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Quantum Science and the Nature of Mind

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Later works of C.G. Jung contain comprehensive descriptions of the relationship between psychological and physical research. These considerations described in Jung's works and in his correspondence with Wolfgang Pauli represent interesting philosophical ideas that are related to interpretation of psychological data. The so-called "collective unconscious" studied by Jung in analysis of dream material, mythology, psychopathological symptoms, and several cultural manifestations led him to postulate complementarity and unity of scientific principles, and to define the psyche as complementary to physical reality. Likewise recent neuroscientific studies and physical analyses on the role of the observer in physical reality led to the study of "quantum consciousness." This review compares the philosophical postulates by Roger Penrose with Jung's and Pauli's studies, and suggests novel links of these concepts to recent findings of chaos theory in the brain.

Keywords: brain, mind, quantum physics

Recent neuroscience of mind deals with various philosophical approaches to the problem of consciousness. Traditional paradigms understand consciousness as a "material" function of neural substrate. Contrary to that, a new paradigm in psychology and neuroscience emphasizes mathematical realism, historically rooted in Platonic forms as an essence preceding any form of existence. This paper compares epistemological concepts contained in the psychological writings of Carl G. Jung and Wolfgang Pauli, and recent hypotheses of quantum consciousness in the work of Roger Penrose. The relationship between psychological and physical knowledge is a major subject of Jung's later works and is primarily formulated in his books *Aion* (1951/1972) and *Mysterium Coniunctionis*

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(1956/1989), as well as in correspondence with Pauli (Laurikainen, 1988). Jung and Pauli discussed philosophical concepts of psychological science mainly using the theoretical principles of quantum physics. Although at the time of Jung's and Pauli's collaboration, recent developments in neuroscience and physics were not apparent, Jung and Pauli proposed a conceptual framework very similar to the novel hypotheses posited in the study of consciousness by quantum theorists.

Brain and Consciousness

In a seminal paper on visual consciousness Crick and Koch (1992) express the view that the main problem of visual consciousness may not be resolved only as a simple consequence of synchronization among large groups of neurons. As a basis for that opinion they emphasize the so-called binding problem; a seen object in the brain is represented by groups of synchronized excited neurons that are located at different parts of the brain. This problem has emerged in connection to findings that features of an object such as color, shape, texture, size, brightness, etc. produce activity in separate areas of the visual cortex (Crick and Koch, 1992; Felleman and Van Essen, 1991; Singer, 1993, 2001). But it is not known how spatial convergency is needed for the synthesis of processed information that emerges — for example, there are only a few neural connections between specific visual areas that correlate with color and motion (Bartels and Zeki, 2006; LaRock, 2006; Zeki, 1994, 2003). The hypothetical center for information convergency was termed "Cartesian theatre" (Crick and Koch, 1992; Dennett; 1991). Recent neuroscience, however, has not located a distinct place in which distributed information in the brain comes together. Additionally, there is evidence that neocortical processing is distributed during all sensory and motor functions (Singer, 1993, 2001). Following these findings Dennett (1991) proposed "a multiple drafts" theory of consciousness model that does not define consciousness as a unitary process but rather a distributed one. Instead of a single central place — "Cartesian theatre," there are various events of content-fixation that occur in various places at various times in the brain (Dennett, 1991, p. 365). The evidence for this view of consciousness presents a whole series of experimental results in cognitive neuroscience and psychology (LaRock, 2006; van der Velde and de Kamps, 2006; Varela and Thompson, 2003; von der Marlsburg, 1996, 1999; Zeki, 2003).

Crick and Koch (1992) suggested that a new scientific framework for the study of consciousness comparable to the formulation of quantum mechanics in physics might be needed. Marshall (1989) proposed a non-conventional concept for the binding of distributed information — in fact, there exists neither classical physical structure nor neurophysiological substrate suitable for explaining consciousness. Instead Marshall focuses his attention on the "quantum wholeness" of initially interacting but (in the future) spatially distributed subsystems. In quantum reality the non-local instant correlations between spatially distributed parts of a system are possible, independently of any connecting signal between them that could explain the unity of consciousness during distributed information processing. Beck and Eccles (1992) suggest a similar proposal of neurotransmitter release from the presynaptic part of the neuron into the synaptic cleft that has a probability less than one. They interpret this probability as a consequence of the quantum "tunneling effect" that enables a particle to overcome an energetic barrier, which is higher than the energy of the particle (i.e., a phenomenon that is impossible to observe in our macroscopic world described by classical mechanics).

