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Geometroneurodynamics and Neuroscience

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ABSTRACT: The Orthodox Interpretation of quantum mechanics, as developed by many physicists, particularly John von Neumann, addresses the role of measurement, available choices and response of the quantum system to questions posed by an observer in specific quantum laboratory experiments. As such, it is, more consistent and clearer than other interpretations of quantum mechanics and it provides an account of the interactions of observers with the external world. However, in order to explore whether quantum mechanics plays a role in the brain, which is the primary issue, one has to examine the applicability of Hilbert space structure as a valid geometric description of neurodynamics. Here, we re-visit previous work involving the orientation selectivity of neurons, which constructed a type of statistical distance function, in agreement with quantum formalism. This is proportional to the usual distance (or angle) between orientations of the neurons. The equivalence between the statistical distance and the Hilbert-space distance was developed before. As such, it gives rise to the possibility of reanalyzing the issue of measurement and information processing in the brain function, what is termed geometroneurodynamics. Several issues of this geometrical approach are examined and work that needs further development identified, such as measurement and observation, what is Nature and who the observer is, all of course relevant to functions of the brain. Extending Orthodox quantum mechanics to neurodynamics may be the ontological opening to the relevance of universal non-dual Awareness, examined in previous works.

KEYWORDS: Brain Dynamics; Neuroscience; Consciousness; Mind; Quantum Mechanics; Philosophy; Orthodox Interpretation; Hilbert-space; von Neumann; Measurement Problem; Qualia; Subject/Object; Fundamental Mathematics; Universal Principles

INTRODUCTION

The discussion here follows the work of Kafatos and Yang (2017). Quantum mechanics (QM), and its modern evolution, quantum field theory (QFT), remain the most successful theories of matter, accounting for both the microcosm and the macrocosm (in addition to General Relativity for the latter). QM has many profound implications for the role of the mind, free choice, measurement and the role of observation. It also opens the door to the entire issue of the nature of consciousness. The nature of the mind, its origin, whether there is fundamental consciousness or Awareness which exists beyond the mind and the brain, these are vexing issues for science, including physics, neuroscience, brain science, and biology as well. In addition, the problem of subjective experience, what are *qualia*, is not accounted by current science and it may even be beyond physical processes. We have the peculiar issue that QM, relevant to physics and biochemistry, is not considered to be important in the brain, other than cellular biochemistry.

QM opened the door to the view that the mind plays a fundamental role in the nature of reality (cf. Kafatos and Nadeau, 2000). The quantum measurement problem (cf. von Neumann, 1955) and the role of the observer (cf. Kafatos, 2015) remain challenges for both theory and different interpretations of quantum experiments.

Observational choices in the laboratory are related to the context of what is to be observed, measured, and concluded. Wheeler (1981) famous statement, "no phenomenon is a phenomenon until it is an observed phenomenon", forms the foundation of the participatory quantum universe. We can state that the observer's choices play a fundamental role in the "external" reality (whatever that means) that one observes, that theory cannot be separated from observations, and that the observer is an integral part of the processes involved in what to be observed and understood theoretically. As Kafatos and Yang (2017) emphasized, what used to be in the domain of philosophy and metaphysics (cf. Kant, 1996), involving questions such as the origin of the mind, the nature of consciousness, and how consciousness arises, can now be approached by science or to be more precise, through a discussion between science and philosophy.

In Immanuel Kant's philosophy (cf. Kafatos and Yang, 2017; Kafatos, 2015) experience is taken as fundamental. In Kant's view, "one never has *direct* experience of things, the so-called *noumenal* world; what we do experience is the *phenomenal* world as conveyed by our senses." (Kafatos and Yang 2017). Kant's philosophy which is tied to experience, supports the idea that qualia, the attributes of experience, play a fundamental role in our views of reality. This idealist view of the world is also a central feature of the philosophy of Georg Wilhelm Friedrich Hegel (cf. Redding, 2014). Hegel's philosophy connects to modern complementarity, one of the three universal principles discussed in Kafatos (2015).

Finally, the emergence QM had a profound influence in the philosophy of Alfred North Whitehead (1925, 1978). His ideas mesh well with the foundations of quantum mechanics, with the view that reality consists of events rather than matter, and that "events cannot be defined apart from their relations to other events". This rejects the belief that reality is fundamentally constructed by "particles" of matter, existing independently of each another. The connection of Whitehead to QM has been pointed on numerous occasions by Henry P. Stapp (2007, 2009, 2017).

