# Beyond Human Intelligence: *Redefining Intelligence*

**Jens Pohl, PhD**
Professor of Architecture (Emeritus)
California Polytechnic State University (Cal Poly)
Vice President (CTO), Engineering & Technology
Tapestry Solutions (a Boeing Company)
San Luis Obispo, California, USA

## Abstract

The digital revolution driven by global connectivity, computing as a utility, artificial intelligence, and information sharing on an unprecedented scale is forcing the redefinition of intelligence in a broader context that extends beyond human intelligence. This paper addresses the principal characteristics of biological intelligence, as it exists on planet Earth and the form it may take in an extraterrestrial context. Human intelligence, as the most evolved form of biological intelligence on Earth, is treated as the aggregation of multiple intelligences that cannot be encapsulated in a single metric such as an Intelligence Quotient (IQ). The concept of a postbiological civilization that combines biological intelligence with artificial intelligence is presented as a cultural evolution that is driven by the replacement of the propagation of genes with some alternative replicator. The paper concludes with speculations of the nature of extraterrestrial intelligence that is likely to be much older and far superior to biological intelligence, and may be of a form that is incomparable to human intelligence and therefore unrecognizable by humans.

## Keywords

artificial intelligence, biological intelligence, extraterrestrial intelligence, human intelligence, machine intelligence, multiple intelligences, postbiological intelligence

## Intelligence at a Turning Point

Human civilization is at the threshold of a remarkable evolutionary period where the combination of instant global connectivity, ever increasing computational capabilities, intelligence embedded in inert objects, and automation are creating a holistic intelligence. We are no longer just concerned with the intelligence of individual members of our civilization, but more profoundly with the collective super-mind intelligence of a civilization. Future generations will look back to the beginning of the 21$^{st}$ Century as a turning point when technological advances allowed humans to network their environment into a global knowledgebase enabled by machine intelligence. As Kelly (2016, 291) ably states, this integration of people, processes, artifacts, sensors, data, information, concepts, and notions in all regions of the planet is the birth of a collaborative interface to human civilization that exceeds any previous advance in terms of power and complexity.

It is indeed plausible that this combination of biological and machine intelligence will evolve into a macro-organism that operates at a level above its individual components. If it evolves on similar principles as the human brain with each component having the intelligence of a single human connectome, it could become a superintelligence that vastly exceeds human intelligence.

In this macro-organism, each human brain supplemented with machine intelligence will represent the equivalent of a single synaptic chain of neurons in the human brain.

In the early 20th Century H. G. Wells (1938) foresaw the eventual evolution of a world brain, while Teilhard de Chardin (1966, 63) saw it as the sphere of thought or *noosphere*. Even in its infancy the scale of this global knowledgebase is somewhat beyond our imagination with five billion mobile phones, more than two billion computers, and trillions of computer chips embedded in objects ranging from satellites to cars to household appliances; - all networked together in a virtual super-mind (Figure 1). This macro-organism is already capable of processing millions of communications each second, in the form of e-mails, text messages, and telephone conversations. It is starting to analyze the vast amount of data generated by the on-line activities of more than five billion humans, the data collected by an ever-increasing number of sensors, and the data contributed by countless embedded chips. Simply stated, it is already operating at a scale that is beyond anything that the biological intelligence of human civilization has accomplished to date.

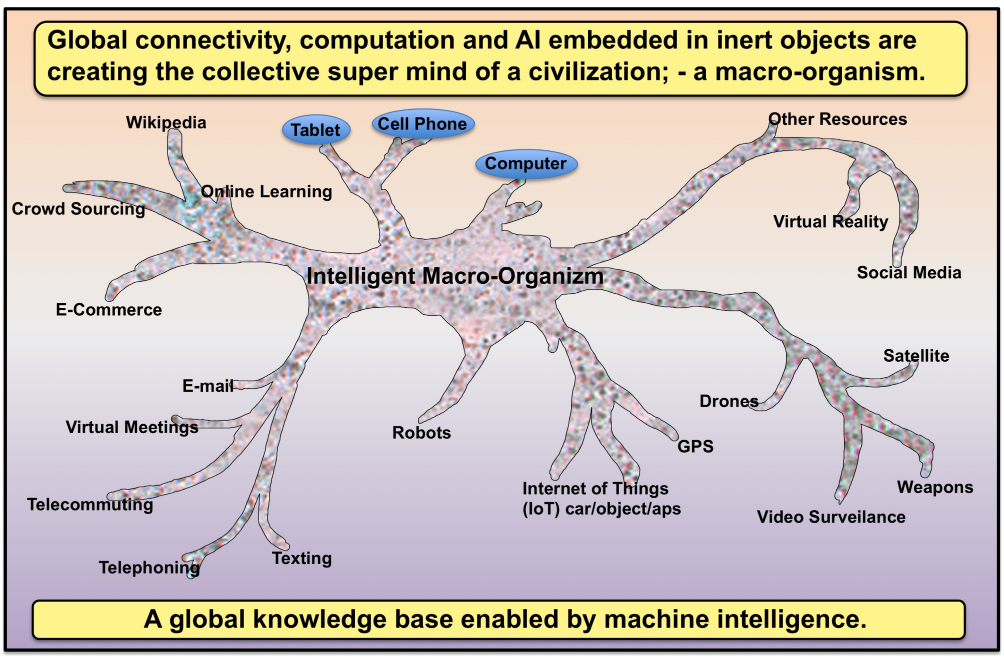


Figure 1: Human society is becoming an intelligent macro-organism

Advances in artificial intelligence are forcing us to realize that human intelligence is only one of many different kinds of intelligences. In parallel, we have already noticed that animals such as dolphins, whales and elephants that are also experience-based have capabilities that the human species does not have. This suggests that there may be even various kinds of experience-based intelligences. Several questions arise: What other kinds of intelligences may exist? Does experience-based intelligence require a living body? Can one kind of intelligence transform into another kind of intelligence? For example, there is currently a fear that our human advances in artificial intelligence will eventually lead to an Artificial Superintelligence (ASI) that could precipitate the demise of the human species. ASI could far outperform human intelligence in most areas, while at the same time having human characteristics like self-awareness and beliefs. However, to date, any attempts to produce an artificial intelligence with general learning and problem solving capabilities has failed dismally. Instead, progress has been more promising in creating specific intelligences that are focused on particular clearly defined problem domains.

