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*Article*

# Mind, Matter, Information and Quantum Interpretations

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**Abstract:** In this paper I give a new information-theoretic analysis of the formalisms and interpretations of quantum mechanics (QM) in general, and of two mainstream interpretations of quantum mechanics in particular: The Copenhagen interpretation and David Bohm's interpretation of quantum mechanics. Adopting Juan G. Roederer's reading of the notion of pragmatic information, I argue that pragmatic information is not applicable to the Copenhagen interpretation since the interpretation is primarily concerned with epistemology rather than ontology. However it perfectly fits Bohm's ontological interpretation of quantum mechanics in the realms of biotic and artificial systems. Viewing Bohm's interpretation of QM in the context of pragmatic information imposes serious limitations to the qualitative aspect of such an interpretation, making his extension of the notion active information to every level of reality illegitimate. Such limitations lead to the idea that, contrary to Bohm's claim, mind is not a more subtle aspect of reality via the quantum potential as active information, but the quantum potential as it affects particles in the double-slit experiment represents the non-algorithmic aspect of the mind as a genuine information processing system. This will provide an information-based ground, firstly, for refreshing our views on quantum interpretations and secondly, for a novel qualitative theory of the relationship of mind and matter in which mind-like properties are exclusive attributes of living systems. To this end, I will also take an information-theoretic approach to the notion of intentionality as interpreted by John Searle.

**Keywords:** pragmatic information; Bohm's interpretation of quantum mechanics; the double-slit experiment; quantum potential; non-algorithmic aspect of the mind

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## 1. Introduction

Reza Maleeh [1–3] has argued that a developed version of "pragmatic information" as interpreted by Juan G. Roederer [4–6] can be a good candidate for a unifying biological concept of information. A unifying biological concept is an objective notion ideally expected to be universally applicable to all sciences at both microscopic and macroscopic levels. According to Roederer's reading, pragmatic information is processed where a repeatable one-to-one correspondence is established between a specific pattern in a complex system and a change in another complex system in such a way that the change would not occur in the absence of the pattern. Originally, such a correspondence is established as a result of a biologically evolved memory which saves a common code between the pattern and the corresponding change. Moreover, in pragmatic information it is the form of the pattern, not its energy, that determines the corresponding change although for the change to occur, energy is necessary as the fuel of the interaction mechanism.

As a part of the identification of pragmatic information as a unifying concept, in this paper I pursue two interrelated aims: (1) to give an information-theoretic analysis of different versions of quantum mechanics in general and two mainstream interpretations of quantum mechanics in particular, *i.e.*, the Copenhagen interpretation, categorized to fall into the so-called collapse theories, and David Bohm's interpretation of quantum mechanics, categorized to fall into the so-called hidden variable theories. Note that each version of quantum mechanics is composed of a formalism and its associated interpretation. I argue that, contrary to the Roederer's claim, pragmatic information is handled in the quantum realm once we adopt an ontological interpretation such as Bohm's interpretation of quantum mechanics corresponding to the de Broglie-Bohm second-order theory with commitment to the notion of the quantum potential; (2) to show that viewing Bohm's qualitative interpretation of quantum mechanics in the context of pragmatic information necessarily leads to the idea that Bohm's generalization of the notion of "active information" from the realms of biological and artificial systems to all levels of reality is illegitimate. Once Bohm's qualitative interpretation in this regard is amended, we will come to a new qualitative, information-based, mind-centered theory of the relationship of mind and matter on the basis of pragmatic information and the de Broglie-Bohm second-order theory of quantum mechanics.

According to pragmatic information, all information processing systems involve living matter at one stage or another. As we will see, this means that "information" plays an active role only in biological systems and artifacts [7]. When it comes to the genuine information processing systems, however, artifacts must be excluded. "Information" in artifacts represents the original information of their purposeful, intentional [8] creators that must ultimately be biological systems. Something seemingly similar to an artifact occurred based on pure chance counts as neither an information-based system nor an artifact. This idea plays a key role in my argument against the ubiquity of information held by Bohm according to which mind is a more subtle aspect of every level of reality via the quantum potential (active information).

To achieve the aims of this paper, where necessary, the artifact I focus on is the setup of the double-slit experiment as a paradigmatic, or even the paradigmatic, quantum experiment. Paradigmatic quantum experiments are those experiments in which the bizarre non-classical features of quantum phenomena manifest themselves. There are different variations of the experiment the most important of which involves single particles. In this paper, "the double-slit experiment" refers to the basic, single-particle version of the experiment. Many interpretations of quantum mechanics, if not all, are motivated by the behavior observed in the double-slit experiment.

In Section 2, I briefly address the key elements of three interpretations of quantum mechanics: The Copenhagen interpretation associated with the orthodox formalism of quantum mechanics, the Neo-Copenhagen interpretation associated with the Feynman path integral formalism and Bohm's interpretation associated with the de Broglie-Bohm second-order theory. I will argue that as we move from the Copenhagen interpretation to the Neo-Copenhagen interpretation and further to Bohm's interpretation, interpretations become metaphysically richer giving significance and priority to ontology rather than epistemology. It should be noted that none of the above three interpretations or the corresponding quantum theories is a unified idea. There are different formulations for each theory and its corresponding interpretation. Even the initiators of the theories and the interpretations dramatically changed their minds in the course of time. As we will see, however, this will not affect my argument as to analyzing interpretations on the basis of pragmatic information. I take for granted those elements of each quantum theory and its corresponding interpretation over which most of the physicists and philosophers have consensus.

In Section 3, I briefly describe the key elements of Roederer's reading of pragmatic information according to which genuine information and information processing are attributes of living systems. According to Roederer, pragmatic information, the one our brain handles, does not operate in the quantum domain. I briefly restate Maleeh's [2] argument that Roederer's reading of pragmatic information is in line with the post-EPR Bohrian version of the Copenhagen interpretation which gives significance and priority to epistemology over ontology. I will show that in the realms of biological systems and artifacts, both at the macroscopic and quantum levels, pragmatic information perfectly supports Bohm's interpretation once we give priority to ontology rather than epistemology. The key claim in Section 3, then, is that although pragmatic information as I develop it in this paper can be extended to the quantum domain, it does not permit for the active role of information to be extended from living systems and artifacts to all levels of reality. In the natural non-living domain, information plays a passive role; it is information for us, the observers. This imposes serious limitations to Bohm's qualitative interpretation of quantum mechanics, in particular as to his ideas about the relationship of mind and matter once such ideas are seen from the perspective of pragmatic information.

Taking the above limitations into account, in Section 4, I propose a refined qualitative information-based interpretation of quantum mechanics, still on the basis of the de Broglie-Bohm second-order theory, according to which Bohm's notion of the quantum potential as it affects particles in the double-slit experiment represents the non-algorithmic aspect of the mind arisen from genuine information processing in the brain. In doing so, I will use an information-based account of Searle's views on the notion of "intentionality".

Finally, Section 5 is devoted to the replies to the plausible objections.

