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Short Communication

Information Theory Explains Life and Refutes Plato

G´erard Battail*

École nationale supérieure des Télécommunications de Paris, France

*Corresponding author
G´erard Battail, École nationale supérieure des Télécommunications de Paris, France

Submitted: 12 Septmber 2023

Accepted: 06 October 2023

Published: 09 October 2023

ISSN: 2333-7141

Abstract

Shannon founded a science of literal communication, referred to as Information Theory, in 1948. It relies on the following physical model: a source delivers a message, i.e., a sequence of physical symbols, intended to a destination, by means of a channel. Perturbations, exclusively located in the channel, entail errors in identifying certain symbols. Error correcting codes can, within certain limits, correct such errors.

Information theory has been very successful in technical matters but is unrecognised elsewhere. It is shown that, due to unavoidable physical perturbations like thermal noise and cosmic rays, the conservation of genomes at the time scale of geology cannot be under- stood without assuming that error correcting codes exist in them. This assumption suffices to explain the main properties of the living world and its evolution. Interpreting according to Brillouin the thermodynamic entropy as measuring a lack of information more- over explains why living things resist the entropy increase promised by the second law of thermodynamics. Still more, the physical nature of the communication process denies Plato's idealism

INTRODUCTION

Technical innovations punctuated human history well before science got efficient means to control things and events. Some of them are lost in the mists of time and science ignored them since its interest was restricted to the study of natural phenomena. It is only since the end of the XVIIIth century that a trend towards applying the methods of physics to study human techniques came out. For instance, the interest of physicists to the steam machine gave rise to thermodynamics.

The means of human communication belong to ancestral techniques which remainded a long time free from the curiosity of scientists. It is not before 1948, thus recently at the scale of the ideas evolution, that a science of communication, referred to as Information Theory, was founded by Shannon (1916-2001), then an engineer at the Bell Telephone Laboratories [1].

INFORMATION THEORY

In order to found this theory, Shannon used the scheme represented on (Figure 1) in its simplest form, referred to as Shannon paradigm. It consists of three blocks, the source, the channel and the destination, which represent physical systems. A message, i.e, a sequence of symbols belonging to some finite and well defined set of physical objects or events said the alphabet, originates in the source and is communicated to the destination by means of the channel. The alphabet is arbitrary but its symbols should be distinguished without ambiguity. Perturbations, exclusively located in the channel, entail that some symbols are erroneously identified by the destination. The following comments about (Figure 1) will more precisely state the main contributions of information theory.

The communication process takes place entirely within the

Figure 1 Shannon paradigm, basic scheme of a literal communication.

physical world since the source, the channel, the destination and the alphabet symbols belong to it. The alphabet symbols, a sequence of which is the message, are represented by physical objects or events according to arbitrary conventions, under the sole constraint to be identifiable without ambiguity. The number of symbols of the alphabet, its size, is at least two but otherwise arbitrary. If this number is larger than two the symbols may be replaced by their binary representations, so assuming the alphabet to be binary actually does not restrict generality. Notice that the choice of both the alphabet size and of its symbols implies the concept of convention, i.e., of an arbitrary option shared by both the source and the destination.

The existence of perturbations which can entail errors in identifying the alphabet symbols is included in the communication model and not a priori considered as ignorable or of secondary importance. Taking the errors into account moreover entailed that the theory has been able to elaborate means to correct them, referred to as error correcting codes, an innovation of major importance.

As just described, the communication is purely literal. Its mere aim is to make a sequence of symbols available to the destination. Semantics, i.e., the meaning that a human culture associates with a message, is completely ignored. Information theory seems thus to be restricted to a very modest role as excluding the very essence of human communication, i.e., the almost demiurgic power of evoking things, beings or events, as

well as ideas or fantasies created by the human mind. Semantics is actually nothing more than a set of conventions specific to some human community.

Triumphant in Technical Matters, Unrecognized Elsewhere

Information theory turned out to be perfectly fitted to communication technologies. According to an amazing coincidence, it arised when the invention of the transitor, also at the Bell Telephone Laboratories, was on the verge of providing the main tool for its technical implementation. To a large extent, information theory is responsible for the explosion of communication means since the second half of the XXth century. For instance, mobile telephony would not exist without the error correcting codes issued from information theory. The sciences of nature, physics and biology, did on the contrary receive almost no benefit from information theory. I questionned in [2] why it was so, mainly explaining it by the difficulty of realising that information theory ignores semantics.

It turns out, however, that if heredity is interpreted as a communication process, information theory brings keys for understanding genetics and biological evolution [3]. On the other hand interpreting the physical entropy as measuring a lack of information, as proposed by Brillouin [4], explains why living beings resist the inescapable growth of their entropy promised by the second law of thermodynamics.

