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The Biological as a Double Limit for Artificial Intelligence: Review and Futuristic Debate

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Abstract: This paper aims to identify to what extent artificial intelligence (AI) is biologically limited and to launch a debate on the issue of overcoming these limitations. To achieve our goal, we utilized a qualitative research methodology framework, providing an in-depth analysis of AI limitations formulated by prominent scholars within this field of specialization. We found that the biological boundary imposes a double limitation on AI, both from a gnoseological perspective and from a technological perspective. This twofold limitation of AI underpins the idea that as long as the biological cannot be understood, formalized, and imitated, we will not be able to develop technologies that mimic it. By adopting an original approach, our research paper focused on mapping out the twofold limitation of the biological with reference to the success of AI. Special attention was paid to the motivational analysis of this limitation in terms of human existence, the opportunity and utility to create artificial intelligences as superior to the human-like condition. We have opened the door for future debates on the need to decode cellular communication by understanding and developing a *natural language of the living cell* (N2LC). Based on the present research, we proposed that within the current technological context, biological computers (biocomputing) could represent a so-called *invisible hand* outstretched by biological systems towards AI.
Keywords: Biological computer, super-AI-slices, technological singularity; limits of artificial intelligence, natural language of the living cell (N2LC).

1 Introduction

Nowadays society is dominated by technology [2, 27, 35], communications,and interaction (analog and/or digital) between different chaotic systems [25], which are sometimes too complicated [1, 38]. Change is essential [4, 7, 24, 33, 44] in our society. As we currently find ourselves at the end of the 801st Tofler lifetime [50], further predictions are being made about how society will develop in terms of technology in the following Toflerian lifetime. One of these predictions, advocated by Ray Kurzweil [30], is that in 2045, human society will reach the point where "the accelerated technological progress will overcome the human ability to understand, evaluate, and control all of its consequences, and when the non-biological intelligence created in that year will be a billion times stronger than human intelligence today" [53]. This technological stage, mentioned by Kurzweil [30] and other field-related specialists [57], is referred to as the *technological singularity*, which translates into technological simplicity with artificial intelligence (AI).

The term technological singularity—put forward by A. Turing [18, 53, 54] in the middle of the 20th century, just before the launching of the AI concept—has played a central role in maximizing profits within various industry and business sectors. The focus on technology simplification imposed by technological singularity has been taken over by artificial intelligence that intersects with genomics and synthetic biology [45], hence placing the biological system as a key element of the future great computing platform [37]. As highlighted by Gartner [8, 12], AI has become the core of new technologies, motivating the need to identify AI limitations in order to avoid and even overcome them.

Embarking to highlight the central role of the biological system in the success of artificial intelligence systems, the present paper aims to identify to what extent the biological system stands as a technological limitation of AI.

2 Methodological issues

To reach the goal set in the present research study, we set out to identify those AI limitations governed by the nature of the imitation of the biological system (brain-body-behavior), hence formulating the following research question: *To what extent is the biological system limit for AI?* To obtain an answer to this question, we mainly utilized a qualitative approach, since throughout time various reliable approaches have already been created with regard to the limits of AI, which made our mission easier. Under the circumstances, we carried out an in-depth retrospective analysis via a meta-analysis [61] of the opinions expressed by prestigious authors within this field of specialization, i.e: Hubert L. Dreyfus, the author of *What computers can't do*; Jacob T. Schwartz, mathematician, computer scientist, former professor of computer science at New York University, creator of mathematical and computer theories, and author of Technical Report # 212 of March 1986 on AI Limits; Donald Norman, cognitive scientist; Gordon Bell, senior researcher at Microsoft and computer industry consultant; James N. Gray, specialist in database and transaction processing computer systems; Franz L. Alt, former president of the ACM; Paul W. Abrahams, consulting computer scientist and former president of the ACM; experts invited by Denning and Metcalfe [13] to put forward their views in the volume *Beyond Calculation: The Next fifty year in computing*; Max Lungarella, Fumiya Iida, Josh C. Bongard, and Rolf Pfeifer, authors of numerous AI research studies and projects and coordinators of the proceeding volume, *50 Years of Artificial Intelligence. Essays Dedicated to the 50th Anniversary of Artificial Intelligence framing the limitations of AI in the 21st century - With Historical Reflections* [34]. Figure 1 illustrates the scope of our meta-analysis for the first 50 years following the launch of the AI concept, as well as references to the predictions launched by the selected authors.

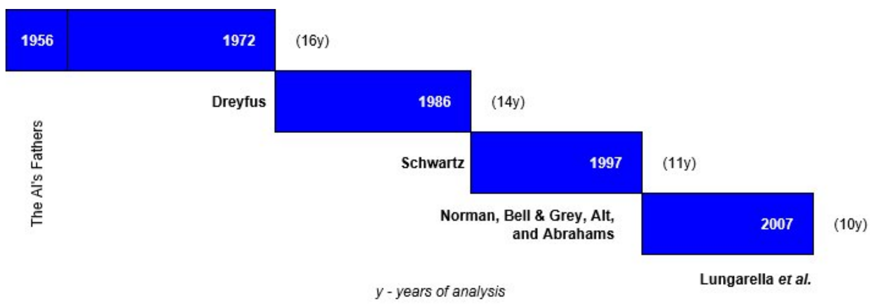

Figure 1: The meta-analysis of the timeline for AI limits

To design and develop our approach, we departed from the outline of the main AI milestones, as well as the initial goals as imagined by the visionary parents of AI. To extract those limitations imposed by the formalization and production of biological-type phenomena, we have undertaken a retrospective analysis of AI limitations as formulated by the selected authors. Having framed the above-mentioned limitations, we went a step further, highlighting their similarities to biological entities in order to establish to what extent such limitations impose actual limitations on AI. We underpinned our research enquiry with systematic implementation of a hybrid approach between biological entities and computers [41] to finally formulate some predictions with regard to what is within the reach of AI and what is not until the technological singularity is attained in our society.

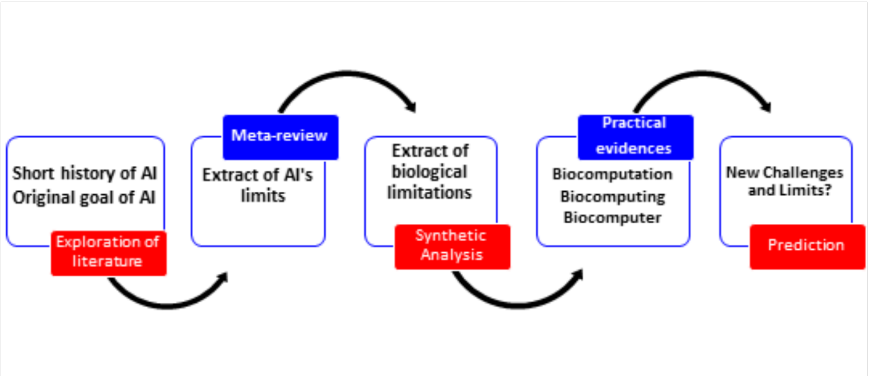

Figure 2: The research modeling stages

The overall approach of our research designed to achieve the goal set is outlined in Figure 2.

