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Reviewing the Concept of Technological Singularities: How Can It Explain Human Evolution?

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Abstract The concept of "technological singularity", while controversial, is typically applied to predict the next explosion of intelligence related to advances in computers and artificial intelligence. A potential "rise of machines" has been explored at length by Ray Kurzweil, Vernor Vinge, and many other scholars and futuristic enthusiasts. This study focuses on the fundamentals of the concept of technological singularity to understand the technological evolution of humankind based on the four main characteristics that constitute this concept. When this method is applied to a historical view, it is possible to isolate four technologies worthy of being called "singularities". In fact, these technologies have formed the basis of human evolution by drastically changing our interaction with the environment, changing how we understand our place in the universe, changing our social behaviour and organizational structure, boosting human intelligence and explaining demographic explosions.

Keywords Technological singularities · Civilization · Human evolution · Artificial intelligence · Anthropology

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Introduction to the Concept of Technological Singularities

The hypothesis of technological singularities was formulated by John von Neumann, together with Stanish Ulam, in 1958, and later explored by Vernor Vinge, Ray Kurzweil and others. According to Vinge, technological singularity refers to an enormous explosion in artificial intelligence (AI) that would occur at some point in future decades. This acceleration of technological progress would be the central feature of the 20th and 21st centuries, and these changes would lead to the creation of a new technological entity with even greater intellectual capacity than human intelligence. Furthermore, this potential singularity could lead to the emergence of an entity with superhuman intelligence in the "following years" of 2005 to 2030, culminating in the rise of machines and the end of the human era. This possibility could be triggered by several elements, such as large computer networks "waking up" this artificial, superintelligent entity, computers and humans interfacing intimately in such a way that users are considered beings with superhuman intelligence, and biological science providing a means to improve natural human intelligence [1].

Sandberg [2] found nine meanings of the term "technological singularity": (1) accelerating change, exponential or super-exponential technological growth following economic growth and social change; (2) a self-improving technology capable of developing new and better technologies; (3) an intelligence explosion caused by smarter systems capable of improving themselves; (4) the emergence of "superintelligence"; (5) prediction horizon, because the emergence of superhuman intelligence will make the future impossible to predict based on our current knowledge and experience; (6) phase transition, in which the singularity brings new forms of organization; (7) complexity disaster, in which increasing complexity and interconnectedness increase instability; (8) inflexion points, in which a large growth of technology or economy follows a logistic growth curve; and (9) infinite progress, in which the rate of progress in some domain goes to infinity in finite time. For Sandberg, these meanings can be summarized in three main aspects—accelerating change, prediction horizon and intelligence explosion. For Armstrong [3], a singularity is a breakdown of our ability to predict beyond that point because our standard tools would become inadequate for understanding and shaping what comes after.

Despite the predictive nature of these views, it is important to discuss the core and fundamental concept of technological singularity. According to Vinge, it is "a point where our old models must be discarded and a new reality rules. As we move closer to this point, it will loom vaster and vaster over human affairs till the notion becomes a commonplace" [1]. This means that the singularity would create a new level of technological advancement capable of changing perceptions of reality. Furthermore, it is described as follows: "It seems plausible that with technology we can, in the fairly near future, create (or become) creatures who surpass humans in every intellectual and creative dimension. Events beyond such an event—such a singularity—are as unimaginable to us as opera is to a flatworm" [4]. A similarly important aspect is presented by von Neumann, who describes technological singularity as the accelerating progress of technology and changes in the mode of human life, which gives the appearance of approaching some essential singularity in the history of the race beyond which human affairs, as we know them, could not continue [cf. 5]. Chatfield establishes singularities as a "point of no return" based on the notion that the development of AI would reach a point of no return when it becomes capable of producing even more sophisticated machines [6]. Other academics lean towards broader aspects, such as accelerating change, self-improving technology, intelligence explosion, the emergence of superintelligence, prediction horizon, phase transition, complexity disaster, inflexion point and infinite progress [2].

The creation of these AI machines would be remarkable because they would have cognitive skills to rival or surpass those of humanity. These machines would be capable of recursive self-improvement by redesigning themselves to be more advanced. This exponential capability to improve themselves in further redesign would eventually lead to an "intelligence explosion", and AI machines would reach levels of intelligence that are beyond human understanding and, consequently, out of our control.

