone has the experience of not being able to open old file formats created with programs that don't run on current computers any more, or the inability to read data from a hard drive from 1995 or 2005 or 2010. There are no boxes in the attic to be discovered by future generations, no scribbles on wood or clay or paper, notwithstanding engraved monuments to political and religious power that are still continually erected worldwide. Perhaps these monuments should only be erected in virtual reality for future generations, and, rather than being toppled after a government is overthrown, an error message will appear: "Cannot open file."

Preserving, Documenting, and Archiving Time-based Arts in the Era of the Universal Time Machine

As noted before, time-based arts encompass all productions that move perceivably on a timeline. In the context of the following considerations, three groupings are addressed: the traditional performing arts, the moving image and recorded sound, and art oscillating between human time and computer time. Each one is based on a different relationship to time and space.

The first group, the traditional time-based performing arts of dance, music, and theater, has three-dimensional, physical bodies and objects at its center and shares with an audience a common space filled with motion in time. Physical objects, lights, machines, humans, sounds, land- or cityscapes: all this envelops the audience in a performance that fills the three-dimensional world as we experience it in everyday life. The visual and auditory, maybe also the tactile and olfactory, scene is now filled with motions differentiated from everyday life (even though the performance might be embedded in an everyday environment or may reflect, very directly, everyday life). What is happening is intentionally focused in the moment of the shared communal event. This also includes all computer-controlled or generated events and objects that extend into this physical space of the performance, from sound to lights, machines, or robots.

The second category consists of captures of time-based events that take them first out of the time of their unfolding, and then reintroducing time again for our perception. The temporal components are reconstituted at the same frequency with which they were removed. As the time-based sequence can get reanimated, spatial components of the captured events are reduced through the technologies used for capture and projection. The capturing devices standing in for our senses – like a lens or a microphone – flatten the spatial environment through their specific properties. Each individual microphone captures the sound from a source with reflections coming from walls, ceilings, and floor surfaces in one "wave", specific to its location and its properties. And the lens of a camera bends everything through its optical system. What has not been captured cannot be brought back, though techniques can be applied to distill some of the spatial properties from a flattened capture and correct or enhance the projections for our perception.

The endless complexities and subtleties of "rays and waves" as they meet our sense organs in their fields of perception cannot be captured despite all technologies applied, and the reanimation of what has been captured works best for an individual in a specific location in relation to the surface of the projected image and to loudspeakers as sound sources, possibly with "stereo goggles and headphones", but not everyone in a group of people sharing a common viewing and listening space will be able to perceive it with the same levels of quality.

The screens and monitors used for the creation of moving images may be curved, panoramic, or domed, but the images themselves are flat and two-dimensional, however "3D" a stereoscopic image might appear. "3D" images, created for a group of spectators to perceive a certain sense of depth, expand only in the two dimensions of one plane, serving each eye a separate image to produce a mirage of three dimensionality. What is currently advertised as "holographic" in stage productions is the resurrection of Pepper's Ghost from the 19th century, which overlays a projected two-dimensional image on the actual three-dimensional physical space behind or in front of the surface reflecting the image. Over the past decades, true holographic capture and projection has decelerated from its once anticipated course of development and the "holodeck" still lingers in the domain of fiction, where it works perfectly.

The capture and production of spatial audio is similarly limited in comparison to physical acoustic immersion. The so-called binaural capture and reproduction with headphones requires highly individualized technology to come as closely as possible "to being there and not here." A fully three-dimensional synthetic wave field synthesis system for audio is (almost) technically possible but is vastly complicated and expensive.

The main point with this second category is that the capture of time-based events up to now always flattens space. In freezing time, space gets lost. In stereoscopic moving images, volume is lost. And in multichannel audio, the effects of space, its volume and material properties on sound are folded on top of each other, reduced to sound points and vectors, eliminating complex spatial patterns as they evolve in space before they meet our ears. Yet, our experience and imagination comes into play as time is reconstituted through the playback of this captured experience; we might not miss the third dimension when the content engages us. This is what makes documentation or technical reproduction without a true third dimension still extremely valuable.

Viewing and listening to something in three physically present dimensions requires independent temporal movement of the viewer/listener independent of the images meeting our eyes and sounds meeting our ears, like the slightest movements of the eyes and head, as well as the movement of the body around an event or object in space, in order to perceive what was hidden at any given point in time and to put together the puzzle of the object or event's spatial and material properties in one's mind.

In the third group of time-based works, where the perceived oscillates between human time and computer time, the human time of action and perception is intertwined with the processing speed of digital technology. This category intersects with the previous two groups, but it relates differently to time and space. It may be described as a category for algorithmically controlled or generated occurrences, which move from digital abstraction in chopped-up time to the physical space and time of our sensory perception. Examples from this category are interactive installations with sounds, images, and true physically three-dimensional objects; web or browser art; computer games; interactive narratives; and virtual environments. The condition here is that the digital processing and generation is happening in "real time," which has to be faster than we can perceive and takes place within the temporal and formal-logical framework of computing. This real-time process fuses with the time and space of our perception, action, and reaction. Interfaces and sensors serve as input from the physical world to the internal machinations of the computer, which then feeds a signal back through interfaces, projections, and actuators into the physical and personal world of perception. The potential of digital technology is integrated with the tangible properties light, sound and objects, and with the different times scales of human perception

In synthetic immersive or augmented-reality environments, the missing third dimension can be added through the processing power of computer graphics at such a speed that it actually seems to be "there" as we move around. It will remain a there and cannot become a here ("there is no there there" – or in this case, "there is no here there"). These environments can only be viewed by an individual with light and sound emitting instruments strapped to their head, with the agency of navigation limited to one person in order to maintain the proper point of convergence and the physical point of view. These are not captured events, as we have no technology to capture light and wave fields in their four-dimensional simultaneity of space and time. Even if this will become possible someday, the gap between the live and captured will not fully close, and most likely never at the same time for a group of people being untethered and moving freely through space.

These three groups can be viewed, analyzed, and compared in their very different relationships to the dimensions of space and time, to which our human communications and shared experiences are bound. The three groups do intersect. For instance, computer-generated stereoscopic moving images can be generated in real time and may be projected into a traditionally staged performance, and live electronic-sound processing can be fused with the performance of a string quartet. The common ground for the three groups is "us" as we relate to those things, which are merged for our focused experience in and through time-based works, using the universal time machine to create, intermingle, mash-up or isolate, generate, process, or control streams of time, media, and space outside of our human scale of time and space.

Time-based arts is not a genre. Any number of genres can exist under this umbrella while rooted in different artistic, historical, and analytical traditions and expertise. New taxonomies are created to bring order to the interpretation of what artists make and do, and which become part of our culture before the "correct" category has been defined (as categories are always defined after the fact). Even though certainly not only limited to the application and use of digital technology, time-based arts acknowledges that the universal time machine unifies different media under the same control structure, which has changed our relationship to time and space and to media and experience like no other device before. Yet, the differences, differentiations, histories, and aesthetic reflections are not flattened by the space, time, and operational modes of the universal time machine; our creation of meaning in its close relationship to our senses, perception, and experience still happens within our framework of time and space, in our living.

Up until the capturing of sound and moving images in the 19th century, there was no way to document time-based events other than putting them in still documents, through descriptions, notes, sketches, diagrams, and pictures. The direct flow of time present was excluded from the documentation. A great example of how descriptions and still images fused with diagrams and texts document time-based human activities and mechanical processes is the Encyclopédie, ou dictionnaire raisonné des sciences, des arts et des métiers by Denis Diderot, which was published between 1751 and 1772. The plates on Trades and Industries offer detailed imagery of how machines functioned and how things were done. Likewise, the instructions of "what to do when and how" for works in the performing arts were – and still are – described in texts, with words and stage instructions, symbolic notation for music, complemented by reports, reviews, and descriptions of performances, engravings of stages, costumes, dance movements, and written treatises on artistic theory and praxis.

With technology capable of capturing time-based events, like the movement of light on film and the movement of sound on tin, wax, shellac, vinyl, or magnetic tape, a technically reproducible physical document of what had happened over time became possible. However, these documents left out chunks of time, movements occurring between the snapshots taken every so often per second on film, and leaving out the fastest movements of sound (high frequencies), while also limiting the range of dynamic bandwidth of color and sound. The three-dimensional space of both image and sound were flattened to two dimensions in the visual domain and to a physically limited sound source in the auditory domain, both fundamentally reducing spatial and temporal information and limiting the bandwidth of what was captured in order to give at least an impression of what had happened, to document.

It was always clear that what was captured was a documentation, something that made a recreation possible in conjunction with knowledge, experience, and imagination. In the beginning of image and sound capture, no one took the documentation of image and sound to be identical with what had been captured; the difference was evident. After being scared by the appearance of an oncoming train during one's first visit to the movies and having survived that, everyone knew the difference. When someone is frightened by a ghost story or horror movie (knowing it is not reality but experiencing it as if it were real), desire and amazement heighten the experience. Technology was continuously developed to shrink further and further the difference between the event itself and what was captured and then reproduced. But, strictly speaking, this gap cannot be closed, not even with the introduction of the universal time and media machine. The magic of the suspension of disbelief and our complementing imagination reaches far beyond the limitations of any technology, however raw or refined it might be.

As long as we are aware of the fundamental difference between a document and the full spatial and temporal sensory experience of an event, using such documentation poses no different problem than reading a description in words. Depending on our experience with what is described and our expertise, we can add ingredients from other experiences and from other sources of still documentation, like notes, scores, and descriptions, to conjure up a "full picture" of what was documented, filling in details, right or wrong, always extrapolating towards a "full" experience. As technology captures more and more detail, we indeed will have the opportunity to perceive more and more, but the difference between the documented and the documentation cannot be overcome.

The twist comes through the technical ability to alter the material substrate of the documentation of an event. There should have never been the issue of mistaking documentation for a "true" capture, but now digital technology offers the tools for total seamless manipulation of the captured, be it still or time-based, and it simultaneously reveals as much as it hides the always-implicit bias of any documentation, of any capturing of history. If we can make anything look as if the original capture is unaltered, then the capture shows its basic characteristic: it has always been an interpretation of the moment that was captured, a filter, a perspective, a glimpse in a certain direction, leaving out everything else that was not captured, visual or auditory, smell or taste, temperature, humidity or wind, the atmosphere of the moment. This is nothing new, it does not dismiss the culture we have created through documenting, writing history, keeping, archiving, interpreting, re-writing. On the contrary, the uncontrollable potential of digital technology to change anything that is handed down, to yield the power of narratives to the holders of the bits and to lose everything in an instant, demands for a review of ownership, as these thoughts about the universal time machine propose.

The third area of time-based arts, where technology is used to process and generate events for the real time of our senses, has been at the forefront of interest for artists, performers, historians, archivists, and conservators for the past decades. Here again the boundary between the mechanical and electric, the so-called analog realm and the digital domain with its intangible speeds, creates a problem. How can the technology used in the realization of a time-based event become part of the documentation that would allow us to perform and interpret a work again at a later date?

