THE ENGINEERING OF SCIENTIFIC INDUCTION[1]

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Abstract

This paper constitutes a speculative philosophical assessment of contemporary research in an area of Computing Engineering with the objective to build machines endowed with intelligent behaviour. Aspects of the state-of-the-art are presented herein as the result of a centuries-long evolution of scientific quest and engineering ingenuity. We argue that further advances in the field might require looking at the world from a novel perspective and we elaborate on the long term potential necessity for machines endowed with intelligent behaviour.

I. Introduction

In standard dictionaries of the English language (for instance Oxford, 1980 or Webster, 1987) a reader may find the following definitions: Engine is "a complex mechanical contrivance; machine; instrument of war". Engineer is "one who constructs or is in charge of engines, military works, or works of public utility (e.g. bridges, roads)". Engineering is "the work of an engineer". Science is "the systematic knowledge; investigation of this; any branch of study concerned with a body of observed material facts". Moreover, theory is "a reasoned supposition put forward to explain facts or events". Information is "knowledge given". Knowledge is "familiarity gained by experience". Intelligence is "the power of perceiving, learning, understanding and knowing; mental ability". All the previous definitions will be handy in the sequel.

In this article we attempt to speculate on the future trends of modern "high" technology based on historical experience. The identification of such trends might be particularly significant if one considers technology's increasing role in everyday life. The title of this article intentionally underlines a far-reaching potential as explained in section V.

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[1] During the preparation of this article I had the benefit of useful discussions with a number of colleagues and friends. I thank in particular Athanasios Kehagias and Vassilios Petridis for their useful comments and suggestions. Of course, I assume full responsibility for possible errors.

In section II we show that the notion "engineering" as implied from the previous definitions is quite restrictive, therefore we enhance the notion "engineering" so as to include recent developments pertaining as well to computer engineering, genetic engineering, artificial neural networks, etc. In section III with the aid of a retrospection we glance backward through human history and we pinpoint the accelerating significance of "technology" in shaping history; moreover, we argue that "information" has been the single agent underlying all technological innovation. In section IV we enumerate major scientific and technical achievements, present our perspective regarding the evolution of science and technology through history and attempt to identify current trends in science and technology. The human brain is presented in section V as the outcome of biological evolution, and we speculate further on the utility of artificial brains in the future. Section VI illustrates how machines endowed with intelligent behaviour might be vitally useful in the future. Finally, section VII summarises the principal contributions of this original work.

II. Putting the Engineering in a Novel Perspective

We believe that it is meaningful to speak of engineering only in the context of an organised community of humans. Therefore it is not meaningful to speak of engineering before the vibrant farming communities were established along such large rivers as the Nile, Indus, Huang He, and most importantly the Tigris and Euphrates in Mesopotamia after 8,000 BC. Generally speaking, we may say that the level of sophistication in engineering grows in proportion to the level of sophistication of the need of humans to interact with their environment. Interaction with the environment includes interaction with other human communities; one primitive way through which the latter interaction takes place is by war.

There is abundant historical evidence in support of the definition in section I regarding an engineer as an individual involved in acts of war. For example, in *the Iliad* Homer describes how Odysseus, "fertile in devices", engineered the Trojan horse. Roman engineers improved catapults and other devices of war. The Byzantines had engineered "liquid fire" to attack hostile ships. During the Middle Ages various people engineered fortifications throughout Europe, the Magreb, the Middle East, and elsewhere. The Great Wall was restored in China during the same period. The role of engineering has been instrumental in most wars on sea/land/air in various parts of the world during the last several centuries.

All the above examples of "engines" fall more or less within the military scope of the definitions in section I, where engineering has been employed for the massive destruction of human life. Note that according to certain opinions (cited for example in Kosko, 1994), "war" has today been replaced by "business" and engineering has assumed its traditional ancillary role, appropriately adapted to the new circumstances. We will not pursue that line of thought here, instead choosing to emphasise the creativity of engineering for potentially everyone's benefit.

There are numerous examples of the employment of engineering to better life, as will be shown in the following section. Moreover, new branches of engineering have emerged outside the old scope of engineering. Sometimes those new branches have sprung out of war needs such as the "operations research" which dealt with the optimum allocation of resources during WWII, and which since WWII has dealt with the optimum allocation of resources in various industrial activities. Lately, entirely new branches of "engineering" have appeared which deal neither with mechanics nor with war. For instance, the term "software engineer" was coined to denote an engineer who develops computer code, the term "genetic engineer" denotes an engineer who deals with the structure of the DNA, while the object of "neurocomputing" is to engineer artificial neural networks endowed, in some sense, with human mental capacities.

