The basic laws of coded information: from DNA to AI

Information is information, not matter or energy.
— Norbert Wiener

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Abstract

The basic laws of coded information that differ from the basic laws of matter have been proposed, and classification of the three major types of "information processing machines" (IPMs) have been given. In addition, the main characteristics of the future Artificial General Intelligence (AGI) have been discussed.

Introduction

Informatics is an important and fast-developing field of modern science and technology. Many great advances in programming, robotics, and artificial intelligence (AI) development have been reported in the past decade. Among others, the ultimate goal of creating fully functional AI systems is probably the most challenging and ambitious. Despite recent advances, such as superior gaming algorithms [1], robots [2], and other autonomous devices [3], it is not clear yet whether any of the existing developments can be considered a fully functional AI due to the absence of a universal comprehensive definition of AI. One main-stream opinion is that any computer program capable of mimicking the process of human thinking well enough can be considered an AI. This opinion has a major problem, as it requires a strict and clear definition of human intelligence. The latter is extremely hard to define, as modern chemistry, neurobiology, and medicine simply lack much of the necessary knowledge related to this issue. General science gives a wide number of broad definitions of intelligence [4], and it is hard to deduce one universal and fully comprehensive definition. Having analyzed various definitions of intelligence, modern AI research has formulated a general definition for so-called "intelligent agents" [5], i.e. computer-based devices that can interact with the environment, learn, and act in a way that maximize chances of successfully achieving predefined goals [4]. This general definition seems quite useful, as it clearly states the technical requirements expected for an AI-driven device or program. However, it assumes that AI always has certain preset goals, and in addition, AI functionality can be restricted within a certain specialization. Notably, the human mind seems to have no specialization or preset goals at its infancy. Moreover, the natural "preset" biological goals (e.g. eating, moving, sex, etc.) seem not to be the only drivers of human intellectual activities. In an information-rich environment (observations, education, interactions with others, etc.), a mature human mind often develops the ability to create a number of purely abstract intellectual goals, such as exercising poetry, philosophy, arts, etc. Thus, the question of AI defining is more than just a technology-related issue requiring a more fundamental understanding of information *per se* and all processes it is involved in. Without a clear description of the latter, it seems impossible to understand all the complexity of abstract human thinking, which AI is expected to mimic or even overcome.

Abstract thinking likely presents the core ability of the human mind, and its understanding is crucial for AI research. As mentioned above, this process cannot yet be described by human-related sciences, hence the informatics approach is only one to follow. Obviously, thinking is a process of acquiring, analyzing and creation of certain types of information. Prior to trying defining thinking, it is important to understand what is the information human mind operate with, and what laws it obeys. Notably, information is not just a type of matter or energy, as it was stated by Norbert Wiener, and hence it should obey its own laws (not contradicting the known laws of physics). Surprisingly, such laws were not yet formulated, although their understanding might be helpful for defining thinking. The presented article focuses on this particular question.

The basic laws of coded information

The basic laws of matter provided by materialism are indispensable for scientific analysis and seem applicable to all the objects and phenomena in nature. Although all natural phenomena, including mental aspects and consciousness, are results of material interactions, the abstract thinking *per se* is somehow more than just material interactions. It seems that the full descriptions of physical, chemical and biological processes are never enough for the general understanding of thinking and intelligence. This discrepancy is a consequence of the unique immaterial qualities of the matter objects augured when the objects carry an artificial (i.e. coded) information. Although the processes of acquiring, copying and sharing the information are purely materialistic, the information *per se* is not.

Let us define artificial (coded*) information as a special category of abstract objects. Coded information should not be mixed with the natural (non-coded) information, such as used in physics for a description of certain types of physical processes (e.g. particle interactions). Artificial information is coded by a certain artificial (not governed by any natural physical or chemical process) order of certain discrete material objects with a certain similarity, which makes them operational as code elements (CE) by the action of a certain information-processing machine (IPM).

One example is the information coded by DNA. There are four types of nucleotides, four CEs, and all the nucleotides of the same type are chemically identical. The unit sequence within the DNA chain is artificial, as it requires certain special molecular machinery and cannot be consistently reproduced within a spontaneous chemical reaction. The information appears meaningful only if the DNA sequence is arranged according to the unique code readable by the cellular machinery.