This problem can still be resolved if we are dealing with just mechanical technology, including electric motors. But already in just the mechanical domain, things can get very difficult. For example, the Abstrakte Revue (der bewegten Flächen) (Abstract Revue [of Moving Surfaces]) created by Andor Weiniger in 1926, a work rooted in the Bauhaus school, was documented with drawings and, based on these drawings, was recreated by the artist group Wanzke/Steger/Budesheim in 1986 under the title Blaugrau bleibt Blaugrau – Elektromechanische Bauhausbühne (Bluegrey remains Bluegrey – Electromechanical Bauhausstage). During my tenure at ZKM, the Center for Art and Media Karlsruhe, where this reconstruction is conserved and part of the collection, I commissioned in 1992 three movement artists and three composers to collaborate in pairs and create new choreographies with instrumental music for this mechanical stage. The stage definitely has an inherent aesthetic, but we do not know how it was used, as there seems to be no documentation of a performance, only drawings of its construction. Since the functionality and structural elements were documented, the instrument could be recreated or rather re-interpreted. Documentation of actual time-based events related to the project have not been found. If there had been a film documenting a performance, we would at least be able to imagine what a performance would have been like (even if the film was black and white and the moving elements of the stage were quite colorful, as the drawings indicate). In the reconstruction, the 27 electric motors moving elements of the mechanical stage were controlled by a computer and the choreographies activating the motors to perform with the live-performed music were programmed. What we are left with today, only three decades after these new works were performed, are elements of the mechanical stage sitting in some depot of a museum, the digital data controlling the recreated stage in the three works being lost or inaccessible due to just having been lost or because of obsolete software and hardware, and video documentation of the performances potentially still being somewhere... or not. If we were able to find this time-based video documentation and view it, we could get a glimpse of what these works might have been like and how they interpreted the still documents from the 1920s. The very few still photographs of the recreated stage, in conjunction with the existing traditionally notated music scores, do not give any idea of the works from the 1990s.

When sound and moving-image capture allowed for the documentation of time-based events by separating the time of the event from the time of the media holding the captured "signals" in the form of still images or frozen sound waves, things were still quite straight forward: time frozen – time restored. What had happened in passing time was brought back into time to be perceived by us. We had to "only" take care of the material substrates holding the frozen signals.

When technology became a production tool to synthetically create time-based events in live performance, the issue became if it was possible to document the process and technology to potentially recreate the original in its full temporal-spatial presence. Otherwise, we are again in the same situation as before, left with a document that captured certain aspects of the live event. An exemplary excursion into the world of sound and music may illuminate what happened when electricity entered the realm of live performance.

The microphone used electricity from its very beginning, not at first for recording sound, but rather to transmit sound in real time over long distances through the telephone. When it began to be used for recording, the process was purely mechanical, without electricity. Up to 1925, the only way to capture sound was by engraving acoustic waves into a rotating cylinder or a disc via a stylus attached to a membrane, which was moved by the sound waves and etched the soundwave into the rotating material. The reproduction was equally mechanical, now following the inverse process: a stylus would follow the previously etched groove in the turning cylinder or disc, and a diaphragm directly connected to the stylus would move the air according to the recorded, etched wave and create an acoustic wave amplified through a bell-shaped horn.

The construction of instruments using electricity to generate sounds started at the end of the 19th century and carried on with many inventions and instruments throughout the 20th century. Thaddeus Cahill built the first electromechanical synthesizers around 1896, the first version weighing 7 tons, the subsequent 210 tons. He later went bankrupt establishing the first on-demand music service, which distributed music over telephone lines to the homes of subscribers. These were live instruments and if a recording were to be done with them, it would only be possible with a purely mechanical system as described above. From such recording alone, without photographs and drawings, it would be quite difficult for us to deduct how the instrument was built, how heavy it was, and how it created the sounds.

After World War II, also as a consequence of the communications technology developed during or after the war, analog (as opposed to digital) electrical music instruments evolved widely in Western culture and have experienced a renaissance in the 21st century after a hiatus created by the rise of digital instruments.

Parallel to the instruments for live performance, there were the machines used to record, mix, cut, splice and loop recorded or electrically generated sounds, creating "fixed media" to only be played back. In the 1920's overdubbing a recording on a record with a new instrument playing along with the play-back of the previously recorded music, while recording both onto a new record; recording sounds onto the sound track of film and cutting and splicing the sound on the film medium; cutting and splicing recordings on magnetic wire and then magnetic audio tape; or closing loops on records and have the wave in that loop repeated with each turn of the disc. The end result of such processes was the assembled audio fixated on a substrate. As with film projection, the presentation from these fixed media took place as a technical reproduction, and the longevity of the material substrate that contained the audio depended on the materials used. The temperature and humidity of the storage environment had a great influence on how the media held up over time. For most works created with such technological apparatus, the technology and detailed production processes, like which sounds and frequencies were created in which way by what manipulations and technical processes, were not documented, unless artists themselves came from the tradition of classical music and cared to create a production score, like Karlheinz Stockhausen.

Since electronics started to be used in live performances, there has been mostly no way to document these devices on such a detailed technical level – how they were built and how they were configured and programmed for a specific performance – that one would be able to perform the pieces with other new devices as technology changed or became obsolete. Audio and video synthesizers and signal-processing gear were built in abundance, commercially and experimentally, or as one or a few of a kind. As audio and video technology became cheaper and more available, such performances were documented with video and audio. These auditory and visual documentations, in conjunction with archival documents and photographs, allow us to have a sense of a work, and it enables us to analyze the performance based on the (limited) view captured in the time-based documentation.

Again, music may serve as an example of this issue in the era of analog live electronics. In the arena of so-called Western classical music, many works were created using analog sound-processing gear, tape loops, delays, ring modulators, vocoders, and spatialization machines that sent sound around the audience. Composers worked in specialized studios. For example, Luigi Nono started his work around 1969 in the Experimentalstudio of the Heinrich Strobel Stiftung in Freiburg, Germany, one of the earliest, most complex and active studios for live-electronic music in the classical realm. Music scores contained schematic diagrams and signal-flow charts between specific, often unique pieces of equipment, as well as scribbled notes of what to do at what point in time during the performance for both the instrumentalists and the audio engineers, so as to perform the sounding work. To perform these pieces, the original equipment or quite similar devices were needed. The performances were recorded – mostly flattened to stereo – so this documentation can be played back. When a machine used as a live instrument could not be found again, the piece could most likely not be performed. As the analog machines disappeared from the Experimentalstudio, great energy was put towards documenting the processes in a way that would allow someone to port them from the analog to the digital domain. This was only possible for the original audio engineers and "Tonmeister" who had performed the pieces many times and knew the technical and musical details. Such detailed documentation required a lot of time and money and has been limited to quite few works based on a decision by "someone" what was worth to be documented. With the vast majority of the pieces from those days, the recordings, together with scores, notes, and some technical documentation, are the only way of imagining how such pieces sounded in a live performance. And there is no way to perform most of these pieces ever again (for better or worse...). The capture of the live event, together with still documents, is the only way to imagine and interpret what it might have been like to experience an actual performance. This is not true only for music, but for all time-based arts using live electronics.

Digital technology and its use in the arts evolved in parallel throughout the second half of the 20th century, starting with still media produced as output, in the case of computer graphics printed on plotters, and computer-generated sound captured on analog sound recording tapes as fixed media. This mostly stems from the fact that the computation of the output did not happen in real time for our senses, and storage media holding the original digital data was expensive and needed to be cleared for new projects. Eventually, real-time and interactive scenarios entered the scene, with video terminals connected to computers, as in "The Mother of All Demos," presented by Douglas Engelbart at a conference in San Francisco in 1968, which demonstrated shared, networked, and interactive communication in real time.

As computer technology changed rapidly in ever-shorter cycles and the processing speed increased so that the technology could be used in real time for time-based arts, the new dilemma became more and more obvious. The hope had been that, with this technology, it would be possible to keep technological environments and artworks "operational forever," since they were executed by a machine in the abstract realm of symbolic operations, forever reproducible in unambiguous ways. But the economics and politics of new technologies and the ever-quicker chopping of time in the universal time machine resulted in quite the opposite. The pressure stemming from economically driven technological change in hardware, software, digital formats and standards disregards the user's actual needs (which may require "non-innovation") and counteracts the idea of a cultural tradition of handing objects and documents through generations, as even still media, like text, graphics, and photographs, became not still anymore but had to go through the described process of time exorcism and resurrection.

The different, interdependent cycles of changing hardware, operating systems, interfaces, programs, and data structures resulted in an overall spiral of accelerating change in digital technology. This made it once-and-for-all clear that computer technology would not resolve the issue of time-based artists wanting to preserve "an original," be it for their own lifetime or for even longer time preserved in a museum. Instead, it reminded them that, once again, performance, experience, interaction, and live time-based art are always subject to changes over time, but now accelerated by the speed of change in computing technology. The only approach possible seems to be through capturing and documenting events or processes that use specific, in the literal sense contemporary soft- and hardware technology, through more generic media and technology, with open standards for video, audio, image, texts and data formats.

Unless there were eternally flowing funds to transfer, emulate, and port the functioning of hardware components, software environments, and data formats to ever-new technological platforms, there is no way for a performance or interaction with time-based arts using digital technology to be maintained on a continual path to be executed, run, used, or performed beyond its "first generation". This is most certainly not only true for time-based arts. As will be addressed below, this is of concern in all instances when we want to preserve what our senses can perceive in digital data, not only for future generations but even just within the span of our own personal life.

Generative and interactive art using computers has become a vast body of work, especially since digital technology became a commodity. Leaving aside the artists and their struggle to keep such works functioning for at least their own lifetime, a great concern for museums and art historians has been how to preserve these artworks. Numerous conferences are held on this topic and new departments in museums and programs at universities have been established for the preservation of "new media art". Strategies are being developed that strive for the preservation of time-based artworks often under the cultural perspective and in an institutional framework of "still art." This includes not only the time-based artworks from the analog era, in which preservation strategies are focused on the hardware (from video monitors to, say, capacitors, as well as the media itself), but also digital artworks based on specific algorithmic processes developed by the artist and collaborators for just one work, with a very specific hardware and software constellation, and potentially dependent upon very specific network configurations and data availability outside the control of the work itself.

Such works seem often to be seen and treated as if they could be frozen in time, taken out of technological time. As we know from the pharaohs, only immense amounts of money and labor can seemingly take something out of time. In treating time-based artworks, more specifically those works incorporating computer technology, the same way as still art, the first and most important step is to decide, which works one wants to invest in to preserve them. This, as always, is a cultural-political decision with all its consequences. And even then, it might not be possible to preserve a work beyond a port to its second generation, because with the next iteration of technology the same process and required investment will need to start all over again, say within the next 5, 10 or 20 years.

The proposal – or rather, the imperative, if one believes in culture as a contract, agreement, and desire spanning generations – is to look at time-based artworks that use electronics and digital technology in the same way traditional performing arts have been understood, produced, and dealt with.

Time-based arts never stand still as different temporal agents merge, from economic time, technological time, the time of the performance or interaction, to the time of experience. With digital technology and the universal time-based media machine, the time of production has been moved below the threshold of human experience into the (currently) nano-time-governed processes of digital technology. The only way to approach time-based arts from the perspective of human culture, history, and the handing down of "an idea of" is to document what and how it does what it does with video, sound, and – however far energy, time, money, and power reaches – with still documents, photographs and screen captures, texts, essays and reports, flow charts and diagrams. If there are funding models to port, emulate, and transfer digital time-based works, including algorithmic and interactive works in perpetuity (meaning usually through one or maybe two technological generations), that is certainly "great" and can be accomplished most likely only in very, very, very few cases.