3 Artificial intelligence: a short history and its original goals

Humans have constantly resorted to technology to achieve goals with the interest of survival and controlling the others. Defined as the scientific study (logos from $\lambda\acute{o}\gamma o\varsigma$ [Gk]) of craftsmanship (techne from $\tau\acute{\epsilon}\chi\nu\eta$ [Gk]), technology has dominated the last 10,000 years of human existence [30] and been the catalyst for the leap from one technological era to the next, including the current era of cybernetics, which was marked by the launch of the first electronic computer in 1946 (ENIAC-Electronic Numerical Integrator And Computer). In the first decade of the cyber revolution, the idea of technological intelligence emerged with the launch of the concept of artificial intelligence at the 1956 Dartmouth Conference, a concept suggested by John McCarthy to his colleagues Marvin Minsky, Allen Newell, Claude Shannon, Herbert Simon, Oliver Selfridge, and Ray Solomonoff [34]. The concept itself was the scientific response to science fiction ideas [53], which included *Elektro and Sparko* at the 1939 World's Fair; Isaac Asimov's *Three Laws of Robotics* published in the May 1941 issue of Astounding Science Fiction; the 1950 novel *I, Robot*, written by I. Asimov; and A. Turing's test in 1951 to answer the question "Can machines think?".

Newell, Shaw, and Simon's validation of 38 of the 52 Theorems of the Principia Mathematica by means of the Logic Theorist software; the 1958 launch of LISP (the first language of AI) by John McCarthy; the launch of the General Problem Solver in 1959 by Newell, Shaw, and Simon to solve complex problems, such as the *missionaries and cannibals* scenario; the publishing of the article "Pattern Recognition by Machine" by Selfridge and Neisser [47]; and the development, between 1959 and 1962, by J. McCarthy and his students at MIT of the first credible chess game software, known as *A Chess Playing Program for the IBM 7090 Computer*, are a few concrete landmarks on the Phase I timeline of AI (1957-1962), as delineated by Dreyfus [15]. Shadowed by the highly interesting achievements carried out during Phase I, the following five years (1963-1968), framed by Dreyfus [15] as Phase II of AI, seem to be less spectacular in reaching further AI objectives such as the simulation of human behavior (particularly in relation to what the human brain can do), highlighting the fact that progress in AI has not been exciting or spectacular [51] and that the following years' predictions (after 1968) are not bright [26]. This view of limited achievements in AI is also shared by Schwartz [46], who adopts the perspective put forward by Dreyfus [15] and highlights that even after 14 years, AI faces "very limited success in particular areas, followed immediately by failure to reach the broader goals at which these initial successes seem at first to hint", motivated in particular by the technological limitations at the time of analysis.

Even 50 years after the term Artificial Intelligence was launched, at the July 2006 Conference in Monte Verita (Ascona, Switzerland), Lungarella, Iida, Bongard, and Pfeifer [34] mentioned the shared opinion of fellow researchers that AI is far from approaching the goals originally set by the first generation of AI visionaries, whereas natural intelligence is still far from being understood.

Over the last decade, and especially after 2013, an increasing number of organizational studies and reports have been registered, focusing mainly on digital economy-related industries. When accessing the Gartner.com platform, in a simple search for *artificial intelligence, AI, intelligent, automation*, and *robot* for the year 2018, we got 1358 entries, of which the content analysis would indicate that the first 427 entries (i.e. 31.44%) have one or more of the requested keywords in their headline.

Setting out to analyze the newsletters received from McKinsey & Company, we carried out an analytical study to validate the information explosion trend in terms of the usability of AI applications in the organizational field. Thus, based on 1189 newsletters received from McKinsey between 2014 and 2018, we developed our investigation for each year and set as query parameters the same keywords as in the Gartner.com analysis, i.e. in the title (subject) and summary.

Table 1 indicates the synthesis of our newsletter queries for 2014-2018 by keywords (title and/or summary), and Figure 3 illustrates the values reported in Table 1. According to our analysis, by April 26, 2017 there were no query titles (Subj.) directly querying artificial intelligence or AI. The situation changed radically after April 27, 2017, when we found that there were 42 pieces of information in which artificial intelligence and AI appeared both in the title and the summary of the investigated information. It is important to note that a McKinsey newsletter can include from one to ten independent notices in which keywords appear either in the summary or in the title and summary. Considering only the newsletter content, we found that after April 27, 2017, the use of the terms selected either in the title or in the title and summary increased from 32 entries in 2014-2017_a to 237 entries between 2017_a -2018, which means an increase of 877% after April 26, 2017.

Consequently, for both the Gartner and McKinsey data processed in relation to the reports, research studies, and surveys about technological trends at the societal level, we marked out an industry-oriented expansion of applied AI theoretical concepts to solve practical issues in order to simplify problem solving and/or replace individuals from various processes. In addition, our organizational analysis registered the occurrence of an inflection point on April 27, 2017, at which time it can be seen that the McKinsey reports focused on the technological expansion of intelligent applications in different industries. This is in fact another argument, an obvious proof of the social view in favor of complexity simplification via the instruments of artificial intelligence on the way towards the technological singularity.

Table 1: Synthesis of McKinsey Queries

Total	**2014**	**2015**	**2016**	**2017$_a$**	**2017**	**2018**
Artificial Intelligence $_{(KW)}$	**7**	**6**	**0**	**0**	**21**	**48**
Artificial intelligence (Subj.)	0	0	0	0	5	11
AI $_{(KW)}$	**0**	**0**	**0**	**0**	**21**	**56**
AI: (Subj.)	0	0	0	0	2	16
Robot $_{(KW)}$	**2**	**0**	**1**	**2**	**9**	**6**
Robot: (Subj.)	1	0	1	0	1	2
Automation $_{(KW)}$	**2**	**1**	**1**	**3**	**31**	**33**
Automation: (Subj.)	2	1	1	3	10	11
Intelligent $_{(KW)}$	**0**	**0**	**0**	**2**	**3**	**4**
Intelligent: (Subj.)	0	0	0	1	1	1

Legend: KW=Key words (Subject+Summary); Subj.=Subject; 2017$_a$: until April 26 2017.

4 The limits of AI in time — a meta-analysis

According to economic theory, every technological revolution is emphasized by the emergence of a new production factor that triggers the concrete manifestation of the new technological age. Under the circumstances, Tapscott [49] has labeled the current economy the digital economy, stating the significant contribution of information to the creation of GDP (Gross Domestic Product) as a specific factor in the cybernetics era [59]. From a societal perspective, Tapscott records an accelerated transition of human society from the industrial society of the early twentieth century to the Internet-dominated post-industrial society and digital technologies specific to the late twentieth century.

In terms of artificial intelligence as a digital technology of the 21st century, our research study aimed to pinpoint the main landmarks as highlighted by the AI visionary parents from its very beginning and analyze to what extent these limitations have been preserved over time and how they influence the evolution of this field of specialization.