Let us analyze the basic properties of coded information using DNA as a natural example appeared spontaneously and not produced by any type of intelligence (assuming Darwin's theory of evolution). By analyzing this example, it is quite obvious to see the main properties of coded information, different from any material object property. As a purely abstract category, the DNA information possesses a number of general properties:

1. Information existence is relative, not absolute. It exists only for those material objects that can use it. Let us call those objects “information processing machines” (IPMs). It also “exists” (or more precisely, makes sense) for intelligent subjects that can understand its meaning. The information is active when used by the IPM (which acts on the material world) or silent over vise. For instance, although the DNA information coding a given protein does “exist” for the cellular machinery (or another IPM) that can operate it, it is completely silent, i.e. “non-existent” (in an absolute meaning) in the absence of such machinery (for now, let us skip the case with an intelligent subject). With no IPM, the DNA code is unreadable, and hence the information is completely irrelevant to the material world. In such case, differences between the DNA molecules are determined only by their natural (material) parameters (e.g. chain length, number of charged chemical groups, solubility, etc.), but not the code.
2. Being an abstract category, information is immaterial. Although the information cannot exist without its material carriers (e.g. DNA molecules), it can be mentally “separated” from the carrier, when understood and manipulated as an abstract category.
3. Information influences matter only indirectly, via the action of IPM. IPM is always a material object that can read the code and change the environment in accordance with the code. Due to the second law of thermodynamics, IPM action always increases order in the system and hence requires energy. Being immaterial per se, the information influences the material world when used by material objects (IPMs) or intelligent subjects that understand it. For instance, bacteria acquiring and using artificial DNA physically change the environment. Similarly, any information received and understood by an intelligent subject can be used to produce certain specific (information-driven) changes in the material environment.
4. Information always has a material carrier and a unique code. For instance, the DNA information cannot exist without the coding nucleotides and the unique code, which makes it useful for cell protein synthesis. Although the DNA information can be translated into a separate form (e.g. the letter code on paper), the carrier and the code requirements are unavoidable. The carrier (e.g. DNA molecule) must include the CE components (e.g. single nucleotides) artificially (not spontaneously) ordered by the action of IPM in accordance with the unique code.
5. Information disappears when: a) the code-driven order of the digital components is disturbed (carrier disordering), and the code is unreadable by the IPM, b) the digital components are changed physically or chemically in such manner that the code is unreadable by the IPM (carrier deformation or destruction), c) when the IPM becomes non-functional (IPM silencing). The case (a) is always irreversible; as no IPM can regenerate the initial order in case the order is changed so that it is no longer obey the code. The disordering can also be non-fatal when the order still obeys the code (i.e. it is readable by the IPM), however, the information is then changed irreversibly (e.g. single- or polynucleotide mutations). The case (b) can be either reversible (deformation) or irreversible (destruction) depending upon the actual change of the digital components. The case (c) is always reversible with an introduction of a functional IPM.

6. Unlike matter, information can be created, multiplied, or destroyed. Being an abstract category, the information generally does not obey the basic laws of matter. According to the fundamental laws of physics, the matter cannot be created, destroyed or replicated. Matter and energy can only change forms in physical or chemical interactions, which are strictly determined by the laws of nature. Obviously, this is not the case with the information. A functional IPM can create, destroy, and replicate the information, and theoretically, this process is limited only by the energy and CE availability to the IPM.

Organic life is as an information-driven process

The DNA information is unique as the only example of coded information not created by intelligent subjects. All other presently known types of information have been created by humans or other intelligent live creatures, e.g. birds or animals. Although the created types of information are generally similar to the DNA information and seem to obey the same basic laws formulated above, they typically have one characteristic difference, i.e. a variable and sometimes complicated code requiring a complex IPM, such as the brain. The DNA code is simple and extremely conservative due to its natural origin. This fact, by the way, may be considered as an additional argument against creationism. The leading modern hypothesis of the origin of life (abiogenesis) is based on the primary appearance of the so-called RNA world. Notably, RNA molecules are ribozymes, i.e. they possess both the genetic information storage property like DNA molecules and the catalytic properties like proteins, and hence, RNA molecules can be thought as the essential molecules of life. According to the RNA world hypothesis [6], first self-replicating large RNA molecules had “populated” the primordial ocean on Earth more than 4 billion years ago. Small organic compounds (nucleic acids, short-chain organic acids and aldehydes, amino acids, etc.) and phosphates were present in water at that time. Thus, the initial organic compounds and energy from the hydrothermal vents are believed to support abiogenic RNA synthesis. However, RNA molecules are easily hydrolyzed in water; thereof, the natural selection promoted the prevalence of not only most stable but also self-replicating RNA molecules, proto-ribosomes. Further selection promoted the appearance of the ribonucleoprotein complexes, in which RNA molecules were stabilized by proteins. Later, those complexes were naturally substituted by the ribosomes that not only read the genetic code but also translate it synthesizing proteins. Finally, DNA in the form of desoxyribonucleoprotein complexes had substituted RNA for information storage.