## Defining Intelligence

While there is a great deal of disagreement on what constitutes human intelligence, there is even less consensus regarding non-biological (i.e., inert) intelligence (Figure 2). The prerequisites for human intelligence such as the recognition of issues, memory, problem solving skills, and the acquisition of knowledge through learning is unlikely to apply to inert sources of intelligence. For example, the ability of some materials to regain their previous shape after distortion is a kind of memory. Admittedly, it is specifically focused on the arrangement of the internal structure of the material and is therefore quite different from the human ability to memorize information in a more general sense. However, it could be similarly argued that human memory is focused on what we humans understand to be information.

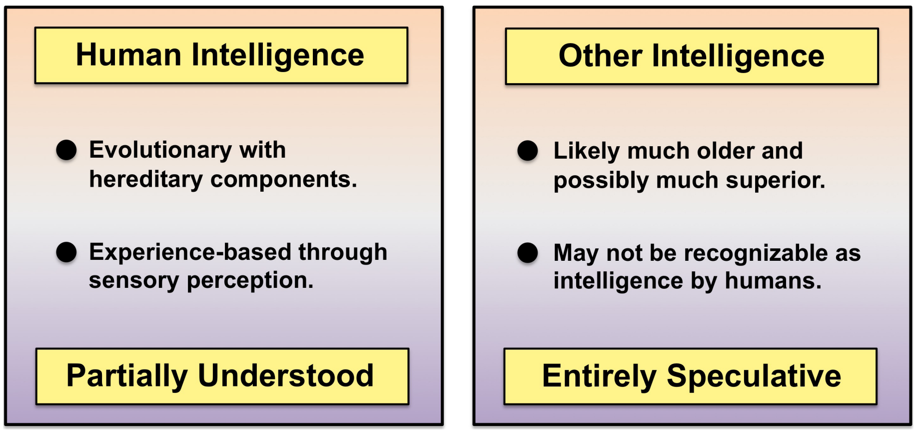


Figure 2: Biological intelligence on Earth is only one kind of intelligence

An extraterrestrial intelligence may have a completely different view of information, such as the origin and nature of the causes that govern cosmological media (e.g., wave forms), events (e.g., energy eruptions) and transformations (e.g., black holes). Human intelligence continues to struggle with the application of scientific principles to explain such phenomena from a human perspective. The hypotheses and theories that we devise are largely based on our attempt to reverse engineer our observations.

Biological intelligence on Earth is fundamentally based on the stimuli that we receive through our senses and which over time create conditioned responses and biochemical activations in the synaptic chains that comprise the neural network of our brain (i.e., connectome). In this regard, our biological intelligence is experience based and typically reactive. Conversely, extraterrestrial intelligence may be largely or entirely impulsive or proactive. For example, an intelligence that is not memory-based but generated spontaneously by transformations. Such an intelligence would not need to rely on learning capabilities since the knowledge would not be acquired through logical thought processes. Instead, the knowledge would be instantaneously available as a result of the transformation perhaps similar to quantum concepts.

It is very difficult if not impossible for us humans to define intelligence in an agnostic manner that does not rely on our human experience. From our human point of view intelligence is closely associated with problem solving. Over the most recent several thousand years of our evolution we have devised a logical approach for solving problems. We define the problem, and if it is a complex problem, we decompose it into sub-problems. This allows us to tackle smaller parts of the problem piecemeal. The sub-problems are likely to be less complex when they are considered in isolation because we are able to temporarily ignore most of the interdependencies within the holistic problem. Since these interdependencies reappear when we try to merge the sub-problem solutions together into a solution of the whole, we are forced to reevaluate them in a repetitive manner until we have finally arrived at an adequate solution of the original problem. Throughout this logical process we utilize deductive, inductive and abductive reasoning mechanisms as deemed necessary.

The question then arises: Is problem solving synonymous with intelligence? Not really, while persons with a higher level of intelligence may be able to perform this reiterative process more efficiently and quickly, the process itself cannot serve as an adequate definition of intelligence. In a more general sense, intelligence provides capabilities and problem solving is one of the capabilities of human intelligence. However, problem solving is not necessarily a capability of extraterrestrial intelligence or even all forms of biological intelligence. While most animals on planet Earth have some level of biological intelligence, the capabilities of their intelligence mostly fall short of the ability to solve problems.

An extraterrestrial intelligence will also certainly have capabilities and may appear far superior to our human intelligence, even though problem solving may not be one of its capabilities. It may have entirely different capabilities such as observation, recognition, and/or exploitation. Its intelligence may not have evolved like biological intelligence has over millions of years, but may have been created instantaneously either naturally or artificially. This also suggests that the search for extraterrestrial intelligence cannot assume that it will be of an artificial nature. Vidal (2014, 202-5) argues convincingly that in the search for extraterrestrial intelligence every candidate must be assumed to be of either natural or artificial origin unless proven to the contrary. Assuming otherwise will lead to many positives; - i.e., apparent detection of extraterrestrial intelligence when encountering a phenomenon that we cannot explain to have a natural origin. He points out that it is highly unlikely that we could fully understand an intelligence that preceded our form of biological intelligence by millions or billions of years.

In subsequent sections of this paper the author will examine the characteristics and origins of four kinds of intelligence; namely biological intelligence, human intelligence, postbiological intelligence, and extraterrestrial intelligence. While much is known about biological and human intelligence, only a little is known about postbiological intelligence, and the discussion of extraterrestrial intelligence cannot be anything but purely speculative.

## Biological Intelligence

As suggested by its name biological intelligence pertains to living things and is of an evolutionary nature. While certain aspects of the biological intelligence of a species evolve slowly over generations in a hereditary fashion, the capabilities of an individual member of the species will increase through a learning process during the lifetime of that member.

The basis of biological intelligence is a complex network of a large number of microscopic cells that are interconnected in a manner that allows very primitive signals to be sent through subnets in the form of electrical impulses. The number of cells and complexity of their interconnections determines to a large degree the level of intelligence. It has both a hereditary component (i.e., genes) that determines certain foundational characteristics such as general-purpose information processing capabilities and a sensory component that through environmental stimulation will allow these foundational characteristics to be extended into more advanced capabilities.

In respect to the biologically based intelligence of humans there are significant differences of opinion among experts in regard to the influence that the inheritance of genes has on the intelligence of individuals. Some will claim that up to 80% of the variability of intelligence, as measured by Intelligence Quotient (IQ) tests, can be ascribed to genetic background. Other experts analyzing the same data but relying on different assumptions will estimate the impact of heritability to be less than 20%. The mean lies somewhere between 30% and 60%, with general agreement that while physical traits and temperament are mostly genetic, cognitive capabilities and personality are greatly influenced by external factors (Gardner 2011, 44).