It is crucial here to emphasize what this paper is not about. This paper is not about the ontology of the wave-function in different formulations of the de Broglie-Bohm theory, the Feynman path integral formulation or the orthodox quantum theory or different interpretations or readings of each of these theories; nor is it about the explanatory value of any of these theories. In sum, it is not about the theories and the interpretations of quantum mechanics themselves. Hence there is no need to address the state of the art in these areas in this paper. The paper is substantially about how pragmatic information analyzes quantum theories and their associated interpretations in general, and the Copenhagen interpretation and Bohm's interpretation in particular. In doing so, I take certain features of each theory for granted, features over which most of the physicists and philosophers have consensus. As to the Copenhagen and the Neo-Copenhagen interpretations, the most relevant key feature taken for granted is that except for the eigenstates of an observable, there is no one-to-one correspondence between the properties (parameters) of a quantum system and any observable macroscopic property obtained by measurement. As to the de Broglie-Bohm second-order theory with commitment to the quantum potential, I take for granted that there is a one-to-one correspondence between the quantum potential and the corresponding particles in the sense that the quantum potential guides each quantum particle through continuous trajectories with the well-defined positions at every instant.

Also, the paper is not about various theories of mind or consciousness and their explanatory values. Thus there is no need to take the state of the art in this areas into account. Again, the paper is about analyzing the consequences of viewing the de Broglie-Bohm second-order theory in the context of pragmatic information as to the relationship of mind and matter. I view all this from the perspective of naturalistic dualism, as a variety of property dualism, taken for granted in this paper. According to naturalistic dualism, phenomenal aspects of the mind are ontologically independent of physical properties but arise from a physical substrate in virtue of certain contingent laws of nature [9].

However, to achieve the aim of this paper, we need to take into account the state of the art in the area of pragmatic information and the way it deals with other notions of information, the task which is fulfilled in this paper.

## 2. Two and a Half Interpretations

In this section, as far as the goal of this paper is concerned, I briefly describe some of the key elements of the Copenhagen, the Neo-Copenhagen and Bohm's interpretation of quantum mechanics. This will help in assessing the interpretations as to their compatibility with pragmatic information discussed in Section 3.

### *2.1. The Copenhagen Interpretation*

The key elements of the post-EPR Bohrian version of the Copenhagen interpretation relevant to the goal of this paper are: Niels Bohr's correspondence principle, Bohr's complementarity and instrumentalism. There are two more key elements which I will address on different occasions where necessary. These elements are: Indeterminism and Born's statistical interpretation of the wave-function.

#### 2.1.1. Bohr's Correspondence Principle

As an inter-theoretical principle with heuristic nature, Bohr formulated the initial version of correspondence principle in 1920. Later on, despite the experimental and conceptual failure of the principle, Bohr and Heisenberg developed a generalized version of the principle for practical purposes. The generalized principle, as proposed by Heisenberg is also a heuristic rule practically useful to establish a coherent quantum theory giving such a theory a physical interpretation [10]: "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" [11] (p. 78) [12].

Here, like the original correspondence principle, two aspects of the principle are concerned: The formal aspect as a methodology in search of a coherent formalism of a satisfactory quantum theory and the qualitative aspect with the semantic function of providing the formalized abstract quantum theory with physical interpretation. The latter aspect is based on the original correspondence principle according to which the quantitative values of the theory of atoms and those of classical physics are comparable only if the meaning of the physical terms in both theories are commensurable. Physical reality is understandable only if classical and quantum phenomena be describable in the same classical concepts enabling us to practically compare different physical experiences. Thus, to understand physical reality, classical concepts are indispensable [14].

### 2.1.2. Complementarity

The post-EPR Bohr regards Heisenberg's "uncertainty principle" as reflecting the ontological consequence of Bohr's idea that kinematic and dynamic variables are ill-defined unless they refer to an experimental outcome [15]. This made Bohr no longer use "descriptions" that attribute kinematic and dynamic properties to atoms as being complementary, but the notions of "phenomena" [16] or "information". By using the latter notions, Bohr emphasizes "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*" [18] (pp. 39–40).

In the context of the double-slit experiment, then, quantum objects become wave *or* particles after a well-defined measurement is performed in the presence of a well-defined measuring instrument. Nothing can be said as to the nature of reality belonging to the quantum systems apart from their phenomenological appearance. In the Copenhagen interpretation, any description attributing any property to any individual quantum system and its behavior behind "phenomena" is in principle excluded.

### 2.1.3. Instrumentalism

When it comes to the applicability of a theory of pure mathematics to the real physical world, Bohr maintains a non-realist view. He sees the value of such a theory as primarily instrumental. For him, any theory of pure mathematics is a useful tool for aiding the understanding of our experience of the world. Bohr is highly doubtful of the idea that the physical world can be uniquely described by some theory of mathematics.

By the same token, the mathematical formalism of quantum mechanics, in Bohr's eyes, does not provide any "pictorial" representation of the world. Whereas parts of the measuring devices can be described by means of classical physics, describing quantum systems in terms of classical or quantum mechanical formalism is impossible. The latter formalism can only be used to predict the outcome of experiments probabilistically. Such a formalism is unable to describe or account for the underlying quantum mechanisms and processes which lead to the observable effects.

### *2.2. Bohm's Interpretation*

Bohm's interpretation, associated with the so-called de Broglie-Bohm theory of quantum mechanics is an alternative to the Copenhagen interpretation which is associated with the orthodox quantum theory. In this subsection, I deal with the non-relativistic version of the de Broglie-Bohm theory and its corresponding interpretation.

The de Broglie-Bohm theory is distinguished from the orthodox quantum mechanics firstly by describing a physical system by a couple of wave-function and configuration ($\psi$, $Q_i$). "$Q_i$" refers to the position of the corresponding quantum objects [19,20]. However, like the orthodox quantum theory, the wave-function in the de Broglie-Bohm theory satisfies the Schrödinger equation.

The particle velocities in the de Broglie-Bohm theory are given by the "guidance equation" which equips particles with a dynamic that depends on the wave-function. Metaphorically speaking, the $\psi$-field guides quantum particles through continuous trajectories with the well-defined positions at every instant.

In the de Broglie-Bohm theory, the so-called "quantum equilibrium hypothesis" represented by the postulate $\rho = |\psi|^2$, where $\rho$ refers to the position-distribution of an ensemble of systems, ensures the reproduction of all predictions of the orthodox quantum mechanics. The equation also ensures that the theory does not experimentally violate Heisenberg's uncertainty principle [21].

In general, there are two mathematically equivalent readings of the de Broglie-Bohm theory, *i.e.*, the so-called first-order theory and the second-order theory. In the first-order theory, the velocity, the rate of change of position (and therefore the guidance equation), is taken to be fundamental. Influenced by John Bell's [22] and de Broglie's presentation of the theory, Dürr, Goldstein and Zangi [23] coined the term "Bohmian mechanics" to refer to the first-order theory in which no emphasis is put on the "quantum potential". Bohm himself, however, fundamentally regarded the theory as a second-order one in which the concepts of acceleration and force, work and energy play a fundamental role and particles move under the influence of forces, among which, a force stemming from a quantum potential [24]. The latter reading appeared in the original work of Bohm [20,25].

As we mentioned earlier, in this paper we are concerned with the second-order theory. However, we do not need to delve into the different readings of the notion of the quantum potential. As we said, the mere acknowledgement that a one-to-one correspondence between the quantum potential and the corresponding particles is established is sufficient to achieve the goal of this paper.

Passon [28] lists the key characteristic features of Bohm's interpretation as: Determinism, complementarity dispensability, non-locality and attribution of no special role to measurements.

