

Article

Pragmatic Information as a Unifying Biological Concept

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Abstract: This paper aims to introduce a developed reading of Roederer’s interpretation of pragmatic information as a good candidate for a Unifying Information Concept required for an as-yet-unavailable Science of Information. According to pragmatic information, information and information processing are exclusive attributes of biological systems related to the very definition of life. I will apply the notion to give new accounts in the following areas: (1) quantum interpretation: based on a modified version of David Bohm’s interpretation of quantum mechanics, I propose an ontological, information-based interpretation of quantum mechanics which, unlike Roederer’s interpretation, satisfies all conditions of pragmatic information; (2) artificial intelligence: the notion successfully distinguishes natural living systems from artifacts and natural non-living systems, providing a context to pose an information-based argument against the thesis of Strong Artificial Intelligence; (3) phenomenal consciousness: I will use pragmatic information to modify and update Chalmers’s Double-aspect Theory of Information to be explanatorily more powerful regarding the physical aspect of his theory; (4) causation: based on pragmatic information, I pose a new account of causation which differentiates causation in biology from causation in natural abiotic world.

Keywords: pragmatic information; biological systems; quantum interpretation; artificial intelligence; phenomenal consciousness; biological causation

1. Introduction

Currently, a Science of Information does not exist. A science of information aims to unify the multiplicity of ever increasing human knowledge by constructing new theories that include the old theories as a type of approximation in such a way that the new theories explain and predict phenomena

that were not covered by the old theories. A science of information is ideally expected to leave no explanatory gap as we continuously move down from phenomena in a society to the bizarre phenomena witnessed in the quantum domain. In other words, a science of information is expected to be universally applicable to all sciences.

Initial steps toward a single and comprehensive science of information were taken by James R. Beniger [1] and Klaus Haefner [2,3]. The interest in constructing a science of information as a transdisciplinary field of research continued to grow and was reflected in works such as J. K. De Vree [4], Tom Stonier [5–7], Klaus Fuchs-Kittowski [8], Søren Brier [9], Mark Burgin [10] and Wolfgang Hofkirchner [11], to cite but a few.

The core of a science of information is a Unified Theory of Information the core of which, in turn, is a Unifying Information Concept. Success of such a science is highly dependent on the success of its underlying information concept/theory. Thus, it should come as no surprise that attempts to construct a science of information start with a quest for a unifying information concept with similar comprehensive, universal features. A unifying information concept must include other information concepts as its special case and allow for better explanations and predictions. Like a science of information, it must be applicable to all sciences.

In this paper, I argue that a developed reading of pragmatic information can be a good candidate for a unifying information concept. To show that, I choose some of the most challenging issues in science and philosophy trying to approach and explain them in a consistent, coherent and new way.

In Section 2, mostly through his own words and terminology, I review the key elements of Juan G. Roederer's [12–14] reading of pragmatic information according to which all information processing systems involve living matter at one stage or another.

Roederer holds that pragmatic information is a macroscopic concept not applicable to quantum domain. In Section 3, I show that a modified version of David Bohm's ontological interpretation of quantum mechanics can be introduced as an alternative to Roederer's epistemological interpretation of quantum mechanics. Such interpretation satisfies all conditions of pragmatic information. According to this interpretation, I claim, the counterintuitive aspects of quantum mechanics represent the non-algorithmic minds of the purposeful, biological setup providers. In this way, the active role of pragmatic information is acknowledged both in quantum and macroscopic domains.

Pragmatic information conceptually and theoretically distinguishes between natural living and natural non-living systems on the one hand and natural living and artificial intelligence systems on the other. In Section 4, I will use this characteristic to raise a new information-based argument against the thesis of Strong Artificial Intelligence according to which the brain is a digital computer and the mind is its program or set of programs.

In Section 5, I claim that substituting pragmatic information for the syntactic notion of information that David Chalmers [15] uses in his “double-aspect theory of information” as a psychophysical law which specifies the dependence of phenomenal to physical properties makes the theory explanatorily richer and more powerful as far as the physically realized information in the nervous system is concerned. I proceed with several cognitive processes and states hypothetically explained by the notion of pragmatic information showing that such explanations are confirmed by recent experimental data.

Finally, in Section 6, I argue that causation in physics should be distinguished from causation in biology showing that pragmatic information corresponds to the latter.

The issues discussed above are among the most controversial issues in science and philosophy. In this *introductory* paper I try to *address* these issues consistently and coherently through applying the notion of pragmatic information as a good candidate for a unifying information concept applicable to all sciences. The paper *only* aims to *explore* new avenues to approach those issues in science and philosophy over which there is no consensus among scholars yet. It does not claim to have provided any ultimate solutions to such issues.

2. Pragmatic Information

In this section, I briefly restate Roederer's [12–14] reading of pragmatic information. In this reading, the notion of “interaction” is projected as a basic, primordial concept. Two fundamentally different classes of interactions between the bodies which fabricate our Universe are introduced with the notions of “information” and “information processing” as the key discriminators between the two. These two mutually exclusive kinds of interactions are Force-driven (or Physical) Interactions and Information-driven (or Information-based) Interactions. Roederer concludes that any information processing system must necessarily involve living matter at one stage or another.

2.1. Force-Driven Interactions

In the classical non-relativistic domain, according to the Hamiltonian mechanics, once we have known the initial conditions of a classical closed system consisting of N mutually interacting material points, *i.e.*, the coordinates q_k^0 of the bodies and the associated momenta p_k^0 at the initial time t_0 , we can in principle calculate the system's coordinates q_k^t and momenta p_k^t at any later time t . Such a system would be in principle reversible as long as the forces between the interacting bodies are conservative. There is no preferred direction of time in such a system meaning that the relationships between the points are *inter*-actions rather than cause-and-effect. In principle, such a system can always be considered a linear superposition of basic interactions between the component parts.

The most important classes of interactions in the above domain are gravitational, electromagnetic and elastic interactions. Gravitational force acts between all material bodies. Electromagnetic interactions are at work between charged or magnetized bodies as well as some kinds of elementary particles. Notice that frictional, chemical and thermal interactions in the macroscopic realm are all reducible to the electromagnetic interactions at the atomic and molecular level. There are also elastic interactions which occur where bodies interact with the mediation of, say, a special physical device or intervention of any other medium.

The above interactions would remain genuine *inter*-actions as long as the interacting bodies are isolated from the rest of the Universe and the force acting between the interacting bodies is conservative. “Such interactions are bidirectional in the sense that neither of the two interacting bodies has a hierarchical ranking over the other. There is no “cause-and-effect” relationship as long as there is no external interference: no irreversibility or asymmetry, and no privileged direction of time” [13] (p. 98).

At the subatomic level, all interactions are reducible to four kinds: gravitational, electromagnetic, strong and weak interactions. What was said about the gravitational and electromagnetic interactions in the macroscopic domain also holds true for the quantum domain. Such interactions in the microscopic realm are bidirectional and reversible with no privileged direction of time as long as they occur in a

closed system in which the force is conservative. This is also true for interactions occurring as the result of strong forces. Strong interactions in the quantum world are bidirectional and in principle reversible. However, weak interactions are unidirectional and irreversible. Weak interactions, however, happen more rarely compared to the other kinds of interactions.

This section, then, can be summarized by saying that in the non-relativistic macroscopic domain, interactions in a closed system consisting of mass points in which the force is conservative can always be reduced to a superposition of physical interactions (*i.e.*, forces) between the system's elementary constituents. In such a system, there is no privileged direction of time which makes the system be bidirectional, symmetric and reversible in principle. The relationship between the interacting bodies in such a system does not count as a genuine cause-and-effect as long as there is no external interference. The system would tend to become irreversible under the effect of some *external forces*. Irreversibility in this context means that reversing all the velocities at the time t would no longer result in reaching the same corresponding initial state at time t_0 with reversed initial velocities. The system under the effects of external forces, then, becomes reversible only if all external interactions follow exactly the same reverse pattern. This requires total information and control of the external parts since any external perturbation, even very weak, would make a system of interacting bodies irreversible.