ORTHODOX QUANTUM MECHANICS

In *Quantum Theory and Free Will: How Mental Intentions Translate Into Bodily Actions* is Stapp (2017) develops the thesis of the connection between the physical and mental worlds. He makes the case that not is QM not just a most successful theory of the microcosm but perhaps more important, it connects Reality to ourselves in a most fundamental way. Specifically, it gives meaning to observational choices to explore physical interactions of quantum systems, it puts these choices and the free will that they presuppose into the very fabric of scientific inquiry. In a sense it provides a framework connecting all levels of experience. These points were brought out in the early versions of twentieth century QM (cf. Kafatos and Nadeau, 2000), what we now know and accept by the term Orthodox Interpretation of QM. The specific interpretation of QM, and there are several such interpretations, developed from the original Bohr's (1934, 1958) Copenhagen Interpretation (CI) primarily through the work of Werner Heisenberg and John von Neumann. The Orthodox Interpretation developed into a world view that brings in the role of observation, measurement and free choices, to just mention some of the most important aspects of the quantum world, as important as specific predictions of dynamics and evolution of quantum systems. These predictions are so accurate and wide ranging, that physicists even today, more than a century after the beginning of the quantum revolution, focus on the scientific results and often bypass or ignore the profound implications of the quantum paradigm.

The Orthodox version which enhanced CI and replaced it (cf. Tomonaga, 1946: Schwinger, 1951), addresses the role of measurement, choices and the response of the quantum system. It is, more clear and comprehensive than other quantum views on the interactions of observers with the external world. As eloquently shown in numerous publications, the Orthodox Interpretation does a lot more than just account for physical interactions in the atomic world, which was the aim of the original QM in the early part of the twentieth century.

The Newtonian view that the universe operates like an intricate mechanical clock, presupposes that an atom has at each instant of time, a well-defined location in 3D space. Kafatos and Nadeau (2000) showed that the one-to-one correspondence between physical aspects, assumed to be "real" and theory describing such physical aspects, is an ontological assumption. In the Newtonian view, physical properties are completely determined by prior physical properties, and there is no input or role from our conscious thoughts. Werner Heisenberg emphasized that in the Newtonian universe "*mental*" realities are completely determined by the *physically described* properties of the associated brains and nervous systems (Stapp, 2017).

In the Orthodox view, QM is be based on properties that we can choose to measure—this is where "free choices, not determined by "physical" laws alone, enter the picture. The mental aspects of psycho-physical observers are paramount, and the classical view seems unnatural (Stapp, 2017). Heisenberg, on the other hand, held the view that "potentialities" for certain experiences are occurring. As such, QM opened the door for observers to actively participate in the universe, rather than being passive observers at best and separated from it, as classical physics assumed.

As Orthodox QM assigns primacy to mental choices, one has to look for connections between the dynamics of cognition (brain dynamics) and the dynamics of the physical system being observed. This is not a trivial task and most physicists as well as scientists dealing with neural processes and the structure of the brain, shy away from it. It is undeniable that modern neuroscience has made great strides in our understanding and treatment of neuronal disorders and syndromes, psychophysical conditions, in looking for connections to well-being, mental health, in assisting psychotherapy and by extension striving to reach an understanding the entire human being, which crucially depends on a well-functioning brain. However, it has achieved precious little in our understanding how subjective experience, decision making, and free will arise, which are central to the Orthodox QM and how they all relate to the physical brain and our entire psychophysical existence.

To begin to address these complex issues, we look at neuroscience as the modern version of the science of physical processes in the brain. What is in order is to briefly study the structure of the brain and look at issues of free will memory, which must play a role in observational choices.

BRAIN DYNAMICS AND NEUROSCIENCE

The brain spans more than nine orders of magnitude in spatial extent and corresponding timescales related from the sizes of neurons, to atomic scales. Starting at the top of spatial scales, we have the structure of the *Triune Brain*. Neurologist Paul D. MacLean (1985,1985b) formulated the corresponding model, according to which the skull holds not one brain, but three actual components. These components (cf. Kafatos and Yang 2017) each represent a distinct evolutionary stratum, namely: Primitive Brain (Reptilian Complex), The Limbic System (Old Mammalian Complex, or Paleomammalian), and The Neocortex (New Mammalian Complex, or

Neomammalian). The division of the brain into three large components is of course a highly simplified conception and may not tell us much in terms of actual brain processes, beyond how perhaps the brain evolved. However, functionally the connectivity between all three components is at least as important or more important, if we are to understand in general terms the dynamics of the brain.

