Quantum Paradigms of Psychopathology

Quantum Logic of the Unconscious and Schizophrenia

Paola Zizzi* and Massimo Pregnolato†

ABSTRACT

We introduce a quantum logic for quantum information, which we identify with the quantum logic of the psychodynamic unconscious, amenable to formal characterization through the theoretical framework of Quantum Mind. We claim that this *sub rosa* quantum logic of the normal mind's unconscious domain is also the dominant, pathologically emerging logic of schizophrenia. We interpret Quantum Meta-language as speaking as a quantum control about such a quantum logic. We then suggest that psychotherapists might learn this formal Quantum Meta-language and apply it in practice in order to communicate more easily with schizophrenic patients.

Key Words: unconsious, schizophrenia, quantum metalanguage, object-language, basic logic, metathought, mind, non-computational mode, consciousness, dissipative quantum field theory, Penrose-Hameroff model

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Introduction

There appears to be a strong logical relationship between schizophrenic psychopathology and the unconscious domain of normal mentation. Bleuler (1911) observed in the cognitive phenomenology of schizophrenia, a diagnostic term which he himself had coined, "*loose*" logical associations. These were said to comprise a crucial part of the "formal thought disorder" intrinsic to that disease. In historically parallel work, Freud (1900) analysed some apparently illogical aspects of normal mental life such as dreams, jokes, and parapraxis. Freud identified these benign phenomena as sharply delimited echoes of unconscious psychodynamics in consciousness. He offered such innocuous conscious instances of "*illogic*" as evanescent surface evidence of the unconscious mind's subterranean "*primary process*" thinking, which by way of fundamental principles violates laws of classical logic, and which hence must invariably appear loosely associated or self-contradictory when viewed from a Boolean or Aristotelian perspective.

Such insights by Bleuler and Freud, still vibrant a century after they were offered, strongly suggest that the logic of the normal unconscious may be coextensive with the logic of schizophrenia. One might very plausibly suspect that, while healthy minds employ both the classical logic of consciousness and the quantum primary process logic of the unconscious, schizophrenic minds use primary process thinking not only in their unconscious psychodynamics but also as their dominant conscious operating mode. In this paper we formalize the logics of both the unconscious and schizophrenic thinking in order to make the case that they are the same.

Corresponding author: Massimo Pregnolato
Address: †Quantumbiolab – Department of Drug Sciences – University of Pavia. *Institute "Paolo Sotgiu": Quantitative and Evolutionary Psychiatry and Cardiology. †Faculty of Human Sciences, L. U. de. S University, Lugano, Switzerland
e-mail: massimo.pregnolato@unipv.it
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We can start by drawing upon recent empirical evidence indicating that the unconscious operates in a much faster manner than does conscious thought (Kennedy, 2010). This fact coexists with the recognition that sudden flashes of creative insight and other intuitive "leaps" arise from states of mind through intermediate steps that commonly remain hidden beneath consciousness. Such ultra-fast processing entailing hidden intermediate step is consistent with quantum computation. The logic of the normal unconscious mind and of schizophrenic consciousness may then be Lq, the logic of quantum information (Zizzi, 2010).

For a healthy mind the passage from the unconscious state to the conscious state is marked, according to the Orch-Or model of Penrose and Hameroff (Hameroff, 1996), by adecoherence of tubulin qubits. This may understood in terms of very fast switches from the quantum logic of the unconscious to the classical logic of consciousness. The present paper will argue that in schizophrenia these switches are not fast enough, and therefore the schizophrenic mind remains trapped in the unconscious logical mode too long.

In Lq, propositions are configured in qubits, quantum information units, which are linear superpositions of classical bits. It is in this sense that the formal interpretation of the unconscious mind may be potentially understood as quantum-informational. The quantum concept of truth within Lq is different from that of classical truth, insofar as classical truth is single-valued and deterministic while in contrast quantum truth manifests itself as many-valued (fuzzy) and probabilistic (Zizzi, 2012a).

The metalanguage of Lq, *i.e.,* that language which "*speaks*" about the language constituted by Lq, is a quantum metalanguage (QML) (Zizzi, 2010). This paper will embrace a physical interpretation of assertions in QML as field states configured by a dissipative quantum field theory (DQFT) of the brain (Vitiello, 1995; 2001). The metalinguistics of primary process thinking and related psychopathological phenomena should be well modelled by QML with particularly apt application to schizophrenia, in which a surplus of quantum propositions dominate classically logical discourse (Zizzi, 2012b). In such a framework it may be possible to introduce the theoretical notion of an Internal Observer (IO) (Zizzi, 2005a), which we will develop into a model for new potential discursive avenues of therapy.