In light of the above illustrations we define engineering as: the art (followed by application) of developing contrivances in order to affect directly the environment according to one's will. Engineering could also be defined as the science of the feasible. We note that the notions "curiosity", "ambition", "synthesis", and "inventiveness" fit well with "engineering", and add that a product of engineering is technology, in particular "high" technology, when speaking of modern engineering.

III. One Way of Unfolding the String of Engineering Achievements

We start by referring to prehistoric man's two grandest inventions. It is argued by some that prehistoric man's most ingenious invention has been the wheel because both its shape and utility are products of the intellect since nothing similar exists in nature to be imitated; moreover, the wheel precipitated subsequent advances in ceramics and transportation. Others argue that prehistoric man's greatest invention has been the use of fire as a source of light and heat, as a defensive weapon, etc. Note that fire itself is not an invention, and humans were aware of fire long before they started using it. This fact is illustrated quite vividly in the Greek mythology with the story of Prometheus who stole fire from the skies and gave it to the people. Today we know that fire was harnessed about 500,000 years ago by *homo erectus* (Asimov, 1996). Both the wheel and fire precipitated further progress.

The passage from prehistory to history is marked by a major engineering achievement. That is the invention of writing; now information could be stored for later accurate recovery. The chronicle of the invention of writing is quite interesting and is cited in our sequel. Writing was invented in Mesopotamia, Egypt, and China at about the same time; initially, it was effected by employing ideograms, where one ideogram stood as the symbol for one concept. While trading between Mesopotamia and Egypt, the Phoenicians had to know two different sets of ideograms and to perform the cumbersome task of converting one set of ideograms to the other; hence, the Phoenicians invented the alphabet which used symbols for concrete sounds (Asimov, 1996). The adoption of that first alphabet by neighbouring people precipitated the dissemination of knowledge and led to science and mathematics by the Greeks. A significant innovation of the Greeks was their habit of keeping detailed records of their thoughts and deeds. Later, scientific knowledge and thought, enhanced mainly by the Arabs, passed to Europe and thence to North America, where it reached new heights. For a comprehensive and detailed chronology of scientific discovery the reader is referred to (Asimov, 1996). We pause here at one specific period of history to which we attach special significance, that is the industrial revolution.

Due to the geographical location and the political constitution of the countries involved, the industrial revolution began in England and the continental Europe, and then spread to North America. Perhaps the most conspicuous feature characterising the industrial revolution is mechanisation which, on many occasions, replaced the human hand and muscle. Considering in retrospect the mechanisation of the 20^{th} century Giedion (Giedion, 1969) argues that it was the collective fervour for invention of the 1850's that foreshadowed future developments in industrialisation. In the seventeenth century the inventive urge was possessed by a limited group of scholars - philosophers and savants like

Pascal, Descartes, Leibnitz, Huygens, or further back, the universal man of the Leonardo type. The orientation towards inventing which was later to sway the masses of the people first took shape in the minds of the few. Until late in the eighteenth century, inventive activity, so far as it has been recorded in the British Patent archives, was no more than a trickle. Toward the mid-nineteenth century it gained its hold over the broad masses, and perhaps nowhere more strongly than in America. The most renowned inventor of that period has been Thomas Edison.

After WWII the need to handle and process information automatically brought about the so-called "information age" characterised by the increasing utility of information. Much credit for the "information age" is attributed to the then director of research of Bell Telephone Laboratories, Kelly, who found the means to commit to the achievement of the anticipated needs in telephony by replacing vacuum-tube technology with solid state semiconductor technology (Ross, 1998). More specifically, Kelly established a research group in New Jersey in the summer of 1945 under the leadership of the physicist Shockley, who discovered the junction transistor in January 1948. In 1955 Shockley departed to California in order to commercialise his inventions and he created what is now popularly known as Silicon Valley in the San Francisco Bay area.

From the previous presentation in this section it could be claimed that the technology stakes the domain of human activities out to a large extent and in this sense we say that the technology shapes human history. Moreover, if we look carefully into the agents that have occasioned and have advanced technology throughout history we may single out "information" as the most important factor. We could even argue retrospectively that information has been the underlying agent which sustained prehistoric man's great inventions, the use of fire and the wheel. Such a line of thought can be pursued by considering "speech". We regard speech as an invention and we maintain that it has been speech that sustained and disseminated both the use of fire and the wheel. Currently information, from an instrument to technology, is simultaneously becoming the objective of technology.