All this leads to the important features characteristic of all force-driven interactions: “The end effect of a force-driven interaction will always depend on some “initial conditions,” such as the initial configuration (positions, velocities) of the interacting bodies. A most fundamental characteristic is the fact that during the interaction, there is a direct transfer of energy from one body to the other, or to and from the *interaction mechanism* itself (in case of fundamental interactions force field; in more complex cases, some process linking the two bodies)” [12] (p. 6).

Two instances of such interactions are a moon of a planet orbiting around it and an electrically charged particle passing by a fixed (e.g., massive) body, See [13] (p. 114) for more illustrative examples. Under similar conditions, what was said about the macroscopic world also holds true for the interactions in the microscopic domain except for the weak interactions.

In systems consisting of force-driven interactions the notion of information can be (and mainly is) treated quantitatively with respect to its amount, transmission and storage by humans.

A clearer understanding of force-driven interactions is possible when the notion is put in contrast with information-driven interactions depicted in the next subsection.

2.2. Information-Driven Interactions

The key difference between information-driven interactions and force-driven interactions is that the former *are not* reducible to a superposition of the basic interactions between the constituent parts whereas the latter are. In such interactions the presence of a specific *pattern*, as the sender or source, in a complex system triggers a causal, macroscopic *univocal change* in another complex system, as the receiver, in such a way that such a change in the recipient would not occur in the absence of the sender or just occur by chance. “Univocal” here means that repeating the interaction process under similar conditions must yield identical results. Therefore, information would be processed where a one-to-one correspondence is established between a specific pattern of the sender and a change in the recipient in

a repeatable manner. In other words, information is defined as that which represents the univocal pattern-change correspondence. Küppers [16] calls this *pragmatic information*.

An important characteristic of information-driven interactions is that, contrary to force-driven interactions, in such interactions the sender and the recipient are decoupled energywise meaning that the energy needed to effect the changes in the recipient must come from some external source; this energy is not provided by the sender itself. This is why all information-based systems are *open* systems.

In information-driven interactions the interaction process must be able to occur repeatedly in consistent manner. This requires the intervening mechanisms of the interaction and changes in the recipient to have the capability of being *reset* to the same initial state each time the system is run. This would in turn require the system to possess some sort of memory to, firstly, ensure the pattern-change correspondence and, secondly, guarantee the repeatability of the interaction process. In other words, the univocal pattern-change correspondence is ensured once a common code is established between the sender and the recipient. If such a common code is not built and the pattern makes the expected change based on the pure chance, then the interaction does not count as information-based.

The complex interaction mechanisms (*i.e.*, the intervening processes) of information-driven interactions can only *emerge* through three fundamental processes: “(1) Darwinian evolution; (2) adaptation or neural learning; (3) as the result of human reasoning and long-term planning” [14] (p. 3). As is seen, at one stage or another all above processes involve highly organized *living matter*. In other words, information-driven interactions represent the defining property of life.

The third mechanism above is exclusively human representing the ultimate source of all artifacts verifying the fact that any information-driven interaction between non-living “complex systems must ultimately be either life-generated or -designed” [*ibid.*]. Therefore, for example, whereas “an electromagnetic or sound wave emitted by a meteorological lightening discharge does not represent any information-driven interaction ..., waves emitted by an electric discharge in the laboratory may be part of an overall artificial information-driven interaction mechanism if they are the result of an action with the purpose of causing a desired change somewhere else” [14] (p. 3).

To recapitulate: information-driven interactions occur only in the realm of living systems or artifacts although, as we will see, there is a substantial difference between these two categories. Only in these two realms information would play an *active* role or as a controlling agent. The synthesis of proteins in a living cell is an instance of the information-driven interactions in the living systems. By being transferred to RNA molecules, DNA molecule as the pattern (sender) makes a univocal change which is the synthesis of specific proteins. A ship on automatic pilot guided by radar waves is an instance of information-driven interactions in artifacts. The pattern of the radar waves makes the univocal change in the movement of the ship. Note that in both examples the energy of the change is provided locally not by the pattern itself.

3. Toward an Information-Based Interpretation of Quantum Mechanics

In this section I argue that: (1) Roederer’s information-theoretic approach to quantum mechanics, restated in Section 3.1 mainly based on his 2012 paper [14], is an epistemological one, similar to the Copenhagen interpretation [17] and (2) Once we adopt an ontological approach, like the Bohmian interpretation, we may reach different consequences other than what Roederer has reached. Finally,

I will show that a modified version of Bohmian interpretation of quantum mechanics allows pragmatic information to apply to the realm of quantum mechanics.

3.1. Pragmatic Information: An Epistemological Approach

According to Roederer, our brains are eminently classical information processing systems evolved and continuously trained on the basis of their informational interactions with the classical macroscopic world. This has important consequences as to the way we treat force-driven interactions in macroscopic domain and quantum systems [13]. As regards the former, the concept of information plays a passive role. That is, in purely force-driven interactions, “information” does not appear as an active, controlling agent. It appears only when an observer intervenes by, firstly, *describing* or, secondly, *manipulating* systems in nature which exclusively include force-driven interactions. The way we associate the notion of “entropy” with the notion of “information” in thermodynamics is an instance of the former. By using the term “information”, then, we mean “information *for us*, the observers” [14] (p. 3). Roederer holds that all quantitative treatments of the notion of information such as Shannon information, algorithmic information, Fisher information, *etc.* refer to the passive role of information, that is, *our* interaction, as active information-processing systems, with purely physical systems to model them mathematically and quantitatively. Pragmatic information itself cannot be measured numerically in principle. By definition, pragmatic information is characterized by what it *does*.

In addition, by setting the initial conditions of a classical mechanical system or preparing a quantum system, we would convert it into an information-driven system with a given purpose. This category includes all laboratory experiments including quantum experiments [14] (p. 3).

How can all this describe the way we imagine, describe and understand the behavior of quantum systems from an information-theoretic point of view according to Roederer? Let us focus on his account of the measurement of a single qubit prepared in a superposed state $\alpha|0\rangle + \beta|1\rangle$ (with $|\alpha|^2 + |\beta|^2 = 1$). We assume that the “quantum end” of the measurement apparatus gets entangled non-destructively with the qubit and the “classical end” of it exhibits a macroscopic change after measurement has taken place. Adopting von Neumann’s formal measurement scheme, for the composite state qubit-apparatus we will have the following evolution in time:

$$(\alpha|0\rangle + \beta|1\rangle) |M\rangle \rightarrow \alpha|0\rangle|M_0\rangle + \beta|1\rangle|M_1\rangle \quad (1)$$

where $|M\rangle$ stands for the initial state of the apparatus, $|M_0\rangle$ and $|M_1\rangle$ for the two possible alternative states of the apparatus after the measurement. Note that (1) refers to the time evolution of qubit-apparatus state with the apparatus deliberately designed so that when the qubit to be measured is in a basis state $|0\rangle$ before its interaction with the apparatus, the final independent state of the instrument after the measurement will be $|M_0\rangle$, and if the state of qubit is $|1\rangle$, the instrument will end up in state $|M_1\rangle$. The end state of the composite system will always be either $|0\rangle|M_0\rangle$ (with $|\alpha|^2$ as the probability of being obtained) or $|1\rangle|M_1\rangle$ (with $|\beta|^2$ as the probability of being obtained).

Does such a measurement represent pragmatic information? Roederer’s answer to this question is “no”. There is no *univocal correspondence* between the properties (parameters) of such a quantum system and any observable macroscopic property obtained after the process of measurement meaning

that “no information can be extracted experimentally on the superposed state of a single qubit” [14] (p. 6). The above correspondence will be established *only* for the eigenstates of the relevant observable.

In Roederer’s eyes, pragmatic information is a macroscopic concept; so is time. A quantum system can be assigned time marks only when it interacts *locally* with a *macroscopic system*. In the case of the notion of a wave function, $\Psi(x, t)$, “the time variable refers to the time, measured by a macroscopic clock *external* to the quantum system, at which $|\Psi|^2$ is the probability density of actually observing the quantum system at the position x in configuration space, which is also based on measurements with macroscopic instruments” [14] (p. 8). According to Roederer, quantum systems appear to behave counterintuitively, then, when we *force* the classical concepts of information and time into quantum domain which results in considering quantum systems and their interactions to violate relativity, causality and locality. The Schrödinger equation for a single quantum system, according to this interpretation, should be viewed as encoding the evolution of the quantum system’s potential macroscopic effects on the environment or a measuring apparatus rather than the time-history of intrinsic properties attributed to the quantum system *per se* [14] (p. 15).