It is fair to say that this type of technological revolution would demonstrate that the only generation capable of understanding technological singularity is the generation that experiences this phenomenon and subsequent generations. Therefore, previous generations would not be able to fully understand this technological concept. In fact, this situation may create a paradox because most academics who write about this concept are generally attempting to predict and explain the next technological shift. Moreover, despite the fact that all of their analyses consider this concept to be related or limited to AI, its characteristics are far broader and can help explain human technological development, especially given that all temporal predictions related to AI and the next singularity at this point have failed.

Nevertheless, it is possible to delimit the concept of technological singularity to four characteristics proposed by these researchers. First, the technological singularity is a type of knowledge acquisition that causes enormous changes in technological development by triggering a series of other acquired knowledge, leading to an "explosion of intelligence". This "Intelligence Singularity" or explosion of intelligence proposed by Vinge and Kurzweil was originally substantiated by Irving John Good in 1965, who described it as an ultraintelligent machine capable of designing even better machines that would surpass all the intellectual activities of humanity, resulting in something that he defined as an "intelligence explosion" ([7]:33). Kurzweil [8] exemplifies this explosion of intelligence as the exponential growth of computing performance. According to him, this would cause supercomputers to match the capability of the human brain by the end of that decade (writing in 2005) and cause personal computing to achieve this around 2020. This exponential growth of computing compared to the human brain is demonstrated in his chart (Fig. 1).

Second, it is "a point where our old models must be discarded and a new reality rules". That is, technology changes the human perception of the universe and humanity's interactions with the environment and

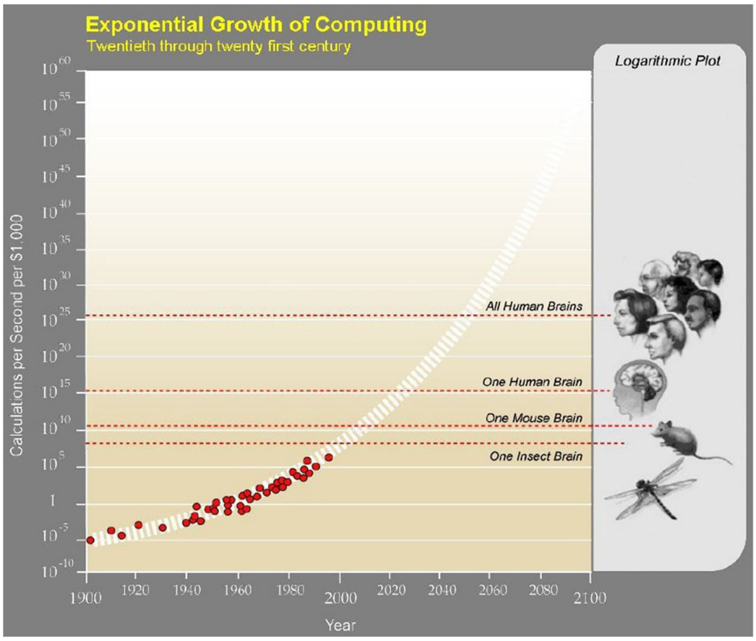

Fig. 1 Kurzweil's ([8]: 71) chart of exponential growth of computing

within social relationships. Third, only the generation that witnesses this achievement and subsequent generations are capable of fully understanding it. Finally, technological singularity involves a "point of no return", which may be interpreted as knowledge that cannot be lost after it has been gained. By considering these four aspects as the main characteristics of technological singularity, it is possible to look retroactively and isolate four advancements that triggered similar reactions worthy of being considered the technological singularities of their time.

The Problems in the Concept

This concept, despite receiving increasing attention, is not free from criticism, especially due to its overreaction and pessimism with regard to the "inevitable" rise of machines against humanity as well as problems with its philosophical core. Some statements related to the possibility of the next singularity are so overblown that it is difficult to take them seriously. For example, Kurzweil [9] writes, "So we won't experience 100 years of progress in the 21st century—it will be more like 20,000 years of progress (at today's rate)". Furthermore, the concept holds some speculative premises.