In essence, AI was seen as an attempt to build systems with human-like or even super-human capacities in certain domains [60], traditionally considered closely related to the human mind. In this endeavor, in order to better understand their target, the pioneers of AI were keen to discover how the human brain functions. Originally considered a *meat machine* by M. Minsky in the late 1960s, two decades later the human brain was characterized by Schwartz [46] as a *biochemical computer*. Without actually defining the human brain, P.W. Abrahams [1], a former student of M. Minsky at MIT, postulated in his essay "The World Without Work" that the human brain is a target that is hard to understand and mimic using artificial intelligence. The author compares the human brain to the Moon towards which the Earthlings have set out to build a tower, but no matter how hard they work to raise it, it is still not enough compared to the Earth-Moon distance.

4.1 AI limitations according to Hubert L. Dreyfus

In his 1972 work entitled *What Computers Can't Do*, Hubert L. Dreyfus carried out a critical analysis of what AI managed to do or not with regard to the expectations postulated by the AI visionary parents during 1956-1972. As illustrated in Figure 1, Dreyfus's [15] answer to the book title question, *What Computers Can't Do*, formulated from a critical perspective on AI, explicitly mentions in the conclusion the limits of artificial intelligence.

Dreyfus [15] explained what computers cannot yet do due to technological limits even with

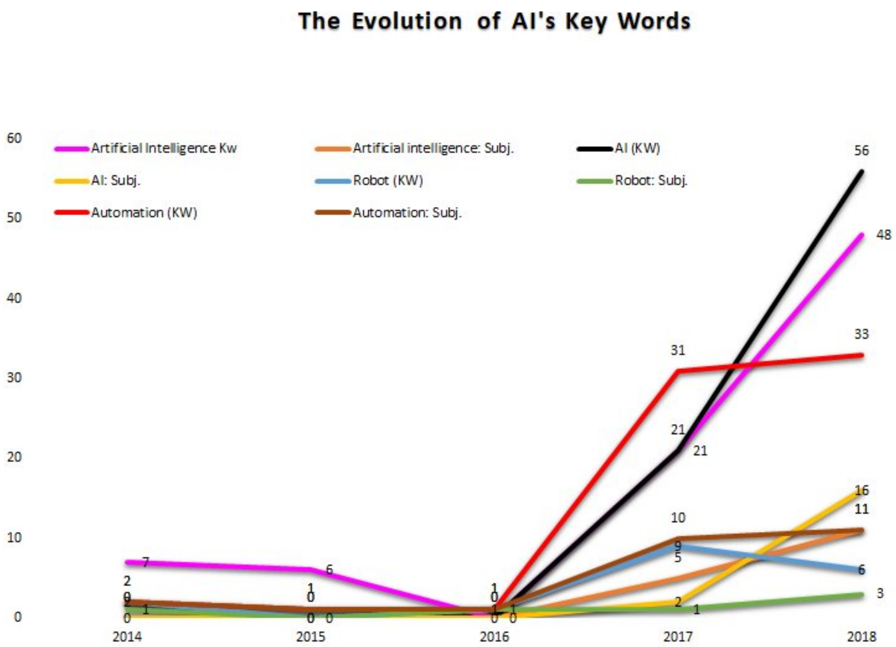

Figure 3: A graphical representation of the organizational explosion of the AI keywords

the creation of equipment capable of huge performances with up to $10^{10^{10}}$ states (Dreyfus's number). He referred to the limitations of processes of informational formalization in the brain and the body, and, additionally, the limits of human behavior formalization (for which there are sometimes no rules), as well as the limitation of the formalization of the non-material aspect of the human soul (immaterial soul) inspired by Descartes' [14] vision and the motives of his Discourses.

In fact, irrespective of the research hypotheses (tested and untested) formulated by AI titans such as Minsky, Shannon, Simon, Shaw, Turing, Neumann, McCarthy, Fodor, and Feigenbaum focused on and connected to ideas and theories of interconnected research areas such as mathematics, physics, chemistry, psychology, and philosophy, AI limitations in Dreyfus's opinion were centered on two key words: technology and formalization. Dreyfus regarded formalization as the main limitation, in the sense of the impossibility of heuristic modeling from the biological, psychological, ontological, and epistemological perspective of the *brain-body-behavior-soul* (SoBrBoBe) grouping in relation to human needs optimization functions.

4.2 AI limitations according to J.T. Schwartz

A state-of-the-art approach to AI limitations was developed by J.T. Schwartz [46], former computer science professor at New York University. Schwartz analyzed what had been achieved in the field of AI in the 30 years after the concept release (1956-1986), as illustrated in Figure 1.

Schwartz featured two categories of limitations, namely the limitations imposed by the concrete physical and logical issues of artificial intelligences design and those required by the ethical dimension of their existence. In the first category, Schwartz included a) the fundamental limits to the constructability of artificial intelligences (AIs), which refers to the (limited) possibilities of systems designed similarly to the human brain (Br) in performance; b) limits imposed by the quantitative theory of computational complexity, motivated by the remarkable, but complicated to simulate, ability of the human brain to manipulate complexity and to reveal it in a simple and efficient manner; and c) knowledge-based limitations on AI detailed on three levels: sensors, with reference to the analysis of images (computer vision) and the analysis of nature; motor control, modeling of spatial environments, and motion planning; and reasoning, planning, knowledge representation, and expert systems with reference to graphical searching, predicate systems, expert systems, knowledge representation, and learning. In the second category of ethical limits, Schwartz included the *fear* induced when such systems are out of control, as well as the methods and rules of human interaction with these systems.

4.3 AI limitations upon the 50th anniversary of the foundation of the ACM

The debates launched in March 1997 on the occasion of the 50th anniversary of the Association for Computing Machinery (ACM) via 20 essays authored by IT experts and specialists [13] triggered an increased awareness of the technological limitations of artificial intelligence, highlighted in a direct or indirect manner by G. Bell, J.N. Gray, D. Norman, F.L. Alt, and P.W. Abrahams in their works. In fact, these limitations are found in the first section, "Coming Revolution," as well as the second section, "Computers and Human Identity," of the volume edited by P.J. Denning (chair of the Computer Science Department in the School of Information Technology and Engineering at George Mason University) and R. Metcalfe (the inventor of Ethernet technology), i.e. the debates on the predictions launched with reference to the future of computing.

Bell G. and J.N. Gray: "The Revolution Yet to Happen"

In their chapter "The Revolution, Yet to Happen," G. Bell and J.N. Gray [5] discussed cyberspace, where information about all real-world physical objects will be found online by encapsulating it in a chip, leading to fully networked systems. The authors' prediction for 2047 was that the operating and storage performance of the computer would equal the human brain (Br) and that the so-called on-a-chip systems, body area networks, and robots would make their presence felt in cyberspace.

Essentially, Bell and Gray were of the opinion that there was a technological limitation to the development (understanding, formalizing, and building) of systems capable of human-brain-like performance that could be overcome by 2047. However, hybrid systems were considered as immediate solutions (after 2025), in which body area networks (as an intermediary step towards biological computers or biocomputing) would play a considerable role.

