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Biomedical Sciences

Original article

The evolutionary singularity: towards the post-human stage, a new era of human evolution

La singularidad evolutiva: hacia la etapa poshumana, una nueva era de la evolución humana

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Abstract

The starting point of our central argument is based on a general understanding of singularity as a point in time at which control is lost as processes break down due to an excessive rate of change. In this scenario, evolutionary singularity may be defined as the point at which 'artificial evolution' outpaces natural evolution to keep up. In such an evolutionary singularity, the editing of our genome, artificial intelligence, and technological and ecological changes on our planet are generating a new culture and ethics. According to this projection, post-humans will appear given the premise that the human species in its current form does not represent the end of their evolution. To understand the interaction of convergent technologies towards a singularity that will transform us into post-humans, it is important to redefine the concept of human evolution to face the advances in the editing of our genome, artificial intelligence, man-computer interfaces, as well as the changes in our physical, cultural, political, and creative environments. The extended evolutionary synthesis (EES) postulates that, in addition to natural selection, other dynamic forces converge, which change in time and space. The transformations in our biosphere, the use of technologies for editing our genome, and the improvement of brain-computer interfaces will condition new biological, social, and political adaptations. This stage of humankind will be that of the post-humans.

Keywords: Singularity; artificial intelligence; transhumanism; genome editing; human evolution; extended evolutionary synthesis; post-humans.

Resumen

Nuestro argumento central parte de una definición general de singularidad como un punto en el tiempo en el que se pierde el control como consecuencia de la ruptura de los procesos a causa de un ritmo de cambio excesivo. En este escenario, la singularidad evolutiva podría definirse como el punto en el que la evolución artificial avanza tan rápido que la evolución natural no puede seguirle el ritmo. En la singularidad evolutiva, la edición de nuestro genoma, la inteligencia artificial y los cambios tecnológicos y ecológicos en nuestro planeta están generando una nueva cultura y una nueva ética. Según esta proyección, los poshumanos aparecerán porque la especie humana en su forma actual no representa el final de su evolución. Para comprender la interacción de las tecnologías convergentes hacia una singularidad que nos transformará en poshumanos, es importante redefinir el concepto de evolución humana para hacer frente a los avances en la edición de nuestro genoma, la inteligencia artificial, las interfaces hombre-ordenador, así como los cambios en nuestros entornos físicos, culturales, políticos y creativos. La síntesis evolutiva extendida (SEE) postula que, además de la selección natural, convergen en la evolución otras fuerzas dinámicas cambiantes en el tiempo y en el espacio. Las transformaciones de nuestra biosfera, junto con la aplicación de tecnologías para la edición de nuestro genoma y la mejora de las interfaces cerebro-ordenador, condicionarán nuevas adaptaciones en lo biológico, social y político. Esta nueva etapa de la humanidad será la de los poshumanos.

Palabras claves: singularidad; inteligencia artificial; transhumanismo; edición del genoma; evolución humana; síntesis evolutiva extendida; poshumanos.

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Introduction

The advances in genetic engineering and gene therapy research and genome engineering technologies, as well as the social changes towards a new world economic system and the accelerated development of artificial intelligence (AI), are creating a new world that has never been seen before. In this challenging scenario, the current evolutionary process of the human species must be revisited in the light of the newest progress in computer sciences, nanotechnology, artificial intelligence, genome editing technologies, and the ecological equilibrium and politics of conservation of our ecosystems around the world. This new scenario will condense in an evolutionary singularity, which can be summarized as changes in the mode of human life nearing an essential singularity in the history of the evolution of the human species, beyond which human processes, as we know them, would not continue (**Fedyniuk**, 2018).

Several lines of evidence based on fossil records have proposed that the oldest *Homo sapiens* found thus far dates 200,000 to 315,000 years ago (**Vidal *et al.***, 2022). Moreover, DNA evidence drawn from comparisons of different human genomes, as well as those of our close cousins, Neanderthals and Denisovans, places the divergence between the three groups at least 400,000 years ago. It is therefore possible that *Homo sapiens* as a species has been on earth for over half a million years (**Hu *et al.***, 2023; **Callaway**, 2021; **Nichols *et al.***, 2024).

A design for life: predicting cognitive performance from lifestyle choices

From that moment on, modern humans progressively evolved and populated almost every place on the planet. In this anthropological and biological scenario, a remarkable fact in *Homo sapiens* evolution was an increasing brain size, which is a good predictor of its cognitive performance as a trademark of our modern human species, capable of transforming not only itself, but progressively changing its technological, social, and cultural environments (**Bruner**, 2018; **Pereira *et al.,*** 2020; **Andrews & Nowakowski**, 2019; **Khvorykh *et al.,*** 2020).

The 21st-century genome editing (**Pacesa *et al.***, 2024), robotics (**Arora *et al.***, 2024), information (**Saeidnia *et al.***, 2024), and revolutionary nano-technologies (**Singh *et al.***, 2024) promise to change the internal constitution of our genome, the functions encoded in the human body, and our very existence. Such transformation involves not only the structure of current societies, but the evolutionary destiny and future of current humans. In this referential framework, GRIN technologies (genetics, robotics, information, and nanotechnology) seem to promise new and unexpected evolutionary paths for living beings and, above all, for man (**Colombetti**, 2014; **Rodgers *et al.***, 2023).