The connection to QM may begin with functionality. Distributed functionality is natural in the quantum paradigm, although the specifics are of course a different story. It is true in a sense that the Triune Brain model is a highly simplified explanation of brain activity and organization. It, however, formed a very influential paradigm, and forced a rethink of how the brain functions, and as such it cannot be ignored in brain dynamics.

The three large brain components (Kafatos and Yang, 2017) have the following characteristics (cf. the Neuropsychotherapist, NPT):

The *Primitive Brain (Reptilian Complex)*, is responsible for the most basic survival functions and overall parameters, such as breathing, heart rate, body temperature, etc., as well as providing a sense of orientation in space. The functions of this part of the brain take precedence over other brain areas and functions.

The *Limbic System (Old Mammalian Complex, Paleomammalian)*, often referred to as the "emotional brain", is the reactive part of the human brain responsible for "fight or flight" responses to present danger. In fact, the hippocampus, the amygdala and the hypothalamus form a very fast subconscious evaluation and response system designed for safety. "The amygdala makes very fast, albeit not always accurate, evaluations and has a fast track from the thalamus (incoming information) through to the hypothalamus that can initiate a stress response to forestall impending doom. The hippocampus plays an equally important role by encoding events in time and space and consolidating them from short-term to long-term memory" (cf. Kafatos and Yang, 2017).

The *Neocortex (New Mammalian Complex, Neomammalian)*, is responsible for all higher-order conscious activity such as language, abstract thought, imagination, and creativity, it is in other words, the advanced intelligence brain. It houses much of a person's memory, all of the automatic memories essential to talking, writing, walking, playing music, and many others. The prefrontal cortex is much slower in responding to incoming information than the limbic system, but is much more sophisticated in its processing as clearly needed in higher functionality. It is such "slow" thinking which is the hallmark of our human intelligence. On the other hand, such higher functionalities and their locus, the prefrontal cortex, can be "hijacked" by the limbic system in the event of a perceived threat (Kafatos and Yang, 2017). Our prefrontal can "go offline" as blood flow is directed to the deeper limbic system, the first priority of the responder to keep us safe.

Memory is distributed across the entire brain, depending on the functions, such as motor memory, higher order memory, etc. For example, the limbic system keeps memory of time and space as well as emotions, i.e. it is responsible for many *qualia* (see below) of experience.

Regarding the specifics of memory and decision making, neuroscience presents a great opportunity to go beyond the most basic brain dynamics and link up to small scale processes, the hallmark of QM. There are several specific works which have examined "where" memory might be associated in the brain (cf. Memory reference). Researchers and psychologists linked to Karl Lashley's work (Dewsbury, 2002), have studied where memory is associated. They have been searching for locating the *engram*, a hypothetical permanent change in the brain accounting for the existence of memory, a memory trace, in other words the physical trace of memory. Lashley did not locate the engram, but did suggest that memories are distributed throughout the entire brain rather than stored in one specific area and as such his contribution is important for historical reasons and to develop a proper neuroscience approach to memory.

Three brain areas (namely the cerebellum, the hippocampus, and the amygdala) play significant roles in the processing and storage of different types of memories, with the following emphasis in encoding: Cerebellum: procedural memories. Hippocampus: new memories. Amygdala: what memories to store and where to store them, based on the strength of the emotional response to specific events. It is believed that strong emotional experiences often trigger a release of neurotransmitters and hormones, which strengthen the corresponding memory although autobiographical memory is not always accurate.

St Onge et al. (2012) discussed "where" decision-making takes place or more correctly how it is associated with the brain. In risk-based decision making, separate prefrontal-subcortical components mediate such decision making. Different biases enter the picture involving more certain or riskier options. Here choices (which would relate to what we can call "free will") are made.

What does neuroscience say about free will? Briefly, as this is truly a vast subject, MacLean's model of the brain provides valuable insight for understanding the biological roots of human social behavior and communication. However, it is not clear if it provided connections between the natural and the social sciences, which would seem necessary. Orthodox QM, on the other and, naturally addresses the entire issue of free will (Stapp, 2017). We know that emotions, memory, which is affected by emotions, neuronal conditions, all affect choices and free will. How "free" is our will depends on what type of decisions we face, the context of such decisions and patterns that exist in the psychophysical human beings. The connection to Orthodox QM is in the beginning stages.