Today the utility of an ever-increasing abundance of information is restricted by the finite capacity of the human brain to store and process it. The need has been felt to resort to devices in order to obtain the most from the available information. Such devices could be regarded as enhanced brains. The classic industrial revolution delivered the human hand and muscle from manual tasks of routine; the contemporary information revolution could ultimately deliver the human brain from mental tasks of routine that require repetition, precision, speed, etc.

We stress that the need to "harness the oceans of information" could lead to novel scientific knowledge and further the progress. To support the latter claim we cite, in the remainder of this paragraph, concrete examples of scientific theories springing from concrete practical needs; in the following paragraph we show how a scientific theory could further the progress. Hence, the need of the Greeks to measure the earth led them to geometry; the need of the British to navigate safely around the planet led them to calculus as well as the study of solar mechanics; the need of the French to produce engines led to Fourier transforms; while science was becoming international the need to understand the effects of the random application of various agents led to the formulation of probability theory; after WWII the need of the Americans to sustain a huge, versatile, and reliable telephony system led them to the theory of semiconductor physics.

The value of a concrete scientific theory in applications could be illustrated by the impact of the mathematical formulation of the operation of levers suggested by Archimedes around 260 BC. While levers had been in use, on occasion, since prehistoric times, it was the mathematical formulation of their operation which made possible their wide proliferation. A more recent example might be the development of the theory of the junction transistor in 1948 by Shockley's research group, which had avoided the empirical approach that aimed at immediate, but short-lived, results (Ross, 1998). Based on Shockley's sound theory, the use of the transistor proliferated, thus leading to the contemporary information revolution. Without a supporting scientific theory, practical progress is blind; on the other hand, when a useful theory exists then it becomes obvious how a device could be improved or what new measurements should be obtained.

In what follows we will limit our discussion mainly to the domain of Electrical Engineering, the area of specialisation of this author. Note that keeping within "Electrical Engineering" might not be particularly restrictive, especially if one considers the domain's ever-growing scope. As a barometer of Electrical Engineering's vigour we consider the diversity and the size of the Institute of Electrical and Electronics Engineers (IEEE), with over 312,000 members in approximately 150 countries (IEEE, 1998).

IV. Induction, Deduction, and Trends

Science proceeds from the specific to the general, that is science proceeds by induction. Mathematics proceeds from the general to the specific, that is mathematics proceeds by deduction. Today science tracks mathematics (Davies *et al.*, 1981) as has been shown in numerous cases. For instance, discrepancies between factual observations and theoretically-expected observations on the orbit of planet Uranus could be compromised either by rejecting the universal law of gravitation as formulated by Newton in 1687, or by assuming the existence of an unknown planet. A celebrated triumph of the Newtonian law was the discovery of the planet Neptune in 1846 by astronomer Le Verrier; likewise the planet Pluto was discovered in 1930 by the astronomer Tombaugh. The four mathematical equations for electromagnetism published in 1865 by the physicist Maxwell constitute another example of how science tracks mathematics. Maxwell induced his equations so as to comply with the experimental facts; later tests on electromagnetism deduced the validity of Maxwell's equations.

It should be noted as well that an established scientific theory could be refined by another one. For example, Newton's universal law of gravitation was refined by the theory of general relativity formulated in 1916 by the physicist Einstein; Einstein's theory has been confirmed by factual observations, including astronomical data regarding the orbit of planet Mercury.

The amount of mathematical knowledge is not constant; rather, it increases. For example, consider the contemporary probability theory which was initiated by the work of Pascal and Fermat in 1654 on combinatorics with regards to gambling. Despite the employment of the notion of probability as a fundamental notion in quantum mechanics as far back as the 1920's few mathematicians outside the old Soviet Union recognised probability as a legitimate branch of mathematics and at that time probability was frequently being taught with semimysterious discussions (Feller, 1968). The mathematician Kolmogorov gave it a rigorous mathematical formulation in 1933; since that time probability theory has gained wide acceptance among mathematicians.

Man's mathematical and scientific preoccupation has developed fairly recently. In 1974 the anthropologist Johanson discovered in Africa the bones of the oldest known anthropoid, estimated to have lived around 3.6 million years ago. Apparently humans have walked on the Earth for millions of years; relatively speaking, they have just started keeping detailed records of their mathematical and scientific thinking.