The predominant view in neuroscience of consciousness is that neuronal synchronization is a phenomenon that is necessary for the large scale integration of distributed neuronal activities. There is increasing experimental evidence that coherent neuronal assemblies in the brain are functionally linked by phase synchronization among simultaneously recorded EEG signals and that this time-dependent synchrony between various discrete neuronal assemblies represents neural substrate for mental representations such as perception, cognitive functions and memory (Lachaux, Rodriguez, Martinerie, and Varela, 1999; Varela, Lachaux, Rodriguez, and Martinerie, 2001). These functions are related to distributed macroscopic patterns of neuronal activity which involve multiple neuronal subsystems bound into a coherent whole (Braitenberg, 1978; van Putten and Stam, 2001). According to recent data, a mechanism that enables binding of distributed macroscopic patterns of neuronal activity, represented by neural assemblies, into the coherent whole is still unresolved and represents a fundamental problem in neuroscience (i.e., the binding problem: how the brain codes and integrates distributed neural activities during processes connected to perception, cognition, and memory) [Arp, 2005; Fidelman, 2005; Lee, Williams, Breakspear, and Gordon, 2003; Woolf and Hameroff, 2001]. The theory of feature binding originates with distributed coding and states that neurons involved in the processing of a single object will tend to synchronize their firing, while simultaneously desynchronizing their firing from the remaining neurons not involved in the processing of the object (von der Malsburg and Schneider, 1986). An essential feature of neuronal assembly coding is that individual neurons or subsystems can participate at different times in an almost unlimited number of different assemblies (Sannita, 2000; Varela et al., 2001); the same neurons can participate in different perceptual events — and different combinations of these neurons can represent different perceptual objects. Synchronization of these different perceptual objects is related to the integration of perceptions into a coherent whole (Singer and Gray, 1995). As a candidate mechanism for the integration or binding of distributed brain activities is the so-called gamma activity — high frequency oscillations of 40 Hz, but often varying from 30 to 90 Hz. This activity occurs synchronously across brain regions and underlies the integration of diverse brain activities (Singer and Gray, 1995). Although the majority of research on feature binding has focused on synchronous gamma activity, there is evidence that synchronous activities in other frequency bands may also participate in functional integration of distributed neural activities into the coherent whole (Bressler, Coppola, and Nakamura, 1993; Lee et al., 2003).

A solution to the binding problem may reside within the fundamental problem of consciousness in modern neuroscience. The predominant opinion is that consciousness emerges from a dynamical nucleus of persisting reverberation and interactions of neural groups (John, 2002). For example, Tononi and Edelman (2000) emphasize that consciousness is the re-entry of neural signals via changes of complexity and entropy in the central nervous system. Libet (1998) suggests that subjective experience represents a field emerging from neural synchronization and coherence, and is not reducible to any physical process (see also John, 2002). In accordance with Libet, Squires (1998) maintains that consciousness may be understood as a primitive component of the world including specific qualities of subjective experience (qualia) that can not be reduced to any other physical quality (see also Duch, 2005; John, 2002). According to Freeman (1991, 2000, 2001), the image of the world we have emerges as a consequence of creating order from non-linear chaotic activity of large groups of neurons. These nonlinear chaotic processes represent a consequence of high system complexity, when the system involves a large number of complexly interlinked and simultaneously active neural assemblies and runs in a desynchronized parallel distributed mode which can lead to self-organization (Freeman, 1991, 2000, 2001) and typical dynamical instabilities in mental phenomena (Atmanspacher and Fach, 2005). This non-traditional view provides the so-called "neurogeometry": a geometrical model of the functional architecture of the primary visual cortex and its pinwheel structure. The problem is to understand how the internal geometry of the visual cortex can produce the geometry of the external space (Petitot, 2003). The solution to the binding problem could principally be explained by a similar mathematical approach used in the general theory of relativity. Accordingly, the distance between two points measured by an observer is influenced by the physical state of the observed system. For example, when the observed system significantly changes velocity approximating the speed of light, the observer registers the distance contraction, time slowing and increased mass and energy. This effect of observer movement with significant acceleration leading to accumulation of high mass and energy is likely equivalent to the influence of gravitational field that presents Einstein's equivalency principle as a basic postulate of general relativity theory (Einstein, 1916/2005). For example, high mass and energy accumulated in a black hole cause similar effects of distance contraction (Einstein, 1916/2005; Penrose, 2004).