GEOMETRONEURODYNAMICS

The following three sections are discussed in greater detailed in Roy and Kafatos (2003). Here we summarize the main findings.

Progress in brain research indicates (Roy and Kafatos, 1999, 2003, 2004) that to apply the wave function formalism used in quantum mechanics, it is necessary to consider relevant Hilbert space structure. One then needs to consider first the geometric structure over the cortical surfaces of brain from the anatomical point of view (Roy and Kafatos 2004), and then its relation to Hilbert-space structure. As Roy and Kafatos (2003) emphasized, no systematic attempt had been made to construct the geometric structure, starting from the neuronal characteristics over the cortical surface of brain and its connection to Hilbert space. The effort to accomplish this is what is meant by *Geometroneurodynamics*.

Amari (2001) studied the geometrical structure of the neuromanifold, involving the multilayer perceptrons (algorithms for supervised learning of binary classifiers, as functions that decide whether an input belongs to one class or another, a type of linear classifier), using an information theoretic approach. In Amari's (2001) approach, a family of neural networks constitutes of neuromanifold with different probability distributions. Using a Baysian approach, Amari (2001) constructed a Reimannian metric tensor and applied this concept to the behavior of learning as well as statistical inferences over the neuromanifold. Roy and Kafatos (2003) examined different works and pointed out the difficulty to define a smooth metric tensor globally, over all the cortical surfaces of the brain, due, among others, to the existence of nonlinearities in many if not all cortical surfaces.

Geometroneurodynamics as Roy and Kafatos (2003) pointed out, aims to study the possibility of assigning non-linear geometrical structure over the cortical areas of the brain. To accomplish this, they approached the problem by considering neurodynamics from the physiological point of view and then by attempting to construct the corresponding Hilbert structure for the cortical surface of brain. The appropriate wave function for the neurons in the brain can be defined in Hilbert space as a geometric description of different cortical areas of the brain. The main fact lying behind the idea is that cells in different parts of brain, for example, the visual cortex exhibit orientation selectivity (cf. Hubel 1995). The orientation selectivity of the cells is similar to polarizing filters producing beams of polarized photons in physics laboratory experiments, including non-locality experiments (Kafatos and Nadeau, 2000).

Roy and Kafatos (2003) examine the notion of statistical distance as related to distinguishability of different oriented states of the cells in the cortical areas. They of course emphasized that they were not attempting to explain the issue of consciousness as such. Rather, the aim was to develop a possible theoretical framework within quantum mechanics to provide understanding of certain brain processes, which for sure do not appear to fit the classical paradigm. In the following sections, following Roy and Kafatos (2003, 2004), the orientation selectivity of neurons as well as the relation between statistical distance and Hilbert space are examined, including the spontaneous activity of neurons.

NEURONS, STATISTICAL DISTANCE, MEASUREMENT AND BRAIN FUNCTION

In addressing the issue of orientation selectivity of neurons, it becomes useful to address the concept of statistical distance. The reason is that there is a very large variety, as well as a large number of neurons, in the brain. Collective effects can only be accounted for in terms of statistical considerations (Roy and Kafatos, 2003, 2004). Experimental evidence points to more than 100 different types of neurons in the brain, although the exact number is not fully known. In neuroscience, it is found that no two neurons are identical, and it becomes very difficult to say whether any particular difference represents more a difference between individuals or a difference between different classes.

Neurons are often organized in clusters containing the same type of cell. The brain contains thousands of cluster cell structures which may take the form of irregular clusters or of layered plates. One such example is the cerebral cortex, forming a plate of cells with a thickness of a few millimeters. In the visual cortex itself (Hubel,1995), certain clear, unambiguous patterns are found in the arrangement of cells with particular responses.

The geometroneurodynamics approach can apply to non-visual neurons, however the applicability to neurons in the visual cortex is more natural as the visual cortex is smoother preventing nonlinear effects. As the measurement electrode is moving at right angles to the surface through the grey brain matter, cells encountered one after the other are found to have the same orientation as their receptive field axis. From a large series of experiments in cats and monkeys, it is found that neurons with similar receptive field axis orientation are located on top of each other, in discrete columns, while we a continuous change of the receptive field axis orientation occurs as one moves into adjacent columns.

In the monkey striate cortex, about 70 to 80% of cells have the property of orientation specificity. In a cat, all cortical cells seem to be orientation selective, even those with direct genuculate input (Hubel, 1995), while Hubel and co-worker Wiesel found a striking difference among orientation-specific cells, not just in the optimum stimulus orientation or in the position of the receptive field on the retina, but also in the way cells behave.

