
Viruses, information and functionalism



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Abstract

Functionalism is a theoretical framework that allows differentiating the information and the physical support in a system. This framework has been used in philosophy of mind and philosophy of artificial intelligence to explain that mind can be understood as information instanced in brain matter. On the other hand, the possibility of differentiating information and physical support has been the center of a deep debate. According to Searle, functionalism is wrong because in nature it is not possible to find a system where the physical and the logical supports are differentiable, because computations are not intrinsic to nature. In this paper, we propose that the infection process of viruses may be interpreted as functionalist, because it is possible to differentiate between computations and the physical storing media for those computations. The objective of this article is to show that molecular biology gives evidence to sustain that in nature there are systems where information can be differentiated from the physical support. We think that the way a virus infects a cell, releasing its genetic instructions to be executed in the cellular machinery to take control of the cell, is strong evidence for the software/hardware distinction.

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Functionalism is a theoretical framework that allows differentiating the information and the physical support in a system (Nelson 1976:380). This framework has been referenced in philosophy of mind and philosophy of artificial intelligence to explain that mind may be understood as information instanced in brain matter (Churchland and Sejnowski 1990). According to functionalism mind can be instanced in a physical support that is not necessarily the brain matter. Nevertheless, functionalism can be used to explain different natural phenomena. On the other hand, the existence of information as something that can be differentiated from the physical support has been the center of a deep debate. According to Searle (1994, 1997), functionalism is wrong because in nature cannot be found a system where the physical and the logical supports are differentiable. In this paper, we propose that it is possible to interpret the infection process of viruses as functionalist, because computations and a physical storing media for those computations can be differentiated. The infection process is even more coherent with the functionalism framework when it is observed that the information is stored and executed in different physical supports. The objective of this article is to show that molecular biology gives evidence to sustain that in nature there are some systems where information is differentiated from the physical support.

This paper has four parts. In the first part we explain the informational and physical differentiability sustained by functionalism. In the second part we expose how information is a main characteristic of genes and DNA in contemporary biology. In the third part we expose the replication process of viruses, know as infection, in which the separation of information from the physical support can be observed. We conclude that in order to refute the existence of information or computations in nature would be needed to refute some proven facts of molecular biology. Some of these facts will be described in the present article.

Accepting that DNA is an organic medium where information and algorithms are stored could be enough evidence to justify a functionalist distinction between information and physical support in nature. Nevertheless, we think that the way a virus infects a cell, releasing its genetic instructions to be executed in the cellular machinery, to finally take control of the cell, is a stronger evidence for the software/hardware distinction.

1. Functionalism, information and physical support.

According to functionalism, in a system it is possible differentiate the information¹ and the physical support (Nelson 1976:380); nevertheless, the information must be always physically stored and realized (Kim 1995:142; Horgan 1984:455). Functionalism is not a dualistic framework because each part of the system - informational and physical- cannot be self-realized; nevertheless, it is usually claimed that functionalism allows a confusion with dualism because the “*software/hardware* talk encourages the idea of a bipartite Nature” (Lycan 1987:38). In mind functionalism it is therefore claimed that that mind -as information- cannot be realized without the brain matter or any other physical support. When analyzing the mind/brain problem under the functionalism framework it is usually claimed that the brain must store and process an input to generate an output according to a particular physical state (Churchland and Sejnowski 1990). Functionalism allows a naturalistic conception of human beings and physical systems: “Under functionalism it is no more difficult to understand how humans, regarded naturalistically, can undergo mental states than it is to understand how the physical devices we call computers can undergo *computational* states” (Horgan 1984:462).

¹ The concept of information has been the center of a debate (Capurro and Hjørland 2003). In order to simplify the present argument, we will refer information as the instructions that specify transformations.