In this century, human knowledge achieved through scientific research has developed so much that to generate more knowledge and produce innovations more quickly, a whole new area integrating the different fields of present human knowledge has arisen: the "knowledge-augmented deep learning" (KADL) (**Cui *et al.***, 2023). Responding to this trend, science is currently being unified around a set of theoretical principles that include complexity, conservation, indecision, configuration, interaction, evolution, information, and cognition, as well as new technologies such as artificial intelligence (AI) (**Kamatani**, 2021), big data, brain-computer interfaces, and genome editing, among others. Given these interactions, a new scenario of converging interfaces has emerged, which requires a change in scientific training in biology, engineering, and social and humanistic sciences. Taking as a starting point the science of cognition, together with developments in nanotechnology, this convergence will expand the social sciences and humanities to unimaginable limits that will transform current societies.

In this context, we will show how the progress of science and technology, along with the development of innovations in the current technological convergence, is generating the conditions for a change of period around the fifth decade of the 21st century. Such a change will produce a phenomenon called "evolutionary singularity", which we have defined as a progressive line of space and time where technological developments are transforming our biological evolution in such a way that a new, modified biosocial and political structure will emerge. This new society will witness spectacular changes in the human genome, an expanded intelligence, and a new ethic. These new specimens of the human species will be the post-humans.

All the evidence described in the present review is supported by papers published in relevant prestigious journals referenced directly from the source they were taken from, respecting the international legislation on intellectual property.

Transhumanism and post-humanism as the base of evolutionary singularity

Some authors think that the remote origin of transhumanism, at least in the formulation of the term and in its general inspiration, can be found in a 1957 text written by the English biologist and philosopher Julian Huxley, a work entitled *New Bottles for New Wine*. In it, Huxley proposed the term "transhumanism" to refer to the perspective according to which human beings should improve themselves through science and technology, either from the genetic point of view or from an environmental and social point of view (**Huxley**, 1957).

According to the World Transhumanist Association, today we can understand TH as a way of conceiving the future based on the premise that the human species, in its current form, does not represent the end of its development but rather a relatively preliminary stage of its evolutionary becoming (**Bostrom**, 2005; **Tamm & Boldizsár**, 2020). Based on this transhumanist conception, questions arise: What do we understand by "human enhancement"? Or, are we facing a reemergence of a new version of eugenics that had such a great impact on many 21st-century ideologies, and whose dire consequences left us a legacy of inequity and injustice?

In 2012, during the workshop on *Human Improvement: Ethical Problems*, organized by the European Parliament Science and Technology Options Assessment - (STOA), human improvement was defined as:

> *... Any modification that is intended to improve individual human performance caused by science-based or technology-based interventions applied to the human body. This definition includes both "strong" forms of second stage human improvement, with effective or permanent long-term results, and "temporary" improvements, which should be limited to improving individual performance through techno-scientific means, and its definition itself should not include the objectives of an improvement of the species or an improvement of humanity.* (**Science and Technology Options Assessment - STOA**, 2012; **Rinie**, 2019).

Post-humanism is usually thought of as the destiny of transhumanism by overcoming the intellectual and physical limitations of present human beings through the technological control of their own biological evolution, which would modify the current biological and social state of the human species. Transhumanism poses the question of a man generated *in vitro*, improved by genetic, bionic, and even clon-editing. In this scenario, post-humanism and technology have progressed hand in hand as a way of accessing current knowledge through new, holistic instruments. Technological advancement shall lead to the emergence of a new hybrid human prototype, containing non-organic and biologically modified interfaces (**Benedikterab** ***et al.***, 2010).

Based on these definitions, transhumanism is conceptually framed within the evolutionary perspective of the human species through improvements. It seeks to apply reason, science, and technology to reduce poverty, disease, disability, and malnutrition around the world. Transhumanists often view the very concept of "natural" as problematic, something that becomes an obstacle to progress (**Karamanou** ***et al.***, 2017).

Thus, post-humanist thought, as we conceive it, is a new anthropological outlook on the concrete evolution of the human being; an outlook that implies an epistemological revolution of the categories that humanism uses to conceptualize the journey that divides *Homo sapiens* from the post-human (**Tintino**, 2014).

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Human versus artificial intelligence

In the actual social and technological scenario of human societies, it is necessary to refer to one of the main critical characteristics of human evolution: human intelligence versus artificial intelligence (AI). Human intelligence can be defined as the ability to learn from experience and to adapt to, shape, and select environments. Intelligence as measured by conventional standardized tests varies across an individual's lifespan and generations. Human intelligence can be partially understood in terms of the biology of the brain, especially regarding the functioning of the prefrontal cortex; it also correlates with brain size, at least in humans (**Sternberg**, 2012). It is highly heritable and predicts important educational, occupational, and health outcomes better than any other genetic trait (**Plomin**, 2018). Recent genome-wide association (GWA) studies have successfully identified inherited genome sequence differences that account for 20% of the 50% heritability of intelligence (**Brandes *et al.***, 2022; **Plomin**, 2018). In contrast, AI is the "technology" of making machines that can think like humans. It does things that are considered "smart." This technology processes large amounts of data in ways unlike humans. AI's goal is to recognize patterns, make decisions, and judge like humans. In a modern approach, AI is the simulation of human intelligence processes by machines, including, among others, computing systems, embodied artificial intelligence (EAI), and biobots (**Ackermann *et al.,*** 2025; **Paterson**, 2025).