The first oriented cell recorded by Hubel and Wiesel (Hubel,1995) which responded to the edge of the glass slide, was a complex cell. The complex cells seem to have larger receptive fields than simple cells, although the size varies. Both type of cells do respond to the orientation specificity. There are certain other cells which respond not only to the orientation and to the direction of movement of the stimulus but also to the particular features such as length, width, angles etc.

Pribram (1981) discussed the question whether single neurons serve as feature or channel detectors. Pribram and his collaborators (1981,1991) made various attempts to classify "cells" in the visual cortex. This as Roy and Kafatos (2003) pointed out proved to be impossible because each cortical cell responded to several features of the input, such as, orientation, velocity, and the spatial and temporal frequency of the drifted gratings. Further, cells and cell groups displayed different conjunctions of selectivities. From these findings and analysis, he concluded that cells are not detectors, and that their receptive field properties could be specified but the cells are multidimensional in their characteristics (Pribram, 1991). Thus, the pattern generated by an ensemble of neurons is required to encode any specific feature.

When dealing with the problem of perception, Freeman and his collaborators (1991) suggested that perception cannot be understood solely by examining properties of individual neurons i.e., by using microscopes as currently is the dominant approach in neuroscience research. Freeman claimed that perception depends on the simultaneous, cooperative activity of millions of neurons spread throughout vast expanses of the cortex. Such global activity can be identified, measured and explained only if one adopts a complementary approach of both a macroscopic view, alongside a microscopic (building up) view.

For a Hilbert space description, one can define the notion of distance between the "filters" as in a non-locality experiment, or the orientation selective neurons in the similar manner i.e., to the statistical distance between two quantum preparations, as introduced by Wootters (1981). The statistical distance is most easily understood in terms of photons and polarizing filters, as is common in many quantum experiments: for example (Roy and Kafatos, 2003), let a beam of photons be prepared by a polarizing filter and analyzed through a nicol prism. Let the angle ϕ in the interval 0 to π be the angle by which the filter has been rotated around the axis of the beam, starting from a standard position ($\phi = 0$) referring to the filter's preferred axis being vertical. Each photon, when it encounters the nicol prism, has exactly two options: to pass straight through the prism (the "yes" outcome) or to be deflected in a specific direction characterized by the prism (the "no" outcome). If ones assumes that the orientation of the nicol prism is fixed once and for all in such a way that vertically polarized photons always pass straight through, then, by counting how many photons yield each of the two possible outcomes, an experimenter can learn something about the value of ϕ through the usual formula the formula $p = cos^2\phi$, where p is the probability of "yes" (Wootters 1981), as used in quantum theory.

Roy and Kafatos (2003) then by following this analogy in the case of oriented neurons in the brain, i.e., as if the filters are oriented in different directions like oriented analyzers, proceeded to define the statistical distance. The experimenter's uncertainty in the value of p causes the experimenter to be uncertain as to the actual value of If the uncertainty could be reduced to zero, one would effectively have an infinite number of distinguishable orientations. This is, however, not the case. We direct the interested reader to the full details, including the definition of statistical distance, in Roy and Kafatos (2003). For example, the statistical distance is obtained by counting the number of distinguishable states and they emphasize, this does not have a priori anything to do with the usual notion of distance (or angle) between ϕ_1 and ϕ_2 which is, of course, $|\phi_1 - \phi_2|$. However, it can be shown that after all these two types of distance are the same.

Now, if one demands that the statistical distance be proportional to $|\phi_1 - \phi_2|$, the $cos^2\phi$ dependence of the probability function necessarily follows and it is possible to define information measure according to the above prescription. This can be reduced to Fisher information measure in a limiting case. An important point follows, with these developments regarding the distance measure, the detailed study of orientation selectivity of neurons might shed new light on the issue of information measure, suitable for the description of activity of brain and information processing (Roy and Kafatos, 2003).

Linking statistical distance and Hilbert Space, it can be shown (Wootters, 1981) that the statistical distance between two preparations, is equal to the angle in Hilbert space between the corresponding rays. The main idea is as follows: Imagine the following experimental set up, where there are two preparing devices, one of which prepares the system in a specific state, say 1, and the other prepares it in 2. The statistical distance between these two states can then be thought as the measure of the number of distinguishable preparations between 1 & 2. However, in treating quantum systems, new features should be observed as opposed to, say, just rolling the dice for a classical system. For dice, there is only one possible experiment to perform i.e., rolling the dice, whereas for the quantum system there are many, i.e., one for each different analyzing device. Furthermore, two preparations may be more easily distinguished with one analyzing device rather than with using another. For example, the vertical and horizontal polarizations of photons can easily be distinguished with an appropriately oriented nicol prism, but cannot be distinguished with a device whose eigenstates are the right and left handed circular polarizations. For this reason, one can speak of the statistical distance between two preparations 1 & 2 to be related to a particular measuring device, which means the statistical distance is device dependent.

