FROM TIME CAPSULE TO KNOWLEDGE ARK:
THE PRESERVATION OF KNOWLEDGE FOR ETERNITY

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Note: this document is the English version of the following document :« De la capsule temporelle à l'arche de connaissances : la préservation de nos connaissances pour l'éternité ». It has been translated automatically and the resulting translation has been crosschecked manually by the author of the document.

INTRODUCTION

What will remain of us centuries from now? Millennia? Millions of years? Many people have already asked themselves these questions. In fact, we're asking them more than ever, given the pressing current events and the growing number of crises that are turning our lives upside down. What on earth will we be able to leave to future generations if the world keeps getting worse and worse? And it's not just about what we'll leave behind on a personal level—that is, what we want to bequeath to our loved ones (especially our children)—but also, more symbolically, all the life projects we undertake because we wish to leave something that comes from us after our death (a cause, a work of art, an invention, etc.). It is also about what we will leave behind collectively, as a civilization. Humanity is not a recent phenomenon, and many human beings have managed to leave such lasting traces of their passage that we continue to rediscover them today. The heritage of our civilization is an accumulation, a raw sum of millions of legacies left by millions of people since the dawn of time, whether in the form of art, ideas, scientific knowledge, techniques, values, customs, languages, and many other things that we cannot list exhaustively. This heritage spans thousands and thousands of years and includes all sorts of things—"items"—that have survived to the present day, sometimes by a miracle. All of this is well and good, but we are not the first to address the issues surrounding heritage and its preservation, and it is clearly not the purpose of this manifesto to emphasize yet again the importance of safeguarding our heritage, even if this is not obvious to everyone.

No, the main goal here is to ask ourselves how we can go further: how can we ensure that all knowledge receives the care it needs to endure? How can we ensure that, even in the distant future, all the knowledge humanity has produced remains safe and accessible—not just parts of it? We are more or less capable of preserving all kinds of items in museums, libraries, archives, and other data storage centers, and even on an individual level, we can also build our own small private collections, diaries, and photo albums. But none of this is necessarily designed to remain available to future generations thousands of years from now: this heritage is scattered and does not receive the same level of care everywhere. We are capable of preserving heritage on a local scale, but we are not yet capable of preserving humanity's global heritage. Above all, current preservation sites remain vulnerable to all kinds of disasters. Or even to deliberate destruction. In this book, we will advocate for what we will call an epistemic memory. At this stage, we can define epistemic memory as a kind of universal and enduring archive—a memory that brings together the entirety (or nearly so) of our knowledge and, indirectly, our intellectual and cultural heritage. An epistemic memory would aim to ensure that all knowledge, particularly scientific knowledge, can endure for generations and generations, in its entirety. To put it plainly, think of the Library of Alexandria, or the lesser-known Library of Pergamon, which even in antiquity aspired to gather all the knowledge and arts available at the time in the Greek world. Libraries that, alas, have not survived to the present day. A Library of Alexandria does not necessarily aim to centralize everything in a single place, nor even to focus exclusively on the sciences and literature. But the philosophy of wanting to create a lasting space, an ark, dedicated to all knowledge remains at the heart of the concept of epistemic memory. Unlike ancient libraries, behind epistemic memory lies the hope of creating a knowledge bank capable of transcending our own civilization and outliving it.

So let's explore together the challenges of epistemic memory—that is, why preserving knowledge is fundamental, what threats it faces, and what the goals of epistemic memory are. In short: why on earth do we need to preserve knowledge in its entirety? Next, we will also delve deeper into the constraints behind such a project, as well as the various possible methods or approaches to address them, in terms of comprehensiveness, accessibility, and longevity. In other words: how can we go about preserving knowledge in its entirety for the long term? It is on this occasion that we will introduce the concept of a time capsule, which is closely linked to that of epistemic memory.

I.1) KNOWLEDGE IS GOLD

Knowledge is proof, and proof is precious

The crux of scientific investigation is material evidence. Scientists seek to accumulate as much evidence as possible to evaluate the quality of their theories, to test hypotheses, etc. Evidences are directly or indirectly related to the subjects of study of the theories: to study the Earth's atmosphere, temperature and pressure readings are collected; to examine living organisms, specimens are observed in nature; to understand deep space, the spectrum of stars is measured, the sky is photographed, radio waves are listened to, etc. Evidence can be of two kinds: tangible and intangible. Tangible evidence is physical evidence itself: fossils, archaeological sites, meteorites, ice cores, Petri dishes, formaldehyde bottles, samples, etc. Intangible evidence consists of all the data that can be derived from tangible evidence: observation reports, measurements, graphs, descriptive notes, maps, interpretations, classifications, and terminology used, scientific laws, related mathematical demonstrations, etc. This “intangible” information is collected in more or less organized databases and is discussed succinctly in scientific publications, the latter forming the backbone of scientific research. These publications are, of course, produced on a physical medium: traditionally, paper, or computer memory, the format adopted is digital. Thus, intangible evidence also ends up, in a way, being converted into tangible evidence: scientific publications. Consequently, this means that scientific research relies on an accumulation of all kinds of artifacts from which knowledge can be gleaned. The sum of our civilization's knowledge is thus made up of the sum of museums, university libraries, laboratory archives, computer servers, and other places dedicated to collection of knowledge all over the planet.

This leads us to make the following observations:

*Knowledge is a virtual entity that exists through a material entity: knowledge is not simply mental information that depends on the subject to exist; knowledge can “survive” independently of the subject through all kinds of media (tangible evidence on the one hand, intangible evidence through scientific publications on the other), facilitating the transmission of knowledge from one generation to the next.

*The longevity of knowledge depends on the longevity of the media: the knowledge accumulated through scientific publications would be lost if all archives disappeared overnight. We cannot rely only on human memory and oral transmission to preserve our knowledge with the adequate level of detail.

*The longevity of knowledge depends also on the longevity of the object of study in the first place: whereas a future astronomer will never have any difficulty studying the orbits of the planets in the solar system, as they will still be there in millions of years' time, a future biologist could have difficulty studying living organisms if entire families of species disappear without a trace, or if they leave behind traces that are too fragile, such as fossils, whose physical integrity cannot be guaranteed for thousands of years once they have been unearthed.

This leads us to the following observation, which is the first major challenge in preserving knowledge: much of our knowledge depends on the accumulation of evidence, which may have a short lifespan. If an entity somewhere in the world (celestial bodies, living species, rocks, humans, cultures etc.) is the subject of a study, then as long as that entity exists, it will not be too serious if evidence about it disappears, since it will always be possible to obtain near identical evidence again. But if this entity were to disappear, leaving only traces of its passage, it would still be possible to create knowledge, but only indirectly, and this knowledge would likely be incomplete. If these traces were to disappear also, all that would remain would be the data that we had time to record somewhere, limiting the extent of our knowledge. Finally, if this data is not recorded or if our media disappear overnight, then future generations will not even be able to create any knowledge about the extinct entity. Knowledge of ancient civilizations, of life forms, of historical events or of habits in a given society, could all be lost one day, and we could be the last to have it.

Some knowledge is unique, and its loss would be irreversible

There are therefore three levels on which our knowledge is scattered: the subjects of study themselves; the material evidence derived from these subjects; and the scientific studies derived from this evidence. In other words, sources of knowledge, evidence of knowledge, and knowledge carriers. The preservation of knowledge is all the more effective when it is carried out at high stream level, that is, as close as possible to the source of knowledge. However, preservation is also less tedious at a downstream level: it is easier to preserve a document about a region of the world than to preserve that region itself. Above all, sources of knowledge are sometimes ephemeral, and publications about them can theoretically have a longer lifespan. Regardless of the level of our knowledge, there is always a considerable portion of it that could not be rediscovered by future generations if it were lost.

At the level of the object of study itself, we can cite the fairly obvious example of animal and plant species distributed across the planet. As long as we can observe a polar bear or a mangrove tree in the wild, it will always be possible to describe these species, even if we had been foolish enough to store all our publications on bears and mangroves in a single archive that caught fire. But if these species were to disappear tomorrow, all that would remain would be the fossils in museums, DNA samples in laboratories, scientific studies, photographs, testimonies, etc. It would technically still be possible to create new knowledge from all this, but as soon as a new hypothesis is formulated somewhere, it will be more difficult to test it immediately, based solely on these archives rather than on direct observation in the wild. Certain species have characteristics so incongruous that the imagination cannot spontaneously invent them. Their survival is essential if we are to ensure that we understand the full extent of diversity that life can take. Thanks to testimonies and bones, we know that dense forests and lions existed in Greece 3,000 years ago, whereas today's flora and fauna are radically different. Without these indirect sources, it would be difficult for us to even imagine that a region like Greece could have looked like that (this phenomenon is even referred to as biological amnesia). The preservation of living species is therefore obviously a major issue for biologists, not only for obvious ethical reasons, but also quite simply for epistemic reasons: the loss of a species also means the loss of a vital source of information about a unique being in the observable universe, and perhaps even, by extension, about the biosphere in general (the knowledge accumulated about individual species can also help us understand more general biological phenomena: selection, natural history, origins, behavior, animal intelligence etc.) and even about human beings (consciousness, group life, population displacement, health etc.). Other sciences are not necessarily left behind. While physicists and mathematicians are luckier than biologists in terms of the longevity of their subjects of study, sociologists, on the other hand, must hope that the communities (generations, ethnic groups, countries, etc.) they study do not disappear too quickly. Linguists can only note with despair that dozens of dialects disappear forever without leaving any sound recordings or written records, while climatologists are well aware of the constant changes in climate over the millennia.

When it comes to tangible evidence, there are still many entities whose existence is unique, truly "miraculous" for a scientist, and whose loss would once again imply an irreversible loss of knowledge. Historians and paleontologists are probably the most concerned by this situation. When an animal dies, its carcass decomposes very quickly under the action of microbes and scavengers. As a result, within a few years, only the bones remain, which themselves eventually deteriorate due to erosion and other chemical reactions. Under specific conditions, bones can "turn" into stone, becoming fossils, but these conditions are extremely rare: for every individual that becomes fossilized, millions of others do not. This proportion is even lower when the individual belongs to a species that does not live in an environment conducive to fossilization (deltas, river valleys, etc.). Add to this the fact that plate tectonics have caused many fossils to disappear or to be buried over millions of years, and add to this the fact that humans may have inadvertently thrown away fossils in the past, everything that comes within reach of a paleontologist is a true scientific miracle. Paleontologists could easily have missed out on the existence of the brachiosaurus or the pterodactyl. If tomorrow, all natural history museums were destroyed by nuclear bombs, we would be the last to know about the existence of such species. What is true in paleontology is also true in human history, given that archaeological sites are equally vulnerable. Many social phenomena can destroy valuable archaeological evidence: urban planning policies (since ancient times, many cities have changed their appearance at the behest of their rulers: Rome, Giza, Beijing, etc.), wars (bombings such as that of Dresden in 1945, looting such as that of the Baghdad library by the Mongols, etc.), superstition (Mesopotamian statues destroyed by religious fundamentalists, handwritten turtle shells crushed for traditional Chinese medicine, etc.), looting (Egyptian tombs, theft of paintings, etc.), natural disasters (fires, earthquakes, floods, etc.) and many other factors that will be discussed later. We could go on and on listing everything that has disappeared and will never resurface: more or less ephemeral works of art (works by Cristo, ice palaces, etc.), specific events (world fairs, Olympic Games, etc.), "lost media" (unrecorded radio broadcasts, lost films, video games that have not been reissued and are technically obsolete, etc.), vanished natural landscapes, and so on.

Some knowledge is difficult to recreate

We have just seen that some knowledge relates to unique entities or phenomena that are unrepeatable and ephemeral, meaning that any trace of these entities is all the more precious because there will never again be an opportunity to study them in the future. Our most specific knowledge, that which relates to particular objects (living species, individuals, civilizations, eras, works of art, historical events, etc.) is the most at risk of being lost forever if all memory of this knowledge were to disappear.

But there is also another important scenario, that of knowledge that is theoretically reproducible by future generations, but in practice more difficult to rediscover in the event of widespread amnesia. In science, the amount of input data is an important factor in the accuracy of a result. Statistics teach us that when studying a sample of a given population (humans, artifacts, animals, etc.), the larger the sample, the more reliable the conclusions that can be drawn from it (provided that it is also representative). This fact can be generalized: for a given category (species family, political regimes, personality types, geographical areas, etc.), the more we know about the specific characteristics of each individual within that category, the more reliable the generalizations we can make about the category will be. This observation is reflected in many disciplines, as there have been numerous instances where the discovery of specific phenomena not predicted by a theory has forced scientists to adjust that theory or even create a new one that is more predictive and inclusive. For example, the study of the Pirahã language, some of whose characteristics are completely unique (no recursion, no abstract words for colors, a very limited number of phonemes, etc.), has cast doubt on the validity of the main theses of modern Chomskian linguistics, i.e., the "universal" laws of language. Without the discovery of Pirahã, it might not have been impossible, but it would have been more difficult to advance research in linguistics. The same applies to other fields in science: as long as there are living species on Earth, it remains possible to develop laws and hypotheses about all living things, but it is clear that the singularities of certain forms of life are useful in limiting excessive generalizations and, therefore, overly simplistic scientific theories. Similarly, the more evidence a historian can accumulate about the past, the better able they will be to describe a more contemporary era, while the more knowledge an anthropologist has of specific social facts, the more likely the conclusions he can draw will be valid, as well as independent from ethnocentric biases. The loss of a culture means not only the loss of a potentially interesting subject of study, but also the potential spread of erroneous beliefs about what is truly universal or not (values, customs, aesthetic rules, culinary traditions, etc.). Incidentally, preserving social facts also goes hand in hand with preserving the memory of past mistakes and their causes.

Furthermore, we must not forget that knowledge is a very time-consuming activity. Several millennia ago, the Greeks did not know much about our universe: the Earth was flat or round, it was at the center of the world, there were three continents (Europe, Asia, Africa), the atom was a vague and speculative concept, things had an eternal essence as well as a few transitory characteristics, and the Earth was considered young and static. It took centuries for Copernicus' heliocentric theory, Newton's laws of gravity, Lamarck's theory of evolution, Maxwell's laws of electromagnetism, Darwin's natural selection, the axiomatization of mathematics, Einstein's special and general relativity, plate tectonics, quantum physics, etc. to appear successively. This evolution of knowledge did not come without obstacles (religious superstition, imperfect methodologies, budgetary restrictions, etc.). Moreover, certain theories have been able to progress indirectly thanks to technology, particularly computing, without which some discoveries would not have been possible (for example, the proof of the four-color theorem in mathematics). All this to say that in the event of general amnesia, these theories could very well reappear generations later, but preserving these theories would save our descendants a lot of time. The work of future scientists and philosophers would be greatly facilitated if all our knowledge, even that which relates to things that will still be there in millions of years (stars, planets, particles, bacteria, mathematics, etc.), were safe and sound. We can therefore understand the need to preserve everything that can be preserved, once we realize that future generations could miss out on crucial discoveries because they are not living in the right era or because they are wasting time rediscovering the laws of nature. This will not only be because species or peoples will have become extinct by then, but also because they may not have favorable conditions to pursue the quest for knowledge. For all these reasons, given the tedious nature of research and the temporary nature of the objects of this research, it seems crucial to create a repository of all our knowledge, from the most specific to the most universal, from the most trivial to the most complex, from the most fundamental to the most tertiary, from least to most accepted. This is called epistemic memory.

Knowledge has become the backbone of our civilization

Knowledge can be considered as a heritage, an object of intellectual wealth that must be preserved in the same way as any other type of heritage (natural or cultural). But in our contemporary society, knowledge, or more generally information, can also be considered as "intellectual capital," which is not only of cultural or epistemic importance, but also of economic and pragmatic importance. Indeed, throughout the parallel evolution of scientific discoveries and technical innovations, several unprecedented phenomena have brought humanity into the information age.

Firstly, there has been exponential growth in the knowledge accumulated by scholars from all walks of life and all disciplines The number of graduates, research organizations, and scientific publications has therefore exploded, especially in the second half of the 20th century and the first half of the 21st century. This phenomenon of knowledge growth has been accompanied by another equally exponential growth, that of information storage banks: libraries multiplied, Electronic and then digital media (magnetic tapes, microfilms, vinyl records, CDs, computer servers, etc.) quickly took over, while the amount of information increased at the same rate. But it is not only the number of storage media that has exploded; the individual storage capacity of all these media has also improved at an ever-increasing rate. Inventions such as printing or rotary presses had already announced this phenomenon before the 20th century, leading to the birth of mass media. But it was mainly during the 1960s and 1970s that the invention of the transistor brought about a series of major innovations that would change everything: information and communication technologies (ICT). These technologies include microcomputers, inter-computer communication protocols (TCP/IP), digital sensors (CCD, etc.), modern computer languages (UNIX, HTML, etc.), compact discs (CDs and derivatives, DVDs, CD-ROMs, etc.), operating systems, the Internet (including search engines, browsers, social networks, streaming, etc.), mobile phones (including smartphones), and the foundations of modern telecommunications (Wi-Fi, ADSL, fiber optics, satellite, etc.). These advances have not only made it possible to overcome the limitations in terms of storage capacity of traditional information media (written and analog documentation, previously stored in libraries and specialized archives), but also to facilitate the dissemination and processing of information stored around the world: the creation of a large interconnected global network of satellites, servers, and computers (the very definition of the Internet) has made access to scientific literature, journalistic publications, and all kinds of information useful for everyday life (weather, news, schedules, administrative services, etc.) widespread. Beyond the impact this has had on the world of research (it has suddenly become easier to publish or find existing scientific publications) and on everyday life (our lives are now based on information: blogs, videos, chats, office automation, messages, news, skills, forms, encyclopedias, etc.), ICT has had a major impact on the very structural foundations of our society. Increased access to information has given rise to new social challenges: misinformation during election campaigns, dependence on social media, demand for skilled personnel in companies, automation of tasks through artificial intelligence, more appropriate energy management through smart grids, new inequalities in terms of intellectual capital due to the digital divide, the launch of alerts, the popularization of science, the increased importance of critical thinking, software or telecommunication in companies.

Knowledge has, of course, always played an indirect role in society, facilitating innovation and therefore practical life. But until the dawn of the information age, knowledge was primarily an end in itself, serving a purely epistemic function: to satisfy our intellectual curiosity and our need for fulfillment. In fact, this remains its primary mission. Knowledge was only used sporadically, most often in politics, navigation, agronomy, medicine, and crafts. Now, knowledge is a resource like any other, a fuel for society, businesses, states, institutions, and all forms of human organization. Our society is now based on knowledge, information, and data, to such an extent that there are fields of study devoted solely to information issues in the business world, notably knowledge management. This covers the quality of knowledge (from raw data to skills, including information and knowledge proper), strategies for moving from one form of knowledge to another (tacit and explicit knowledge), knowledge sharing and transfer (learning, databases, research, software, etc.), management (collaboration, motivation, senior management, etc.), and knowledge engineering (methods of collection, structuring, exploitation, quality control, etc.). We use formulations such as the “information society,” the “knowledge society,” or even the “information age” to describe the unprecedented importance that knowledge has taken on in our contemporary world. It should be noted that we are referring here to knowledge and information in the broadest sense (raw data is already economically valuable, even when it has not yet been processed to become usable information.).

Preservation is a crucial step in knowledge management

Given that knowledge is now essential to the functioning of our contemporary societies, preserving it is no longer just a matter of safeguarding our heritage, but also of ensuring the survival of civilization. The preservation of knowledge is no longer just an epistemic issue, helping future generations to improve their understanding of reality, but also a social issue, helping future generations to create an ever more prosperous society. This prosperity is only possible if we make sure that no mishap leads to the sudden and irreversible deletion of massive amount of information. Knowledge management just so happens to be a field of study which addresses (among other things) the issue of knowledge storage. In our modern economic systems, preservation is closely linked to knowledge sharing, insofar as the choice of methods for sharing information is important in safeguarding it.: learning, for example, makes it possible to maintain skills (a specific form of knowledge: know how) within an organization, notably when a member leaves. In fact, knowledge management within an organization can be considered a form of preservation, in that capitalized knowledge “survives” the various changes that may arise within the organization. This unspoken culture of preservation is also reflected in terms such as “intellectual capital” and “economic heritage,” which blur the line between epistemic and financial worlds. Our contemporary organizational methods could thus pave the way for even more ambitious memory projects.

Similarly, despite their seemingly volatile nature, dissemination tools also indirectly constitute methods of capitalizing on and preserving knowledge: a social network, for example, allows a message to be stored indefinitely on a computer server somewhere on the other side of the world, and if that message is shared and saved by network users, it is very difficult to delete permanently. This is one of the paradoxes of the Internet: any piece of information can get lost in the crowd, making it difficult to access, just as if it just disappeared. But since the duplication of information is commonplace on the Internet, deleting it is not exactly child's play either. Of course, preservation issues are not only related to transmission, but also to storage methods and the longevity of the storage tools themselves. However, this is a less central issue in knowledge management, even though it is fundamental: the quality of the information medium obviously determines our ability to preserve that information. Moreover, our information world is far too dependent on technologies with a very limited lifespan. Electronic media can function for a few decades at best, and different digital formats can become obsolete in just a few years, rendering much information unreadable, even though it paradoxically still exists. Implementing the preservation of knowledge, implying the creation of a true epistemic memory, also means seeking solutions to obsolescence and setting up backup information media.

I.2) SEVERAL THREATS LOOM OVER OUR KNOWLEDGE

Our knowledge is vulnerable to natural hazards

Knowledge is, as we have seen, not only a heritage, but also a resource for our contemporary civilizations. All kinds of obstacles have existed and still exist that can hinder the advancement of knowledge, such as dogmatism, misinformation, cognitive biases, or even the concept of common sense. These thought processes have mainly hindered the development of science, but once knowledge is "established," or even simply formulated, its long-term preservation is not entirely guaranteed. Risks related to human behavior are still present, and by extension, risks related to politics or risks related to the very functioning of society. These risks can take various forms, such as conflicts, industrial disasters, censorship, looting, neglect of heritage, etc. Above all these dangers looms also the risk of the unintentional destruction of our body of knowledge, whether sudden (natural or technological disasters, etc.) or gradual (wear and tear, corrosion, obsolescence etc.). In summary, there are all kinds of risks that may be reasons to start preparing a proper epistemic memory now. Those risks can be classified into three main categories: natural risks, political risks, and industrial risks, which we will discuss in that order.

Firstly, it should be remembered that knowledge can be preserved by being "crystallized" in physical media, whether tangible evidence or the publications we mentioned earlier. Except, of course, that these media are vulnerable to the ravages of time and the effects of entropy. Mechanical wear, corrosion, demagnetization, and many natural phenomena can render all our electronic media irreversibly inoperable over time. Paper can be degraded by moisture, exposure to light, fungi, and other biological species. Ink can sometimes fade even before the paper degrades. Even stone can suffer the effects of entropy through erosion, although the oldest written records ever found by archaeologists are most often made of granite, marble, or clay. Gold, which is reputed to be stainless, does indeed suffer the effects of corrosion, but only at a much slower rate than other metals. Ultimately, therefore, copying is the only guarantee of long-term preservation of knowledge. Negligence cannot be an option if we want to preserve our knowledge for as long as possible, particularly if it is non-reproducible. Many archives have already disappeared simply due to a lack of resources or interest in preservation, whether it be lost films, obsolete software, or abandoned libraries.