The degree to which biological intelligence can be extended through external intervention appears to depend greatly on the complexity of the network of cells, from virtually no extensions in very primitive organisms to moderate extensions in animals and orders of magnitude more sophisticated capabilities in the human species. The human connectome (i.e., brain) consists of over 80 billion neuron cells and more than 1000 trillion interconnections or synapses. Every time our brain performs any operation hundreds of thousands of its neurons are activated through the electrical and biochemical processes of their synapses. A key aspect of these neural interactions is that some memory of these activations remains so that the next time a similar operation is required to be performed the same activations are more easily executed. This learning process greatly facilitates the extension of the foundational characteristics of the human brain through sensory stimulation and has allowed the human species to far exceed the intelligence of all other forms of life on planet Earth.

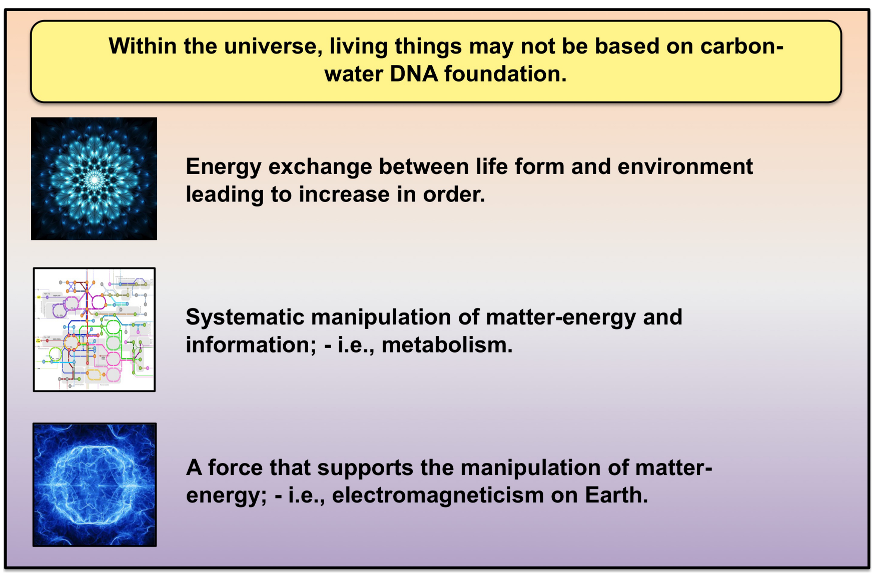


Figure 3: Basic building blocks of life from an agnostic standpoint

However, within the wider realm of the universe biological intelligence may exist in living things that are not based on a carbon-water-DNA foundation and are therefore very different from life on Earth. Feinberg and Shapiro (1980) suggest that the basic building blocks of life should be described in general terms as energy exchanges between the life form and the environment leading to an increase of order[1] (Figure 3). Freitas (1981) expands this concept further with the suggestion that life requires metabolism, a systematic manipulation of matter-

[1] Feinberg and Shapiro (1980, 147): "… *a highly ordered system of matter and energy characterized by complex cycles that maintain or gradually increase the order of the system through the exchange of energy with the environment.*"

energy and information. Apart from electromagnetism, which applies to all life on Earth, the force required for the manipulation of matter-energy could be provided by any one of the other three known fundamental physical forces, namely; nuclear energy, weak force, and gravitation.

While the nuclear force is the strongest in nature, it is effective only over a very small distance (i.e., $10^{-15}$meter). Such nuclear life forms may exist in neutron stars where under a relatively thin crust of crystalline iron nuclei a sea of neutrons at a temperature of millions of degrees may contain macronuclei. The latter could be the equivalent of amino acids, carbohydrates and nucleotides in the prebiotic origin of life. Weak forces are known to operate only at subnuclear distances (i.e., $10^{-17}$meter) and are too weak to hold anything together. They appear in decay processes involved in certain kinds of nuclear collisions and cannot be considered a good candidate for representing a form of life. If on the contrary weak force lifeforms did exist, they would be so unlike anything that we could imagine that we are unlikely to recognize them as lifeforms. Gravitational lifeforms hold out more promise. Gravity is the most abundant and most efficient form of energy in the universe. According to Freitas (2018, 201) "…*gravity beings could be the most efficient creatures in the universe* …" deriving their energy from "… *collisions between black holes, galaxies or other celestial objects* ".

## Human Intelligence

Human intelligence is the most advanced form of biological intelligence that we know of. The creation of neurons and synapses starts in the womb prior to birth and most are created within two years of birth. While additional neurons and in particular, synapses may be grown throughout the lifetime of an individual, much more prominent with increasing age is a pruning process. It appears that synapses and neurons that are not in frequent use gradually wither away. The early formation of the brain during the first two years of childhood and the strengthening of neural pathways through repeated stimulation is the basis of the human learning process. From a biological point of view, it could be argued that the human species have an experience-based intelligence. While this kind of intelligence allows us to gradually extend our knowledge by very small increments, it does not permit leaps in knowledge.

We have great difficulties imaging anything that is not relatively closely related to our experience-based understandings, perceptions and beliefs. In other words, human intelligence is very limited in its ability to innovate because we gain our knowledge and capabilities through experience. At the same time, however, our experience-based intelligence is not problem or domain specific. We are endowed with a general learning and problem solving capability as long as the problem is within the realm of our human experience.

Our learning process is both voluntary and involuntary. We are situated in our environment and are conditioned to a great extent by the input that we receive from our environment through our senses. This conditioning is a form of subconscious learning that occurs continuously and is often combined with our conscious learning. For example, our sense of night and day is not a consciously acquired skill but rather an involuntary reaction to our environment that manifests itself in a daily rhythm of sleeping and awake hours in the form of a virtual body clock.

While problem solving and intelligence are integrally linked, they are broad terms that can be defined in only vague terms. The challenge of problem solving is to accomplish a specified objective under constraints. The ability to meet this challenge and the manner in which the problem solving process is undertaken are greatly influenced by the intelligence of the problem solver. The vagueness of this sentence suggests that intelligence encompasses more than problem solving. In the broadest terms, intelligence is the ability to acquire and apply knowledge and skills. This includes the capacity for logic, understanding, learning, planning, creativity, and problem solving. Since the skills required for these competencies may vary depending on the nature of the competency, it is likewise likely that intelligence cannot be defined as a single holistic capability. For example, an artist who is highly creative may be far less competent in planning and a mathematician who is skilled in logic may lack creativity.