If we do not take this documentary approach, we will lose many works and their contributions and place in history and culture because of obsolete technology. These works will never have the potential to be "rediscovered." An old CD-ROM from the 1980s, found in some box, has a different place in time and underlies different historical and financial interests than a painting from the second half of the 15th century. The painting can be looked at right away. A video capturing the screen as a person navigates through an interactive CD-ROM, a work of algorithmically generated web art, or of a person interacting in an installation will certainly not convey the "full experience," and it will not substitute for the experience "as if one were there," but this is true for any documentation of time-based events as expanded above. The documentation of time-based arts does not preserve the "original" work, cannot follow all of its potential branching and alternate modes, but it opens a window framing a view into the work as it was captured for the documentation.

This now raises the final and crucial question: Is it at all technically and economically feasible to keep even only such audio-video documentation and the accompanying documents accessible in their digital format further into the future? Considering the obsolescence cycle of hardware and software environments, the change of digital formats, and their dependence on the accelerated changes in time-chopping and reassembling by the time machine, can any digital documentation in moving and still formats be possibly maintained and kept accessible, even just for one's own lifetime?

Digital Archiving across Times, Spaces, and Places

With the introduction of electromagnetic systems for the distribution and storage of images and sound in radio and television, the captured individual stills on film and the continuously inscribed recordings of sound in wax, vinyl on tape were transposed from the time of the captured perceivable medium into a different temporal domain. The captured auditory and visual events were accelerated, transposed, and modulated with high frequencies, and it was necessary for the encoded signal to be extracted and decelerated to again meet the speed of our senses. However, there remained an inherent, physical, one-to-one relationship between the points in time of the captured images and sounds, their modulated transposition, and their reintroduction into the realm of human perception.

A qualitative leap took place through the quantitative change in using ever-shorter intervals of time as the fundamental constituent of digital tools. With the introduction of the ever-higher clocked synchronization of abstract formal-logic processes in computers, and with the potential for arbitrary and disjointed mapping across any media that digital technology can ingest, process, and generate, the relationship between the captured and the stored, between documentation and archive changed fundamentally.

The internal functioning of digital technology and the interdependency of hardware, software, and data necessary between all components inside and outside the "time-machine" computer underlie the driving economic forces of the information-technology complex. Digital technology grew out of the military-industrial complex, moved to a multi-national industrial complex, and has by now radically transformed human culture, history, and tradition. But considering pre-digital concepts of communication across generations and the archiving of material objects we can hold in our hands, look at, or read, are still the path to realize the radical change time-based digital technology has brought to history, culture, and tradition. We have been made to believe over the past 50 years, and indeed we like to believe, that when everything can be stored and copied digitally, this is more reliable than clay tablets, letters and images on paper, images on film, and painting on stone, wood, or canvas.

Artists using digital technology for the real-time processing and generation of time-based events know as much as any other engineer and programmer that there is no eternity in the trinity of hardware, software, and data, no equivalent to the 8000 years of written documents or the more than 50,000 years of stone painting and engraving. Not even a decade or two are within the reach of users of commodity computer systems unless constant care, copying, updates, and ports are followed religiously. The change of hardware, operating systems, programming environments, and data formats are accelerating as the clocks of computers get faster, the processing bandwidth increases, and storage media hold ever-denser packed information. The interdependency of all physical, material substrates like disks, tape, or flash memory used to store digital information also when the computer is turned off, as well as the content converted to and from digital data is governed by our dependency on the technology we use and the accelerating changes of technology we have to follow. It appears to be a self-propelling system, like a natural phenomenon outside of human control – which it certainly is not. Humans drive the speed of change in commodity, consumer, semi-professional and enterprise technology as a consequence of the economic system in conjunction with basic and applied research for the next generation of highest-end computational technology.

Programs, hardware, and software integrated with time-based artworks become as quickly obsolete as the industry changes computational environments. This is certainly true for any computer-based project and is well exemplified by NASA's search a few years ago for a programmer who was an expert in the almost obsolete FORTRAN programming language. Old computers orbiting the Earth in satellites had to be maintained independent of the technological changes that had taken place on Earth since their launch, with the subsequent waning of human expertise for such "antiquated" systems.

The obsolescence of computer environments can be countered by translating (porting) programs and data formats to the next new environment and its changed technology; by programming emulators, which simulate old systems and programming environments on new hardware; and by building new hardware interfaces for interactivity, display systems, and actuators for physical devices that function identical to the old ones but that can be connected to the systems of the day.

Web-art and other installations, which use resources from the World Wide Web, run up against old links, since the eternal time machine in general and, for instance, the Wayback Machine as a specific Internet archive, does not keep "everything," let alone "for eternity." Museums, artists, and art historians continue to struggle with the complexity and cost of keeping, maintaining, and reviving any time-based real-time digital artwork. They see the artworks turning nonfunctional or disappearing within a decade or less; the only traces left are at best the announcements, catalogs, academic writing, and curricula vitae of the artists, and possibly a video and sound documentation of the work in action.

Once it is accepted that time-based, real-time works using digital technology have the same underlying conditions as works of traditional performing arts, some relief might be found in the acceptance that digital technology is simply the fastest-changing medium invented so far. As clocked time has become the fundamental basis for technology, anything the technology performs is a dance to metric beats below the threshold of human movement and perception.

Let us assume for a moment that a museum would agree with this perspective and would take the approach performing arts have taken ever since it was possible to capture movement and sound on fixed media. Not only would descriptions, scripts, drawings, and still photographs be stored together, maybe with the source code of the computer program, flow-charts and specifications of hardware components, but also the output of generative programs and one or several interactive sessions would be captured, recorded, and placed in the digital archive as well. But how will this archive then travel through time?

The Digital Time Capsule

The horizon of the following discussion of a digital time capsule is defined by the current (2020) state of commonly available technology and the few decades since the invention of the electronic digital computer. After a decreasing interest in the challenges of archiving digital data between 2010 and 2015 nourished by the notion of “the cloud” holding “everything forever”, a renewed interest in the question of the longevity of the physical bits that hold digitally encoded information has risen. The development of new materials with ever higher storage capacity that simultaneously secure the physical integrity of the stored information, has been conducted for commercial solutions that are integrated in high-end and proprietary systems. When and how such technology will trickle down to become widely available for consumers and institutions is unknown, especially as cloud storage and its convenience factor of data synchronized across devices overshadow questions of the longevity of independent and locally stored data. Interestingly, optical storage and retrieval is still the archival medium of choice, be it the writing or “engraving” into newly developed complex crystalline structures or exposing visual images containing data, for instance packed into QR code, onto film, which then is stored deep in a mountain.

The rapid development and world-wide spread of the CD in the 1980’s from factory-manufactured to an individually writable medium over only 8 years was followed by the optical medium DVD with about 7 times as much storage capacity and similar wide-spread use, and the Blu-ray disc with at minimum 5 to 6 times the storage capacity of a DVD, but with declining consumer base. This rapid development and spread of optical storage media for consumers will surely not be repeated with another optical medium, especially given that music and film streaming has removed individual ownership of media, that cloud storage is increasingly convenient and that the cloud business models are so highly profitable to manufacturers and providers.

Despite of currently around 80% of data being never accessed once stored (according to an estimate by a highest level executive of IBM), the amount of data created and stored is ever-increasing. Even data saved by those who carefully select, prepare and store it for posterity (whether to be handed down from parents to children, to be transmitted from author to reader, or saved by researchers and archivists that contribute to scientific, social, cultural and historical memory) will not easily find a durable storage and retrieval environment that does not require constant tightly knit maintenance schedules and a continuous stream of financial support.

Having researched the available technology with which to build a digital time capsule, lead from an initial, possibly naïve concept down the rabbit hole of technology and the intertwinement of data, software and hardware towards the perspective that the only solution might be to print words, data and images on paper, bind them as books and put them on a shelf.

Continuing down the technological rabbit holes of our current time (2018-2020) may prove to be fertile or futile. The fundamental conceptual considerations will likely be valid for some time, especially those regarding the sustainability of the computer hardware as part of a time capsule. Even though there had never been another time in human history where such an abundant amount of information, data and documents were created, these technical considerations may explain to a future archeologist why there might be a big hole in the records from individuals and institutions in the decades around the turn from the 20th to the 21st centuries – already now called the "digital dark age" because of the irretrievable digital data and documents.

Digital Documents vs. Books and Boxes – Ownership, Maintenance, Durability

As previously described, still media like paintings, sculptures, books, prints, and photographs abduct what they display out of the passing time of moving and speaking. When viewers and readers then look at or read such objects of frozen time, they infuse their own personal time into them, when "taking them in". The infusion of time through attention and perception moves the still to life, as eyes move over a picture or follow lines of writing to recreate language in time. This infusion of time takes place without any technical tools. Even the frozen movement of still photographs that are animated by a filmstrip moving through a projector can be viewed without the apparatus and accelerated in one's mind to get an impression of the progressive changes.

In the case of sound, a transubstantiation has to take place. The changes of air pressure, which we perceive as sound, are captured and inscribed into a medium such as wax, tin or vinyl. By infusing the same removed time through the playback system by spinning the cylinder or record and creating again changes of air pressure by a moving loudspeaker membrane, we can perceive the recorded and now-reproduced sound. Simply looking at the grooves does not convey much.

This leads to an inherent property of time-based digital technology. Changes on the macro level – new products, environments, operating systems, programs, and formats – are tied to higher clock and processing speeds resulting subsequently in more data to be stored on the nano level, and the need of more and more physical storage for data. This asks for ever-denser data packing methods with both immediate, as-fast-as-possible online access and off-line archiving outside of the time of the time-machine. As hardware, operating systems, programming environments, and formats change, the old stored data might not only become inaccessible because of technological change, but the bits themselves will most likely have vanished, their disappearance rooted in the physical properties of the storage media.

Consider a time capsule made out of bronze that is airtight, watertight, and sealed, and buried with a cornerstone of a building. It holds a snapshot of information about the era or moment in time when it was walled in. It is meant to communicate what happened at the time the building was erected to a future generation of owners or historians.

Would it be possible to design a time capsule with digital information that is equally stable and self-contained? The time capsule should be inexpensive and based on widely available, low-cost commodity hardware and software, as well as using only widespread and well documented data formats. It should be storable in a box or on a shelf, surrounded by four stable walls and a roof, without being connected to electricity and without requiring special environmental conditioning to control temperature and humidity.

The challenge for such a time capsule is threefold: to determine media that holds the bits under such conditions without deterioration; to ensure that file formats used are predictably supported and documented; and to investigate if a self-contained hardware combination could be configured that would start up after many years.

The other most important aspect of the digital time capsule is that the data should allow individuals and institutions to personally own, store, and access the data on their premises and under their control; the data is not to be handed over to third parties like companies that own cloud storage. Any computer user should be able to use the capsule, which may hold anything from personal photographs and documents to the holdings of institutional repositories like museums, universities, or libraries. The individual or the institutional approach to a digital time capsule require a robust, self-contained archive that does not need constant support and maintenance and that can be kept intact and functioning without the necessity of continuous funding and technical "life support" like climate control.

If we put a hard disk in a box and store the box in an attic, library, or vault in hopes that future generations will be able to just connect the drives to a computer and start it up, to then access, see and hear what we stored for them, it is clear that this will not meet our goal. We know from our own experience that we will probably not be able to retrieve data left to sit on a hard drive, even for only five to ten years. Firstly, older forms of digital storage media have been replaced by new technology. No one uses punch cards or 9-track digital tape any longer. Floppy disks have become obsolete. In the unlikely event that the actual data is still retained on such a storage medium, the hardware to read such obsolesced media is difficult or impossible to find. But as discussed, the chances that the data will have vanished is probably more likely than the availability of obsolete hardware. An informed estimate of longevity for data stored without air conditioning on a magnetic or solid state drive is 3 to 10 years, whereas the hardware to access the data might function for 15 to 25 years.