Functionalism does not specify a particular physical support needed to store and process a particular package of information (Block 1996), but it does specify that proportionality between both of the supports is required. According to Chalmers (1994), it is needed some proportionality between the causal possibilities of the physical support and the computations executed in that support. If mind is software that can be stored and realized in any physical support (Bechtel 1985; Churchland and Sejnowski 1990; Churchland 1999), it may be thought that even a beer-can system can instance mind. Nevertheless this is not the case; in fact, a beer-can is not a physical system capable of instancing all the states and transformations needed for realizing the mind software. Only some physical systems, as the brain matter and some silicon systems, among others, are capable of instancing the mind software; according to Bechtel: “[...] the nature of the hardware constrains what software can run” Bechtel (1985:160). A particular software could be instanced in different hardware, but *different* is not *any*. The informational support specifies physical transformations of the system, according to a given input and a particular state (Block 1981). It means that transforming the instructions will cause transformations in the physical support and, therefore, in the whole system (Block 1980).

When arguing against functionalism, it is usually claimed that there is no information but only physical support (Churchland 1999). Because only physical transformations can be perceived, it can be claimed that physical transformations are explainable only in physical terms. Nevertheless, it is impossible “to predict and control the behavior of the machine if we described it in only 'hardware' terms” (Rorty 1972:218).

According to Searle (1994, 1997), any physical system could be interpreted as executing computations because syntax is not intrinsic to physics. Computations and information cannot be intrinsic to a physical system because (i) syntax is relative to observers and (ii) all the characteristics of computations are merely syntactic (Moural 2003). According to Searle (1994), computation results from the observers' point of view. Any observer can interpret any pattern as computation by assigning this characteristic, but computations, algorithms or strings of information are not something that can be found in nature:

“The really deep problem is that syntax is essentially an observer-relative notion. The multiple realizability of computationally equivalent processes in different physical media is not just a sign that the processes are abstract, but that they are not intrinsic to the system at all [...] There is way you could discover that something is intrinsically a digital computer because the characterization of it as a digital computer is always relative to an observer who assigns a syntactical interpretation to the purely physical features of the system. [...] The characterization of a process as computational is a characterization of a physical system from outside; and the identification of the process as computational does not identify an intrinsic feature of the physics, it is essentially an observer-relative characterization [...]. By its own definition of computation and cognition, there is no way that computational cognitive science could ever be a natural science, because computation is not an intrinsic feature of the world. It is assigned relative to observers” (Searle, 1994:212).

2. DNA, Genes and information

There is a deep debate about the definition of genes (Lederman 1987; Kitcher 1982)²; nevertheless, in contemporary biology it is commonly referred the informational aspect of genes. In any contemporary biology textbook it is accepted that genes are patterns of information. It is also common to talk about genetic “information” and about the information contained or encoded in the DNA molecule (Waters 1994:174). Genes are instruction about how cells must be transformed into a body (Dawkins 1976), and these instructions are stored in the DNA molecule:

“There is a consensus in biology that a simple form of the "central dogma of protein synthesis" is correct. This form of the "central dogma" holds that information flow is from DNA (or RNA) to protein, and thus that DNA (or RNA) has a special informational priority” (Schaffner 1998:234).

² There is also a debate about the nature of the information that may be considered a gene. It has been said “that genes have little meaning (as "informational molecules") per se, only in context with other genes, and in an environment that is cellular, extracellular, and extraorganismic.” (Schaffner 1998:233). Oyama (1985) and Lewontin (1993) have also claimed that DNA sequences are information only in context. Nevertheless, as it will be shown in the present article, it is usually accepted that a gen is a piece or a unit of information, specifically, a unit of self-replicating information.

The informational aspect of genes is relevant for the “central dogma” of molecular biology because the expression of genetic information explains the connection between genotype and phenotype (Waters 1994:175). The informational capacity of DNA, as storing genes that are patterns of information, has even allowed talking about the computability capacities of DNA (Bhalla et al. 2003). In different researches it has been referred the interpretation of nucleic acids as expressions that can be considered and even defined as algorithms (Dirks et al. 2004). Electronic and robotic researches have showed the storing and electronic capacities of DNA (Winfrey 2003a). It has been said, for example, that the storing capacities of DNA could help surpassing the economic and storing limitations of quantic computation (Bhalla et al. 2003: 442). In the same sense, Adleman (1998) has proposed a similarity between polymerase and the Turing machine (Turing 1950).