For example, the first assumption is based on the premise of fast computers and an increasing rate of improvement. This theory does not consider the possibility of a technological plateau and a slowdown in innovation, but this possibility cannot be ignored. This issue is explored by Leitner [10], who argues that despite increasing investments in research and development (R&D) and innovation, technological output and progress may be in decline in relation to output, which, per worker, has only marginally increased or stagnated in the last two decades in several highly industrialized countries. In fact, he estimates that the average R&D worker in the United States in 1950 contributed seven times more than an R&D worker in 2000, which may suggest a technological plateau. Generally, R&D companies have reduced their expenditures in innovation activities due to a decline in appropriate economic returns. Cowen [11] argues similarly (although from an economic perspective) by questioning the quality of recent innovations and events, stating that apart from the Internet, most material aspects are the same as in the 1950s. In fact, the rate of global innovation reached a peak in the year1873 and declined after 1955, which could indicate the onset of a technological slowdown. It is unclear whether such a plateau will affect AI. However, this possibility cannot be ignored or dismissed.

Potapov [12] also criticized the concept, explaining that the design of new, faster computers and attempts to design these computers more quickly is just an illustration of an "intelligence explosion". In fact, this could be another form of singularity technology or a set of technologies that could replace it. Potapov cites examples of humans using computers to conduct genetic research and improvements to computers that result in smarter humans as well as faster computers. According to him, the necessity of superintelligence being artificial is simply an additional and independent premise.

Also problematic and generally exaggerated by theorists of the concept of technological singularities are the ideas of supercomputers that are capable of emulating the human brain as well as the creation of even more intelligent machines in an exponential development of AI. As Allen [13] explains, despite the appeal of developments in AI, overall, AI-based capabilities have not been exponentially increasing as originally predicted, especially when measured against the creation of a fully general human intelligence. The detailed mechanisms of human cognition are extremely complex. The complexity of the brain is based on several different structures that have been shaped by millions of years of evolution to do particular things, while computers are based on billions of identical transistors in regular memory arrays that are controlled by an electronic circuit with just a few different elements.

Appropriating the Computational Concept to an Anthropological–Historical Context

Despite the problems with predictions, Vinge's and Kurzweil's methodology can be appropriated and even expanded beyond their original focus of computing and AI to a historical and sociological perspective, making use of the key aspects explained above: a substantial increase in intelligence; a point at which our old models must be discarded; a temporal point at which only the generation and the subsequent generations that witnessed this achievement are capable of fully understanding it; a point of no return; and, finally, accelerated progress of technology and changes in the mode of human life for a period of time. In this case, as also discussed above, we should consider the possibility that such an explosion or accelerated progress could be followed by a technological plateau for another period of time (with technological developments at a slower speed). Based on this, it is possible to observe specific points in human history that are similar to events but not hypothetical. Only a few technologies strictly obey the definition of technological singularity and would be worth considering as past technological singularities. This is not only because such technologies would be based on the previously mentioned aspects but also because these technologies were the core, basis or matrix of several derivative technologies that were developed during the subsequent brief timeline.

Only four knowledge or technological events can be considered technological singularities: (1) the control and manipulation of natural elements triggered by the manipulation of fire by early humans; (2) mass energy production in a controlled environment triggered by farming; (3) the ability to store and pass on knowledge to future generations triggered by writing; and, finally, (4) large-scale automated production triggered by machinery, which we are still experiencing. These four events resulted in an explosion of intelligence, triggering other derivative technologies in a relatively short time. They brought new perceptions of reality and understanding. Two (of countless) examples show how technology has changed the perception of the universe. First, fire changed the human brain size, enhancing human intelligence and memory. Second, humans who received modern education from the middle of the 19th century on had a good understanding of the mechanics and physics of the universe, while only one or two hundred years before, mythological aspects still dominated the human mind. The above-mentioned key technologies were points of no return. Regardless of what happens in the future, it is illogical to assume that humanity could forget how to handle and create fire, how to read and write, or the basics of farming and modern mechanics.