Roy and Kafatos (2003) indicated that the statistical distance between two preparations is equal to the angle in Hilbert space between the corresponding rays. This equivalence between the statistical distance and the Hilbert space distance, gives rise to the interesting possibility that statistical fluctuations in the outcome of measurements might be partly responsible for the Hilbert space structure of quantum mechanics. In this way, the statistical fluctuations are as basic as the fact that quantum measurements are probabilistic in their nature, in agreement with Orthodox QM. Nonlinearity is neglected in Roy and Kafatos (2003), as they have adopted a statistical consideration which averages out nonlinearities. They considered the distance between the different clusters of neurons or between the ensemble of neurons only.

It is clear that the statistical distance can be related to the angular distance in Hilbert space by applying the concept of measurement in quantum mechanics, an important hallmark of the Orthodox view. Roy and Kafatos (2003, 2004 emphasize:

> One needs to address the issue of measurement in the context of brain function, to consider the Hilbert space structure needed for any kind of quantum formalism. This in turn is closely related to the information processing in brain function. The information generated by integrated neural processes and its measurement remains one of the central issues of brain dynamics and needs to be developed fully. Note that the measure of information, essentially depends on the basis of statistical foundation of information theory. One of the intriguing question arises is how far the statistical aspects of information theory can help one to assign a measure to differentiate the informative character of the neural processes without any reference to an external observer. The issue of external observer is debated in various branches of science and philosophy over the last century, since the birth of quantum mechanics. In the standard approach, one generally assigns a number to measure the information and probability of states of the system that are distinguishable from the point of view of an external observer. But the brain not only processes the information but also interprets the pattern of activities (Pribram 1991). Therefore, one must avoid the concept of privileged viewpoint of an external observer to understand the information processing in the

neural processes of the brain.

On relatively long-range scales, the $cos^2\phi$ law follows from the requirement that the statistical distance in case of neurodynamics is proportional to the usual distance (or angle) between orientations of a set of filters or a set of neurons. It may be possible that in case of neurodynamics, the statistical distance is equivalent to the Hilbert Space distance. Then one can apply the formalism of Hilbert Space structure over the cortical areas of the brain. Once this kind of Hilbert Space structure is accomplished over the cortical areas of the brain, it will then be plausible to define quantum processes to be valid underlying the neuronal dynamics.

IMPLICATIONS OF GEOMETRONEURODYNAMICS

It is evident from the above analysis of Roy and Kafatos (2003, 2004) that the law of probability related to the statistical distance is similar to the channel representation as considered by Granlund (1999). Some aspects of an object are sufficiently familiar in order to begin the process of recognition even for arbitrary orientations. This may be the reason why one is interested in the simultaneous appearance of similarity and difference in the properties of objects. A representation of similarity requires a metric or characteristic distance measure between items to be defined. Granlund (1999) defined one type of such distance which is related to channel representation.

In biological vision one can think of several examples for the properties like edge, line or orientation detectors. If we consider the channel output as derived from a band pass filter, we can establish a measure of distance or similarity in terms of the properties of the filter. For this channel representation, Granlund (1999) considered the measure for the output of the channel as $cos^2\phi$ where ϕ denotes the orientation of the filter. Debates about the applicability of the wave function formalism in quantum mechanics as well as the relevance of quantum coherence for the information processing in the brain in various regions like visual cortex, auditory regions, olfactory bulbs etc. are continuing.