In the case of a box with obsolete storage media, which we can no longer connect to our current computer and its operating system, we might be successful to pull all the old hardware together, but even then, the physical layers of a tape holding the data might have delaminated, a spinning hard disk might be stuck because the grease used to lubricate the ball bearings caked together, or so-called solid-state data storage devices like a "thumb drive" or SSD device have lost the stored data. In the case whereby we overcome hardware obstacles and find a computer with an operating system to access the storage media, it may turn out that the programs needed to turn specific formats of digital data into perceivable texts, images, or sounds are no longer available and it will be time-intensive to source, install, or write programs to convert the data to current formats. However, the point is to not imagine what one could do with major financial resources and human expertise, but to arrive at an understanding of what it would take to create a digital time-capsule as accessible as a bronze time capsule or a book – open it and look at what it contains.

If we copied data every five to eight years while checking the integrity of the data even more regularly; if we had the media stored in a temperature and humidity controlled environment; if we had been continuously porting all our documents and required programs to new systems, programs and data formats before they were not supported any longer by hardware and operating systems, or if we sourced and maintained emulators, running old programs on technology of the day – only then might we be able to pull the old data into the time horizon of that current moment. This process requires constant attention, labor, updates and investment, and climate control to keep the stored data stable. In institutions, it requires continuous funding and an institutional continuity across changing staff. A book on a shelf did not care if the king went broke and a looter took it from the court library, and then sold it to someone who would read it.

In 1989, the International Digital Archive for Electroacoustic Music (IDEAMA) was founded in a collaboration between ZKM, Center for Art and Media Karlsruhe in Germany, and the Center for Computer Research in Music and Acoustics (CCRMA) at Stanford University as a result of my then concurrent engagement with both institutions. A major objective was to find the best storage media for the digitized works of electronic/electro-acoustic music up to around 1970, which arrived to become part of the archive already digitized, but in different formats on many different digital media. In 1990, the first CD writer became commercially available, and I was able to purchase the very expensive system for the ZKM-Institute for Music and Acoustics that I had founded. We determined that the "write once read many" (WORM) CD with a gold reflecting layer and an anticipated range of 50-100 years of retaining data would be the longest lasting available media in comparison to computer hard disks. In 1990, a large foundation in the USA declined grant support for the project, because an "all-digital archive" was not regarded as feasible... The archive was subsequently realized with support from ZKM and CCRMA (when funding ran out at CCRMA, it was finalized by ZKM) and distributed to over 20 international institutions and libraries as a set of written CDs. Ironically, in the 2000s, ZKM changed the CD distribution to hard disks, since 100 hours of audio could be put on a single drive, making it faster to copy and easier to ship – not considering that the bits would be lost after just a few years if not copied by the partner institutions. The golden CDs will have outlived most of the hard disks by now.

Today, 30 years later, digitization has become the main technology, approach and mode of thinking for many archives pushing to store more information on an ever-smaller physical footprint, and assuming that the data will be eternal and could be copied "without loss." Today, culturally important books, documents, photographs and laser-scans of buildings, which are doomed to be lost through wars, terrorist acts or air pollution, are scanned and stored in digital archives and in "the cloud".

Creating the first instantiation of a digital archive and not having the funds for the subsequent constant maintenance of the data and computing environment is a misleading effort. For example, many highly important books from libraries in Timbuktu, Mali, were saved from being destroyed by Al Qaeda and were digitized through great effort and personal sacrifice. The question now is what keeps these digital scans "alive" and accessible for the next fifty, one hundred, or even seven hundred years – the oldest document held in Timbuktu is from the 13th century. Seven hundred years amounts to approximately one tenth of the time since writing came about in human culture, and today it seems to be an unfathomable length of time through which to keep digital documents. In Timbuktu, the books and collections were often part of private archives and libraries, which were handed down through generations. This will not be possible with their digital scans. No one today believes that a digital document from today will still be accessible so many centuries in the future. Even if the data were engraved in five-dimensional crystalline structures, the machines to access them would most likely be lost or needed to be reconstructed. Many generations of Rosetta Stones would be needed, with manuals and data formats chiseled into granite, keeping masons today and data archeologists in the future busy.

Digital and digitized documents certainly allow for worldwide access, reaching orders of magnitude beyond the distribution of a copied manuscript or printed book. The fundamental question is, who is going to maintain the data and keep it as part of the digitally accessible cultural heritage spanning generations?

Presently there are several options. One can rent storage space "in the cloud." Here the main issue is ownership. There is no guarantee that the data will last longer than the corporation operating the cloud, even if we pay our fees regularly. The cloud is not an adequate solution to keep data accessible for one, two, or three human generations. Not even just for our own lifetime. We certainly have no chance to "insist on our data", when a cloud company goes bankrupt, since the physical representation of our uploaded bits is not ours. So, what do we do when – based on the small print in the contract, which we never read – we get a six months' notice like "download your data or otherwise it will be gone"?

To protect their data, their business, and to achieve so-called "load balancing" for all those millions of people accessing their cloud, the largest and dominating companies have mirrors of their data in far flung locations, so users have uninterrupted access and war or disaster should not destroy it. For our personal data, we can pay extra to have it mirrored in different locations. And the data, which the companies hold as basis for their own online business, is protected as the most important asset in their business model. Such companies strive for or have reached a monopoly on digitized documents and can calculate a cost-profit ratio. They will keep data as long as the financial return generated through the exploitation of the access is satisfactory to their shareholders, through advertisement next to publicly accessible data, through licensed commercial use of specific data, or by renting out cloud storage and cloud computing. This strategy and operation is certainly not anything new and is along the lines of popes, kings or civil societies and their cultural-political strategies and interest in managing their "cultural assets" as part of their political identity and control. But in the case of the multinational companies of the digital economy today, we are confronted with far wider consequences for small islands of cultural identity and history, larger cultural and thus political contexts, as well as for humanity as a global web.

Besides the enormous technical infrastructure, its updates and maintenance, cloud storage uses immense amounts of energy, but since the cost is split between all users, this is not visible to the individual archive. To alleviate the cost of spinning discs and split-second access to data in "hot" data storage environments, so-called "warm" and "cold" storage offer alternatives for not so often or rarely accessed data. Here the data is stored on older, slower discs, or on tapes or optical discs, which may only get activated when needed. Still, air conditioning, active computers, and data maintenance are needed and the responsibility for the accessibility of outdated formats lies with the owners of the data.

An alternative may be a cloud in "public ownership" by governments or – depending on specific political-economic systems and conditions – non-profit foundations. This would prevent the market risks of investment-driven archival operations, but just several years of waning staff and financial support for such archives would likely also result in the loss of data. (And even if we have created a robotic self-replicating archive, human support and funding will still be needed somewhere in this process, since robotic environments need maintenance and replacement as well.) To re-instate discontinued support for an archive is difficult and unlikely for such public or private organizations once they experienced a phase with lack of support and maintenance. Besides the creeping obsolescence of hard- and software, the deterioration of stored data will be immensely accelerated by loss of tightly controlled air temperature and humidity.

Another option might be a block-chain based distributed archive with data spread across machines all over the world. This would also use enormous amounts of energy, but as with cloud storage this will be of no major concern to most users, as the physically decentralized model would come with the cost limited to each user's individual system. The ownership of the physical parts, the computers, storage media, and network access is distributed, so only the interest of the individual owner will determine the sustainability of the overall system. Decentralized systems only survive if there is a continuing financial return on investment. Decentralized organizational structures which are "just human centered" – societal, political, or cultural in contrast to "just financially driven" – often fade out as the founders of the first generation start to die, a sustainable succession has not been put in place, and funding becomes an issue.

An institution – a museum, a university, or a research group – may create their own digital archive and may follow the recommendation to have copies of their archive in three different locations. But, here again, the most important factor will be the continuous financial support for environmental control, media integrity, and data maintenance after the initial generation of archiving. The sculptures and paintings in a museum's physical collection are by far less vulnerable than their digital assets. Even if the museum could not pay for the air conditioning for a substantial period of time, the deterioration of these physical assets will occur at a slower pace and will affect individual works and documents unevenly, depending on the materials used, whereas digital storage has a much higher "packing density" and loss affects data indiscriminately of what it represents. To give an example, if the environmental storage conditions for magnetic tape deviate from 50% relative humidity to 80% relative humidity, the projected thirty years of data retention on tape can rapidly go down 5 years, not accounting for other reasons for failure like mold and fungi that may feed on chemicals provided by the tape.

An individual or institution can build a data repository, maintain the data, and fund all the necessary steps continuously, from checking the integrity of the bits, copying the data to new media, to porting data and programs to new systems. In this scenario, the ownership and responsibilities are clear. As long as the needed funds are available, the data can be kept accessible.

Powerful institutions, the clergy, nobility, and the wealthy created large libraries, collections, and archives over hundreds of years. As smaller collections came into reach for individuals since the era of printing, many books – if not destroyed by fire, flood, or war – found their way through changing times and, most importantly, were and are accessible over many generations and up to hundreds of years without the need of technology and electricity. Open the book and read it. This has changed radically with digital documents, their highly compressed storage, their short data-retention spans, and built-in obsolescence of hardware, software, and digital formats that move through several cycles within the lifetime of an individual human.

Criteria and Critical Issues of the Digital Time Capsule

The digital time capsule developed and implemented at EMPAC is based on the following criteria:

- The "capsule" is a stand-alone system containing all components necessary to keep a digital archive accessible to sight and hearing for two to three human generations, up to 100 years.
- The digital technology and the stored data should maintain their functionality when stored under environmental conditions that humans feel comfortable in and without the need for air conditioning.

- The capsule should never be connected to a network but be fully functional in stand-alone mode. The devices, operating systems, and programs should never be updated and they are also backed-up on optical discs as part of the time capsule. The computer can load the operating system and programs from an optical disc.
- The computer will start with the power supply connected to AC (avoiding laptops that do not turn on if the internal battery is dead).
- The program on the boot chip of the computer and of the optical disc drive can be rewritten (reflashed) with the code stored on optical disc.
- The archived data may be accessible parallel to the capsule through an online copy or other storage media through other computers than those of the capsule. The media on the optical disc is the “unchangeable”, but always accessible, main repository.
- Data may be added through a clone system of the time capsule that writes discs in the same standard as the body of discs making up the capsule and uses identical data formats which are used for the archive.
- The time capsule does not need continuous electricity and maintenance. To be safe, the capsule should be checked once per decade.
- The system of the time-capsule should cost very little and be simple to operate. All components are mass-market items – devices, interfaces, operating system, programs and data formats. The cost point should allow individuals to have two or three sets of hard-and software for redundancy purposes, for a total cost for two or three systems of around US$2,000 in 2020. Institutions with additional resources can store multiple hardware items for redundancy and spare parts.

Three critical issues should be evaluated:

- The stability of the media on which the data is stored (optical discs).
- The stability of the data on the boot chip of any digital device of the archive and essential to initialize its operations; the possibility to rewrite (reflash) that data; and the same stability for flash memory chips integrated across the computer board, especially for USB chips on the computer and the optical drive, which are necessary to connect the computer with the optical disc drive.
- The stability and durability of electronic components integrated in the hardware, particularly capacitors, which are responsible for providing the smooth quality of electricity electronic components require for operation and that are essential to initialize the hardware to start up and to maintain functioning properly.

“Non-volatile” Data Storage and its Volatility

The purpose of the time capsule is to store and retrieve digital data independent from the continuous changes inherent to all levels of digital technology. Such a goal stands in opposition to the core of this technology, which is rooted in continuous change rooted in its assigned and applied economic, engineering, societal, and scientific functions.