But worse still, our knowledge is not only threatened by entropy, it is also threatened by other phenomena that are much more sudden, albeit rarer. Fires, earthquakes, floods, volcanic eruptions, tsunamis, hurricanes, tornadoes—all these disasters can destroy entire cities and historic buildings in a matter of moments, and of course, they can wipe out our most precious places of memory: libraries, museums, laboratories, archives, and other heritage institution. In the worst-case scenario, and although this is more unlikely, certain totally unpredictable disasters could even have less localized effects and lead to the total loss of our civilization (super volcano eruption, particularly virulent pandemic, asteroid strike, etc.). If our knowledge of Greek literature is so fragmented today, it is because much of what the Greeks wrote did not survive the multiple fires that occurred in libraries, notably those of Pergamon and Alexandria, renowned for having attempted to centralize as much knowledge as possible at that time. Of course, other human causes have sometimes contributed to such disasters (war, arson, looting, etc.), but fire is a capricious element that quickly escapes human control, and many library fires, even if they did not have a completely natural origin, often spread without any control of those who started them. The key point to remember is that phenomena of this kind, whether fully natural or not, are very often accidental and therefore unpredictable. For example, no one could have imagined a few years ago that Notre Dame Cathedral in Paris would catch fire. Further back in time, no one could have predicted the catastrophic flooding of the Arno River in Florence (1966), which resulted in the loss of several thousand, if not millions, of ancient and unique books. This latter event even led to improvement in risk prevention in libraries, museums, and other archives. The fact that a disaster can strike at almost any time should alert us to the vulnerability of our knowledge.

If less than 1% of the writings of the ancient Greeks have survived to this day, it is not unreasonable to think that in a few millennia, our descendants may only have access to 1% of written materials produced by our modern industrial civilization. We might as well ensure that this 1% is as representative as possible of our knowledge, and ensure that the remaining 99% consists only of duplicates or reproducible knowledge whose loss is not irreversible. Our archives would benefit from existing in multiple copies, storing the same information on a variety of media, and being distributed evenly across the planet (or beyond?), if possible, in locations that are less likely to be affected by natural disasters (far from dry and hot climates, away from seismic faults, coasts, flood zones, and traditional storm paths). As for architectural heritage, which is immovable and difficult to duplicate, it can be "preserved" in a way by storing a very precise description of the sites, accompanied by representations of the monuments that are as accurate as possible (3D models, photographs, maps, etc.). Many monuments now exist only in this way, through the testimonies of their contemporaries, fortunately allowing for a form of preservation, even if incomplete: the Colossus of Rhodes was destroyed by an earthquake, but knowledge of this monument has nevertheless come down to us thanks to the writings of the Ancients, who considered it a world wonder, and numerous attempts at reconstruction have been made as a result.

Knowledge can be silenced by those in power

It is not only nature that could conspire against our knowledge; we must also not underestimate the fact that man is a wolf to man, that he can put obstacles in his own way when he has the opportunity. Dogmatism, the biggest adversary of rational knowledge, is an important factor in the evolution of science, since it can not only lead to censorship and therefore oblivion, but also nip new knowledge in the bud. The scientific community has sometimes slipped through the net, but this has not always been possible. If this dogmatism is supported by political power, research can be considerably hampered (budget restrictions, personnel layoffs, misinformation, etc.), while certain well-established knowledge (or at least promising hypotheses) can be rendered inaccessible overnight. For a government in power, there are several more or less radical methods for eradicating knowledge:

The first method is exclusive appropriation by an elite. For example, a political power may prevent the dissemination of knowledge to a fairly wide audience, make access to scientific publications very expensive, or simply refuse to invest in education. In this type of situation, some people may have access to all kinds of knowledge, including sometimes taboo knowledge, but only a handful of people. Some areas of knowledge thus become more difficult to advance or challenge, due to a lack of people to study them, which can lead to stagnation. There are a few rare legitimate situations where knowledge cannot be easily accessed, such as anything related to sensitive technologies (nuclear, defense, space, etc.) or people's private lives (medical confidentiality, personal digital data, etc.). And even then, these are situations in which there is relatively little risk of the knowledge in question disappearing in the blink of an eye due to the resources invested. Because this is the heart of the problem when it comes to appropriation: the risk of knowledge disappearing is all the greater when access to it is limited. All over history, the reasons for concealing knowledge can often be considered questionable: preventing the poorest from learning crucial social facts to prevent rebellious activity, silencing political opposition, or promotion of an official religion or official pseudo-science. For example, consider the situation of black people in the southern United States (before the 1960s) or in South Africa (before the 1990s), who were denied access to certain libraries museums reserved for a Caucasian elite. The level of education was also much lower among part of the American and South African populations, while the scientific community in these countries deprived itself of an important human resource.

The second method is censorship. This is a step more dangerous than the first, because in the case of selective appropriation by an elite, knowledge is still there and can theoretically still be made accessible again after a major social change. But with censorship, on the contrary, the specter of irreversible loss of knowledge looms large. Censorship is not only about preventing the slightest contradiction, debate, or argument; it is also a form of destruction of existing knowledge. In the best-case scenario, when a work is censored, the original work is stored away in an archive that is closed to the public (which brings us back to the first method). In the worst-case scenario, a censored work can only exist in its altered form, and it will no longer be possible to reconstruct the original work. For instance, there is archaeological evidence that Egyptian pharaohs sometimes ordered the destruction of certain engravings in bas-reliefs recounting the exploits of their -rival- predecessors, in order to replace them with their own propaganda. Whether the censored work is artistic, scientific, or other, censorship can cause an irreversible loss of information for future generations, and even when the original work still exists, it may only exist in a small number of copies, which significantly reduces its potential longevity.

The third method, even more violent than the second, is outright suppression. It is no longer a question of making information inaccessible or partial, but of destroying it entirely, along with everything that could be valuable and unique about it. These include autodafés, large-scale deliberate burning of texts by those in power, with the aim of “protecting” a population from ideas perceived as dangerous. One can think of the Spanish conquistadors in the 16th century, who ordered the destruction of all Mesoamerican writings (Mayan, Aztec, etc.) so that the Bible would become all the more indispensable to Native Americans, who had become subjects of the Spanish crown and converted to Catholicism. As a result, only four Aztec codices have survived to this day, giving us only a very limited glimpse of the extent of this civilization's ideas; society and technique. One can naturally also think of the fascist regimes of the 20th century, which ordered to burn books whenever they were written by Jews, pacifists, or socialists (whether proven or not). Of course, equivalent phenomenon can also exist in other media, including digital media.

The motivations behind these attacks on knowledge are very varied. Of course, the most common reason is often a conflict between new scientific discoveries on the one hand and the dominant ideology on the other: the Church's condemnation of Galileo's works (heliocentrism versus geocentrism), the Soviet Union's ban on natural selection during the Stalinist period (“bourgeois” sciences versus “proletarian” sciences), rejection of the idea of global warming (climatology versus climate skepticism), restrictions on sociology in authoritarian regimes, etc. Added to this are other motivations such as budgetary restrictions, dependence on industrial espionage, or even indifference or contempt on the part of public authorities towards certain sciences. Not to mention cases where the destruction of our heritage is not even intentional, but simply the result of collateral destruction caused by war between several belligerents (bombing, looting, fires, etc.).

Authoritarian drifts are more likely than ever

Until recently, Western civilization experienced a period of relative calm since the end of World War II: all Western countries were democracies, there has been few wars in 80 years, armed revolutions were extremely rare, and ruling political parties would change constantly over the years. However, we should not believe that individual freedoms, including everyone's right to access knowledge and culture, are guaranteed simply because our Western democratic regimes are stable and relatively respectful of human rights. Indeed, phenomena that could lead to a rise in authoritarianism in otherwise stable democracies are always possible in the relatively short term: a proliferation of crises, polarization of political life, isolationism, nationalism, demagoguery, an increasingly blurred separation of powers (i.e., executive, legislative, judicial, and even media), the spread of fake news, monopolies of the mainstream media, vertical hierarchy of political parties, warmongering, dissemination of conspiracy theories and pseudo-scientific theories (alternative medicine, flat Earth, creationism, climate skepticism, etc.). This combination of factors is entirely capable of transforming democratic regimes into authoritarian ones, and doing so quickly enough for those in power to endanger the scientific community and established knowledge, but slowly enough for the general public not to immediately perceive the danger and even to become accustomed to the situation. There are numerous historical examples of transitions from democracy to authoritarian rule (or transitions from intermediate regimes with democratic potential to authoritarian rule) (contemporary Hungary, post-Soviet Russia, the Weimar Republic, the Second French Republic, etc.), and such phenomena could become more common in the future if sufficient precautions are not taken now (independence of the supreme court or equivalent institutions, protection of whistleblowers, diversification of information sources, education in critical thinking, duty to remember, guarantees of free elections, more regular referendums, and participation of the people in major political decisions, etc.) Protecting our knowledge from censorship and large-scale destruction is one of the most important reasons in protecting democracy, as for other reasons (oppression, murder, corruption, obstruction to culture, conformism, etc.) And epistemic memory is the best guarantee of the survival of our knowledge in the event of failure.

Of course, we have discussed the case of Western democracies, since this book was written in one of them, but many countries on Earth are already authoritarian regimes, sometimes even totalitarian (North Korea, China) or theocratic (Iran, Saudi Arabia), where censorship is omnipresent and where science only progresses in areas where the benefits for the nation are obvious (nuclear physics, computer science, surgery, AI, chemistry, etc.). For example, the Chinese government practices heavy censorship, to the extent that no alternative thinking that contradicts the official state ideology (market socialism) is possible, nor, more broadly, any alternative view of the country and its government. Thus, during the 2020 coronavirus epidemic, the Chinese government initially decided to silence scientists who were beginning to warn of the risk of an epidemic. The practice of sociology and political philosophy is obviously complicated, as their conclusions can sometimes clash with the ideas of the Chinese regime. Chinese internet users are unable to search for all possible and imaginable information on the events of Tiananmen in 1989 or on the situation of the Uyghurs and Tibetans in the 21st century. Similarly, in theocracies such as Iran, even though it is not an official ideology but a religion that dominates political life, censorship works in the same way, and scientists and philosophers face the same difficulties in thinking about the world in peace, without offending Koranic precepts that are perceived as immutable (for example, positions such as natural selection or the natural and non-pathological nature of homosexuality are difficult to defend in the face of religious dogmas that are sacred and therefore, by definition, impossible to question). As we can see, authoritarianism can hinder the development of knowledge, but it does so even more when it is accompanied by a single way of thinking: political agenda (extremism and fundamentalism), sacred texts (the Bible, the Vedas, the Koran, etc.), official ideology (communism, nationalism, capitalism, fascism, etc.), or even pseudo-scientific theories endorsed by the state. In the latter case, one might think of Nazi Germany, where history, genetics, and linguistics were stripped of their scientific elements and used to fuel and justify the Nazis' nationalist and revisionist theories: human race theory, the superiority of Germanic peoples, the need for living space, etc.

To all this must be added another major political risk, which is correlated with that of authoritarianism: conflict. Authoritarianism has the disadvantage of leading to instability, both internal and external. Internal because in authoritarian regimes, there is always a significant risk of coups and violent revolutions, especially if the ruling power is incompetent and fails to win the favor of an elite (economic, military, or religious) that is essential to the stability of the country. Externally, because authoritarian regimes are more bellicose than democratic regimes and tend to favor national priorities, even if it means jeopardizing international treaties and appropriating their neighbors' resources. The risk of war, whether internal or external, can obviously further contribute to the irreversible loss of knowledge through the more or less unintentional destruction of heritage during military campaigns or looting, in addition to causing the flight or death of intellectuals who could have contributed to scientific research. There is no shortage of examples of wars throughout history that have resulted in the destruction of heritage that could have advanced fields such as archaeology or ethnology (the Vietnam War, the Iraq War, the Syrian Civil War, the Chinese Civil War, etc.).In extreme cases, countries can shoot themselves in the foot by committing genocide, annihilating a large proportion of their intellectuals (the Cambodian genocide for instance was specifically directed at the most educated at the time).

Given the many threats posed by authoritarian regimes to science, it is clear that we do not need to wait for the end of the world for our knowledge to be seriously threatened. Even if our civilization survives for several centuries, despite a lot of existential threats, there is no guarantee that our descendants will continue to have access to everything we know today if unscrupulous political powers come to power in the meantime. During the 2010s and 2020s, many whistleblowers have noted that threats of authoritarian abuses are multiplying in democratic or hybrid regimes around the world. As a result, we are already seeing the scientific community coming under increasing attack in the media and on social networks (while fake news spreads), massive disinvestment in certain promising fields of science (medicine, climatology, gender studies, etc.), and that political leaders increasingly have the means to "cancel" scientific research, sometimes in favor of new dogmas (conspiracy theories, ultra-nationalism, pseudo-therapies, etc.). Added to this is the prospect of a Third World War, which has never been more relevant than in the 21st century, with the proliferation of conflicts (Ukraine, Gaza, Yemen, Sudan, etc.) and tensions between rival powers (China, the United States, Russia, the European Union, India, Pakistan, Israel, Iran, etc.). The need to create backups for our knowledge (and by extension, the creations and ideas of our contemporary civilization) thus becomes more and more pressing as the global political climate deteriorates. It is no longer simply a matter of protecting our heritage from occasional disasters.

Preserving knowledge also means preserving the mistakes of the past

As we have seen, our knowledge can be a source of considerable power, particularly when it is exclusively reserved for the most powerful people in the world, just as it can be perceived, rightly or wrongly, as a spanner in the works of the well-oiled machinery of power. Certain types of knowledge can challenge the established order when they relate to the functioning of an economy, a society, or even nature. It often happens that a policy has undesirable or unforeseen effects for those who implemented it, sometimes even when warnings were issued by well-trained specialists. Knowledge also often contradicts certain narratives staunchly defended by those in power, whether they be national narratives, founding stories, myths, or legends. If these beliefs are sacred or official, they are difficult to knock off their pedestal, and the scientific community has often paid the price in the past.

But the great mistakes of human history are not just epistemic errors or conflicts between rationality and ideology. History is also full of moments when humanity has committed the worst possible tragedies, regardless of the ideologies in place. These tragedies take various forms: wars, genocides, species extinctions, climate change, torture, exploitation, and slavery, among others. These events tend to occur regularly all over the globe, and while they are often motivated by ignorance or ideology, the core problem is not so much that these events were committed in the name of some form of irrationality, but rather that the consequences of these events have been traumatic for humans. These events are so traumatic that knowledge of these events is considered crucial to prevent the world from repeating the same tragedies over and over again. This importance given to specific knowledge of the great mistakes of human history is what we call the duty to remember. If properly observed, this duty makes it possible to anticipate a potential new atrocity and thus prevent it from happening. However, such events often do not suit those who are responsible for them, and constitute considerable challenges in official narratives: national histories punctuated by mass murders in the country concerned, economic growth driven by the exploitation of workers and the environment, massacres perpetrated in the name of one or more deities. For this reason, this duty to remember is as much a necessity as it is a danger: there are many institutions that want to prevent certain important knowledge from being disseminated. The Soviet Union went to great lengths to hide the existence of the great famines of the 1930s (Holodomor) from the world, multinational corporations rely on lobbies to muffle their abuses, while accusations of blasphemy and the concept of holy war are used to counter those who denounce atrocities committed in the name of religion.

Certain powers therefore have every interest in suppressing the memory of certain major historical events. Moreover, the duty to remember does not only involve disseminating knowledge about tragic events, but also disseminating explanatory theories that enable us to identify their root causes, whether it be climate models for predicting climate change or the theory of the banality of evil for modeling the rise of totalitarianism. The world of research in general can therefore also be put at risk. Certain types of knowledge are therefore valuable for the development of humanity, and not only because they are useful or because they constitute a heritage in themselves. The entire body of scientific knowledge, complemented by philosophy, is probably an indirect remedy for some of the great atrocities committed by civilizations, and forgetting it could have dire consequences. Epistemic memory is therefore also a means of helping humanity move forward.

A civilizational collapse would mean the end of our science

We first focused on the natural risks (disasters, the passage of time, etc.) that threaten the body of established knowledge, before emphasizing the political risks that could lead to the same outcome. However, there is a separate category of risks that also deserve our attention: industrial risks, i.e., risks that threaten the integrity of our contemporary industrial civilizations. These risks not only have the potential to lead to the end of industrial civilization, but also, indirectly, to the global destruction of the intellectual heritage accumulated to date. Of course, civilization does not need to disappear completely for our heritage to be in danger. We have clearly identified that natural and political risks alone are already sufficiently worrying to justify the need for an epistemic memory. Except that, on the one hand, these natural and political risks have been multiplying in recent decades due to multiple factors that influence the decline of our civilizations (global warming, resource scarcity, technological runaway, demographic crisis, the race for weapons of mass destruction, etc.). And above all, on the other hand, the collapse of modern society is not a risk to be taken lightly, given that many civilizations have already disappeared abruptly in the past.

Much of the knowledge of the ancient Greeks was already destroyed by the Roman conquests and then the Christianization of the Roman Empire. Few examples of Mesoamerican texts remain following the Spanish conquests. But we could also have mentioned the Indus civilization, the society of Easter Island, the Nazca's, Great Zimbabwe, Mesopotamia, ancient Egypt, etc. Not to mention the many nations that did not disappear, but saw radically different periods follow one another, sometimes interspersed with phenomena of massive de-urbanization (Burma, Cambodia, the Mayan Peninsula, etc.). During these phases of decline, the knowledge acquired by these civilizations fades with time, due to the lack of archival maintenance and the disappearance of skilled labor, which was responsible for keeping knowledge alive. All that remains are the few selected media that have been copied thousands of times over generations (think of the copyist monks who preserved part of ancient literature) or some "indestructible" media (bas-reliefs, steles, epitaphs, etc.), which are veritable time capsules of these dead civilizations.

The circumstances surrounding decline are often poorly understood and/or complex, which should remind us that the disappearance of our own modern society is completely unpredictable. There is no need to detail all the possible scenarios for collapse, but we can dwell a little on those that are specific to our contemporary society. The latter is indeed an industrial civilization, a feature unprecedented in history, which also entails risks unprecedented. While natural hazards (droughts, earthquakes, volcanic eruptions, etc.) and geopolitical events (conquests, ethnic cleansing, colonization, looting, etc.) have been the main drivers of the rise and fall of civilizations until now, our civilization is now facing new challenges due to the proliferation of industries, massive urbanization, and increasingly powerful technologies (artificial intelligence, air transport, agricultural machinery, etc.), with all that this implies in terms of energy and material consumption, particle emissions, urban sprawl, and radioactivity. Since these risks are recent, it is difficult to quantify with a high degree of accuracy when our civilization will come to an end. And even if our civilization survives the challenges it faces, it is also impossible to predict what the negative consequences of this survival will be. This makes it all the more urgent to create a backup for our knowledge.

Of course, the collapse of our contemporary society would have disastrous consequences for human beings as a species. Not even mentioning possible extinction, the resulting death and suffering would be incalculable. But the epistemic and cultural consequences are also very worrying: most of our knowledge is stored in information media that cannot be read without specific tools (films, computer memory, discs, etc.) and that have a limited lifespan if the conditions for preservation are no longer met (temperature, humidity, isolation from the outside world, fire protection measures, etc.). In the event of industrial collapse, it is clear that the direct and indirect effects of this collapse will destroy a large part of our heritage if nothing is done to prevent that from happening. This also means that future generations will have to start all over again and relearn everything rediscover everything. Worse still, we established much earlier that the loss of certain knowledge would be irreversible, particularly that linked to archaeological evidence, to extinct life forms or non-reproducible works. The knowledge of future generations, particularly that relating to the history of Earth and humankind, could thus be much more limited. If we add to this the fact that our civilization will already have exploited a large part of the most accessible energy and mineral resources, the emergence of a potential second industrial civilization after ours would be all the more unlikely, and it would then be more difficult for our descendants to once again reach the level of technological development necessary for certain scientific discoveries (space probes, computer simulations, particle colliders, radars, etc.). With the loss of important archives on extinct species, past civilizations, previous celestial observations, climate and meteorological measurements, and languages and customs recorded on Earth, future generations will have much more difficulties to rediscover certain ideas with profound implications, to re-achieve great medical feats, and to definitively emerge from the age of superstition and obscurantism. It would be a shame if we were the only ones to benefit from the knowledge we might have created, given that we are just a tiny fraction of humanity, living in a very special and limited period of prosperity.

There are varied factors contributing to collapse

While it is difficult to predict the exact circumstances under which our civilization could disappear, we are still able to identify certain threats to it. These threats, most of which result from industrialization, are as follows:

First over-exploitation of resources: productivism is the main driving force behind industrial civilization to this day. The more industrialized a society is, the more resources it consumes, whatever their nature. These resources are also increasingly varied: they include not only resources that are vital to human beings (water and food), but also energy resources (oil, gas, coal, uranium, etc.) and raw materials (metals, salt, sand, chalk, building stone, etc.), whose importance has grown considerably over the last three centuries, even though they are not, in absolute terms, necessary for individual survival. The problem is that most of the resources we consume today are fossil fuels, which means they exist in limited quantities on Earth, while our consumption continues to grow due to economic development in emerging countries on one side, and economic growth policies in already rich countries on the other side. All this combined with the development of domestic markets, advertising and, more simply, the current economic model, which is based more on the continuous accumulation of wealth than on the production of what is strictly necessary. Therefore, the possibility that we will run out of exploitable resources is becoming increasingly serious, especially since alternatives are not always possible depending on the situation: while renewable energies could replace fossil fuels (albeit with a very significant investment upstream of energy production peaks), there are not always alternatives for metallurgical resources, for example (How can concrete be produced without sand? How can electrical conductors be made without metals? How can heat be made without coal or wood? etc.). Sometimes, even renewable resources are threatened if production is too high in relation to the rate at which these resources are renewed: this is the case for forests or fishery resources for instance, both are theoretically renewable but in practice are also threatened). In addition, the unequal distribution of resources across the planet could be a source of new conflicts (hydraulic dams at river sources, oil-producing countries arousing nation's envy, deforestation threatening indigenous societies, etc.). Our civilization could very well be the first and last to have ever achieved such a high level of technology using cheap but scarce resources.