As a rule whenever humans employ science and mathematics they typically apply it outside their own mental constitution, hence the scientific study of various cognitive-, learning- etc. schemata has been rare to date. From the natural philosophers of ancient Miletus of the 6^{th} century BC to the quantum physicists of the 20^{th} century, science has studied nature successfully using mathematics. Nevertheless no scientific study of either man or of life as such has been attempted mathematically until recently. The work of physiologist Pavlov on dependent reflexives in 1907 could be regarded as pioneering in this direction.

There would appear to be a new scientific trend gaining momentum during the last few decades . That is the trend to model mathematically aspects of life or of human capacities. For instance, some new approaches involving mathematical models for human learning capacity have been shown in (Carpenter *et al.*, 1987), and in (Kohonen, 1995); the biological evolution has been modelled in (Rechenberg, 1973), "genetic" algorithms were modelled in (Holland, 1973), and various models are shown in (Zurada *et al.*, 1994); moreover, the establishment of a few centres for studying various aspects of learning has lately been announced (Mitchell, 1998). The number of new publications on such topics as "artificial neural networks" for emulating the human learning capacity, "fuzzy systems" for emulating the human capacity for decision-making under uncertainty, "evolutionary computation" for seeking optimum solutions to engineering problems by emulating the biological process of the survival of the fittest, etc. is accelerating world-wide. All evidence indicates that from a mathematically-based modelling of nature we may be proceeding to a mathematically-based modelling of life. Nevertheless, for the latter undertaking currently-known mathematics may not be enough.

In the study of nature science has always followed mathematics. It could be the same for a scientific study of the human per se, should suitable mathematics be available. It might be beneficial to attend to philosophy as a pool of ideas from which to draw useful ideas. In this regard we point out that during the past century philosophy has had as one of its concerns the study of mathematical sets and their properties (Scruton, 1995). The work of logicians such as Frege, Russell, Taski, Lukasewisz, Wittgenstein, and others has already influenced the work of scientists and engineers.

In the context of modelling mathematically human intellectual capacities, the theory of "fuzzy sets" could be pointing in the right direction. We explain that a "fuzzy set" is a collection of elements characterised by partial membership in the fuzzy set in question. For example the set A of "tall people" is a fuzzy set; hence a child with height 100 cm has a 0 % membership in the set A, a basket-ball player with height 220 cm has a 100 % membership in the set A, whereas we may argue that a person with height 175 cm has a 40 % membership in A and another one with height 185 cm has a 70 % membership in A. Fuzzy sets have demonstrated a practical capacity for efficient decision making in uncertain, complex environments. Fuzzy sets, of course, are opposed to "crisp sets", an example of which is the set of people with a South African passport. Apparently a specific person either does or does not have a South African passport. We remark that the conventional (Aristotelian, or crisp) logic deals solely with crisp sets. On the other hand, fuzzy set theorists argue that humans actually think in fuzzy sets. Knowledge or intelligence results from associating two fuzzy sets. Fuzzy logic ties words with fuzzy sets, followed by reasoning with fuzzy sets and has made computers more "intelligent" (Kosko, 1994).

It is worthwhile and necessary to define what we mean by an "intelligent" computer or "intelligent" machine. We call "intelligent" a computer if it passes the Turing test (Hofstadter, 1984) set forth by the mathematician Turing in 1950. We give a description of the Turing test: an interrogator sits in a completely isolated room, whose only contact with the outside world is through two computer terminals, A and B. Terminal A is connected to another terminal in a different room operated by a human; Terminal B is connected to a computer. If the computer manages to fool the interrogator into believing it is a human then the computer can be called intelligent.

In February 1996 Deep Blue, IBM's parallel computer, beat Kasparov, World Chess Champion for 11 consecutive years. With respect to a "restricted Turing test" focusing solely on chess, Deep Blue is intelligent. Nevertheless, philosopher John Searle had argued in the 1980's that even when a computer applies successfully an algorithm and passes the Turing test we cannot call it intelligent because it does not really comprehend the problem. Searle gives the "Chinese room" example (Penrose, 1994): consider a human sitting in a completely isolated room, whose only contact with the outside world is through one computer terminal. Questions are given to the human written in Chinese and a "yes" or "no" answer is sought. The human doesn't know Chinese but s/he is given instructions regarding the correct response to any sequence of Chinese ideograms, in another language that the human understands adequately.

