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Suspended Animation, Gateway to a Second Life and Interstellar Travel

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Abstract

Suspended animation (SA) is the temporary (short- or long-term) slowing or stopping of biological processes. Here, we will briefly review two major applications of SA. There are two main fields where long-term SA constitutes an irreplaceable technology, namely manned deep space travel and cryonics, the cryopreservation of humans after clinical death with the aim to reanimate them in the future. We will present a brief overview reviewing the evidence on which is based the expectation that in the future it will be possible to revive cryopreserved animals and humans. For many years cells have been cryopreserved in liquid nitrogen (LN) and then thawed and cultured indefinitely. It has also become routine to cryopreserve human and animal embryos in LN, which are then rewarmed and implanted into the uterus of females that become pregnant and give birth to healthy individuals. There has also been much progress in cryopreservation of adult tissue, such as the ovarian cortical tissue of young women suffering from cancer, in order to preserve viable oocytes for post treatment. The final section provides an overview of a group of emerging technologies that seem to propose to us a Faustian pact, achieving immortality in exchange for abandoning our biological nature. The vertiginous advances that science has shown in recent decades create well-founded hopes that, in a not too distant future, technology will be able to free the human species from the tragic final destiny that nature imposes on each individual, death.

Mortality, an Ominous Burden

Death always brings sadness to us but it has also been a source of inspiration for the creation of expressions of art of unsurpassed beauty **(Figure 1)**.

Figure 1: Mausoleum where an angel lies over a grave weeping in sadness for the loss of a loved one. Cemetery Montjuïc, Barcelona, Spain.

Men have always sought a way to escape their mortality, a chance for a second life. There is a group of individuals who believe that there is a technology that can offer them a second chance to live after natural death; its name is **cryonics,** which can be defined as the technology dedicated to the cryopreservation of human beings after their natural death, usually caused by diseases for which there is currently no cure. The hope of those who resort to cryonics is that in the future, when science discovers the cure for the disease from which they died and the way to revive them, they will be able to return to a healthy and long life. There are several organizations in the world dedicated to cryonics, the two largest are in the US, namely, the Cryonics Institute in Michigan **(Figure 2)** and the Alcor Foundation in Arizona **(Figure 3),** smaller ones are in Russia, Switzerland, Spain, Israel and Germany among other countries. Currently, the Cryonics Institute keeps about 250 patients frozen, Alcor keeps 242 bodies and 116 heads cryopreserved (the head-only option focuses on preserving the brain in the hope to retrieve the patient 's mind after reanimation). This activity began in the mid-1970s in the US, led by Robert Ettinger, considered the father of cryonics. The total number of patients in cryonic suspension today is about 600 and there are about 7,000 active members of cryonics organizations worldwide.

Figure 2: Storage area where large cryostats containing liquid nitrogen (LN) are kept in which the patients (typically 6 per unit) are stored in LN at -196 degrees. The logo on these thermos reads, “Cryonics, technology for life.”

Figure 3: Brochure from the Alcor. Foundation of Arizona. The right panel shows one of the cryostats (thermos) where patients (or heads) are stored in LN.

Clinical cryonics has been in practice for over 50 years [1,2] and involves two stages at which the temperature of the deanimated patient’s body is lowered. The first stage involves short-term (hours) Suspended Animation (SA) and takes place immediately after deanimation of the patient, when a standby team lowers body temperature to around 10 ºC, taking special care to keep the brain cool in order to lower oxygen consumption during cryopatient transportation from the site of deanimation to the facility where the body will be placed in long-term storage cryostats at Liquid Nitrogen (LN) temperature (Figure 2 and 3) [3].

Space travel Concerning space travel, flying to distant extra solar planets orbiting neighbor star systems, is a journey likely to take decades or even centuries (Flight time for Voyager 2 to Neptune, 12 years [4]). It would make it necessary to keep crews in biostasis in order to prevent aging and resource consumption [5]. For interstellar space flight, ultralow subzero SA strategies will be mandatory since interstellar travel will probably take a number of years measured in 3-digit figures. For instance, at its present speed of 17.3 km/s, it would take 73,000 years for the Voyager 1 spacecraft to reach Proxima Centauri, the closest star to the Sun, at 4.24 light years of distance, some 4 x 10^{12} Km [6]. An interstellar spaceship of the future is likely to be driven by highly advanced robotic AIs and to carry human passengers in SA pods, as already depicted in science fiction movies **(Figure 4 and 5).**

Figure 4: Starship Avalon from the ilm "Passengers", traveling at a significant fraction of the speed of light from earth to a habitable exoplanet. The duration of the trip is 120 years.