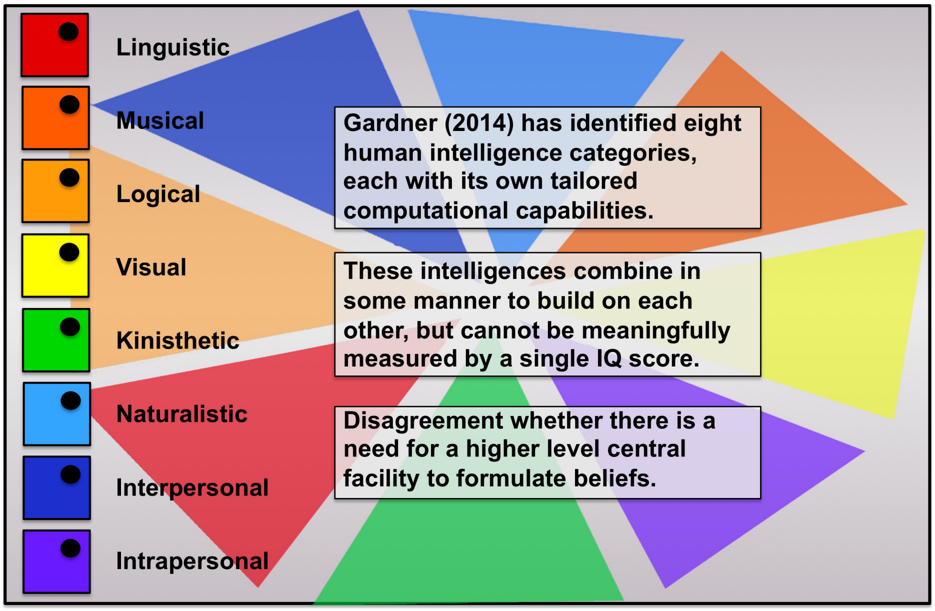


Figure 4: Variously identified human intelligence categories

Gardner (2014)[2] has identified eight human intelligence categories; namely linguistic, musical, logical-mathematical, visual-spatial, bodily-kinesthetic, naturalistic, interpersonal, and intrapersonal. These interact with and build on each other. Each has its own computational capability that is tailored to support the particular type of intelligence. It is somewhat humbling to recognize that human intelligence is essentially the product of rather unintelligent (reactive) processes that are automatically triggered to carry out specific operations whenever certain stimuli are received. Repeated activation will make these processes more responsive, thereby extending their influence on other processes and the kind of intellectual capability that they support. Of course the opposite applies as well. Any such fundamental process that is not repeatedly activated will not develop and eventually atrophy through neglect.

There is some disagreement among researchers in respect to the existence of and need for some central processor in our brain to coordinate the operations and interactions of these specialized computational units. Allport (1980, 5) argues that the human brain should be thought of as consisting of a large number of independent production systems that are content dependent. Since Allport's production units are much more numerous than Gardner's seven fundamental processes, it can be inferred that each of Gardner's processes relies on several production units and that production units may play a role in several fundamental processes. While there may be a need for some higher level central facility that formulates beliefs based on the repeated activations of Gardner's lower level processes and/or Allport's much lower level production

[2] In his excellent book 'Frames of Mind' (latest edition 2011) Gardner discusses each of these intelligences within the context of a theory of multiple intelligences.

units, experimental evidence suggests that human intelligence (and by inference biological intelligence) is multifaceted. In other words, there are multiple human intelligences that cannot be meaningfully measured in terms of a single collective intelligence metric, such as an IQ score.

Both motivation and attention (i.e., ability to focus) are contributing factors to the effectiveness of external intervention. External intervention essentially involves a learning process that may be subconscious as for example the reaction to a repeated threatening situation (or reflex reaction to avoid pain, such as removing the hand from a hot surface) or conscious to gain additional skills or knowledge. Any conscious learning process is very much dependent on the level of motivation and the ability to focus.

As previously suggested, individual intelligences do not operate in an isolated fashion but combine in some manner to build on each other. This interaction among individual intelligences could form the basis of overarching skills such as *commonsense* (i.e., the ability to deal with situations or problems in an intuitively unbiased manner), *originality* (i.e., the ability to produce an innovative result), *metaphorically* (i.e., the ability to form analogies), and wisdom (i.e., a general synthesizing ability).

### Postbiological Intelligence

Postbiological evolution can be described as the transition from *biological evolution* to *cultural evolution*, with the maintenance, improvement and perpetuation of intelligence and knowledge being the primary driving force; - also referred to as the *Intelligence Principle* (Dick 1996). It is argued that since cultural evolution is much faster than biological evolution, our human biology and our biologically based brain will become a limiting factor to further increases in knowledge and intelligence. In this regard, artificial intelligence would be utilized to analyze situations and solve problems much faster and more accurately than is possible with the human brain. Two routes towards cultural evolution are proposed:

(a) The merging of biological and artificial consciousness, possibly through the digitization of human consciousness. This route would require a high level of technology and is therefore likely to take a long time. However, the progressive supplementation and gradual replacement of the biological brain would increase the computational power and intelligence of the human consciousness exponentially, and eventually eliminate the weakness of a biological form.

(b) The replacement of human consciousness with artificial intelligence is an alternate route that would presumably lead to the demise of the human race. While natural disasters, disease, warfare might lead to the loss of the human species, an artificial intelligence could survive due to its adaptability and robustness.

Dick (1996) has proposed the following five assumptions for the formation of a postbiological civilization: that evolution by natural selection results in biological intelligence beyond Earth; that intelligence results in culture; that culture evolves; that increasing intelligence is a central goal of cultural evolution; and, that extraterrestrial intelligence is older than human intelligence. The first four of these assumptions are validated by what we have been observing on Earth. The fifth assumption appears to be creditable based on the timescale of the universe. Current estimates suggest a gap of about seven to eight billion years between the formation of the first Sun-like star and the beginnings of intelligence in our galaxy. The existence, therefore, of an extraterrestrial intelligence that is older than intelligence on Earth would certainly appear to be feasible.

Postbiological evolution presumes the transition from a biological paradigm, driven by the propagation of genes to a non-biological paradigm driven by some alternative replicator, potentially resulting in the extinction or trophic reorganization of the former, and typically presumed to be marked by the maturation of high technologies such as artificial intelligence or nanotechnology.

The path from biological intelligence to postbiological intelligence is treated in the literature variously under the acronym BISA, which stands for Biologically Inspired Superintelligence. It is argued that once a biological civilization develops an intelligence that allows it to explore the cosmos (through travel) it is only a few hundred years away from changing its paradigm from biology to artificial intelligence (Petigura et al. 2013, Moravec 2000, Voss 2015). This relative short time period is supported by the evolution of our own civilization on Earth. We discovered radio signals about 130 years ago and our first space travel dates back 60 years ago[3]. Today (2018) we already depend on ubiquitous digital technology in the form of computation, communication and automation. The transition to neural implants is already in progress with digital interfaces to artificial limbs and implants that are designed to control various medical conditions (e.g., post-traumatic stress disorder, Parkinson's Disease, arthritis, depression, Crohn's disease).