"Determinism" in this interpretation refers to the thesis that the couple of wave-function and configuration of the system uniquely fixes the time evolution of the system at any given time. Determinism thus construed does not contribute the de Broglie-Bohm theory more predictive power than the orthodox quantum mechanics. The notion of "determinism" in Bohm's interpretation, then, is different from the Copenhagen interpretation which tacitly identifies determinism with exact predictability and controllability. [26] (p. 19) Note that determinism is not a fundamental element in Bohm's interpretation. Bohm and Vigier [29] also developed a model with a stochastic background.

In Bohm's interpretation, "complementarity" is dispensable in the sense that explaining many phenomena, such as the appearance of the fringe-like patterns in the double-slit experiment, requires both wave and particle aspects of the atomic objects to be simultaneously taken into account. Matter, in this interpretation, is described by both the wave-like (the wave-function) and the particle-like (the position) quantities.

The de Broglie-Bohm theory is also non-local since in an *N*-particle system, the guidance equation simultaneously links the motion of every particle to the position of others. Thus, particles are able to influence each other over arbitrary distances.

Finally, by introducing the notion of the quantum potential as a novel quantum force under the action of which particles move along Bohmian trajectories, Bohm maintains that in the double-slit experiment, for example, every particle follows a particular well-defined real physical path and go through one slit or the other leaving an individual spot on the photographic plate placed behind the slits. The spots would collectively form an interference pattern [30]. In this scenario, then, no special role is (and should be) given to the act of measurement.

### *2.3. Something in Between: The Neo-Copenhagen Interpretation*

There is yet an alternative interpretation to the above two interpretations which somehow can be placed between them, *i.e.*, the one associated with the Feynman [31] path integral formulation. Following Posiewnik and Pykacz [32] (p. 6), I entitle this interpretation the "Neo-Copenhagen interpretation".

In the context of the double-slit experiment, an anthropocentric account of the interpretation holds that the interference pattern arises from our lack of knowledge of the path (or trajectory) of the quantum particle. More technically, the fringe-like patterns show up in view of the fact that there are two *indistinguishable* paths available.

Since the Neo-Copenhagen interpretation uses the classical concepts of "paths" and "trajectories" (though unlike Bohmian trajectories they are not physical, real paths) the interpretation resembles Bohm's interpretation. However, the Neo-Copenhagen interpretation, like the Copenhagen interpretation, forbids delving into the deeper mechanisms to explain the appearance of the interference patterns. Another similarity with the Copenhagen interpretation is that the Neo-Copenhagen interpretation uses the paths as the mathematical tools to compute the evolution of the wave-function. The Neo-Copenhagen interpretation, however, practically deviates from the Copenhagen interpretation where it holds that it is experimentally possible to have both non-perfect knowledge of the path through which the quantum particle has passed and a non-perfect, but still visible interference pattern [32] (p. 6).

Clearly, as we move from the Copenhagen interpretation to the Neo-Copenhagen interpretation and further to Bohm's interpretation, descriptions become metaphysically richer. In the context of the double-slit experiment, for example, whereas any attribution of any property or behavior to the individual quantum systems regardless of their interaction with measuring instruments is prohibited by the Copenhagen interpretation, Bohm's interpretation provides a full ontological description of the mechanisms involved in the appearance of the interference pattern, from the very start of the emission of atomic objects toward the slits to the very end where objects leave marks (spots) on the photographic plate. A shift from the Copenhagen interpretation to Bohmian interpretation via the Neo-Copenhagen interpretation would result in the priority of ontology over epistemology. Consequently, despite their conceptual differences, we expect to turn one interpretation into another by adding or removing ontological ingredients to the formalisms and corresponding interpretations. This claim can be supported by a few works. For example, Hans Halvorson and Rob Clifton [33,34] show that by adding the metaphysical postulate that position measurement is always dynamically significant, Bohm's interpretation can be obtained from Bohr's complementarity.

Adding more metaphysical ingredients to the interpretations, however, comes at the cost of the impossibility of observation of some of the properties of particles with complete precision within the limits set by the uncertainty principle. This is why the de Broglie-Bohm theory is called a "hidden variable" theory.

Thus, although, for example, in an experiment Kocsis *et al.* [35] managed to measure the average Bohmian trajectories of single photons undergoing two-slit interference, as far as the phenomenology and formalisms are concerned, such an experiment can equally and successfully be explained by the Neo- and Copenhagen interpretations of quantum mechanics. The same goes for a highly publicized paper in which Menzel *et al.* [36] identified the path of each particle without any adverse effects on the interference patterns generated by the particles.

The move toward Bohm's interpretation makes the associated quantum formalism play a realistic role, not an instrumentalistic one. Bohm maintains that the formalism of his theory refers to what actually is happening in the quantum world. In other words, the de Broglie-Bohm theory refers to the physical reality irrespective of its being observed or not.

Psychologically, as we move from the Copenhagen interpretation toward metaphysically richer interpretations, such as Bohm's interpretation, we witness an increase in the thirst for recognizing quantum mechanics as being fundamentally about atoms and electrons, quarks, strings, or, in general, about the nature of physical reality of individual quantum systems themselves, not about those particular regularities observed after measuring some properties of these things.

A proponent of the Copenhagen interpretation, such as Bohr, would object to the possibility of the above recognition due to the limits intrinsically set by the laws of nature, *i.e.*, the uncertainty principle. He would hold that it is in principle impossible to know anything behind the "phenomena", since objects are in the phenomena [37] (p. 185).

In the next section, introducing the notion of "pragmatic information" as interpreted by Roederer, I provide an information-based interpretation of the interpretations. I show that contrary to the Roederer's ideas, pragmatic information can be handled in quantum domain once we give priority and significance to ontology rather than epistemology.

## 3. Interpretations and Pragmatic Information

The key elements of pragmatic information are outlined as follows. I will proceed with the Copenhagen and Bohm's interpretations analyzed on the basis of pragmatic information.

### *3.1. Pragmatic Information*

In Roederer's reading of pragmatic information, the notion of "interaction" plays a central role. He introduces two fundamentally different classes of interactions between the bodies that fabricate our universe, *i.e.*, Force-driven (or Physical) Interactions and Information-driven (or Information-based) Interactions. The key discriminators between the two kinds of interactions are "information" and "information processing".

### 3.1.1. Force-Driven (Physical) Interactions

In the classical non-relativistic domain of physics, systems which exclusively consist of force-driven interactions have the following features.

(1) They can always be *reduced* to a *linear superposition* of physical interactions (*i.e.*, forces) between the systems' elementary component parts [6] (p. 2).
(2) They are in principle bidirectional and reversible meaning that there is no preferred direction of time in such systems. The relationships between bodies in such systems are genuine *inter*-actions rather than cause-and-effect. Interactions in such systems tend to become irreversible under the effects of some external forces. Making the latter systems reversible again requires total information and control of the external parts since even very weak external perturbations would make a reversible system of interacting bodies irreversible.
(3) The final states of the interactions in such systems always depend on the "initial conditions" of the interacting bodies energy-wise. This is a result of the fact that:
(4) In these interactions, "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)" [4] (p. 6).

Any interaction in the *natural abiotic world* counts as a physical interaction. In natural non-living systems, interactions between "elementary particles, nuclei, atoms, molecules, parcels of fluid, chunks of solid bodies, planets and stars" [6] (p. 2) are some instances of physical interactions.