*The other major existential risk facing our industrial society is, of course, global warming. For several decades, the scientific community has observed that average temperatures are rising worldwide due to the accumulation of greenhouse gases (particularly CO2 and methane). There are many sources of these gases (heavy industry, electricity production, transportation, construction materials, deforestation, intensive livestock farming, etc.), and the extent of the current warming will depend considerably on the responses taken to counter (or not) greenhouse gas emissions: energy efficiency, frugal lifestyles, technological innovations, economic sovereignty, degrowth, etc. The extent of global warming will also depend on certain natural feedback loops (such as the melting of Arctic permafrost), which can add additional gases to the atmosphere. The fact remains that, for the moment, the global average temperature has risen by +1.5°C in just 150 years, a rate never before seen in the planet's climate history, and warming of around +4°C is expected if nothing is done within just a century. Therefore, given the slow response from governments, the general public, and multinational corporations, the scientific community is naturally concerned about the many consequences of global warming that await us in the future. The increase in global average temperature will lead to an increase in the frequency of droughts and even desertification (therefore, indirectly, a sharp decline in agricultural production, leading to more and more famines), an increase in the number or intensity of natural disasters (and therefore increasingly high repair costs for all countries), a rise in sea levels (thereby reducing habitable areas, causing recurrent flooding, and much more expensive costal infrastructure), as well as an acceleration in the decline of biodiversity (with all the unpredictable effects that this could have on our agriculture or on pandemic spread). The combination of all these phenomena will result in massive human displacement (climate refugees), chronic instability (hunger riots are a precursor to this), forced economic decline (more and more costly infrastructure), a more expensive life (certain resources will be scarcer), demographic decline (more famines and more epidemics), and unprecedented conflicts over control of the remaining habitable land. In some regions, the onset of "humid heat" waves could even render them inhospitable to humans. Global warming is therefore an existential threat to our industrial civilization, in addition to having the potential to lead to the extinction of many species and cultures.

*The rise of high technology can be seen both a miracle and a curse, depending on how it is used. We do not wish to condemn innovation in general, and even less so Science as a whole (especially since applied sciences are not representative of science in general), but it is clear that certain technological developments are significant causes for concern. Examples include, but are not limited to, nuclear weapons (with the risk of nuclear war and the resulting nuclear winter), artificial intelligence (due to the unpredictability of such intelligence, even if unconscious, and the potential global computer failure it would cause), chemical synthesis (excessive and overly concentrated doses of certain chemicals—pesticides, fertilizers, cosmetics, etc.—can have an impact on human health, fertility, and even the ozone layer), bacteriology (with the associated risk of a particularly destructive pandemic if a virus created by humans—or by AI—escapes from a laboratory), and many other threats that cannot be cited here. As technological innovations have made society increasingly complex, the evolution of industrial society has become much more difficult to anticipate, and it is increasingly likely that technology will turn against us if we do not regulate it quickly.

Whatever phenomenon or phenomena might trigger the collapse of civilization, it is clear that this will be accompanied by numerous collateral effects (wars, rise of authoritarian regimes, natural disasters, etc.) which alone will have the capacity to destroy the masterpiece of our civilization: our knowledge.

I.3) THE GOALS OF A GREAT EPISTEMIC MEMORY

Epistemic memory can save civilization

Let's recap: knowledge can relate to fragile, ephemeral, vulnerable things that can disappear at any moment, never to return. Without improving the preservation of knowledge, we will definitely no longer be able to recreate it if it were erased, whether intentionally or not. Furthermore, knowledge has become an indispensable virtual resource for our industrialized world, which is fed by ICT. We increasingly need the help of knowledge to improve our standard of living in our society, with the additional consequences of greater prosperity, better education, better management, etc. At the same time, however, numerous phenomena threaten the integrity of this knowledge: entropy, natural disasters, wars, censorship, and even the simple collapse of our industrial civilization. Its days are numbered, with the proliferation of factors contributing to its decline: authoritarian tendencies, warmongering, global warming, resource scarcity, technological disruption, etc. For our knowledge to survive a potential civilization collapse, an action plan must be put in place to ensure the preservation of information on a large scale and over the very long term. This is what we will refer to here as an epistemic memory, a backup of all our knowledge, created with the aim of preventing collective amnesia among future generations in the event of a catastrophe. As has been said, future generations will not be able to rediscover everything we have discovered to date in terms of history, biology, archaeology, ethnology, and other fields if all or part of the world's heritage institutions were to disappear, unless all these discoveries survive in a “black box”, an emergency Library of Alexandria, that is well shielded from destruction. One could even add that if a distant civilization developed its own science, part of it could be redundant with ours, and that civilization would then waste time trying to solve certain problems, while our current civilization has already done the work and our efforts are directly accessible in our information banks. In other words, the contribution of our civilization and that of our predecessors (Greco-Romans, Indians, Chinese, etc.) to our understanding of the world around us could become completely null and void if our knowledge were to be erased forever. All of this leads to the conclusion that epistemic memory is also an advanced memory of our own civilization, in addition to being a memory of our knowledge.

In fact, there are not only pragmatic issues at stake, although they are good justifications enough for an epistemic memory, but there are also many symbolic issues. Preserving our knowledge is not only about making it available to distant future civilizations, it is also an opportunity to immortalize many aspects of our civilization, much like the pyramids of Giza did for Ancient Egypt. First and foremost, the preservation of knowledge is an indirect means of ensuring the “survival” of our civilization beyond its expiration date. Preserving our knowledge would provide future generations with information about the different cultures of the Earth, through our documentation on our works of art, monuments, traditions, moral values, political systems, languages, lifestyles, social causes, etc. Certain achievements, everything that is dear to us today, could live on if our descendants set about deciphering our knowledge banks. Moreover, in addition to safeguarding what we are most proud of, preserving knowledge would also be a good way to pass on the memory of our biggest mistakes (world wars, genocides, ecological disasters, financial crises, social injustice, economic inequalities, etc.), thus providing feedback on what our civilization has failed to achieve, so that our descendants can succeed better than us in building a brighter future. This duty to remember would continue over time, along with the memory of our civilization's great achievements (wonders of the world, great artists, space exploration, culinary specialties, etc.). If we manage to effectively preserve our knowledge in the midst of civilizational collapse, we could even create a kind of civilizational black box, a means of passing on to our descendants the data they need to analyze the exact causes of the collapse of our own civilization. A potential second industrial civilization would thus become much more sustainable, with access to entire chapters of our history, such as how we managed resources, how we legislated, or how we accepted or rejected certain new discoveries. Moreover, if we are going to pass on knowledge to distant generations, we could also pass it on to the generations that will exist just after the collapse: it might be possible to convey valuable information and know-how so that the dark interval between two industrial "golden ages" is as short as possible. This would include, for example, agronomy, metallurgy, DIY, recycling, pharmacology, etc. Perhaps even post-industrial societies (in the strict sense) could test new political and economic models that are healthier than our current ones, thanks to our science and philosophy, before even attempting a transition to an advanced civilization.

Epistemic memory can save our culture

When we talk about knowledge, it is easy to immediately think of scientific knowledge, particularly that which relates to the so-called "hard" sciences, namely physics, chemistry, biology, earth sciences, and mathematics. It is also easy to imagine that safeguarding knowledge also indirectly involves safeguarding technological and medical expertise, i.e., the applied sciences. However, the goal of epistemic memory is to preserve all knowledge, or at least as much as possible. Although the natural and formal sciences already represent an immense body of knowledge, there are also many branches of science devoted to the study of humankind, society, culture, and history. These form what are known as the humanities and social sciences (HSS), and although there are methodological differences with the natural sciences, these differences exist mainly because humans are difficult to study in the same way as any other object in the universe. Furthermore, the rigorous nature of the HSS is not questioned in the scientific community, and the general functioning of these sciences remains familiar: a cycle of scientific publications with peer review, hypothesis testing, experimental protocols, logical reasoning, etc. Added to this is the fact that, more than in any other science, the social sciences and humanities place great importance on a plurality of scientific approaches and working methods, in order to multiply the avenues for solving a problem. All this is to say that all sciences deserve to be preserved, and not just those considered the most "fundamental" or "essential." In fact, sciences dealing with specific subjects of study (specific periods, specific ethnic groups, specific species, specific systems, etc.) undoubtedly deserve greater attention, as these subjects of study are much more ephemeral, making knowledge more difficult to reproduce once these subjects are no longer there. How would our descendants retrace the history of their own civilization if ours disappeared without a trace?

Furthermore, when we talk about knowledge, we are referring by default to scientific knowledge, but it is important to realize that there are many disciplines in this world that attempt to solve the great mysteries of the cosmos. Admittedly, some of these fall under the category of pseudoscience and produce only "knowledge" of limited epistemic value (astrology, homeopathy, Scientology, ufology, etc.). However, on the one hand, there are many reasons to preserve the attempts from these disciplines nonetheless (they are expressions of our belief systems, they are hypotheses that should be preserved on principle "just in case," they have value for a certain number of people, etc.), and on the other hand, not everything that falls outside the realm of science necessarily lacks rigor. Philosophy is another important part of culture that is dedicated to understanding the world and what it contains, including humans. Philosophy is a discipline that, in addition to science, offers all kinds of avenues for reflection, questions to explore, hypotheses, and theories about how things work. Admittedly, it is difficult to speak of philosophical "knowledge," since knowledge is something that can be proven (or at least substantiated), whereas philosophy mainly produces speculation. But these speculations are complementary from scientific knowledge and, due to their -more or less- rational nature, they still have great value in the foundation of knowledge. The various other forms of wisdom developed throughout the world also deserve to be preserved, insofar as they are unique and can shed interesting light on the world and on humanity.

Consequently, an epistemic memory does not simply serve to preserve all existing scientific publications (articles, journals, conferences, debates, etc.), or even scientific archives (we mentioned earlier fossils, archaeological sites, ancient writings, etc.), but also other non-scientific publications, such as philosophical works, encyclopedias, journalistic media, or any "item" that can constitute a study of something. In fact, since science and philosophy have a cultural side to them, by safeguarding ethnological and anthropological knowledge, an epistemic memory also indirectly safeguards all kinds of aspects of our earthly culture. By saving literature on art history, for example, we could also indirectly save all kinds of masterpieces. By saving analyses of a particular work, we would also save the work itself at the same time. By saving old historical archives, we would also indirectly save all kinds of creations from past periods. By seeking to save all of our science, we can therefore save our entire heritage by extension. So even though scientific knowledge has been at the heart of the discussion so far, the sole purpose of epistemic memory is not to preserve all or part of our scientific literature for entire generations, but also to make our entire culture accessible to our distant descendants, including all philosophical, artistic, cinematic, musical, literary, political, anthropological, sociological, etc. It would be a shame if we were able to pass on our science, but not all the many other creations that make human life much less miserable.

Epistemic memory can immortalize the Universe

Saving knowledge is also a goal in itself, since knowledge could be defined as a form of immortalizing things. Knowledge is, in a way, the power to capture an aspect of the real world, to transform ephemeral existences into virtual eternity. Every tree that has ever been described by a human being has managed to survive beyond its death, by first being converted into a mental object called "knowledge" about that tree, which can only be understood by human beings. Isn't it said that if humanity were to die out, the Universe would lose its best biographer? Moreover, the natural environment is not the only container in the Universe that can escape death through "epistemification": we must not forget that we ourselves, as a species or as a civilization, are also containers of this Universe, particularly ephemeral ones at that, and that by converting ourselves into knowledge, we are able to transcend our own mortality. We individually leave traces of our passage through our epitaphs, our biographies, our testimonies, and our artistic creations. We collectively leave traces of our passage through libraries, museums, archives, monuments, and other repositories of knowledge. Humanity as a whole could therefore leave the ultimate trace of its passage in the Cosmos through an epistemic memory.

An epistemic memory, something that by definition centralizes as much information as possible about the known world, can also be seen as a great triumph of humanity in the face of the universe that surrounds it. Even if we cannot know everything about Reality in its entirety, our species is unique in that it is still capable of virtualizing the world around it into a handful of concepts, ideas, and representations. The simple act of accumulating theory upon theory, school of thought upon school of thought, question upon question, is in itself an enormous and unparalleled achievement, light years ahead of anything else. Being able to centralize this knowledge in a dedicated place would be a way for humanity to duplicate our universe, to recreate a second universe that is certainly imperfect and distinct from its model, but which is nonetheless a very rich and close reflection of it. A reflection whose diversity is matched only by the diversity of what it reflects. By making this place resistant to the passage of time, it would be as if the Cosmos were endowed with a memory of itself, with human beings as its workers. This would result in a sort of miniature universe encoded within itself, at a very specific point in space-time. A whole within the greater whole.

Achieving such a feat would also send a signal to other potential major civilizations that populate the cosmos, whether human or not, terrestrial or not. It is not certain that among the many intelligent civilizations that may populate our world (statistically, this is quite likely, given the estimated number of planets in a galaxy, as well as the estimated number of galaxies in the observable Universe), all succeed in creating such a profusion of knowledge as ours. It is not impossible that many species and civilizations will become extinct before they have had time to create a great memory of the Universe on their part. But if humanity was at least able to create a memory of the richness of our civilization, a comprehensive and lasting memory, before it disappears itself, we may have achieved a rare feat in the cosmos. We would satisfy our anthropocentric pride with the most humanistic of projects. Perhaps this could even be a starting point for new civilizations or even new species that would inherit our knowledge after bumping into traces of our civilization. We would have bequeathed the best possible message to our descendants, to other life forms, and to the universe itself in its entirety. The ultimate message of our civilization is the most complete of all, that is, the biography of the great Whole.

Finally, on an individual level, such a project would also be a way to preserve our small existences, our names, our lives, our achievements, and our mistakes, to throw a bottle into the sea that will survive longer than us but that will appease and reassure us before we die. A bottle that will remind us that, deep down, we were part of something grand, we were part of the great Whole, we were part of the project to make it immortal, and to remind the Universe of our little existence.

Preserving knowledge is less costly than preserving ourselves

Whatever the (many) reasons that might lead us to consider an epistemic memory, it should be remembered that even now, before such a memory has been created, the maintenance of archives, museums, libraries, computer servers, and all other forms of cultural capital does not come at a considerable cost compared to many other aspects of society. Nations spend dozens of billions of dollars on defense, advertising, construction, industrial zones, and gigantic infrastructures, gigantic even in relation to the size of the planet (viaducts, tunnels, skyscrapers, road network etc.) Additional billions are also allocated to scientific research, education, technological development, and medicine. We need an astronomical amount of energy and materials to run our modern society, via thousands of power plants, factories, mines, vehicles, roads, railways, gas pipelines, oil pipelines, electrical cables, etc. And yet, in parallel to this, heritage institutions like archives represent only a tiny fraction of all the buildings constructed by civilization. Computer servers and maintaining the correct temperature for ancient manuscripts require only a fraction of global electricity production, while the rest supply our homes, our industries, our public lights etc. The amount of money needed to maintain museums is significant, but ultimately insignificant compared to what is needed to maintain other parts of our civilization. Even education does not require as many resources as the military or public health to be effective. In terms of human resources, it is also not essential to mobilize a large portion of the available payroll in order to effectively preserve intellectual capital around the globe, even though this capital is immense. Even when we send samples of our knowledge into space, aboard probes or in the form of radio messages, The creation of the message itself is significantly less expensive than the manufacture of other instruments on board a probe, or even less expensive than the construction of powerful radio transmitters. In fact, even in terms of time, sending a message into space requires few resources and therefore does not interfere with the smooth running of the aforementioned space exploration programs.

The negligible cost of a kind of “epistemic black box” is also insignificant compared to the cost of preventing global industrial disasters: energy transition, mass recycling, research and development—all these efforts to combat global warming and the increasing scarcity of resources may well be within the reach of the global economy, but they still represent a considerable expense. We can therefore consider that it is much easier to create a backup of our civilization's knowledge than to save civilization from its downfall, although both are possible. To be clear, though: epistemic memory is not intended to replace the fight against global warming; at most, it’s a Plan B. In any case, it is so insignificantly costly to build an epistemic memory that launching several such projects at the same time would come only with a negligible increase of global expenditure for nations seeking to protect themselves from disasters. In fact, since longevity is an important aspect of the design of an epistemic memory project, with very little ongoing maintenance once the project is set up, this means that the cost of such a project would ultimately be immediately amortized. This logically leads us to the following conclusion: since the objectives of a large knowledge preservation project are very important, both from symbolic (create a buffer memory for our Universe, no less) and pragmatic (create a useful memory of our Science for our descendants) point of views, since we do not need all the money, all the time, all the staff, and all the energy in the world to carry out such a project, and since such a project would not really compete with other major social projects (medical research, education, poverty alleviation, energy transition, space exploration, defense, etc.), what real objection can be made to such a project? The only remaining obstacle, namely the need for technology capable of gathering a huge amount of information, is about to be overcome. Ultimately, despite the ambition to create a new, more sustainable Library of Alexandria, we are fortunate that this ambition is purely intellectual and much less of a financial drain than many other projects (nuclear arsenals, fighter jets, viral marketing campaigns, new cities, expeditions to Mars, etc.), while potentially having a much more lasting impact than the latter. Especially since the failure of such a project is a relative concept: if the project succeeds, the benefits of making knowledge available to our descendants would in any case be enormous: all our science, our ideas, our culture, our history. If the project doesn't get off the ground, then we'll have nothing left to lose, only our descendants could lack knowledge that they would not even suspect existed.

TRANSITION

From the outset, we have discussed at length the needs that drive us to advocate for the long-term preservation of knowledge, but we have described this approach in terms that are ultimately rather vague. We have talked about “epistemic memory,” “modern Library of Alexandria,” “black box,” “project” to safeguard knowledge, etc. We have outlined, without going into detail, the different forms that traditional knowledge preservation centers can take: museums, libraries, archives, computer servers, and electronic media. We have touched on the distinction between knowledge media, a tangible object that can exist independently of the user, and knowledge itself. We focused primarily on the justifications for an epistemic memory project, whether it be the highly valuable nature of our body of knowledge, the potential threats to it and to our culture, or the main objectives of a large epistemic memory. From now on, we will need to be more precise in defining the contours of an epistemic memory: we need to describe how to centralize a body of knowledge, and thus discuss the potential difficulties of such a project, the measures to be implemented to ensure its preservation over a very long period of time, the means to ensure that the potential recipients of this memory will be able to decipher its content, the types of projects that can be implemented, the resources to be mobilized, and so on.

Before getting to the heart of the matter, let us once again ask ourselves the fateful question: what exactly are we talking about when we talk about a major epistemic memory project? Until now, we have used the term “epistemic memory” to describe minds without prejudging what such a project would look like. At best, we can imagine a kind of huge abstract database. Epistemic memory is above all a concept distinct from that of “collective memory” or “cultural memory.” Collective memory refers more to a set of information shared within a group, relating to historical events or a given narrative of the past, as an extension of individual memory. Collective memory is a concept that aims to make crucial information about the history of a given community accessible to as many people as possible, while cultural memory aims above all to preserve items, regardless of their level of vulnerability, which requires constant maintenance, made possible by heritage institutions (libraries, universities, museums, archives, etc.). All of this is therefore mostly a matter of education and heritage conservation. However, when we talk about epistemic memory, what we mean is the very long-term preservation of knowledge, which means limiting access to it in the present as much as possible to maximize the chances that this knowledge will be passed on to our descendants. With epistemic memory, the most important thing is the information itself, not the item that contains the information. And the fact that it is “epistemic” reflects the fact that science remains at the heart of this preservation, even though we have seen that the preservation of knowledge can also lead to the indirect preservation of our philosophical ideas and our culture in the broadest sense. Epistemic memory should be thought of as a “backup” for collective and cultural memory.

The fundamental function of an epistemic memory is to enable its recipients to reconstruct a vast body of knowledge without starting from scratch. In other words; the main objective is protecting this knowledge from potential setbacks to which the education system and heritage institutions may be vulnerable. This epistemic memory project can be compared to another type of project that already has a similar function: time capsules. A time capsule, to put it succinctly, refers to any message intended to be deciphered in the distant future, whether it be a message in a bottle, a space probe, a radio message sent into space, or quite literally a “hidden” capsule that is only to be opened after a very long time. Most time capsules are fairly simple and do not always contain a significant amount of information, but in recent years, a new type of capsule has emerged, containing encyclopedias, copyright-free works, DNA samples. Therefore, these time capsules have increasingly extensive content. Whereas "1.0" time capsules are primarily designed to be traces of those who created them, as a kind of challenge to the apparent eternity of the universe, these new "2.0" capsules aim to preserve scientific and philosophical knowledge, which is reminiscent of the main objective of an epistemic memory. Of course, not all "2.0" time capsules necessarily aim to protect knowledge in its entirety and tend instead to focus solely on knowledge perceived as "essential," particularly the so-called "hard" sciences. Conversely, epistemic memory does not necessarily imply an artistic impulse like that of traditional time capsules, while the time frame envisaged for the preservation of knowledge is not necessarily as long as that of many time capsules: epistemic memory is required to survive a catastrophe that could span several generations, while some time capsules could remain intact for thousands or even millions of years. Nevertheless, there is a convergence between time capsules and epistemic memory: this convergence is the knowledge ark. The knowledge ark is therefore any project that consists of both preserving as much knowledge as possible for future generations (i.e., an epistemic memory) and safeguarding this knowledge for a very long time (i.e., a time capsule, a "3.0" capsule). From now on, when we talk about epistemic memory, we will implicitly be referring mainly to this variant of epistemic memory that constitutes knowledge arches.

From the main function of a knowledge arch, we can deduce three main constraints, which are the three axes around which such a project must be positioned:

***Constraint #1: as much data** as possible must be preserved. We want our science to be preserved for future generations, which means that the scope of preservation must be as broad as possible. We want to save as much knowledge as possible, or even more basic raw data if necessary.

***Constraint #2**: the data must be **accessible**. Beyond exhaustiveness, we must of course ensure that it is relatively easy for our descendants to access our knowledge, so that they are not completely helpless in the face of our preservation methods.

***Constraint #3:** Data must remain **intact for as long as possible**. Preservation means resistance to the passage of time, and therefore a response to all the natural, industrial, or political risks we mentioned earlier that could destroy knowledge. There may also be a balance to be struck with the accessibility of our knowledge, as too much ease of access could compromise it.

Each of these constraints hides all kinds of challenges (centralization, storage capacity, language, transmission, standardization of media, etc.) that we will address.

II.1) CONSTRAINT N°1: COMPLETENESS

Cataloging is the first step in preservation

For any knowledge ark project, the first major challenge is ensuring completeness. If we want to ensure that our knowledge survives for centuries to come, all the information contained in the documents selected for preservation must be complementary, and nothing must be forgotten, either by mistake or deliberate omission. This step already presents its own set of difficulties, since our knowledge is scattered across the globe, in various forms and in a wide variety of locations. Beyond the problem of ensuring that everything can be preserved if our knowledge is not centralized at one specific place, it can be especially difficult to keep track of it, trace all the information, and verify that nothing has disappeared. This difficulty is of course amplified by the considerable diversity as well as the number of items that have been accumulated everywhere (books, articles, sound tracks, films, websites, etc.), sometimes in multiple copies, sometimes even in “fakes.”

Therefore, the first step in preservation is cataloging. The purpose of cataloging is both to index everything that can be indexed, i.e., to identify all items that have something to do with our knowledge, and to sort through them in order to identify the rarest items, i.e., those that are most likely to disappear quickly if nothing is done. Cataloging is therefore an opportunity to classify knowledge by level of vulnerability, thus, identifying what has to be preserved in priority. As a result, all kinds of ancient manuscripts, unique art works, or archaeological remains, for example, can be tagged as “high priority” items with a view to creating rapidly more durable copies, in digital format if necessary. Simply put, the sooner an item of knowledge is identified as rare, the sooner it can be duplicated and preserved for the long term. Cataloging therefore makes it possible to limit blind spots in heritage preservation and ultimately guarantee the existence of sustainable versions of all kinds of items, not based on their supposed or actual “essential” nature, but rather on their uniqueness.