Over the course of the short history of digital technology, different approaches have been developed to store digital data out of time on “non-volatile” media, that is, media that holds information without relying on the constant flow of electricity. Holes punched into paper cards; magnetic patterns created on tape or disk; read only memory (ROM) or optical disc (CD, DVD, Blu-ray) that data can be “burned into”; flash memory or solid-state memory (EEPROM, SD cards, thumb drives, SSD solid state drives) that hold the bits in electronic traps. All these strategies are designed to access and retain information at ever-increasing density on a smaller and smaller area as the data churned out by computers explode into larger and larger amounts of data.

Despite the use of the term “non-volatile” in the context of data storage, most material substrates that digital data are stored on today are quite the opposite in relation to a human life span and as such are most certainly volatile in comparison to materials such as paper or granite. The term non-volatile only indicates that the data is stored outside the speed of computer clocks and without the need of constant electrical current to maintain the state of the data. If electricity is shut down from non-volatile data storage, the data stays put and, once the computer is turned on again, it can be reintroduced into the time of the machine by picking it up from the non-volatile storage.

Two areas of non-volatile data retention are important for the time capsule: the physical properties of the media, which the archived data is stored on; and the quality of chips that hold the firmware, which are essential to initialize a computer, when powered on, and to configure all components on a computer board.

Most essential is the chip or the part of a chip that holds the boot-loader, which is an essential part of any digital device. The legacy name BIOS (Basic Input/Output System), stemming from the PC world, might be known to many. The boot-loader is necessary to “bootstrap” (boot, for short), to initialize any digital device once the power button is pushed. If these boot instructions are corrupted, the computer (or any other digitally controlled device be it a cell phone, an optical disc drive, a video monitor, or the endless numbers of computers in a car) will not start up at all. In the context of the time capsule it would mean that the externally archived data cannot be accessed at all with this computer or disc-player, since the devices will not start up but stay “dead”.

The development of non-volatile data storage shows how the ever-increasing demand for speed, flexibility and more storage capacity changed the concept of “non-volatile” to “not-so-volatile”.

The first widely used technology of non-volatile storage were paper cards and paper tapes into which patterns of holes were punched. The holes represented the bits of data that were loaded into the computer’s electronic components via an electro-mechanical reader that converted the holes to electricity, which then as “bits” started up the initialization of the machine.

Similar to punch cards and equally permanent data storage is “mask ROM” or Read Only Memory, which has been widely used since the 1960s to keep boot instructions intact once a digital device is turned off (ROM being the non-volatile counterpart to RAM, or Random Access Memory, which holds and can change its information only as long as electricity is provided). The bits are physically “etched” into silicon at a factory, using a mask for what has to be etched, and they cannot be changed. Such technology is ideal for not losing information, but it is only useful for a small amount of data like that which is needed to initialize a computer once the power is turned on. The information on a ROM chip cannot be updated but the physical chip has to be replaced — unimaginable in most of today’s computing environments. Paper or etched silicon retain their information as long as their physical properties are intact.

Subsequent developments led to chips that do not need to be physically replaced, but which can be re-programmed in-situ and still retain their data when the computer is turned off. The next iteration with Erasable Programmable Memory (EPROM) still needed physical, though not manual access to the chip by exposing the chip to ultraviolet light to erase the stored information before new data could be written to it. Then Electronically Erasable Programmable Read-Only Memory (EEPROM) allowed the erasure and writing of new data without additional physical access, just by sending electricity to the chip. Further development of this technology led to Flash Memory (named for the speedier way of erasing the data compared to EEPROM). Different from ROM, where the information is etched into a physical substrate, this technology holds information by trapping electrons between two gates or leaving the space between the gates empty. This memory can be read and re-written and has evolved over time to hold increasing amounts of data in a given physical area the holy grail of data storage: more data on less physical real-estate with faster and faster access for reading and writing data. Increasingly common are “SSDs” or Solid State Drives (which are actually not “drives” like hard disks as they do not contain spinning discs). SSDs belong to this family of chips, as do USB thumb/-drives and SD cards for cell phones or cameras.

Besides the essential boot program in non-volatile memory, many other such “non-volatile” chips are part of a given computer architecture. For instance, in the case of the time capsule described here, the computer and the optical disc drive contain each a flash memory network chip that is needed to connect both devices via a USB network cable. Without the chips on both ends functioning, the time capsule cannot bootstrap itself and get the operating system from the optical discs and then possibly refresh all flash memory chips used in the system as described further below. But first and most importantly the computer has to start up.

For such flash memory chips, the data retention under everyday environmental conditions is usually estimated at 10 – 15 years. Their data retention depends on how many times a data cell is written to, the physical packing density of data, and it depends highly on (operating) temperature and humidity. There are higher quality chips based on the same technology, that are estimated to yield 40 or even 250 years of data retention. However, there seems to be no way to find out which quality of flash memory chips a commodity computer manufacturer used where in a system and so it seems impossible to find out details about the expected data retention of the chips used.

So to be on the safer side, the strategy for the time capsule described in more detail below is based on the 10–15 year time span for data retention.

The only other widely used data storage that physically punches, burns, etches or imprints data in a material substrate as with punch cards or ROM chips, are optical discs, like CDs, DVDs, and Blu-rays. (The storage of digital data which is formatted to be embedded in exposed and chemically developed images on photosensitive film is a unique solution that does not fulfill the parameters set for the time capsule under the perspectives of low cost, general availability and not being affected by fluctuating environmental conditions.) Depending on both the material compounds used to manufacture optical discs and the technical process used to write the data into the material substrate of such discs, optical discs may indeed retain their data for decades or centuries. All other so-called non-volatile storage media one might use for one's "digital keepsakes" – like hard disks, tape, or flash-memory cards and sticks – are certainly much more volatile in relation to just one human lifetime or to two human generations. But again, as detailed below, the specific composites used for optical discs determine how long they may retain their data.

Spinning hard disks hold data in the form of magnetized areas and the data may already degrade after 3 to 5 years, or if you are lucky after ten or more years, but that is without warranty or guarantee and one cannot rely on it. They may fail mechanically or electronically or fail to keep over time the magnetic orientation of the particles representing the bits. It is recommended to check hard discs used for archival purposes every three years and to back-up on other discs or media continuously.

Data tapes, which also hold information as magnetized particles, may retain the stored data for 25-30 years under strict environmental control. If temperature, humidity, and clean air control in the storage area is not maintained for reasons of a period of loss of electricity or the hosting institution losing funding, the data retention may or will drop down rapidly to 5 years and less.

For the time capsule, we have identified the so-called M-Disc DVD as the only optical storage medium currently available and supported by everyday commodity technology that does not require environmental control beyond what is comfortable for human life. We have researched the M-Disc DVD in depth over the past several years We have not come across any other optical storage medium today that meets the requirements for the time capsule.

Optical Discs – More and Less Volatile

A brief synopsis of the technical background of commodity optical storage media (discs) explains the different reasons, why and how regular discs may lose their data or render unplayable in a disc player, and why the M-DISC resists such failures.

There are two most commonly used types of optical discs. One kind is manufactured in high numbers in a factory, the other is written individually, disc by disc. Though the methods of getting the data onto the discs are very different and have consequences for their data retention, both kinds apply the same underlying technology to read data from a disc.

Optical discs have a data track similar to the grove of a vinyl record, but reading in opposite direction, from the inside towards the edge of the disc. The “zeroes and ones” of data are represented in “pits and land”, pits being tiniest depressions in the otherwise smoothest “land” surface of the spiraling data track. Above the data track is a shiny layer covering the whole disc, mostly silvery, sometimes golden, which creates the typical appearance. When the data is read by a disc player, a laser light scans the track from underneath the spinning disc. When there is “land” on the data track, the light gets reflected from the shiny layer above the track and this reflection is picked up by a detector. If there are “pits”, the light is scattered and not reflected back strongly to the detector. These changes are then used to reconstruct the digital signal.

Factory replicated optical discs, like the ones that hold movies for home viewing or computer programs, are “replicated”. The whole spiraling data track with its pits and land areas is molded from a master in one whoosh that takes about one second, similar to vinyl records being pressed. Then the metallic reflective surface is applied and finally a protective acrylic layer, lacquer and label.

The other kind can be “burned” as individual discs – WORMs, “write once – read many”. In contrast to the factory stamped discs, this type of disc has an additional layer upon which the data is written by a laser that burns tiniest holes into the pre-grooved data track. The differentiation of “zeroes and ones” is the difference between tiniest light absorptive spots and spots that allow the light from the laser to pass through to the reflective surface and this reflection is then again captured by the detector. Writing such discs takes much longer than the replicating process in a factory. And the data written onto a disc may be duplicated through writing it onto a new, blank disc. (This is the difference between replication and duplication of optical discs.)

So in both types of discs, the contrast between the two states of light received by the detector allows to recreate the “zeroes and ones”.

A brief interjection on “Information in Contrast”: Barry Lunt, one of the inventors of the M-DISC, pointed out to me that all information humanity stores up to now depends on contrast, with one property of material being differentiated from another through contrast. This is as simple as it is fundamental. (Certainly contrast is basic for all human perception, but the focus here is on the encoding of what is to be taken out of time, to be kept beyond the very moment of immediate perception). Text, numbers and drawings written or printed on paper depend on the contrast between the paper and ink. If the contrasts fades over time by the paper aging and the ink losing its color, we may not be able to read it any longer. Letters or images engraved in stone may disappear slowly through weathering, until we cannot interpret any more contrasts in the surface of the material.

Digital encoding is based on the binary contrast between “1” and “0”, between “there is something” and “there is not something” which allows the processing through formal logic as implemented in computers. This excludes “there might be something” or “almost”, or “with good intentions you will see that...”, like one might apply when reading a faded manuscript. Certainly, digital technology can present different or for our perception fuzzy outcomes, which we then might interpret in different ways. But at the very core of its processing, the distinction between “there is something” and “there is not something” – even if derived from “there is simultaneously something and not something” – needs to be clearly delineated.

The focus on all stored communication being based on contrast may yield an interesting perspective on the human relationship to history and time, and to the carriers of communication and information through the ages, from which we then create history. And it may give rise to a different understanding of the combination of calculator and clock, of formal logic and time as the foundation of the universal time-machine and as it relates to our continuous need, desire or compulsion to create meaning in all human endeavors, including from the output from computers.

As mentioned, optical discs are comprised of several layers. The writable CD, DVD, or Blu-ray discs have a data layer made of special material, which the data can be written onto. This special layer is not needed for the factory replicated disc production where the data track with its pits is “stamped” (injection molded) into clear polycarbonate material. Once the data is on the disc, it cannot be changed anymore, but the data can be read back as long as it is not corrupted. Up to a certain degree, corrupted bits can be restored through error correction data, which are embedded along with the actual data of the document.

For all writable CDs and DVDs (with exception of the M-DISC DVD and most writable Blu-ray discs), the layer onto which the data is written contains an organic dye. This dye changes the light transmission of the dye when exposed to the writing laser light of the disc recorder during the burning of the sequence of “zeroes and ones”. The organic materials of the dye deteriorate over time under UV light as from the sun, and through oxidization with oxygen creeping in from the relatively rough and non-sealed edges of the disc. Through such chemical reaction the light absorbing and transmitting patterns representing the bits can disappear beyond repair, and the error correction data contained on the disc gets corrupted as well. In the 1990’s, when people started to write their personal music collections on CDs, a disc simply stopped playing at some point in time, especially when left out of its case or on the dashboard of a car because the data layer of the disc had been affected by sun light, temperature, humidity, and oxygen.