### 3.1.2. Information-Driven Interactions

None of the features stated above applies to information-driven interactions. In particular, the irreducibility of information-driven interactions to a linear superposition of basic interactions between the constituent pars is an essential feature of information-driven interactions making them fundamentally different from physical ones. In such interactions, it is the presence or absence of a specific *pattern or form* (in space and/or time), *not its energy*, that determines whether or not an interaction would occur although for information-driven interactions to happen, energy and/or matter is necessary [6] (p. 2). "Physical energy" in information-driven interactions is the "fuel" for the interaction mechanism and plays a subsidiary role; physical energy does not represent the interactions per se. In every information-driven interaction, a repeatable one-to-one correspondence is established between a specific *pattern* in a complex system and a change in another complex system in such a way that the change would not occur in the absence of the pattern [5]. More importantly, the change must not occur as a result of chance events. This means that an established memory must save a common code between the pattern, as the sender, and the change, as the receiver, to ensure a repeatable pattern-change correspondence. Pragmatic information, then, is defined as that which represents the "univocal pattern-change correspondence" as Küppers [38] has put it. Interactions with such specifications are called "information-driven" interactions. "Univocal" in this context means that similar conditions of preparation in every information-driven interaction must yield identical results. In other words, the interaction process in such interactions is deterministic.

In information-driven interactions, the "complexity" of intervening processes, *i.e.*, the interaction mechanism, which is often considered as one part of the pattern and/or change, is an important feature which gives rise to some novel and interrelated features the most important of which is, as said, the irreducibility of interactions to a linear superposition of elementary interactions. The complex interaction mechanism also makes the energy relation between the pattern and the change irrelevant. This means that, firstly, as opposed to physical interactions, the final states in such interactions depend very little on the initial conditions energy-wise and secondly, the energy required to effect the changes in the recipient is provided by some external source. Thus, all information-driven interactions occur in open systems. All this leads to another key feature of the systems consisting of information-driven interactions: They are unidirectional comprising genuine cause-and-effect relationships.

The pattern of a sign which contains information as to how to get to the men's room triggers a very complex chain of evolved interaction mechanisms and cause-and-effect relationships in the recipients. The cause in such information-driven interactions comes in the form of "information" embedded in the particular pattern of the sign with a specific corresponding meaning to each recipient. The cause does not come in the form of energy, matter or forces although the latter are necessary to carry information in question [5] (p. 2) Such a sign is meaningful to the recipients since a common code is established between the pattern of the sign and a corresponding change in each recipient. The intentionality and purpose of the pattern of the sign represents the original intentionality and purpose of its designer who ultimately must be a biological system and who is aware of the fact that the sign has a specific meaning for the recipients. Without such a common code, there would be no information and information processing at work.

It should be noted that all basic information-driven interactions as well as information-processing mechanisms work on the basis of physical interactions which are physical gadgets in the case of artifacts and chemical reactions in biological processes. In this sense, both basic information-driven interactions and physical interactions are reducible to physics as we know it. However, they fundamentally differ from one another as to how a mechanism is put together. The way a mechanism is put together makes force-driven interactions between natural non-living bodies (not between artificial or biological systems) reduce to a linear superposition of the physical interactions between their parts. However, no such linear superposition of effects exists in information-driven interactions as a result of the complex interaction mechanisms in these interactions.

Roederer [5,6] holds that there are only three fundamental mechanisms leading to the emergence of information-driven interactions: "(1) Darwinian evolution; (2) adaptation or neural learning; (3) as the result of human reasoning and long-term planning. In other words, they all involve *living matter*—Indeed, information-driven interactions represent the defining property of life" [6] (p. 3).

The third mechanism above represents artifacts as the result of goal-directed actions of living systems. Thus, any information-driven interaction occurring in the realm of unnatural non-living systems must ultimately involve, at one stage or another, the action of a purposeful, intentional living system. Something seemingly similar to an artifact occurred based on pure chance would not count as an artifact or an information-based system. No account of information (*i.e.*, syntactic, semantic or pragmatic) considers chance events as information events. Artifacts then represent the original information of the livings systems who purposefully put such information into them by making them, designing them or setting up their initial conditions. Without such original information, interactions in artifacts would be purely physical.

*3.2. An Information-based Interpretation of the Copenhagen Interpretation*

Roederer holds that our brains are eminently classical information processing systems. They are evolved and continuously trained on the basis of their information-driven interactions with the classical macroscopic world. This idea leads to the important consequences regarding the way we treat force-driven interactions in both macroscopic and quantum domains [5].

As regards the macroscopic world, recall that interactions in the natural abiotic world are all force-driven. In such interactions "information" does not appear as an active, controlling agent; it plays a *passive* role. In physical interactions, "information" shows up only when an observer intervenes by (1) describing, or (2) manipulating systems in nature which exclusively include force-driven interactions. Point "1" above represents the way we model systems mathematically. In general, all quantitative and *formalistic* treatments of the systems, whether purely physical or information-based, refer to the passive role of information. An example of a quantitative treatment of purely physical systems is where we select a portion of the universe (as a system) to study it thermodynamically and associate the notion of "entropy" with "information". Such an association does not exist in nature but arises from the way *we*, the observers, describe nature by "counting molecules in a pre-parceled phase space; mentally tagging molecules according to their initial states; coarse-graining; looking for regularities *vs.* disorder; predicting fluctuations; extracting mechanical work based on observed patterns in the system; *etc.*" [6] (p. 3).

An instance of treating original information-based systems quantitatively is when we calculate the number of "bits" contained in the patterns (senders) and changes (receivers) involved in the mental and cognitive processes in the brain or assign numbers that represent the amount of (e.g., Shannon) information transmitted from such senders to their corresponding receivers. In this way, we are assigning computational interpretations to the brain. However, this does not mean that the brain functions computationally. Such computational treatments represent the passive role of information and are the products of original information-driven interactions in the brain that are only characterized by univocal pattern-change correspondences. In other words, pragmatic information handled in the brain is characterized by what it *does* not by how much it is or in what form it is expressed. Pragmatic information "represents a correspondence which either exists or not, or works as intended or not, but it cannot be assigned a magnitude" [6] (p. 3). Here, the notion of information plays an active role. However, when we, as original information-based systems, model other systems mathematically and quantitatively, we are indeed assigning computational interpretations to the systems under consideration. In such cases, information plays a passive role and by the term "information", we mean information for us, the observers. All quantitative treatments of "information" such as Shannon information, algorithmic information, Fisher information and so forth, then, refer to the passive role of information.

We can also manipulate nature (Point "2" above), turning force-driven interactions into information-driven ones. Artifacts are products of such manipulation. By setting the initial conditions of a classical mechanical system or preparing a quantum system, we would have an artificial information-based system with a purpose: To establish a desired univocal pattern-change correspondence in order to fulfil a certain task defined by the biological goal-directed creators or designers. Information in artificial systems plays an active role. However, such information is not original but derived [2]. Information in artificial systems represents the information that we, as purposeful, intentional, original information systems, put into them. Without the intentionality and the purpose of the biological creators, no information and information processing would be at work; all interactions would be chance-based and purely physical. We put information into the artificial systems by generating or designing an artificial memory containing a common code between the sender and the recipient ensuring a univocal pattern-change correspondence. Interactions occurring in the laboratory experiments, including quantum experiments, are all derived information-driven interactions [39].