For efficiency, the cataloging of our knowledge must follow the following steps:

*Exploration: we search for all items that could constitute the ark of knowledge and prepare an inventory of the heritage to be preserved. For example, we investigate writers from a given geographical area.

*Identification: we take stock of the evidence proving the existence of a particular item and give it a unique name. In the example, this is the title and identification number of a document written by a given author.

*Location: we identify and track the exact location of the item at all times. In the example, we regularly check that a particular document is still in the library or private collection where it was originally found.

*Indexing: we describe the nature of the item (descriptive cataloging), the nature of its content (subject cataloging), rank it in relation to other items, and classify it. In the example, we determine that the document in question is a book, that it deals with art history, and that it belongs to the category of anthropological essays.

*Authentication: we ensure that the item is genuine and not a forgery. In the example, we certify that the book is an original or an authorized copy.

*Condition: We assess the degree of protection required for the item. In the example, we determine the ideal climatic conditions for preservation based on the type of paper and ink used.

*Metadata creation: multiple data items are associated with each item, including those identified in the previous steps (unique name, location, nature, context, etc.), to facilitate future searches related to the item. In the example, a separate but unique file is created that is inextricably linked to the book to which the file refers, and as much information as possible about the book itself is entered: summary, themes, publication date, author's name, language, etc.

*Duplicate search: we identify whether the item is a variant or a copy of another, if we have already identified it elsewhere. In the example, we try to determine the number of copies produced, whether sold or not.

*Copy: if only a few copies of the item exist, or even just one, a copy is created, either physical or virtual, which must be stored in another location. In the example, a digital copy of the book is created so that the essence of the book will survive if the original book is destroyed.

*Protection: we ensure that at least one of the locations where a copy of the item is stored is well protected from external threats and censorship. In the example, we ensure that the original copy is kept in a heritage institution (public library or other) and that the digital duplicate is stored on an accessible and secure server.

For this last point, we begin to go beyond simple cataloging and enter into the preservation of the item itself. But the priority given to an item in preservation depends considerably on certain information identified during cataloging. If we identify early enough that an item is too fragile, we can plan preservation methods more quickly and, if necessary, take the initiative to create digital copies—such as 3D scans or digitized versions—even before the cataloging process is complete, to ensure that the item’s legacy is not lost. This is particularly true for items that are not written, visual, audio, or audiovisual documents, such as immovable heritage (buildings, fossils, fragments of historical documents, etc.) or intangible heritage (representative arts, crafts, traditions, etc.).

Consequently, the protection of this category of item is obviously a priority. Massive monuments, such as the Great Wall of China or the Pyramids of Giza, original works of art, such as Da Vinci's Mona Lisa or the Venus de Milo, and even cities such as Venice or Teotihuacan, and natural spaces such as the Amazon rainforest or the Arctic ice cap, all constitute heritage that is given priority attention because it cannot be replaced except by simulacra. But these simulacra are more likely to reach our descendants than the items they simulate. In descending order of priority come items of high historical and cultural value (holy books, the American Declaration of Independence, Antoine de Saint-Exupéry's The Little Prince, the Apollo 11 archives, etc.), items representing a very rare type of item (Aztec codices or Inca quipus, for example), or items with a comparative value that is more interesting than other items of the same type in terms of rarity (Fabergé eggs for example), completeness (a complete dinosaur skeleton is more interesting than a single isolated femur from the same species; a complete manuscript is more interesting than scattered fragments), integrity (an item in good condition will be easier to protect than an identical item that is badly damaged), or quality.

It should be noted that the examples of items cited above are more sources of knowledge than knowledge itself, but as we saw earlier, the preservation of science also requires the preservation of everything that can enrich it, including philosophy and the arts, as well as culture in the broadest sense. The cataloging of everything that can be cataloged can also serve other complementary preservation objectives: ensuring that the general public is aware of the existence of a given source of information and has access to it, preparing a bank of quotations and possible sources for future study, helping those seeking specific source through rigorous classification, or facilitating centralization of established knowledge in specific locations.

> *Depending on the preservation strategy, information may or may not need to be centralized*

A secondary objective of a knowledge ark would be to centralize this knowledge. Since the whole point of a large epistemic memory is to store as much knowledge as possible, it is clear that centralization would facilitate this. Historically, many civilizations quickly understood the need to collect as many documents as possible, notably through the first antic libraries, including the famous libraries of Alexandria and Pergamon, which aimed to gather all the knowledge and literature of the Greek world. Or through cabinets of curiosities, private collections, and other proto-archives that may have been assembled by the intellectual elites of yesterday. Nowadays, this centralizing role is mainly held by what are known as heritage institutions, i.e., all kinds of organizations that are most often (but not exclusively) public, whose goal is to preserve as many items as possible. There are several major collection sites, depending on the nature of the preserved items:

*Libraries: these sites primarily collect written documents, books, manuscripts, parchments, and any other conceivable writing medium. Libraries can be public, private, school or academic, and may sometimes include additional archives containing completely different information media (magnetic tapes, discs, photos, etc.).

*Museums: these places tend to collect objects that are not strictly speaking information carriers, but rather objects of scientific, philosophical, historical, and artistic interest, such as: works of art (visual arts, sculptures, ruins, etc.), realia (everyday objects such as textiles, currency, tools, etc.), technologies (vehicles, instruments, etc.) and other artifacts used in scientific research (fossils, stuffed animals, astronomical photographs, prototypes, formaldehyde bottles, chemical samples, seeds, etc.). Museums are most often organized around a particular theme or field of search.

*Archives: these places bring together eclectic media and most often constitute the material memories of specific organizations, such as companies, public institutions, schools, universities, research centers, associations, cultural centers, administrative centers, etc. Although the information stored in archives is usually written, as in libraries, there are also institutions that specialize in preserving specific types of media: sound or music recordings, films and audiovisual items, photographs, digital data, optical media (CDs, DVDs, etc.), magnetic media (magnetic tapes, cassettes, etc.), metals, special papers, etc.

*Data centers: these places specialize in the preservation of digital data, ranging from raw data to more sophisticated information, such as software; computer files, communications or websites, which may themselves constitute multimedia media (videos, articles, music, blog posts, etc.). These facilities are designed to centralize information that can be stored on mass storage media.

It should be noted that the main objective of a heritage institution remains the centralization of the items themselves, since it is these items that must be maintained in good condition, whereas a knowledge ark prioritizes the centralization of information and aims to preserve knowledge, regardless of the physical media, and does not necessarily aim to maintain the physical integrity of the latter, although this is equally desirable.

Of course, much of the heritage cannot be gathered in one place, if only because of the immovable objects we mentioned earlier. More prosaically, it would in any case be very difficult to gather most of the existing artifacts in one place, for obvious reasons of space and logistics. But in any case, if we centralized all of our assets in one place, the risk of a disaster wiping them out would be considerably greater. For safety reasons, it is much more desirable to distribute humanity's heritage across the globe to ensure that at least part of it survives in the long term. On the other hand, centralization is entirely possible, and even desirable, when it comes to storing items that can be easily duplicated or digitized. We may not be able to make copies of every painting in every museum, but we can take high-quality photographs of them, accompanied by metadata (title, date, location, medium, texture, etc.). In other words, while it may be futile to create a global museum, it is entirely feasible to create a global library. This global "library" may only contain copies or digital copies, or even consist solely of a digital library. Thus, the destruction of such a library would not pose a problem as long as other traditional forms of archives remained intact. Furthermore, a digital library, even a global one, would be easier to duplicate in multiple copies across the planet, which would greatly increase the chances of survival of the stored information, while ensuring that as many different regions around the globe as possible have access to this information. Another function of centralization is also to simplify access to our entire heritage as much as possible, while facilitating research: if an item is missing from library A but present in another library B, while another item is missing from A but present in B, this obviously complicates the parallel study of these two items and their possible interconnection. A heritage that is too scattered is an obstacle to comparative research. The advantage of effective centralization of information is, beyond facilitating its preservation, ensuring every possible source of information produced by humanity is identified and available, mapping our knowledge, and, more generally, facilitating the organization of this information.

Moreover, a network of "global libraries" would perfectly complement existing decentralized networks; that is: they would not replace existing libraries. We could even assign different missions to each of them: traditional libraries would mainly aim to preserve items as items (manuscripts, books, films, parchments, etc.), as vulnerable objects of value, while global libraries would aim more to preserve knowledge itself. In traditional libraries, every effort is made to protect priceless and sometimes irreplaceable physical objects: this is direct preservation. In this case, decentralization is the best strategy for promoting the survival of items over time. In a global library, every effort is made to store as much information as possible, and protecting this information involves converting it into a medium that is optimal in terms of both wear resistance and storage capacity: this is indirect preservation. In this case, centralization is the best strategy for ensuring the survival of information. The traditional library exists to ensure that copies of Gutenberg's Bible will always exist in the future, while the global library will exist to ensure that the contents of such a Bible will always be available, and that we know that it existed in such and such forms in the past. Once again, these two systems complement each other. Both networks share the same goal of preserving our cultural heritage and can both constitute variants of a large epistemic memory. One of these networks would simply be decentralized to ensure the preservation of material heritage, while the other would be completely centralized to ensure the completeness of the heritage content to be preserved. In addition, there are also "items" that do not exist in material form, namely intangible heritage: know-how, practices, customs, oral histories, languages, etc. These "items" cannot be preserved in the traditional way, and only indirect preservation is possible. These cases are therefore even more suitable for centralization in a global memory than material heritage.

Pre-existing organizations would facilitate the creation of a knowledge ark

To sum up, in order to catalog, classify, and centralize knowledge, there are already many institutions, whether private, public, or other. Most of these organizations are local, meaning they are capable of managing information found in a given city, region or country. One difficulty in centralizing knowledge may also lie in the multiplicity of national organizations, which may want to retain exclusive rights to preserve certain items that are of importance in the countries concerned. However, there are international organizations with the capacity to carry out ambitious indexing and preservation programs on a global scale. One example is UNESCO, which has already carried out several (decentralized) cultural memory projects. Among the most notable are: the creation of a network of geoparks (to preserve important nature reserves and thus the world's natural heritage), the UNESCO collection of representative works (to translate each country's most emblematic works into multiple languages), the creation of World Heritage lists, both tangible (particularly for monuments, historic centers, museums, and archaeological sites) and intangible (particularly archives, oral traditions, and specific cultural practices), the creation of a World Digital Library, and the "Memory of the World" project, which is a kind of global archive.

These last two projects in particular focus on the preservation of a few representative works, but would undoubtedly constitute a very good foundation for a knowledge ark project, provided that these projects are extended to include the preservation of a much wider variety and greater number of items. An "expanded memory of the world" could thus help us to preserve knowledge and intellectual heritage, rather than limiting ourselves exclusively to the preservation of a restricted selection of works based on national criteria. That said, in the context of an international project supported by several different countries, it would probably be much easier to obtain the necessary funds than with separate initiatives. It would also be easier to establish a global treaty to reform the scientific publishing circuit or even to ensure that different copyright jurisdictions authorize the copying of a work if it is dedicated exclusively to the long-term preservation of knowledge. Such a project would be much more difficult to implement if it came from a specific private or national organization than if it were initiated by an UN-related agency such as UNESCO. Nevertheless, UNESCO is undoubtedly the organization that currently has the most power to initiate a truly ambitious knowledge ark project, while more modest private and non-governmental initiatives are multiplying around the world (Arch Mission Foundation, Long Now Foundation, Memory of Mankind, Internet Archive, etc.) and that the first steps toward "universal library" projects are beginning to take shape: these include, to name just a few, the Wikimedia Foundation; the European Library; Project Gutenberg; the "Global Memory Net"; the "Digital Public Library of America"; and the "Chinese Text Project.". This means that the world is probably ready for a fully-fledged knowledge ark.

A knowledge ark must strike the right balance in terms of completeness

Another important aspect of epistemic memory is the amount of information that needs to be stored. Until now, we have more or less assumed that in order to ensure the preservation of as much of our knowledge as possible, we need to be as exhaustive as possible: preserving as many items as possible, creating copies, even “virtual” ones, anything with even the slightest scientific or cultural potential, however tenuous. Admittedly, centralizing all our heritage is very difficult if we stuck to preserving physical media (books, films, tapes, artifacts, etc.), but the creation of a kind of global library was less problematic if it consisted of a digital information bank. However, even in this case, there are obvious practical limitations to the creation of an exhaustive collection of information. But above all, even if we manage to overcome all these obstacles and create a magnificent universal library capable of standing the test of time, how can we ensure that our descendants will be able to navigate the vast ocean of information thus accumulated? In other words, shouldn't we select the information we want to preserve? There are three possible answers to this question, each of which outlines three broad approaches to what a knowledge ark should be:

*The solution of raw, exhaustive storage: epistemic memory revolves around accumulating as much information as possible, without distinguishing between different types of information. The major drawback of such an approach, as has been noted, is the complexity of the research required for anyone seeking to navigate such a mountain of information. The slightest search for information would be like looking for a needle in a haystack, and our descendants might have a very hard time rebuilding a new foundation of knowledge. It would also be more difficult to distinguish between truth and falsehood if every single idea expressed by anyone were preserved the same way. But—and this is precisely where the great advantage of a non-selective epistemic memory lies—by ensuring that every single idea is preserved, we also increase the likelihood that good ideas that have been unfortunately overlooked will endure. Above all, we avoid much of the ideological bias that can arise during a selection process: if all hypotheses and all philosophical positions are preserved—even the most flawed ones—this reduces the risk that our descendants will be manipulated by the information they might encounter. It should also be reminded that we cannot necessarily realize at a given moment everything that may have a significant impact later on. Many works of art or scientific discoveries that are considered important today sometimes went unnoticed in their time, even falling into total oblivion, and it is therefore not extravagant to imagine that current archives possess items gone unnoticed, that will be identified as important in the future. In the specific case of scientific publications, the term “drawers’ effect” refers to the tendency to overlook or set aside scientific articles with inconclusive findings, even though these articles are, paradoxically, crucial for assessing the current state of knowledge on a given subject. The rule of absolute exhaustiveness therefore has the merit of eliminating a great deal of selection bias, and for our descendants, this would result in a fairly representative picture of our civilization and our science.

*The solution of non-exhaustive selection: epistemic memory revolves around giving priority to information considered “relevant” for preservation. The main advantage of a selective information library is that it makes it easier for future generations to analyze this information. The advantage of a limited amount of information, apart from the fact that it requires less energy from our descendants, is that it offers them a concise overview of our knowledge. This solution also has the advantage of being more feasible with current technologies, pending the emergence of new information medium with significantly more advanced storage. Among the most relevant information that could be stored in a selective archive, priority should be given to preserving the most comprehensive sources (encyclopedias, dictionaries, atlases, etc.), the most significant sources in historical and cultural terms (memories of important events, artistic masterpieces, the most popular works, historical legal treaties and documents, etc.), the most scientifically rigorous sources (serious scientific publications and meta-studies), the most representative sources for each existing media category, and the most representative sources for each era and geographical area on Earth. While these criteria do not eliminate bias, they do allow for a synthesis of our heritage, which can already serve as a fairly rich foundation for future generations. Another possible criterion for selection is to prioritize the preservation of anything that is vulnerable or rare, because, let us remember, certain items (fossils, ancient manuscripts, archaeological sites, endangered species, languages, customs…) will be irretrievably lost once destroyed, whereas theoretically our more general knowledge (mathematics, physics, astronomy…) might not disappear irreversibly if lost. A good ark of knowledge would not necessarily be an ark of our most essential knowledge, but, counterintuitively, an ark of our most specific knowledge—that is, also the most ephemeral.

*The solution of comprehensive yet hierarchical storage: epistemic memory is based on accumulating as much information as possible, but this information is organized hierarchically in relation to one another. This approach represents a compromise between the two previous solutions, since it retains the advantage of "forgetting nothing" while also making what is "more important" more accessible. In this way, our most valuable knowledge would be more accessible to our descendants than our more "unfinished" information. It would still be like crossing a vast mountain range for them, but the range would be crisscrossed by a network of marked and mapped trails. In concrete terms, this could mean the following: we could easily envisage a global archive in which the most important information is stored on medium A (easy to access, easy to decode, and not too detailed, like clay tablets), which would serve as a kind of "introduction" to our civilization. Then, deeper within this archive, we could find medium B, containing a much larger amount of information, on a more difficult to access media (like optical discs), and more of an encyclopedic nature. Then medium C even further in, containing even more information, and so on. Thus, if each of these repositories were to contain audiovisual archives, Repository A would contain a selection of photographs, Repository B would contain a collection of thousands of films and documentaries as well as thousands of historical video documents, and Repository C would be the equivalent of a universal audiovisual archive containing as many documents as possible (including forgotten films, reports, clips, advertisements, TV shows) and their associated metadata. Ultimately, the greatest challenge of such an archive would be to determine the appropriate level of detail for the information and to decide which types of information to prioritize. If there were to be a "Chapter 1" for a knowledge repository, then this chapter could include, for example, an index, a guide to interpreting our materials, "Rosetta Stone"-style glossaries, and so on.

All of these approaches to knowledge arks are schools of thought that complement one another perfectly. The diversity of these projects would provide a better guarantee that at least one of them will survive in the very long term.

There are many relevant criteria for selecting intellectual heritage

In the case of a knowledge ark project that involves selecting or prioritizing information, the list of criteria used for these operations will be a crucial decision. Indeed, the major difficulty with selection, apart from the risk of relegating crucial information to the background, is that it also provides a potentially biased view of our civilization to future generations. This question arose, for example, at NASA when creating the Voyager Golden Record in 1977, a disc containing a selection of images, music, and words in several languages. For example, the decision was made not to show "negative" images (scenes of war, tragic historical events, etc.) of the human race, and therefore to include photographs of planets, cities, scenes of everyday life, vehicles, and works of art, among other things. This approach may raise questions because it does not paint a fully representative picture of our industrial civilization, which accomplishments were matched only by its atrocities. One could even add that preserving knowledge of these atrocities could be useful for future generations, who would benefit from being aware of the risks they face if they rediscover a particular technology (nuclear energy, greenhouse gas-emitting machines, information technology, organic chemistry, etc.) or if they adopt combination of policies similar to those that may have led to tragic events in the past. Thus, among the knowledge that would fall under the category of history, tragic events would probably be among the priority knowledge in the selection process.

When it comes to scientific knowledge, it might be tempting to prioritize the most groundbreaking scientific articles (for example, those on quantum physics, natural selection, the theory of general relativity, Gödel's incompleteness theorem, etc.). However, as noted, some publications did not have an immediate impact upon their release, which implies that the selection of scientific works should not be overly restrictive, so as not to allow major forgotten articles to slip through the cracks of preservation efforts. Furthermore, there are many fields that are still poorly understood by scientists, or that cannot really be approached through a scientific method (metaphysics, ethics, ideologies, aesthetics, etc.), even though they are major areas of human thought that offer a wealth of avenues for reflection on the meaning of existence, the origin of the world, good and evil, the pursuit of happiness, beauty, and many other more or less universal existential questions. In other words, even if it means preserving scientific knowledge that does not all have the same degree of reliability, it would be worthwhile to also seek to preserve more philosophical or speculative works, whose insights can complement those of the sciences.

In addition, there is also a very specific category of works that could be given special attention: encyclopedias. An encyclopedia is a literary work consisting of a multitude of articles covering as many topics, concepts, or people as possible. Each article does not provide exhaustive knowledge on the subject it covers, but despite its concise nature, it can contain most of the key information about the subject covered (definitions, main characteristics, classification, relationships, etc.) and has the advantage of being much more accessible to the general public than a scientific publication or philosophical essay. Therefore, if an encyclopedia is successful, it can provide an excellent summary of all our knowledge, whether they are ideas, questions, established facts, or doctrines. As there are several encyclopedias, sometimes with different editorial philosophies (encyclopedias by experts such as Encyclopedia Britannica, encyclopedias based on the collective knowledge of the general public such as Wikipedia, encyclopedias specializing in a specific field such as the Stanford Encyclopedia of Philosophy, etc.), the risk of errors within an article can be offset by the existence of multiple alternative articles on the same subject. While encyclopedias do not in themselves constitute an exhaustive epistemic memory, they provide a sufficiently comprehensive overview of our knowledge, especially when accompanied by other reference works such as atlases, maps, dictionaries, data tables, and graphs. In short, where an exhaustive epistemic memory would be an important source of information for idiographic studies, a selective and encyclopedic epistemic memory would be a useful source of information for nomothetic studies.

Finally, when it comes to cultural heritage in the broadest sense, both intangible and tangible, immovable and movable, there are again many possible selection criteria. We have already mentioned a few of them: rarity, state of preservation, replicability, representativeness of a specific category of items, among other things. In the case of works of art, we can also consider masterpieces, i.e., works of art considered to be key pieces in their field (genre, period, culture, artistic movement, author, style, etc.). Of course, we encounter the same problem as with scientific publications, namely that the historical importance of a work can vary over time, and therefore selecting works can cause potentially major works to fall into oblivion. The problem is further exacerbated by the fact that the aesthetic criteria used to define a "masterpiece" are much more arbitrary than those used to define the scientific rigor of an article. We can at least limit the problem by seeking to create a selection in which as many artistic movements, genres, nationalities, eras, etc. as possible are represented. The same applies to heritage that does not strictly speaking fall within the realm of the arts: any documentation of lifestyles, techniques, trades, customs, languages, and many other aspects of culture must not leave out any people, any era, or any social milieu. Incidentally, we should not neglect the preservation of anything that might be considered non-artistic, since, on the one hand, art is only one part of culture and, on the other hand, art is a concept with rather vague boundaries that have fluctuated throughout time: certain activities considered artistic at one time were no longer so at another, or became so again later. The fact remains that, even if selective, an ark of knowledge is all the more relevant when it spans a wide variety of diverse fields. It is also conceivable to bring together a multitude of thematic repositories (artistic, philosophical, scientific, historical, etc.)—or even local ones (regional, ethnic, and/or national)—to form such an ark.