Norman D.: "Why It's Good That Computers Don't Work Like the Brain"

"Why It's Good That Computers Don't Work Like the Brain" is the chapter [41] where psychologist Donald Norman (keen on both human and computer behavior) adopted a positive approach to the differences between the individual, as an intelligent, unpredictable, robust, relatively error-insensitive, and redundant being, and the computer (including robots) as an abstract, linear, consistent, rational, and precise machine. This mirror characterization reflects the irrefutable limits of artificial intelligence. Norman is of the opinion that computers and robots will never come to mimic or surpass people, and that due to technology, the human species is condemned to an ever-growing complexity, which will lead to a continued loss of privacy and freedom of action. Within this context, the technological limitation of computers (including artificial intelligence) compared to the human brain is decided from the concept, design, and realization stages, since we place into discussion two totally different entities, namely the human brain (Br)— the result of an evolution marked by continuous adaptations and interactions over millions of years, where the natural selection criterion was that of survival of the species — and computer technology, which is limited in terms of its the evolution over time (little over 50 years at the date of the author's analysis) as well as its design and development by reference to efficiency optimization functions and computational algorithms.

Norman was categorical and clearly stated that a computer would not be able to mimic or surpass people. The solution recommended by the author to overcome this technological limitation envisages the human-computer relationship seen as an interaction between cooperative and even hybrid systems towards the development of the so-called *biological computer*.

Alt F.L.: "End-Running Human Intelligence"

The marked difference between human intelligence and artificial intelligence is also shared by F.L. Alt [3] in his chapter "End-Running Human Intelligence." The author features several domains where AI las proven to be less successful, such as "chess playing, legal problems, medical diagnosis, weather prediction, public opinion surveys, and the understanding of natural language."

Some limitations identified by Alt are already outdated at present, proving that AI has made remarkable progress over the past two decades.

Abrahams P.W.: "A World Without Work"

Disappointed with the failure to meet the goals he had predicted during AI's debut in the late 1950s and early 1960s when he was M. Minsky's student at MIT, 40 years later, P.W. Abrahams [1], in his chapter "A World Without Work," outlined some of the most important AI failures, including not having met the goal set by Japan in the Fifth Generation Computer Project, despite the contemporary appreciations of Feigenbaum and McCorduck back in 1983 [22], and the cultural and emotional limitations of robots' interactions with human subjects in the field of service provision (such as telephone services, taxi services, and cuisine). For example, with regard to the interaction with human subjects, Abrahams added one of the most challenging limits, i.e. the inability to feel the same type of love for a robot as for a person, or even the same intensity of sexual attraction (even if 20 years later this limitation seems to be somewhat conceptually overcome via conferences on topics such *Love and Sex with Robots, LSR 2016* and the special issue "Love and Sex with Robot" in the *Robotics* journal [62]). Towards the end of his chapter, Abrahams launched a series of rhetorical questions to highlight AI behavioral limitations in comparison with the biological system (BrBoBe), as well as various aspects with regard to the utility of intelligent humanoid machine design. Among such rhetorical questions, we identified those related to the capability of intelligent humanoid machines to engage in activities or situations specific to humans, such as eating, bleeding, dying, procreating, and the feeling of pleasure or pain. Moving a step towards an affirmative answer related to procreation, Abrahams wondered if robot children would be subject to the same ethical imperatives specific to our children? Could the robots be treated like slaves without any compassion? And what would then be the reason for designing robots, apart from intellectual curiosity and desire for power, provided that humans can easily create people and do so with pleasure? We considered that all these questions, which are difficult to answer, impose the limitations of AI as a form of manifestation and level of development. In addition, Abrahams also drew societal boundaries (including ethical ones) in the sense that robots cannot succeed in creating a better world than the one people created on their own, even if robots undertook all social/economic tasks and overcame different cultural, racial, and religious differences. Consequently, the role assigned to intelligent computers is to complement the individual in his/her actions, such as managing, exploiting, recovering, and recycling the planet's limited resources.

Abrahams' approach encompasses both constructivist limitations, which involve the understanding-formalization-construction process, and behavioral limitations (including feelings, states, and manifestations specific to humans) as well ethical ones. Abrahams' recommendation was to create systems assigned to humans (living systems) similar to those put forward by D. Norman in his chapter.

4.4 AI limitations on the 50th anniversary of the concept launch

On July 9-14, 2006, AI specialists attending the 50th Anniversary Summit of AI, held at Centro Stefano Franscini, Monte Verita, Ascona, Switzerland, celebrated 50 years since the term artificial intelligence was launched. Although the summit agenda listed the launch of speculations about the future of AI, we found that no actual limits were discussed, but rather the challenges and development directions applicable in different areas. Lungarella, Iida, Bongard, and Pfeifer [34] wrote "AI in the 21st Century - With Historical Reflections", as forward-thinking paper showing the evident advantage to having obtained a clear picture of the stage reached by AI in the first 50 years since its launch, and to having synthesized in a prudent manner expectation forecasts for the next 25-50 years. We shared the same motivation to have selected this paper for our meta-analysis timeline.

In the first decade of the 21st century, Lungarella et al. [34] stated that there was still a technological limitation imposed by the fact that *natural intelligence* (the topic of behavioral emulation by artificial intelligences) was "far from being understood", saying that the "basic theories of natural intelligence are lacking" while "artificial forms of intelligence are still much more primitive than natural ones". Thus, the authors insisted on the limitation of the understanding and the conceptual formalization of the biological system (the brain-body-environment triplet) within the constrained limitations still imposed by a rudimentary and unavailable technology. This overview of conceptual and technological limitations was articulated amid the paradigm shift in the stated purpose of artificial intelligence. Thus, if intelligence was initially thought to be located in a box in the human brain (Br), after 2000, a novel perspective focused on the distributed intelligence located throughout the whole organism (Bo), which interacts with and explores the environment (En). In other words, the authors endorsed the paradigm shift from a computational approach to an embodied perspective.

5 The result is a biological limitation

Following our meta-analysis of the main limitation-related views put forward by Dreyfus, Schwartz, Norman, Bell, Gray, Abrahams, Lungarella, Iida, Bongard, and Pfeifer, we synthesized a series of methodological assertions to highlight the essence of AI limitations.

The first methodological assertion, based on the limitations of AI as formulated by Dreyfus, states the existence of a technological limitation to building systems with huge performances ($10^{10^{10}}$ states, a value that even today does not work), which is a performance with which the biological system is indirectly credited via the brain-body binomial (BrBo), complemented by the individual's inability to achieve complete self-understanding and the formalization of his/herbehavior (Be) and soul (So) as a manifestation of the whole SoBrBoBe.

Departing from the AI limitations as formulated by Schwartz, we extracted the second methodological assertion, namely the existence of a concomitant limitation of scientific and technological knowledge in constructing artificial intelligences similar to the human brain (Br) in terms of its remarkable ability to manipulate and reveal complexity in various AI applied domains, to which ethical limitations of the biological interaction (BrBoBe) are added. We noted that Schwartz focused on the biological component (BrBo) of AI limitations, which cannot yet be understood or formalized so as to design AIs.

The experts summoned by Dening and Metcalfe [13] as contributors to the anniversary volume of the 50th anniversary of the foundation of the ACM clearly identified a series of interesting AI limitations, from which we extracted the third methodological assertion to identify the technological limitation in system designs (computers) that mimic or surpass people [41] in their behavior regarding survival, feelings, moods, and manifestations within a lack of utility context [1]. In essence, the proper design involves the understanding and formalization of the biological system (BrBoBe), and the authors endorse this as a possible solution to the design of cooperative systems based on human-computer [1] interaction, hybrid body area networks [5], and the development of the biological computer [41].