Having said that pragmatic information is a macroscopic concept and it is not possible to extract information on the superposed state of a single qubit experimentally, then, according to Roederer, any interpretation of quantum mechanics would also be of pedagogical nature not just philosophical.

Clearly, the above approach to quantum mechanics is primarily an epistemological one, similar to the Copenhagen interpretation: it is directed towards the question of how *we* can obtain knowledge as well as the question of what *we* can do with such knowledge.

Here, the way Roederer thinks of quantum concepts is in line with Heisenberg’s generalization of Bohr’s correspondence principle: “In its most general version, Bohr’s correspondence principle states a qualitative analogy (which can be carried out in detail) between the quantum theory and the classical theory belonging to the respective picture employed. This analogy does not only serve as a guide for finding formal laws, rather, its special value is that it furnishes at the same time the physical interpretation of the laws that are found” [18] (p. 78), Translated from German by Brigitte Flakenburg [19] (p. 190). As is seen, the generalized correspondence principle has a qualitative aspect with a semantic function of providing the formalized abstract quantum theory with physical interpretation. In other words, the principle is supposed to fill a quantum concept with classical physical meaning. Maleeh [20,21] shows that despite the later failure of Bohr’s correspondence principle with regard to the quantum phenomena which did not have any classical counterparts, still both Bohr and Heisenberg continued to think of a *generalized version* of the principle as a methodological and heuristic principle for *practical purposes*.

According to Bohr, attributing any property to any quantum object (quantum system), before, during, or after measurement is precluded. What would be describable and publicly communicable in terms of classical concepts, then, are “*phenomena*”, that is, the effects of the interactions between quantum objects and measuring instruments which classically manifest in measuring instruments [22] (p. 168). The classical concepts, such as “the concepts of distance and time interval between different superposed or entangled components *are undefined* as long as they remain unobserved, *i.e.*, free of interactions with macroscopic systems [14] (p. 8)”.

The concept of phenomena is the culmination of Bohr’s argument on “the *impossibility of any sharp separation between the behavior of atomic objects and the interaction with the measuring instruments which serve to define the conditions under which the phenomena appear*” [23] (pp. 39–40). By using this

concept, Bohr emphasizes “the necessity of considering the whole experimental arrangement, the specification of which is imperative for any well-defined application of the quantum mechanical formalism” [23] (p. 57). The notion, then, encompasses the idea of the wholeness (indivisibility) of the quantum object and the instrument. Such attitudes of the Copenhagen school of thought towards quantum systems are in line with Roederer’s claim that “quantum systems, while left alone, follow the proverbial policy of don’t ask, don’t tell!” [13] (p. 49).

Finally, the role Roederer assigns to the mathematical formalism of quantum mechanics is on the basis of Bohr’s approach to the quantum mechanical formalism: “The entire formalism is to be considered as a tool for deriving predictions of definite or statistical character, as regards information obtainable under experimental conditions described in classical terms and specified by means of parameters entering into the algebraic or differential equations of which the matrices or the wave-functions, respectively, are solutions. These symbols themselves, as is indicated already by the use of imaginary numbers, are not susceptible to pictorial interpretation; and even derived real functions like densities and currents are only to be regarded as expressing the probabilities for the occurrence of individual events observable under well-defined experimental conditions” [24] (p. 144).

To summarize, adopting the orthodox quantum theory and the associated (the Copenhagen) interpretation, as we saw, leads Roederer’s notion of pragmatic information not to be applicable to the quantum domain (except for the eigenstates of an observable).

In the quantum realm, it is normal to consistently reach the consequences that Roederer reached once one takes an approach which emphasizes what information *does on the basis of how we obtain and use our knowledge*. However, once we adopt, say, the Bohmian mechanics and the associated interpretation which is based on an ontological attitude, we may reach completely different consequences. This becomes apparent when we survey different interpretations of, say, the study conducted by Kocsis *et al.* [25] (selected the top breakthrough in physics in 2011 by *Physics World*). They reported the experimental observation of the “averaged trajectories of single photons” in a double-slit experiment. They used the so-called “weak measurement” method, first introduced by Yakir Aharonov, David Albert and Lev Vaidman [26], and managed to measure the Bohmian trajectories [27] of single photons as they undergo two-slit interference. According to Roederer [14] (p. 8), this “provides the geometric visualization of something on which, for an individual particle, pragmatic information could never be obtained”. The latter consequence arises from an epistemological approach to the results of the above paper. The adherent of Bohmian mechanics, however, will take the results of the above paper as confirming Bohmian ontological interpretation of quantum mechanics according to which at the quantum level, information plays an active role, as we will see in what follows.

3.2. Pragmatic Information: An Ontological Approach

Bohmian mechanics reproduces all predictions of the orthodox quantum mechanics but introduces a radically different perception of the underlying processes. As opposed to the orthodox quantum mechanics in which a physical system is described by the wave-function (Ψ), the description of the physical system in the Bohmian theory necessitates the couple of wave-function and configuration, *i.e.*, the position of corresponding quantum objects [27,28]. The wave-function in Bohmian theory satisfies Schrödinger equation.

In this theory, the particle velocities are given by the so-called “guidance equation” which equips the particles with a dynamic that depends on the wave-function. Metaphorically, this means that the quantum particles are guided by the Ψ -field. Particles in this theory possess well-defined positions at every instant and are moving on continuous trajectories.

In Bohmian mechanics, the wave-function describes the position-distribution, ρ , of an ensemble of systems through $\rho = |\Psi|^2$. This postulate is called “quantum equilibrium hypothesis” and is needed to reproduce all predictions of the orthodox quantum mechanics. The postulate also ensures that the Bohmian theory does not allow for an experimental violation of Heisenberg’s uncertainty principle [29,30].

Determinism, complementarity dispensability, non-locality and attribution of no special role to measurements are the most important characteristic features associated with the Bohmian theory which comprise the Bohmian interpretation of quantum mechanics [31].

The Bohmian theory is deterministic since at any given time, the time evolution of the system is fixed uniquely by the wave-function and the configuration of the quantum system. However, this does not contribute more predictive power to the theory compared to the ordinary quantum mechanics. Like ordinary quantum mechanics, all predictions of the theory remain probabilistic. However, in contrast to the orthodox quantum mechanics, this randomness arises from averaging over ignorance. Note that determinism is not the key element of the theory. For instance, Bohm and Vigier [32] developed a model containing a stochastic background. Indeed, what initiated Bohmian interpretation as an alternative to the Copenhagen interpretation was not its indeterminism, but rather the vague way that the orthodox formulation explains the measurement process. Recall what was said as to Roederer’s account of the measurement of a single qubit prepared in a superposed state. According to him, the Copenhagen interpretation, the original qubit *emerges* from the measurement process called state reduction [14] (p. 6). Here, the term “emergence” epistemologically refers to the impossibility of the explanation of the phenomena appeared as the result of measurement process. This is also in line with the Copenhagen interpretation of quantum mechanics. As we will see, adopting an ontological approach, as opposed to the Copenhagen interpretation, the Bohmian interpretation does not encounter such an epistemological problem [33] and [34] (p. 1).

Within the Bohmian theory, matter is described by the wave-like quantity (the wave-function) and the particle-like quantity (the position). Indeed, the Bohmian interpretation holds that explaining many quantum phenomena, such as the appearance of the interference pattern in the double-slit experiment, requires both the wave and the particle aspect of the quantum particle. Therefore, according to the Bohmian interpretation, Bohr’s notion of complementarity is dispensable.

Non-locality in the Bohmian theory means that the motion of every particle is simultaneously linked to the position of the other particles by the guidance equation of an N -particle system.

Bohm also introduces the notion of “quantum potential” according to which the motion of particles along the Bohmian trajectories takes place under the action of a novel “quantum force”. In the double-slit experiment, for example, every quantum particle, affected by the quantum potential, follows a particular pass, going through one of the slits leaving an individual spot on the photographic plate. The spots collectively form a fringe-like pattern [33]. This way construed, in the Bohmian theory, as opposed to the Copenhagen interpretation, the act of measurement would deserve no special role.