Thus, the eukaryotic cellular genetic IPM is a complex gene expression machinery involving DNA storage in the genes, its replication, DNA coding conversion into RNA coding (transcription), and consequent protein synthesis (translation). Notably, the hypothetical proto-ribosome was likely just an RNA molecule capable of self-replication, and it was not yet an IPM. The first IPM was the archaic ribosome capable of translation (RNA based protein synthesis). The simplest presently existing live IPMs are viruses and bacteriophages, self-replicating DNA/protein and RNA/protein complexes parasitizing on live cells. Although the eukaryotic ribosome is a complex structure, the translation itself is a simple process fully determined by the three chemical factors: 1) binding affinity of the given amino acid towards the given tRNA molecule, 2) binding affinity of the given tRNA coding triplet towards the complimentary triplet of the mRNA, 3) the ribosomal ability to catalyze peptide bond formation between the amino acids. The entire process of translation is essentially the same as the action of a self-playing piano when the information written as holes in the perforated paper is mechanically translated into the string sounds.

From these positions, life can be seen as an information-involving process. Life is a spontaneously-originated energy-consuming process based on the functioning of self-replicating IPMs operating with a single conservative code. Although life on Earth has chemical nature, we cannot exclude a general possibility of different types of extraterrestrial life, which is based on material processes other than chemical reactions. However, such a possibility is elusive, as no material objects except the complex molecules possess sufficient complexity and relative stability allowing both coding and self-replicating. Thus, possible life on the other planets (if exist) is likely based on the RNA or RNA-like complex molecules with possible support of other complex molecules, such as DNA, proteins, carbohydrates, lipids and/or similar complex chemical compounds. The ongoing search for extraterrestrial non-intelligent life is indeed based on the monitoring of such chemicals in the space and on distant planets and planetoids. In addition, it might be possible to detect remnants of bygone life on other planets by finding preserved (e.g. frozen) long-chain complex molecules carrying some kind of coded information.

The general classification of IPMs

The cell transcription machinery is an example of the simplest possible IPM, which has fully conservative functionality and a conservative code. Let us call this kind of IPM a type I IPM or a simple translator. This kind of IPM cannot use a different code without any physical modification, i.e. it is code-conservative. The more advanced kind of IPM is a programmable machine or type II IPM, e.g. computer. The simplest example of the type II IPM is a programmable calculator. A simple nonprogrammable calculator is only a set of simple translators, as each button has only one conservative function and hence works as a type I IPM. However, a programmable calculator has an additional “layer” of translation, the coding system that codes all the button functions. Thus, the input is no longer conservative, as the second “layer” of codes can be changed providing different functionality within the available limits (actual button functions). This kind of IPM can have more than two code “layers” (e.g. a personal computer organization: hardware functions -- Basic Input/Output System (BIOS) -- operating system (OS) -- software applications). Although the computer operations can be very complex, every operation (taken from the physical input down to the physical output) is still conservative and can be described by a fully determined algorithm. Thus, the characteristic limit of the type II IPM is its conservative functionality, when a given physical input promotes only one physical output (assuming bugless operations). Simply put, a computer cannot create.

A special type of IPM-like functionality is a non-coded conversion/recording. Certain types of electronic devices may look like IPMs, however, are actually not such. Analog recorders and signal converters are characteristic examples. A transistor radio simply converts an airwave signal into the AC electric wave signal with the same pattern of timely changes of the signal amplitude. A vinyl record presents a conversion of an airwave signal into the surface lane using a very similar principle. Although any analog record can be considered as informationcontaining an object, the information is not coded, and hence, an analog recorder is not an IPM.

Human intelligence and AI are obviously more than just type II IPMs. The human brain, as well as brain of any other intellectual species (e.g. an animal or a bird), is a highly organized complex IPM capable of creating and executing dynamic algorithms (learning ability), creating and using *de novo* codes (super-coding), and self-control. These abilities allow one to put them to the next step in the IPM hierarchy and thus consider the human brain, as well as a fully functional AI, a type III IPM.