The fourth methodological assertion, extracted from the AI limitations identified by Lungarella, Iida, Bongard, and Pfeifer [34], consists of the lack of basic theories with regard to what natural intelligence is as the subject of AI emulation and the continued existence of a limitation of the understanding and formalization of the biological system (BrBo) in the interaction with and exploration of the environment (En). Essentially, it is a reformulation of human behavior (Be) with the interaction with and biological exploration (BrBo) of the environment (En) that forms the BrBoEn triplet, while the biological system (BrBo) is still largely unknown.

By examining the four methodological assertions, we found that the biological represents a common and important limitation of AI, hence it must be first understood, then formalized, and finally imitated by technology. As long as the biological cannot be understood, formalized, and imitated, we will not be able to develop technologies that can mimic it. Surface imitation of natural intelligence can only lead to superficial results, such as the tower that the earthlings would propose to build in order to reach the Moon, and no matter how much of it would be built each day, it would remain insignificant compared to the Earth-Moon distance [1]. Subsequently, we can say that both the gnoseological and technological boundaries of human beings are automatically limitations of AI.

All previously mentioned authors investigated the key role of the biological component in AI limitations by limiting the initial understanding of natural intelligence — in fact, self-understanding, which must be the premise of success in the theorization and formalization of natural intelligence and the technological stage in the process of AIs design that mimics the biological system. In other words, in compliance with the four methodological assertions, all the limitations identified by Dreyfus, Schwartz, Norman, Bell, Gray, Abrahams, Lungarella, Iida, Bongard, and Pfeifer are located on the following logical trace: biological $->$ technology $->$ biological $->$ AI (Bio-Tech-Bio-AI).

We can then explain the logical route Bio-Tech-Bio-AI in the simplest way; the individual is not capable of self-understanding (*the first biological limit*) in order to create fundamental theories of natural intelligence and is still limited in the design and use of appropriate technologies (tools and materials), technologies that in turn would be used to mimic the biological system (*the second biological limit*) in order to design what we should have understood, i.e. artificial intelligences.

Consequently, our meta-analysis, based on the four methodological assertions, highlights that the biological boundary remains the main limitation of AI, both from a gnoseological perspective (due to the impossibility of self-knowledge) and from a technological perspective (given by the impossibility of formalization, design, and use of technologies — instruments and materials — that imitate natural intelligence). When implying the limitation of the biological systems, we found that the natural intelligence of the individual is limited from a gnoseological perspective. The gnoseological and technological limitations fall into a spiral pattern similar to DNA, in which the two boundaries communicate, but as of yet do not intersect. The above analysis justifies the conclusion that the human being is still at this moment a double limit for artificial intelligence.

6 Current AI records and limitations — futuristic debate

The two limitations — gnoseological and technological — approached as a double limit of the biological in terms of the success of AI, were analyzed in a direct manner by Norman [41]. In the attempt to answer "Why It's Good That Computers Don't Work Like the Brain", the author asserted that computers and robots would never come to mimic or surpass people. Accordingly, Norman advocated the idea of parallelism between the two boundaries, while he identified a bridge between them through biological computation via a biological computer. Even though the Merriam-Webster Dictionary notes that the term biological computer (bio computer) was first used in 1952 in the sense of a "computer that uses components of biological origin (such molecules of DNA) instead of electrical components", this sense was taken over in 1958 and Heinz von Foerster [55, 58] created the Biological Computer Laboratory at the Department of Electrical Engineering, the University of Illinois. It was not until 1997 that Norman endorsed a fusion-oriented approach (in the sense of merge) between the biological cell and the classical computer that would lead in the coming years to a hybrid biological computer capable of notable performance in the applicative field of artificial intelligence. Within the framework of the double biological limitation highlighted above, corroborated with societal expectations of AI design that would predominantly replace human activities, we considered it appropriate to continue our discussion with some promising achievements in recent years as arguments for the success of AI and launch further questions about future challenges and limitations.

6.1 Some actual evidence of AI

The idea of the biological cell's assimilation into the future biological computer gives us biocomputing, a concept used since 1965 [36] as an "application of computer science to biological research", though in tandem with the notion of biological computation (not yet defined in Merriam-Webster's collegiate dictionary [36]), meaning that a system of neurons, grown biologically [41] is used to design AIs. If at first the biological computer was defined as a system of neurons, artificially grown, capable of problem solving via biologically real, brain-like operations [13], later on we could speak of DNA computers [29, 45] or computers using synthetic biological components in order to manipulate, store, and retrieve data. As in any technological field, the field of biological computers is mainly concerned with achieving a stable and reliable technology. In terms of the understanding and formalization of the biological system and ultimately the development of stable and reliable technologies leading to the development biological computers, it is worth highlighting some of the most important achievements of the past five years.

Parallel computation between computers and molecular motors

In the attempt to concretize Norman's idea of efficiently involving the biological system in the creation of hybrid systems [41], the complex research team coordinated by Professor Nicolau of McGill University (Canada), with representatives from the Lund University (Sweden), Molecular Sense Ltd. (UK), Technische Universitat Dresden (Germany), Philips Research and Philips Innovation Services (The Netherlands), and Linnaeus University (Sweden) [39], obtained in 2016 the "proof of concept" of a computer that operates in parallel using mobile molecular proteins that exploit a nanotechnology-based network and codes a problem still unsolvable by electronic computers. In particular, the authors [39] put forward a "parallel-computation approach, which is based on encoding combinatorial problems into the geometry of a physical network of lithographically defined channels, followed by exploration of the network in a parallel fashion using a large number of independent agents, with very high energy efficiency." This project, initiated by D.V. Nicolau [39], a professor at McGill University, incorporates the development of various ideas on the design of molecular motors at the micro- and nano-biocomputation level, published in 2006 in Microelectronic Engineering [40].

Stable storage of digital data in DNA

A practical achievement of great importance in the field of bio computers was the research study completed in 2016 by Erlich and Zielinski [19], researchers at Columbia University and the New York Genome Center, who informed the scientific community about a major improvement in DNA information storage and retrieval when they succeeded in implementing "a new coding strategy to encode text, images, a movie, and an operating system in 2 megabytes of DNA, and retrieve it back perfectly in multiple trials" [21]. The two researchers, through their strategy, managed to store 215 petabytes of data on a single gram of DNA [11].

Biological Computers Inside Living Cells

One of the most striking achievements in the field of bio computers was announced by A. Green, an engineer at Arizona State University, who informed the public that together with researchers from Harvard University, they had developed a biological computer "that controls how cells behave," [28, para. 1] including the construction of biological circuits that behaved similarly to digital circuits and used the logical operators AND, OR, and NOT to make decisions. The research team thus managed to create a biological transistor (called a transcriptor), a specialized computer that could be programmed to monitor and affect the functions of living cells. To achieve this, the team used DNA that could store up to 455 exabytes of data per gram [28].