Clearly, contrary to the Copenhagen interpretation that prohibits attribution of any property to the quantum objects and counts any description of their behavior as meaningless, the Bohmian interpretation

gives a full ontological account of quantum systems before measurement has taken place. Such a fundamental difference can be seen from another perspective: whereas the Copenhagen interpretation holds an instrumentalist approach towards the mathematical formalism of quantum mechanics, as discussed earlier, in Bohmian interpretation, Bohm's formulation of quantum mechanics refers to what actually happens in the quantum world before measurement has taken place. In other words, Bohmian interpretation *does* make claims about elements of physical reality.

More importantly, the interaction between the quantum potential and the corresponding particles meets all requirements of information-driven interactions stated earlier. This is the result of the novel features of the Bohmian quantum potential; whereas in classical (Newtonian) physics the effect of the classical potential on a classical particle is always proportional to the intensity of the field, in the deterministic version of Bohmian mechanics, the quantum potential depends only on the form, and not on the intensity of the quantum field. This is the form (or pattern) of the field, not its energy, that deterministically guides the quantum particle. In other words, “the information in the quantum potential is *potentially* active everywhere, but *actually* active only where this information enters into the activity of the [corresponding] particle” [33]. Where the “form” is active, Bohm calls it “active information”. There is a one-to-one correspondence between the quantum potential (as the pattern) and the change in the corresponding particle where the energy of the change is not provided by the pattern. Such correspondence represents pragmatic information.

However, it should be noted that information-driven interactions in the quantum level cannot be reduced to Newtonian mechanics; for example, such interactions violate Newton's third law of motion: in spite of the action of the quantum field on the particles, they remain passive and do not exert reciprocal reaction as envisaged by the third law. Quantum potential also affects the particles non-locally which is prohibited in the macroscopic level.

As stated, the quantum potential-particle correspondence in Bohmian mechanics has an important aspect as to the way it solves the so-called measurement problem regarding the collapse of the wave function. Bohmian mechanics does not encounter the explanatory problems associated with the standard presentations of quantum mechanics such as von Neuman's proposal of the collapse of the wave function which develops a non-linear model for the collapse mechanism without specifying the physical conditions under which the linear evolution of the wave function fails.

Consider the time evolution of qubit-apparatus represented by relation (1) in Section 3.1. Suppose for example that the measurement yields the outcome “1”. According to Bohmian interpretation of quantum mechanics, in this case, the initial position of the Bohm particle was such that the deterministic evolution developed into a configuration that lies within the support of $|1\rangle|M_1\rangle$. The Bohm particle will be guided by this state because the non-overlapping $|0\rangle|M_0\rangle$ is dynamically irrelevant. Such account provided by the Bohmian theory is called “effective collapse” of the wave function. The quantum equilibrium hypothesis ensures that the probability for this effective collapse obeys Born's rule [31].

This section, then, can be summarized as follows:

- (1) An epistemological, inherently probabilistic interpretation of quantum mechanics, such as the Copenhagen interpretation, would generally prohibit a univocal correspondence between the properties of a quantum system prepared in a superposed state and some observable macroscopic property. At the epistemological level, this means that no information can be extracted

experimentally from the superposed state of a single qubit. Pragmatic information does not operate in the latter quantum domain. Here, we are concerned with how we obtain our knowledge and possibly with what we can do with it. “Observation” plays a central role in such interpretations; what would be real, describable and publicly communicable in terms of classical concepts, then, are “*phenomena*”, that is, the effects of the interactions between quantum objects and measuring instruments which classically manifest in measuring instruments.

- (2) However, in a deterministic ontological interpretation of quantum mechanics, such as Bohmian interpretation, pragmatic information plays an active role; it *does* something: though it is impossible to confirm experimentally, the quantum potential actually guides its corresponding particles. In other words, there is a one-to-one wave-particle correspondence. In this interpretation, we are primarily concerned with ontology, *i.e.*, that which *is*. Of course the way we use the notion of pragmatic information within the two different types of interpretations is fundamentally different but this mere fact should not force us to prefer one approach (epistemological or ontological) to the other. Bohmian theory “is formulated basically in terms of what Bell [35] has called “beables” rather than of “observables”, where “Beable” is the term John Stewart Bell [36] devised to refer to those elements of a theory which are “to be taken seriously, as corresponding to something real” [35] (p. 234). These beables are assumed to have a reality that is independent of being observed or known in any other way. The observables therefore do not have a fundamental significance in our theory but rather are treated as statistical functions of the beables that are involved in what is currently called a measurement” [34] (p. 41).
- (3) Having the previous point in mind, the results of the experiments such as the one conducted by Kocsis *et al.* [25], followed by numerous subsequent papers confirming their work such as Menzel *et al.* [37], *can also* be interpreted as confirming Bohmian theory.
- (4) Regarding our concerns in this paper as to introducing pragmatic information as a suitable candidate for a unifying information concept, Bohmian mechanics can be a good alternative to the Copenhagen interpretation to adopt as it includes pragmatic information to operate at the quantum level as well. Note that like most alternative interpretations, Bohmian mechanics and the associated interpretation is not distinguishable from orthodox quantum mechanics and the Copenhagen interpretation by any *experimentum crucis*.

Although we introduced the Bohmian interpretation as a legitimate account of quantum mechanics, the way Bohm extends his idea of quantum potential to the whole universe as well as the relation between mind and body does not count as a legitimate generalization. In the next section, adopting an information-theoretic point of view, I will show where Bohm went wrong and in what respect his idea should be amended.

3.3. Bohmian Interpretation: A Pragmatic Approach

In his 1990 article, Bohm gives four examples of information-driven interactions in the macroscopic world, three in the realm of artifacts and one in the realm of living systems: “[C]onsider a ship on automatic pilot guided by radar waves. The ship is not pushed and pulled mechanically by these waves. Rather, the form of the waves is picked up, and with the aid of the whole system, this gives a corresponding shape and form to the movement of the ship under its own power. Similarly, the form

of radio waves as broadcast from a station can carry the form of music or speech. The energy of the sound that we hear comes from the relatively unformed energy in the power plug, but its form comes from the activity of the form of the radio wave; a similar process occurs with a computer which is guiding machinery. The “information” is in the program, but its activity gives shape and form to the movement of the machinery. Likewise, in a living cell, current theories say that the form of the DNA molecule acts to give shape and form to the synthesis of proteins (by being transferred to molecules of RNA)” [38] (p. 279).

Clearly, the above examples represent the active role of information (information-driven interactions) where in each of which the presence of a pattern (form) makes a univocal change in the corresponding component of the system and the energy of the change is not provided by the form, but by a third component.

Bohm’s proposal, then, is to extend the notion of active information to the quantum realm while emphasizing major differences between the notion of “fields” in the classical mechanics and in the quantum level.

Then, Bohm extends his idea of quantum potential to the whole Universe: “as the quantum potential constitutes active information that can give form to the movements of the particles, so there is a superquantum potential that can give form to the unfoldment and development of this first order quantum potential. ... Of course, there is no reason to stop here. One could go on to suppose a series of orders of superquantum potentials, with each order constituting information that gives form to the activity of the next lower order ...” [38] (p. 283).

As to the relationship between mind and body, Bohm qualifies “mind” as a certain level of the quantum potential which guides the whole Universe at different levels. By reaching such a certain level, mind will move and guide the body in a natural way (*ibid.*).

My claim is that the above view on mind stems from an illegitimate extension from what we witness in the realm of information-driven interactions to the realm of force-driven interactions. Bohm begins with some instances of information-driven interactions in artifacts (the ship on the automatic pilot, radio waves as received by radio, computers) and in living systems (synthesis of proteins in a living cell) and extends the idea to the quantum realm giving an information-based explanation of the interaction between the guiding field and the particles in the double-slit experiment. This is a legitimate generalization; despite having new features, such as non-locality, the nature of the field-particles system in the double-slit experiment is not different from other artifacts [39]. What makes interactions in the double-slit experiment be information-based is the involvement of a mindful, goal-directed living system that provides a specific setup for the experiment to fulfill a certain task in the laboratory. The presence of quantum potential in such an experiment simply represents the mind of the setup provider. The notion of quantum potential as a part of an information-driven interaction in such situation cannot be generalized to the natural non-living Universe since interactions occurring in the latter are purely physical and fundamentally different from information-based interactions.