The equally absolutely critical layer of optical discs is the reflective layer, which makes the discs shimmer silver or gold. With the sole exception of the M-Disc DVD. all CDs, DVDs and Blu-ray discs – be they factory replicated or written with a disc recorder – need this layer for reflecting the reading laser that detects the “zeroes and ones” by differentiating where on the track its light is reflected with a certain strength and where not. This reflective layer can be made of cheaper reflective metallic material, like an aluminum alloy, or of more expensive material, for instance silver or gold. Since this layer is metallic, it is also prone to oxidize through oxygen finding its way into the disc from its rim. The oxidization makes the layer dull and lose its reflectivity. As a consequence, the laser of the disc player cannot read the data anymore. The material properties of this layer determine how quickly it corrodes, and obviously, gold is more stable than aluminum- based compounds.

The fate of a deteriorating reflective layer may affect any optical disc, be it replicated in a factory or duplicated and written individually. Again, the only exception is the M-Disc DVD, which does not need such a reflective layer. The data layers of most Blu-ray discs do not contain organic components, however they require the reflective layer for reading the data and which underlies the process of deterioration.

The chemical processes that destroy the reflective layer and the data layer of writable discs are accelerated by higher temperature, higher humidity and exposure to UV light. In order to keep the material stable, they need continuous air conditioning without much fluctuation. This is also true for discs of higher archival quality – like those with a golden reflective surface and higher quality dyes for the data layer – in order to reach the advertised time of data retention.

Based on our investigations, research and material analysis, the M-Disc DVD is the only optical storage medium that contains no material, the oxidization of which would destroy the data, nor does it contain a reflective layer, which can oxidize. The data-layer itself is a compound of three layers. The data is burnt into a Tellurium alloy layer, which is sandwiched between layers of "glassy carbon", which combines glassy and ceramic properties with those of graphite and isolates the data layer from oxygen and humidity, that might affect it. For these reasons, the data layer of the M-Disc is advertised as being "rock like". This DVD disc does not need a temperature and humidity controlled storage environment beyond what is comfortable for human beings to retain the data for a very long time (based on accelerated aging tests), hence the name "Millennial Disc".

The M-DISC DVD became available in 2010. Despite its tested and documented properties, it was not acknowledged and understood widely and did not become part of archival strategies in general, because of communication and marketing challenges of the start-up company bringing the disc to market. As of today, the M-DISC DVD can still be ordered. The EMPAC archive is currently written on about 10,000 such discs, purchased directly from the manufacturer without any logo printed on their surface, which might add potentially destructive chemical compounds.

The cost per disc is reasonable considering that the price of highest quality CD or DVD writable optical discs has dropped to around 1% of their cost in 1992. More importantly we are considering the archive for only a highly selected (curated) sets of data, and the savings are calculated from the time capsule not requiring special air conditioned storage areas and continuous maintenance. It also should be foregrounded that we do not have any business relationships with the patent-holders or the manufacturers of the discs. On the contrary, it was extremely difficult to obtain any information at all from the M-Disc business organization for our research of the media. However, with support of the original M-Disc inventors Barry Lunt and Matthew Linford, both Brigham Young University, and Rensselaer's laboratories we were able to verify claims about the components of the discs.

The M-DISC Blu-ray: There is also an M-DISC Blu-ray disc on the market that has much higher storage capacity per disc than the DVD. It is declared to be composed of "similar material" to the millennium DVD and thus would have the same data retention. Based on our research, this is not so. Like most Blu-ray disc, it does not have a data layer with organic material, so it is potentially a useful archival media. However, according to our analysis, it does contain a reflective surface made of a metallic compound which is susceptible to deterioration like any reflective surfaces in regular optical discs. For that reason, it does not meet the stability of the original M-Disc DVD.

Granted that one cannot prove anything of this by “just the looks of it”, and for that reason we analyzed the material of the discs. In the case of the M-DISC DVD it is amazing to see that the disc is nearly transparent and has no shiny reflective layer. This is the result of using the contrast between the burned pits and the untouched land of the specific material of the data layer and the disc, which yields the same results as regular optical discs without needing a reflective surface. For writing these discs, a disc writer with the M-DISC label is needed, which has a stronger laser to write the bits. There are still many such writers available. Importantly, the written discs can be read by most any optical disc player (or writer) without them needing to be M-DISC specific; we have not yet come across devices that could not read these discs.

The difference between CD, DVD and Blu-ray discs, which have all the same diameter, the same available area to write data to, is the amount of data each type of disc can hold. They differ in how tightly the data is packed, how much physical space is allocated for each “zero and one”, how many data layers a disc might have, and how closely the data layer is sandwiched just below the surface of a disc. A scratch on a Blu-ray disc may go right through to the data layer, which is very, very close to the disc surface, whereas the same scratch on a DVD may not reach the data layer, which is in the middle of the thickness of the disc. A similar scratch will destroy the least data on a CD, where the data is no so tightly packed and the track is also the widest of all three types of dics.

There are many other current developments in optical data storage that aim for “eternity,” including ever higher packing on the standard 12-cm optical disc format; storing data with thin-film carbon nanofuses on a silicon dioxide film (coming from a research team with Barry Lunt at Brigham Young University, which includes researchers who developed the M-DISC); recording data in nanostructured glass as “5-D digital data”; and other research projects to store enormous amounts of data written into quartz glass, which then requires machine-learning algorithms to retrieve the data. (DNA storage falls in a very different category of material.)

All these new developments are for “cold” storage, where accessing the data might take longer than data in “hot” storage. The terms hot and cold denote that hot data is directly and immediately accessible in blinding speed by the computer systems they are connected to, whereas media in cold storage still need to be put – by a robot or manually – in a device, which then can read the data at a slower speed. But the terms also reference the different levels of electricity consumption through data being “hot” and online with energy being used through constant accessibility, which in turn creates heat, and which then requires more energy for air conditioning versus the storage media being only ″spun up″ when needed.

Once such new technologies have left the R&D stages, they will certainly not meet the requirements of the time capsule of being “commodity devices” or personally affordable. Such new systems are developed for “highly, highly sensitive data” by entities with enough funding to meet the perceived value of their data and for companies providing cloud services and their ever expanding needs for data storage, while reducing “the footprint per bit” and saving expenses for electricity and maintenance. They will be high-cost, proprietary systems and will undergo continuous change. And in case a large external entity wants to keep the stored data under their own physical control, service contracts will be required. There will be no interest in making such technology a mass product, since the current market forces have moved towards online cloud storage, which are fee-based and distribute the high cost of ever-changing technology and very fast access across millions of users. These users in turn rely on their personal devices to access the cloud, which are similarly part of the cycles of technological change and rapid new product roll-outs. Personally owned and controlled methods of archiving data for even a human life-time or generation contradict the demands of the economic system.

In other words, however simple it is to develop and market a life-time or generation-spanning storage and retrieval system for digital data that could be purchased by anyone, there is absolutely no economic incentive to provide a solution for keeping data in one physical, personally controlled location for an extended period of time. The synchronization across personal devices offered by the cloud and the publicly sustained myth of digital data being eternal fuels this major economic engine.

Storage Capacity and Documents to be Stored

A major question asked in the context of the time capsule arises from the capacity of a DVD as storage medium. Compared to the ever increasing density of other storage media, the 4.6 GB a disc can hold seems outdated and significantly too small. Most any computer sold today has at least 200 times that capacity as internal storage, and most smart phones currently have between 15 and 30 times the capacity of a DVD. For the EMPAC time-capsule we use only around 4GB per disc leaving a wider strip of unused area towards the outside perimeter of the disc (the disc is written from the center out). This allows for a safety margin when physically handling the disc. The criteria to evaluate the capacity are the kind of files, which are written to the disc, and what to do with larger files that do not fit on one DVD. The data retention of the discs, the fact they do not need to be continually backed up and copied, and the high tolerance for fluctuations in the air quality have already been determined as most positive factors.

The time capsule is meant for intentionally selected (curated) documents, which excludes the usual data dump of everything that has accumulated over time, as is the tendency with large storage media. With the very low initial cost for the hardware and the cost for the media being low, and the space for keeping the discs having no special needs, the labor and time invested into selecting the documents and writing them to disc are the factors weighing most.

The cost for one Gigabyte of storage in the proposed time capsule, including M-DISCs and protective a crystal cases for each disc, is 40 US cents (2020). (The preferred choice of crystal cases versus thinner protective envelopes stems from potential imprints of even Kevlar sleeves onto the surfaces of discs and the better mechanical protection.) A living room book shelf of about 2m (6.5ft) high by 3m (10 ft) wide can hold up to 20 Terabytes, which would mean, for instance, up to 10 billion (with a “b”) pages of simple, unformatted text, or 140,000 hours of sound in highest quality MP3 format. The Encyclopædia Britannica Ultimate Edition 2015 with over 100,000 text articles, thousands of images and media files (granted at low resolution), fits on one DVD. An image file larger than 4.5 GB is at this point in time rare and would need to be split into components. Likewise, large data files of any type can readily be split to span across discs and be concatenated upon retrieval.

The EMPAC time capsule currently holds over 600 high resolution video files, none of which fit on a single disc. We use a public-domain program that automatically splits such files into segments of any size, in our case to 4GB, spanning however many discs are needed. The individual component files are self-contained video files and can easily be merged when retrieved. Each files has the necessary header information regarding its format, which a split by just an operating system would not yield. So even if the first or any other disc of the series gets damaged or lost, the others can still be viewed and put back together.

Based on the concepts put forward in this essay, the only data considered for this version of the time capsule are documents, which our senses can perceive, such as text, numbers, drawings and images, audio recordings, and moving images. Applications programmed for a specific project, artwork, or scientific application, which rely on project-specific hardware, processors, operating system, programming languages, interfaces and protocols, are not within the scope of this time capsule. Since anything in bits can be stored under this concept, the time capsule can be expanded to contain such specific programmed environment by integrating a sealed-off, never-updated configuration, which does not rely on external resources (not relying for instance on data from the Ever-changing World Wide Web), and which keeps all hardware, software and data away from technological changes. For instance, this would allow for generative art works to be kept working as long as the hardware and operating system start up. However, as previously discussed, it is worth considering to archive a video documentation of the generative program running to accompany the code of the artwork itself. It is most likely that such video documentation can be ported with greater ease to a later computer environment than the original program. This way, an "impression" of the work will still be available.

To wrap up the question of programs and file formats used for documents contained in the time capsule, we believe that less than ten data formats would suffice to capture a snapshot of all types of current digital files. These data formats should be either public domain or publicly documented through the International Organization for Standardization (ISO), or so widely in use at the time of the capsule's creation, that there will always be someone with a program capable of opening or porting such documents to then current new formats. We rely on the business world, banks, the military, governments, large institutional archives, and geeks to keep these data formats accessible on the latest machines. In a worst case scenario whereby the documents can only be viewed and listened to on the time capsule's own computer, the documents displayed on the video monitor of the time capsule can be captured with cameras and the analog audio outputs can be recorded to the then contemporary technology and formats.

The fundamental issue raised in the reflections of the very first part of this essay on the interdependency of clocked time, digital technology and perception becomes clear when analyzing how data formats hold the essential key to how time was taken out of the documents, how the data is segmented and packaged, and how the data needs to be put back together and reinfused with time to make it again perceivable by our senses—in order to make sense.