Thinking ability as the main characteristic of intelligence

There are three exceptional abilities characteristic to the human brain: 1) thinking ability, 2) consciousness, and 3) emotions. Emotional reactions and intuitive behavior are likely predetermined by biological reasons. E.g., fear is driven by the biological necessity to protect oneself or a valuable resource; love excitement is driven by the biological requirement for multiplication, etc. Consciousness is likely a result of abstract thinking when intelligent being analyses itself and the surroundings and models own behavior. Consciousness seems impossible without thinking. Thus, it seems that the thinking ability is the only indispensable characteristic of the intelligence, and a fully functional AI should be able of thinking.

What is thinking? In humans, thinking is processing of information coded as abstract categories: 1) simple ones (e.g. image patterns or sound patterns), 2) more complex word-associated categories used in describing of the surrounding world (e.g. an abstract understanding of "animal" or "doing"), and 3) highly complex purely abstract categories not connected to the material world directly (e.g. "moral obligation" or "mathematical function". Operating with these categories, a mind first creates an abstract model of the surrounding material world (or its part) or models a certain abstract thing or process (e.g. "god" or "gravitation") and then, analyzes various aspects of the world by comparing the inputs (sensual signals, observations or any other acquired information) to the model. Interestingly, the mind does not require specifically formulated tasks but does need a constant informational feed. Experiments with humans showed that healthy persons in a closed space with highly restricted informational feed (visual, sound and other) started to experience hallucinations within a few hours [7]. Notably, thinking itself brings a pleasure not defined by any strictly biological reason (e.g. mathematical exercises, board games). Thus, abstract thinking requires a constant informational feed, creation of operational abstract categories (*de novo* codes or super-codes), dynamic algorithms (e.g. learning capabilities), and development of an informational model of the material world or some part of it in the mind.

The human mind is not pre-programmed but rather develops continuously by processing random incoming information. A newly born infant lives solely on reflexes having "blank" intellect, which is likely functional but lacks information about the world around. During the first few years of life, human intellect acquires lots of information on the surrounding material world and creates an internal model of this world. As the informational model becomes more complex, the human becomes more intellectual and capable of deeper thoughts involving highly complex abstract categories and theories. As a part, the model inevitably includes an understanding of the "self" existing in the "world" providing self-consciousness.

A simple thought starts with an initial signal produced by a reflex. E.g., hunger feeling creates a biologically important task of finding some food. The intellect driven by this feeling acquires monitoring information from the sensory systems and feeds it to the “model of the world”. As a result, the intellect creates a plan for what to do in order to feed the organism. It is likely that this general scheme works for any kind of thoughts including most complex abstract thinking. This kind of thinking is goal-driven and matches AI definitions as "intelligent agents" (see Introduction above). However, it is not the only kind of thinking. A more advanced kind of thinking is creation-driven thinking, an “information-in, information-out” process aimed solely for processing or creating complex information patterns (e.g., solving a puzzle, making up a story, developing a philosophical concept, etc.). These processes often involve code editing/adjustment (learning) or creation of the “super-codes” (e.g. a puzzle-solving algorithm development, changing or creating of an abstract category or concept).

An important example of creation-driven thinking is any processing of the informational “model of the world”. The characteristic property of intellect is that it has no conservative code for the “model of the world”, which is entirely dynamical (changes depended upon the incoming information and memories) and auto-created. Although the electric signals exchanging between the neurons have to be coded conservatively for normal processing, the thoughts cannot have any conservative code, as if so, they will be predetermined by the inputs becoming reflexes. Thus, one of the core characteristic property of intellect is the ability to create dynamic algorithms with auto-coding (“super-code” processing) for a purely dynamical informational “model of the world” used for the informational analysis of the material surroundings and creating more information and more complex codes. Technically, the human mind is a network of neuron cells, type II IPMs capable of receiving, transmitting, and storing of certain electric signals (with relatively simple conservative codes). However, a certain complex neuronal organization makes the brain a type III IPM capable of auto-coding, self-programming, and “super code” learning/creating, which in total realizes as a thinking creative mind.