Now suppose that just by chance an interaction occurs in the natural abiotic world which is exactly the same as what we witness in the laboratory with the double-slit experiment. Do we count it as an information-driven interaction? The answer is “no”. There are fundamental differences between interactions occurring in the double-slit experiment in the laboratory and a similar event happening by chance somewhere in the Universe. In the former, the setup has intentionally been ordered to establish

a correspondence between an input pattern (quantum potential) and a univocal change (e.g., movement of electrons along a predetermined trajectory). The energy of the change in such interaction must be provided from outside making the field-particles system an open system. Any purposeful change to the pattern (*i.e.*, any change to the guiding field made by the change in the setup we provide) would make a different corresponding change in the recipient (*i.e.*, change in the movement of electrons and consequently the fringe-like pattern). In the case of the event happening by chance, however, no purpose and information are included. There are just physical processes at work not informational. The following example may clarify the differences between information-based systems as the result of a goal-directed action of a living system and a similar interaction happening by chance.

Consider a book written in Chinese. Those who do not know Chinese would attribute meaning and information to the content of the book only if they know that someone purposefully has put Chinese words (as the common code among Chinese) together in order to make a certain change in the mental state of the reader. If they find out that the words are put together by chance, they would not attribute any meaning and information to the content of the book.

Thus, as regards information-driven interactions, two kinds of fundamental distinctions are in order: firstly, the distinction between information-driven interactions that occur as the result of a goal-directed action of a living system and similar interactions occurring in the natural non-living world just by chance and secondly, the distinction between information-driven interactions in living systems and artifacts.

Living systems are products of Darwinian evolution; they do not arise spontaneously; “[t]hey must *evolve*—in fact; Darwinian evolution itself embodies a gradual, species-specific information extraction from the environment. This is why *natural* information-driven interactions are all *biological* interactions” [13] (p. 116).

Artifacts, however, do not need to evolve. They are products of goal-directed living agents in order to fulfill a certain task. They represent the information that living systems purposefully put into them. Without original living systems they would not happen.

Other than interactions in the biological systems and artifacts, other interactions in the world are force driven, not involving any purpose and meaning, the notions which are the key requirements of the information-driven interactions.

Thus, any extension of interaction processes from living and artificial systems (both in the macroscopic and quantum level) to the natural abiotic world would not be legitimate. Therefore, Bohm’s generalization of the notion of quantum potential from what is witnessed in the laboratory to the whole Universe is not valid. Quantum potential guides particles since a purposeful living system has set up the initial conditions to establish a one-to-one correspondence between the field and the particles in the laboratory. In other words, contrary to Bohm’s claim, mind is not part of the more subtle quantum potential, but the quantum potential represents the mind without which there would be no information and information processing in the world.

The new interpretation I propose in this paper, then, would substitute a modified version of the Bohmian interpretation of quantum mechanics for the Copenhagen interpretation adopted by Roederer. In this way, contrary to Roederer’s ideas, there will be no gap as to the active role of information as we move down from living systems to the quantum phenomena observed in the laboratory. In such a thesis, the counter-intuitive puzzling non-classical aspects of quantum mechanics represent the complexity of the mind which some of its features are not reducible to classical physics. Quantum formalism in my

approach refers to something real, that is, to what is actually happening in the quantum domain within a preplanned framework of a laboratory experiment which itself represents the mind of its setup provider.

The fundamental distinction I made between the living systems and artifacts, as information-driven systems, has some other advantages; for example, it rejects “strong artificial intelligence” through a natural information-based argument.

4. An Information-Based Argument against Strong Artificial Intelligence

In this section, I argue that once we adopt an information-theoretic approach based on pragmatic information, we inevitably end up with the idea that: (1) the only genuine information-processing systems are biological systems; and (2) biological systems are fundamentally and conceptually different from artifacts. This idea will provide a ground for: (1) advocating the thesis of “weak artificial intelligence” (weak AI) as opposed to “strong artificial intelligence” (strong AI); and (2) modifying and updating Chalmers’s “double-aspect theory of information” which I will address in the next section.

As was stated, in information-based interactions, to ensure the one-to-one correspondence between the pattern and the change as well as the repeatability of the interaction, there must exist a common code between the sender and the recipient. This requires an established memory within the interaction mechanism of the system. In living systems, such a memory must evolve. Consider a large number of identical copies of a pattern-change system in nature with the following features: (1) all copies of the system have all specifications of the information-driven interactions, but just by chance; (2) there are some processes which introduce small random variations (errors) in the reset mechanism of the systems. Now only those systems which evolve in the right direction would survive while the less fit copies would disappear. Hypothetically, we say that the fitter copies which manage to develop a memory to ensure the univocal correspondence between the pattern and the change would become alive. Such systems are not run by chance anymore. They become alive when their interaction processes become information-based, *i.e.*, when the pattern-change correspondence becomes repeatable as a result of the memory evolved between the sender and the recipient.

Any artificial memory with the task of establishing a univocal pattern-change correspondence must be generated or designed either by a biological system (with a naturally evolved memory) or by another artificial system. The latter, again, must be generated or designed either by a biological system or an artifact and so forth. We will then encounter an infinite regression unless the chain ends up with a living system as the generator. Therefore, artificial memories responsible for information-driven interactions in artificial intelligence systems (as artifacts) just represent the intentionality and the purpose of the biological systems that designed them. Without goal-directed biological systems they would not occur. The common code established between the sender and the receiver in artificial intelligence systems reflects the intentionality of the biological code-writer. Artificial intelligence systems do nothing but to represent the information that their purposeful designers put into them. A map that contains information about how to get from, say, point A to point B representing cities, highways and the like contains the information derived from the original information of the map makers. Without the intentionality of the map makers and users, the map would just be a sheet of cellulose fibers with ink stains on it.

Therefore, I categorize information-driven interactions into two major groups: *original* information-driven interactions which occur *only* in living systems and *derived* information-driven interactions which occur in artifacts. Systems falling under the latter group do not count as genuine information processing systems; they just represent the intentionality of their biological makers as original information-based systems. The only genuine information-processing systems, then, are biological systems.

The difference between the two kinds of information-based systems can be seen from a different, but highly related, perspective: whereas original information-based systems are teleonomic systems, derived information-based systems are teleological. The quality of apparent purposiveness [40] and goal-directedness of structures and functions of living organisms, as teleonomic systems, derives from their evolutionary history and adaptation for reproductive success. Such systems are not planned by any agent to reach a goal. Teleological systems, in contrast, are systems planned by an agent who can internally model/imagine various alternative futures enabling intention, purpose and foresight. This conceptual distinction importantly “allows a distinction between natural and artificial objects. The artifact is produced by humans with regard to a particular application or performance, planned in advance. Thus, the final purpose determines the form of a man-made object. For natural objects, however, we do not presuppose any kind of ultimate purpose, at any rate not if we are prepared to accept what Monod called the “postulate of objectivity” as a basic postulate of scientific method: “Nature is *objective* and not *projective* [41]” [16] (p. 7).

Thus, as is seen, biological systems are theoretically and conceptually different from artifacts once we adopt an informational approach. This provides the ground for rejecting the thesis of strong AI through an information-based argument. According to strong AI, the brain is a digital computer whose program is what we call “mind”. In this view, mental states are computational states of the brain. Strong AI is distinguished from weak AI in the following way: whereas weak AI aims to study the mind by doing computer simulations, as opposed to purporting to create the mind, on strong AI view, an appropriately programmed digital computer literally has a mind; it does not simulate it [42]. In other words, whereas according to strong AI an artificial intelligence system can think and have mind, weak AI holds that an artificial intelligence system can only act as if it thinks and has mind.

Clearly, the distinction I draw between original information-based systems and derived ones rejects the proposal of strong AI coming closer to the thesis of weak AI. According to the proposal of this paper, artificial intelligence systems only *represent* the information that a biological mind puts into them by making them, designing them or setting up their initial conditions. They are not genuine information-processing systems [43].

The information-wise distinction between the biological systems and artifacts becomes even more highlighted when we deal with the so-called hard problem of consciousness as depicted in the next section.