Some scholars have attempted to point to past technologies as examples of previous technological singularities. For example, Desai [14] argues that the mechanical advantage present in former technologies increased the physical ability of humans and was used over the centuries to build complex structures: to humankind, machinery became a kind of "Strength Singularity". The computational revolution became the "Computing Singularity", and the development of automation became the "Robotic Singularity". According to Magee and Devezas [15], past singularities were large-scale societal transitions, such as the birth of globalization in the 15th and 16th centuries initiated by the Portuguese empire and the evolution of time measurement between the 17th and early 20th centuries, when clocks became sufficiently accurate to establish work times.

Hanson [16] also attempted to identify past singularities but through an economic growth perspective. For Hanson, there were two events worthy of the name "singularities": the agricultural and industrial revolutions. Most of the time, economic growth has proceeded at a relatively stable exponential rate in the past few centuries. However, the Industrial Revolution caused an abrupt increase and doubled time by approximately 15 years, creating something approximately 60 times as fast as it had been in the previous seven thousand years. This phenomenon was similar to the transition caused by the economy based on agriculture, which changed the population level from approximately 10,000 protohumans to approximately 4 million modern humans. However, he hypothetically and speculatively explored the possibility of two other previous singularities: the emergence of animal life into the first protohumans and the growth of the universe from the time after the Big Bang to the first animals. This approach cannot be methodically applied to human civilization because it cannot be properly measured and compared and thus would not fit to theaspects of what constitutes technological singularity.

Fire: The Control and Manipulation of Natural Elements

The importance of fire is well-established in many ancient civilizations, and the discovery of fire constitutes a watershed in human history. In ancient China, fire is presented in the legend of Suirenshi (燧人氏). In Greek mythology, fire is related to the story of Prometheus (Προμηθεύς). In the Book of Enoch, fire is related to the fallen angel Azazel. Fire is represented among other mythologies and is often portrayed as an ability restricted to the gods that is stolen by a legendary character. In each case, this event becomes the impetus for human development. Since fire is a natural chemical reaction, it is challenging to establish accurate data on the use of fire as an artefact. There is clear and varied evidence of ancient uses of controlled fires in contrast to contained and maintained natural fires. However, it is generally reasonable to assume that this development occurred between 0.2 and 1.7 million years ago [17], and the habitual use of fire began only 300,000 to 400,000 years ago [18]. While some scholars have considered the development of writing the distinction between civilization and barbarism [19], it would be more accurate to consider the controlled manipulation of nature (fire, in this case) the trigger that initiated the concept of civilization. It ultimately provided human beings with control over their own destiny and separated humans from their predecessors as well as other animals.

The development of controlled fire changed the course of human evolution in drastic ways, triggering chain reactions in human relations with nature, social organization and even humanbiology. Because of the use of fire, the earliest hominids were able to use caves as regular home bases, and as beings without fur could counteract the loss of corporal heat. Until then, the loss of corporal heat was problematic in open fields [20]. In addition to protection from the cold, fire allowed radical changes in human biology as well as in humanity's relations with nature. Prior to the use of fire, humans were easy prey for large predators (especially at night). However, with the use of fire, humans gained a tool that could be used as protection from predators, permanently establishing humans at the top of the food chain. Related to the biological effects, fire made it possible to cook food, which changed human digestion and increased the absorption of proteins. In turn, as meat consumption increased, humans gained more energy, which influenced the reproduction rate ([21]:55, 179) and most likely fuelled brain growth. This change is explained by improvements in cooking techniques ([21]:105; [22]), which most likely boosted human intelligence. Additionally, it is fair to assume that because of cooking, humans were capable of adapting to a larger variety of diets in different regions. Local cuisines have been developed to improve different food types [23], which have helped humanity to successfully spread worldwide.

Moreover, fire clearly altered socio-cultural aspects by triggering several other technologies. With fire and cooking, early humans were able to develop pottery to store food [24], which opened the doors to the concept of manipulating further elements and, eventually, to metallurgy several thousands of years later (approximately 4000 BC). This technology, in turn, allowed humans to manipulate metals to create desired shapes, which until then was impossible or extremely difficult because hammering was the only option. With knowledge of heating via fire, metals could be softened and manipulated ([25]:2).