At the present, algorithms and information are considered as important aspects of biology:

“Information and algorithms appear to be central to biological organization and processes, from the storage and reproduction of genetic information to the control of developmental processes to the sophisticated computations performed by the nervous system. Much as human technology uses electronic microprocessors to control electro-mechanical devices, biological organisms use biochemical circuits to control molecular and chemical events.” (Winfrey 2003a).

If it is accepted that genes are pieces of information, it must be also accepted that it is not important to specify a particular physical support where those pieces are stored:

“The gene is a package of information not an object. The pattern of base pairs in DNA molecule specifies the gene. But the DNA molecule is the medium; it’s not the message. Maintaining this distinction between the medium and the message is absolutely indispensable to clarity of thought about evolution [...]. The constant process of transferring information from the physical medium to another and then being able to recover that same information in the original medium brings home the reparability of information and matter. In biology, when you’re talking about things like genes and genotypes and gene pools, you’re talking about information, not physical objective reality. They are patterns.” (Williams 1996:42).

The same informational interpretation has been sustained for experiments that show how biomolecular processes can be programmed to carry logical algorithms (Winfrey and Bekvolato 2003).

3. The virus as a floating piece of information

A virus “[...] possesses a relatively simple structure” (Leigh-Brown and Holmes 1994) composed by a protein envelope called *capsid* that locks a core with genetic material (Hutchinson 2001). The viral genetic material, which may be a single or double DNA or RNA strand (Nahmias and Reaney 1977), consists of instructions to achieve self-replication (Hutchinson 2001). The viral genetic material also allows the virus to evolve in order to generate mutant copies “with enhanced survival and/or replication abilities” (Hutchinson 2001:89)³ in “varying frequencies” (Nahmias and Reaney, 1977:31). Viruses are characterized by a basic genetic organization (Nahmias and Reaney 1977:43).

Altering the own viral genetic information is interpreted as an evolutionary process (Bull and Wichman 2001). Some viruses, like HIV, present higher genetic diversity levels (Hutchinson 2001; Vartanian et al. 1992) and higher evolutive rates (Bull and Wichman 2001:188) than other viruses. Three main genes that encode the proteins and enzymes needed to complete the replication cycle of the retroviruses have been found: *gag*, *pol* and *env* (Dimmock and Primrose 1987; Stine 2000; Greene 1993; Fauci 1988; Leigh-Brown and Holmes 1994). Proteins around the capsid allow the virus to adhere to the cell in order to release the genetic information into it. We are simplifying the description of this process, because what matters for our argumentation is the release of genetic information from the virus to the cell.

The size of a virus oscillates around the 100 nm. It means that a virus is smaller than a mitochondrion, which is cellular organelle. The amount of information carried by a single viroid can be calculated:

“The simplest viroid contains only 240 bits of information, near ten million times less than the information contained in the human genome (three trillions of bits). These 240 bits are arranged in a circular chromosome (the equivalent one of the medium of the storage of the computer) and contains a set of signals that allow the molecule to duplicate itself” (Levine 1991:2).

³ For example, inside the HIV’s core, the genetic material is composed by two strands of RNA with about 9200 nucleotide bases (Greene 1993, Stine 2000, Fauci 1988).

Viruses are *acellular* and do not have organelles. It means that viruses do not have a reproductive system. A virioid only carries genetic information, which allows interpreting it as a piece of algorithms protected by a capsid. These algorithms always need a specific hardware in order to be executed and to be replicated, which is a characteristic of genes and DNA molecule: the eternal self-replication (Dawkins 1976:23). The reproduction of viruses implies the replication of the carried viral genetic information (Kay 1986). Because a virus only carries genetic information and isn't composed by any organelle, a virioid is defined as piece of self-replicating information (Nahmias and Reaney 1977); a virus is a piece of self-replicating information floating through the environment.

4. Releasing information into the cell

The fact that a virioid is morphologically simple and the fact that it does not have a reproductive system, have an important implication: The virioid needs some kind of machinery to accomplish the replication process. The virus itself has a physical support for storing information but this physical support is not physically capable of executing the information that carries. The host cell machinery is the physical support needed for executing the viral genetic information. Because the virus is carrying only genetic information, and because genes are self-replicating information, then viruses are always replicating themselves by using the cell machinery needed to accomplish this process.