Technical solutions enable us to store as much knowledge as possible

Whether we decide to store a selective amount of information or not, the quantity will likely be enormous. Therefore, we will need to find a suitable technological solution, i.e., an information medium with maximum storage capacity. Before the industrial era, storage methods were very limited: any material that could be written on would do (leather, bark, turtle shells, stone, clay tablets, etc.). The most widely used medium was, of course, paper, due to its practicality (it is light and thin, which limits bulk) and its relative ease of duplication, especially after the invention of printing. In fact, the development of science is closely correlated with the advent of this latest innovation. However, despite its advantages, paper, and by extension books, are not insignificant in terms of volume, and the accumulation of paper has imposed a major constraint: the need to construct buildings dedicated to the storage and preservation of books, whose size and number have had to increase tenfold over time. In the mid-20th century, some estimates at the time indicated that the size of libraries would have to double every 16 years if we wanted to continue to store all the books and other writings produced in the world. Even then, it was clear that miniaturization of information media would be necessary to avoid libraries around the world from being overwhelmed by books. Microfilm and microform photographs were the first avenues explored for concentrating the information contained in a book into a smaller, less cumbersome medium. But the digital revolution provided a temporary solution to the problem with the advent of computer memory, whose storage capacities were far superior to those of previous media. Furthermore, the pace of innovation in computing is able to keep up with the growth of information. While computer processing power has doubled every two years since the mid-20th century (Moore's Law), storage capacity has doubled at the same rate, due to the miniaturization of transistors and their proliferation within a single computer. Storage capacity therefore follows another law, Kryder's Law, which is very similar to Moore's Law, i.e., it increases exponentially over time. As a result, the amount of information produced on Earth in 2023 was 120 zettabytes, or a thousand billion of billion bytes, which is equivalent to a stack of books 16,200 billion km long (for comparison, a light-year is equivalent to a distance of 9,461 billion km). It is clear that all the libraries on Earth would be incapable of storing such a mass of information. However, this volume remains so high that it still requires thousands of data centers (themselves containing thousands of servers) to store all the information available on the planet. Furthermore, these data centers are used for a wide range of tasks (social media, communications, stock exchanges, AI, etc.) and consume vast amounts of energy, which thus represents the new upper limit to the centralization of information. Consequently, even today, the creation of a comprehensive epistemic memory does not seem feasible with existing technical solutions, and any "ark of knowledge" project is doomed to be selective or decentralized—that is, to consist of multiple storage media scattered across the globe.

That said, technological progress continues, and there is still hope that the miniaturization of computer components will become so advanced that it will reach the molecular level. There are two particularly promising ways to achieve dramatic progress in miniaturization: nanotechnology on the one hand, and storage on artificial DNA strands on the other. As with traditional media, information is stored in the form of computer bits, which can take the value "1" or "0," and these "1"s and "0"s were linked to electronic components that had a given size. But with nanotechnology and DNA, these "1"s and "0"s could now be the size of a molecule or even an atom. To give you an idea, a DNA molecule has a diameter of 2 nm (1 nm = 0.000000001 m) and each basic "piece" of the molecule (nucleotide) is 0.33 nm long. If we take the 16,200 billion km long stack of books and assume that each nucleotide pair can hold 2 bits (0.25 bytes), we would need a molecule 43,000 km long (more than 10% of the distance between the Earth and the Moon). This distance may still seem very large, but each human chromosome has 220 million nucleotide pairs spread over a length of 7 cm, and humans have 24 chromosomes per cell. In theory, we could store all the information produced on Earth in 2024 in strands of DNA contained in a volume smaller than a human body. DNA storage technology is still in its infancy, and there are still a few technical obstacles preventing its widespread use for everyday activities (notably slow write and read speeds), but teams of researchers are now able to store the entire contents of the English Wikipedia (2 gigabytes) in strands of DNA, which is already sufficient to envisage the existence of a new category of data center, with a very small volume, and whose purpose would not be to replace existing data centers in order to keep the Internet running, but rather to create a sort of "black box" of the Internet at a given point in time—a back box that would not be accessed and that would updated regularly. In other words, DNA storage would be a satisfactory solution for digital archiving purposes. By deciding to store only the content of existing encyclopedias (not just Wikipedia), we could already create a gigantic epistemic memory by using a ridiculously small amount of space, without requiring considerable energy and investment upstream. Every library, archive, museum, or other institution could easily create its own black box by using a medium that would fit in the palm of one's hand. If we were to combine all the DNA archives from every cultural heritage institution, we would end up with a kind of universal library—not particularly large, but exceptionally rich in information—which would be a good starting point for comprehensive "ark of knowledge" project, even a decentralized one. It is worth noting that since 2024, there has already been a "lunar library" aboard the Lunar Odyssey probe, containing about twenty books and 10,000 images encoded in strands of DNA, as well as other information stored on various media—a project spearheaded by the Arch Mission Foundation.

An "Ark of Knowledge" project would have technological benefits

In addition to DNA-based technologies and nanotechnologies, other mass data storage solutions are currently under development. This is the case, for example, with 5D optical discs, whose very existence is based on the promise of exceptional longevity—an important criterion for an archive of knowledge, a topic we will revisit later. Other technologies include holographic storage, as well as the use of advanced materials (PCM, glass, or ceramics) on which micro-engravings are made. Some knowledge ark projects, in fact, utilize some of these emerging technologies, such as the "Rosetta" project by The Long Now Foundation or the high-profile example of the 5D optical disc containing a copy of Asimov's

Foundation series, aboard a car launched into space in 2018. Many of these technologies are still in the early stages of development, and the market for new storage technologies is still quite small at the time of writing. DNA appears to be the most promising technology, given that numerous companies are interested and that the total amount of investment (R&D, startups, sequencing, equipment, etc.) ranges from tens to hundreds of millions of dollars. A drop in the bucket compared to other technologies such as AI, nuclear power, or space exploration, but also a sum far greater than what the few research centers are investing in 5D optical discs.

The fact remains that data storage is a major challenge for today's society: let us not forget that our industrial civilization now depends on information and knowledge. The physical limitations imposed by data centers (space requirements, energy consumption, maintenance, etc.), combined with the exponential growth of digital data, will create an increasingly significant burden in the years to come. Consequently, it is inevitable that the industry will take an interest in all of this, which may also mean that investors face little risk in supporting projects with high symbolic value that will serve as the standard-bearers for these innovations. A "knowledge ark" would serve as both an opportunity to test these new technologies in a "spectacular" way while paving the way for other, more concrete applications: improvements in data centers and cloud computing, innovations in photonics, optics, and biotechnology, as well as applications in the space sector, defense, and more. In other words, a "knowledge ark" would serve both to highlight these new technologies and to demonstrate their feasibility prior to their potential widespread adoption, all at a relatively affordable cost. Finally, archiving could likely be one of the first use cases for new information storage technologies, for the simple reason that one of the main current limitations of these technologies is their write speed—and especially their read speed—which do not yet match that of traditional digital media. Since certain archives are not necessarily intended for regular consultation (to facilitate preservation, in particular), the "slowness" of these new technologies would not constitute a major drawback for this use. Knowledge archives could very well become the vanguard of 5D, holographic, nanometric, or genetic optical media before these technologies mature, while the fact that applications are already possible could help fund research and development in these fields.

Our knowledge is spread across too many different media

New information storage technologies offer a golden opportunity to build a massive, more or less centralized repository of knowledge. But another advantage of these media lies in the fact that the maintenance required to preserve them is minimal. One of the greatest challenges in preserving cultural heritage today is that not only is the quantity of items to be preserved considerable, but also that these items come in a wide variety of forms, which in turn requires equally varied preservation conditions (temperature, security, light exposure, contamination, etc.). New storage technologies would provide an opportunity to establish a new kind of archive, requiring little or no human intervention and minimal protection against external threats, all while utilizing a "universal" medium tailored for any type of information: text, audio, audiovisual, digital files, 3D models, photographs… A single standardized medium could therefore be used for a knowledge repository, eliminating the drawbacks of preservation using current methods. Today, the wide variety of information media also implies a wide variety of institutions dedicated to their preservation, while the indexing of preserved items constitutes a major challenge in itself. This variety can manifest itself at several levels:

*Fundamental level: heritage items, i.e., the things we seek to preserve. There are two types: duplicable items and non-duplicable items. The latter category includes, on the one hand, physical objects that cannot be reproduced or replaced if destroyed, such as architectural heritage (monuments, villages, cities, major structures, etc.), archaeological heritage (archaeological or paleontological sites and their contents: ruins, fossils, time capsules, traces, etc.) and natural heritage (landscapes, living species, interesting geological formations, and even planets and stars). This is also known as “immovable” heritage. On the other hand, there is heritage that can be described as intangible, which includes all traditions and social phenomena that do not involve a material medium per se (at most, an ephemeral physical signal): the performing arts (theater, dance, rituals, etc.), oral traditions (stories, legends, founding myths, languages, etc.), culinary traditions, music, and many other social phenomena (trades, sports, leisure activities, behaviors, values, beliefs, etc.), or even natural phenomena that have been identified. It is understandable that for this category of non-duplicable items, long-term preservation is difficult, as the items in question are bulky, intangible, or unique. This is where we see the value of a knowledge repository dedicated to preserving information rather than directly preserving heritage: all non-duplicable items become virtually duplicable, while also becoming reproducible in the process, in the form of 3D models, photographs, video footage, computer simulations, audio recordings, and so on.

*Secondary level: heritage objects. Among all tangible and reproducible items, there are two main categories: information media and information sources. The first category includes everything used by humans to “write,” to convert information (images, text, sound, etc.) into something that can last for a certain amount of time: photography for images, books for text, sound recordings for sound, etc. In some cases, these media are part of artistic heritage: paintings, sculptures, musical scores, films, etc. They therefore straddle the line between objects that can be duplicated (reproducible in absolute terms) and those that cannot be duplicated (unique and inestimable). Some objects are not designed to contain information, but can still be preserved because they are interesting artifacts in more ways than one. These objects are known as realia: currency, tools, inventions, herbariums, clocks, vehicles, pottery, furniture, chemical or culinary substances, seeds, clothing, and many other objects. Here, the long-term preservation of objects is not limited by non-reproducibility, but rather by the fragility of these objects, which can vary considerably depending on their nature, as well as by the wide variety of methods that must be implemented to restore these objects. As for copying, this is limited by the risk that the recreated object will not be completely identical to its model.

*Tertiary level: information. Information can be classified according to the type of medium (book, disc, film, etc.), but it can also be classified according to the content of the information itself (scientific, artistic, philosophical, religious, political, mundane, etc.) or even according to the form of the information (image, volume, movement, text, speech, music, etc.). Beyond the information medium itself, which can be preserved over the long term, there is the information itself. The challenge of an approach to preservation based on information rather than the object is therefore to safeguard an intellectual element, independently of the medium. The philosophy behind such an approach is to preserve knowledge itself, and more broadly data, ideas, words, etc., to accept the fleeting nature of most of the tools we use today to keep track of everything we do. Furthermore, there are elements of heritage that are only of interest in the form of information: notably literature (it is not the books themselves but the writings that are appreciated for their artistic or intellectual value) and digital arts (3D animation, website design, video games, etc.). Here, the limitation of copying lies primarily in the quality of the stored information, especially when it is copied numerous times and passed from source to source.

This brings us back to the challenge of cataloging and centralization, for which strategies vary according to these three levels. If what we seek to preserve above all else are items, the smallest elements of our universe or our civilization that have been examined by our species, then we must be able to "virtualize" all items that cannot be reproduced identically in the future, converting them into information. If it is objects in particular that interest us, then preservation must be adapted to each type of object and medium, and our epistemic memory suddenly takes on a very protean appearance, making it impossible to standardize preservation methods. If it is information that interests us, then, on the contrary, our epistemic memory will be able to use media that are as standardized as possible in order to facilitate preservation (using preservation methods that will not become technically obsolete) and take into account the nature of the information itself (both content and form). These forms of preservation are complementary: information-oriented preservation may reach its limits if the information to be preserved is copied a large number of times without "remastering," hence the value of combining the preservation of information with the preservation of the physical items containing that information. Conversely, item-oriented preservation has the drawback that, in the event of an item's loss, that loss is irreversible unless the item has been virtually reproduced. Knowledge archives and other "universal" libraries will therefore always need to coexist alongside traditional heritage institutions.

Digitization makes it possible to create a massive repository of knowledge

The fact remains that for today's heritage institutions, fully preserving whatever can be preserved remains an immense challenge, given the vast diversity of media we have just reviewed: it requires mobilizing different skills, different methods, and different facilities; it requires adapting to the materials used; it requires maintaining the ability to decode certain types of items (turntables for vinyl records, computers for websites), not to mention the ability to decipher all kinds of languages and writing systems. Furthermore, in the very long term, this diversity of media may pose a serious obstacle for our descendants (assuming our media are still available in the distant future). The Knowledge Ark therefore aims to circumvent this problem through digitization, using a standardized format.

Digitization consists of "converting" the content of any physical medium into a "virtual" version of it: for example, we can obtain a digital photograph from a printed photograph, create a 3D model of an object that has been scanned, convert the content of a book into text files or web pages, etc. The practice of digital archiving serves several purposes. On the one hand, it allows us to create a "backup" of each item of heritage that has been digitized, thus preserving the object in a certain way even after its destruction. On the other hand, it also facilitates the preservation of intangible heritage as well as immovable heritage, as mentioned earlier. We cannot protect a cathedral or a ritual dance, but we can at least easily preserve an archive of them. Before the advent of computers, this was only possible in a very fragmented way. We could make engravings or photographs of monuments, we could write descriptive accounts of the traditions observed in a particular culture, we could make models or artistic representations. However, on the one hand, all these methods are very varied (So we're back to the problem of the tedious task of preserving such a wide variety of media), and on the other hand, they did not necessarily allow for a very faithful transcription of the items they represented. A photograph does not always allow us to know the layout of a building down to the last brick; it may be blurry, have poor resolution, or be in black and white, and a photograph can usually only preserve information in visible light, not in other areas of the electromagnetic spectrum. Similarly, a detailed report may overlook certain details, contain subjective comments, and be less valuable than a recording, for example using a digital camera. When it comes to preservation of more “invisible” things (systems of values, definitions, meanings, beliefs, etc.), the difficulty will always be the same, whether digital or not. But thanks to digital technology, we can at least store much more data, so we can afford to be much more precise and rigorous, without any technical limitations forcing us to be concise. What's more, by being able to store radically different types of information (visual, textual, audiovisual, audio, etc.) on the same medium and in the same format, we can create a centralized information repository in a single location. Our descendants will still need to decipher digital information, but they won't need to grapple with a multitude of different technologies to do so.

As a result, with all the advantages of digital storage, mass digitization projects have multiplied in recent years (Google Books, Project Gutenberg, etc.): databases and servers are now dedicated to preserving millions of books, millions of pieces of music, hundreds of thousands of films, and many other iconographic and audiovisual archives. Initiatives such as Google Street View enable us to preserve the memory of many geographical locations on Earth (streets, building exteriors, landscapes, etc.), and thus part of our immovable heritage. We are also beginning to create “virtual museums,” where we can find digitized content from traditional museums, and there are a growing number of initiatives to scan as many artifacts, archaeological finds, and more or less ephemeral objects as possible. There are even digitization projects focused on preserving minority cultures, or sometimes even those in danger of disappearing, projects such as “Gi-gikinomaage-min” for Native Americans or “SAADA” for Asian Americans, with all the challenges that this entails in terms of adequately cataloging everything that can represent a culture (speeches, ideas, folklore, living histories, lifestyles, etc.). In short, digitization has led to the emergence of a “mass memory” that is much more comprehensive than any other more traditional form of memory, facilitating the preservation of the cultural heritage of many civilizations, as well as the preservation of all cumulated knowledge across the world.

The main obstacle to completeness remains a legal one

To address the issue of centralizing all our knowledge, there remains a major problem we have not yet discussed: copyright. While certain encyclopedias like Wikipedia and certain elements of our cultural heritage (particularly the oldest ones) are not affected, most scientific and non-scientific works are subject to copyright. In practical terms, this means that the works in question cannot be copied, shared, or distributed. While this is not necessarily a problem for selective knowledge repositories—those whose philosophy is to preserve a synthesis of our knowledge rather than comprehensiveness—for repositories aiming to be more complete, it becomes an obstacle for various reasons:

*In the case of a “knowledge ark” project that takes the form of a private collection, the patron establishing such a project would, at best, need to seek permission from the rights holders to keep a copy of each work in their collection, and at worst, would have to pay to obtain that copy. Since the goal here is to preserve as many works as possible, this can quickly cause the investment required to create this “ark of knowledge” to skyrocket. It should be noted that once the copies have been obtained, they can be digitized without issue; they simply cannot be shared and distributed to the general public. However, since this is not the objective of a knowledge ark, it does not really constitute a drawback in and of itself. Nevertheless, a collection that is both private and exhaustive seems hardly viable, and a patron who sets out to collect as many copies of works as possible would quickly find themselves forced to scale back their ambition and settle for assembling a selection of works. This brings us back to the issue of choosing a selection criterion, discussed earlier

*In the case of a “knowledge ark” project that would take the form of a private archive, the situation would be much the same as in the previous example: the archive would necessarily have to pay to obtain copies of copyrighted works. It should also be noted that a legal entity (company, association, NGO, etc.) has a different legal status than cultural heritage institutions and individuals, notably the inability to reproduce and digitize copyrighted works. Here again, for an archive project initiated by a private company, achieving comprehensiveness may prove impossible.

*In the case of a knowledge ark project that would qualify as a heritage institution, the rules regarding copyright are very different. In fact, in most countries, the law requires that copyrighted works be deposited with the national library or another equivalent institution, depending on the nature of the work. This means that libraries, museums, public archives, and other such institutions do not necessarily have to pay for all the items they collect. Furthermore, heritage institutions enjoy “privileges” such as the right to reproduce and digitize materials, provided that these actions are justified by preservation. At first glance, a legally recognized library that would transform into a “universal” library collecting all the world’s knowledge would suddenly seem more realistic. However, there are still two major obstacles. The first is that copyright jurisdiction is not entirely the same from one country to another. This means, in particular, that for a heritage institution, it is sometimes theoretically possible to collect virtually all the works from the country in which it is located at little to no cost, but this is not always the case, and, more importantly, it implies that for works from other countries, authorizations and payments are still required. The second obstacle is that heritage institutions are obligated to do everything in their power to preserve the works in their possession, which, paradoxically, can create a number of constraints for the creation of a universal library. In particular, a heritage institution is required to store its collection in an accessible location and must be able to retrieve its contents at any time. And this applies equally to original items and to copies—whether digital or not. But as a result, this accessibility constraint means that an “ark” project initiated by a heritage institution cannot be sent into space, nor can it be buried underground for a very long period, which is, however, entirely feasible for a private initiative. In summary, an ultimate national library is conceivable, but it would not be universal and would not have much leeway regarding very long-term preservation methods.

For all these reasons, most of the knowledge archiving projects that have emerged in recent years (Lunar Library, Memory of Mankind, Knowledge Vault, etc.) do not yet aspire to become “ultimate” libraries, and are content to centralize books, encyclopedia articles, and royalty-free images, possibly supplemented by a handful of paid works, for lack of a better option. For a comprehensive knowledge ark project to be feasible, there are three possible solutions. The first is to slightly modify copyright law to create a special status for “knowledge arks,” which would still impose obligations on them (authorization from rights holders, guarantees regarding preservation, prohibition on distribution…) but also greater privileges than heritage institutions, such as an expanded right to digital copying or the ability to make preserved works accessible only to distant future generations. A knowledge archive would thus have the right to create digital copies of any work, without mandatory payment, and the right to make these digital copies irrecoverable, provided that this applies only to digital copies, and not to physical copies or even directly to the original items. Another possible strategy to circumvent the copyright issue would be for rights holders worldwide to no longer be required to send a copy of their works only to the cultural heritage institutions of the country in question, but to also send them to a kind of international body tasked with cataloging the world’s intellectual and cultural heritage (perhaps overseen by UNESCO, for example). Since it would be physically impossible for such an organization to collect all the works from every country, it would “settle” for collecting digital copies that cannot be distributed to the general public. Such an organization would thus serve as a simple international extension of national heritage institutions, and even if the countries involved would still have the right to “retrieve” their digital copies for whatever reason, the organization’s collection would remain fairly comprehensive at all times. One could even consider provisions preventing countries from retrieving their digital copies in certain very specific situations (such as a coup d’état or civil war). And provided that this global digital collection is located in a neutral territory, relatively far from population centers and conflict zones, it could very well last for a very long time. Finally, a third possible strategy, though less likely, would be for a billionaire to decide to create his own private collection of digitized copies of non-public-domain works and to store his collection in an isolated location, still without sharing the contents of his collection with the rest of the world.

II.2) CONSTRAINT N°2: ACCESSIBILITY

No obsolescence of storage media is a prerequisite for accessibility

The other major challenge facing knowledge repositories is that of accessibility: we want to ensure that our distant descendants (or any other recipient) can access the knowledge we wish to pass on to them. This issue is all the more pressing given the immense amount of information that needs to be gathered. Indeed, if we are content to preserve only a selection of our knowledge, a relatively universal medium can be used, such as engraved tablets. But if the volume of knowledge to be preserved is large, as we have seen, only mass digitization can get the job done, which requires technologically complex storage media—electronic, nanotechnological, or otherwise. These are media that are highly susceptible to obsolescence, which our descendants may simply be unable to read if they do not (or no longer) have the appropriate hardware. This a major difficulty, that adds to other well identified challenges such as copyright (refusal to allow the digitization of a given work or article without financial compensation), the fragility of certain artifacts (some items are in such poor condition that the digitization process could destroy them), the cost of the equipment (which can be a particular problem in less economically developed countries, or in smaller institutions that do not maintain a huge collection), or the considerable time needed to digitize the contents of museums, archives, or libraries.

The biggest problem with digitization, is that everything that has ever been digitized—the web, the internet, private archives—is stored in reality on a multitude of servers, in computer memory banks. Unfortunately, computer storage technologies are constantly evolving: the first generations of physical media were cards and punched tapes. Then magnetic media became widespread (magnetic tapes, then hard drives and floppy disks). Subsequently, optical media became the norm (CDs, DVDs, Blu-Ray), sometimes in networks. Nowadays, media such as USB keys, SD cards and SSDs (as well as all kinds of variants) have become widely available. Added to this is the multitude of formats and programming languages appearing and disappearing on a regular basis. As a result, computer media must be constantly updated, either by converting the content from an obsolete medium to a newer one (if applicable) or by re-digitizing a given item. This last option may occur if previous technologies are no longer as common, if time has caused significant mechanical damage, or if considerably better technologies are emerging (better storage capacity, faster writing and reading speeds, better resolutions etc.). In addition to the various forms of hardware obsolescence, there is also software obsolescence. Sometimes, it is the application that allows access to information that is no longer compatible, the operating system may change, or programs may be completely redesigned.

Between 1984 and 1986, a project called the “BBC Domesday Project” was launched with the aim of digitizing all kinds of studies, maps, testimonials, videos, and statistics on the British population at the time. However, the medium chosen at the time to store all this information, the Laserdisc, is no longer in use, and no company produces machines capable of reading it. Furthermore, the code used at the time (in BCPL language) poses serious backward compatibility issues, so it is difficult to emulate the content of the project's laserdiscs with current technologies, even when laserdisc players are available. As a result, new projects had to be created to convert the disc content into a more durable format and medium, sometimes involving reverse engineering, i.e., analyzing obsolete technology in order to “recreate” it long after production had ended and the engineers who designed it had passed away. A similar problem arose at NASA when it suddenly became impossible to read magnetic tape archives from certain past missions (Apollo missions, Viking probes, etc.) because the machines that could read these tapes had been scrapped, and that the programming languages of that era were mastered only by people who are now either deceased or retired. Once again, reverse engineering was the solution to the problem. These two examples illustrate the need to properly manage any large-scale digitization project, which means carefully planning ahead to ensure the long-term viability of the hardware and any software. Digital preservation therefore requires taking into account the evolution of physical media as well as that of the associated computer programs.

Among the various methods used to address this issue are (non-exhaustive list):

*Refreshing: this involves transferring the content from one medium to another of the same type.