Thus, AI can be designated as the result of the technological convergence between information and communication technologies (ICT) and cognitive sciences. However, due to the rapid development of technological convergence in the near future, it may come to include nanotechnology, genome editing, and biotechnology to produce "intelligent bio-agents" with a potential greater capacity than that of the current human brain (**Intelligent Bio Solutions Inc**, 2024). Once the point has been reached where an artificial intelligence superior to its human correlate is developed, a "post-human" stage would be entered, probably leading to the transformation of our human species as it is currently conceived and unleashing, therefore, unimaginable changes in the structure of societies.

Although some authors think that computers will not become intelligent (in the sense of the "Turing test"), the biological path to reach technological singularity does not seem to have any limits. The developments in interfaces between computers and the human brain suggest that a supra-human intelligent entity is possible and potentially achievable (**Patel *et al.***, 2024).

Singularity as a force to drive human evolution

According to different authors (**Vinge**, 1993; **Kurzweil**, 2005; **García**, 2020), arriving at this singularity entails that technological developments would have to be able to make each of the following products a reality:

1. A kind of computer that reaches the level of human intelligence and later surpasses it (**Dunjko & Briegel**, 2018).
2. Computational networks that behave like "super-neurons" of a distributed brain acting as an intelligent entity (**Pei *et al.***, 2025).
3. Elements of interaction with computers allowing a human to behave as a super-intelligent being (**Magnuson & Luthra**, 2024).
4. Biological manipulations that would improve the current human level of intelligence (**Martins *et al.***, 2019).

Whether the singularity will occur or not, it is a fact that it is becoming a matter of serious debate among scientists, technologists, and sociologists. Although there is no general agreement, a consensus situates the beginning of the singularity as a period of change around the fifth decade of the 21st century (**Muehlhauser & Salamon**, 2012). However, much of the discussion about technological singularity revolves around developments in artificial intelligence (AI), i.e., machine intelligence. Its theoretical definition focuses on the intelligent agent paradigm, being one of the most promising areas of computer science (**Qilin & Chengdu**, 2011).

Regarding this issue, some of us even think of the confluence between human consciousness and a "technological consciousness", which would promote the emergence of a new species or new technologically modified organisms that we will call "post-humans". A post-human, then, would be a human being in transformation, with some physical and psychic capacities superior to those of a current normal human, generated by the application of technological "improvements" and programmed changes in its genome (**Zagoskin & Wang**, 2021).

Human evolution: a new synthesis to face the post-human era

To understand the concepts of singularity and transhumanism in a more coherent way, it is important to create a new scenario of the human species' evolution to face the changes produced by the editing of its genome and those of the physical, ecological, technological, cultural, and political environments. The theory of evolution by natural selection, proposed by Charles Darwin and Alfred Russell Wallace more than 160 years ago, has undergone a series of changes compared to its basic premise that the evolution of species occurs by a general mechanism called natural selection, which generates new conditions to adapt to a dynamic and changing environment in space-time (**Darwin & Wallace**, 1858). From the theory of natural selection, which was the first approach to a rational explanation of biological evolution, the modern synthesis (MS) arises as the result of an integration between Darwin's proposal and that of the inheritance of hereditary characteristics proposed by Mendel, which was later modified by Wright and Fisher and their molecular inheritance (**Mayr & Provine**, 1998; **Kalchhauser *et al.***, 2020). In this new context, two important integrative concepts were introduced: genes as the molecular units of evolution and neutral selection as a mechanism of evolution. Although with some reinterpretations and adjustments, the ES has managed to explain in a coherent way the biological evolution until now. However, in relation to this generalized but simple concept, a series of forces emerge to make up a new evolutionary complexity (**Petri & Schmidt**, 2004).

Today, the theory of extended evolutionary synthesis (EES) has emerged (**Laland *et al.***, 2015) as a result of advancements in the field of evolutionary biology and the new transdisciplinary vision of the physical and social world. In its conceptual framework, **Jablonka & Lamb** (2006) postulated that the evolution of the nervous system in modern humans not only modified the mechanisms by which information was transmitted between cells, but also profoundly altered the nature of individuals, leading to a new type of inheritance which they called "social and cultural inheritance" (SCI). This inheritance has transmission as an epistemological basis of behaviorally acquired information. **Table 1** summarizes the core assumptions of modern synthesis and contrasts them with those of extended evolutionary synthesis. The starting point of Jablonka and Lamb's proposal is that the evolution of the human species is dynamic and changing, but that it also extends in time and space in a cultural environment. In this context, human evolution occurs via the genetic, epigenetic, behavioral, and symbolic inheritance systems (**Dickens *et al.***, 2012). These four inheritance systems provide variation patterns that influence evolutionary processes in modern humans (**Laland**, 2015):

1. Genetic inheritance refers to the transmission of the information contained in the genome and perpetuated from one generation to another. Both gene mutation and recombination are the forces that control this type of inheritance.
2. Epigenetic inheritance affects pre- and postnatal development. Epigenetic changes are transferred from one generation to the next without alterations in the nucleotide sequence of the genome. This inheritance is referred to as translational, since it is generally transmitted from mother to child up to a third generation. Epigenetic inheritance is highly dependent on the dynamics of the environment in which the population interacts, highlighted by a generationally changing imprint.