Despite being able to answer correctly any question posed, the human inside the room hasn't understood the questions asked in Chinese. In the same manner, argues Searle, a computer applies blindly an algorithm without any comprehension. In this article, we are concerned only with the intelligent behaviour of machines and hence we call intelligent those computers which pass the Turing test. Therefore we call intelligent IBM's Deep Blue in the sense that Deep Blue has passed successfully the "restricted Turing test" which focuses on chess. Below, we elaborate on the chronicle of the development of fuzzy set theory as well as its potential utility.

Heisenberg's 1927 uncertainty principle in quantum mechanics suggested that we really deal with three-valued logic: statements are true, false, or indeterminate. In short order, Polish logician Lukasiewicz chopped the middle "indeterminate" ground into multiple pieces and came up with many-valued or multivalued logic. Until then logicians like Russell had used the term "vagueness" to describe multivalence. In 1937 the quantum philosopher Max Black published a paper on vague sets or what we now call fuzzy sets; in 1965 the electrical engineer Lofti Zadeh attached the label "fuzzy" to such vague or multivalued sets.

Fuzzy logic opposes Aristotelian logic, where a contradiction can imply everything. Aristotelian logic, formulated by the philosopher Aristotle in the 4th century BC, assumes the bivalence of a statement, that a statement is either true or false. The truth or falsehood of a concrete statement may be implied from the truth or falsehood of other statements by applying certain laws of logic. Aristotelian logic was introduced to Europe by the philosopher and theologian St. Thomas Aquinas in the 13th century. Aristotle's logic was cast into algebraic form by the logicians Boole and De Morgan in 1847, and has since been enhanced in various ways (Church, 1956).

Fuzzy theorists regard Aristotle's logic as a special case of fuzzy logic and they argue that a conclusion reached within Aristotle's system of logic could be free of contradiction, yet it may not correspond to the facts. A popular example cited by fuzzy theorists to show the inadequacy of Aristotelian logic is philosopher Zeno's paradox: Consider a heap of sand. Is it a heap? Yes. Throw out a grain of sand. Is it still a heap? Yes. Keep throwing out grains of sand and keep asking the bivalent question and eventually you end up with no sand grains and no heap. The heap has passed into nonheap and you can blame no single sand grain. Fuzzy logic responds to Zeno's paradox by accepting a degree of truth of a statement which (degree of truth) corresponds to the fact.

As an additional example consider Tarski's "statement formula" of truth:

"STATEMENT" is true if and only if STATEMENT.

The quotation marks mark off an asserted description. The unquoted statement describes a fact. For example "grass is green" if and only if grass is green. Aristotle's logic assumes that the sentence "grass is green" is either true or false. Fuzzy set theorists argue that the sentence "grass is green" is true to the degree to which the grass is green.

From a theoretical point of view an advantage of the theory of fuzzy sets might be the fact that the fuzzy set theory is required to satisfy fewer axioms than other sound mathematical theories such as probability theory. We cite Gudder from *Quantum Probability*: "A slight variation in the axioms at the foundation of a theory can result in huge changes at the frontier". As regards the theory of fuzzy sets in particular, we note that fewer axioms to be satisfied could account for fuzzy set theory's closer correspondence to the real world. Moreover, fuzzy systems are not domain-specific like conventional "expert systems" (Giarratano *et al.*, 1994), which can respond successfully only within a narrow problem domain but are incapable of responding at all outside their narrow domain.

Apart from theoretical considerations, fuzzy theory's firmest argument is that it frequently gives better results in applications than other methods such as probabilistic ones (Kosko, 1994). Fuzzy sets are sensible to deal with and they are easily applicable by practitioners in their areas of expertise. We propose herein that the many "success stories" of fuzzy logic, mainly in the Far East (Kosko, 1994), could be regarded as the result of a division of labour (Smith, 1776). In (Smith, 1776) it is explained how ten persons working on an assembly line in pin-manufacturing could make 48,000 pins, that is 4,800 pins per person; whereas had they all wrought pins separately and independently, without any of them having been educated to this particular business, they could certainly not each of them have made twenty pins in a day. Likewise, fuzzy logic can easily capture an expert's knowledge on a specific sub-task. Furthermore, a microchip can accommodate fuzzy logic and hence it can automate with repetitive precision an expert's decision-making. By breaking a complex task down into several simpler sub-tasks and then assigning one "fuzzy logic-based" microchip per sub-task, we can carry out the overall task automatically with an expert's effectiveness. In this sense we regard the success of various fuzzy-logic based "intelligent" machines as the result of division of labour and expertise.