Information Theory Explains Life

In its original form, information theory deals with communication though space as operated by telecommunication means. However, it is as well relevant to communication through time, especially to heredity. The genetic message borne by the DNA, the genome, is assumed to be conserved at the time scale of geology. Due to the unescapable perturbations by thermal noise and cosmic rays, this is only possible if there exist means to correct errors which affect genomes. May one ignore that information theory has shown the possible existence of such means, which have been successfully implemented? Assuming error correcting codes to be present in genomes suffices to explain their resilience.

Genomes are extremely long: e.g., the human genome, which is not the largest existing one, is made of more than three billions quaternary symbols consisting of groups of atoms, referred to as nucleotides. Such immense lengths match the need of any error correcting code to be redundant, as resulting from constraints which entail a dependence between the successive symbols of a message. Certain constraints which affect genomes are steric, i,e., due to the fact that groups of atoms occupy an irreducible volume in space. Within the genes, other constraints result from a semantic feedback effect because certain structures of proteins, such as α helices and β sheets, impose constraints to the sequence of amino acids they are made of, hence to the sequence of triplets of nucleotides which specifies these amino acids in the genes according to the genetic code. Many other constraints remain to be discovered: for lack of experimental studies these codes and the molecular machinery which enables their decoding remain largely unknown. The only certainty is their absolute necessity.

The assumption that genomes use error correcting codes does not only explain the resilience of genomes with respect to errors, hence their (relative) permanence. In conjunction with the Darwinian selection, it suffices to explain the main structure and the evolution of the living world [3], for:

- An error correcting code results in eliminating all errors from the encoded message only provided the number of symbols in error remains less than some threshold. If this threshold is exceeded, the decoding operation generally increases the number of symbol errors;
- Any decoding error creates new information which entails a genetic mutation;
- The constraints which affect the genomes are cumulative, so that a same symbol of the message very often belongs to several correcting codes, which are therefore interwoven. The most efficient of these codes, i.e., the most redundant, are also the most unfrequent. This suffices to explain the arbore scent taxonomy of the living world, explaining why it is not an indescribable chaos populated with chimeras;
- Mechanisms referred to collectively as horizontal transfer tend to produce longer and longer genomes. The codes being the more efficient, the longer they are, the Darwinian selection operating on genomic error correcting codes tends to favor long genomes;
- The mutations due to decoding errors are the motors of evolution. The mutating genomes specify, by means of the genetic code, the assembly of proteins by ribosomes. These proteins result in the construction of new phenotypes which are the targets of the Darwinian selection.

The main features of the living world and of its evolution, which biologists simply record, find thus an explanation in information theory [2,3]. Other biological disciplines than genetics and evolution can advantageously use information theory, e.g., immunology and oncology.

Information Theory Explains the Relationship of Life with Thermodynamics

The word "entropy" designates in thermodynamics a statistical measure of the disorder of a physical system, especially at the molecular level. According to a suggestion of von Neumann based on a formal analogy, Shannon used the same word in order to name the statistical measure of information he introduced in his founding paper [1]. L´eon Brillouin (1889-1969) interpreted the thermodynamic entropy as actually measuring a lack of information, and proposed to rename Shannon's measure "negentropy" [4].

A major result of physics is the "second law of

thermodynamics", which tells that the entropy of any isolated system can but increase. According to the above interpretation of the entropy concept, this system thus tends to become disorganized.

The behaviour of any living being as a physical system is at the exact contrary. From a microscopic object, a fertilized egg, a system of many highly differentiated and strongly interconnected organs is built according to the instructions borne by its genome. Besides the initial assembly of the system, these instructions are used so as to maintain the system's structure all its life long. Any living thing thus appears as successfully resisting the entropy increase. It may be thought of as an entropy well. Of course, a living being cannot be considered as an isolated system, but the idea of such a system is a mere theoretical fiction. Clearly, its opposition to the entropy increase suddenly ceases when it dies. Moreover, living beings possess reproduction means which generate similar beings which similarly resist the entropy increase. This is enough to assert that the second law of thermodynamics does not apply to the living world. Still more, the depth of the entropy wells thus created tends to increase with the Darwinian selection which results in more complex and diversified beings. The whole living world appears as a gigantic entropy well of increasing depth.

Information Theory Refutes Plato's Idealism

An incommunicable idea is a mere nonsense. By anchoring communication in the physical reality, Shannon refuted the Platonic myth of a world of Ideas radically foreign to the physical world where we live. Plato had a great influence on philosophy and science, so one may reasonably question the possible presence of Platonic idealism in the conceptual bases of science, and especially of physics, and try to eliminate it. In this perspective, one may think of resuming the analysis of the measurement operation made by Heisenberg [5], interpreting a measurement as a communication between the observed object and the observer, which can be modeled according to Shannon's paradigm [2]. Oee may thus hope to better understand the limits of quantum physics.

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