Roy and Kafatos (2003) showed that Wootter's measure of information (and distance) is related to Fisher information measure, considered as the mother of all information measure, including Shannon's measure. Their approach regarding information processing in brain should be reanalyzed using the concept of statistical distance function. Many arguments and successful counter arguments (cf. Hagan, Hameroff, and Tuszynski, 2002), have been raised about the applicability of QM to brain dynamics or the application of quantum mechanical concepts. It is generally argued that the brain is warm and wet. The prevailing opinion seemed to be that the large warm systems in brain dynamics will rapidly lose quantum coherence and classical properties will emerge out as a result. This rapid loss of coherence (decoherence problem) would naturally be expected to block any crucial role of quantum theory in explaining the interaction between our conscious experiences and the physical activities of our brain. However, in the Orthodox QM quantum theory of mind (cf. Stapp, 2000a), based on the relativistic version of von Neumann's quantum theory, as we have been referring to, the Orthodox view, the efficacy of mental effort is not affected by decoherence problem. As discussed in several works, in Orthodox QM, briefly, two separate processes occur (cf. Stapp, 2000a):

> There are the unconscious mechanical brain processes governed by the Schrödinger equation which involves processing units that are represented by complex patterns of neural activity (or more generally, of brain activity) and, subunits within these units that allow "association" i.e., each unit tends to be activated by the activation of several of its subunits. The mechanical brain evolves by the dynamical interplay of these associative units. Each quasi-classical element of the ensemble that constitutes the brain creates, on the basis of clues, or cues, coming from various sources, a plan for having a possible coherent course of action.

OPEN ISSUES AND FUTURE DEVELOPMENTS

Orthodox QM has produced a paradigm wherein the mind plays a fundamental, participatory role in understanding and interacting with the universe. It has gone much further than other quantum ontological views. The question remains, can we go beyond the implied dualities? Is the separation between object and subject fundamental? What is the ultimate "stuff" or reality? Where is the "Heisenberg Cut"?

Can we express in a mathematical formalism the fundamental relationships between subjects and objects? If yes, it is important to understand the common framework that may be applicable to all levels of experience, as revealed primarily by the quantum nature of interactions but, by far, not limited to interpretations of QM. The world of experiences reveals three fundamental Laws of Nature applicable everywhere (Kafatos, 2015): *Complementarity, recursion and creative interactivity*. The three Laws *give meaning to the universe,* they are the workings of how Consciousness manifests the universe and apply at all levels, beginning with the fundamental subject – object relationships and the mathematics of Consciousness (Kafatos, 2015; Kafatos and Kato, 2017).

The ontologic framework of Consciousness or fundamental non-dual Awareness is described by Theise and Kafatos (2016):

> *Qualia* (from the Latin term *qualis,* which means "of what kind") are the fundamental components of how non-dual Consciousness projects out the

> universe and are at the heart of an experience-based philosophy of mind (Kafatos, 2015). The so-called "hard problem" (Chalmers, 1995) addresses the difficulty of accounting for experience in terms of physical theories and in itself implies the fundamental role of qualia. Erwin Schrödinger himself held the view that qualia are not material and cannot be accounted by material theories.

Moreover, Kafatos and Yang (2017) state:

> The "hard problem" of consciousness, rather than being a desperate statement, is, instead, a statement that experience cannot involve just the physical and, certainly, not the physical world view of classical physics. It begs a psychophysical approach, a *mental quantum reality.* Experiences or qualia in the world (Kafatos and Kato 2017) are the glue that holds the five senses (vision, audition, somatic sensation, gustation, olfaction) as well many other modalities, together and gives the appearance of an "external" reality. All experiences, whether of the body or the outside world, consist of qualia. Our world only exists because we perceive it and act as conscious agents (Kafatos and Kato, 2017). Thus, all interactions with the universe are experiential and subjective. What we call "objective" in science is that which we can measure within patterns of qualia dictated by mathematical laws. Quantum mechanics is a mathematical model for formalizing and measuring what are nothing other than experiences (cf. Bohr's, 1934 and 1958, view of reality).

There is no possibility of proving anything existing outside of qualia (Kafatos and Kato, 2017). Qualia are distinct and are tied to the experiencing individuals, they are *not* the same. They have *qualitative* differences, not subject to *quantitative* analysis. This is why qualia are associated with the "mental" realm (beyond physical, space and time). In fact, space, time, particles, all objects are nothing other than qualia when they are reified, i.e. possible subjective experiences. Mathematics itself is the most *refined* form of qualia. Even our neuronal system is a product of a possibility in consciousness, which has evolved as a mode for interpreting consciousness from a perspective that makes humans unique (Kafatos and Kato, 2017). The underlying world is pure non-dual Awareness, with no qualities, being the pre-created state, in fact the ever-existing state.

Extending the successful Orthodox framework in our view requires going beyond the object-subject separation. This is at the heart of the issue of subjective experience, as the very idea of experience blurs the "boundary" between the subjective and the objective.