Despite the successful heuristics of fuzzy set theory, we believe that mathematical rigor, perhaps to be achieved by a more general theory - yet to come - inside which fuzzy set theory is a special case, will be for the better. Our arguments are the same as for the "levers of Archimedes" in section III, viz., that a sound theory would facilitate further improvements in the task of building machines endowed with intelligent behaviour. A farther-reaching practical objective would be the effective emulation of human brain functioning.

V. The Engineering of Scientific Induction

It is generally acknowledged that the single biological feature that differentiates humans from other living creatures is the brain, where the sophisticated human behaviour and reflection originate. It has been argued that the brain has been the long-term effect of the "shallow" S-shape of the spine by an evolution-driven process of natural selection; specifically the "shallow" S-shape of the spine has occasioned upright posture, biped walking, and hence it freed two limbs, which ultimately became the hands (Asimov, 1996). The argument continues as follows: upright posture could help the head move more easily in more directions, whereas the hands could bring nearer to the head a great variety of materials from the environment. In that way the brain was deluged with information from the world through the sensory organs. A few million years of natural selection resulted in bigger and more sophisticated brains because the chances for survival were larger for the latter brains as they could process sensory information more effectively. We will try to build on this conjecture.

Today the industrialised societies, have moved to the so-called "information age", characterised by a deluge of signals pouring into the brain from human-made sources of information including TV signals, computers, the internet, and so forth. As this deluge of information intensifies we would expect that human brain capacity would increase over the long run through a process of natural selection- and survival-of-the-fittest- brain structures, the way it has happened in the past. That is, we would expect those biological brain structures to be promoted in the future which can discern and process more efficiently vital information stemming from the new, man-made sources of information.

That is to say, improvement of the brain faculties boils down to feeding it with abundant information for a sufficiently long "training time", promoting along the way only those brain structures which better fit the environment. It has taken the human brain a few million years to evolve into its present state; that is a very long time compared to the span of human life. We would like to shorten the "training time" and this can be affected in two ways: by (practice #1) directing selectively the flow of information to the brain, and by (practice #2) intensifying the flow of information to the brain. Practice #1 is an issue of design. That is, we would have to select the contents as well as the sequence of the pieces of information to be fed to the brain the way a school teacher designs the contents of a class at the beginning of a semester in order to maximise the performance of the students; a prudent design would be expected to shorten the amount of time required to train a brain. Nevertheless practice #2 will run up against the capacity and endurance of a biological brain. Returning to our school teaching example, consider the following experiment. In a class of elementary-school students randomly selected we assign a group of "good" instructors to teach in one year the full sequence of mathematics normally taught in the whole of elementary school, high school, and the first years of college. Then a multiple-choice test is given to those elementary school students. We wouldn't expect the test results to be very different than a random selection of the answers. The reason is that even though the correct mathematical contents had been taught by "good" instructors it will be the restricted capacity of the biological brains of most children which does not enable them to comprehend higher-level mathematics. Likewise the restricted capacity of the biological brain may hinder the rapid and effective comprehension, whatever that means, of novel information. We could overcome the latter problem by replacing the biological brain by a non-biological one, for instance, some type of an electronic brain.

Suppose now that an electronic brain's "training" has gone on long enough to produce some type of intelligent behaviour. We assume that intelligent behaviour originates from some type of knowledge induced in the electronic brain in response to information signals from the environment. We call the process that induces the latter knowledge scientific induction. Note that such scientific induction has been the result of a designed contrivance (engineering), therefore in this sense we speak of "the engineering of scientific induction". We remark also that the design of artificial brains is currently well under way in the research domain of "neurocomputing", which offers a concrete contemporary example wherein the objective of engineering is not a tangible contrivance but rather a largely abstract methodological contrivance.

The knowledge induced by an artificial electronic brain does not have to be similar to contemporary human knowledge; it could be inferior, or it could be superior, or it could simply be different. It would be an interesting problem to elicit the knowledge stored inside an electronic brain. We remark that experiments are currently being performed world-wide for knowledge extraction from artificial neural networks (Ishibuchi *et al.*, 1993). Acquisition of such elicited knowledge could improve our own perceptions regarding the world. But it might not be necessary to extract at all any knowledge from the electronic brains as long as those machines perform their tasks as required. That issue brings us to the conclusion of this article, where we consider the potential utility of machines with a learning capacity.