Figure 5: Passenger hibernation bay in the Avalon, which carries 5,000 colonists, kept in individual SA pods. Separately, a crew of 250 is in SA at the command ring.

Feasibility

The idea of freezing oneself after death, hoping to be revived in the future, seems at first glance a fantasy disconnected from reality. Physical death has always been considered an irreversible step and the reanimation of a frozen individual as an absolute impossibility. However, in science and technology it is risky to state that something is impossible. Throughout the history of science it has often been stated that certain technological advances were impossible to achieve and today such advances are part of our daily lives. That is why we want to present a brief overview reviewing the evidence on which is based the expectation that in the future it will be possible to revive cryopreserved people. So far all attempts to freeze and revive mammals have failed. However, for many years cells have been cryopreserved in LN and then thawed and cultured indefinitely. It has also become routine to cryopreserve human and animal embryos in LN, which are then rewarmed and implanted into the uterus of females that become pregnant and give birth to healthy individuals **[7,8]**.

There has also been much progress in cryopreservation of adult tissue, such as the ovarian cortical tissue of young women suffering from cancer, who must undergo aggressive therapies that kill their entire oocyte reserve. After the patient has recovered satisfactorily from the treatment, the cryopreserved ovarian specimens are thawed and implanted into the ovary of the patient, who then ovulates again and can conceive healthy babies **[9,10].** The technique used to freeze embryos or adult ovarian tissue is called vitrification **[11].** This technique works in all cases where the specimen to be cryopreserved is small, a few mm in size. Typically, a cube of ovarian cortex measuring about 10 mm on each side and 3-4 mm thick is removed from the patient by laparoscopy. It is immersed in vitrification solutions at 4ºC and then cooled very quickly by immersing it in LN. The specimen is frozen virtually instantly thanks to its small size. This is key to preserving the integrity and viability of the tissue. It is then stored in LN. To rewarm it, the reverse procedure is performed and here the speed of rewarming is particularly critical. Vitrification solutions contain Cryoprotective Agents (CPAs) that prevent the formation of ice crystals that are sharp and cause substantial damage to cells. Vitrification works excellently on all types of biological specimens provided they are only a few mm in sizes **[11]**. One example are certain nematodes of the species Caenorhabditis elegans (C. *elegans*), which are free living small worms. **Figure 6** shows reanimated C elegans after vitrification in LN and reanimation, 94% of the young animals revive and show a fully preserved memory **[12].**

Figure 6: Adult specimens of C elegans one day after vitrification in LN and subsequent reanimation by ultrafast rewarming. The procedure used is the same used for human embryos. After renimation the animals fully remember tasks learned before vitrification **[12]**.

Figure 7: Tardigrade in one of its normal habitats, mosses, lichens and ferns. These animals are classified as extremofiles due to their resistance to very severe environmental conditions. They have been shown to resist exposure to the vacum of space on shuttle missions.

Nature also offers concrete examples that cryopreservation is possible. The most remarkable example is perhaps that of some small animals whose size is 1 mm or less, the tardigrades. **Figure 7** shows a tardigrade magnified several times. What is interesting about tardigrades is that they are animals with a nervous system (constituted by a primitive brain and segmental ganglia), as well as a reproductive and digestive system with the basic characteristics of those of more advanced animals. Tardigrades belong to a group of organisms known as extremophiles because they can tolerate high levels of radiation, UV light, the vacuum of space or enormous pressures. They also tolerate extreme cold like that of Siberia, which in winter reaches -40ºC or less. When the temperature falls, these animals, which normally contain 85% water, dehydrate until they have less than 3% water. They also produce a sugar, trehalose, which is a very powerful cryoprotectant of cell membranes. Under these conditions, their metabolism is virtually suspended and they can remain in this condition for years. When the ambient temperature rises to normal values, tardigrades rehydrate, their metabolism is reactivated and the animals resume their normal life, being able to reproduce normally.