5. An Information-Based Approach to the Hard Problem of Consciousness

Taking for granted that: (1) only biological systems are genuine information processing systems; and (2) phenomenal properties are not reducible to physical properties, in this section I use the notion of pragmatic information to modify and update Chalmers’s “double-aspect theory of information” as the fundamental law which relates physical aspects of consciousness to phenomenal ones. Such

modification makes the double-aspect principle explanatorily richer and more powerful as far as the physically realized information in the nervous system is concerned.

5.1. Chalmers's Double-Aspect Theory of Information and Its Shortcomings

In contrast with the easy problems of consciousness which aim to address the question of “how” brain processes information physically, the hard problem of consciousness seeks an explanation for “how” and “why” some of such physical processes are accompanied by qualia or phenomenal experiences [15]. David Chalmers approaches the issue firstly by rejecting physicalism according to which physical facts exhaust all facts about the Universe and the current laws of physics suffice for explaining any phenomenon including consciousness. Then, he proceeds with projecting the thesis of “naturalistic dualism” according to which phenomenal consciousness is ontologically independent of physical properties but arises from a physical substrate in virtue of certain contingent laws of nature. Phenomenal consciousness, in this view, is a fundamentally new feature of the world ontologically and explanatorily irreducible to physical properties. Such an idea, which considers consciousness as a feature ontologically over and above physical features of the world, requires a construction of new fundamental psychophysical laws specifying the dependence of phenomenal to physical properties.

In the most speculative part of his book, Chalmers [15] proposes his double-aspect theory of information as such a psychophysical law which brings out a crucial link between physical and phenomenal properties. According to the double-aspect principle, “whenever we find an information space realized phenomenally, we find the same information space realized physically. In addition, when an experience realizes an information state, the same information state is realized in experience’s physical substrate” [15] (p. 267).

The notion of information Chalmers adopts is a syntactic or formal notion similar to the notion depicted by Shannon [44] in his *Mathematical Theory of Communication* (Shannon information hereafter) in which, according to Chalmers, information is *physically* realized when a “state” is selected from an ensemble of possibilities. Chalmers calls such possible states as “information states” which comprise an abstract space called “information space”. There is a basic structure of “difference relations” between such states. According to Chalmers, the nature of states is exhausted by the fact that they are different from each other. For example, information space of a fair coin contains two states: heads and tails. By tossing the coin, one of these two states will be realized. In this case, one bit of information is processed.

Information is realized *phenomenally* when “states of experience fall directly into information spaces in a natural way. There are natural patterns of similarity and difference between phenomenal states, and these patterns yield the difference structure of an information space. Thus, we can see phenomenal states as realizing information states within those spaces” [15] (p. 266).

Having all this in mind, the double-aspect theory of information can be rewritten as follows: “Wherever there is a phenomenal state, it realizes an information state, an information state that is also realized in the cognitive system of the brain. Conversely, for at least some physically realized information spaces, whenever an information state in that space is realized physically, it is also realized phenomenally” [15] (p. 268). In other words, as the information spaces required by physics are themselves grounded in phenomenal properties, each instantiation of such physical information space

is in fact a phenomenal realization. The realization of “mass”, for example, would have a phenomenal property behind it [15] (p. 286).

Chalmers’s account of physically realized information suffers from the following shortcomings. The concept of information Chalmers adopts is the syntactic notion of information which originally and mainly focuses on communication and control systems, computers, and the like, defining a mathematical measure of the *amount* of information contained in a given message or of the average amount of information transmitted from the source to the receiver. However, Chalmers is not concerned with such amounts. Rather, he is concerned with the “information states” themselves. The relation between the “states” and the amount of information in Chalmers’s point of view is analogous to the relation between “matter” and “mass”. Such an analogy is wrong. “Matter” is out there in the real world. It is the substance of which physical objects are composed. It constitutes much of the observable Universe. The notion of matter per se has some explanatory power compatible with the laws of physics, capable of standing independent of the notion of mass. However, states in Shannon information are our abstractions to know the probability distribution among them in order to *calculate* the average amount of information in data transmission.

First of all, as was stated in Section 3.1, such abstractions or calculations refer to the passive role of information, that is, *our* interaction, as active information-processing systems, with purely physical systems to model them mathematically and quantitatively.

Second of all, what Shannon information is concerned with is how probabilities are distributed among the possible states, not what possible states are and how they are related or structured. Therefore, Chalmers, who “seems to think that the information theoretic notion of information is a matter of what possible states there are, and how they are related or structured [...] rather than of how probabilities are distributed among them” [45] (p. 480), has been confused. In Shannon information, using the notion of state without having to do with amounts of information is senseless. The relation between states and amounts of information in Shannon information is not like the relation between matter and mass.

In short, Chalmers either is faithful to Shannon information or wants to use the notion of “state” in a new theory of information other than Shannon information. In case that the former holds, he should use such a notion in an appropriate way just for quantitative purposes as the theory serves just as a mathematical tool for the calculation of the average amount of information in data transmission and optimization of such transmission. If we leave the computational power of Shannon information out, there remains nothing of the theory. Shannon information has no explanatory power as far as the notion of information is concerned.

It seems that Chalmers is aware of this. Acknowledging that information spaces and information states are abstract entities Chalmers seeks a new qualitative way of defining physically realized information in terms of a slogan due to Bateson: information is a *difference that makes a difference* [46] (p. 428) and [47]. A light-switch, for example, will turn the light off when it is in positions more than about, say, one-third of the way down. Such a difference in the light-switch would make a difference to the light’s state. In this account, an information space corresponding to a physical object will always be defined in terms of a causal pathway and a space of possible effects at the end of the pathway. In the light-switch example, these two factors physically correspond to the pathway from the light-switch to the light and the on/off state of the light, respectively. According to Chalmers, then, any causal relation

would physically realize information, no matter it is simple or complex or the causation occurs in the abiotic world (e.g., in a rock), living systems (e.g., in the genome or neural networks) or artifacts (e.g., in a thermostat or a computer).

The very first problem associated with such an account is that the notion of physically realized information in the form of “the difference that makes a difference” makes both causation and information be ubiquitous and explanatorily loose notions. If we ask “why and how is information processed in the nervous system?”, Chalmers’s answer would be: because there are some differences in such and such regions of the brain that make some differences somewhere else. He would also give a similar answer to the question “why and how is information processed in a computer?”.

Furthermore, if the account of physically realized information does not go further than the causal account formalized through “the difference that makes the difference”, why should we use the notion of information at all? Substitute “double-aspect theory of *causation*”, according to which every difference that makes a difference realizes physical and phenomenal properties, for the “double-aspect theory of information”, do we miss anything explanatorily?

The notion of physically realized information combined with the double-aspect principle would lead to the idea that any causal relation can raise phenomenal experience. In other words, causation, information and experience are ubiquitous. Chalmers encounters the issue dually: on the one hand, he seeks further constraints on the *kind* of information relevant to experience as, he holds that, not any physically realized information space would realize experience. On the other hand, he bites the bullet and accepts that experience is ubiquitous [15] (p. 275); even a rock can have experiences. Chalmers’s first solution shows that he sees the ubiquity of information counterintuitive, if not a problem associated with his double-aspect principle. By accepting the ubiquity of information, however, he acknowledges that there can be something it is like to be, say, a thermostat: the only difference between a thermostat’s experiences and, say, a mouse’s experiences lies in the degree of complexity. To make such an idea less crazy, he moves down the scale of complexity gradually. He begins with humans as the most complex information-processing systems and moves to less complex systems such as dogs, mice, lizards, and fish to slugs. He sees no reason to consider consciousness winking out altogether as he moves down the scale, though the experiences would be less complex. Then he proceeds with “thermostats” as the extension to the simpler and simpler systems and says: “Someone who finds it “crazy” to suppose that a thermostat might have experiences at least owes us an account of just *why* it is crazy” [15] (p. 277).

The reason that Chalmers does not see any problem with making an extension from living systems to nonliving ones regarding their having experiences stems from the notion of information he adopts for his double-aspect principle. However, then he encounters unwanted issues: the counter-intuitivity of the idea of a rock having experiences and the weakness of the notion of information he adopts in providing explanation.

Pragmatic information does not encounter such issues since it considers any generalization from natural living systems to *either* natural non-living systems *or* artifacts and vice versa illegitimate. Combined with the double-aspect principle, then, pragmatic information would count the idea of rocks or thermostats having experiences as crazy; the only genuine information-processing systems are living systems. Thus, only biological systems can have experiences.