Biology: the next great computing platform

Within the last two decades, and particularly after 2012, biology has enjoyed increased attention from researchers in different areas of specialization. For example, a step forward was made in the formulation of theories such as the theory of electrodynamic instabilities in biological cells [32] and the design of specialized sensors for the reception of emotions-on-a-chip [31], towards the recording of the extracellular neural activity [20], not to mention the continuous-flow biochips [43], the design of revolutionary gene-editing technologies such as CRISPRs [37], and the design of nano-biologic computers as reliable alternatives for quantum computers [9, 39]. All these intersections between AI, genomics, and synthetic biology as highlighted by Rosso [45] will help specialists turn biology into the next great computing platform [37] of society.

6.2 Futuristic debate and next questions

The topic of AI limitations has always been a sensitive issue for society in general and for the individual in particular. Following our meta-analysis, we highlighted the importance of ethical [46] and spiritual or soul-related [15] limitations that are difficult to overcome [48]. To successfully outline AI limitations, since the individual stands as the double limit meant to secure the success of AI, motivates us to shed some light on our limits as a species in the universe. In what follows, we discuss some central topics of reflection on our human-like interaction with AI.

Do we really know our limitations as a species? It is quite obvious that the individual, as a human, manifests a rather limited understanding and self-understanding. For example, from an existential perspective, we do not yet know with utmost certainty where we come from and where we are going on the path of our existence. We cannot yet understand ourselves or explain and formalize our own intelligence in a credible way, and we do not have yet an explanation of why humanity displays (at least for now) superior intelligence to the other species on Earth. We certainly do not know, and there is no clear evidence of our appearance on Earth and which of the creationist or evolutionary theories is true [10, 16, 17, 42]. In addition, even if we were to be given a proof to demonstrate one of the two theories, we would still wonder how this evidence should be exhibited to be irrefutably credible. Are there temporal, spatial or other limits to our ability to understand that proof? On this level, the list of questions remains open. The only certainty is that we have many limitations as a species-that is, we know very little about what we want to know.

Is it necessary and appropriate to plan the design of such AI that go beyond the human being? The usefulness of the descriptive truism formulated in the previous question, rounded by the obvious conclusion that we have many limitations, helps us to clearly understand another aspect: *Someone* (from the creationist perspective) or *Something* (from the evolutionary perspective) has contributed to our development as a species. Are we able to compete with the *Creator* or the *Millennia-long evolutionary process* in our attempt to design AIs? Should we attempt to do so? And if yes, are we firmly convinced that we will succeed? And if we succeed, is it prudent for the human species that these AIs be superior to us in terms of intelligence? It is obvious that the human has been overcome in many areas by technology, as far as efficiency is concerned [56]. Is it necessary and opportune that we be overcome by technology and from intelligence perspective? The positive answer to such a question, correlated with the ethical limitation regarding the exploitation of these AI as highlighted by Abrahams [1], should encourage a serious reflection on the future sharing of the exploited and exploiter roles.

How far should AI reach? The answer is simple. As long as the individual has his/her own gnoseologic and technological limits to which the existential ones are added, AI cannot overcome us for a very simple reason—we cannot build something we can not formalize, to which we add our fears and/or pride in relation to a technological entity created by ourselves. However, biocomputing, bio computers, and DNA computers could lead to the design of AIs that overcome natural intelligence on certain levels, which means we could talk about the *slices of super AI* (super-AI-slices), without the scope to completely overcome the natural intelligence.

Biocomputing—The invisible hand of AI? Fascinated by the secrets of medicine, in an informal discussion in 2014, we asked the famous surgeon I. Lascar, a professor at the University of Medicine and Pharmacy in Bucharest, *what the secret was to a successful operation.* Among the syntheses and content-related explanations, Professor Lascar pointed out that surgery is assisted, besides a number of strictly scientific factors, by a so-called *invisible hand* that contributes to the success of an operation and which all physicians rely on. In this context, the success of biocomputing research and development as part of the bio computer could be the catalyst for leaping to a level of AI that surprises us in terms of intelligent performance and behavior. Current achievements, such as the design of the biological transducer; the monitoring, programming, and behavioral control of the live cell (via logical operations AND, OR, and NOT); and technological challenges such as the decoding of live cell communication and the future development of a *natural language of living cells* (N2LC) used in biocomputing could turn biocomputing into the invisible hand of biological systems stretched towards artificial systems, especially AI.

All the questions raised in our present paper are aspects of AI boundaries in relation to natural intelligence, but also future research topics in relation to the following premise: nature is very simple and efficient in everything she makes [52]. It is very important for us, as humans, to understand the simplicity of nature in creating biological entities, decoding the biology, and applying it to communicate via an NLLC to build calm technologies [6, 23] at the societal level.

7 Conclusion

The research study carried out in this paper, motivated by the need to clarify to what extent technological limitations are based on biological limitations and departing from the methodological assertions extracted via our meta-analysis, highlighted that the biological boundary represents the main limitation of AI from both a gnoseological and a technological perspective. Thus, we have come to the conclusion that as long as the biological system cannot be understood, formalized, and imitated, we will not be able to develop technologies that can mimic it.

We highlighted the double biological limitation as a conclusion of the Bio-Tech-Bio-AI logical pathway, to which we assigned the results of our meta-analysis with respect to AI limitations as identified in Dreyfus, Schwartz, Norman, Bell, Gray, Abrahams, Lungarella, Iida, Bongard, and Pfeifer. We registered on the Bio-Tech-Bio-AI path the inability of the individual regarding self-understanding *the first biological limitation* in order to develop theories about natural intelligence, which induces a limitation on the creation and use of technologies appropriate to the process of imitation/mimetization of the biological system (the second biological limitation) in order to design what we should have understood, i.e. artificial intelligences. Within this framework, we conceptually embraced the gnoseological and technological limitations in a DNA spiral model through which the two boundaries communicate, but which do not intersect as of yet.

At this stage of human scientific knowledge, as far as the double limitation of AI is concerned, we highlight that the technological limit is not a mere consequence of the gnoseological limit, motivated by the fact that from a causal perspective we are talking about the same biological system which is analyzed at two different moments. At the first moment, the biological system searches for and does not find the answer to the question "What do we imitate?", while, at a second moment, the same biological system is looking for the answer to "With what (technology) do we imitate?". That we have to deal with two limitations resides also from the procedure of forcible and sequential elimination of one of the two limits, hence reaching the obvious result that the un-eliminated limit will always be valid. Plainly, if we assume that we were now provided a wonder technology, we would grow aware that we still do not have an answer to the question of what to imitate with this technology. Likewise, if we suddenly understood what natural intelligence is, we would find that we do not have at the same time (simultaneously) a technological solution to imitate natural intelligence. Considering the current level of technological development, it is important to understand this dual limitation of AI in order to establish clear and separate research goals aimed at advancing from both directions to achieve the original goals assigned to artificial intelligence.

Furthermore, the motivational analysis of AI limitations was supported by our futuristic discussion structure on three levels. The first level approached via the existentialist dimension, i.e the perspective of knowing our limitations as a species on Earth, a discussion that ends with the certainty that humans have numerous limitations and that we know very little about what we would like to know, alongside a long series of unanswered questions. The second level was the launching of unanswered questions about the opportunity to design AIs that are superior to human beings. The third level focused on the usefulness of designing such AIs. Here we placed into discussion the idea of building *super-AI-slices*, i.e. those AIs that overcome natural intelligence in certain directions and that would be more useful at the societal level than a global artificial intelligence.