This paper is organized as follows:

In Sect. 1, we give a general overview of the biochemical, neurobiological and pharmacological studies relevant to schizophrenogenesis.

In Sect. 2, we review the most important theories of the Quantum Mind paradigm. We discuss in particular the concept of quantum coherence in Quantum Mind.

In Sect. 3, we introduce an alternative concept of reality necessitated by Quantum Mind.

In Sect. 4, we discuss issues concerning quantum metalanguage, quantum control and weak measurements.

In Sect. 5, we set forth in detail the logic of quantum information.

In Sect. 6, we elaborate the desired features of unconscious logic.

In Sect. 7, we compare the concept of Truth-Observable with Penrose's mathematical truth and investigate the potentially therapeutic Internal Observer.

1. Schizophrenia: A General Overview

Schizophrenia (SCZD) is a serious, chronic and often disabling psychiatric disorder that affects about 1% of the population in the USA. In addition to gravely disrupting the lives of patients and their families, SCZD imposes a huge cost to society in terms of lost productivity and expenditures related to inpatient confinement, psychotherapeutic labor, and pharmacological treatment (Koyama, 2008; Chien, 2008).

It is known that dopaminergic hyperfunction in the limbic system and dopaminergic and glutamatergic hypofunction in frontal cortex play an apparent albeit potentially epiphenomenal role in the pathophysiology of SCZD. This knowledge notwithstanding, the deep etiology remains elusive. There is a strong genetic component with an estimated heritability of 80–85% (Sullivan, 2003). The Gage group published evidence of hiPSC neuronal phenotypic and gene-expressive changes associated with SCZD (Brennand, 2011) in support of the *"watershed model,"* whereby many different combinations of gene malfunction may disrupt potentially key pathways affected in SCZD.

Recently Monji (2009) reviewed the *"microglia hypothesis"* of SCZD. Immunological/inflammation activators such as interferon-gamma (IFN-γ) and lipopolysaccharide (LPS), induced by a variety of stressful events, activate microglia in the central nervous system, which in turn release pro-inflammatory cytokines and free radicals. These mediators are known to cause decreased neurogenesis, white matter abnormalities, and neuronal degeneration. Such microglia-neuron interactions may be an important factor in the pathogenesis of SCZD. Another very recent hypothesis posits involvement of essential fatty acids (EFAs) in the affinity of neurotransmitters and of other immunologically relevant molecules to brain receptors. The neural membranes contain phospholipids considered as reservoirs for the synthesis of specific lipid messengers triggered by neuronal stimulation or injury. These messengers in turn participate in cascades of signals that can promote neuronal injury or neuroprotection (Chang, 2009).

SCZD is also described as a *"disconnection syndrome"* associated with dysfunction of interneuronal coordination manifested by the electroencephalogram (EEG) and by fluctuations in local field potentials (LFPs) that are abnormal in both sub-cortical and cortical regions of the brain. It is important to note that oscillations at different frequencies and from disparate interactions may be correlated with the physiology and/or pathology of distinct classes of neurons and interneurons. Recent work by Jones shows that dysfunction of a particular class of interneurons, expressed through a calcium-binding protein, parvalbumin, and could possibly contribute to the wide range of neurophysiological and behavioral symptoms encountered in SCZD (Jones, 2010).

A deficit of working memory is considered to be a central feature of SCZD. Several recent articles have provided mechanistic computational and neurobiological models for the origins of these cognitive deficits. However, work by Gold (2010) shows that, although patients demonstrate a sharp reduction in the number of memorized elements within working memory, these cases do not differ from controls in the precision of their working memory representations as would be predicted by current neurobiological models of schizophrenia.

Apart from these recently identified neurochemical, physiological, and classical functional manifestations, and apart from the logical issues raised by "formal thought disorders", SCZD is well known as a state of being "out of touch" with reality. In this context, hallucinations experienced by patients suffering from SCZD and other psychotic disorders are commonly considered to represent a perceptual subset of detachments from reality with nonperceptual detachments categorized separately as delusions (Cocchi, 2011; Schneider, 1959).

2. The Quantum Mind

As reported in a recent Ciba Foundation Symposium (Bock, 2007), current mainstream theories about mechanisms underlying the clinical phenomenology of schizophrenia can be divided into four categories: neuroanatomic, neurochemical, cognitive, and symptomatic. In that context, it is noteworthy that a unifying, classically non-quantum theory relating the phenomena of conscious events and the biophysics of the brain has remained elusive even in principle. This conceptual barrier, which the philosopher David Chalmers has called "The Hard Problem" (Chalmers, 1995), continues to impede formulation of any orthodox theory which makes productive contact with the causal bases of subjective schizophrenic experience.