Knowledge of fire and its use in controlling and manipulating natural elements fulfil every defining characteristic of a technological singularity. In fact, this was the first singularity because it allowed the species to reconfigure its surrounding environment and unconsciously alter its biology. This technology not only triggered several other technologies but also caused an explosion of intelligence due to its effects on human anatomy. Fire also changed human interaction with nature as well as human perception of the universe. In fact, this technology was responsible for enabling humans to develop sapience by introducing an entirely new perception of reality. Additionally, the domain of fire was restricted to the hominids who witnessed and developed it. It was not possible for prior generations to fully understand and control it. Furthermore, the manipulation of fire was a point of no return. This technology is such an essential concept for humans that its existence has become a fundamental part of humanity, and the loss of this technology is impossible.

Farming: Mass Energy Production in a Controlled Environment

The second noteworthy technology that can be considered a technological singularity is mass energy production in a controlled environment, initiated by the development of farming. The word "energy" refers not only to the energy required to sustain life through food in agriculture but also to the human capacity to develop large-scale sources of energy for varied use. This reference to energy involves broader terminology that includes even industrial cases. For example, in the last century, ethanol extraction was used for production, illumination and logistic purposes.

According to Paterniani [26], the survival and success of human beings were only possible because of the agricultural techniques developed approximately 10,000 years ago. Specifically, before agricultural development, nomadic humans were focused on hunting and harvesting the food provided by nature. To feed one person, 2500 ha of land was required, whereas after the development of agricultural techniques, 250 ha was able to feed 3600 people. The impact of agricultural development caused a drastic change in human organization by reducing nomadism and causing a population explosion. Even with the ability to primitively control natural elements, humans remained very vulnerable to the challenges posed by nature. Because groups of nomad hunters lived in smaller communities, extended families typically consisted of approximately 50 people. Agrarian communities, however, required a larger labour force to work in the fields. Additionally, non-nomadic groups that produced their own sources of energy were much less vulnerable to food shortages and environmental changes that affected the available food supply. A diminished food supply directly caused decreased birth rates and increased mortality rates in nomadic groups ([27]:9). Additionally, in some cultures, the development of seeds that could be fermented likely constituted the earliest forms of medicine to ward off diseases. Grains were fermented to add alcohol to water as a way to prevent diseases. The process of heating water when brewing grains and producing alcohol through fermentation was a way to make water relatively safe to consume ([27]:12).

Similar to fire, farming had a biological impact on the human body. It was responsible for shaping the human immune system while introducing many new diseases; the majority of diseases today are related to some level of the domestication of animals as sources or vectors. Many infectious diseases today or in the recent past are the result of contact with and exposure to animal excrement and contact with pest species, such as rodents. This contact became more frequent with farming, urbanization and a sedentary lifestyle. Furthermore, human red blood cells changed to confer resistance to malaria in some individuals [28]. For Wilde and colleagues [29], the light hair, eye and skin colour in the European population was the result of a diet poor in vitamin D due to the switch from a vitamin D-rich aquatic or game-based hunter-gatherer diet to a vitamin D-poor agriculturalist diet.

However, the greatest impact related to agricultural development was behavioural. As a requirement for land cultivation, the earliest human societies were pushed towards settlement life, which led to the development of a complex political structure based on hierarchical food production [30]. The increased food storage freed parts of the earliest societies to work in different areas rather than remaining limited to food production. This gradually divided society into various types of professions. Moreover, through this technology, humans were able to expand their influence over their environment and to use other sources of energy, such as domesticated animals. In particular, large mammals could be used as a source of food protein, provided tractive force on farms, and subsequently served as a mode of transport. The technology of farming enabled humans to directly influence the biological aspects of plants and animals through artificial selection ([31]:83).

The discussion of the causality of agriculture is explored by Kelly [32], who presents academic arguments that agriculture was the result of many factors. It is speculated that these earliest societies considered the genetic characteristics of squash, beans and maize or used their long-term memory to store information that they would need to decide on collection strategies or to intentionally increase foraging efficiency. As Kelly states, agriculture consisted of different strategies at different times and places. It involved the intentional use of plants that could be directed towards various goals. Kelly's assertions are complemented by the fact that these achievements in agriculture could not have been possible without a certain degree of high and complex intelligence. This was only achievable due to the changes in the human brain triggered by the knowledge gained about fire, as previously explained. This boosted human intelligence, making humans capable of understanding and applying complex tasks to different contexts.