The claim of this paper is that the double-aspect theory of information will not face the above problems and counterintuitive issues if we substitute pragmatic information for Chalmers's notion of physically realized information used in the theory. Pragmatic information has the following advantages over Chalmers's notion of information which makes it explanatorily more powerful.

- (1) The notion can conceptually and theoretically distinguish between natural living and natural non-living systems on the one hand, and living systems and artifacts on the other.
- (2) The notion can successfully explain the physical correlates of mental states and processes in an information-based manner confirmed by recent experimental findings.
- (3) The notion draws a clear-cut distinction between two fundamentally different kinds of causation, *i.e.*, (what I call) information-based causation and physical causation. Information-driven interactions fall under the former category and force-driven interactions under the latter.

Number (1) above has already been discussed in detail in Sections 2, 3 and 4. In what follows, I will discuss (2) describing the way Roederer [13,14] successfully uses the notion of pragmatic information to explain cognitive states and processes. Section 6 is devoted to an information-based account of causation.

5.2. Pragmatic Information and the Explanation of Cognitive States and Processes

As far as physically realized information is concerned, pragmatic information goes much farther than Chalmers's syntactic notion in the form of "the difference that makes a difference" which, as stated, is explanatorily a loose notion. Pragmatic information theoretically provides detailed explanation as to how information emerged through the course of evolution and why only biological systems are genuine information-based systems [13,16]. In particular, it focuses on the hypothetical explanation of the evolution of genome and neural networks [13] (Chapter 4).

What evidence do we have confirming the role of pragmatic information in the nervous system? Experimental evidence in real-time cognitive tasks shows that pragmatic information is encoded in the brain as a task-specific spatio-temporal distribution of neural activity in certain regions of the cerebral cortex [48,49]. Roederer [13] (p. 204) and [14] (p. 4) gives an illuminating example in this regard: when we actually see, hear about, think or just dream of, say, a "shiny red apple", *nearly the same* specific neural electrical impulse distributions arise in parts of the prefrontal lobes and in certain regions of the temporal, parietal and occipital lobes; only the order in which they appear will differ depending on whether we perceive, imagine or remember the "shiny red apple" [50]. In other words, there is a univocal pattern-change correspondence between the presence of the pattern of the "shiny red apple" (in different forms) and certain neural activity distributions corresponding to such specific pattern satisfying all conditions of information-driven interactions.

Likewise, when we study a physical system, there is an external pattern, *e.g.*, the positions of a system of mass points or the dice on cast dice, corresponding to a specific spatio-temporal neural activity pattern in the prefrontal lobes representing that particular state and not any other possible one. The synaptic wiring of the neural networks controls the actual information-processing mechanisms in the brain linking one neural distribution with another. Such synaptic wiring of the neural networks in certain regions, in particular in the hippocampus and the cerebral cortex, "has the ability of undergoing

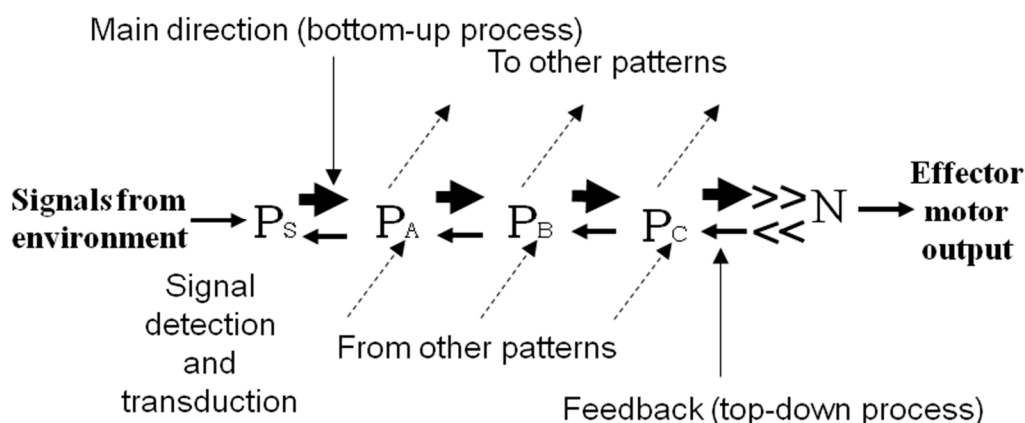
specific changes as a function of use (“plasticity”)—the physiological expression of long-term memory” [14] (p. 4).

Modern neurobiology confirms the way pragmatic information hypothetically extends to cognitive processes and states. For example, according to pragmatic information, a specific mental image *is* a specific neural activity distribution *corresponding to* and triggered by a specific pattern of an external or internal stimulus (stored in the long-term memory for example). Such correspondence would be very different in different persons physically/physiologically but the pragmatic *information* it bears and the activated cerebral regions would be the same [13] (p. 204).

Roederer divides [13] (pp. 140–141) neural activity distributions into two types which together are the physical realization of the global state of the functioning brain at any instant of time: the *dynamic* spatio-temporal distribution of neural impulses (*type 1* of information representation in the nervous system) and the *quasi-static* spatial distribution of synapses (*type 2* of information representation in the nervous system).

Figure 1 hypothetically shows why perception and mental images have nearly the same processes according to pragmatic information. Suppose that some environmental signals coming from an external object to sensory system S, say in the retina of the eye, are converted into homologous patterns of neural activation. The neural patterns in the first stage S exclusively represent information in the nervous system in a dynamic form (type 1 above) whereas the patterns at the higher levels A, B, C, ... may also include type 2. When pattern P_A is activated by the input pattern P_S , a chain of information-driven interactions happens by the activation of corresponding patterns P_B , P_C , etc. which eventually leads to the visual perception of the external object. There can also be information-driven *feedback* relationships between the consecutive neural levels A, B, C. When a higher-level pattern, say P_B , is evoked in some independent way at a later time, the original pattern P_A to which it corresponds is, at least partially, elicited. In this case, we say that information in P_A , and also in P_S , is stored in the *long term or structural memory*. Such a top-down process through which an internal pattern (without any need to an external input P_S) can elicit corresponding patterns at lower levels is the basis for mental imagery.

Figure 1. Bottom-up process of perception and top-down process of mental imagery hypothetically explained by pragmatic information, Based on Roederer [13] (p. 141).



Numerous studies confirm the above hypothesis showing that mental imagery resembles perception. For example, Stephen Kosslyn [51,52] has put forward an extremely influential theory based on the assumption that visual imagery resembles visual perception. In addition, Kosslyn and Thompson [53] considered numerous studies assessing the activation of early visual cortex showing that tasks involving visual imagery were associated with activation of early visual cortex in about half the studies reviewed. This is strong evidence showing that visual imagery can involve very similar processes to those used in visual perception. Other studies such as Pearson *et al.* [54], Klein *et al.* [55], Ganis *et al.* [56] confirm Kosslyn's theory [57].

Thus, not only does pragmatic information conceptually and theoretically distinguish between non-living (natural or artificial) and biological systems, but also it provides an information-based explanation of the evolution of genome and neural networks as well as the neural correlates of cognitive processes and states. Therefore, compared to the notion of information introduced by Chalmers, pragmatic information is explanatorily richer as far as the notion of physically realized information is concerned. In particular, as was stated in Section 2.2, at one state or another, information-driven interactions necessarily involve highly organized living matter, the fact that can justify the emergence of phenomenal consciousness as an irreducible property of neural processing. This makes pragmatic information a more legitimate concept for the double-aspect theory.

Surprisingly, like Chalmers's thesis, pragmatic information equates causation with information but unlike Chalmers's account, such an equation makes both notions explanatorily richer. I will discuss this in the next section.

6. Pragmatic Information and Causation

Substituting pragmatic notion of information for Chalmers's syntactic notion of information legitimately provides constraints on the ubiquity of information and causation. In the previous sections I dealt with the constraints put by pragmatic information limiting information and information processing to biological systems. In this section, I deal with the notion of causation proposing that firstly, we should distinguish causation in biology from causation in physics and chemistry, and secondly, causation in biology and in physics corresponds to information-driven interaction and force-driven interactions respectively.