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3. Behavioral inheritance is the passing down of behavioral traits from one generation to the next; it is a common feature in some nonhuman primate species.
4. Symbolic inheritance is exclusive to modern humans; it is the transmission of ideas, symbols, and perceptions that influence our lifestyle and the environment in which we use our bodies. It is crucial to consider that this type of inheritance can potentially affect the transmission of biological information across generations (**Whiten**, 2017).

As we know, the archaeological records stamped on the Upper Neolithic cave paintings about the communal hunting of large animals such as mammoths (6,000 to 2,200 BCE) evidence how the Neolithic evolutionary dilemma was that if humans wanted to be successful as a species, they not only had to increase birth rates but also improve health to have longer lives and reproduce. Such a dilemma required a nutritional solution, a higher protein intake to increase the capacity of their musculoskeletal and nervous systems, as well as a greater supply of carbohydrates to increase their energy reserve and perform high efforts and long walks (**Potticary *et al.***, 2019).

Finally, our brains and minds, the most distinctively human features, will evolve, perhaps dramatically. Over the past six million years, human brain size roughly tripled, suggesting the development of big brains driven by tool use, complex societies, and language. It would seem inevitable that this trend should continue, but it probably won't,

Table 1. A comparison of the core assumptions of classical modern synthesis and extended evolutionary synthesis

Modern synthesis core assumptions	Extended evolutionary synthesis core assumptions
Pre-eminence of natural selection: The major force of evolution is natural selection, which explains evolution through the interaction with the environment (adaptation)	*Reciprocal causation*: Development processes operating through developmental bias and niche construction. Involvement in the directionality of evolution through environment complimentary (complex) variables
Genetic inheritance: Genes only contribute to the general inheritance.	*Inclusive inheritance*: Inheritance extends beyond genes to encompass transgenerational epigenetics, physiological, ecological, and social transmission mechanisms, among others.
Random genetic variation: There are no relationships between the direction in which a mutation occurs and the direction that would lead to enhanced fitness.	*Non-random phenotypic variation*: Developmental bias resulting from non-random mutation or phenotypic accommodation
Gradualism: Evolution via mutation of large effects is unlikely. Multiple small steps leading to gradual evolutionary change.	*Variable rates of change*: Variants of large effect are possible, allowing a rapid evolutionary change.
Gene-centered perspective: Evolution requires change in the gene frequencies. Population evolves through changes in gene frequencies.	*Organism-centered perspective*: Developmental systems can facilitate adaptive variation and modify selective environments.
Macroevolution: Macroevolutionary patterns are explained by the microevolutionary process of selection, drift, mutation, and gene flow.	*Macroevolution*: Additional evolutionary processes, including developmental bias and ecological inheritance, help to explain macroevolutionary patterns and contribute to evolvability.
Evolutionary time: Long, i.e., thousands to millions of years; geological eras.	*Evolutionary time*: Variable and progressively short times dependent upon the development of technologies to manipulate the genome.

however, as our brains are getting smaller. In Europe, brain size peaked 10,000-20,000 years ago, just before the emergence of farming. Then, the brains got smaller (**Beaudet & Du**, 2019). Why do Modern humans have smaller brains than their ancient predecessors, or even medieval people? There is no clear answer.

In this scenario, cooperation produced another evolutionary conditioning factor, the generation of a niche to have space and time to rest from exacting tasks and provide comfort to the family group. The first attempts at construction and remodeling of space were undertaken, beginning with the adaptation of the caves where family groups lived, which later led to open-air constructions and the first agricultural systems (**Kurzban *et al.***, 2014).

We described before how the EES preserves MS foundations, but introducing a more integrative vision of the role that development processes have in biological evolution (evo-devo) as a conceptual element that shapes the evolutionary process in general and promotes new solutions of continuity and complementarity between the organism and the environment. Among other consequences, EES overcomes many of the limitations of the traditional gene-centered explanation and entails a detailed review of the role of natural and social selection in the evolutionary process (**Futuyma**, 2017). On the other hand, EES introduces a new evolutionary force, namely symbolic inheritance, which gave greater complexity to the evolutionary process of the human species (**Steels & Luc**, 2007). This complexity promoted an expansion imprint through the invasion of niches based on creativity, generating substantial changes in culture and technology. Such force has become the trademark of our species throughout time and will continue to be so in post-human societies.

At this point, we should ask ourselves: What has changed over the generations in the evolution of our species? We are continuously conditioning our environment, transforming it for our benefit (not well-being); we continue pursuing cooperation to develop more efficient instruments and cultural forms to obtain animal protein for our ingestion so we can dominate and exercise control over our niche. According to the definition of human evolution directed towards singularity, our post-human evolutionary course will include non-organic interfaces, modified genomes, controllable epigenetic systems, adjustable behaviors, and even a new concept of symbolic thought. This new way of seeing ourselves within the complex system of the biosphere and the "culturosphere" gives us an epistemological basis to analyze the biological and cultural processes that will transform our species in the future. From that point of view, this thesis is the epistemological basis of post-humanism and its integration into the technological singularity towards the consolidation of post-humans.