The search for exoplanets[4] started in earnest only about 30 years ago. The data that has been collected at an increasing rate suggests that there are likely to be millions (if not billions) of planets in our galaxy that are in some ways similar to Earth. Since biological life is greatly concerned about its own survival and reproduction, we might expect that postbiological life on an exoplanet will have adopted similar goals. BISA may take various forms:

(a) It may be intent on not only deciphering but also manipulating the computational connectome of the biological brain. This would likely lead to biological life and intelligence being subservient to postbiological intelligence.

(b) It may not have viewpoint-invariant representation capabilities and instead compute everything from first principles. With access to vast computational and storage facilities BISA would not have the need to adopt efficiency measures in its evolutionary path. The concept of constraints may not exist at all or may be subject to an entirely different interpretation in BISA.

(c) While BISA may have a need for communication, it may not be based on language-like mental representations that are recursive and combinatorial. Human civilization has found it productive to form relationships that lead to teamwork, communication and specialization. The biological brain needs combinatorial representation because there are an infinite number of linguistic combinations.

(d) If BISA has different kinds of senses then its thinking process may also be quite

[3] On April 12, 1961, Yuri Gagarin of Russia became the first human to orbit Earth in Vostok 1. On July 20, 1969, Americans Neil Armstrong and Buzz Aldrin in Apollo 11 were the first humans to step on another planet (the Moon).

[4] An exoplanet is a planet outside our solar system that orbits a star. The first evidence of an exoplanet was noted as early as 1917, but was not recognized as such. However, the first scientific detection of an exoplanet was in 1988. Shortly afterwards, the first confirmed detection was in 1992. As of 1 January 2018, there are 3,726 confirmed planets in 2,792 solar systems, with 622 of these solar systems having more than one planet.

> different from humans. It can be argued that concepts are modality specific since they are governed by the nature of the senses such as vision and hearing (Prinz 2004). Under these circumstances, it may be difficult or even impossible to comprehend the thinking process of BISA with entirely different senses. However, at higher levels of abstraction the influence of sensory input becomes less important (Hawkins and Blakeslee 2004). It is not only possible but likely that BISA may have an inner mental language that is independent of any sensory substrate. Such a language could form a communication bridge among different types of intelligences and may also become a stepping stone to superintelligence on Earth.

Whether or not consciousness and self-awareness are essential features of postbiological advanced intelligence is a debatable question. One could argue that consciousness is a product of the kind of sensory perception that is the basis of biological intelligence. Being *situated* in an environment and dependent on the sensory input received from the environment, the development of both self-awareness and consciousness have become the basis of the kind of biological intelligence that has evolved on Earth. However, while postbiological intelligence may build on the foundations of self-awareness and consciousness, the same cannot be assumed for non-biological forms of extraterrestrial intelligence.

**Extraterrestrial Intelligence**

As we speculate about extraterrestrial intelligence, we are confronted by a number of propositions that are difficult to fathom (Figure 5). First, there is the issue of timescale. Recent microwave probe results estimate the age of the universe at 13.8 billion years (± 1% uncertainty)[5], with the oldest Sun-like star in the universe forming about 12.5 billion years ago and the oldest star in our galaxy forming about 10 to 11 billion years ago. Using the history of the Earth as a guide the first signs of intelligence may have evolved in the Universe some seven to eight billion years ago, while intelligence in our galaxy is estimated to have evolved about four to five billion years ago (Rees 1997). Therefore, human intelligence may be no more than a fleeting moment on a cosmological timescale.

Table 1: Evolution of life on Earth in comparison with the age of the universe

| Intelligent Life on Earth | Real Time on Earth | Compressed Universal Year |
|---|---|---|
| Earliest bipedals | 4,000,000 years ago | 2 hrs 35 min 16 sec ago |
| Beginnings of Homo genies | 2,000,000 years ago | 1 hr 17 min 38 sec ago |
| Beginnings of Homo sapiens | 200,000 years ago | 7 min 38 sec ago |
| Appearance of modern humans | 50,000 years ago | 1 min 55 sec ago |
| Oldest example of prehistoric art | 30,000 years ago | 1 min 9 sec ago |

If we compress the estimated age of the universe (13.8 billion years) into a standard Earth year of 365 days (Table 1) then: life on Earth started in mid-July[6]; bipedals appeared less than three

[5] The most recent (2013) results of the Wilkinson Microwave Anisotropy Probe (WMAP).

[6] The history of life on Earth began about 3.8 billion years ago, initially with single-celled prokaryotic cells, such as bacteria. Multicellular life evolved over a billion years later and it is only in the last 570 million years that the kind of life forms we are familiar with began to evolve, starting with arthropods, followed by fish 530 million years ago, land plants 475 million years ago and forests 385 million years ago. Mammals did not evolve

hours ago; the Homo genies began a little over an hour ago; Homo sapiens appeared less than eight minutes ago; and, according to the *great leap forward* theory (Klein 1995) modern humans evolved less than two minutes before midnight on the last day of the year.


Figure 5: Difficulties encountered when speculating about extraterrestrial intelligence

Second, how do we recognize extraterrestrial intelligence if it bears no resemblance to biological intelligence on Earth. It may be so different from our biological intelligence that we may not consider it to be a form of intelligence, if we recognize it at all (Davies 2010, 124). In the vast amount of data that we have been collecting from thousands of radiowave sources and millions of optical sources there is little if any certainty that we even have the capacity to distinguish between natural and artificial sources. We are quick to jump to the conclusion that some unexpected light in the night sky is an alien spaceship, rather than systematically reviewing other natural explanations such as a meteor or atmospheric phenomena.

Third, our search for extraterrestrial intelligence is greatly biased and limited by the nature of our own biological intelligence. Our ability to perceive external stimuli is restricted to our five senses of sight, hearing, touch, smell, and taste. While some potential communications from extraterrestrial sources that fall outside of these senses (e.g., neutrino radiation[7] and gravitational waves) have been and will continue to be theoretically projected and experimentally verified, there may well be others that we are oblivious to.

Fourth, we cannot assume that extraterrestrial intelligence has evolved on a path that is similar to biological intelligence on Earth, where life has adapted through specializing to different physical environments. For example, on Earth it is difficult to argue whether an elephant has superior intelligence to a dolphin or a cockatoo. Each species has adapted to its particular environment. Human intelligence has forged a similar path of specialization based on collaboration and

until 200 million years ago, and our own species, Homo sapiens, only 200,000 years ago. (Ref.: BBC Nature – Prehistoric Life, http://www.bbc.co.uk/nature/history_of_the_earth.