These examples suggest that it would not be impossible to cryopreserve a larger animal and then revive it. Furthermore, there does not seem to be any physical or biological impossibility to achieve this goal. What is clearly needed is a sufficiently advanced reanimation technology. The freezing and subsequent successful rewarming by means of magnetic nanoparticles and magnetic fields (nanowarming) of rat kidneys has recently been reported, which opens the future possibility of creating organ banks **[13].** Nano-warming has also been used to reanimate vitrified C *elegans* **[14].** Cryonicists believe that future generations will succeed in developing freezing and resuscitation technologies capable of reviving larger animals and eventually human beings. Many consider that achieving the reanimation of a patient who has been frozen for several years or decades would seem more an act of magic than one of medical technology. This view is reflected by the third law (of science and technology) formulated by the science fiction writer Arthur C. Clarke. It reads: "Any sufficiently advanced technology is indistinguishable from magic” [15].

The Future

This section provides an overview of a group of emerging technologies that seem to propose to us a Faustian pact, achieving immortality in exchange for abandoning our biological nature. The vertiginous advances that science has shown in recent decades create well-founded hopes that, in a not too distant future, technology will be able to free the human species from the tragic final destiny that nature imposes on each individual, death. Although today's emerging technologies promise increasing advances in the treatment of different diseases, the indefinite prolongation of life and the radical rejuvenation of our bodies will require technologies that belong to the future. One of these technologies is nanomedicine; nanomedicine will be based on nanotechnology. The formal birth of nanotechnology took place in 1986 with the publication of the seminal book "Engines of Creation", **(Figure 8),** whose author, Eric Drexler, is considered the founder of this revolutionary discipline [16]. Nanotechnology has been defined by Drexler as a technology that is based on the manipulation of individual atoms and molecules in order to build complex structures, specified atom by atom. In fact, there are already systems that have been using the principles of nanotechnology for a very long time: these are the living organisms, who build structures as complex as a man, assembling them atom by atom. Drexlerian nanotools should be able to manipulate individual atoms and molecules, positioning them precisely to shape them into the desired structures. **Figure 9** illustrates an example of this. The image shows 35 Xenon atoms forming the IBM logo on a Nickel surface. The image represents the electron densities of the atoms that constitute the surface, as recorded by the Scanning Tunneling Microscope (STM). The false color differentiates the two atomic types [17]. There are now a growing number of physicists and engineers who believe that this technology will begin to make concrete contributions to our way of life in 2 or 3 decades, perhaps even sooner. There are also a growing number of biomedical scientists who believe that one of these contributions will be the emergence of nanomedicine, a medical specialty based on the use of intelligent nanoinstruments capable of repairing or "curing" at the molecular level from within the body. Although nanomedicine has not yet had any applied developments, an increasing number of theoretical articles on nanomedical applications are already being published. **Figure 10** illustrates the cover of a text on nanomedicine [18].

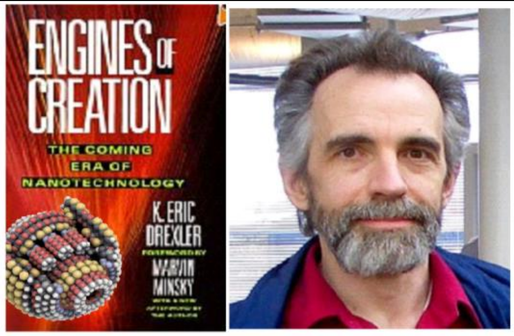

Figure 8: Eric Drexler, and his 1986 book “Engines of Creation”, which constituted the foundation of nanotechnology, a manufacturing strategy based on the manipulation of single atoms and molecules to build nanoinstruments. This book started a new era in technology.

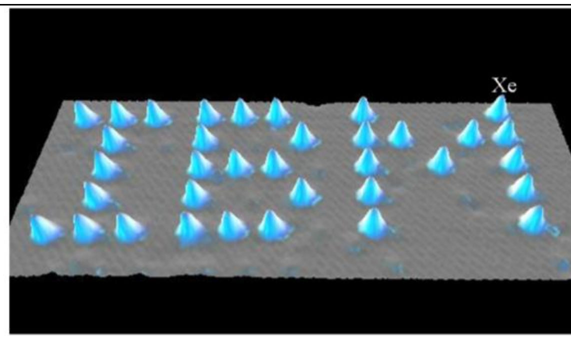

Figure 9: The image shows 35 Xenon atoms forming the IBM logo on a nickel surface. The image represents the electron densities of the atoms that constitute the surface, as recorded by the scanning tunneling microscope. The false color differentiates the two atomic types.