Writing: Storage and Transfer of Knowledge to Future Generations

The importance of storing and transmitting data accurately to different individuals and groups in different places and times should be considered another technological singularity, represented by the development of writing. It is important to note that this does not include symbols of proto-writing because of its lack of accuracy; rather, this technological singularity refers to a complex system of writing capable of transmitting desired information in a precise way.

Whether this achievement was accidental or consciously made, the development of writing was necessary to organize the social structures of growing human settlements, which became increasingly complex and divided. Specifically, with accounting, writing was necessary to mark possessions and information about the storage of commodities ([33]:22), which eventually led to the basis of an economy. Additionally, writing was used to efficiently organize resources on a universal scale and permanently record necessary information (such as numbers, counts of items, persons involved, times and places) [34] and to avoid losing them due to an oral system of record-keeping. Information about these commodities was recorded first, and religious information, such as prayers and incantations, was recorded later. Early civilizations built libraries to be used in the education of scribes, who were initially focused on religion but later expanded to formal scientific knowledge, such as botany, zoology, mineralogy and mathematics ([35]:13). In general, it is fair to say that these writings and libraries, except in the case of wars in which they were destroyed, were the most (if not the only, including current digital libraries) efficient way to pass information to different groups on a large scale.

Another important impact of the development of writing were the bureaucratization of society and the regulation of property and social institutions, including marriage and legal codes to standardize punishment and rights, such as the Hammurabi code. While agricultural knowledge established clear divisions in society by giving people in different castes varied access to production means, the development of writing expanded this division to increasingly complex hierarchical urban structures at the same time that administrative efficiency was increasing its control over society. Illiterate groups were limited in number and in their ability to coordinate collective action. However, literate societies had virtually no limits to their population, and they had the ability to coordinate efforts under a centralized and organized command [36].

The development of writing not only helped early societies create social and economic standards but also boosted the capacity of humans to influence their environment, leading to an entirely new view and comprehension of the universe through advanced mathematics and number writing. The use of a sophisticated system for writing numbers and the development of equations and numerical systems (in the Babylonian case, the sexagesimal system) were an enormous technological revolution at the time. They allowed humankind for the first time to perform research beyond their current location and extend scientific observation to stars (astronomy) ([37]:21), expanding the understanding of humanity's place in the universe. It is reasonable to connect this revolution to the development of engineering (in every field), which eventually increased humanity's ability to influence nature and the planet. On some levels, engineering has even led to what can be interpreted as an initial form of terraforming. The course of humanity, from its first technological singularity to climbing the food chain to gradually becoming capable of reconfiguring the shape of the earth to the point of no return, is shown in primitive examples. In 2000 BC, the Yellow River was tamed by the Chinese through the construction of canals and dikes. Another example is humanity's ability to change the flow of a river ([38]:227). This would not be possible without the ability to store and transmit information as initiated by the development of writing.

The Industrial Revolution: Automated Work on a Large Scale

The Industrial Revolution (also called the First Industrial Revolution) started in Britain at the end of the eighteenth century and the beginning of the 19th century. It can be considered the fourth and most recent technological singularity because of its enormous social and scientific impact on humankind. It fulfils all four aspects of a singularity. Moreover, we are still living under its influence and will likely remain this way for a long time because it is still evolving. The best way to understand how machinery and industrial automation can be considered a singularity and why humans are still influenced by it is to explore the impact of this achievement.