[7] A neutrino is an elementary particle that interacts only with the weak subatomic force and gravity. It was first detected in 1970 at the Argonne National Laboratory during a hydrogen bubble chamber experiment. The neutrino is so named because it is electrically neutral and because its mass is so small that it was originally thought to be zero.

technical advances. We use our technology in the exploration of the Universe in the hope that extraterrestrial intelligence is similar in nature and at a reasonably equivalent developmental level. The probability that these two assumptions are valid is very small, given the timescale of the Universe and the different kinds of biological and non-biological intelligences that may exist.

Fifth, even though our exploration of the Universe has been encompassing the entire range of the electromagnetic spectrum from radiowaves to X-rays and gamma rays, we are still very much bound to our human visual scale as far as our observations are concerned. While we do see and study many kinds of stars, black holes, pulsars, clusters of stars, planets, and galaxies in all wavelengths, we may be missing the presumably much weaker transmissions released by smaller scale energy sources.

Finally, virtually our entire search for extraterrestrial intelligence has been focused on the interception of some form of communication. However, we should not assume that an extraterrestrial intelligence has any interest in us or is even aware of the existence of biological intelligence. Accordingly, both the focus of our search on signals from outer space and that such signals are likely to come from other earth-like planets may be totally unfounded.

Since there is no reason to believe that extraterrestrial intelligence will be biological in nature, other assumptions related to life on Earth must also be abandoned in the search for extraterrestrial intelligence, namely: using oxygen; made from carbon; requiring water; located on a planet revolving around a Sun-like star with an ambient temperature range that is similar to Earth; using technology that is at least comprehensible to us; and, having a desire to communicate to external civilizations.

In this regard, the starivores[8] concept proposed by Vidal (2014, 231-265) is of particular interest because it postulates a form of extraterrestrial intelligence that is entirely different from biological intelligence on Earth. It has two principal characteristics that are appealing. First, it addresses the need for the very large amount of energy that might be expected of an extraterrestrial intelligence that is millions of years more advanced than life on Earth. According to the Kardashev Scale[9] the higher the intelligence level of a civilization the greater its energy consumption. Second, since an intelligent civilization will want to sustain itself indefinitely it would need to find a way to survive beyond the life cycle of its energy providing star(s). Potential options include star lifting and travel. In star lifting[10] the ultimate destruction of a sun is delayed and perhaps prevented through continuous removal of material. High speed travel, on the other hand, would allow a civilization to avoid its eventual demise through migration to another star system within its universe or another universe if there are multiple universes. Such travel could be facilitated through black holes or by devising a means for changing the orbit of a binary system or planet.

The possible relationship between black holes and extraterrestrial intelligence is consistent with

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[8] An hypothetical extraterrestrial civilization that uses energy derived from its slow non-conservative transient accreting binary star to sustain its enormous need for energy (i.e., K-II or higher on the Kardashev Scale). The dense primary could be a white dwarf, neutron star, black hole, or planet.

[9] On the Kardashev Scale K-I, K-II and K-III equate to an energy consumption of approximately $4x10^{19}$, $4x10^{33}$ and $4x10^{44}$ erg/second, respectively. The human civilization on Earth is currently rated at K-I (i.e., $4x10^{19}$ erg/sec).

[10] While the amount of mass that a star loses through solar wind and coronal ejections is relatively negligible, the loss of mass increases dramatically as it becomes a supernova towards the end of its life. Several hypothetical processes have been proposed by which a sufficiently advanced civilization (i.e., at K-II or higher on the Kardashev Scale) could continuously lift material from the surface of the sun to prolong its life indefinitely.

the extrapolation of a metric proposed by Barrow (1998, 133) to measure the developmental level of a civilization. The Barrow Scale (Figure 6) classifies a civilization's ability to manipulate smaller and smaller entities in a range of BI (ability to manipulate objects of its own scale; ~ 1 meter) to BΩ (ability to manipulate space-time's structure; ~ $10^{-35}$ meter).[11] A civilization at BΩ, with the ability to manipulate space-time would satisfy Freitas' speculations relating to gravitational beings (Freitas 2018, 201). However, gravitation is a relatively weak force and therefore a great deal of mass and density would be required to produce a significant level of intelligence.

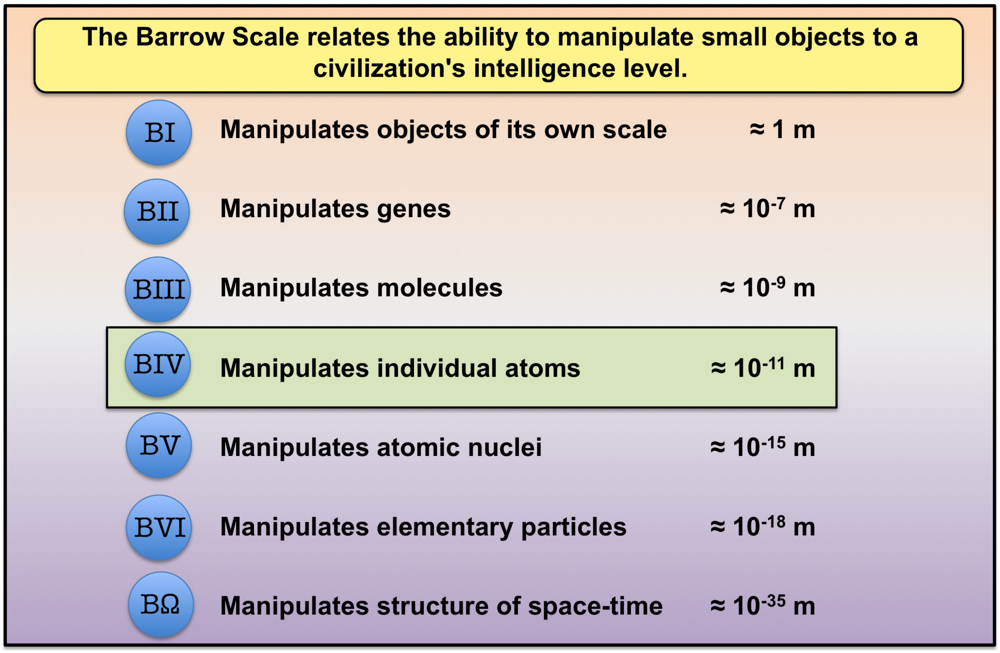


Figure 6: Developmental level of a civilization according to the Barrow Scale

Black holes are the densest objects in the Universe with an enormous attractor capability due to their staggering gravitational field. Vidal (2014, 220-3) has discussed the potential of black holes as an attractor for intelligence from several points of view:

- ***Energy Source:*** Since increasing energy consumption appears to be a characteristic of the evolution of intelligent civilizations, black holes could potentially serve as an energy source and energy store. Possible mechanisms for extracting energy from black holes have been variously postulated. Examples include: Penrose (1969, 270) who suggested the extraction of rotational energy through the injection of matter into a black hole; Frautschi (1982) who proposed the creation of a power source by merging black holes; and, Crane (2010, 370) who suggested that small black holes could become a source of energy due to the great efficiency with which they are able to convert matter into energy (i.e., via Hawking radiation).
- ***Travel:*** Taking advantage of the gravitational field of a black hole to launch a spacecraft at close to the speed of light has been suggested by Davies (2010, 142). The possible existence of wormholes, as predicted by Einstein's general relativity theory, could provide passage through space-time for long journeys across the

[11] On the Barrow Scale human life on Earth is currently at BIV, with the ability to manipulate individual atoms; approximately $10^{-11}$ meter.

Universe and beyond, if other universes exist.

- ***Scientific:*** Westmoreland (2010) has postulated the possible artificial production of black hole energy sources through electromagnetic radiation. At the same time concerns have been raised that microscopic black holes could be accidentally created in a particle accelerator. Perhaps more intriguing is the possibility of using a black hole as a telescope or communication mechanism through *gravitational lensing*[12].
- ***Philosophical:*** If intelligence is the capacity to solve problems then the ultimate problem facing any natural or artificial intelligence is survival. The human species has focused on survival of the individual by constructing shelters to moderate temperature, producing food to ensure adequate nutrition, applying medical treatments to remedy biological dysfunction, inventing weapons to protect against enemies, and enforcing education as a means of maintaining and progressively improving problem solving capabilities.

Two larger problems facing any higher-level extraterrestrial intelligent civilization will be to preserve itself within a relatively unstable universe and to ensure its indefinite survival as it increases its consumption of energy. Star lifting has been mentioned previously as a postulated solution to the first problem. While the Barrow Scale measures the developmental level of a civilization by its ability to manipulate smaller and smaller entities (Barrow 1998, 133), the Kardashev Scale ties the evolution of an intelligent civilization to its exponentially increasing energy consumption (Kardashev 1964) in quantitative terms of erg/second.

The second problem then becomes how to ensure the infinite survival of the civilization when its energy consumption exceeds the available energy. This leads us to consideration of the energy flow between binary stars. The astrophysics literature suggests that there are three kinds of binary stars (Lipunov 1989, Duquennoy and Mayor 1991, Lada 2006), namely: detached binaries that do not interact; semi-detached binaries consisting of a very small and a much larger star with the small star emitting a stream of material to the larger star; and, contact binaries in which the two stars exchange matter unstably and rapidly until equilibrium is reached. Of these three types, the semi-detached binaries are of particular interest in respect to extraterrestrial intelligence. Subject to the thermodynamic criteria of living systems: there is an energy flow between the small star and the much larger star (i.e., an energy gradient)[13]. An extraterrestrial civilization would not need to exist on one of the binary stars to take advantage of the energy flow between the two stars. Observations have shown that it is possible for a planet to revolve around a binary star; - at least one such observation has been recorded (Backer 1993).

The potential exploitation of the enormous energy flow within a binary system is not confined to binary stars. A binary black hole is a system consisting of two black holes in close orbit around each other. Like black holes themselves, binary black holes are often divided into two categories, namely: stellar binary black holes that are formed either as remnants of high-mass binary star systems or by dynamic processes and mutual capture; and, binary supermassive black holes that are believed to be the result of galactic mergers.

For many years, proving the existence of binary black holes was difficult because of the nature

[12] A gravitational lens is a distribution of matter (such as a cluster of galaxies) between a distant light source and an observer that is capable of bending the light from the source as the light travels towards the observer.

[13] Some matter is ejected through periodic jets or novae, without destroying the stars.

of black holes themselves and the limited means of detection available. The merging of two black holes will generate an immense amount of energy, resulting in gravitational waves with distinctive waveforms that can be calculated using the general relativity theory[14]. The existence of stellar-mass binary black holes (and gravitational waves themselves) was finally confirmed in 2015 when the Laser Interferometer Gravitational-Wave Observatory (LIGO) detected the distinctive gravitational wave signature of two merging stellar-mass black holes of around 30 solar masses each, occurring about 1.3 billion light years away.

## Conclusion

While it is certainly interesting to speculate about possible extraterrestrial forms of intelligence that may be very different from the biological intelligence on planet Earth, we can relate more easily to the continuing evolution of our own human civilization. Enabled by instant communication and readily available computational capabilities, we are drawn into sharing information at an unprecedented scale. The Internet, serving as a vast information repository with feeder tentacles available to virtually every individual member of our civilization, has become a global knowledgebase.

The increasing collective intelligence of this knowledgebase will not be surprising to us because we will change with it and our dependence on it will change our perceptions and expectations. As Brooks (2017) pointed out in a recent article, our perception of future capabilities must be based on our future understandings, beliefs and pursuits rather than our current mindset. The collective intelligence will not be a single cluster of computers like IBM's Watson was when it won Jeopardy against the best human players, instead it will be spread among thousands of networked computers on a grid. A user will draw as much intelligence from the grid as is needed or desired for the performance of a task. According to Kelly (2016, 33) artificial intelligence will be like electricity. It will be infused into tasks like electricity was used to automate manual tasks such as drilling, sawing, sowing, and washing clothes. It will be enabling by adding intelligence to the human user, by making connections between information and processes that the user would have missed, and by proactively anticipating the user's need for changing plans and objectives.

The ability to embed intelligence in inert objects is automating a wide range of tasks that were time consuming and required specialized skills and training when performed manually. For example, a competent amateur photographer of less than 15 years ago was forced to carry dozens of film roles, several heavy glass lenses, a light meter, and an expensive camera. Then the photographer had to mount the correct lens, make numerous adjustment for distance, light and film type before taking the photograph. Today, the camera in the user's smart phone is almost weightless, functions equally well regardless of light conditions, and zooms automatically. While the camera has certainly be miniaturized, it is the embedded intelligence that has converted a complex sequence of operations into a simple point and click action. The layers of glass lenses and shutters have been replaced by sophisticated computation (Figure 7).