VI. Speculating about the Future

The short-term gain from machines endowed with intelligent behaviour might be primarily an increased profit margin for individuals with stakes in the industrial produce or in the business of providing services. On the other hand, the long-term gain from those machines might be the survival of the human species. Herein we are concerned with the potential long-term gain. We begin our argument by pointing out mankind's grandest underlying problem, that is population explosion.

It has been broadcast lately by the major stations that in June of 1999 world population is expected to exceed 6 billion for the first time. The problem of overpopulation has been studied analytically since 1798 by Malthus, who demonstrated that the population increases geometrically, that is as the numbers 2, 4, 8, 16, and so forth. It has further been argued that the rapidly-increasing human population underlies all environmental problems (Hitchborn, 1997). We resort to an historical example in order to demonstrate the fatal dangers of overpopulation. Specifically, we will consider the history of Easter Island, as this history has been pieced together by archaeologists.

Located in southern Pacific over 1,400 miles from the next closest inhabited isle, Easter Island is almost completely isolated. When the first Polynesians landed on Easter Island around 400-700 AD, the island was a sub-tropical paradise covered with thick forests of palm trees. The community soon flourished, and trade developed well. The islanders invented the only written language in Oceania and developed the technology required for erecting the huge statues that still cover the island. The human population quickly swelled. Estimates of population range up to 20,000 at its peak, far exceeding the capabilities of the small island's ecosystem. By 1400 AD the palms were well on their way to becoming extinct. Other resources were becoming scarce as well. War spread among clans. Cannibalism appeared. By the time of its discovery in 1722 the population numbered around 2,000 on an island short of trees (Diamond, 1995). The history of Easter Island shows that it is possible to destroy a closed ecological system by overusing its resources.

Having restored and understood Easter Island's history let us try to appreciate man's position on planet Earth. Until today we have been able to maintain the production of materials needed to sustain population growth, but at the price of environmental pollution. Nevertheless, natural resources are being overused. We have devastated most of the Earth's forests. At the moment we are burning organically-derived energy minerals such as oil, gas, and coal. It is true that there are still vast expanses on the planet to be exploited and inhabited like North Africa, Australia, and Siberia. And people are also considering the area under the oceans, which covers about 70% of the planet's surface, in order to grow seaweed for food and find metals or other raw materials.

While the geometric population growth can be countered only with birth control, a large population on the Earth appears to be inevitable and difficult to sustain without depleting natural resources and without polluting the environment. The whole planet is a closed system just like Easter Island. However, we have an important advantage over those islanders: we have access to the virtually infinite Space beyond the Earth. We illustrate in the sequel that approaching Space can be managed effectively by employing "intelligent" machines.

Due to its dimensions and its materials, Space appears to be particularly promising as a potential supplier of raw materials and moreover as a potential place of inhabitation. Nevertheless, Space activities could be dangerous in many ways. First of all, a danger is the environmental threats to Earth associated with human activities in Space (Spyrou, 1998). One way to avoid those threats would be to perform space activities at locations far removed from Earth such as on distant planets or beyond. And that is where "intelligent" machines come in the picture. That is, "intelligent" machines could be employed in the future to perform tasks demanding skills and dexterity in remote or dangerous places. For instance, nuclear testing could be conducted in Space by "intelligent" machines and the results could be reported electromagnetically to human administrators. Moreover, mining or selected industrial and manufacturing activities could be carried out on remote sites in Space by "intelligent" machines and the products could then be shipped to the human end-users. Future dispatches of communities of human workers or immigrants to inhospitable celestial bodies could be supported by dispatches of colonies of "intelligent" machines. We note that in preparing for such an undertaking it might be useful to study the ancient colonisation of the Mediterranean basin, or the more recent immigrations to the New World.

VII. Conclusion

In this essay we have presented out the reasoning that it has been science, and in particular the various transformations of information, which have shaped human history. We have shown that our latter claim is becoming increasingly more apparent today.

We have called the science of the feasible "engineering", the products of modern engineering "high" technology, and have stressed the potentially important role of "intelligent" machines in the future.

In conclusion, citing sociologist Max Weber that "science acts like a road map; it can tell you how to get from one place to the next but not where to go", we point out that the direction for future developments in science and technology remains a matter of human choice.

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