The problem of observation that plays part in "reality formation" explicitly emerges also in the quantum theory. Heisenberg (1958, p. 22) thought that the transition from the "possible" to the "actual" in quantum theory takes place during the act of observation. More explicitly, it was said by Bohr (1958, p. 81), who shortly presented a key consequence of the quantum theory that: "in the great drama of existence we ourselves are both actors and spectators." According to von Neumann (1955, p. 418), interpretation of the quantum theory requires the existence of a subjective (i.e., conscious) observer — the observer's mental activity influences physical processes.

More detailed description of the quantum process during the act of observation was developed by Bass (1975), who proposed a semirealistic neurochemical model that describes the entry of a datum into the consciousness of an observer that influences excitation of a nerve cell in the observer's central nervous system. Bass suggested that mind can induce muscular movements by choosing to note or not to note a relevant datum originating from specialized elements of the nervous system. The specific arguments for quantum description of the mind suggested by Mould (1995, 1998), who proposed that the conscious brains, similar to atoms or to black holes, are parts of the quantum mechanical universe. He proposed specific conditions and rules that define the conscious brain as an inside observer, in contrast to a conscious observer existing outside the system, and suggested that there exists a neurological mechanism responding to the presence of an inside observer with experimentally testable consequences. Further applications of the quantum physics in psychology and neuroscience were also suggested by Stapp (2005) who proposed that quantum theory could prove vital for experimental neuroscience.

These ideas in physics parallel a key concept in modern psychology formulated already by William James that mind is a part of the world and interacts with its brain during biological evolution (James, 1890/1983). This concept is particularly relevant for modern psychotherapy, which indicates that the mind develops during psychotherapy and may positively influence processes in the brain (Andreasen, 1997), and that stress-related psychopathology damages the brain as well (Teicher et al., 2003).

The different perspectives between external and internal observation and experience may imply that the spatial distance between two points in the brain must not be the same from the point of view of an external observer in comparison to an internal observer, which is the subject's mind itself. These effects could be mathematically interpreted as changes of space metrics caused by physical processes in the brain. Even time significantly changes during these processes — relativity theory provides heuristic possibilities to use space–time geometry as a description for the mind through the language of mathematics. Application of this heuristic to the brain implies that brain metrics from the point of view of the observer (brain as object), may not be the same as the brain's interpreter that enables consciousness. From this point of view the binding problem may be resolved by a non-existent distance among the parts of the brain from the view of brain's interpreter, because of different space metrics that enable brain synchronization and coherence. An analogous situation may occur in the so-called quantum non-locality. Non-locality, in principle, means entanglement between two initially interacting micro-objects across a distance with zero lag correlation. At this point both relativity theory and quantum theory, or their prospective synthesis looked for in the quantum theory of gravity, may be potentially useful for the study of brain and consciousness.

Quantum Brain and Quantum Gravity

Penrose has developed a system to formulate a quantum theory of gravity that is important for unifying quantum mechanics with Einstein's general theory of relativity (Hagan, Hameroff, and Tuszynski, 2002; Hameroff and Penrose, 1996; Penrose, 1989, 1994, 2001; Penrose and Hameroff, 1995; Woolf and Hameroff, 2001). The crucial problem is presented by the issue of measurement during microphysical processes in quantum mechanics. In a classical solution by Bohr (called the Copenhagen interpretation) a collection of possibilities (e.g., all possible trajectories connecting two spatially distributed points) in the development of a system (characterized by wave function Ψ) is reduced to one macroscopic actualized possibility (e.g., one of the set of possible trajectories) by measurement or observation performed on the quantum system (Laurikainen, 1988; Penrose, 1994; Wheeler and Zurek, 1983). This classical concept of reduction of the wave function led to the well-known Schrödinger's cat paradox. The paradox demonstrates the conflict between quantum theory and macroscopic observations performed on the quantum mechanical system. In a thought experiment, a living cat is placed into a box along with a bottle containing a poison. In the bottle is a very small amount of a radioactive material. If even a single atom of the radioactive material decays during the experiment, a relay mechanism with a radioactive detector will trip a hammer, which will, in turn, break the bottle containing the poison and kill the cat. The observer cannot know whether or not an atom of the substance has decayed and that the cat is killed. According to the Copenhagen interpretation, the cat is in a superposition of states and is both dead and alive (Penrose, 1994, 2004; Wheeler and Zurek, 1983). When the observer opens the box, the superposition is lost and the cat becomes dead or alive. According to Penrose, a solution of this problem can be found in the theory of quantum gravity that might explain the spontaneous (or objective) reduction of the superposition determined by inner process of a quantum system that is not caused by measurement or observation (Penrose, 1994, 2001, 2002).