So far in this subsection I have explained and developed Roederer's ideas as to how our classically trained brains deal with the macroscopic world. We adopted an information-based approach as to explicating the way our brain describes or models nature and assigns computational interpretation to nature. Also, by manipulating nature we have managed to make artificial information-processing systems which represent the original information we humans have put into them. By analyzing the Copenhagen interpretation from an informational point of view, now it is time to turn our attention towards the quantum world.

According to Roederer [4,5], pragmatic information is a macroscopic concept and is not applicable to the quantum domain. His reason for this claim is that, except for the eigenstates of an observable, there is no univocal correspondence between the properties (parameters) of a quantum system and any observable macroscopic property obtained by measurement. Therefore, for example, in general, "no information can be extracted experimentally on the superposed state of a single qubit" [6] (p. 6).

For Roederer, "pragmatic information" and "time" are macroscopic concepts. Only when a quantum system interacts locally with a macroscopic system it can be assigned time marks. And when it comes to the time evolution of the 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. Non-locality in space and time really means that for a composite quantum system, 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" [6] (p. 6).

Now if we force our classical concepts of "information" and "time" into the quantum world, we will face the counter-intuitive behavior of the quantum systems and their interactions violating relativity, causality and locality [5] (p. 51).

Roederer, then, concludes that any interpretation of quantum mechanics would be of pedagogical nature not just philosophical. Clearly, this approach is directed towards the question of how we gain knowledge and what we can do with this knowledge. As Maleeh [2] has already argued, this is totally in line with the Copenhagen interpretation which gives priority and significance to epistemology rather than ontology. The pedagogical role he assigns to the interpretations of quantum mechanics can also be interpreted on the basis of the correspondence principle in the Copenhagen interpretation of quantum mechanics. The way pragmatic information deals with the mathematical treatment of systems (applicable to artificial, natural, macroscopic and quantum systems) is also in harmony with the instrumentalistic role assigned to the mathematical formalism of the orthodox quantum mechanics by the Copenhagen interpretation.

Roederer's pragmatic information confirms Bohr's "complementarity" in the context of the double-slit experiment as follows: "Our brain trained in a classical world obliges us to follow mentally each quantum along one of its possible courses between the … [two slits]—But the fact is that as long as the experiment is not arranged to determine the photon's actual path, this particle does not follow a single course! We must not imagine the photon as 'splitting' in two either, because a split photon has never been observed we would only encounter a whole one if we were to look for it!" [5] (p. 48).

Now if we choose to find out which path the photon has taken, we need to change the experimental setup by adding a which-path detector to the experiment which invariably spoils the original situation with the interference pattern: "However frustrating to our intuition, a necessary condition for the interference of a quantum 'with itself' is that the experiment be such that it is impossible, even in principle, to obtain information on the particular path the quantum has taken. In other words, quantum systems, while left alone, follow the proverbial policy of 'don't ask, don't tell!'" [5] (p. 49).

To recapitulate: Roederer's reading of pragmatic information supports the Copenhagen interpretation by claiming that the notion of information is not applicable to the quantum world. He provides a psychological account for the rise of quantum paradoxes. All this results from the fact that Roederer's reading of pragmatic information is primarily concerned with epistemology.

In the next subsection, I argue that in the realm of biological systems and artifacts, pragmatic information perfectly supports Bohm's interpretation once we give priority to ontology. However, I will show that to provide an acceptable interpretation of quantum mechanics informationally, Bohm's extension of the notion of active information (or the quantum potential) to all levels of reality should be revised.

### *3.3. An Information-Based Interpretation of Bohm's Interpretation*

According to pragmatic information, as is developed in this paper, there is physically no difference between an event occurred by chance in nature and a seemingly similar event in the laboratory. We can assign the same physical formalism (computational interpretation) to both events. However, from pragmatic information point of view, there is conceptually a fundamental difference between these events. To clarify the point, I begin with an example in the realm of classical electromagnetism. According to pragmatic information, "an electromagnetic or sound wave emitted by a meteorological lightening discharge does not represent any information-driven interaction; on the other hand, 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" [6] (p. 3).

An electromagnetic or sound wave emitted by a meteorological lightening discharge is considered a chance event. There is no one-to-one repeatable correspondence between a pattern and a change in such an event. The latter correspondence requires a memory containing a common code between the sender and the receiver. In chance events, there is no memory, common code, purposiveness (or purpose), and meaning involved. Applying physical formalism to such events represents the way we model or describe nature and refers to the passive role of information, that is, information for us, the observers. The way we extract information from such a natural event is exactly the same as the way we extract information about the age of a tree from the rings in the tree stump.

In the case of waves emitted by an electric discharge in the laboratory, however, we prepare the setup of the experiment so that a repeatable one-to-one correspondence is established between a pattern and a change which is the emitted waves. In other words, we establish a memory which contains a common code between the sender and the receiver. As a result, in each run of the experiment, there is a certain pattern with a "purpose" to make a univocal change in a corresponding receiver. Such a purpose has a "meaning" for the receiver. The energy of the change is not provided by the pattern itself but by a third source that we, the setup providers, define. Here, information plays an active role and represents the information that we, as original information-driven systems, put into an artificial system by providing the setup of the experiment. So, while the physical formalism (and perhaps the physical interpretation) we apply to both (chance and information) events is the same, the informational interpretation is fundamentally different.

The same goes for the quantum experiments. Whereas we assign the same physical formalism to the quantum situations happening in nature and seemingly similar quantum situations artificially created in the laboratory, from pragmatic information point of view, they are fundamentally different. Natural quantum situations and processes are not information events and have to do with the passive role of information (*i.e.*, information for us, the observers) while artificial quantum situations and processes are information-based events in which information plays an active role representing the information we put into the system by providing the setup of the experiment.

Maleeh [1,2] has argued that Bohm's understanding of the interactions occurring in the realms of living systems and artifacts is in perfect harmony with pragmatic information: "Consider 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. […] 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)" [40] (p. 279).

Acknowledging the active role of (pragmatic) information in the macroscopic domain of biological systems and artifacts, by introducing the non-classical notion of the "quantum potential" (active information), Bohm is now ready to extend the idea to the quantum domain. He proposes that in the double-slit experiment conducted by electrons, for example, there is a univocal correspondence between the pattern (form) of the quantum potential and the change in particles moving along Bohmian trajectories. Here, the energy of the change is not provided by the quantum potential: "We may therefore propose that an electron too moves under its own energy, and that the information in the form of the quantum wave directs the energy of the electron" [30] (p. 326) [41].

According to Bohm's interpretation, the "quantum potential-particles" interaction fulfils all conditions of information-driven interactions although such an interaction cannot be reduced to Newtonian (classical) mechanics. [42]

Bohm, however, does not stop here, extending the idea to every level of reality. Each level of reality has a mental side corresponding to the notion of "active information", which is more "implicate", more "subtle" and has a wave-like quality, and a physical side, which is more explicate, more manifest, less subtle and has a particle-like quality. Thus, even the quantum level can be thought of as having a mental aspect (wave-like aspect), a primitive mind-like quality, via the quantum potential, and a physical side which is manifest in the particle aspect of a quantum system.