Motivated by the outstanding practical achievements of biocomputing, we focused on the technological challenge of decoding cellular communication through the understanding and development of the *natural language of the living cell* (N2LC), leading to the understanding and acquisition of novel information needed to monitor, coordinate, and direct cellular behavior, and we highlighted the topic of the so-called *invisible hand* outstretched by biocomputing towards AI.

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Author contributions. Conflict of interest

The authors contributed equally to this work. The authors declare no conflict of interest.

Bibliography

[1] Abrahams, P.W. (1997). The World WithoutWork, In *P. Denning, R. Metcalfe, R. (Eds.), Beyond calculation: The nextfiftyyears of computing*, Santa Clara, CA: Springer-Verlag Telos, 135-147, 1997.

[2] Alles, M. (2018). Examining the role of the AIS research literature using the natural experiment of the 2018 JIS conference on cloud computing, *International Journal of Accounting Information Systems*, 31, 58-74, 2018.

[3] Alt, F.L. (1997). End-Running Human Intelligence, In *P. Denning, R. Metcalfe, R. (Eds.), Beyond calculation: The nextfiftyyears of computing*, Santa Clara, CA: Springer-Verlag Telos, 127 - 134, 1997.

[4] Badica, A.; Badica, C.; Ivanovic, M.; Buligiu I. (2016). Collective Profitability and Welfare in Selling-Buying Intermediation Processes. Computational Collective Intelligence, *Lecture Notes in Artificial Intelligence*, 9876, 14-24, Springer, 2016.

[5] Bell, G.; Gray J.N. (1997). The Revolution Yet to Happen, In *P. Denning, R. Metcalfe, (Eds.), Beyond calculation: The next fifty years of computing*, Santa Clara, CA: Springer-Verlag Telos, 127 - 134, 1997.

[6] Brown, J. N. A (2015). Once More, With Feeling: Using Haptics to Preserve Tactile Memories, *International Journal of Human-Computer Interaction*, 31(1), 65-71, 2015.

[7] Bruksos, R. (2005). *Turning Change into a Payday. Re-inventing Yourself Throughthe Eight Stage of Change.* Seatle: Training Consultants, 2005.

[8] Cearley, D.; Burke, B. (2018). *Top 10 Strategic Technology Trends for 2019*, Gartner Report, Available online: https://www.gartner.com/en/doc/3891569-top-10-strategic-technology-trends-for-2019, Accessed on 18 December 2018.

[9] ColdFusion TV. (2016, Mar. 29). *Nano-Biological Computing - Quantum Computer Alternative!* Video File, 2016,. Available online: https://youtu.be/xcHcNyC6O84, Accessed on 10 December 2018.

[10] Crawford, R. (2005). *Is God a Scientist? A Dialogue between Sinceand Religion*, Palgrave Macmillan, 2005.

[11] Data Science Institute (2017). *Researchers Store Computer Operating System and Short Movie on DNA*, Columbia University, 2017 Available online: https://datascience.columbia.edu/researchers-store-computer-operating-system-dna, Accessed on 10 December 2018

[12] Dekate, C.; Brethenoux, C.; Hare, J.; Chandrasekaran, A.; Govekar, M.; Ric, C. (2018). *Predicts 2019: Artificial Intelligence Core Technologies*, Gartner Report, 2018 Available online: https://www.gartner.com/doc/3894131?ref=mrktg-srch, Accessed on 18 December 2018.

[13] Denning, P.; Metcalfe, R. (Eds.); *Beyond calculation: The next fifty years of computing*, Santa Clara, CA: Springer-Verlag Telos, 1997.

[14] Descartes, R. (1864). *Discours de la Methode*, Emprimerie et Librairie Classiques, 1864.

[15] Dreyfus, H.L. (1972). *What computers can't do. A critique of Artificial Reason*, Harper & Row, 1972.

[16] Ecklund, E.H.; Scheitle, C.P. (2018). *Religion vs. Science: What Religious People Really Think*, Oxford University Press, 2018.

[17] Ecklund, E.H. (2012). *Science vs. Religion: what scientists really think*, Oxford University Press, 2012.

[18] Eden, A.H.; Steinhart, E.; Pearce, D.; Moor, J.H. (2012). Singularity Hypotheses: An Overview, In *A.H. Eden, J.H. Moor, J.H. Soraker, Steinhart, E. (Eds.), Singularity Hypotheses. A Scientific and Philosophical Assessment, The Frontiers Collection*, Springer-Verlag, 1-12, 2012.

[19] Erlich Y.; Zielinski, D. (2017). DNA Fountainenables a robust and efficient storage architecture, *Science*, 355(6328), 950-954, 2017.

[20] Eversmann, B.; Jenkner, M.; Hofmann, F.; Paulus, C.; et al.(2003). A 128 /spl times/ 128 CMOS Biosensor Array for Extracellular Recording of Neural Activity, *IEEE Journal of Solid-State Circuits*, 38(12), 2306-2317, 2003.

[21] Evolution News (March 10, 2017). *The Hottest New Computer Is: DNA, Evolution News*, Available online: https://evolutionnews.org/2017/03/hottest-new-computer-dna/, Accessed on 10 December 2018.

[22] Feigenbaum, E.A.; McCorduck, P. (1983). *The FifthGeneration: Artificial Intelligence and-Japan's Computer Challengetothe World.* Reading, Mass.: Addison-Wesley, 1983.

[23] Fiaidhi, J. (2011). Towards Developing Installable e-Learning Objects utilizing the Emerging Technologies in Calm Computing and Ubiquitous Learning, *International Journal of u- and e- Service, Scienceand Technology*, 4(1), 2011.

[24] Fotache, M.; Dumitriu, F.; Greavu-Serban, V. (2016). Differences in Information System Skills of Offshoring Source Markets and Destination Markets. A Romanian Perspective, *Transformations in Business & Economics*, Vol. 15(3C)/(39C), 42-59, 2016.

[25] Frankston, B. (1997); Beyond Limits, In *P. Denning, R. Metcalfe (Eds.), Beyond calculation: The nextfiftyyears of computing*, Santa Clara, CA: Springer-Verlag Telos, 43–58, 1997.

[26] Greenwood, P.E. (1967). Review of A View of Artificial Intelligence, by F.M. Tonge inProceedings A.C.M. National Meeting, 1966, *Computing Reviews*, 31, 1967.

[27] Hamidi, H.; Jahanshahifard, M. (2018). The Role of the Internet of Things in the Improvement and Expansion of Business, *Journal of Organizational and End User Computing*, 30(3), 24-44, 2018.

[28] Inside Human. (2018, Jul. 6); *Scientists Have Created Biological Computers Inside Living Cells*, Season 11. Video File. 2018, Available online: https://youtu.be/0hv3tzxb2IU, Accessed on 20 December 2018.