*Migration: this involves transferring information from one system to another. For example, from one file format to another, or from one operating system to another.

*Replication: this simply involves creating as many copies as possible to improve the probability that one of them will last for the desired length of time.

*Emulation: this involves replicating the system surrounding the medium, in a way, to make the medium "believe" that the tool used for writing/reading is the same as the one used previously.

*Encapsulation: this consists of objects that contain information about how they can be decrypted, facilitating reverse engineering and backward compatibility.

One final persistent difficulty with all these techniques is identifying the blind spots of digital preservation, i.e., the difficulty of identifying items that have been forgotten or not adequately updated or rescanned. Digital preservation, which complements digitization, is therefore a long-term, ongoing process.

Our descendants will need the technical ability to read our information

We note that digital technologies evolve and disappear frequently, but so far, we have assumed implicitly that future generations will still be able to decode digital information, at least partially, using the methods of their time and continuously converting data from one format to another. However, we have overlooked an important scenario, that of the collapse of civilization (linked to industrial risks). In this case, technology would disappear, and future generations would be helpless in the face of our information media, as they would no longer have a command of computer science, signal processing, encryption, electronics, etc. To remedy this problem, a digital medium would need to be invented that is capable of storing large amounts of information and can be decoded relatively easily, even by a civilization that is not very technologically advanced. This is the major drawback of digital preservation: the media we have used to date are very specific and require very specific machines (DVD players, magnetic tape readers, projectors, etc.), which can limit the universality of digital mass storage. With molecular storage, this problem would be reduced, since in theory, any machine capable of detecting the structure of a molecule (DNA or other) would be able to read that molecule, whereas for a specific electronic medium, a specific reading machine is required. Furthermore, if computer bits are stored directly in the form of molecules or nucleotides, with one type of nucleotide associated with "1" and another with "0," the program needed to read the molecule's content may be less complex to recreate than one conceived for an electronic medium, in which “1”s and “0”s cannot be equated with simple elementary components.

Despite the advantages of DNA, or more broadly molecular storage, our descendants will still need to have a basic understanding of microscopy, algorithms, and macromolecular chemistry in order to decode the contents of a strand of DNA. So, even if we make some progress, we still haven't completely solved the problem of the non-universality of digital media. There are two complementary solutions that will enable our descendants to cope:

*The first solution is to leave instructions for our descendants, a kind of “user manual.” Let’s say that a digital data storage center capable of withstanding the passage of time will exist, we could also store in a separate location, on an engraved tablet for example, a set of very specific technical details on the operation of the center as well as useful technical basics (genetics, mathematics, user manuals, etc.).

*The second solution is to use a less massive memory than conventional digital memory, which brings us back again to the issue of the degree of information selection that we discussed earlier (should we provide our descendants with a selective or exhaustive epistemic memory?).

There is one important thing these two solutions have in common: information must be stored on a medium that is easy to decrypt, even for a less advanced civilization, and that has a very long lifespan. One possible avenue is existing physical media, such as paper, clay, or basalt, which can have a long lifespan. It will indeed be less difficult for a culture with no knowledge in computing technology to understand instructions left on sturdy tablets. However, the amount of information that can be recorded on these media remains very limited, if only because the amount of information that can be written on a tablet is inversely proportional to the size of the characters used. By writing all our knowledge of chemistry, genetics, mathematics, and computer science on plates, on which the size of the characters does not exceed a few tenths of a millimeter (as is the case in the “Memory of Mankind” project in Austria), it is still possible to avoid using too much physical media. But for a more extensive knowledge ark, even if we select the information, this technique is unsatisfactory. Just to write the contents of an “ideal library” of a few thousand books (which is already a very restrictive selection), several thousand plates are needed, which must be stored in a sufficiently large space. A possible compromise between accessibility and mass digitization is to use optical disc technology, in which information is stored by means of small engravings, but can be read using only rudimentary optical tools, such as conventional microscopes, and polarizers. 5D optical data storage is a well-known example of a medium capable of holding a reasonable amount of information while requiring a relatively simple reading tool. It also conveys the advantage of an excellent lifespan. This technology has already been tested for the lunar library project we mentioned earlier.

Language evolution must be taken into account for transmission

In order for our knowledge to be usable by our descendants, we will need to use technologies that are sufficiently simple and standardized. If software components are necessary to read the information media, an easy-to-decipher computer language will also need to be developed. But there remains another major challenge: finding a natural language that future generations will understand. Regardless of the expected longevity of an epistemic memory project, and regardless of the recipients of such a project, the problem of language barriers will have to be addressed. Indeed, it cannot be ruled out that the languages we speak today will no longer exist by the time our descendants rediscover traces of our civilization. There have been many instances where a people outnumbered by another in a given territory has adopted the language of the dominant people, first as a lingua franca, then as their mother tongue. This assimilation can be forced (colonization, military conquest, etc.) or more "natural" (cultural influence, migration, the importance of trade, etc.), but in all cases, it can lead to the extinction of entire languages. Currently, it is estimated that of the 7,000 languages spoken on Earth, between 50% and 90% of them are threatened with extinction during this century. While the languages most at risk today are often those spoken by a small number of speakers, it is not impossible that the "major" languages (English, French, Mandarin, Arabic, etc.) will one day be endangered themselves. Incidentally, language can also be a heritage in itself, to be preserved for posterity and for the great joy of future linguists who strive to understand the structure, diversity, and dynamics of language. Efforts are sometimes made to preserve as much as possible of endangered languages through sound recordings, the creation of dictionaries that are as exhaustive as possible, or the most accurate documentation possible of the language's usage. One example is the UNESCO Collection of Representative Works. However, this work is often complex to implement for many languages that are too isolated.

But languages do not necessarily have to disappear for the obstacle of translation to arise for our descendants; it is enough for current languages to change radically. Many languages have not disappeared because they have become extinct, strictly speaking, but simply because they have gradually evolved into new languages, without any real break during this evolution being identifiable. Latin evolved into French, Spanish, Italian, and other languages; Coptic evolved from ancient Egyptian; Hindustani and many Indian languages evolved from Sanskrit, etc. However, the consequences remain the same: over the centuries, our writing will become increasingly difficult for our descendants to decipher. One study estimates that in 20,000 years, 99 out of 100 basic vocabulary words in the Swedish language will have disappeared by then, and this observation can probably be extrapolated to other languages around the world. While it is not possible to prevent languages from evolving (nor is this actually desirable), and, as a corollary, while it is not possible to remove the language barrier, workarounds are possible. To ensure that a repository of knowledge remains accessible to future generations, the following strategies can be employed:

*The use of multiple languages: if archaeologists were able to decipher ancient Egyptian, this is mostly because legal texts in several languages were found: this is the case for the famous Rosetta Stone, written in Egyptian and ancient Greek, the latter helped to decipher the former. The more languages in which our knowledge is transcribed, the greater the likelihood that future archaeologists will be able to decipher it. Differences between the languages used can also be a decisive factor: by using languages that are not closely related to one another, we can potentially make the translation process easier. In any case, using a single language for a knowledge base can be a major risk.

*The use of multiple writing systems: in the same vein as above, we could consider using several different writing systems, including for a given language (transliteration), in order to increase the chances that at least one of them will be accessible to our descendants. Writing systems also evolve, and it is not unreasonable to think that the current systems (Latin, Cyrillic, Sinographic, Devanagari, etc.) could disappear in a few millennia.

*The dispersion of "Rosetta stones" across the globe: in parallel with knowledge arks, "instructions for use" could be created in several languages and writing systems, which can be duplicated and spread on several different locations across the globe, again to maximize the probability that future linguistic communities will be able to understand our information. We must not forget that with the significant population movements that can sometimes occur, languages can also move and end up being used far from their territory of origin (Portuguese in America, French in Africa, Turkish in Europe, etc.).

*The use of images: text alone is not enough to preserve many elements of our heritage: photographs, films, visual arts, etc., and much of our literature (including scientific and encyclopedic articles) illustrate their subject matter with schematics anyway, so it would be a shame to preserve only the body text. In line with the previous tactics, it is entirely feasible to create simplified dictionaries, mainly containing basic terms and words referring to less abstract concepts, illustrated with photographs, diagrams, and pictograms.

All these tactics can also facilitate the translation of formal languages (mathematics and computer science), but also and above all the instructions that will need to be passed on to our descendants in order to decipher the digital storage media used for mass preservation. We must also remember that many of the conventions used in mathematical language (symbols in equations, the decimal system, arrows, etc.) and even in other sciences (SI units, the periodic table of elements, electronic diagrams, etc.) are arbitrary, and therefore temporary, and must therefore be given special attention.

Knowledge ark can also be immaterial

The transmission of language is therefore essential for future generations to be able to decipher our knowledge, and this is possible with the creation of a dedicated memory, made of simple material supports scattered throughout the world. But language can also be transmitted through other means that do not require any physical media. Historically, humanity has not always mastered writing, which has actually only existed for 5,000 years, whereas the human species is much older. However, peoples have been able to pass on not only their language, but also stories, anecdotes, knowledge, moral codes, and traditions without the use of writing. This transmission was essentially oral, with little or no use of writing medium, at most, mnemonic devices such as carved bones to count the days of the year, or visual representations such as the paintings in the Lascaux cave). This form of transmission relies on three factors for success: oral elaboration, individual memory, and ritualization.

For an idea or story to be passed down from generation to generation, it must first be shaped by the storyteller in such a way that it is more impactful, so that those who hear it are more motivated to pass it on in turn. This can be achieved through all kinds of techniques such as rhetoric (the art of speech), stylistic devices (alliteration, assonance, proverbs, etc.), rhythm (verses, rhymes, repetitions, etc.), music, oral performance, and the gestures associated with it. This construction also makes oral teaching more memorable for the recipient, which brings us to individual memory. In each generation, once the storyteller can no longer tell the story, the listeners must be able to recall the story perfectly, down to the smallest detail, so that they, in turn, can become storytellers for future generations. This is, in fact, the whole point of oral teaching: to ensure that stories survive beyond death, despite the cognitive limitations of the individual. Thus, successful oral transmission depends not only on the storyteller but also on the listener; the former must employ techniques to facilitate learning, while the latter must have the mental capacity to memorize and must use mnemonic devices. Finally, to further ensure the successful transmission of an oral story, it is preferable that it constitute a kind of “ritual,” a tradition that, if not sacred, is at least considered important to the group within which this transmission takes place. Teaching of stories then becomes not only simple learning, but a cultural heritage, knowledge from ancestors, something that is part of the group's identity.

Thus, many peoples who did not master writing managed to preserve tales, legends, philosophical ideas, ethical teachings, and even knowledge of very specific historical events such as volcanic eruptions or floods for thousands of years, with relatively little alteration. Even in our contemporary societies, where most learning requires material support (textbooks, guides, tutorials, etc.), part of it still takes place orally, whether through radio programs, political speeches, public debates, documentaries, or even school. Admittedly, the limited cognitive abilities of individuals, even taking into account the size of the world's population, make it impossible to transmit the entirety of our knowledge, especially the most complex or abstract aspects. However, relying on intergenerational oral memory would have certain advantages: knowledge learned orally benefits the individual throughout their life and is immediately available to them. Moreover, the more fundamental knowledge is known by the greatest number of people, the more resistant it will be to attempts at censorship or any form of unintentional or collateral destruction. Thus, if tomorrow civilization collapses or a particularly autocratic regime takes hold, what survivors remember today will have a decisive impact on what will be available to future generations, including key information for understanding the world (natural selection, atomism, the Big Bang theory, critical thinking, history, etc.). In other words, passing down certain parts of our knowledge orally would have two advantages: first, our distant descendants would be better equipped to interpret our written knowledge because they would be on familiar ground, and second, our more immediate descendants would always have access to fundamental knowledge, even in the event of a societal collapse.

Integral transmission of knowledge will be successful with the help of critical thinking learning

To ensure that our knowledge is available to future generations, current generations must be able to store as much information as possible, so that the most important ones can survive a catastrophe that could damage our heritage and our science. This method is part of the broader issue of what is known as “collective memory,” i.e., all the information shared within a group, whether it be a family, an organization, a country, or even humanity as a whole. Collective memory is a concept that refers to the way in which knowledge, values, and subjective experiences are disseminated within a group. The concept is mainly used to refer to historical memory, the memory of the past, particularly traumatic events, which is similar to the concept of the duty to remember. But oral transmission can also, more broadly, be seen as part of epistemic memory—and thus of the very long-term preservation of ideas, key discoveries, theories, cultural elements, and, indeed, all of the more or less ephemeral intellectual heritage that civilization has produced. The challenges associated with oral transmission remain the same, and the successful transmission of knowledge across generations can only be achieved by overcoming the following obstacles:

*Error: collective memory is obviously not some kind of memory that “floats” above society and is completely immaterial; it is in fact a way of referring to all the individual memories surrounding a given subject at a given moment, distributed among each member of a society. Collective memory exists, in a sense, in a tangible form, through the bodies of individuals. This means that any information that can be memorized by an individual can be altered by that individual, sometimes unintentionally: errors can arise during learning due to cognitive biases, sensory illusions, paralogisms, or simply because the brain is unable to store information the way it is emitted. False memories and quid pro quos can therefore distort oral transmission.

*Appropriation: another way of altering knowledge is to transform it at will, to twist it so that it appears consistent within a pre-existing mental framework. We can give a new definition to a word, exaggerate a point of view with which we disagree, minimize a fact, omit a “detail” that is not really a detail, etc.

This appropriation can be beneficial for the creation of new ideas, but can be problematic for the proper understanding and transmission of existing ideas.

*Communication: Knowledge can also be altered when information is shared between several members of a group, whether directly (verbally) or indirectly (typically via social media). The infamous "fake news," false information about an event in the recent or distant past, is a well-known example of distortion occurring during learning, rather than after the fact due to poor memory. In this case, it is often the person sharing the false information who is at fault, rather than the person receiving it. Understanding of a philosophical or scientific subject can thus be reduced if the least reliable information on that subject circulates more widely than other information within a group. This is an even more significant problem given that certain types of information, particularly partial information and information associated with strong emotions (anger, joy, sadness, etc.), are transmitted more easily than impartial or emotionally neutral information.

*Omission: sometimes, someone who wants to pass on knowledge may deliberately alter it by deciding not to reveal everything. Omission is a form of misinformation, but in this case, the cause is not so much related to the nature of the information or to an actual modification, but simply to a selection of information. Whereas communication problems are most often errors or lies, omission is more of a half-error or half-truth, since the information conveyed is accurate, but simply not complete enough for the learner to have a good understanding of a given subject. This omission may be intentional or unintentional, but when it happens, this means that censorship and taboo are not far away.

*Dogmatism: conversely, knowledge may be considered so important to the group that the slightest alteration is unthinkable, which paradoxically undermines the preservation of that knowledge. Indeed, preservation is not for preservation's sake; it must also help knowledge to evolve and accumulate over generations. Preservation is also a means for future generations to continue to progress, to create new ideas, to construct new theories, to discuss alternatives, to explore consequences, etc. Dogmatic knowledge, or doctrine, constitutes a form of "local" knowledge that is unalterable and resistant to the passage of time, but dangerous for all other knowledge that also deserves preservation. In other words, all knowledge must be treated equally so that it can continue to evolve and we do not become complacent with what we have already achieved.

All these challenges, which are already paramount for the memory of history, are also paramount for the proper transmission of our intellectual and cultural heritage to our descendants. Therefore, teaching as much knowledge as possible to as many people as possible is not a viable strategy on its own. If we want our heritage to survive through the ages, this strategy must be accompanied by learning methods that limit dogmatic thinking, selection or confirmation bias, and the sharing of unverified information. In other words, the intangible transmission of knowledge also involves the teaching of scientific methodology and critical thinking: knowledge of cognitive biases, the importance of sources, scientific experimentation, hypothesis testing, logic, rhetoric, media literacy, fact-value distinction, etc. In order for our descendants to be better able to welcome the wealth of information we wish to pass on to them, we must ensure that the rudiments of critical thinking are firmly rooted in the current population. Of course, an "immaterial" epistemic memory is not necessarily an alternative to the traditional material memory we discussed earlier. but it is a complementary form of memory, aimed at facilitating access to our knowledge for future generations in the event of any form of cultural amnesia. The critical oral transmission of knowledge aims to foster open-mindedness, curiosity, perspective, and rigor among future generations, so that the preservation of knowledge does not devolve into a kind of intellectual stagnation, scientism, or censorship of new theories, especially when they concern topics on which there is no scientific consensus.

II.3) CONSTRAINT N°3: LONGEVITY

When faced with natural hazards, the choice of storage environment is essential

In creating a knowledge ark, there remains one last major challenge to overcome: longevity. We have discussed all kinds of techniques and storage method to overcome various constraints such as technological obsolescence, language barriers, the quantity of information, and centralization. The avenues explored so far range from traditional digital media to oral transmission, emerging molecular storage technologies, and engraved tablets. But ultimately, all these constraints are subordinate to another, arguably the most important one: longevity. For a large-scale epistemic memory project to be relevant, it is not only necessary to be able to safeguard as much of our heritage as possible and make it available to our descendants, but also to ensure that this accessibility is not limited to our direct descendants and that our knowledge benefits generations that will arrive long after the potential decline of our civilization. The knowledge preservation strategies we have discussed so far have focused mainly on knowledge articulation (accumulation, sorting, transmission, selection, etc.), and less on preservation itself, although it is the core of the project. Preservation is the collection of methods and procedures aimed at keeping the preserved heritage in good condition, and even in good working order if this heritage includes machines. Three main areas of preservation can be identified: preservation against natural damage, preservation against anthropological damage, and preservation against internal wear and tear. In the first two cases, it is mainly the environment surrounding the preservation location that can be configured, while in the last case, it is essentially the nature of the medium itself that determines whether or not it will last.

Firstly, in order for our knowledge to withstand the passage of time, it must be kept in a controlled environment, sheltered from natural disasters. In our section on natural hazards, we saw that there are all kinds of major phenomena that can destroy our heritage: we mentioned floods and fires, which have been responsible for the loss of many priceless structures over time, but we could also mention earthquakes, cyclones, volcanic eruptions, landslides, tornadoes, and other violent winds. The first step in preservation is therefore to choose a geographical location that is relatively spared from this type of violent disaster: avoid geologically active regions, avoid the coast or any waterways, avoid floodplains, and avoid forest areas vulnerable to fire. But there is more: the effects of entropy are not only manifested in violent events, they also leave their mark through common physical phenomena such as temperature, magnetism, humidity, light, etc. There is therefore a second major step to take in preservation, which is to create a healthy preservation environment in which these kinds of external aggression are curbed. Many modern institutions such as museums, libraries, and archives already implement environmental control measures: the temperature must be kept at a relatively constant level to slow down deterioration caused by mold, insects, or microorganisms; while books are not piled up haphazardly to prevent the rapid spread of fire. Artifacts are not exposed to daylight; they are stored in special rooms or even sheltered boxes that allow little or no moisture and contaminants (acid, ozone, dust, fungi, etc.) to pass through; and in the meantime, building foundations must be designed to withstand high-magnitude earthquakes or powerful explosions.

Finally, if a disaster does still occur, numerous procedures must be in place to limit the damage. These procedures may consist of protective installations (fire extinguishers, sprinklers, thermostats, etc.) and detection devices (hygrometers, thermometers, etc.), safety measures, special partitioned rooms that are off-limits to the public, staff training, identification of actors who can help fight disasters (firefighters, police, etc.), the creation of documentation to provide feedback on previous disasters, or restoration plans to repair damaged but not destroyed objects. These measures can have a major drawback: they require significant facilities and personnel, which is fine for contemporary institutions such as libraries and museums, but more problematic for preserving heritage over the very long term: it is best not to assume that the necessary resources will always be available to protect and restore items throughout the duration of a knowledge ark project, which can span several thousand years. In other words, "active" preservation—which relies on agents to ensure everything remains in good condition—is much riskier than "passive" preservation, which would not require the continuous allocation of significant resources. Ideally, an "ark of knowledge" might simply consist of storing our knowledge in a secure, sealed facility, completely isolated from the outside world and never visited by any human being other than those for whom the knowledge is intended. We can therefore understand the value of centralizing knowledge (to limit the number of epistemic memory centers requiring active monitoring), digitization (some digital media are easier to preserve than traditional media such as books, microfilm, etc.), and above all, physical media of sufficient quality to withstand the ravages of time without maintenance.

When faced with human risks, the right balance in terms of accessibility must be found

Secondly, still with a view to ensuring that our knowledge survives the passage of time, we must take anthropological risks into account. On political risks, we discussed conflicts and censorship (in a broad sense: censorship itself, but also selection bias, propaganda, discrimination, etc.), which can damage at least part of our heritage. On industrial risks, we discussed the plausibility of our industrial civilization eventually collapsing due to poor macroeconomic choices (overexploitation of resources, unlimited greenhouse gas emissions, uncontrolled technological developments, etc.), which could also be combined with political risks (an increase in wars and forms of authoritarianism) and even natural risks (increase in natural disasters linked to global warming). To this we can add more trivial risks: theft and vandalism, which in the past have often prevented the scientific community from benefiting from certain archaeological treasures that had survived the passage of time. Consequently, the conservation strategies discussed earlier—namely, selecting locations away from disaster zones, environmental management, and conservation policies—must also take into account all these anthropogenic factors. When choosing a location, the knowledge ark should be far from any conflict areas or even any areas of significant population, these being more vulnerable to bombing than uninhabited areas. On the issue of a controlled environment, intrusion detection and prevention of deliberate damage must be added to the preservation measures. Finally, the preservation center must be as resilient as possible to a military attack.

However, one question remains: if we want to preserve our intellectual heritage as much as possible, isn't it in our best interest to isolate it as much as possible? If human beings are a potential source of destruction and censorship, how can we balance environmental integrity with resource availability for future generations? It may indeed seem paradoxical to talk about deliberately making our knowledge inaccessible in order to ensure its longevity, even though the measures we might implement would run counter to the need for our knowledge to be accessible to our distant descendants. Doesn't the issue of longevity conflict with that of accessibility? In this regard, one might refer to the many time capsules left in space in the past—that is, the place par excellence that is inaccessible to humans. For example; we can refer to the objects left behind by the Apollo missions, the plaques onboard Pioneer 10 and 11 probes, the “Golden Record” from the Voyager 1 and 2 probes, and the already mentioned lunar library aboard the Odyssey probe. The advantage of space, apart from the fact that natural hazards are much more limited than on Earth (no wind, no fire, no humidity, etc.), is that it is a rather inaccessible and gigantic area, where humans cannot easily wage war, steal, or censor archives. But precisely because a space memory project is by nature virtually inaccessible, it will be more difficult for our descendants to retrieve the contents of a hypothetical space knowledge ark, especially if they do not master space technologies. Space is clearly the best way to ensure the longevity of knowledge, but this comes at the expense of passing it on to our distant descendants.