The proposed time capsule is geared towards documents and files, the data of which are not changed or changing once part of the disc archive. Certainly, it is possible to include custom programs, algorithms or generative real-time processes in the time-capsule, which run on the hardware and under the conditions of the frozen and isolated operating system, but this is not the goal of this time capsule.

Starting the Machine – Firm, Flash and Boot

As discussed, the crucial part in verifying if the hardware used as part of the time capsule meets the requirements is the boot sector program and its retention for computer and disc player. Without this functioning initialization sequence the device will not start at all.

Depending on the quality of the specific chip holding the boot instructions, the data may be retained for between 15 and 40 years and potentially more. But for mass-produced digital devices, there seems to be no way of finding out, what exactly the quality of the used boot chip might be, and usually a range of 10 – 15 years is given. Even though the chip manufacturers do have information based on aging tests, the difficulty is finding out, which chip exactly has been used in a device. It seems impossible to confirm how long a specific chip used in a specific computer or device will retain the state of these all important bits, and in consequence it is impossible to know after what time the computer or device may not restart.

A consolation and most important result of our investigation is that the time span such a chip retains its data starts anew, when the data is rewritten onto the chip. Once a computer starts up and is running, it is possible to "reflash" the chip and renew the state of the stored bits. The clock of data decay is reset and takes the assumed number of years to fade again. As a consequence, part of the maintenance strategy for the time capsule is to refresh this boot information for the computer and for the disc player in a cycle of 8-10 years, which is well below the expected data retention time of such chips.

The refreshing procedure is easily accomplished once the computer starts up and is running, so it is crucial that this procedure happens well before the expected deterioration of the stored bits. This refresh process is simple, is documented as part of the time-capsule'smanual and does not require special expertise. The data for the boot program of computer and disc player are part of the time capsule's optical disc archive and can be retrieved from there.

In 2020, chips of the flash family are integrated into numerous components of a computer. It is confirmed that their "life" cycle can be reset by re-writing the required code to such chips, although this still requires that the computer will start up initialized by the boot loader. The required code for other such chips in a computer is integrated with the boot and operating system initialization. (It is also possible that somewhere in a system a flash chip is used that is not enabled to be reflashed. We were not able to find information on this possibility yet. Any pointer is welcome.) The required z. Care has to be taken with the time-capsule to include a disc player that allows the reflashing of its information, since some players do not allow a refresh, but only updates with newer version numbers.

The boot and operating data for the EEPROM/flash memory chip in the optical disc player is also included in the time capsule's archive. Again, the most important chips to reflash are the boot chip of the computer, the USB interface chips of the computer and the disc player, and the disc player's main chip. If one of these chips does not work, the hardware of this time-capsule will not start up at all or will not connect with each other, which is vital to load the operating system from the disc archive. This is where redundant machines of the time capsule's computer and disc player are valuable.

In addition to the requirement for the boot program to be stored on an optical disc, the operating system and all programs and utilities that are needed to activate and access the time capsule are stored on optical discs as well. A computer and operating systems should be chosen that after the initializing booting can build up the operating system by reading it from a disc of the external disc player.

In addition to the complete specifications of the file formats used for the documents of the archive, the discs of the time capsule should contain all technical information and documentation in respect to interfaces, cables, connectors, and protocols.

Besides the optical discs, computer and disc player, the time-capsule needs a video monitor and an analog audio-out jack. It should contain everything needed to open it "like a book", whenever one wants to view and listen to the documents. A laptop that integrates the video display is potentially possible with the caveat that the laptop needs to power on even when the internal battery is dead. Alternatives, such as what we are using at EMPAC, is a small form factor mini PC like an Intel NUC, or a larger desktop, which allows easy access to its internal boards. Fundamentally, the computer should be as "stripped down" as possible.

Institutions may follow the recommendation for digital archives that three copies should be kept in separate, physically distant locations. In the case of the time-capsule, this protocol is simplified given there is no need for stringent environmental controls.

Certainly, all documents archived on the optical discs may also be kept online in "hot" storage devices connected to any computer or network, for instance a spinning hard-disk or a solid-state drive (SSD) or stored "in the cloud". The optical disc archive as part of the time capsule is primarily the reference storage, which can be accessed, restored, captured or ported to other computer systems as long as the computer and an optical disc drive in the time-capsule are operational. Once programs used with the archive have changed or disappeared, the old formats stored may not be accessible on newer systems, and exactly for that reason the time capsule's computational environment is never updated and should not be connected to any external network. Beyond a certain point, the time-capsule may or will be the only way to access the documents, be it for viewing, listening or ripping them and porting them to new data formats.

Capacitors and the Slow Fade

Another critical issue for the time-capsule is the stability of mechanical and electrical connections, like the drawer or slot for the discs of the optical disc drive, wires and soldered connections, and additionally the shelf and operating timespan within which any electrical and electronic component remains functioning. I will neglect the potential of loosened wire connections, the breakdown of insulation around wires, or soldering points turning cold. Such cases either happen and can be tracked down and get fixed (with most likely a lot of patience), or they don't occur. For this reason, an institutional time capsule should contain several computers and disc players, which will be very feasible at the price level of commodity hardware. And to have a second system will be very affordable for an individual as well.

Recently, towards the end of researching and developing the digital time capsule and in the attempt to cover all aspects of the seemingly straightforward initial concept for the time capsule, another hardware component raised its time-based head: capacitors (in other languages called condenser or condensator). They are used throughout any electric, electronic and digital hardware. They condition electrical energy and ensure that the flow of energy meets the requirements, specifications and level of quality for each component, that needs electricity to function and do what it is designed to do.

Fundamental to the use of electricity, a capacitor is a passive electronic component that stores and releases an electrical charge at different intensities and rates. Capacitors come in a range of physical dimensions from refrigerator-sized to the microscopic found in integrated circuits. The first examples of capacitors were experimented with in the 1740s and they have since undergone continuous development for almost three hundred years.

In the context of the computer and disc player as part of the time capsule, the main focus of concern is on those capacitors which are "visible". These visible capacitors are discrete components used in a power supply or on a computer board together with other electronic components as opposed to the capacitors that are fully integrated in chips. These capacitors help provide smooth, consistent, and uninterrupted power at specific voltages to electronic components. Capacitors may also be used to eliminate noise, "dirt" generated in one circuit of an electronic device so as not to pollute or corrupt the behavior of another circuit, maintaining clean power to all areas. Thus, capacitors condition electrical power as it is used across a system of electronic components as assembled on the motherboard of a computer.

A capacitor's electrical properties degrade with time. Unless they are physically damaged, exposed to electrical or environmental conditions that are out of their operational tolerances, they should not just stop working all of a sudden. As capacitors degrade and move out of their designed range of performance, the quality of power they can supply also degrades. Once a certain level of degradation has been reached, the components served by the capacitor may not work correctly, they may get damaged, or they stop working altogether. Digital technologies are much more sensitive to receive clean power than most analog components, and they require much tighter tolerances in fluctuations and distortion than, for instance, audio amplifiers or big electrical transformers, which also depend on the use of capacitors, but which are more forgiving to changes in the power they are served.

The design and applications of capacitors have changed considerably over time. Today, a large variety of fabrication materials and methods are developed and continuously evolve, so the extremely divers sizes, specifications and contexts of technical integration of capacitors can be met. Many factors influence the longevity of capacitors. Depending on the specific materials used, their chemical stability and quality, the timespan of operational performance of capacitors can vary greatly. Besides the actual voltage and current applied to a capacitor, humidity and the temperature of the environment significantly impact the operational functioning of capacitors, their “life”, and also their “shelf life”.

The shelf life of capacitors refers to how long they can be stored just for parts without being connected to other components; it is influenced by capacitor type, temperature, and humidity during storage. Moisture, beyond impacting the internal composition of a capacitor, can cause corrosion of soldered leads by which they are integrated into circuits. Storing replacement capacitors in a box with the time capsule may not work, however, this is likely unnecessary as capacitors will no doubt be around as long as we have electricity.

The operational life of a capacitor – when connected and with current flowing through it – is measured in hours. To give an idea of what this means, assume the life span of a capacitor is given by the manufacturer with 2000 hours, which means the capacitor should last for 200 days with 10 hours per day usage, or 100 days of 20 hours each. For regular computer usage with a machine continuously turned on, such capacitor would be useless, but for this time capsule this might be sufficient. Two thousand hours would mean that over a period of fifty years the capacitor could be used on average four days per year; enough to restore plenty of data from the optical discs and to reflash the boot chips. Of course, this would not be enough time if using the time capsule as a research tool in order to watch, listen and read. But capacitors used on motherboards are not rated for such a low number of operational hours. A major influence beyond the actual operational hours is the kind and make of the capacitor, if it is “wet” or “solid” and which materials are used in its manufacture. Often the lifespan of capacitors is estimated by the manufacturer at the maximum voltage the capacitor can work at and at a high operating temperature. When operated in the conditions our homes provide – with the associated environmental parameters of temperature and humidity, the quality of electricity, and the actual operating temperature of the electronic environment inside the computer – their operational life can increase radically by years and decades.

To retreat from the capacitor rabbit hole back to the time-capsule, we can note that the lifespan of capacitors can be anywhere between 15 and 50 years. Many people have computers that still start up after twenty or more years. Since the time capsule will not be updated and will run only with its original programs, we are “only” dealing with the aging of the hardware components, an issue that will not often surface for consumers who purchase a new computer every 5 to 8 years. If using a simple computer as proposed for the time capsule, a bad capacitor on the motherboard can be replaced relatively easily by someone with experience, patience, and a steady hand. And if all fails, there is the backup computer (which is not a real consolation, as it is clear by now that a computer cannot replace a book.)

All electrical power supplies have a particular type of capacitor that will definitely fail at some point in time as they have a short lifespan. Again, the quality of the capacitor, the quality of electricity it takes in, the actual operational hours, temperature and all parameters previously discussed contribute to its lifespan between 5 and 20 years. Thankfully the capacitors of power supplies are the easiest to identify and replace.

The complexity of parameters contributing to the lifespan of capacitors may only be countered with hope and the assurance that capacitors will be in use as long as there is electricity. A major point of frustration, as we defined and assembled a time capsule, is the impossibility to get a clear indication of the quality of the approximately 50 "visible" capacitors on a simple computer motherboard today (neglecting the "invisible" capacitors, for instance as those that form part of currently used DRAM memory chips).

Another issue is the difficulty in sourcing a computer manufacturer who would design a long-lasting basic computer with only prime hardware components. Considering that such a computer with clear indications of the quality of all material components does not seem to exist as consumer or even enterprise level product, the approach might as well be to use commodity products. Any information about computer motherboards, whose quality of used capacitors can be determined, would be very welcome. If the archiving community came together or an "archival philanthropist or foundation" would come forward, it would certainly be possible to design a motherboard with verified quality components.

This circuitous journey away from the focus on data storage devices, media, flash memory and firmware, operating systems, programs and data formats to the underworld of capacitors certainly reveals the complexity of the scales and interlocking layers of time required to access a single text in the archive. This complexity reaches from the abstract discussions of how the universal time machine relates to the time scales of human perception and tradition down to chemical reactions within its components.

Technical Synopsis for the Digital Time Capsule

The Goal

Store and access selected data for fifty to one hundred years as a self-contained, stable system that is cheap to set-up (in 2020 this costs approximately US $1000 per complete capsule, plus the media, which for M-DISC is around $400 per terabyte). The time-capsule requires human labor to create the archive. It is not dependent on continuous funding, uninterrupted electricity, environmental conditioning of storage, support of an institution (though absolutely qualified for institutions), continuous copying of data, or back-up in the cloud.