The relationship between these two aspects is mutual participation which has two sides, “to partake of” and “to take part in” [40] (p. 284) & [26] (p. 323). The more subtle, higher level partakes of the less subtle one by gathering of information about the latter. It also takes part in the lower, more manifest level “by organizing it on the basis of what the information gathered means” [43] (p. 38).

Obviously the whole view is based on the ubiquity of information as the mind-like aspect of all levels of reality. Therefore, the above idea is in line with “panpsychism” according to which mind and consciousness are universal features of all things. Note that in Bohm’s view, matter (the particle-like aspect of reality) has “meaning” which affects the mind.

This section can then be summarized as follows.

(1) Contrary to Roederer’s idea that pragmatic information is not generally handled in the quantum domain, we saw that by giving priority to ontology rather than epistemology, Bohm’s interpretation maintains that pragmatic information plays an active role in the quantum world; it does something though it is impossible to fully verify this experimentally. In Bohm’s interpretation, the quantum potential actually guides the corresponding particles although this cannot be observed with complete precision due to the limits set by the uncertainty principle.

(2) However, whereas the active role of information in Roederer’s reading is correctly limited to interactions in biological systems and artifacts, Bohm extends the idea to all levels of reality. In constructing a new qualitative quantum interpretation based on the de Broglie-Bohm second-order theory, I will amend Bohm’s interpretation as to the above extension which, on the basis of pragmatic information, counts as illegitimate as I showed. I will argue that the new interpretation does not encounter problems (such as panpsychism) that Bohm’s interpretation is faced with.

## 4. A New Qualitative Interpretation

As we saw, the Copenhagen interpretation prohibits us from going behind the phenomena. In other words, if we tend to go beyond what can be known through the effects of the interactions between the quantum objects and measuring instruments classically manifested in the measuring devices, if we are interested in individual quantum systems and some of their properties without expecting such properties to be observed with complete precession due to the limitations set by the uncertainty principle, if we give priority and significance to ontology rather than epistemology, then the Copenhagen interpretation is not an appropriate interpretation for us.

Other options are those interpretations, such as Bohm’s interpretation, which are more concerned with ontology. However, the fact that descriptions in such interpretations cannot be completely verified experimentally would expose the interpretations to the risk of going too far in assigning properties to individual quantum systems. This is the problem associated with Bohm’s interpretation once seen in the light of pragmatic information. In what follows, the latter interpretation is amended on the basis of pragmatic information.

Recall that pragmatic information is processed in systems in which a univocal correspondence is established between a pattern and a change. Chance events in principle do not count as information-based events.

The univocal pattern-change correspondence requires a common code between the sender (pattern) and the receiver (change). This common code must be saved in a memory. In biological systems, such memories do not arise spontaneously; they must evolve in a Darwinian process. This is why natural biotic systems are all information-driven systems.

Artificial memories, however, do not need to evolve. Such memories are produced by goal-directed living agents that already underwent a Darwinian process. Artificial memories are intended to save a common code with the purpose of establishing a univocal pattern-change correspondence as defined by their creators. Once the purpose and the intentionality of the creators are eliminated from the story, we will face chance-based, purely physical interactions with no information and information processing at work. Any artificial memory represents the original intentionality of its maker(s).

To sum up, there are only two kinds of systems in which a memory guarantees information-driven interactions: Biological systems and artifacts. Only in these two sorts of systems information plays an active role. In biological systems, information is original and in artifacts it is derived representing the information of the first kind. Thus, assigning information to natural non-living systems consisting of purely physical interactions would only refer to the passive role of information, namely, information for us, the observers. And it is exactly where Bohm informationally goes wrong in his interpretation [44].

Bohm is well aware of the fact that the best realms where he can find convincing examples of the way his notion of active information works are the realms of biological systems and artifacts in which interactions, as discussed, are information-driven. One of his favorite examples for explaining the notion of active information is a ship on automatic pilot guided by radar waves, stated above. Obviously, this is an artifact (derived information-based system) in which a biological goal-directed, intentional system has established a univocal correspondence between the patterns of the radar waves and the movement of the ship where the energy of the movement is not provided by the waves themselves. He also emphasizes the univocal correspondence between the pattern of a DNA molecule and the synthesis of a specific protein. Again, we see that we are in the realm of original information-based systems [39]. As I have frequently stressed, according to pragmatic information these two realms are not merely the best realms, but the *only* realms in which information plays an active role.

Let us now switch to the quantum world addressing Bohm's interpretation of the underlying mechanisms and processes of the double-slit experiment leading to the appearance of an interference pattern. According to Bohm, the active information contained in the form (pattern) of the quantum potential guides the corresponding particles which move on their own energy. According to pragmatic information, the double-slit experiment is an artifact the setup of which must have ultimately been provided by a purposeful, intentional human being. By determining the initial conditions of the experiment, the setup provider establishes a univocal correspondence between the quantum potential and the corresponding particles. Here we have a derived information-based system. Once the setup provider changes the initial settings, a different univocal correspondence is established between the quantum potential and the particles leading to a different fringe-like pattern. In other words, by providing the setup, a common code is defined and established between the interacting parts while the energy of the interaction (energy of the moving particles) must come from a third source (*i.e.*, other than the quantum potential) defined by the setup provider. The active information in the double-slit experiment, then, represents the original information that the setup provider has put into it. Seemingly similar interactions occurring in nature based on chance would lack the defining elements of information-driven interactions stated above. Any extension of the notion of active information from interactions in the realms of biotic systems and artifacts to interactions occurring in nature, and from there to all levels of reality, is illegitimate. Assigning "information" to all levels of reality refers to the passive role of information, namely information for us, the observers. In this respect, Bohm's qualitative interpretation of quantum mechanics should be informationally amended. Such an amendment, then, would bring us to a new qualitative interpretation of quantum mechanics. The emphasis on the term "qualitative" means that the new interpretation I propose can still be supported by the de Broglie-Bohm second-order theory.

A good understanding of the interpretation I advocate in this paper, firstly requires an understanding of two distinctions that John Searle (e.g., [45–47]) makes between "observer-independent" and "observer-dependent" features of the world on the one hand, and "original intentionality" and "derived intentionality" on the other.

Things such as force, mass, planetary system and photosynthesis exist regardless of what human beings think or do; the existence of such things does not depend on human attitudes. However, as opposed to the latter things which are observer independent, there are lots of things that their existence depends on human attitudes; things such as money, government and football games are observer dependent. Searle maintains that whereas the natural sciences deal with observer-independent phenomena, the social sciences address observer-dependent ones. More importantly, observer-dependent facts are products of conscious agents whose mental states which create observer-dependent facts are themselves observer independent. Thus whereas I, and others, regard certain pieces of papers as "money", as an observer-dependent thing, the fact that we regard it as money is observer independent [45] (p. 6).

Let us now see what such a distinction has to do with the proposal of this paper. Consider a quantum interpretation proposed on the basis of a formalism that refers to a quantum experiment. The quantum experiment in question requires a setup provider that must ultimately be a biological system who deliberately arranges the setup so that a univocal pattern-change correspondence is established to fulfil a certain task. In our proposal, the interactions in the mind of the setup provider resulting in the arrangement of the setup of quantum experiment are original information-driven ones and observer independent. "Information" in the mental processes leading to designing the setup of the experiment plays an active role.