In light of this dilemma, there are therefore two strategies: if we prioritize longevity over availability, in which case space is the best place for a knowledge ark project. But in this case, it must either be stored in a fixed location (on the Moon, for example), or be able to return automatically to Earth after a certain amount of time (on board satellites orbiting Earth for instance; even those in distant orbits eventually fall back to Earth after several hundred thousand years). Otherwise, if we prioritize availability over longevity, in which case the knowledge ark project has to be located on Earth, it must still be in a sufficiently isolated location so that our descendants have a chance of finding the contents of the ark intact. In any case, this points to a “passive” rather than active preservation strategy, which is easier to implement far from civilization. Incidentally, the issue of isolation raises two other subsidiary questions: that of secrecy and that of consultation. Should we favor a secret location (to limit the risk of theft or deliberate destruction) or not (to make it easier for our descendants to find our knowledge)? Should the contents of an epistemic memory be accessible in our time or not? These issues must be considered when designing a knowledge arch.

When faced with wear and tear, the choice of physical medium is crucial

Finally, to ensure that our knowledge repository endures over time, we must take into account the natural degradation of information storage media. It is primarily for this reason that the choice of storage medium will be a decisive factor. This choice has already been discussed earlier, since depending on the form a knowledge repository takes, certain technologies are more suitable in some situations than in others. For example, the latest advances in information storage are better suited for a comprehensive knowledge ark. Conversely, more traditional media are better suited for a more selective knowledge ark, as well as for any appendices intended to make our knowledge more accessible to our distant descendants. The choice between a digital or analog medium will also depend on the design of the knowledge repository, depending on whether one wishes to create a “library,” focused primarily on written materials, or a “universal archive,” which would then be multimedia.

Added to all this is longevity an ideal medium must certainly have a large capacity, be versatile, and be accurate, but above all, it must be reliable over the very long term. For these reasons, most traditional media are not truly suited for preservation. For example, although paper can theoretically last for several centuries under good preservation conditions, in reality, it is vulnerable to water and fire. As a result, most documents produced by humans have not survived to the present day, due to fires, shredding, or floods—not to mention the many books lost to mold or biological organisms. In addition, the industrial paper used for most contemporary publications is of poor quality, and can deteriorate fairly quickly compared to more traditional paper. When it comes to electronic media, the situation is not much better. Not only do most media (vinyl records, optical discs, memory cards, USB drives, etc.) only last a few decades at most, but they quickly become obsolete as new information technologies emerge. Magnetic tapes and microfilms for instance, which were historically used as substitutes for books, have a lifespan of 10 to 20 years and are no longer widely used today because of the digital revolution.

Of the many information storage techniques we know of, relatively few are actually capable of lasting long enough. But the good news is that these techniques do exist, and some may even be just as suitable in terms of durability, storage capacity, and ease of use. Among the most relevant technologies for a knowledge ark are the following:

*The writing tablet: this is literally the oldest form of writing medium known to us, and paradoxically, it is also one of the most durable. Wooden tablets dating back 5,000 years (Egypt, etc.), clay tablets dating back 6,000 to 7,500 years (Mesopotamia, Europe, etc.), and stone tablets with a similar lifespan have been found. The choice of materials is decisive in terms of lifespan. Organic materials (bone, wood, ivory, wax, etc.) have the disadvantage of being "biodegradable ", even though they can last for thousands of years, whereas metals (silver, gold, etc.) and minerals (slate, basalt, clay, etc.) can withstand exposure to light, living organisms, and even fire to a certain extent. Among these, gold and stainless steel are the metals most resistant to the ravages of time, as they are the least prone to corrosion, while among minerals, basalt, ceramics, and marble are among the rocks most resistant to erosion. The real disadvantage of tablets (and by extension, steles, bas-reliefs, etc.) is their very limited storage capacity and the difficulty of transcribing anything other than text. However, it is undoubtedly the most universally accessible medium, as it does not require a reading device. And if one writes with very small characters, a writing tablet can hold much more information than a book and can even rival certain types of hard drives.

*Molecular storage (including DNA storage): this is a very recent medium, which has not yet been used on a large scale due to limitations in read and write speeds, but which has already been used for knowledge “ark” prototypes. We have discussed this before, but the major advantage of DNA (or molecular storage in general) is its immeasurable storage capacity: DNA strands that are nanometers wide but several meters long could theoretically contain more information than all the libraries on the planet, or even all the data centers and computer servers on the planet. This type of storage is therefore essential for this reason, and also has the advantage of very good longevity, since DNA, under the right preservation conditions, can last for thousands of years. It is estimated that strands of DNA stored in stainless steel capsules could last 50,000 years (on Earth). Traces of DNA from animal species that have been extinct for millions of years can be found in nature, and logically, attempts are being made to reconstruct their genomes. DNA storage could be a much more advanced form of digital storage than traditional media for these reasons, while retaining the advantages of digital technology (variety of information formats stored—video, text, images, etc.—and accuracy). Furthermore, although it is not exactly a universal medium, since a computer language is still needed to encode the information in the DNA, as well as tools capable of reading the DNA (microscopes), the risk of obsolescence remains lower than for conventional electronic media.

*5D optical data storage: this involves the use of crystals with certain light polarization properties, which, depending on the angle at which the content is read, allow several levels of information to be “superimposed” on the same volume. This is also a recent technology, which has been used mainly for long-term storage. The storage capacity of disks using this technology is high (360 terabytes), although lower than that of molecular storage. However, it may be a good compromise between the latter and writing tablets, and, as with DNA, it is a more universal medium than conventional electronic media, since any microscope equipped with a polarizer can theoretically read the contents of the disc. But above all, there is another huge advantage: it is currently the medium with the longest lifespan ever designed. It is estimated that a 5D optical disc could theoretically remain readable for at least billions of years. Thus, to create an archive of knowledge that would remain intact for hundreds of thousands of years or more—and not just for the millennia following the end of our civilization—5D optical storage appears to be the most suitable medium at the time of this writing.

There are many knowledge arch strategies, and not all of them are designed for long periods of time

In summary, we have so far considered three main constraints for the creation of a knowledge ark: comprehensiveness, accessibility, and longevity. Each of these constraints involves all sorts of problems, for which there are all sorts of strategies and technical solutions. This means that the concept of a knowledge ark—and thus also the concept of epistemic memory—are not easy to define, but rather encompass a wide variety of very different projects. Knowledge arks can thus be classified into different categories based on the motivations they primarily seek to address: an ark can be comprehensive or selective, even specialized; hierarchical or non-hierarchical; centralized or decentralized; object-oriented or information-oriented; analog or digital; physical or digital; designed for very long-term preservation or not. Those categories can be summarized the following way:

*Anarchic memory: knowledge is preserved in the form of collections of items scattered across the globe. The primary objective is the preservation of artifacts and literature. This is a decentralized, object-oriented mass memory: it is the main way knowledge is currently preserved within heritage institutions and various private archives scattered across the globe.

*Digital memory: knowledge is preserved in digital storage arrays, which today is done through computer servers and data centers using electronic media. The primary objective is the preservation of information. This is a mass memory system, still decentralized but information-oriented.

*Heritage memory: knowledge is preserved with minimal use of storage and is transmitted from person to person through education, the media, and simple oral transmission. The primary objective is the continuous development of humanity despite crises. This is a selective, decentralized, and information-oriented memory.

*Thematic memory: knowledge is preserved in a kind of library, each one packed with information, as they are able to centralize a large portion of our knowledge within as limited a storage space as possible. The main objective is the preservation of a specific type of heritage (from an academic discipline, a particular country, a major institution, an encyclopedia, etc.). This is a selective, centralized, and information-oriented memory. This form of memory is ideal for serving as a “backup” for anarchic memory.

*Universal memory: knowledge is again preserved in libraries packed with information, but this time, EACH of these libraries must be exhaustive or nearly exhaustive. The main objective here is the centralization of the entire cultural heritage. This time, it is a mass, centralized memory, still information-oriented. This form of memory does not yet exist because current technology and legal frameworks do not permit it, but this could change.

*Encapsulated memory: knowledge is preserved in the form of a few objects and messages inside time capsules. The main objective is the duration of preservation of the "encapsulated" item. This is a form of selective, centralized, and object-oriented memory.

*Hybrid memory: the various forms of knowledge arcs mentioned above complement one another (for example, thematic memory can serve as a "backup" for anarchic memory, heritage memory can facilitate navigation within digital memory…) and some may even merge (anarchic memory may be gradually transforming into digital memory, and when technology allows it, a time capsule could very well serve as a suitable container for thematic memory or even universal memory).

Each type of knowledge repository has its merits, and none is truly more relevant than another. It's especially important to keep in mind that certain design constraints are difficult to reconcile. Accessibility and longevity, in particular, can be conflicting constraints, since to ensure that an ark survives as long as possible, the best solution is often to place it as far away as possible from any human beings; while this certainly helps avoid many risks of external threats, it limits the value of a knowledge ark, which is ultimately intended for future generations. To put it another way, all the forms of knowledge arks we have discussed and will discuss are complementary, and all these forms deserve to be realized, without this entailing truly astronomical costs.

But since we are discussing the typology of knowledge arcs, let us now turn our attention to a specific case that will be of particular interest to us going forward: namely, knowledge arcs designed exclusively for a long and specific duration (encapsulated memory). In fact, this is the only category of arks we haven't discussed so far, even though it is the one for which the requirement of durability is most critical. This is also an opportunity to revisit the concept of a time capsule: a time capsule consists of creating a "box" into which any object or information medium chosen by the creator of the box can be inserted. This box is then stored or even buried in a relatively isolated location and is only intended to be opened after a very long period of time, or even not to be opened at all. The time capsule is therefore designed either for maximum longevity or for programmed longevity. In any case, the idea of time capsules is based entirely on a desire for preservation for preservation's sake, and by extension, on a desire that nothing and no one should open the contents of the capsule, at least for a certain period of time. The main virtue of time capsules is therefore that they largely escape the accessibility paradox, since in theory, for a well-designed time capsule project, no one can access the contents of a capsule before a certain date, and in some cases, the contents and/or location of the capsule may even be kept secret. A knowledge ark is ultimately a specific type of time capsule, designed to serve as a repository of knowledge and even of humanity's entire cultural heritage; but in essence, nothing fundamentally distinguishes arks from other forms of time capsules, beyond the amount of information they preserve. But so far, we have assumed that a knowledge ark must absolutely be comprehensive, accessible, and durable all at once, whereas if we look at other forms of time capsules, not all of them are designed with these three objectives in mind, and more often than not, it is longevity that takes precedence, with the capsule's contents serving merely as a symbolical pretext to leave behind something capable of defying the immensity and apparent eternity of the cosmos.

Let us now turn our attention to the specific case of knowledge archives that set aside the constraints of comprehensiveness and—above all—accessibility in favor of extreme longevity. It is worth noting in passing that with the storage technologies we mentioned earlier, the constraint of exhaustiveness is much easier to reconcile with longevity than is the constraint of accessibility: media that are both durable and have high storage capacity do exist. If this form of "ark" is of particular interest to us, it is notably because it allows us to bypass many obstacles (particularly those of active preservation and transmission) and because such a project can have a much stronger symbolic significance. The goal of preserving our knowledge intact for our distant descendants becomes secondary to that of creating a sort of ultimate library of human knowledge, one capable of surviving even the extinction of humanity. By chance, these arks might even be discovered by “someone” who has no idea of the existence of our civilization, and would then hold in their hands a veritable black box of the knowledge of an entire vanished world.

> *Knowledge arcs are the ultimate form of the most ambitious time capsules*

Time capsules are not a recent invention, since, technically speaking, most of the archaeological traces left by our ancestors can be considered unintentional time capsules. Every archaeological discovery, in fact, contains its share of objects, human traces, and sometimes even texts and other artistic representations. The Lascaux caves, the ruins of Çatalhöyük, and the Rosetta Stone are all examples of time capsules. But what interests us most are intentional time capsules—those that specific individuals decided to leave for future generations, or even for no one in particular. The oldest known example is that of the tablets recounting the Epic of Gilgamesh, carved in Iraq during the Mesopotamian era (around 3000 BCE), since these tablets mention the existence of a metal box buried underground near the city of Uruk, containing a copy of the said epic, but carved from lapis lazuli. Letters and books have also been found buried by various individuals, whose names are sometimes unknown to us, but who nevertheless managed to leave a trace of their passage, a part of themselves, long after their death.

Over time, these individual initiatives became increasingly ambitious and even began to involve far more people: this was the case with the Crypt of Civilizations at Oglethorpe University in Atlanta (in 1936), the time capsules from the 1939 and 1965 World’s Fairs in New York (Westinghouse Time Capsule I and II), the one from Expo ’70 in Osaka, and the Millennium Vault in England, created for the turn of the millennium. While most time capsules are generally simple sealed boxes or chambers containing various objects and documents, some can be of a much more unusual nature. For example, the Zeitpyramid in Germany consists of a pyramid made of 120 concrete blocks, with one block to be added every 10 years, meaning the pyramid will not be completed until the year 3183, as the project began in 1993. There is also a film titled “100 Years” intended to be viewed only in the year 2115. We can also mention the Long Now Foundation’s 10,000-Year Clock project, which has not yet been realized, or the numerous initiatives to warn our distant descendants of the presence of nuclear waste disposal sites. But above all, many ambitious time capsules are also “spacetime” capsules—that is, projects carried aboard spacecraft launched by humankind. Ever since the Apollo missions to the Moon, humans have left behind small works of art and messages of goodwill. After that, the Pioneer and Voyager probes became famous, among other things, for carrying on board, respectively, a plaque and a vinyl record, each containing basic information about Earth and humanity. Human DNA can also be found aboard the International Space Station (Immortality Drive), depictions of continental drift aboard the LAGEOS-1 probe, a DVD aboard the Phoenix Mars lander, and there are now even proto-space libraries on the Moon and around the Sun, thanks to an initiative by the Arch Mission Foundation.

Indeed, as the concept of the time capsule gains popularity, technology advances, and the impending end of civilization seems increasingly likely to many, numerous organizations have emerged around the world, whose goal is no longer merely to encapsulate a few scattered objects or overly selective information, but to go much further and ensure that as much of our heritage and knowledge as possible survives for as long as possible. In other words, the first knowledge ark initiatives began to emerge fairly recently, at the start of the 21st century. The Arch Mission Foundation’s lunar and solar libraries date back only to 2018 and 2017, respectively, while this organization is also behind a “Global Knowledge Vault” in Switzerland, which was established as recently as 2024. These projects are no longer mere messages but small libraries containing the contents of Wikipedia, linguistic archives, DNA samples, and copies of books engraved on discs designed for long-term preservation. This closely aligns with the spirit of the knowledge arks and epistemic memory we have been discussing from the start. But the Arch Mission Foundation isn’t the only organization seeking to preserve our civilization’s knowledge; we can also mention the “Memory of Mankind” project (a collection of ceramic tablets with eclectic content, stored in the Hallstatt salt mines in Austria), the “Arctic World Archive” project (a collection of digitized works and guides in five languages housed in a room dedicated to the Svalbard Islands—not to be confused with the Global Seed Vault on those same islands), or the “Human Document Project” (an initiative by the University of Twente in the Netherlands to preserve documents for up to one million years). At the same time, the digitization of documents and the preservation of internet content—which is not always archived properly—are becoming major concerns for many people, as illustrated by initiatives such as the Internet Archive, Wolfram Alpha, the Universal Digital Library, and Project Gutenberg, to name just a few. With the proliferation of time capsules, the growing number of players in this field, and the increasing ambitions of these players, the world has never been closer to creating repositories of knowledge worthy of the name. And it is the time capsules that are leading the way.

There is a wide variety of time capsules

There are at least two main categories of deliberate time capsules (which include arks of knowledge). On the one hand, there are capsules with a scheduled retrieval date, i.e., capsules designed to remain sealed for a fixed period of time, usually intended to be opened on a date chosen by the capsule's designer. These capsules are generally designed to be made accessible to future generations after a long period of hibernation, in decades, centuries, or even millennia for the most ambitious ones. In any case, they are primarily intended for other human beings. On the other hand, there are capsules with unscheduled recovery, which are intended to be opened at an indeterminate time. Although this isn’t always the case, these capsules often have an exceptionally long lifespan, and given that longevity, they aren’t necessarily designed for humans, but sometimes even for potential extraterrestrials or for post-human civilizations on Earth. Sometimes, these capsules serve only a symbolic purpose and aren’t even intended for any specific recipients. To put it simply, programmable time capsules are designed primarily for practical reasons (to convey knowledge), whereas non-programmable time capsules tend to be designed for artistic reasons (to leave a lasting testament to our civilization).

The first category we will focus on here is that of programmable time capsules—that is, those with a set opening date. We see that their designers usually have a clear desire to communicate with other people, to pass on a legacy from one human being to another. Most of the time, these capsules are designed during important cultural events. such as the turn of the millennium for the Millennium Vault, international exhibitions such as those in New York in 1939 and Osaka in 1970, or anniversaries such as the independence of a country or the founding of a city. Also, the opening dates of the capsules are often scheduled to coincide with an anniversary date, i.e., such that the interval between the burial of the capsule and its scheduled opening is 100 years, 1,000 years, or a multiple of these numbers (for example, the Westinghouse capsule buried during the 1939 World's Fair is scheduled to be opened in 6939, 5,000 years later). There is no shortage of important anniversaries for the rest of the 21st century: the centenary of the end of World War II in 2045, the centenary of Indian independence in 2047, the centenary of the founding of the People's Republic of China in 2049, 1000 years of the Kingdom of England in 2066, the 300th anniversary of the French Revolution in 2089, etc. There are also many approaches and subcategories of time capsules with scheduled retrieval:

*Underground capsules: Most traditional time capsules are literally capsules, small hollow but sealed metal objects containing various types of items. These capsules are usually buried in the ground, sometimes under a commemorative plaque or monument, warning passersby not to open the capsule before a certain date. These are the most common types of time capsules, as well as the most criticized, since the amount of information they contain is very limited. A typical example of an underground capsule is the British Columbia Time Capsule, buried in Victoria, Canada, in 1967, scheduled to be opened in 2067.

*Time rooms: a step above traditional capsules, entire rooms inside buildings or underground galleries are sometimes specially designed to store a large quantity of objects as part of a time capsule project. One example is the "Crypt of Civilizations," a room at Oglethorpe University in Atlanta (United States) that was set up in 1936 and intended for the inhabitants of the year 8113.

*Digital capsules: In the past, time capsules occasionally contained manuscripts, photographs, books, or even microfilms to hold a lot of information in a small space. Nowadays, capsules can contain electronic and digital storage media, capable of storing much more information. There are many spontaneous initiatives to bury or protect hard drives and other digital media in small capsules placed underground.

*Architectural projects: These are not strictly speaking "capsules," but rather human constructions specially designed to last a very long time, or even to be built over a very long period of time. Examples include the Great Wall of China, certain cathedrals, necropolises, and nuclear waste disposal sites. The Zeitpyramide is another contemporary example of a time capsule of this type, which is scheduled to remain in place until 3183. By extension, this can also include certain types of street furniture (plaques, statues, or commemorative steles, for example).

*Orbital capsules: some capsules are attached to satellites orbiting the Earth, meaning they can fall back to Earth after a certain amount of time. For example, DVDs are to be placed in the KEO satellite (the launch of which has not yet been announced) to fall back to Earth in around 50,000 years and thus be available to any humans living on Earth at that time. Of course, capsules sent to the surface of other celestial bodies or into interstellar space are not considered programmable recovery time capsules.

It should be noted that in all cases, to ensure that time capsules are not opened before their scheduled date, it is crucial to first list all time capsules that exist around the world, along with their scheduled opening dates. Secondly, it is obviously also necessary to find ways to ensure that the existence and location of these capsules are not forgotten by future generations, which can be achieved through all kinds of techniques: commemorative plaques, public education, Rosetta stones scattered around the globe, etc. One of the biggest risks associated with these capsules is that forgetting about them could lead to their accidental destruction (during renovation work, for example).

Today's time capsules have enormous potential but are still too limited

At present, the contents of most programmed capsules are relatively limited: everyday objects, small devices, sound recordings, messages of goodwill, samples of materials or seeds, a few copies of documents, sometimes converted into film or digital media, etc. However, for a time capsule to be of real interest to future generations, it must not be a simple "sample" of objects from the era in which it was created, even if this sample is representative. In fact, the opening of some time capsules buried in the early 20th or 19th centuries has often led to disappointment, particularly for historians and archivists, as the contents of the capsules are often too sparse to provide information about the era in which they were created. This, for a time capsule to be a relevant project, i.e., an "ark" of knowledge, it should ideally contain as much information as possible, including encyclopedias, languages, scientific works, images, representations, videos, music, sound recordings, artistic or historical works, and many other elements of heritage. Consequently, a "2.0" time capsule project is much more useful to future historians if it contains information that is not only representative of our civilization (our knowledge in the strict sense, our traditions, our art, our lifestyles and ways of thinking, etc.), but also very comprehensive. As mentioned above, there are now media that can store large amounts of data, and with digitization, it is possible to save immovable or fragile heritage items that cannot be "encapsulated" in other ways. Projects such as "Memory Of Mankind" in Austria and the "Global Knowledge Vault" in Switzerland are moving in the right direction by proposing to archive the contents of several encyclopedias on ceramic tablets or on the famous 5D optical discs that we constantly refer to.

A further step would be achieved by also preserving the contents of entire libraries and national or private archives, as well as to massively digitize the contents of museums and important cultural sites, so that future generations will have much more usable knowledge at their disposal. This would enable time capsules to truly fulfill their role as "arks" of knowledge, thereby effectively countering the risk of mass social amnesia in the event of the collapse and/or totalitarian takeover of civilization. Moreover, it should be remembered that an epistemic memory can also be seen as a "black box" that can warn our descendants of the dangers facing our civilization (conflicts, economic management, global warming, ethnocides, etc.) or even, in extreme cases, warn our descendants of a potential future catastrophe. Examples include the markers planned for nuclear waste disposal sites (Waste Isolation Pilot Plant in New Mexico, Bure site in France, etc.) or in areas of high radioactive contamination around Chernobyl and Fukushima. The creation of time capsules with a scheduled retrieval date is therefore part of a long-term approach, i.e., an ethical approach that focuses on the perspectives of future generations.

Time capsules may not have a specific recipient

The other major category of time capsules includes all those that were not originally designed for retrieval at a specific date. Here again, as with capsules designed for retrieval, there are a wide variety of approaches:

*Terrestrial capsules: many voluntary time capsules do not necessarily have an opening date and are designed to last a long time without being intended for a specific era. One example is the Arctic World Archive on the island of Svalbard, which contains thousands of digital archives (offline) converted into films, as well as guides in five languages. Earth capsules can be traditional capsules, digital capsules, or architectural projects, similar to the scheduled recovery capsules seen above. By extension, this subcategory can also include "bottles in the sea," bottles emptied of their liquid contents and filled with handwritten letters, which are then literally thrown into the sea in the hope that someone will recover them "one day." Earth-based capsules have the disadvantage of being vulnerable to wear and tear (particularly erosion and corrosion) as well as to destruction, whether intentional or accidental. On the other hand, they are the most accessible of all subcategories of unprogrammed capsules, since they are located on Earth.