Fortunately, there are also several quantum theories of the normal mind, based on a shared premise subsumed by the phrase Quantum Mind, that quantum mechanics might be useful in accessing an understanding of the physical origins of classically emergent mental subjectivity and consciousness, which classical physics seems unable to explain (Vannini, 2008; Smith, 2009). In fact, Manousakis (2009) has presented a formalism to describe basic aspects of the first person perceptual experience, which parallels the features of quantum mechanics. Throughout the current paper, we will develop rigorous arguments in favour of the idea that quantum theory and its adaptations in Quantum Mind can provide powerful formal tools for constructing a therapeutically exploitable pathogenic theory of schizophrenia.

2.1 The State of the Art

Microtubules (MTs) and actin filaments can be viewed as computationally relevant nanowire networks that, operating within neurons, provide several functions, among them connection of the cell nucleus with the postsynaptic density (Woolf, 2010). Potential computational modes for MTs and actin filaments are emerging with two main quantum models for MT information processing having been proposed: the "double-well" potential, advanced by Craddock and Tuszynski (Craddock, 2009; 2012) and "Orchestrated Objective Reduction" (Orch-OR), put forward by Penrose and Hameroff (Hameroff, 1996; Penrose, 2011).

The approach authored by Craddock and Tuszynski is based on particular biophysical aspects of MTs. Tubulin possesses a dipolar momentum due to an asymmetric distribution of the molecule's electric charge; the MTs can undergo bifid conformational modelling in such a way as to orient the dipoles either in a photoelectric phase, with parallel alignment, or in an intermediate phase, whose weak ferroelectric character is similar to that of a spin-glass (Tuszynski, 1995; 1997; 1998). Craddock and Tuszynski describe classical and quantum processing of the information in MTs on the basis of a consequent a double-well potential inside the tubulin dimer. The double-well shape of this potential enables a mobile electron to pass over an energy barrier, transitioning from a ground state to an excited state, whereupon these states interact with MT lattice vibrations. It is acknowledged that isolation of the system from ambient thermal energy present at physiological temperatures would be necessary to allow these fragile quantum states to affect functionally robust neurophysiology and neuroplasticity (Craddock, 2010). Nevertheless, the model has been supported by Faber (2006), although he considers the MTs fundamentally as sub-neuronal classical informational systems. In reference to these proposals, we should remember that in the human brain there are 10^{10} or 10^{11} neurons, each of them containing 10^4 MTs, each made of the even smaller protein structures constituted by tubulin (10^8 per neuron).

The Penrose-Hameroff Orch-OR hypothesis, which has been investigated and revised for more than ten years, is associated with greater vetting, both in terms of sceptical examination and thermodynamic defense, than is the Craddock-Tuszynski model. In particular, much attention has been paid to the problem of thermal decoherence in Orch-OR, following objections appearing in a widely cited critique by Tegmark (2000a, b). Since publication of Tegmark's criticisms, hypotheses have been proposed regarding possible shielding of neuronal MTs from environmental decoherence (Wolff, 2001; Hagan, 2002): in the seminal Penrose-Hameroff model, the MTs perform quantum computation through tubulin structures which also behave like cellular automata (Hameroff, 2007); Nanopoulos and collaborators have enlisted string theory to develop their "QUED-Cavity" model, which is able to predict non-dissipative energy transfer through MTs and the teleportation of quantum states at room temperature (Nanopoulos, 1995; 1996; Mavromatos, 2000).

According to the Penrose-Hameroff model, a conscious event, that is, passage from the pre-conscious state to a conscious state, happens when a maximum of *"coherent excitation"* has been reached inside the MTs. One of Hameroff's recent papers proposes that the best measurable "neural correlate of consciousness" (NCC) is electroencephalographic gamma synchrony, coherent oscillations of field potential in a range between 30 and 90 Hz. Gamma synchrony, along with consciousness, apparently migrates and evolves through various global distributions and brain regions (Hameroff, 2010). Hameroff and Penrose further suggest that, building toward a mode analogous to superconductive electrons (which, by moving as a coherent aggregation of particle-waves, allow electric current to flow without resistance), quantum states in the brain's MTs every 25-500 ms reach a cyclic maximal threshold value of coherence and then, due to gravitational effects, collapse in an orchestrated fashion. Periodically repeated orchestrated loss of coherence ("objective reduction") is thereby postulated to generate classical physical events responsible for the punctuated occurrence of conscious moments, which Hameroff calls "BINGS" (Hameroff, 2008).