> Rather than chasing an outdated world view of fixed boundaries, "hard" particles which are after all manifestations of probable outcomes, does it not make sense to take a *reasonable* or *common sense* approach? Quantum theory opened the door to the mental universe *but* cannot account for the nature of the mind, or consciousness or awareness. Simply put, we cannot "take out" the subjective

> experience from the practice of science (Kafatos, and Kato, 2017). In the end, it boils down as to what the ontological assumptions (or axioms) of a system of thought are. Bohr in the CI argued that QM is silent on this. He opted for an epistemological approach instead. As in the Orthodox QM (Stapp, 2017), we argue that ontology is *implied* in QM (Kafatos 2015) and presents with a new vision of reality wherein qualia play a fundamental role (Kafatos and Kato, 2017).

We note that several issues and questions need to be addressed by Orthodox QM as well as by the extended view of non-dual Awareness, beyond the duality that Orthodox QM implies. Is it not after all that a mental view of reality asks for a non-dual framework? The subjective aspect of qualia renders dual insistence to be outside the quantum framework itself.

Finally, as Kafatos and Yang (2017) pointed out:

> The vexing problem of collapse of wave function is a good starting point and in fact in the Orthodox QM it opens the door to mental view of the quantum universe, that competing versions such as the many-worlds Interpretation and Bohm's ontology do not possess. However, the collapse may be a special case as the work of Narasimhan and Kafatos (2016) who examined the quantum retrocausal experiments implies. In fact, this work points to the important issue of the (mental, in the fundamental Consciousness sense) informational nature of reality and the illusion of a separate observer in space-time. The information "space" can be termed the *plenum-void* and would also account for the existence of a transcendent field of mathematical structures, where the Laws of Nature reside. Nature itself would be the immanent complementary part of the non-dual field of Awareness.

The view proposed here and in previous works (Kafatos, 2011; 2015; Kafatos and Kato, 2017) is that working with physical theories alone will not lead to a unified framework addressing consciousness and such efforts are doomed to fail. The lesson from the quantum view of reality is that the implied world opens the door to mental phenomena through observational choices (cf. Bohr 1934; 1958; von Neumann, 1955; Kafatos and Nadeau, 2000; Stapp, 2007, 2009, 2017). It also opens the door to a true dialogue and interaction with the monistic schools of the East. And even though consciousness is *implied* in Orthodox QM, the theory is *agnostic* as to the nature of consciousness. The justification for a mathematical approach suggested by Kafatos (2015) and Kafatos and Kato (2017) is that *any* theory in science is based on mathematics and, therefore, to get as close as possible to formulate, or at least to attempt to formulate, a scientific view of Consciousness, we must start from mathematics. Mathematics also provides powerful constructs such as sheaf cohomology that physics theories lack.

Moreover (Kafatos and Yang 2017):

> In the new quantum paradigm, the mind, human beings, all life, matter. We are faced with a lot of consequences from the new paradigm, consequences which will likely open new opportunities for humanity to advance beyond the current era of strife and division. We cannot deny the power of our minds but at the same time we should be careful to not over-depend on belief systems, which are products of the mind, that are outdated, inconsistent and in fact dangerous for the very existence of humanity. The quantum paradigm, taken to its logical conclusion, gives meaning of life as it makes us all participants and actors in the drama of existence. The inclusion of the quantum element of random chance rather than being a hindrance to the understanding of the cosmos, actually gives meaning to life as it empowers us to use our free will. Extending the quantum paradigm will involve interdisciplinary and transdisciplinary approaches, enabling dialogue between quantum physics and neuroscience, between physics and biology, between science and philosophy, between science and perennial philosophies of the East and the West, between sciences and social sciences.

In conclusion, as Roy and Kafatos (2003) point out, quantum uncertainties entail that a host of different possibilities will emerge, welcome in the quantum universe but a hindrance in the classical universe:

> The meaning of geometroneurodynamics can be summarized in that the mechanical phase of the processing already involves some selectivity, because the various input clues contribute either more or less to the emergent brain process according to the degree to which these inputs activate, via associations, the patterns that survive and turn into the plan of action. This could provide hints on the issue of free will. In approaches examined, a Hilbert structure has been assumed in order to produce an evolution equation like Schrödinger equations. We like to emphasize that our approach gives rise to a new possibility to construct the Hilbert space structure over the cortical surface of brain from an anatomical perspective. However, the issues, like concept of measurement, the role of observer and information measures should be thoroughly analyzed in the context of brain before applying any kind of quantum mechanical formalism.

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