Hobsbawm [39] explained that the Industrial Revolution shook society by drastically changing productivity quantitatively and qualitatively without requiring great technical sophistication. Machinery triggered a massive chain of events in the fields of science, politics and economics. In fact, this event deepened interactions among different societies across the globe by increasing the exchange of products, people and knowledge on a scale never seen before. For example, the changes during the 19th century were so rapid that the chronicles documented in Jules Verne's *Around the World in Eighty Days* were possible when it was published in 1873; however, just a couple of decades before, such an adventure would have been impossible. In fact, the same travel just 30 years earlier would have taken approximately one year, especially without the enormous expansion of railways outside of Great Britain. In 1840, Europe had 1,700 miles of railway and North America had 2800 miles of railway. By 1880, those figures climbed to 101,700 miles in Europe and 100,600 miles in North America with the addition of increased locomotive speed ([40]:64). Another type of technology that was achieved because of the technological explosion initiated by the Industrial Revolution was long-distance communication. It began with the telegram, which shortened the time to send and receive messages from months to just a couple of minutes. During the first half of the 19th century, it would have been unfathomable that a message from the other side of the planet could cover that distance in such a short time. By the second half of the same century, this had become commonplace. This rapid development in communications and logistics also led to unprecedented levels of immigration. For example, in the United States, California saw its population of almost 100,000 people in 1849 explode to 500,000 in 1852 ([40]:75).

In cities such as London in the early 1840s, the life expectancy was approximately 36 years. The life expectancy was 25 years in Manchester, 27 years in Glasgow and approximately 45 years in rural areas of England. This high mortality rate was worsened by the fact that child mortality rates could be as high as 348 per 1,000 inhabitants ([41]:285). However, by the 19th century, the mortality rate decreased due to the impact of the agricultural, industrial and sanitary revolutions. Deaths related to environmental infectious diseases caused by water and food sources, childhood infections and pulmonary tuberculosis declined first, reducing mortality, especially among youth ([42]:29). Scientific fields, such as medicine and pharmacology, as well as all other fields in the natural and human sciences, experienced a great leap during the 19th century. The difference between the "average person" in 1800 and the "average person" in 1899 was much greater than the difference between the "average person" from the 1800s and the "average person" in 1500. Some people, such as Jules Verne and H.G. (Herbert George) Wells, were capable of imagining technologies that were not achieved until the next century or even the 21st century.

The impacts of automation today follow the same patterns as fire and farming by changing human biology or intentionally enhancing and improving it. For example, according to Miller [43], China is researching human genetics to determine which genes make people smarter. The country's scientists have collected DNA samples from 2000 people around the world (who are considered smart) to explore the entire genome in an attempt to identify the alleles that determine human intelligence. According to Miller, embryo screening will allow parents to pick their brightest zygote and potentially increase every generation's intelligence by five to 15 IQ points. Other interventions aim for more direct improvements, such as the development of artificial muscles with carbon nanotubes to boost athletic performance or nanoparticles that bind to red blood cells to improve drug delivery. In general, it is fair to say that these improvements will eventually change the human species, especially if nanoparticle-based gene transfer technology enhancement develops enough to sufficiently change the genetic code of individuals [44]. It is also possible to establish as a consequence of this singularity (automated work) increasing human–machine interaction, such as exoskeletons. These wearable external mechanical structures enhance the power of a person, in some cases actively comprising one or more actuators that augment an individual's power and help in actuating human joints or passively using materials, springs or dampers to store energy harvested by human motion and using it to support a posture or a motion [45].

In addition to a pattern of previous technological singularities, the Industrial Revolution increased average human intelligence to levels that were not seen in earlier centuries. Previously, the progress of human intelligence was not necessarily stagnant but was slow. The rapid and incredible advances during and after the 19th century altered human perceptions of the universe. At the same time, they created a point of no return because it was unfathomable that machinery and industrial automation could become lost knowledge. Furthermore, only the generations that experienced the changes during the 19th century and afterward were capable of understanding these new models.

Identifying Patterns in Technological Singularities

Based on various patterns, it is not difficult to understand why these four specific events must be considered technological singularities while other technologies, despite their significance, do not reach the same level of importance. These four technologies served as a foundation and triggered chain reactions that opened doors to the development of other technologies centuries or millennia later. No possible achievements in metallurgy or chemistry could occur without the basic domain of fire and knowledge of natural elements. Agriculture first required energy and remains a main source of the economy in the world, providing food and water to other energy sources for different purposes, such as ethanol. It is impossible to imagine the construction of long bridges or high buildings without the development of writing. Additionally, information would be lost at a high rate if it were only orally transmitted. Moreover, all nuclear technology, robotics and the Internet are direct derivatives of the expansion of machinery during the Industrial Revolution. Any of these achievements would have been impossible or even unfathomable prior to the revolution. Of course, all technologies eventually lead to other technologies. However, only these four are breakthroughs that have created an enormous range of other technologies for which these singularities are their shared foundation.