[29] Johnson, B. (2018). Beyond the Hard Drive: Encoding Data in DNA, *Future-Literacy*, Jul 10, 2018, Available online: https://medium.com/future-literacy/beyond-the-hard-drive-encoding-data-in-dna-1d5c2bad5289, Accessed on 18 December 2018.

[30] Kurzweil, R. (2011). *The Singularity is Near: When Humans Transcend Biology*, Old Saybrook: Tantor Media Inc, 2011.

[31] Lee, J. H.; Hwang, Y.; Cheon, K.A.; Jung H. I. (2012). Emotion-on-a-chip (EOC): Evolution of biochip technology to measure human emotionusing body fluids, *Medical Hypotheses*, 79 (2012), 827-832, 2012.

[32] Leonetti, M.; Dubois-Violette, E. (1998). Electrodynamic Instabilities in Biological Cells, *Physical Review Letters*, 81(9), 1977-1980, 1998.

[33] Loonam, J.; Eaves, S.; Kumar, V.; Parry, G. (2018). Towards digital transformation: Lessons learned from traditional organization. *Strategic Change*, 27, 101-109, 2018.

[34] Lungarella, M.; Iida, F.; Bongard, J.C.; Pfeifer R. (2007). AI in the 21st Century - With Historical Reflections, In *M. Lungarella, F. Iida, J.C. Bongard, R. Pfeifer R. (Eds), 50 Years of Artificial Intelligence. Essays Dedicated to the 50th Anniversary of Artificial Intelligence*, Springer, 1-8, 2007.

[35] Martin-Pena, M.L.; Diaz-Garrido, E.; Sanchez-Lopez J.M. (2018). The digitalization and servitization of manufacturing: A review on digital business model, *Strategic Change*, 27, 91-99, 2018.

[36] *Merriam-Webster's collegiate dictionary* (10th ed.) (1999). Springfield, MA: Merriam-Webster Incorporated, 1999.

[37] Molten, M. (2018). Biology Will Be theNext Great Computing Platform, *Wired Science*, 5.3.2018, Available online: https://www.wired.com/story/biology-will-be-the-next-great-computing-platform/, Accessed on 20 December 2018.

[38] Naisbitt, J. (1982). *Megatrends. Ten New Directions Transforming Our Lives*, WarnerBooks, 1982.

[39] Nicolau, D.V. Jr.; Lard, M.; Korten, T.; van Delft, F.C.M.J.M.; et al. (2016). Parallel computation with molecular-motor-propelledagents in nanofabricated networks, *Proceedings of the National Academy of Sciences*, 113 (10), 2591-2596, 2016.

[40] Nicolau, D.V.; Nicolau, D.V. Jr.; Solana, G.; Hanson, K.L.; et al. (2006). Molecular motors-based micro- andnano-biocomputationdevices, *Microelectronic Engineer*, 83(2006), 1582-1588, 2006.

[41] Norman, D. (1997). WhyIt's Good That Computers Don't Work Like the Brain, In *P. Denning, R. Metcalfe, R. (Eds.), Beyond calculation: The nextfiftyyears of computing*, Santa Clara, CA: Springer-Verlag Telos, 105-116, 1997.

[42] Perez, G. (2015). *Science vs. Religion: The Search for a Rational Approach*, Algora Publishing, 2015.

[43] Pop, P.; Araci, I.E.; Chakrabarty, K. (2015). Continuous-FlowBiochips: Technology, Physical Design MethodsandTesting, *IEEE Design & Test*, 32 (6), 8-19, 2015.

[44] Popescul, D.; Georgescu, M. (2015). Generation Y students in social: what do we know about them?, *BRAIN - Broad Research in Artificial Intelligence and Neuroscience*, 6(3-4), 74-81, 2015.

[45] Rosso, C. (2019); AI Created in DNA-Based Artificial Neural Networks. The intersection of artificial intelligence, syntheticbiology, andgenomics. *Psychology Today*, January 2019, Available online: https://www.psychologytoday.com/intl/blog/the-future-brain/201901/ai-created-in-dna-based-artificial-neural-networks, Accessed on 31 January 2019.

[46] Schwartz, J.T. (1986); The Limits of Artificial Intelligence. Technical Report #212, New York University, In *Encyclopedia of Artificial Intelligence*, 2 vols., John Wiley and Sons, 1986.

[47] Selfridge, O.G.; Neisser, U. (1960). Pattern recognition by machine. *Scientific American*, 203(2), 60-68, 1960.

[48] Starkermann R. (1993). The Functional Intricacy of Neural Networks A Mathematical Study, In *R.F. Albrecht, C.R. Reeves, N.C. Steele (eds), Artificial Neural Netsand Genetic Algorithms*, Springer, 1993.

[49] Tapscott, D. (1996). *The digital economy: Promise andperil in theage of networked intelligence*, McGraw Hill, 1996.

[50] Tofler, A. (1970). *Future Shock*, Bantam Books, 1970.

[51] Tonge, F.M. (1966). A View of Artificial Intelligence, *Proceedings A.C.M. National Meeting*, 379–382, 1966.

[52] Tugui, A. (2004). Reflections on the Limits of Artificial Intelligence. *Ubiquity*, ACM, 2004.

[53] Tugui, A.; Gheorghe, A. M. (2017). Review of the Book: The Singularity Is Near: When Humans Transcend Biology, by R. Kurzweil, *Transformations in Business & Economics*, 16(1), 252-256, 2017.

[54] Ulam, S. (1958). Tribute to John von Neumann, *Bulletin of the American mathematical society*, 64(2-3), 1-49, 1958.

[55] Vallee, R.(2009). An Unfinished Revolution? Heinz von Foerster and the Biological Computer Laboratory/BCL, 1958-1976, *Kybernetes*, 38 (1-2), 271-272, 2009.

[56] Vijayabanu, C.; Arunkumar, S. (2018). Strengthening the Team Performance through Personality and Emotional Intelligence: Smart PLS Approach. Scientific Annals of Economics and Business, 65(3), 303-316.

[57] Vinge, V. (1993); The coming technological singularity: how to survive in the post-human era, In NASA, *Lewis Research Center, Vision 21: Interdisciplinary Scienceand Engineering in the Era of Cyberspace*, Chapter 1, 1993.

[58] Von Foerster, H. (1966). *The Numbers of Man, Pastand Future. Biological Computer Laboratory Report 13.0*, Department of Electrical Engineering, University of Illinois, Urbana, IL 61801, 1966.

[59] Watanabe, C.; Naveed, K.; Touc, Y.; Neittaanmäki, P. (2018). Measuring GDP in the digital economy: Increasing dependence on uncaptured GDP, *Technological Forecasting and Social Change*, 137, 226-240, 2018.

[60] Winston, P. (1984); *Artificial Intelligence*, Adinson-Wesley Publishers, 1984.

[61] Zait, A. (2016). Conceptualization and Operationalisation of Specific Variables in Exploratory Researches - An Example for Business Negotion. *Scientific Annals of Economics and Business*, 63(1), 125-131, 2016.

[62] [Online]. *Love and Sex with Robot*, Robotics. Special Issue LSE 2016. Available online: https://www.mdpi.com/journal/robotics/special_issues/LSR, Accessed on 10 December 2018.