The whole experimental setup of the quantum experiment counts as an artifact. Let us focus on the double-slit experiment as a paradigmatic quantum experiment. Information in such an experiment plays an active role but the whole experimental setup is observer dependent. It is us, the setup providers and the observers who regard the experimental setup as a quantum experiment with the purpose of making a desired change somewhere. Interactions in such a setup are derived information-driven and the processed information represents the intentionality and the purpose of the setup provider without which there would be no information and information processing at work.

The "information" in the quantum formalism that mathematically represents the experiment and the information in the associated interpretation that represents the experiment ontologically and/or epistemologically on the basis of the formalism both play a passive role, not an active one. By constructing a quantum formalism, we are indeed assigning a computational interpretation to a quantum phenomenon or a quantum system. A quantum interpretation refers to the way we describe a quantum formalism. Both the "formalism" and the "interpretation" count as observer-dependent entities. However, any form of documentation through which a quantum formalism and its associated interpretation are recorded counts as an artifact containing active but derived information.

Finally, there must be a "user" at the end of the line who may be the same as the setup provider. This user, again, ultimately must be a biological system. All processes resulting in proposing an interpretation will ultimately make a corresponding change in the mind of the user as an original information-based system whose mental processes involved in this change are observer independent.

The second distinction Searle makes is the distinction between original and derived intentionality. "Intentionality" is a property of the mind by which it is directed at or about objects or states of affairs in the world independent of itself.

Searle explains the distinction between original and derived intentionality by a clarifying example: "I have in my head information about how to get to San Jose. I have a set of true beliefs about the way to San Jose. This information and these beliefs in me are examples of original or intrinsic intentionality. The map in front of me also contains information about how to get to San Jose, and it contains symbols and expressions that refer to or are about or represent cities, highways, and the like. But the sense in which the map contains intentionality in the form of information, reference, aboutness, and representations is derived from the original intentionality of the map makers and users. Intrinsically the map is just a sheet of cellulose fibers with ink stains on it. Any intentionality it has is imposed on it by the original intentionality of humans" [47] (p. 7).

The two sets of the distinctions that Searle makes are systematically related by proposing that derived intentionality is always observer dependent [47] (p. 7).

Searle emphasizes that the talk of "intentionality" in cognitive science is the talk of "information". However, he prefers the former to the latter because for him, "information" is "systematically ambiguous between a genuinely observer-independent mental sense (for example, by looking out the window now I have information about the weather) and a nonmental observer-relative sense (for example, the rings in the tree stump contain information about the age of the tree). This ambiguity can also arise for "intentionality," but it is easier to avoid and confusion is less likely" [47] (p. 162).

Obviously, the account of information proposed in this paper does not face such ambiguity. Indeed, not only does this account provide an information-based account for a quantum interpretation, but also for "intentionality". In this account, observer-independent mental processes that are about weather count as original information-based processes. Information in this example plays an active role but in the second example a passive role. The second example has to do with the way we model systems mathematically or descriptively.

In this account of information, "original intentionality" corresponds to the properties of observer-independent original information-based interactions in which information plays an active role and "derived intentionality" corresponds to the properties of derived-information driven interactions in artifacts which are observer-dependent although information plays an active role in them.

Thus, the intentionality of the whole double-slit experiment's setup as well as the associated formalism and interpretation is derived. However, in the double-slit experiment, information plays an active role while in the formalism and interpretation a passive one [48].

Now we are fully equipped to propose our new information-based qualitative interpretation of quantum mechanics on the basis of the de Broglie-Bohm theory of quantum mechanics.

Genuine information and information processing are exclusive attributes of living systems. In such systems information processes are observer independent and information plays an active role. Artifacts represent the original, informational aspects of the minds of purposeful, intentional living systems who created them to achieve a certain task. A computer, for example, represents the algorithmic (computational) aspect of the mind of its hardware maker and programmer. By "algorithmic aspect" or "computational aspect" I refer to a property of the mind by which it assigns computational interpretations to both its own (or to others' mental) processes or to the outside world. These terms also refer to the ability of the mind to produce algorithmic programs and run such programs in artificial intelligence systems which can functionally simulate human cognition. [49] One can also think of the other aspects of the mind represented by artifacts. For example, a painting represents the visual/perceptual aspect of the mind. These aspects of the mind belong to a broader category, *i.e.*, the "psychological aspect" of the mind characterized by what mind does.

Now given that the quantum potential as an unobservable entity in the double-slit experiment actually exists and contains active information as to its interaction with the corresponding particles as described by Bohm, according to the informational approach adopted in this paper, these quantum potential-particles interactions are observer-dependent, derived information-driven interactions representing the original information that the setup provider has put into the system by arranging the setup. Without the setup provider, interactions would be purely physical not informational.

Having said all this and concerning the features of the quantum potential, in particular its mind-like property as Bohm describes, it now seems natural to think that the quantum potential in the double-slit experiment represents the non-algorithmic aspect of the mind of the provider. Non-algorithmic aspects of the mind are those aspects which are not algorithmic and cannot be simulated by the computational capabilities of the mind. Non-algorithmic aspects can only be reproduced by *duplication* not simulation. Whereas we can assign a computational interpretation to the quantum potential or write a program to simulate the fine-grained functions of neurons and their relations with each other in the brain, no algorithmic program can simulate the quantum potential or the phenomenal aspect of the mind which is characterized by the way it feels.

Thus, according to the information-based proposal of this paper, contrary to the Bohm's claim, mind is not a more subtle aspect of every level of reality via the quantum potential, but the quantum potential as it affects particles in the double-slit experiment represents the non-algorithmic aspect of the mind arisen from genuine information processing in the brain. The only interactions that genuinely contain active information occur in (the minds of) living systems without which all other interactions in the world would be purely physical. It is then a plausible idea that the non-algorithmic aspect of the mind potentially gives rise to phenomenal consciousness. The non-algorithmic aspect thus construed qualifies it as the phenomenal aspect of the mind. Phenomenal consciousness in such a thesis can be considered as a non-algorithmic, non-local, unobservable, natural, information-based property of the mind arisen from (but irreducible to) its correlated physical mental processes.

The above thesis is in harmony with Chalmers' [9] "double-aspect theory of information" with the major difference that contrary to Chalmers' view, "information" in this thesis is not ubiquitous but is limited to living systems and artifacts, considering only living systems as *genuine* information processing systems. This results from adopting a different notion of information. As opposed to Chalmers who adopts a syntactic notion of information (a Shannon-like notion) for his double-aspect theory, I adopt pragmatic information. Taking the latter notion would not lead to panpsychism [2].

## 5. Replies to the Plausible Objections

The very first objection to the idea proposed in this paper may target the notion of pragmatic information itself: Why should we adopt pragmatic information as an appropriate notion of information playing a central role in this paper? My reply to this objection is that as Roederer [5] has also argued, pragmatic information is a good candidate for being the only objective notion of information. Contrary to pragmatic information, other notions of information deal with the passive, observer-dependent role of information, *i.e.*, information for us, the observers.

If the above claim is correct, then it is natural to think that pragmatic information must in principle be applicable to all sciences. Following Roederer [5], Maleeh [1,2] has argued that pragmatic information has the potential to count as a candidate for a unifying information concept addressing different as-yet-unexplained issues in science and philosophy. For example, Roederer and Maleeh have shown that many mental processes and states can hypothetically be accounted for by the notion of pragmatic information. They claim that such accounts can be well-supported by the recent experimental data in the neurobiological literature.