Towards the unification and convergence of science and technology

The path to post-human evolution will be conditioned by CT+I convergence. In this context, human knowledge resulting from scientific research has reached such a development that generating new expertise and innovations more quickly requires a novel transdisciplinary area integrating these different fields (**Byrne *et al.***, 2021). The unification of science and technology will surely generate shocking results in the next two decades based on four key principles (**OECD**, 2021): the unity of matter at the nanoscale, the transformation of NBIC tools (nanotechnology, biotechnology, informatics, and sciences of cognition), hierarchical or non-linear systems, and an increase in human performance according to the following premises:

1. Nano convergence is based on the unit of matter at the nanoscale and integration at this level. Nowadays, scientific research can better understand how atoms combine to form complex molecules and how these, in turn, aggregate according to a common fundamental principle to form not only organic but also inorganic structures. Technology can leverage natural processes towards engineering new materials, new biological products, and nano-scale machines.
2. The same principles will allow us to understand and, when required, control the behavior of complex microsystems such as neurons and computer components, and of complex quantum systems such as human metabolism.

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3. Revolutionary advances in interface integration between previously separate fields of science and technology that are creating key NBIC tools, including radically new scientific instruments, analytical methodologies, and materials systems.
4. Developments in systemic approaches, mathematics, and computation, in conjunction with NBIC areas, will allow a much better understanding of the natural world and cognition in terms of complex hierarchical systems. This complex systems approach will produce a holistic space of integration opportunities to obtain maximum synergy towards a general stream of progress.

The NBIC convergence offers the means to successfully meet these challenges by substantially increasing our mental, physical, and social capacities. Moreover, a better understanding of the human body and the development of tools to direct human-machine interaction have opened a completely new landscape of technology and innovation. Efforts must focus on both individual and collective advances in terms of emphasizing the definition of human benefit that articulates change while preserving fundamental values.

The human genome and its manipulation as an alternative to evolution

In 1973, Stanley Cohen and his coworkers reported the construction of new plasmid DNA species through the *in vitro* enzymatic binding of separate fragments of plasmids obtained by hydrolysis with restriction endonucleases. The newly constructed ("recombinant") plasmids were introduced by transformation into the bacterium *Escherichia coli*, then replicated in this new genetic system where they expressed the introduced genetic information. The publication of this new *in vitro* recombination mechanism produced a great revolution in the scientific world, as it transformed not only the way in which molecular biology was investigated at the time but also generated a great transformation in biotechnology and in the ethical and social implications of genome manipulation of organisms.

The consolidation of genetic engineering, as this directed DNA recombination methodology is commonly known, opened a new scenario in the *in vitro* production of molecular inputs for health, food, and industrial processes, besides promoting the correction of mutated human genes by implantation of classical gene silencing or allele substitution therapies and gene editing (**Westmann *et al.***, 2019).

As a result of this advance in genetic engineering, a few years later, another significant transformation of scientific knowledge began for mankind, with an enormous impact not only on science but also on production systems and the socioeconomic structure world of the 21st century: the Human Genome Project (HGP), which constituted a milestone in the way of associative research, since it was initially led by the United States National Institutes of Health (NIH), but later by an international alliance of several countries, the Human Genome Consortium (HGC), whose director was Francis Collins. However, also a private company, Craig Venter's Celera Inc., entered the race to sequence the human genome.

The initial goals of the HGP were to sequence human DNA and identify and map the approximately three billion nucleotides in the human reference genome, which contains between 19,000 and 20,000 protein-coding genes. On April 14, 2003, the International Human Genome Sequencing Consortium, led in the United States by the National Human Genome Research Institute (NHGRI), the Department of Energy (DOE), and Celera Inc., announced the successful completion of human genome sequencing more than two years ahead of schedule (**Collins & Patrinos**, 2003).

Besides obtaining detailed knowledge about the structure and function of our genome, the results of the HGP project promoted a much deeper vision of how to understand biology in molecular terms. The new dominant paradigm of biology in the 21st century is information; thus, molecular biology is essentially an informational science. The integrated analysis of the human genome, comprised by the so-called "omics sciences" (OS), is done in terms of storage, transmission, and transformation of biological information. In this context, the human genome is essentially digital information that encodes for phenotypes. The fundamental question of biology, then, is how this information is contained in the genome and decoded to produce human form and functions. In the OS framework, biological systems are complex networks of thousands of pathways, many of which are interconnected in biosynthetic, signal transduction, and gene expression regulation pathways. Thus, the integration, representation, and modeling of biological information interconversion networks require systemic analyses whose complexity varies (**Moreno *et al.***, 2011).

Systems or integrative biology is one of the current fields in trend, since it banished the dominant reductionist approach to biological knowledge predominant throughout the 20th century and substituted it by that of a systemic interdisciplinary approach, where large research groups formed by geneticists, molecular biologists, bioinformatics, biochemists, physicists, mathematicians, and doctors, among others, work together to explain the emergent properties of biological systems (**Veenstra**, 2021).

Evolution directed by human genome editing

Genome editing consists of modifying specifically the nucleotide bases sequence of a cell's DNA by inserting, deleting, or correcting it, which can be done in somatic cells and germ lines (**Cyranoski**, 2016; **Zhao *et al.***, 2021), i.e., only cells where DNA has been "edited" will carry gene modification. In this case, only the specific individual will be affected, either because the modification is made in his/her cells or because modified cells, his/her own or others, are transferred to him/her, and their impact can be evaluated with some ease (**Bainbridge**, 2024).