*Immaterial capsules: this category of capsules mainly includes radio messages and, by extension, any form of electromagnetic signal sent in a particular direction in space. Since humanity invented radio signals powerful enough to penetrate the atmosphere, the content of radio broadcasts, television programs, and even the Internet has been dispersing into space, in a radio bubble that extends at the speed of light around the Earth. It should be noted that these unintentional radio signals become weaker as the distance traveled increases. However, there are also radio signals sent intentionally into space, toward specific solar systems, in the hope that a response will one day be sent by a possible extraterrestrial civilization toward Earth. One example is the Arecibo message, a short binary-coded radio message sent to the Messier 13 nebula (25,000 light-years from our solar system) in 1974. While most experts agree that there is a very low probability that an extraterrestrial civilization will ever actually receive a message sent by humanity, we can nevertheless consider that these "messages" have a much more symbolic purpose and are created on behalf of our own civilization rather than for potential extraterrestrials.

*Space-time capsules: this type of capsule consists of non-recoverable objects or information carriers that are scattered throughout space, where preservation conditions are much more favorable (provided there is no collision with a celestial body, the probability of which remains negligible given the immensity of the vacuum of space), since many terrestrial hazards (humidity, wind, conflicts, censorship, etc.) are absent there. For this reason, space capsules are designed to have a considerably longer lifespan, in the order of millions or billions of years. Furthermore, when recipients are designated for these capsules, they are not necessarily our distant descendants, but potentially also other intelligent species, possibly even extraterrestrial. There are several possible strategies for this subcategory of time capsules: deposit the capsule on or below the surface of a body in the solar system (think of the "lunar museum" deposited on the Moon by the Apollo 12 astronauts), send the capsule into distant orbit around the Sun (think of the Arc Mission Foundation's solar library aboard a car sent into space), or send a probe into deep space (think of the Pioneer 10 and 11 probes and the Voyager probes, which carry a plaque and a gold vinyl disc, respectively). In the very distant future, some even envision the possibility of creating interstellar probes capable of leaving the galaxy or even capable of self-replication, but for now, this remains the realm of science fiction.

In all cases, it should be noted that many examples of time capsules with unscheduled recovery are potentially not even recoverable in the first place, or are not even designed to be recovered. For example, the Voyager Golden Record, the gold disc aboard the Voyager 1 and 2 probes, is in a way less designed to be recovered by extraterrestrials than to serve as the "ultimate" message in a bottle for humanity. This is where we must remember that time capsules should not be viewed "only" as repositories of knowledge (which is already ambitious in itself), but also as means for humanity to challenge its mortality and the ephemeral nature of the world around us. This act of defiance involves creating an object, ideally a new Library of Alexandria, focusing on longevity and nothing but longevity during its design. Unscheduled recovery capsules, particularly space capsules, are less about preserving our heritage than about the more symbolic goal of leaving something in the universe that transcends us, yet which we can proudly claim as our own creation. Our science and our heritage are our response, as creatures, to creation.

We can go very far in designing the ultimate epistemic memory

The design of time capsules has become increasingly sophisticated over time. While the first-time capsules in history contained relatively little information, technological innovations and the enthusiasm of a growing number of initiators have given rise to increasingly ambitious initiatives. We've gone from simple boxes containing a few messages and items to massive storage arrays capable of holding the entire contents of the web, models of entire cities, traditions from around the world, or the genetic code of thousands of living species, and much more besides, etc. With the mastery of new materials, we can hope to store information for very long periods of time, whether using gold, stainless steel, DNA, concrete, nanomaterials, or even certain crystals, such as those used for 5D optical memory, which could survive for up to several thousand billion billion years, which is quite close to the estimated time scale for the end of the stellar era of the Universe. Contemporary industrial society is now capable of digging increasingly long and deep underground networks in increasingly inaccessible places, where a time capsule is much more likely to remain sealed for a very long time.

But it is mainly thanks to space exploration and astronomy that there has been a turning point in reaches of time capsules in recent decades: we can now send radio signals in all directions, we can scatter probes throughout the solar system from Luna 1, and even throughout the galaxy from Pioneer 10. As we have seen, space offers many advantages for the longevity of capsules, if only because of the virtual absence of natural or anthropogenic hazards, but also because our planet Earth is doomed to disappear when the Sun dies, while certain distant bodies in the solar system (gas giants and their natural satellites, comets, and planetoids) will survive well beyond this event. In interstellar space, where the density of celestial objects is even lower than in the solar system, the longevity of a time capsule could be even greater. It is estimated that the Pioneer and Voyager probes are not likely to collide with another star or star remnant for approximately 100 billion billion years. Of course, the more time capsules are sent into space, the greater the probability that one of them will remain intact for longer.

After the era of small sealed boxes buried in the ground, the new "2.0" time capsules are now veritable encyclopedias scattered across the Earth and throughout the cosmos, with the possibility of further developments in the years to come to centralize even more of our knowledge in even more limited space. With nanotechnology, perhaps the maximum lifespan of an information medium could be extended even further, without sacrificing storage capacity. With advances in astronautics, we may be able to create probes capable of navigating intergalactic, rather than interstellar, space, or even equip each probe with a shield strong enough to protect a time capsule from any collision with a relatively small celestial body (comet, asteroid, etc.), even at high speed. With advances in robotics and 3D printing, we may even be able to consider creating probes equipped with relatively autonomous intelligence, possibly capable of self-maintenance or even self-replication, further increasing the lifespan of the knowledge stored inside those probes. Political and legal changes are also conceivable in the near future, facilitating the preservation of artistic works and scientific and other publications by overriding copyright, which is one of the main obstacles to the creation of a modern Library of Alexandria. Come to think of it, it doesn't really make sense to try to protect the copyright of works contained in a time capsule, where they cannot be viewed or distributed, and where they will be preserved for eternity. One could even consider storing confidential information in time capsules, as these are in any case inaccessible to the entire human race at present.

Finally, one last possible development concerns the organization of the information contained in the time capsule, i.e., the creation of new methods for prioritizing, classifying, or linking all the information together. The “3.0” time capsule would then be not only a knowledge bank, but also a highly structured database, an information network capable of at least partially mimicking the organization of the real world. One could consider integrating a computer program into such a capsule that is capable of performing many kinds of computer simulations of complex phenomenon (celestial movements, climate, human mobility, electromechanical circuits, etc.). In short, the most complete possible version of an “ark of knowledge” would be a comprehensive model of the observable universe, including humanity.

CONCLUSION

We will all die one day, and in the meantime, we all live without any particular well-defined reason. As individuals, we are constantly confronted with the absurdity of existence, the absence of clear, consensual goals, even if we are sometimes convinced that our lives have meaning or that we try to create meaning for ourselves. The only "certainty" of death pushes us to choose all sorts of criteria for leading a satisfying life despite its limited duration (pleasure, moral good, sacrifice, altruism, creation, knowledge, etc.), and sometimes without even realizing it, we need to leave our mark (a new idea, an artistic project, a profession, offspring, etc.) that will survive our death. By extension, civilization as a whole works to maintain its own stability over time, despite the enormous number of constraints and internal divisions within society, exacerbated by the continual cycle of births and deaths. We will die as individuals, but we will also one day die as a civilization. Inevitably, some catastrophe will eventually wipe out our species. Either that or genetic mutations and the fact that we may not have found a "planet B" before the final hours of the solar system. Indeed, the Sun itself will burn out in 5 to 7 billion years, after a phase of expansion that will render the Earth uninhabitable and then vaporize it. Then, in about a hundred thousand billion years, the Universe will enter a phase during which all the stars will have burned up their fuel and no new stars will be able to form due to a lack of available matter. By way of comparison, with 5D optical storage, the estimated lifespan of a time capsule using this technology would be in the order of 30 to 3,000 billion billion years. As a result, all that will remain in the Universe will be the corpses of stars (black holes, pulsars, white dwarfs, and black dwarfs) and isolated grains of dust, which will also eventually disappear after an even longer period of time: in at least 10^100 billion years, the Universe will reach thermal death. The particles of matter will also be so far apart from each other due to the expansion of the Universe that no new material bodies will ever be able to form again. Long after that, no particles will exist and the Universe will enter its final energy state, unless space-time itself breaks down in the meantime or quantum fluctuations give rise to a new Universe.

If extreme longevity is part of the very essence of any knowledge ark project, then this means that such a time capsule should not only be understood as a "trace" of our passage, like any work of art. First of all, unlike a work of art, which is primarily an individual legacy, the knowledge ark is a common legacy of all humanity, or at least of all the peoples and civilizations that designed it and whose heritage has been passed down to us today. Whereas a work of art is traditionally a labor of love for an individual, or even a small team, who consciously or unconsciously wanted to leave their mark on the rest of the world, an ark is a collective, civilizational, and even planetary work. It is not just a matter of imprinting a personal vision of the world, but of imprinting a wide range of perspectives and knowledge and maintaining it alive for generations to come, and beyond. The knowledge ark serves as an epistemic memory, but it also serves as a "vessel" for all artists, whether they are painters, writers, playwrights, filmmakers, musicians, etc. Thanks to new technologies, we could encapsulate thousands of works of art of all kinds and from all sources, whether masterpieces or not, on a small volume. This could even extend to any creative project that is unpretentious but highly personal to the person who created it, such as a message, a drawing, a naive watercolor, or any other personal mark. It is no coincidence that in many existing time capsules, the content consists mainly of testimonials, memories, messages, and other signatures. The knowledge ark could therefore be the vehicle for everything that once motivated a living person to leave a symbolic legacy after their death. The ark is in fact an extension of any work of art, but on behalf of a civilization, a species, or even an entire biosphere.

Still in line with the will of an epistemic memory creation, the knowledge ark is also the memory of all knowledge, or potential knowledge, that civilization has accumulated over the centuries in an attempt to understand this great Whole in which we wake up every day. All our science, embellished with all our philosophical speculations, is another collective legacy of our civilization, but this time it is not an aggregate of several individual perspectives, but rather a kind of "golem," a patchwork with no defined author other than the human species on planet Earth. Our scientific heritage (and by extension, epistemic heritage in the strict sense) can also be seen as an attempt by the Universe, through humanity, to contemplate itself, and arks would therefore be a crystallization of this attempt. As we have said, there are many symbolic issues behind the creation of an ark, and one of them is the opportunity to give the Universe a kind of internal memory, much more durable than that of the fragile beings that we are. The collection and preservation of knowledge is in fact equivalent to inventing a recipe for immortality, artificially prolonging the life of all things, of every element of the Universe that has been the object of its attention through humanity. Every tree that has been photographed will always exist through photography, every person who has signed their name will always exist through their signature, every phenomenon that has manifested itself to humans will have its eternal and virtual double through mountains of images, texts, computer simulations, databases, sounds, and other encapsulated descriptions. The knowledge ark gives (almost) eternal life to everything that was destined to be ephemeral, whether in nature or in human life. It is a way of defying the instability of the Universe, of giving it a virtual replica that could perhaps even survive beyond its heat death. When humanity itself disappears, the universe could "lose its best biographer," as the saying goes, but through knowledge arks, the universe would not lose its best biography.

APPENDIX 1: NOTEWORTHY TIME CAPSULES

Project	Date of creation	Recovery date	Capsule type	Content
Epic of Gilgamesh	-3000	N / A	Metal capsule buried underground	Instructions at the beginning of the Epic of Gilgamesh to find a copper box near the wall of Uruk, containing a copy of the Epic of Gilgamesh (Mesopotamian mythology) in lapis lazuli
The Crypt of Civilizations (Oglethorpe University, Atlanta)	1936	8113	Dedicated room	Microfilms, books (Bible, Quran, Homer's Iliad, Dante's Inferno…), script of the film “Gone with the Wind”, voice recordings of various leaders, typewriter, radio, cash register, dental floss, plastic toys, Budweiser beer bottle …
Westinghouse time capsule I (New York World's Fair)	1939	6939	Metal capsule buried underground	Textiles and materials, microfilms containing 10 million words (1 catalogue, 1 dictionary and 1 almanac) and 1000 images, microscope, RKO newsreels, copies of Life magazine, doll, a dollar, a pack of cigarettes, a hat, seeds…
Westinghouse time capsule II (New York World's Fair)	1965	6939	Metal capsule buried underground	A guestbook containing numerous messages and signatures, everyday items, an assortment of materials developed between the 1940s and 1960s, a selection of writings (nuclear, space, humanities…)…
British Columbia Time Capsule (Confederation Garden Court, Victoria, Canada)	1967	2067	Metal capsule buried underground	Recordings dating from 1966 and 1967
Goodwill messages from Apollo 11	1969	N / A	Objects deposited on the surface of the Moon	Silicon discs containing messages from numerous world leaders of the time, as well as the Pope. Other items: Apollo 1 badge, Soviet commemorative medals, olive branch, American flag
Lunar Museum (Apollo 12)	1969	N / A	Ceramic plaque deposited on the Moon	Various drawings
Osaka Castle (Expo'70, Japan)	1970	6970	Metal capsule buried underground	2098 items: radio, recording of a popular Japanese song, account book, fiberscope, astronaut food, seeds…
Pioneer plates (Pioneer 10 and 11 probes)	1971	N / A	Plaque attached to a space probe	Representations of human beings and various symbols
Fallen Astronaut (Apollo 15)	1971	N / A	Object placed on the Moon	Aluminum astronaut statuette and plaque containing the names of the 14 astronauts who died up to 1971
Message from Arecibo	1974	25974	Interstellar radio message	Symbolic representations (numbers, atomic numbers, chemical formulas of DNA, etc.) coded in binary
LAGEOS plate (LAGEOS-1 probe)	1976	N / A	Plaque attached to a space probe	Representations of continental drift
Voyager Golden Record (Voyager 1 and 2 probes)	1977	N / A	Disc attached to a space probe	Sound recordings in several languages, musical recordings, about a hundred images, pulsar map
Time Pyramid (Germany)	Started in 1993	3183	Construction	Pyramid of 120 concrete blocks added one by one at 10-year intervals
Millennium Vault (Guildford, England)	2000	3000	Metal capsule buried underground	20th century items : car, postman's bicycle, microwave, mailbox…
High-Density Rosetta (Rosetta probe) (Long Now Foundation)	2004	N / A	object attached to a space probe	Prototype disc for the Rosetta Project

Project	Date of creation	Recovery date	Capsule type	Content
Svalbard Global Seed Vault (Norway)	2006	N / A	Dedicated room	Seeds of all food crops
Yahoo Time Capsule	2006	N / A	Dedicated room, digital data	Compilation of digital content (videos, messages, images...)
"Visions of Mars" (Phoenix Mars probe)	2008	N / A	object attached to a space probe	DVD containing a library about the planet Mars
Immortality Drive (ISS)	2008	N / A	Information support on board a space station	Human DNA samples and a copy of a children's book
Memory of Mankind (Hallstatt, Austria)	Started in 2012	N / A	A dedicated room in the underground levels of a salt mine	Ceramic tablets (content provided by individuals, collection of newspapers, Facebook profiles, magazines or monthly publications, content provided by institutions - universities, nuclear industries, libraries...)
Film "100 Years "	2015	2115	Film kept in a sealed safe	Movie
Arctic World Archive (Svalbard Islands, Norway)	2017	N / A	Dedicated room	Offline films (digital versions of Edvard Munch's The Scream, Dante's Divine Comedy, the Galileo series, open source code on GitHub...), guides in 5 languages (English, Arabic, Spanish, Chinese, Hindi)
Solar Library (Arch Mission Foundation)	2017	N / A	Object adrift in space	Automobile containing a 5D optical disc
Lunar Library (Beresheet probe) (Arch Mission Foundation)	2018	N / A	Information carrier attached to a space probe	A library of 30 million pages (30 languages, encyclopedias including Wikipedia...), tardigrades, David Copperfield's magical secrets, the Guesco coffee recipe , a microscopic sanctuary, Bodhi tea leaves
Lunar Library (Odyssey probe) (Arch Mission Foundation)	2024	N / A	Information carrier attached to a space probe	Nickel discs (60,000 pages of text) and molecular storage on DNA (20,000 images and 20 books)
Global Knowledge Vault (Flums , Switzerland) (Arch Mission Foundation)	2024	N / A	Mass information support	5D optical discs containing Wikipedia content and a Rosetta-type linguistic archive, DNA samples from several animal species
Rosetta Project (Long Now Foundation)	To be defined	N / A	Mass information support	Discs containing word samples and archives of several thousand languages
10,000 Year Clock (Long Now Foundation)	To be defined	In 10,000 years	The artifact is kept in a dedicated room.	Mechanism designed to function for 10,000 years
Permanent markers at the Waste Isolation Pilot Plant (New Mexico)	To be defined	In 10,000 years	Granite pillars	Pictograms and warnings in 7 languages (English, French, Russian, Arabic, Spanish, Mandarin, Navajo) about the dangers of radioactive waste stored on the site
Human Document Project (University of Twente, Netherlands)	To be defined	1 million years	To be defined	To be defined
KEO	To be defined	In 50,000 years	Objects attached to a satellite	DVDs containing personal messages, samples (air, seawater, soil), a diamond containing traces of human blood, an astronomical clock, photographs, an encyclopedia
Bracewell probe	To be defined	N / A	Autonomous, potentially self-replicating interstellar probe	To be defined

APPENDIX 2: FICTIONAL KNOWLEDGE ARK PROJECTS

Designation	Inauguration date	Brief description	Typology (memory…)	Preservation site	Quantity of information	Format	Time deadline
			Anarchic, Digital, Heritage, Thematic, Universal, Encapsulated, Mixed	***Earth / Space Centralized / Dispersed***	***Massive / Intermediate / Very selective***	***Physical / Digital / Intangible***	***Undetermined / < 1000 years / < 10000 years / > 10000 years***
Human Blackbox Project (HBP)	2037	*Collection of initiatives from heritage and related institutions to ensure the very long-term preservation of what they conserve *Improved preservation while maintaining current methods (disorganized memory) *Heritage institutions worldwide use "backup" systems *Latest technologies used for backups (DNA, 5D optronics…) *Massive digitization programs *Possible supervision by international organizations (UNESCO…) *Some institutions act as guarantors for other institutions (redundancy) *Emergence of companies and NGOs dedicated to digitization, backups, etc.	Mixed (anarchic / digital)	Earth, scattered	Intermediate	Hardware / Digital	Undetermined
Internet Arch	2034	*Private initiative to archive the Internet (as an extension of what already exists - Internet Archive, Mega, Wolfram Alpha…) *Creating an internet "backup" *Internet content is duplicated and stored on a handful of dedicated servers around the world (centralization) *Use of the latest technologies (DNA, 5D optronics…)	Digital	Earth, centralized	Intermediate	Digital	<1000 years
Universal Library	2045	*An international initiative, a global approach, possibly overseen by UNESCO, to create a global archive of all heritage on Earth *Initially, an international and standardized index will be created so that each item is identified with a unique code. *The subsequent creation of an international public library containing a digital copy of all identified items on Earth *This project is carried out as an extension of what national libraries are already doing on a national scale. *The content of this library may be distributed to a handful of locations on Earth, or even just one, depending on geopolitical tensions between member countries. *Possible implementation of an international treaty to ensure that this project is compatible with the laws of different countries (regarding copyright and preservation)	Universal	Earth, centralized	Massive	Digital	Undetermined

Designation	Inauguration date	Brief description	Typology (memory…)	Preservation site	Quantity of information	Format	Time deadline
		*This is not a library accessible to the general public for legal reasons and to facilitate very long-term preservation.					
Basalt forest	2400	*Architectural project whose construction is planned to last for several centuries *Burial of engraved clay tablets, bas-reliefs and rosette discs below the monument *The tablets are engraved in the 6 official languages of the UN (English, French, Russian, Arabic, Mandarin, Spanish) as well as in Hindi, Kiswahili, Malay and Japanese. *The tablets contain scientific laws and mathematical theorems, as well as extracts from various literary works from around the world.	Encapsulated	Earth, centralized	Very selective	Material	<1000 years
Eldorado Laboratory	2035	*Research laboratory relatively isolated from the rest of the world *The community of researchers and students living on site is quite self-sufficient, and manual labor plays an important role in the educational curriculum. *The laboratory is equipped with an archive containing a significant number of scientific works, though not exhaustive. *Learning and memorizing fundamental knowledge in all fields is one of the special features of this laboratory. *A monthly journal is published, which is distributed beyond the campus, and which has a certain international reputation. *The compilations in this journal form a kind of synthetic "bible" of scientific knowledge and thought	Heritage	Earth, scattered	Very selective	Intangible	Undetermined
Intergenerational user guide (IGUG)	2041	*Multilingual user manual on the operation of a nanometric memory *This is a very detailed technical datasheet and manual that theoretically allows the use of a nanometric substrate, and even the construction of a machine to read such a substrate. *Some basic principles of chemistry, programming, genetics, mathematics, and cryptography are reviewed in the preamble. *Many copies are being distributed worldwide by the company behind this initiative	Encapsulated	Earth, scattered	Very selective	Material	<1000 years
Encyclopaedia orbitalis	2057	*Time capsule with programmed retrieval carried on board a satellite in Earth orbit *The satellite is designed to fall back to Earth after several thousand years * The time capsule itself consists of a digital archive of most of the world's major encyclopedias (Encyclopaedia Britannica, Wikipedia, Encyclopaedia). Universalis etc.) *Use of 5D optical discs to store information *International collaboration required for the space mission	Mixed (encapsulated / thematic)	Centralized space	Intermediate	Digital	<10000 years
The Eternal Archive	2049	*Private archive held by the owner of a large transnational corporation *This is not strictly speaking a heritage institution, but rather a personal multimedia library "disguised" as an archive	Encapsulated	Earth, centralized	Intermediate	Physical / Digital	<10000 years

Designation	Inauguration date	Brief description	Typology (memory…)	Preservation site	Quantity of information	Format	Time deadline
		*The archive mainly contains copies (digitized or not) of copyright-free items, accessible online Additional copyrighted content is also present on the site, but this time, it is not accessible to the general public for legal reasons.					
Star Radio	2038	*Time capsule designed as a radio transmission sent into space *Continuous flow of information sent in several simultaneous directions, including to the Moon, from which this flow is received by the astronauts present there *The amount of information transmitted is limited by the transmission speed	Encapsulated	Space, scattered	Very selective	Intangible	>10,000 years
Pergamum	2067	*The "ultimate" space-time capsule aboard a series of spacecraft sent into deep space *The first ships contained only digital copies of a selection of media and encyclopedias. *The latest vessel consists of a universal space library, a historic first. *The vessels have no recipients, and their sole purpose is to constitute comprehensive testimonies of the extent of our civilization's knowledge and culture. *Molecular mass storage (DNA) as well as 5D optical discs have been used *These should survive for trillions of years, until the stars of the Universe begin to gradually die out	Universal	Space, centralized	Massive	Digital	>10,000 years
FIAME	2035	*INTERNATIONAL FORUM OF ACTORS IN EPISTEMIC MEMORY *Network of associations, lobbies, heritage institutions, companies specializing in the digitization or preservation of archives, and all kinds of stakeholders involved in knowledge ark projects *Several objectives: pooling funds, influencing state legislation, investing in new information storage technologies, joint initiatives for new time capsules *A system of labels and awards that annually recognizes an actor working for epistemic memory. *Providing significant media coverage to various knowledge ark and time capsule projects around the world *Provision of a near-exhaustive index of terrestrial heritage.	N / A	N / A	N / A	N / A	N / A

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