Also, as stated earlier, pragmatic information is processed in systems the *complexity* of which has exceeded a certain degree and represents the defining property of life. The complexity of the interaction mechanism in information-driven interactions allows for novel features, such as non-algorithmic properties, to emerge from the whole process. This provides a ground for addressing as-yet-unexplained philosophical issues in the areas of foundations of quantum mechanics and philosophy of mind through an information-based approach.

Furthermore, the notion of pragmatic information theoretically draws a clear-cut distinction between the natural living and natural non-living systems on the one hand, and natural living and artificial systems on the other. This can successfully address many philosophical issues in the areas of philosophy of artificial intelligence and philosophy of biology [3].

One may also target the key claim of this paper, *i.e.*, the view that artifacts represent the original information that we put into them by creating or designing them. One may object that the premise that humans made device D does not license by way of conclusion about what D can or cannot do, or what it embodies. In general, this is true. However, at least in some cases, device D may truly represent some aspects of the mind of its generator(s) by embodying such aspects. For example, a nuclear submarine can truly represent (embody) the complexity of the minds of its creators; a book embodies the communicable aspects of the meaning in the mind of its author; a painting would embody the visual/perceptual aspect of the mind of the painter or, as I stated earlier, a computer can truly embody the algorithmic aspects of the minds of its generators and programmers.

The above idea would be even more acceptable when we think of the relationship of the creator and the artifact in the context of Bohm's notion of active information as modified on the basis of pragmatic information in this paper. This modification suggests that the direction of the extension of the notion of active information must be reversed: The notion of active information must be extended from the mind of the biological creator, as an original information-based system, to the artifact in which, for example, the quantum potential as a pattern guides particles in the double-slit experiment. This is the requirement imposed by pragmatic information as I have developed it in the paper.

## 6. Conclusions

The orthodox formalism of quantum mechanics can be constructed by analyzing the Feynman path integral formulation. The interpretation associated with the Feynman path integral formulation (the Neo-Copenhagen interpretation) allows for more conceptual ontological ingredients [50] than the Copenhagen interpretation associated with the orthodox formalism of quantum mechanics. Likewise, despite the fact that the de Broglie-Bohm path integrals (with real, physical paths) and the Feynman path integrals (with non-physical paths) originate from completely different conceptual bases, the Feynman path integrals can also be constructed directly from an analysis of the de Broglie-Bohm path integrals [51]. The interpretation associated with the de Broglie-Bohm theory allows for a full realistic ontological description of mechanisms and processes of individual quantum systems.

From a philosophical point of view, as we move from the Copenhagen interpretation toward the Bohmian interpretation via the Neo-Copenhagen interpretation, the significance of ontology over epistemology increases. However, this ontological journey must not end here. There is one more step to be taken, *i.e.*, to include "mind" and its phenomenal aspect as the reality represented by the double-slit experiment in the form of the quantum potential. Pragmatic information as depicted here prevents us from attributing the quantum potential to contain genuine active information. The only genuine information-based interactions occur in the living systems.

The proposal of this paper, then, is that the active information contained in the quantum potential in the double-slit experiment is constructed through a setup arranged by an originally intentional, purposeful mind without which no information-based interaction would occur. The non-classical, bizarre features of the quantum potential would then represent the non-algorithmic aspects of the mind of the setup provider.

The whole idea is summarized in Table 1. A setup provider (maker) that must ultimately be a purposeful biological system, arranges a setup for an artifact such as the double-slit experiment. The active, observer-dependent, derived information that is processed in the artifact, then, represents the active, observer-independent, original information driven interactions occurring in the mind of the setup provider.

**Table 1.** Different elements involved in the production of an interpretation of quantum mechanics and its usage and the associated information in each element.

| Elements / Information | Maker | Artifact | Formalism | Interpretation | User |
|---|---|---|---|---|---|
| Original | × | | | | × |
| Derived | | × | × | × | |
| Active | × | × | | | × |
| Passive | | | × | × | |
| Observer Independent | × | | | | × |
| Observer Dependent | | × | × | × | |

Since artifacts are observer-dependent, quantum formalisms and the associated interpretations can be different. Information in the formalisms and interpretations plays a passive role; it is information for us, the observers. The "user" that again must ultimately be a biological system, would complete the whole process.

Applying the above thesis to Bohm's interpretation, then, provides a new qualitative interpretation of quantum mechanics. It also provides a new theory of the relationship of mind and matter which does not lead to panpsychism.

## Conflicts of Interest

The author declares no conflict of interest.

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25. Later, it also appeared in e.g., Bohm and Hiley [26] and Holland [27] although the presentation of the theory as to the notion of the quantum potential showed differences.
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41. See also [26] and [30] for further details.
42. Such interactions, for example, violate Newton's third law of motion: Particles remain passive and do not exert reciprocal reaction to the action of quantum field on them. The quantum potential also affects particles non-locally which is prohibited in the macroscopic world. Also, contrary to the notion of classical field, the effect of the quantum potential on particles depends only on its form not on the intensity of the quantum field.
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44. In [30] (Section 5), Bohm discusses quantum transitions independently of the preparation of the initial state by a human being. In doing so, he considers an atom which is to jump from one stationary state to another. Clearly, according to pragmatic information, this has to do with the *passive* role of information, namely the way we describe nature. We can also provide an experimental setup in which exactly the same event happens, *i.e.*, an atom jumps from one stationary state to another. Here, we need to define a setup for a univocal pattern-change correspondence. The change in this case is the transition of the atom to another stationary state. In this case, information plays an *active* role. The formalism Bohm provides is correctly applicable to both natural and informational events. However, the formalism and the corresponding interpretation Bohm provides result from what we have witnessed in the laboratory. Then, Bohm takes the next step generalizing such a formalism and interpretation to the events occurring in nature. While such a generalization is legitimate from physical point of view, it is not acceptable from the perspective of pragmatic information. In other words, while the formalism and physical interpretation are the same for both events, the informational interpretation, according to pragmatic information, is not.
45. Searle, J. *The Rediscovery of the Mind*; MIT Press: Cambridge, MA, USA, 1992.
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48. One should distinguish between the process of assigning computational interpretations to systems by an original information-based system and any form of the documentation containing such an assignment. When we assign computational interpretations to systems we are dealing with the passive role of information. Once such assignments are recorded, e.g., in a book or paper, the book or paper counts as an artifact in which "information" is derived but plays an active role.
49. However, note that all this does not mean that the brain is a digital computer. Computation and syntax are observer-relative concepts and "[e]xcept for cases where a person is actually computing in his own mind there are no intrinsic or original computations in nature. When I add two plus two to get four, that computation is not observer relative. I am doing that regardless of what anybody thinks. But when I punch: "2 + 2 =" on my pocket calculator and it prints out "4" it knows nothing of computation, arithmetic, or symbols, because it knows nothing about anything. Intrinsically it is a complex electronic circuit that we *use* to compute with. The electrical state transitions are intrinsic to the machine, but the computation is in the eye of the beholder. What goes for the calculator goes for any commercial computer. The sense in which computation is in the machine is the sense in which information is in a book" [46] (p. 91–92).

50. Though such ontological ingredients have merely instrumentalistic functions and are not considered as physically real.
51. Oltean, M. De Broglie-Bohm and Feynman path integrals. *Waterloo Math. Rev.* **2011**, *1*, 19–31.