However, if genome editing is carried out in germ-line cells (oocytes, sperm, stem cells), the genetically modified cells can transmit the modifications introduced to future generations, and the eventual impact cannot be so easily assessed. Despite calls for caution by the discoverers of the clustered regularly interspaced short palindromic repeats (CRISPR)/CRISPR-associated protein (Cas)9-mediated genome modification (CRISPR/Cas9) technology in the face of its potential, the race for a clinical application of these techniques has already begun (**Li *et al.***, 2023; **Bhatia *et al.***, 2023).

In recognition of the pioneering work with gene editing technology, the 2020 Nobel Prize in Chemistry was awarded jointly to Emmanuelle Charpentier and Jennifer A. Doudna for the development of the CRISPR/Cas9, a method for genome editing (**Doudna & Charpentier**, 2014; **Derry**, 2021). CRISPR/Cas9 enables us to edit the genomes of a variety of organisms rapidly and efficiently, and it has the potential to perform gene editing in humans. CRISPR/Cas9 is an RNA-guided gene editing tool that offers several advantageous characteristics, including cost-effectiveness, flexibility, and easy use, in comparison with the conventional methods of gene editing by nuclease-directed guide-specific DNA, such as zinc-finger nucleases (**Bialk**, 2015) and transcription activator-like effector nucleases (TALEN) (**Miller**, 2011).

CRISPR-Cas9 is still the most convenient tool for gene editing purposes (**Li *et al.***, 2021). Due to the potential capability of the CRISPR-Cas9 system in genome editing and correction of several types of DNA mutations, it can be considered as a possible therapeutic system in the treatment of several disorders, including gene mutations associated to hereditary pathologies, particularly complex diseases like cancer (**Zuo *et al.***, 2017), and some chromosome syndromes (**Tanaka & Chung**, 2025). Also, it has increased awareness about the molecular basis of disease and the development of new and targeted therapeutic approaches (**Khadempar *et al.***, 2019; **Perez *et al.***, 2018). It's undeniable that with the introduction of precision genome editing using CRISPR-Cas9 technology, we have entered a new era of gene therapy and the potential modification of human genomes, thus opening the road for the evolution to post-humans (**Furtado**, 2019).

Although genome editing has been a momentous step on the road to post-human evolution, it is essential to exercise caution with controlled human experiments aimed at correcting genetic diseases (**Cavaliere**, 2019). On this issue, a group of UNESCO experts called for the prohibition of human DNA "editing" to avoid an immoral manipulation of hereditary traits. In a report released on February 14, 2017, compiled by a committee

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of 22 specialists in basic sciences, political sciences, law, industry, and patient defense from developed and developing countries, the scope and limitations of gene editing in humans were analyzed. The report acknowledges that gene editing in basic research helps us understand the links between genes and diseases, such as cancer, and its effects on human fertility and the treatment of genetic diseases, encouraging the exploration of this therapeutic route to cure and avoid diseases in "situations where there is no other alternative." However, they cautioned against its use in somatic therapies, such as blood cell editing to treat sickle cell disease or cancer, highlighting that it should be approached carefully and only to treat and prevent the disease. The committee also determined that any use of human gene editing for genome alterations aimed at enhancing human characteristics is currently inappropriate. The report included ethical recommendations on how to protect patients' dignity, evaluate the safety and efficacy of new medical applications, or provide broad and fair access to the benefits of human gene editing and its governance (**National Academy of Medicine *et al.*,** 2020).

In September 2020, another report by the US National Academy of Medicine, National Academy of Sciences, and the UK Royal Society on the same subject analyzed the state of the art regarding human germline genome editing and urgently called for the adoption of an international mechanism by which concerns about the research or development of heritable human genome editing deviating from established guidelines or recommended standards should be transmitted to relevant national authorities. The report also urged public health and research authorities to develop national laws to protect the human genome and its manipulation by gene editing therapies (**National Academy of Medicine *et al.***, 2020). However, genome editing will soon become a force that will steer the human species' evolution towards post-humans.

Human evolution and artificial intelligence

The first significant leap in the evolution of humans was, arguably, the discovery of fire and agricultural methods. More than a thousand years later, we created the internet, which, again, transformed our way of thinking and doing things by offering a range of tools that enabled us to perform actions that weren't otherwise possible (**Colther & Pierre**, 2024). Today, with the advent and the ceaseless development of AI, we are experiencing a similar, transformative phase along the trajectory of human evolution. Even in its present nascent stage, AI has opened promising avenues and is transforming almost every industry, including health, finance, transportation, logistics, and so on. AI further development will only make it more efficient and will elicit the evolution of advanced humans. As of now, there seem to be at least two ways for this to happen.

Artificial intelligence augmentation

Neuralink is a neurotechnology company founded by Elon Musk that is building an implantable, brain-computer interface capable of translating thought into action (**Peksa & Mamchur**, 2023); it was launched in 2016. This private venture claims its neural device will allow people with paraplegia to regain movement and restore vision to those born blind. It is striving to develop brain chips that will enable us to control technology with our thoughts. If actualized, this would mean that tools and technology would cease to be entities external to humans. Instead, they would become an integral part of us (**Mridha *et al.***, 2021). At its logical best, this will even allow communicating with one another only by thinking, i.e., without speech, or any other form of expression for that matter. In other words, we would be able to transmit our thoughts, just as we can send emails today.