Another pattern related to singularities is the requirement to initiate a point where our old models must be discarded and a new reality rules. Each of these four achievements changed the way human beings viewed themselves and their role in their environment and the universe. By succinctly changing human biology for the long term or creating new ways to understand advanced mathematics and, consequently, astronomy and philosophy, these technologies gradually or promptly disrupted old views and models. Most of these previous views and models were unable to add new discoveries that would have changed the organization of society and forced outdated models to be eventually discarded. In view of these drastic changes and complexities, the four singularities discussed could only be fully understood by the generations who witnessed these revolutions and those that followed. Furthermore, each of these four singularities increased the intelligence of society during its development. Of course, some exceptions exist, such as the Greek inventor Ctesibius (*Κτησίβιος*), who predated the mechanical revolution by centuries; however, the knowledge did not spread at the time.

The next pattern, the point of no return, involves the inconceivability (except for cases of dystopic science fiction) of domains such as fire, agriculture, writing or machinery eventually becoming lost knowledge. While some very important technologies were not ultimately shared between different civilizations (such as the wheel, which was not used by pre-Colombian societies; despite its importance, it does not constitute a technological singularity), these singularities can be considered a "must go" step in technology and are shared by different societies, even without contact among them. For example, writing originated in different and independent regions of the world ([33]:32). In other words, it is not possible to return to the point at which the technological singularity first appeared because it has spread too widely across the planet and become too deeply rooted in the foundation of human existence.

A final pattern of singularities (not based on the previously described four principles) is the population explosion that follows singularities. It is difficult to calculate the human population during the Pre-

Palaeolithic Age and Palaeolithic Age, and estimates are mostly based on skeletal remains and characteristics of inhabited sites. According to Biraben [46], the human world population grew dramatically between 300,000 and 200,000 BC. It is important to note that this time period involves the evolution of human biology and a population explosion that occurred during the earliest domain of fire, which was previously described as the first singularity. Eventually, this population peaked at 1.5 million individuals between 50,000 and 40,000 BC. Another population explosion appeared during the Neolithic Age, more or less between 10,000 BC and 4500 BC, when the population of 1.5 million grew to at least 10 million people [47]. This time period immediately followed the development of agriculture, the second singularity.

The third population explosion again immediately followed another singularity (writing). Between the last time period mentioned and the first century CE, the human population grew to 250 million with consistent growth (with few retractions caused by plagues and wars) until 1800, when the fourth singularity (Industrial Revolution) began. For the first time, the human population crossed the 1 billion mark, and, after only 200 years, it reached more than 6 billion persons [46, 47]. As previously explained, singularities have boosted human intelligence while also increasing the human population. For this reason and the four main characteristics described, only these four technological achievements may be considered technological singularities.

Conclusion: The Myth of the Next Singularity

The concept of technological singularity was created to predict the next singularity, when machines would surpass human intelligence and perhaps ultimately even rebel against humans. Kurzweil [48] calculated that at some point in the early 21st century, a new singularity would occur through the improvement of AI, and machines would surpass human beings using recent technologies with global impacts, such as the Internet. However, not only can this hypothesis be denied [13], but we may assume that the Internet, AI and many other new technologies are, in fact, the result of the last singularity. In other words, technological singularity is not imminent because it has already happened. For every recent achievement, the four characteristics that need to be met to constitute a technological singularity and the population explosion that follows it have already been found in the Industrial Revolution. These new technologies appear to be only variations or derivations of the large-scale automation typical of the Industrial Revolution.

Despite using it in a questionable way to predict the "rise of machines", Vinge and Kurzweil created a basic idea and methodology grounded in four characteristics that can explain progress in civilization, and their work can be used to define standards in technological evolution. Moreover, their work could potentially be used as a paradigm for future observations. If this concept became universally fundamental, it would not be unfathomable (albeit possibly audacious) for it to also help in the search for civilizations in outer space. In fact, instead of posing a superintelligence AI threat against humans, I believe the last singularity (i.e., automation) will change humans at such a level that our biology and intelligence will greatly improve—and possibly even include a merging of the human body and machines.

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