Bernroider (2005) has discussed the possibility of consciousness arising in ion channel mechanisms within the neuronal membrane. He postulates the existence of microscopic ion traps in potassium channels. This would result in a quantum-computational mode of neuronal activity. Due to the trapping mechanism, Bernoider's model is not plagued by Tegmark's concerns about the fast decoherence of quantum brain states (Tegmark, 2000a, b).

Stapp (2007) favours the idea that quantum waves collapse only when they interact with consciousness. He argues that collapse occurs when intelligent brains choose as a basis for future action one among many alternative quantum possibilities. His theory of mind's interaction with matter via quantum processes in the brain thus differs from that of Penrose and Hameroff. While the latter two authors postulate objective, gravitationally mediated collapse following quantum computation in brain microtubules, Stapp postulates more global collapse via subjectively 'mind like' wave-function reduction that enlists certain aspects of the quantum Zeno effect within synapses to explain conscious arousal and selective attention.

Jibu and Yasue (1995) described the modalities by which MTs might be expected to carry information. Fröhlich dynamics of ordered water molecules inside MTs and the quantum electromagnetic field can generate a collective quantum optical mode subserving super-radiance phenomena by which incoherent electromagnetic energy is transformed into coherent photons within the MTs themselves. These photons can then propagate inside the MTs as if the optical medium were transparent; the authors have called this phenomenon "self-induced transparency".

Ten years prior to the super-radiance work of Jibu and Yasue, Del Giudice (1982; 1983), applying quantum field theory (QFT), had already predicted that electromagnetic energy penetrating the cytoplasm would become focused into filaments, whose diameter must depend on Bose-Einstein-condensed symmetry-breaking of aqueous dipolar moments. The computed value of that diameter exactly matched the internal diameter of relevant MTs (15 nm). It also turned out that, more generally, phenomena occurring inside the brain at both macroscopic and microscopic levels may be related to some form of phase transition.

A number of researchers have marshalled this last idea in addressing the inconsistency of attempts to formulate a quantum-biophysical theory based on conventional computational schemes (Alfinito, 2001; Pessa, 2007). In point of fact, such conventional schemes have been introduced to facilitate non-biological research on atoms and elementary particles, but they are not adequate for the study of biological phenomena.

Pessa (2004) has suggested that, using a dissipative thermofield elaboration of QFT (DQFT) based on a "doubling" mechanism (Vitiello, 1995) it is possible to obtain a generalization of quantum theory which takes into account the characteristic dynamical processes of the biological world (Globus, 2003; 2009; Freeman, 2006).

2.2 Quantum Coherence in the Mind

Quantum coherent phenomena, beyond their participation in the dynamics of thought processes, are also consonant with a philosophical concept that Penrose calls the "holistic aspect of the mind." According to this idea, conscious processes cannot be generated by the isolated activation of a single locus within the brain but instead should emerge from action integrated across a large number of different regions. Coherent oscillation of the MTs encompassing most of the brain can provide that kind of non-local connection, which in general terms is fundamental for preconditions culminating in decoherence into classical manifestations of consciousness. Unconscious preparatory processing of information leading thereafter to conscious mentation requires some specifically instantiated underlying logic. The critical issue in this discussion is: what concretely definable kind of logic actually applies?

For a classical physicist, classical logic is sufficient. For a quantum physicist, it was once believed that standard quantum logic is enough (Birkhoff, 1936). However, quantum information is processed by a quantum computer, which is not just a quantum system *tout court* but is a *computational* quantum system. As such its extra computational features should be taken into account by the associated logic. Nevertheless, the so-called quantum computational logics described by Dalla Chiara (2003) have no deductive calculus but only semantics. A needed quantum-computational logic comprising both semantics and syntax was therefore introduced by Zizzi (2010). The physical interpretation of quantum logical coherence should take into consideration concepts of quantum coherence not only in non-relativistic quantum mechanics (QM) but also in relativistic quantum field theory (QFT).

Quantum coherence in QM is a property of pure states, whose linear superposition is also a pure state, whereas the concept of coherence is different in QFT, for which coherent states are eigenstates of the annihilation operator. Although the quantum object language (QOL) containing quantum-coherent propositions are interpreted in QM, the quantum metalanguage (QML) must be interpreted in QFT (Umezawa, 1993; Blasone, 2011). More precisely, QML is a non-computational aspect of the mind (Zizzi, 2012c) and is strictly related to brain processes described by dissipative quantum field theory (DQFT) (Vitiello, 1995; 2001). QML can be viewed as a quantum control on the quantum mind or on a quantum robot (Zizzi, 2009; Pessa, 2009) whose logic is the QOL. In this context, it would be especially fruitful to investigate the distinctive role of that QML sector corresponding to quantum-coherent propositions in the QOL.