Transhumanism as a new eugenics in the 21st century

Developments in genetics, genome editing, and reproductive technologies in the 21st century have raised numerous questions regarding the ethical status of eugenics, effectively creating a resurgence of interest in the topic. Some scientists have claimed that modern genetics technologies, including genome editing, are the back door to eugenics (**Friedmann**, 2019).

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Eugenics (from the Greek "eugoniké", meaning "good origin") is a philosophical and social conception that defends the improvement of human hereditary traits through various forms of manipulative intervention and selective methods. The improvement of qualities in the human population can be achieved by discouraging the reproduction of those with genetic defects or who have allegedly inherited undesirable traits, which is considered negative eugenics, or, on the other hand, promoting the reproduction of people who have allegedly inherited desirable traits, which is defined as positive eugenics (**Hammerstein *et al.***, 2019). Both types of eugenics pose serious bioethical dilemmas, mainly due to their effects on human history and the future risk our species would have to face. Historically, the origin of eugenics is strongly rooted in the rise of social Darwinism in the late 19th century (**Connell & Ruse**, 2021).

According to these considerations, transhumanism has a strong eugenic basis, since it takes up the old conception of the human being as "mängelwesen" (from the German "defects of beings") but reformulates it, adopting the concepts of deficiency (deficient-being) and limitation (limited-being). The human species is deficient in its biological specificity; therefore, *Homo sapiens* is, by definition, a conditioned being, not predestined to be something fixed. Biology is not a destination, but a fact, so scientific advances and technological manifestations, especially future ones, will allow (in a period still not clearly established) to transcend this type of limitations through a kind of body reengineering that will expand, enhance, and improve its capabilities, ultimately, the promise of a "modified positive eugenics" (**Rutherford**, 2021).

We consider that, despite the promise of genetic and technological transformation posed by transhumanist eugenic thinking, we will never stop being human; however, biology and technology will mix in nature, perhaps towards a new species, *Homo tecnologicus*, a term we have coined. The eugenic reality posed by post-humanism will begin with the technological modification of our body and the programmed edition of our genome, which will condition a new human reality (**Evans**, 2021).

According to transhumanists, the human body follows Cartesian logic, which views it as a mere extension (*res extensa*). Biological reductionism considers the body as a material reality product of our genetic inheritance, which, at the same time, is spatially and temporally conditioned, interacting with the environment on the physical and biological levels. This conception does not exclude emotions, seen as adaptive responses (pleasure and displeasure in all their manifestations) in the face of environmental and/or cultural stimuli. Although it is not easy to isolate biological traits from cultural ones (suffice to mention the inputs provided by epigenetics), the biological aspect is privileged, i.e., human beings are fundamentally the result of ontogenetic and phylogenetic processes product of evolution. The "defective-being" is projected from an evolutionary point of view; corporeality, therefore, is also conceived as based on a classic functionalism of clear Darwinian influence. In this context, the structure or composition of the genome is subject to its functions, and, therefore, it appears desirable that body modifications may increase such functionality. The human body, then, should be described according to the question: what for? Similarly, the cognitive sphere may also be considered in terms of functional systems.

Conceived in this way, transhumanism has been subject to criticism, as its assumptions would endanger "human nature". In this respect, one of the most important critics is the American philosopher and political scientist Francis Fukuyama, who called transhumanism "*... the most dangerous idea for democratic systems*" (http://www.frasesgo.com/frases-de-democracy.html), describing it as a threat to the human essence, since it violates the principle of equality of all men (**Coeckelbergh**, 2020). To Fukuyama, the transhumanist project was born in a society marked by objective, material, and concrete conditions that determine a growing inequality. The "improvements" proposed by transhumanism are not generalizable for most human societies and would lead to a radicalization of inequality, rendering it irreversible due to its biological nature (**Palmer *et al.***, 2015).

Fukuyama´s second criticism refers to the ethical framework we live in, which is marked by hyper-individualism, hedonism, and the desire for possession, sex, money, and

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power. In this context, the transhumanist wave would further destroy the weakened moral cohesion of societies (**Bourgois**, 2019). His third objection lies in the forgetfulness of the natural dimension of the human being. We are rational, not just thinking entities, and this condition determines some demands that are ignored by transhumanism (**Bourgois**, 2019). Moreover, other thinkers argue that the eventual bifurcation of humans into post-humans would lead to slavery and genocide between both groups, whose ideas can lead to the extinction of our human species (**Snyder *et al.***, 2019).

Evolution towards post-humans: cyborgs and biobots

As we described previously, EES's notion of biological evolution describes the progression of human beings. This theory sparked widespread controversy among scientists and ordinary people because it contradicts the actual concept of humanity. Can humans truly evolve, not in the EES biological sense, but in the manner of machines and artificial intelligence? What limits can they surpass, and are they truly capable of colonizing space? (**Mirkovic**, 2018).