An acceptable answer to the questions addressing the differences between explanations in biology and physics starts with the observation that organisms are highly organized: not only do their capacities and characteristics critically depend on the characteristics of their parts but also on the spatial arrangement of those parts and on the order and timing of their activities. Explanations in physics and chemistry derive the behavior of a system (e.g., the behavior of a volume of gas as described by the Boyle-Charles's law) by aggregating the behavior of the parts of that system (e.g., the behavior of the molecules of a volume of the gas as described by Newton's laws of motion). However, in highly organized systems, there comes a point where such aggregative explanation is no longer possible necessitating the system's organization to be taken into account [58] (p. 707).

In biology, organisms are seen as mechanisms for being alive [59]. For the purpose of this section, a mechanism for a certain behavior can be defined as a complex system producing behavior by the organized interaction of its parts [60,61]. Living systems are those organisms that emerged, based on the carbon atom chemistry, from highly organized structures in the Universe capable of maintaining a

metastable nonequilibrium state of low-entropy and high organization in a changing and often hostile environment during a certain period of time [62]. Understanding how the existence of living organisms is possible, then, as many biologists have recognized (such as [63]), would require four kinds of explanation: mechanistic, functional, developmental and evolutionary explanation. Such explanations address both “how questions”, referring to functional biology, and “why questions”, addressing evolutionary biology [64] (Chapter 6). Physics and chemistry are only concerned with “how questions”.

Similarly, as many philosophers and scientists have noticed, the notion of “causation” in biology needs to be treated differently than in physics and chemistry, see for instance [61,65–68]. Joffe [69] (p. 181) distinguishes three distinct types of causation operating in physiology corresponding to four types of explanations in biology stated above: “the evolutionary cause that explains how a particular feature (including genetic variation) came to be present in a particular type of organism; the developmental cause that brought it about in that individual; and the “current” or proximal cause or mechanism that is the consequence of these”. What makes the concepts of causation in biology address additional types of causes compared to those in physics is, again, the fact that living organisms are highly organized. Thus, any concept of causation dealing with biological systems must take such a fact into account.

Information-driven interactions, as was seen in Section 2.2, legitimately fulfill all conditions of causal relationships in biological systems. Recall that all information-based systems were open, irreversible, unidirectional systems involving living matter at one stage or another. As we also saw, the key characteristic of information-driven interactions was that they were *irreducible* to a superposition of the basic interactions between the constituent parts. When an exit sign at the end of a corridor pointing to the left causes you to turn left, a very complex chain of interaction mechanisms and cause-and-effect relationships is at work. In such relationships the cause does not come in the form of energy, matter or forces; the cause is “information” embedded in a particular pattern in space and time although energy and/or matter are necessary to carry information in question [13] (p. 2). The complex chain of interaction mechanisms in such relationships makes the cause and the effect decouple energywise. It means that the final states of the systems which include information-based causal relationships would depend very little on the initial conditions. Every information-driven interaction is an information-based causal relationship and vice versa. Such “information-based causation” is fundamentally different from what we may call “physical causation” occurring in natural abiotic systems (e.g., a moon of a planet orbiting around it).

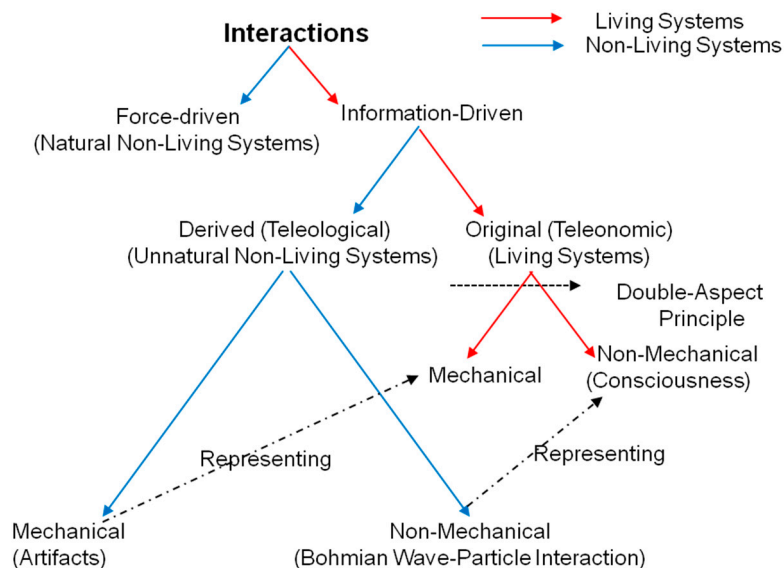
Let us now restate Chalmers’s idea who holds that “we find information everywhere we find causation. We find causation everywhere, so we find information everywhere” [15] (p. 275). The claim of this paper is that although we find information everywhere we find causation, causation is not found everywhere. Therefore, information is not found everywhere. Causation and information are found where, at one stage or another, a living system is involved. Without the intervention of a biological system, all we have would be physical causation which obeys the rules of force-driven interactions.

7. Conclusions

Figure 2 summarizes the claims of this paper in an illuminating way. It shows two fundamentally different classes of interactions the characteristics of which were clarified in Section 2. We saw that in the natural abiotic world, information plays no role. It is only by interaction of a living thing with

non-living physical world that information comes into play: when a scientist extracts information through observation and measurement, models some aspects of nature, sets up initial conditions of a system or generates an artifact.

Figure 2. Two fundamentally different classes of interactions and their subclasses.



However, for living organisms, information, as the essence of their existence, plays a genuine active role from the very beginning; information-based interactions in which a form or pattern, not energy, is the controlling factor are required to maintain a long-term state of unstable thermodynamic equilibrium with organism's surroundings, consistently increase its organization and reproduce. This latter class comprises *biomolecular* information processes controlling the metabolism, growth, multiplication and differentiation of cells, and *neural* information processes controlling animal behavior and intelligence. The only way new information can appear is through the process of biological evolution and, in the short term, through sensory acquisition and the manipulation of images in the nervous system [12] (pp. 3–4).

Information-driven interactions include two different subclasses: original and derived. Derived information-driven interactions happen in unnatural non-living systems planned by human beings or by other living systems. They are purely physical mechanisms but with a purpose to achieve a goal which the setup provider, designer or generator has determined. Such systems are categorized as information-based because they represent the information that their purposeful designers or generators put into them. This way construed, these systems are not considered genuine information-processing systems leading to the rejection of the thesis of strong artificial intelligence.

A computer (an artificial intelligence system) is an example of systems realizing *mechanical derived* information-driven interactions meaning that both ontologically and epistemologically they are reducible to Newtonian mechanics. Such interactions represent those parts of the mind which process information algorithmically. However, we can prepare a setup in such a way that it represents *non-mechanical derived* information-driven interactions. In the experimental setup provided for the double-slit experiment, Bohm's description of the wave-particle interaction refers to such an interaction. The counterintuitive features of "quantum potential" in such description, *i.e.*, non-locality and irreducibility to Newtonian

mechanics, plausibly represent those parts of the mind which process information non-algorithmically, e.g., those parts which give rise to phenomenal consciousness.

Original information-driven interactions exclusively occur in the realm of living systems. It is in this realm that the double-aspect principle applies since it is only in this realm that information is genuinely generated and processed. Such a thesis rejects Chalmers's claim according to which there is no reason to consider consciousness winking out altogether as we move down the scale of complexity.

As is seen, pragmatic information as depicted in this paper, not only is a legitimate candidate for the substitution for Shannon information in the double-aspect principle, contributing more explanatory power to it, but also provides a conceptual framework to address the most fundamental questions in science and philosophy in a coherent and consistent way, questions which deal with the foundations of quantum mechanics and biology as well as fundamental questions in philosophy of mind and artificial intelligence. This makes the notion of pragmatic information, as a biological notion, a legitimate candidate for a unifying information concept too.

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Conflicts of Interest

The author declares no conflict of interest.

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processes and states such as: perception, short-term memory, memory recall, long-term memory, anticipation, thinking, reasoning, imagination and binding.

50. Perception is a bottom-up process whereas mental imagery is a top-down one which means that no-one would expect *precisely* the same brain areas to be involved these two processes. See Eysenck [73] (pp. 53–62) for the detailed discussion of the similarities and differences between bottom-up and top-down processes regarding perception and mental imagery.
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