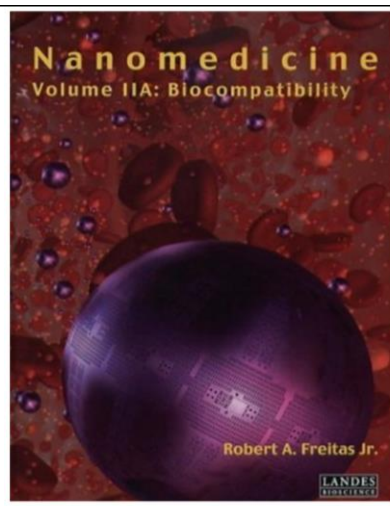

Figure 10: **Advanced medical nanoinstruments.** Artist´s view of future therapeutic nanobots injected into the blood stream [F**ront cover from ref. 18, with permission]**.

The Prospect of Becoming non Biological Humans

Ray Kurzweil is an American engineer and futurist who are considered by many one of the most influential minds in the field of emerging technologies. According to his vision, the use of electronic microimplants that optimize our body and brain functions will progressively be adopted in medicine. He believes that in the not too distant future, advances of such magnitude will be achieved in the field of electronic implants in the brain that probably these implants will not only be used to cure diseases, but will also be employed to optimize the brain (and other parts of the body) capacities of young and healthy individuals. In his best seller "The Age of Spiritual Machines" [19] he predicts that in the not too distant future man will merge with his technology and we will end up as beings in which biological and electronic structures coexist. Furthermore, Kurzweil predicts that during the course of this century, artificial intelligence combined with biotechnology and nanotechnology will have achieved such a knowledge of the functioning of the human brain and the nature of the mind that it will be possible to migrate our mind from the fragile biological body that houses it today to advanced cybernetic supports, turning us into a kind of "avatars" in which our mind will reside, benefiting from the unimaginable physical and intellectual capacities that these artificial bodies will offer. We will enjoy a precise and powerful memory like that of large computers and physical capacities reminiscent of Superman's [20].

Immortality

Perhaps the most transcendental implication of mental migration is the achievement of immortality since our bodies could be permanently repaired and updated as we do today with our PC. And we could also make backups of our minds, which would protect us from any type of accident. These are the postulates and aspirations of Transhumanism. According to the vision of transhumanists, man will eventually merge with his technology (Figure 11). We will become nonbiological humans [21].

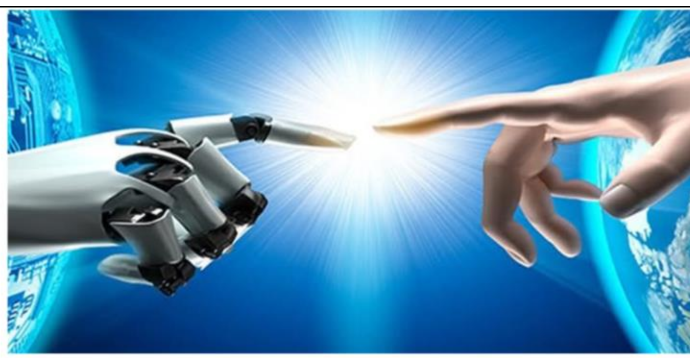

Figure 11: Allegorical image representing the coexistence of non-biological humans with biological people during an era in which humanity will transition to what R. Kurzweil calls the Singularity. In an initial stage, reproduction will be limited to biological humans, but it is likely that advances in medical biotechnology will make it possible for non-biological humans to conceive human babies who may, after puberty, have the option of becoming non-biological beings.

The achievement of immortality and eternal youth has been a longing of man since the most remote antiquity. Sought for millennia almost exclusively through religion or alchemy, the vertiginous advances of current science create well-founded hopes that in the not-too-distant future, technology will be able to free the human species from aging and death. Throughout the history of life, not only individuals are born, reproduce and die, but also animal and plant species arise, flourish and become extinct. This is the mechanism that nature uses to ensure the evolution of life towards increasingly advanced forms, of which the culminating exponent today seems to be our species. If we lived indefinitely, we would not be immutable like stones, we would change and our vision of the cosmos would evolve continuously. But we would maintain our identity and memories. It would be the same case that happened to us when we transitioned from childhood to adulthood. We remember our childish vision of the world with tenderness and a smile. It was a naïve and inexperienced view, very different from our adult vision. We evolved, yes, but the continuity between that child and us has not been broken; our identity remains. Death, on the contrary, extinguishes that identity and after it occurs we no longer evolve, the mind ceases to exist and our bodies degrade irreversibly **[22].** Without doubt, future generations will live in an increasingly interesting world and universe. Perhaps cryonics will allow some of us to wake up in that paradise-like world of the future.

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