The term 'cyborg' arose as a short form of 'cybernetic organism', i.e., an entity made up of both biological and technical elements. Initially, it was used to describe any system of this mixed type. However, more recently, the term 'biobot' has been employed specifically for entities where biology and technology are integrally attached, thereby removing people riding bicycles or wearing glasses from the definition.

The topic of human evolution is no longer science fiction, as cyborg humans, partly human and partly machine, have emerged. If some humans were to leave Earth in the future to establish a civilization in space, as Elon Musk and Jeff Bezos propose, and then return to Earth, would we, regular humans, perceive them as aliens at that time? (**Warwick**, 2024).

In the realm of what might one day become a reality, humans could enhance and expand their physical abilities to live in outer ecosystems with advanced bodies. Cyborg-building efforts are serious and progressing rapidly to maximize human capabilities by implanting smart chips in brains and bodies and developing organs with intelligent systems until humans become cyborgs (**Gillett *et al.,*** 2006).

Soon, these cyborg enhancements could grant the human body unprecedented capabilities. Today, sensory probes can detect the touch of light, while ultrasound can detect the sounds of typically silent animals like fish, giraffes, and bats. Cameras implanted in the eyes or connected to the vision centers in the brain can help the blind see, and the deaf and mute might communicate through thought alone, using telepathy technology. Such advancements could also enable humans to withstand pressure and gravity differences in outer space (**Papakonstantinou *et al.***, 2022).

By integrating artificial intelligence techniques into their bodies, humans could transform into machine-like beings with steel limbs. Organs at the end of their lifespan could be replaced with those composed of living fibers and silicone via 3D printing. Additionally, a new type of skin could be developed that remains unaffected by environmental conditions. Consequently, humans would eventually evolve into cyborgs, enhancing their strength and skills (**Ru *et al.***, 2024; **Li *et al.***, 2024; **Xing *et al.,*** 2024; **Herzog**, 2002; **Li *et al.***, 2022).

Final considerations

In our view, the evolution of the human species is irreversibly linked to an alliance between the biological and cultural spheres, as postulated by the extended evolutionary synthesis (EES). These sets of evolutionary forces will define complex scenarios far from the current ones. These will shape our biological and cultural future evolution. Besides, techno-culture has become an indissoluble brand of our current human societies.

The human species is endowed with the expansive force of life in a constant evolutionary process, as proposed by evolutionism. Becoming "superhuman" demands overcoming the traditional and decadent morality and reaching the new one resulting from the symbolic inheritance process. In the face of this horizon, it is worth asking ourselves: Is this new morality considered in the evolutionary transhumanist concept?

The Canadian sociologist and bioethicist James Hughes has argued that "bio-politics" is emerging as a fundamental new dimension of political opinion. In Hughes's model, bio-politics joins the more familiar dimensions of cultural and economic politics to form a three-dimensional space of opinion. According to **MacDonald** (2024), in *Citizen Cyborg*, Hughes presents what he calls "democratic transhumanism", which combines transhumanist bio-politics with social democratic economic and liberal cultural policies. He argues that we will achieve the best post-human evolutionary future when we ensure that technologies are safe, available to all, and respectful of people's right to control their own bodies.

The evolution of the human species will not stop, and biology and technology will finally mingle in nature. Science and technology in the 21st century could have paradoxical effects on the consolidation of a world sustained by a post-human social architecture unified by technological culture, on which many subcultures can be built. In this panorama, the question arises about how we face the evolutionary singularity of the human species with the emergence of a new and almost unpredictable generation of social and human sciences based on the convergence between cognitive and natural sciences. From such a perspective, we face the challenge of whether technological convergence could sustain the evolution towards post-human societies.

It is clear, however, that the progress of techno-sciences in this field has experienced great advances and is being implemented at an unimaginable speed and mostly unnoticed by current humans. These developments do not attract much politicians' attention and hardly that of some media. They practically occur behind the backs of ordinary citizens, but some of the present techno-societies are promoting eugenic processes leading to discrimination and inequity.

The concept of technological singularity, as proposed by **Kurzweil** (2005), must be redefined, since in today's human evolutionary scenario, the development of artificial intelligence, the genome-editing technologies, the innovations in nanotechnology, as well as 21st-century social and cultural developments, shall condition the real evolutionary future of present-day humans. This scenario raises some questions that are now subject to debate: How far can we go along this path towards the transformation of our genome to post-humans? Shall we one day be able to manipulate, through the development of technological interfaces, the intelligence, body size, physical strength, or beauty of our future generations, and give them the possibility to choose their sex and the color of their eyes and hair? In science, technology, and society's present state, we are irreversibly addressing a technological singularity event that will impact the ecological balance of the planet and promote TS for the biological and social transformation of our current human species towards future post-humans (**Susen**, 2021).

A general conclusion is that the present state of science and technologies, the transformations of our biosphere, the genome-editing technologies, and the improvement of the brain-computer interfaces shall condition new adaptations in the biological, social, and political spheres, opening the way to a new stage of humankind, that of post-humans.

Authors' contribution

FGV: Conception of the study, systematic analysis of publications, and drafting of the manuscript. **MEM**: Systematic analysis of publications, critical content review processing, and support in manuscript writing. All authors actively participated in the preparation of the manuscript.

Conflicts of interest

The authors declare that there are no conflicts of interest that could have influenced the outcomes, interpretation, or writing of this manuscript.

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