3. The Concept of Reality and the Quantum Mind

Philosophically, the concept of reality grows from the discipline of ontology, a philosopher's mode of inquiry into the nature of *being* or *existence*. However, the concept of reality looks very different from the vantage point of a physicist (particularly a quantum physicist), a mathematical logician (particularly a constructivist), or a psychiatrist (particularly when diagnosing a psychotic disorder in a patient with "poor reality testing").

For a physicist, what is real is what is measurable. In quantum mechanics a measurable physical quantity, called an observable, is mathematically described by a hermitian operator.

For a classical logician, truth and reality are very often almost synonymous. This correlation was explicitly stated by Tarski (1944) in his semantic theory of truth, based on the correspondence theory of truth, which states that the truth or falsity of a proposition can be determined only by its accuracy in describing the real world (Prior, 1969).

For a constructivist logician, what is true is what can be proven. This definition of truth is a way to escape from Platonism and to affirm that the mind creates rather than discovers the "truths" of mathematics. However there is a formal catch: Gödel's first incompleteness theorem (Gödel, 1931) stipulates that, in a formal system strong enough to encompass arithmetic, there are true propositions that nevertheless are not provable. The Godelian difficulty can be bypassed using constructivist logics, which in general are very weak and hence are not constrained by Gödel's theorems.

In "standard" quantum logic (Birkhoff, 1936) a proposition, *i.e.,* a logical entity bearing a truth-value, corresponds to an observable (a projector). The projector performs a quantum measurement, producing an event with a given probability. In this standard version of quantum logic, there is a strict relationship between truth and classical reality, which is coextensive with the "event." Hence, although the standard approach fits into the context of quantum logic, its concept of truth remains classical; that is, access to truth occurs outside the quantum system. The problem lies in the semantic content, which is the classical output of the quantum measurement.

Semantic content of a proposition can also be detected in the quantum information encoded by a qubit. This is another point of view pertaining to so-called "quantum-computational" logics (Dalla Chiara, 2003), where the role played by the quantum superposed state is that of a single atomic proposition. Therefore in such logics the one-to-one correspondence between the internal physical truth of the quantum system and the logical truth of the corresponding proposition is lost.

For the theoretical physicist John Archibald Wheeler, father of quantum gravity, the concept of reality is: *"It from bit"* (Digital Physics); that is, reality is information, denoted by *I*. One of this paper's authors (Zizzi, 2005b), working from Wheeler's notion of reality as a starting point, has proposed a quantum extension of digital physics, the model of Computational Loop Quantum Gravity (CLQG), from which it follows that the concept of reality can be expressed as *"It from qubit"* with reality cast as quantum information denoted by *QI*.

Classical Information, I	Quantum Information, QI
I = N (N = number of bits)	QI = 2^N (N = number of qubits)
Classical digital reality (Classical truth) N = 1, I = 1 (Yes =1 **or** No = 0)	Quantum extension of digital reality (Quantum truth) N = 1, QI = 2 (Yes = 1 **and** No = 0)

The question is: How can one reconcile the concepts of reality, logical truth, quantum observables, and *"It from qubit"*? And how can one relate all that to the apparently self-contradictory logic, disintegrated subjectivity (Globus, 2010), and ambiguous mixture of internal and external realities in schizophrenia?

Before trying to offer any kind of solution to this puzzle, we should address the general belief that symptoms of acute schizophrenia are aberrations of explicitly conscious experiences. We challenge this belief with the idea that the mind of the schizophrenic patient is merely trapped for too long a period of time in the unconscious, which is quantum-computational and has a different logic. Propositions in schizophrenic thinking can be true and false at the same time. Schizophrenic perception of reality encloses the internal phenomenal world (hallucinations), and subjectivity is in a one-to-one correspondence with the Internal Observer (IO) (Zizzi, 2005a), who can *"see"* all the hidden information (giving rise to the feeling of a disintegrated self).

We think that the starting point to be adopted in studying schizophrenia should be an agreement that internal stimuli reflect an inner reality whose quantum-physical substrate in the brain is as ontologically valid as "external reality" is. Even when considering hallucinations such a consensus should apply, insofar as hallucinations originate in their own brain processes which, although faulty, are physically real. "Internal" stimuli impinging on first person experience are not less physically real just because third parties cannot experience them; the ontology does not depend upon epistemology. Our assertion here relies on the assumptions of scientific realism, insofar as an unobservable entity is deemed to possess the same ontological status as an observable entity. This philosophical viewpoint will lead us to develop further the concept of the Internal Observer (IO) in Section 7.