Similarly: music can be created algorithmically in real time and printed music scores can be converted into sound; clothes can tell the washing machine how they need to be washed; data recorded by measuring time and eye movement of how people perceive advertisements can be

[14] As the orbiting black holes give off these gravitational waves, the orbit decays and the orbital period decreases. This stage is called binary black hole *inspiral*. The black holes will merge once they are close enough. Once merged, the single black hole settles down to a stable form, via a stage called *ringdown*, where any distortion in the shape is dissipated as additional gravitational waves.

analyzed to drive marketing strategies and optimize advertising budgets; patients with sensors that track their vital signs can generate customized medical treatments that can be adjusted in near real time; and, sensors that continuously monitor activities and vital signs can enable personal health maintenance.


Figure 7: Transformation of photography by automated computation

While the automation of manual tasks has been proceeding on an individual basis, the combination of such capabilities into intelligent mechanisms modeled on our own human image is becoming an increasingly desirable objective. There are promising signs that such robots are on a path to becoming invaluable assistants as our human pursuits become more ambitious and demanding. Baxter, an industrial robot designed by a research team in the MIT robotics laboratory (Knight 2012), has three features that designate it as a more advanced class of robots. First, it has eyes that rotate for 360$^{o}$ vision to see any objects (e.g., human coworkers) in its immediate vicinity. In this way, it is designed to perform tasks that require the closest human and computer collaboration. Second, it can be trained in a manual manner by a human coworker who will take one of its mechanical arms and guide it through a sequence of movements. Baxter then learns to repeat the movements in the correct sequence. In other words, Baxter has been programmed to learn to perform sequences of movements of its mobile components rather than the movement sequences themselves. Third, at around (US)$25,000 Baxter is much less expensive than its predecessors that cost well over (US)$250,000. What is particularly superior about Baxter is that while the extent of the movement of its mobile components in terms of reach, accuracy, speed, and direction are predefined, the tasks that it can perform within these constraints are not pre-defined and essentially unlimited.

What will be the role of us humans in this new world of ubiquitously embedded intelligence where virtually all tasks that preoccupy us today are performed by robots and other computer-based automation? Certainly, motivation, imagination and innovation will become highly valued capabilities. As we become increasingly more enabled in our endeavors there will be mounting pressure to exploit opportunities. However, to pursue an opportunity we must first recognize that an opportunity exists and this in turn means that we must be motivated to seek new opportunities. This is a decided change in desirable human qualities and capabilities that will have a cascading impact on many aspects of life, but in particular education. The emphasis in education will shift from the acquisition and honing of skills to the orchestration and coordination of those skills that have now become the province of our automated and intelligent surroundings. Our human capabilities will not be judged by what we know but by what we can accomplish through the orchestration of the knowledge and capabilities embedded in our environment.

**References**

Allport D. (1980); 'Patterns and Actions: Cognitive Mechanisms Are Content Specific'; in Claxton G. (ed.) 'Cognitive Psychology: New Directions', Routledge & Kegan Paul, London, UK.

Backer D. (1993); 'A pulsar timing tutorial and NRAO Green Bank observations of PSR 1257+12'; Planets around Pulsars, Pasadena, California Institute of Technology (pp. 11-18).

Barrow J. (1998); 'Impossibility: The Limits of Science and the Science of Limits'; Oxford University Press, Oxford, New York, New York.

Crane L. (2010); 'Possible Implications of the Quantum Theory of Gravity: An Introduction to the Meduso-Anthropic Principle'; Foundations of Science 15(4) (pp. 369-373).

Davies P. (2010); 'The Eerie Silence: Are We Alone in the Universe'; Penguin Books, London, UK.

Dick S. (1996); 'The Biological Universe: The Twentieth Century Extraterrestrial Life Debate and the Limits of Science'; Cambridge University Press, Cambridge, Cambridgeshire, UK.

Duquennoy A. and M. Mayor (1991); 'Multiplicity Among Solar-Type Stars in the Solar Neighborhood'; Astronomy and Astrophysics, 248 (1 August) (pp. 485-524).

Frautschi S. (1982); 'Entropy in an Expanding Universe'; Science 217(4560) (pp. 593-599).

Freitas R. A. (1979); 'Xenology: An Introduction to the Scientific Study of Extraterrestrial Life, Intelligence, and Civilization'; First Edition, Xenology Research Institute, Sacramento, California, USA [http://www.xenology.info/Xeno.htm].

Gardner H. (2011); 'Frames of Mind: The Theory of Multiple Intelligences'; Basic Books, New York, New York.

Hawkins J. and S. Blakeslee (2004); 'On Intelligence: How a New Understanding of the Brain Will Lead to the Creation of Truly Intelligent Machines'; Time Books, New York, New York.

Kardashev N. (1964); 'Transmission of Information by Extraterrestrial Civilizations'; Soviet Astronomy, 8(2) (pp. 217-220).

Kelly K. (2016); 'The Inevitable: Understanding the 12 Technological Forces that Will Shape Our Future'; Viking, New York, New York.

Klein R. (1995); 'Anatomy, Behavior, and Modern Human Origins'; Journal of World Prehistory, 9 (pp. 167–198).

Knight W. (2012); 'This Robot Could Transform Manufacturing'; MIT Technology Review, September.

Lada C. (2006); 'Stellar Multiplicity and the Initial Mass Function: Most Stars are Single'; The Astrophysical Journal, 640(1) 20 March (pp. 63-6).

Lipunov V. (1989); 'In the World of Binary Stars'; (translated from Russian by A. Kandaurov) Science for Everyone, Mir Publishers, Moscow, Russia.

Moravec H. (2000); 'Robot: Mere machine to Transcendent Mind'; Oxford University Press, Oxford, UK.

Penrose R. (1969); 'Gravitational Collapse: The Role of General Relativity'; La Rivista del Nuovo Cimento 1 (pp. 252-276).

Petigura E., A. Howard and G. Marcy (2-13); 'Prevalence of Earth-Sized Planets Orbiting Sun-Like Stars'; PNAS (Proceedings of the National Academy of Science), 110(48), 19273.

Prinz J. (2004); 'Furnishing the Mind: Concepts and Their Perceptual Basis'; MIT Press, Boston, Massachusetts.

Rees M. (1997); 'Before the Beginning: Our Universe and Others'; Perseus Books, New York, New York.

Teilhard de Chardin P. (1966); 'The Vision of the Past'; Google Books.

Vidal, C. (2014); 'The Beginning and the End: The Meaning of Life in a Cosmological Perspective'; Springer-Verlag, London, UK.

Voss P. (2015); [http://www.agi-3.com/technology.html].

Wells H. (1938); 'World Brain'; Methuen & Co., Ltd., Garden City, New York, New York: Doubleday, Doran & Co., London, UK.

Westmoreland S. (2010); 'Optical Black Holes and Solitons'; PhD Thesis, Kansas State University, Manhattan, Kansas.