The archive is as a snapshot, not a continuously incremented archive. As long as the hardware, software and identical data formats, which constitute the time capsule and its archival media, are available, data can be added to the archive.

The Data

Without data, we have nothing to see or hear, observe, read or listen to. The data is the foundation of a window into the past.

For the past decade, the M-Disc DVD is the medium that has the best and longest data retention without special environmental requirements, stored within the temperature and humidity range comfortable for human beings, and without the need to copy the data to new media within a few years.

Data formats used in the archive are limited to a handful different formats, which are widely used at the time of archiving. The used formats are accessible by the programs, which are part of the time capsule. Wherever possible, the formats are in the public domain, ISO certified, or used widely used across the globe. The documentation of used formats is part of the archive.

Operating System and Programs

The operating system and programs used in the time capsule are never updated. They are stored on the optical discs and do not depend on magnetic or flash-based data storage. Upon start-up, the computer has to be able to load the operating system from an optical disc.

The Hardware

The computer hardware should be as minimal as needed for the functioning of the archive and its components should be as accessible as possible. It should be equipped with as much RAM as possible.

The enclosure of the external optical disc player should be as sturdy as possible.

The boot memory on the motherboard of the computer and of the optical disc player can be refreshed when the computer is running, with the code read from optical disc, which is part of the archive.

An external read-write storage medium can be connected to the system, if and when needed for its operation and for when the internal storage of the computer stops functioning. The computer should not need to rely on its internal "non-volatile" storage medium (hard disc, SSD, etc.)

Documentation of cables, connectors, and protocols are included on optical disc as part of the archive.

Optical Storage

Discs used to store data are M-DISC DVDs. They are transparent, should not have a white inkjet printable surface or anything printed on their surface (though the latter most likely does not result in any damage to the data). Larger quantities can be obtained from the manufacturer Ritek.

M-DISCs can be read by all regular optical disc drives (though testing of those included in the archive is always necessary). If it is also intended to use the optical disc drives for writing M-DISCs, the drive has to be certified to write these discs because the write laser has to yield more power than for the writing of regular discs.

The discs are to be stored in crystal cases rather than in envelopes, so it is ensured that nothing touches their surface and leaves imprints.

Usage

The time capsule is only running when accessing documents directly or when restoring or copying data to other external storage. The computer should not run continuously. It is recommended to have at least one redundant computer and 3 or 4 optical disc players. It is preferred to work mostly with one system until it fails and then switch to the next (certainly following the maintenance schedule for all.)

Maintenance

All hardware, including the redundancy systems, should be started up every 8 to 10 years in order to reflash the boot memory of computers and disc players.

Today, there seems to be no alternative to the digital time capsule for storing and archiving digital documents without the need for absolutely continuous and uninterrupted environmental conditions, maintenance and copying of data, and the financial support to support these requirements.

Based on the prototype developed at EMPAC and the considerations of this essay, it might be suggested to initialize another research project supported by the archival community or a start-up company that can put together a digital time capsule with a computer providing only the needed basic functionality and where the critical electronic components are verified as being of high quality yielding greater expected longevity and stability.

The digital time capsule is a thought experiment as well as a concrete technical proposal to address digital technology as fundamentally time based on all levels of its components. The intertwining of the extremely far apart timescales of the "nano-sliced" time in computer processing, data storage and retrieval and those of human perception, tradition and history affects all areas of human activities. For the duration of our personal life, we would like to access documents and the thoughts, stories and communications they hold, our valued still or moving images and audio without worrying that such digital representations might have vanished. And the changes for the collective memories of societies and cultures that came from extending oral traditions into tangible, visible documents and artifacts that lasted longer than an individual's or generation's lifetime, are now, so to speak, moved back in time to an invisible, time-based medium with its constantly changing data formats, software and hardware environments – to "shorter than an individual's lifetime", to shorter than a blink of the eye and to quicker than can be heard, undetectable to technologically unaided perception.

Texts and images written, drawn, or printed on paper can be kept under traditional archival conditions. Today most texts and images are created in a digital medium at the outset. The diaries of soldiers from current, most recent, and future wars will not be available like those from World Wars I and II, Vietnam, the Balkan, Darfur, Mali, or Sudan. There will be no documentary films on "real film", whose longevity is well understood, but digital film bits need to be continuously copied. The majority of digital communication never moves out of the time-based digital domain with its inherent short-lived temporality. Who prints emails received from their children or parents? It is understood that the by far greatest majority of human thoughts, documents or memories have never been "saved". But this does not mean that the tools developed over the past 5000 years with the resulting expanding of education to more and more individuals should be returned to only the few entities that retain the power over means and technology and from whom we have to license the view into our own personal life and cultural history.

Besides being a technical blueprint, the proposed time capsule is a political statement: a statement about ownership, access and the potential to hand what is cherished to next generations. The current digital situation inhibits any such handing-over, of "tradition" in its original meaning, unless being able to follow the fast economy driven cycles of technological change and relying on the shareholders of the Clouds; or alternately being part of a government or private philanthropic enterprise with the means to constantly maintain, copy and port the data and keeping it accessible across changes of digital hard- and software. The communication created by and flowing between individuals, families, and groups of any size, previously expanded through writing and printing on paper, is indiscriminately flattened under the rule of the "digital complex" and the required continuous flow of money to keep that very communication accessible. For libraries and archives this certainly has not changed very much over the past centuries since they were always depending on funding that was not driven by a financial return on investment. Our current situation, however, narrows the potential of keeping, archiving and accessing even further than in previous centuries as it is subjugated to the changes in digital technology many times over in a human generation and the consequences for continuous investment, amplified through the inherently short life span of stored data on the majority of storage media.

The last 500 years of education, reading, writing, and book printing changed the course of tradition and with that of all aspects of human life radically. Equally radical are the consequences of digital technology as the foundation for distributing, archiving and accessing human doing and thinking. The past 20 to 30 years have seen the disappearance of personal and institutional documents just because of their digital format. It is already evident now, that future archeologists will find a digital black hole of the 1990s, with a wide-spread loss of documents in the abyss of changing digital technology.

The EMPAC time capsule is the attempt to understand and potentially use digital technology

EPILOG II

The universal time machine is a tool for time-based arts, spanning all media and being used for the ever-evolving web between the human body (what meets our eyes, ears, minds and hearts) and our experiences through the arts. The foundation of time-based arts is intrinsically linked to our encounter when an artwork is performed, activated, and experienced in the moment. This has not changed with digital tools. The difference between what is "live" and what is "documented" remains.

With the universal time machine, we have created a convolution of time and space that radically revises the contracts between the different timescales of individuals, generations, communities, institutions, and economic and political power structures. These revisions are driven by the continuous and all-affecting technological changes with their built-in cycles of obsolescence, revolving many times through the lifetime of an individual and across human generations.

Digital technology is rooted in its potential for endless repetition, its effortless permutation of what has been, and its generation of the new. All of which is subjected to the driving forces of changing digital standards, protocols, hardware and software as part of the industrial fabric of digital entanglement. Obsolescence and oblivescence are linked on the economic and subliminal timescales of the time machine and its components.

against its inherent forgetfulness, contrary to the mantra that everything will be saved for ever because it is now digital. Over just a few millennia humans developed strategies to move thoughts, knowledge, information and considerations of groups and individuals through writing and printing, through creating and capturing images and sounds out of the time of human heartbeats, and allowing distribution and access through books, sketches, drawings, photographs, and audio records into the time and ownership of an individual owner. Time-based digital technocracy turns the wheel back to a purely time-based communication and tradition – almost like oral tradition before writing and printing, but now with several iterations of obsolescence and "forgetting" over the lifetime of an individual person.

The holders of power over technology, its development, production and distribution, are the new holders of tradition parallel to the Western European Medieval era, when the holder and gatekeeper of knowledge, its passing on and controlling access, was The Church. This parallel includes the non-coincidental proclamations of the secondcoming of a savior – anticipated in major religions as an end to the battle between good and evil and as end to all human misery – through the so-called technological singularity, when technological development will move beyond the limits of its human inventors in their constant exploitation of other humans, away from war and terror to a transhuman, autonomous state.

The considerations leading to the digital time capsule do not come from a Luddite or from Rage Against the Machine. On the contrary, it comes from an analysis of how technology has changed what we can keep throughout our individual lifetime; how history is created, and which thoughts and objects are handed down through the times; and how the masters, dictators, mentors and creators of history are changing their strategies as they always have with and through technologies. New horizons of time have always been inherent to every newly developed technology, be it a hammer, the book, the electrical motor, the refrigerator or the nuclear bomb. With digital technology bridging unfathomable splits of seconds with the "slow" time of our perception, we create meaning, fantasies, probabilities and

Scientific and engineering changes in concepts of time will – as through the ages – result in new technology and new applications, which in turn affect human life, existence and history deeply. With the universal time machine, any media can be stored, shaped, generated, controlled, and distributed within one complex set of tools, "the computer". The foundational principle for this is the encoding in digital formats, which can be freely defined under the conditions and within the limits of the digital. These limits will be expanding and changing radically over the course of time.

The computer operates outside human perception. As a result, anything it stores and creates needs to be brought into the time of our human senses, if and when we want to make sense of it. This is only possible if the data stays intact and if the exact digital formats in their historical configurations at the point in time, when the data was generated, are available. This stands in destructive tension with the complexity of the universal time machine and its constant technological change, which is driven by new discoveries and developments and by the economic goals of the holders and manufacturers of the digital domain. As a result, the historical, hermeneutical and political horizon changes with the speed of changing technological conditions. And the necessary construction of continuity over an individual's lifetime or across a few generations, has been moved from "the book" to "the clock", from what we can hold in our hands to what needs to be put back together for us each time we want to perceive what it holds.

Storing, finding and accessing that which is captured and held digitally has characteristics of the temporal realm of oral tradition, that is to say, the telling, retelling, altering and adding across changing contexts over the lifetime of individuals and generations. Now, institutions and technology companies hold all the keys to knowledge, memory and history, to what is told, what is kept and what discarded.

The radical change paper production and the movable type printing press brought about for the endurance of individual knowledge, thoughts and memories six centuries ago, expanded with predictions, looking back and forward, integrating what digital technology puts together for us in the moment it meets our senses.

The longevity, or rather brevity of digitally stored documents together with the required care and expenditures to keep them accessible across one's own lifetime or even generations, led in this very moment of technological development to the digital time capsule. Since the earliest beginnings, technical tools have been used to create, shape and rewrite histories on all levels of human societies and cultures, to construct and legitimize continuity or revolutions; winners or losers; friends and foes; remembrance, goals and visions; forgetting and elimination.

For humans living in digitally permeated parts of the world, the question of power over individual keepsakes now in digital format may be as important as it is for humanity as a whole in how the outcomes from thinking and reflections, research and the arts may be passed on.

subsequent technologies to print diagrams, drawings and images. This radically changed again with the digital storage of "all" information and documents. But now, the universal time-machine counteracts its very potential to capture, hold, reconstruct and generate all such information and documents by its constantly changing technology.

The traditional performing arts and the traditional visual arts have also changed radically since time can be captured, removed and reinjected again through photography and film and audio recordings. In particular, time-based artists continue to shift traditional boundaries by using computer technology as a unifying platform for production, creation and documentation. The digital time capsule is an attempt to use this very technology against its obsolescence to document and capture a glimpse of what flies by in the moment of experiencing a time-based artwork or performance.

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The M-DISC DVD is manufactured by Ritek, Taiwan.

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