That mathematical formulation of Penrose's ideas is linked to the theory of "Newtonian quantum gravity" that represents quantization of gravity in the classical (non-relativistic) space and time (Ghirardi, Grassi, and Pearle, 1990). Objective reduction, according to Penrose, is linked to non-computability which corresponds to an interpretation of Gödel's theorem. The theorem postulates that it is not possible to express the whole world by any system of mathematical axioms (Penrose, 1994). From the philosophical point of view objective reduction can be interpreted as a non-predictable spontaneous expression of a Platonic idea (or archetype) into the world of things; at this point Penrose's opinion is similar to Jung's or Pauli's view of archetypes as transcendental reality (Pauli called Ψ the Platonic world) that constitutes empirical reality (Laurikainen, 1988).

Penrose (1997, p. 1) wrote: "Since I shall be talking about the physical world in terms of physical theories which underlie its behaviour, I shall also have to say something about another world, the Platonic world of absolutes, in its particular role as the world of mathematical truth . . . as a structure precisely governed according to the ('timeless') world of mathematics." This problem, although formulated in modern language, leads to a dilemma: whether mathematical truth is only an idealization of the external world or represents a realistic entity. This is an old problem known from Plato's time — usually formulated as a conflict between realism and nominalism in medieval philosophical history. Nominalism emphasizes that abstract terms, general terms, or universals do not represent objective real existents, but are merely names. The problem of modern mathematics manifests itself in the dilemma whether mathematics is a language of description of the world or whether it is a law of the world. The remarkable ability of mathematics to describe the world may lead to the idea that the physical world emerges from the Platonic world of mathematics. In a similar way Penrose dealt with the role of objective reduction in brain functions: the functions enable us to create an inner psychological world, in a similar way as the external world of things is created. Penrose links this objective reduction process with quantum gravity. Because the quantum gravity state may enable the so-called quantum entanglement of distributed neurons, that approach may resolve the binding problem of distributed and synchronized neural populations (Crick, 1994; Crick and Clark, 1994; Penrose, 1994, 2001; Woolf and Hameroff, 2001). Penrose has drawn the model of biological coherent quantum states which was initially proposed by Fröhlich (1968, 1970, 1975; see also Marshall, 1989). These coherent quantum states, according to Fröhlich, are caused by electron conformational dynamics of proteins of the neural cytoskeleton (Penrose, 1994) and are linked to inter- and intra-cellular communication in the central nervous system (Zaccai, Massoulié, and David, 1998). Distributed information in the brain, according to this view, is "non-locally" linked by electron conformational dynamics of microtubule structures (Penrose, 1994, 1997). The principle of non-locality is analogical to Jung's principle of synchronicity that describes the temporally coincident occurrences of acausal events (Mansfield and Spiegelman, 1989, 1991). This principle of acausal connections was linked by Jung to archetypes and the collective unconscious, which represent a governing dynamics (analogous to chaotic self-organization) that underlie the whole human experience fragmented into divided states of consciousness (Bob, 2003b, 2004).

Unus Mundus of Psychological and Physical Knowledge

According to Penrose's hypothesis, psychic processes and consciousness emerge from the Platonic world of mathematics by process of objective reduction. Similarly Jung (1956/1989, p. 537) wrote: "Undoubtedly the idea of the *unus mundus* is founded on the assumption that the multiplicity of the empirical world rests on an underlying unity, and that not two or more fundamentally different worlds exist side by side or are mingled with one another." Jung thought that even the psychic world, which is extraordinarily different from the physical world, does not have its roots outside the one cosmos because causal connections exist between the psyche and the body that point to their unitary nature.

Jung thought that microphysics comes under the unknown side of matter, just as the psychology of complexes and archetypes is pushing forward into the unknown side of the psyche, uncovering underlying dynamics governing the human mind. According to Jung both lines of inquiry have yielded findings which can be conceived only by means of antinomies and developed concepts which display important analogies. Jung thought that if this tendency should become more pronounced, the unity of both disciplines would be probable. According to Jung's view, the empirical reality is as much physical as psychic and therefore neither, but rather a third thing, something transcendental. He conjectured that the background of our empirical world appears to be an *unus mundus* and that: "The transcendental psychophysical background corresponds to a 'potential world' in so far as all those conditions which determine the form of empirical phenomena are inherent in it" (1956/1989, p. 769). The epistemological views of both authors Jung and Penrose here converge. According to Jung the theory of archetypes is analogical to the "Platonic world" in which psychic contents and complexes originate in the archetypal background (von Franz, 1964, 1974). Similarly Penrose postulated that quantum-gravity processes in the brain lead to a reduction and expression of the "Platonic idea" into the world of things by the objective reduction in the brain. Jung and

Penrose using the modern language of science have expressed an old epistemological idea: the Platonic mathematical world incarnates into the physical world of objects as well as into the contents of the human mind. It may thus be that the so-called "brain centered" theories are not necessary for the study of consciousness (Tonneau, 2004) and the underlying physical processes important for consciousness in *principle* must not be included within existing neurophysiological concepts of brain processes.