4. Quantum Metalanguage and Quantum Control

Elucidating the "natural" logic intrinsic to mental processes is very important in the context of a constructivist approach to logic (Heyting, 1971). In fact, according to constructivism, logic is an inherent byproduct of the mind and not at all preexistent "out there" in the ambient Platonic "world of ideas."

To frame this issue, one can adopt either the macroscopic or the microscopic point of view. The macroscopic perspective starts from the phenomenology of "thought processes" as they are approached by cognitive science, which, however, still lacks a unified theory on this topic. Philosophers of mind also generally adopt the macroscopic point of view (Kim, 2006; Braddon-Mitchell, 2007; McLaughlin, 2009). The same applies to constructivist approaches such as dynamical constructivism (Sambin, 2002), which seem to rely on a cognitive/social interpretation of mental processes. In contrast, the microscopic perspective focuses on quantum processes occurring in the brain and can be formalized by quantum theory. These two points of view are not incompatible but rather concern diametrical scales in complementary contexts. However, the microscopic point of view, which relies on a mathematical formalism, offers richer detail than the macroscopic perspective does as the potential locus for a logical system adequate to describe mental processes.

We will adopt a microscopic viewpoint to hone in on the foundations of quantum metalanguage, which, we believe, is an emergent aspect of quantum processes occurring in the brain. Generally the term *"metalanguage"*, to be denoted by M, indicates a language which "talks" about another language, *i.e.*, an object-language, to be called L. If a constructive approach to logic is adopted, then M can be viewed as an emergent feature of human thought. In another, classically mechanistic context, the role of M is very important for computer science, where it formally describes the control system of a given device or software (Van Harmelen, 1991). However, in the case of a quantum system, the action of the quantum control (D'Alessandro, 2008), and of its formal metalanguage M, cannot be performed through usual projective measurements. These operations would destroy typical quantum-mechanical features, like quantum superposition, because measurement "projects" the multiple potentialities of an uncollapsed quantum state into a single collapsed implementation.

Hence, one should consider the so-called *"weak measurements"* (Aharonov, 1988) which permit measurement without inordinately disturbing the quantum system.

Weak measurements concern a peculiar kind of quantum state, called the *"generalized coherent state"* (GCS) (Prelomov, 1986), a generalization of the *"coherent state"* (Glauber, 1963), which refers to a special sort of quantum state corresponding to a single resonant mode of light. Coherent states describe a maximal degree of phase-correlated coherence, and are the most classical among quantum states, because their dynamics closely resemble the oscillating behaviour of a classical harmonic oscillator. They find applications in quantum electrodynamics and other bosonic theories such as those describing Bose-Einstein condensates.

GCS play an important role in the dissipative quantum field (DQFT) of the brain (Vitiello, 1995). Therefore we believe that they might illuminate the core nature of high-level mental processes and in particular describe the control actions of thought itself on the logical languages of the mind.

The (meta)-logical formalization of GSC requires introduction of an explicitly quantum metalanguage (QML), which should control the quantum mind's logic, Lq (Zizzi, 2010). The latter, although it is founded upon some species of constructivist logic like Basic Logic (BL) (Sambin, 2000), has in addition its own characteristic features, which are typically quantum. For example, the truth-values born by the propositions of Lq are both fuzzy and probabilistic, and there is a new logical connective, namely the connective of quantum superposition, which is the quantum analogue of the classical logical conjunction "and." Assertions originating in the new QML are labelled by a complex number, called the assertion degree, physically interpreted as a probability amplitude. The ensemble of assertions having the same assertion degree are conceptualized as a GCS (Zizzi, 2012a).

This paper has posited that the logic of schizophrenia is the same as the quantum logic Lq. The latter, as we have seen, is also plausibly understood as the logic employed by healthy minds while in the unconscious state. However, whereas in mental health Lq is used for very short time intervals, in the case of schizophrenia Lq becomes dominant and long-lasting. This predominance of Lq in schizophrenia might well stem from flaws in the QML, perhaps a dearth of requisitely configured assertions (Zizzi, 2012b). Because of strict relations between QML and the brain's DQFT, one may hope to find within QML's flaws those pathological quantum-dissipative brain processes which are responsible for schizophrenia.

5. The Logic of Quantum Information

What is quantum computation? While in classical computation the unit of information is the bit (0, 1), in quantum computation the unit of information is the qubit, a linear superposition of the two bit values 0 and 1:

$$\alpha|0\rangle + \beta|1\rangle$$

where α and β are complex numbers called probability amplitudes, satisfying the condition:

$$|\alpha|^2 + |\beta|^2 = 1$$

that is, the probabilities sum to one.