A computer model (e.g. an artificial neuronal network) capable of the same would be considered as a type III IPM as well and a true Artificial General Intelligence (AGI). How the process of thinking occurs in the human brain is yet unclear. However, some promising predictions can be drawn from the analysis of computer neural networks. Currently, the neural networks present a notable advance in programming, i.e. dynamic or adjustable coding. As the inputs do not need to be strictly defined, but rather can be “learned” by the algorithm, the coding system becomes highly flexible and adjustable. Although such machine learning algorithms show unprecedented advancements for certain practical tasks, this feature alone cannot make a neural network a true AGI. Unlike human or animal intellect, any presently known machine learning algorithm has a very limited modeling power, cannot generate “super codes” (e.g. own *de novo* machine language), and lacks any self-controlling ability. Nevertheless, a learning-capable neural network is more than a type II IPM due to the ability to generate adjustable codes during the learning process. Thus, they should be considered as an intermediate step between statically programmed algorithms (type II IPMs) and future AGIs (type III IPMs).

In general, neural network algorithm design should allow reproduction of all the necessary features of human intellect (auto-coding, self-programming, and “super code” learning/creating). Notably, cyclic organization of the recurrent neural networks (RNN) generally allows the auto-coding and auto-decoding and thus can have an ability of self-control. Theoretically, an RNN can be organized in a way that 1) it can produce a dynamical auto-coded model of the material environment, 2) it can generate self-controlling inputs, and 3) it can accommodate and even generate “super codes” (e.g. human or machine languages) and thus be capable of "thinking“, “understanding” and “information creating”. Thus, it is likely that a certain complex organization of RNN would be able to mimic human thinking. To do so the RNN should be capable of generating dynamic auto-coded self-inputs, self-controlling, dynamical auto-coding/decoding (with self-created codes and “super codes”), creating, evaluating, analyzing, and storing in the memory unique informational models of the “outside world” and using it for the continuous analysis of the surroundings and “super-coded” information creation. Obviously, the present RNNs are yet far from fulfilling all these requirements, and the development of a fully functional AGI is still in the future. However, current advancements in the fields of hardware (multi-billion-transistor chipsets) and software (neural networks) clearly have set the start.

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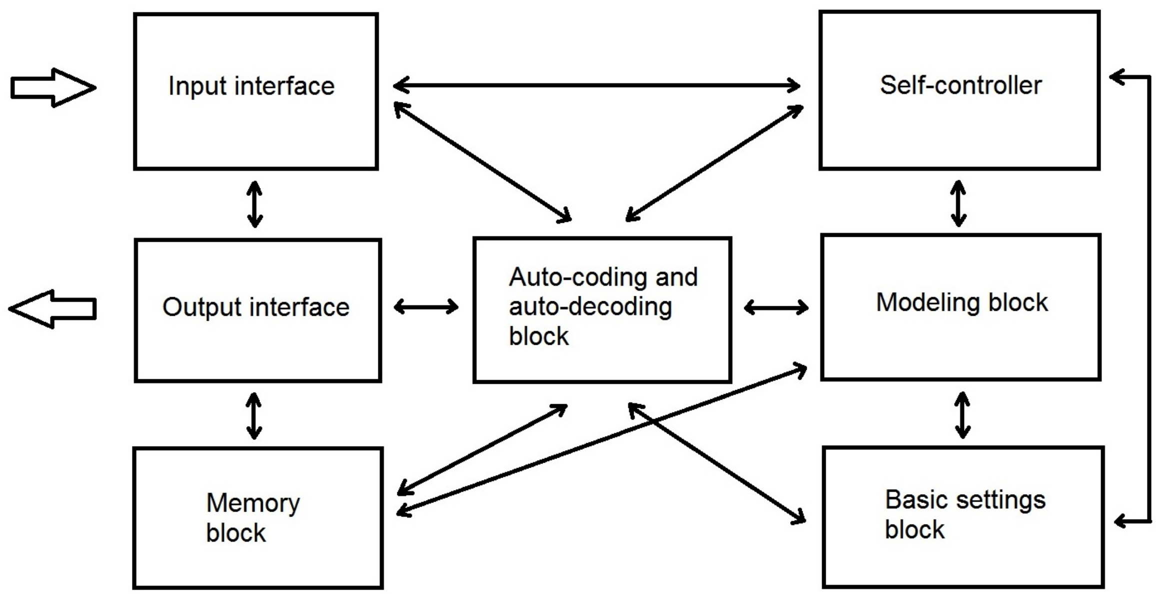

Figure 1. Proposed organization of RNN "thinking processor" that can generate dynamic auto-coded self-inputs, provide self-controlling and dynamical auto-coding/decoding (with self-created codes and "super codes"), create, evaluate, analyze, and store in the memory unique informational models of the "outside world" and use it for the continuous analysis of the surroundings and "super-coded" information creation. Large arrows show the main information flow between the unit and its environment; small arrows show information exchange inside the unit.