Once inside the cell, the gene "*Nef* may modify the cell to make it able to manufacture HIV virioids later" (Hutchinson 2001:89). This modification process consists in integrating the viral genetic material to the cellular genetic material (Nahmias & Reaney 1977). It means that the genetic instructions carried by the virus are combined with the genetic instructions originally located inside the cell. The genetic information contained in the host cell's nucleus specifies the functions of that cell. This information is altered when it is combined with the viral genetic information: "The double-stranded retroviral HIV DNA moves into the nucleus, where it inserts into the host DNA and becomes a provirus. Infection of the cell is then permanent" (Hutchinson 2001:88). In the vertical parent-to-progeny transmission, especially in asexual forms, it is also observed that the viral genome is integrated into the "host cell chromosomal DNA" (Nahmias & Reaney 1977:35).

When the instructions originally located in the host cell are altered, the new version of the instructions - the one containing viral and original genetic information- is executed by the cell machinery to produce and pack copies of the original virioid (Leigh-Brown and Holmes 1994), creating new viral units: “The DNA copy of the virus is then integrated into the host genome where it resides as a provirus and is replicated, along with the host genome, by the cellular enzymes DNA polymerase I and RNA polymerase II.” (Leigh-Brown and Holmes 1994:129).

When the viral genetic information is released into the cell, the host cell machinery is used for two main events: (i) the synthesis of new proteins that will be expressed sequentially and (ii) the replication or duplication of its nucleic acid with the purpose of producing a new lineage: “In the second phase unspliced RNA transcripts become new viral strands (genome RNA or structural genes) and migrate out of the nucleus into the cytoplasm” (Hutchinson 2001:88). Each new virioid then leaves the infected cell and continue with the same process in a new and healthy cell.

Once combined with the host cell genetic information, the viral genetic information - which is the virus itself in that moment - is able to execute the instructions immediately or remain dormant. When a virus remains dormant inside a host cell, the viral genes are extinguished, except those associated for transcribing to latency; “The provirus can remain dormant for a long time. Its genes cannot be expressed until RNA copies are made by the host cell's transcription machinery” (Hutchinson 2001:88). Three phases for the cycle latency-reactivation are observed: (i) establishment, (ii) maintenance and (iii) reactivation. The dormant state can be maintained for the whole life of the host cell. Changes in proteins or hormones that control the immune system may reactivate the replication cycle (Dimmock and Primrose 1987; Fauci 1988; Greene 1992).

5. Conclusion

When the virus releases its genetic information to be executed in the cellular machinery, the basic functionalist distinction between the physical and the logical support is evident: the virus dismisses the physical support where the viral genetic information was originally carried and then releases and executes the genetic information inside the host cell machinery in order to achieve the self-replication process. It means that in nature it is possible to find a phenomenon where information is separated from its original storing media, executed in a new physical support and then self-replicated.

The existence of a natural system where the physical and the logical support can be distinguished is sustained by the following syllogism: (i) (ii) genes are self-replicating information or self-replicating algorithms, and not physical objects; (ii) viruses only carry genes; ergo, (iii) a virus only carries self-replication instructions. This syllogism is supported by experiments and theoretical work in fields like molecular biology and computational analysis. In those fields algorithmic order in the base pairs of nucleic acid is considered as patterns of information; altering those patterns modify the physical transformation of the system.

It may be thought that Searle (1994) does not recognize the importance of patterns of information – genes- in biological transformations, specifically, in the biological and physical transformations that allow the existence of species. If Searle, among others, wants to sustain that computations and syntax cannot be found in nature, he must deny that genes are information and instructions for replicating life. Searle would also have to deny that when genes are executed a self-replication process is accomplished and that changing the syntax of the original information modifies the specified physical transformations. Searle would have to assure that genes are nothing but physical objects without any kind of information that can be distinguished from the physical support where they are stored or executed. It does not seem like an easy work to prove that information does not exist in nature since current biological observations prove that once inside the cell, genes are nothing but instructions being executed in order to produce new copies of the initial virioid.

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