In vector notation, we have:

$$|0\rangle = \begin{pmatrix} 1 \\ 0 \end{pmatrix}, \qquad |1\rangle = \begin{pmatrix} 0 \\ 1 \end{pmatrix} \qquad \alpha|0\rangle + \beta|1\rangle = \begin{pmatrix} \alpha \\ \beta \end{pmatrix}$$

Two or more qubits may become entangled with each other to form a whole in which the original qubits merge indistinguishably. Quantum superposition and entanglement together are collectively called massive parallelism, a property that makes a quantum computer exponentially more efficient than its classically computational counterpart. The measurement of a quantum computer's quantum state "collapses" that state into a classical bit with a given probability: either $|0\rangle$ with a probability of $|\alpha|^2$ or $|1\rangle$ with a probability of $|\beta|^2$.

The Orch-OR model locates neurocognitively relevant quantum computation in the MTs. Here classical input is assumed to occur through a connection with MT-associated proteins (MAP-2), which induce and "orchestrate" quantum computation. Classical output is mediated by the component conformational state "chosen" by each tubulin molecule at the moment that its quantum superposition collapses. What follows are classical events, dictated by appropriate laws, which are the basis for subsequent neural events, including action potentials, complex interactions among cytoplasmatic proteins, and modulation of MAP-2 and of gap-junctions; these then prepare the next classical input.

Such cyclic events have been postulated by the authors of Orch OR to undergird subjective experiences, which are also called qualia by phenomenalist philosophers and are limited to first person perspectives. The pan-proto-psychist philosophical viewpoint associated with Orch OR embeds qualia within the fundamental geometry of space-time at the Planck scale, where spatio-temporal manifolds are poised to separate. The "collapse" process of Orch-OR operates to select a subset of qualia among Planck scale superpositions for each single consciously "observed" event.

If the unconscious really quantum-computes along lines postulated by Penrose and Hameroff, then it "orchestrates" at high speed coherent preparation for what immediately follows in spatio-temporal "separation" as a consciously recognized thought, coextensive with the effectively classical outcome of a selective quantum collapse. The cyclic process then repeats itself, allowing about 0.5 seconds to re-elaborate the preparative machinations of the unconscious. Therefore, classical consciousness according to Orch OR must be manifested as a succession of staccato flashes rather than a continuously evolving, properly algorithmic computation. In effect, generation of consciousness from the unconscious through modalities proposed by Orch OR does not even compute anything new but instead uses partial information precipitated selectively from a given sequence of orchestrated quantum collapses. In light of such considerations, the authors of this paper agree with Penrose that at bottom cognitive processes are indeed not algorithmic. When we prove a theorem through deep insight, we just translate, in terms of classical logic, a distillate of what we have already quantum-computed in an unconscious mode.

Gödel's First Incompleteness Theorem states that any effectively generated formal system capable of expressing arithmetic cannot be both consistent and complete. Here "effectively generated" means that in principle there can exist a computer program which is able to enumerate all the axioms of the system; "consistent" means that there exists no statement of the system, such that both the statement and its negation are provable from the axioms; "complete" means that, for any statement of the system, either the statement or its negation are provable from the axioms. For any effectively generated, consistent formal system *F* that includes arithmetic, there exists a statement which is true, but not provable within the system. Such a statement is called the Gödel sentence *G(F)*.

The Gödel sentence *G(F)* is:

G(F)= "This sentence cannot be proved in F".

Penrose, prompted by Orch OR's implication that consciousness is not computable, justifies this assertion through the striking fact that human minds are able to recognize the truth of the Gödel sentence *G(F)* although the latter is not demonstrable within its own axiomatic system. Penrose interprets the First Incompleteness Theorem as affirming that, while no computer working within a consistent formal system *F* can prove the sentence *G(F)*, we humans can *"see"* the truth of *G(F)*. In fact, we do indeed "see" that *G(F)* is true, because, if it were false, then it would be provable in *F*, an absurdity insofar as *G(F)* asserts its own unprovability in *F*. In this process of recognizing the truth of *G(F)* the human mind is able to develop intuitive mathematical insight, a capability which is not shared by any algorithmically based system of logic.

If we reinterpret this theorem from a quantum point of view, it follows that we "know" its truth by virtue of its quantum-parallelistic provability at the unconscious stage. To our unconscious, the theorem is true and false at the same time (truth and falsity are in a quantum superposition) and its proof proceeds with smooth unitarity via quantum parallelism. For that reason, during the quantum computational stage comprising unconscious "processing," the formal system behaves as if it were self-contradictorily inconsistent (in the classical sense) but complete. However, at the end of the quantum-parallel proof, the final value will be 1 (true), but only with a given probability. We will not then able to go back over all the quantum computational steps; that is, we will not be able to translate, even retrospectively, quantum computation into a classical computation of the "reduced" post-superpositional outcome. Therefore, the result of quantum computation will appear consistent but incomplete to us. We can conclude that the Gödel theorem appears true but unprovable to us when we are in a conscious state of mind, but the apparent limitation relates to an artefact of our classical consciousness and is not an authentic "no-go theorem."