Conclusion: Toward a Complementarity of Mind and Brain

According to philosophical tradition essence precedes existence but whether mathematical knowledge is only an idealization of the external world or represents an essence of the physical world is an open question of science. The dominant paradigm in psychology and neuroscience at present is neuronal materialism, although modern physics includes findings that lead to a substantial revision of our opinion about space and time. When we think of the complexity of the human mind and brain functions, it might be necessary to consider that modern mathematics and physics in their applications in the field of neuroscience may substantially change our understanding of mind and brain. For example, nonlinear mathematics and chaos theory in the field of neuroscience could explain brain complexity and interactions among neural assemblies. Because there is no rigorous border for (classical and quantum) chaotic fluctuations it is possible that the mental state related to quantum fluctuations may induce chaotic self-organization on neural or other hierarchical levels of the living organism with fractal structure (Basar and Guntekin, 2007; Courtial and Bailon–Moreno, 2006; King, 1991, 1997). From this point of view, an ultimate level of chaotic self-organization might originate in the process of wave function collapse that may cause the chaotic process of "creating information." This concept could potentially be supportive for the existence of consciousness as an entity "beyond" its neural correlates and its possible archetypal demonstration related to quantum phenomena (Kuttner and Rosenblum, 2006).

Chaotic transitions probably emerge in a wide variety of cognitive phenomena and likely reflect also the parallel, hierarchical and divided (or dissociated) structure of the mind (Bob, 2003b; Faure and Korn, 2001). According to Putnam (1997), retrieval of a dissociated mental state may lead to rapid changes in mood and behavior. Specific characteristics of these changes may be the chaotic shifts in neural dynamics with extreme sensitivity at the initial phase of the mental process (Bob, 2003b; Putnam, 1997) that can be assessed by nonlinear analysis of EEG or other psychophysiological measures such as electrodermal activity (Bob, 2007; Bob et al., 2006, 2009). For example, increased nonlinear behavior in electrodermal activity during hypnotic recall of dissociated traumatic memories from early childhood has been observed (Bob, 2007).

Werner Heisenberg thought that a revival of the Aristotelian concept of *potentia* was important for understanding of quantum physics; quantum entities did not possess positions and momenta but rather the potentiality for such properties when they were actually measured (Heisenberg, 1958; Wheeler and Zurek, 1983). The category of "potentiality" may represent a useful analogy for the neurobiological approach to consciousness. Consciousness from this point of view may be understood not only as an artifact of biological processes but as a complementary part of the material world of things. Accordingly, the mind as a self-organizing component of the neural system is linked to fundamental physical processes of self-organization within nature and the cosmos. This philosophical view extends the term complementarity as defined by Bohr; i.e., a concept that a single model may not be adequate to explain all the observations made of atomic or subatomic systems in different experiments (Isaacs, Daintith, and Martin, 2003; Wheeler and Zurek, 1983) — which implicates wave–particle duality for the description of quantum phenomena. Similarly, the complementarity and duality between the self-organization as analogue of Aristotle's *causa formalis* and *causa materialis* represented by chemical and subatomic structures is a prerequisite for description of living structures and brain organization. The complementarity between self-organizing mind and biological systems of the body represents an important postulate for psychosomatic processes which show that the disordered mind leads to illnesses of the body, and on the other hand, that destructive influences from the outside world disturb the mind and body self-organization. These processes might represent macroscopic analogues to objective (spontaneous wave collapse) or subjective reduction (caused by interaction with the outside world). From this point of view the complementarity principle for description of psychological and physical disorders is needed and represents a necessary paradigm for medical science and practice.

Mathematical realism in the theory of relativity and quantum mechanics negotiates naive realism and shows our seeing of the world as a special case of more general mathematical and physical laws. Similarly, applications of chaos theory in psychology and neuroscience — as well as early theoretical and empirical studies that focused on applications of quantum theory in neurobiological systems — represent a new paradigm for the study of consciousness.

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