6. The Logic of the Unconscious

To the extent that this self-referentially paradoxical perspective on quantum proof offers isomorphisms with the odd, apparently self-contradictory thinking characteristic of schizophrenia, significant opportunities for a mathematically more rigorous physical understanding of pathological psychodynamics open up. In particular, there arises the real possibility of productively reinterpreting schizophrenic thought disorders, along with their attendant psychoses and problems communicating with conscious agencies in the external world, in terms of quantum logic.

In order to exploit this reinterpretive possibility, it will be necessary to flesh out more formally a consideration of the unconscious as a quantum computer. Information processing in a quantum computer is performed by quantum logic gates, which are mathematically described by unitary operators U.

An operator U is unitary if it satisfies the relation:

$$U^{-1} = U^{\dagger}$$

where U^{-1} is the inverse of U, and $U^{\dagger}$ is the hermitian conjugate (that is, the complex conjugate of the transpose).

Unitary operators perform reversible transformations on a quantum state $|\psi\rangle$:

$$|\psi\rangle \xrightarrow{U} |\psi\rangle' \xrightarrow{U^{-1}} |\psi\rangle$$

Two important quantum logic gates are the Hadamard gate, H, and the XOR gate:

$$H = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}$$

$$XOR = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

The former acts on a classical input (a bit) and gives as its output a quantum superposition of two bits (a qubit). The latter acts on two qubits and gives as its output an entangled state.

If for some reason the reversibility of these quantum logic gates becomes blocked so that it is no longer possible to perform the inverse operations of decoherence and disentanglement, the mind remains trapped in the quantum-computational unconscious.

It should be said that these quantum logic gates are indeed material structures, formed by atoms, ions, etc. Hence, it is plausible to hypothesize that the drugs used to ameliorate schizophrenia are able somehow to reset at least partially and temporarily the damaged quantum logic gates in the brain.

For our purposes, another important quantum logic gate is the *"mirror" M* (Zizzi, 2006). When acting on a quantum state, M preserves the probabilities. It is the "most classical" gate among quantum logic gates, or, in other words, it is semi-classical. Its mathematical expression is:

$$M = e^{i\theta}(\alpha P_0 + \alpha^* P_1)$$

where α is a complex number, α^* is its complex conjugate, $|\alpha|^2 = 1$, and P_0, P_1 are the two projectors of the Hilbert space C^2 of one qubit state.

Let us consider the qubit state $\begin{pmatrix} \beta \\ \gamma \end{pmatrix} \equiv \beta|0\rangle + \gamma|1\rangle$, where α and β are complex numbers called probability amplitudes, satisfying the relation $|\beta|^2 + |\gamma|^2 = 1$. The action of the mirror M on the qubit is

$$M\begin{pmatrix} \beta \\ \gamma \end{pmatrix} = \begin{pmatrix} \alpha_0 \beta \\ \alpha_1 \gamma \end{pmatrix}$$

where $\alpha_0 = e^{i\theta}\alpha$, $\alpha_1 = e^{i\theta}\alpha^*$, and $|\alpha_0|^2 = |\alpha_1|^2 = 1$. The probability amplitudes of the qubit are modified, but the probabilities are unchanged.

Now, the pre-conscious state (which in this paper's theoretical framework might be considered as semi-classical) is the psychological state which it should normally be possible to access en route from the quantum unconscious to consciousness, insofar as the pre-conscious stands in the middle between consciousness and the unconscious (Kircher, 2003). When passage from the unconscious to consciousness does not find a way through the pre-conscious, classical communication becomes impossible as in the case of schizophrenia. In this light the semi-classical mirror gate M appears to be potentially very important for schizophrenia.

When we want to communicate with other people, we think about what we are going to say, and to do this we use a metalanguage. In most cases, such a metalanguage is classical or at least semi-classical. Unfortunately, classical and semi-classical metalanguages when used by the psychotherapist are not recognized by the fully quantum-logical language of the patient. A fully quantum logic, in contrast to classical and semi-classical logics, is substructural, paraconsistent, symmetric, fuzzy (Zadeh, 1996) and probabilistic at the same time (H'ajek, 1995).

7. The Truth-Observable and Penrose's Mathematical Truth

In what follows, we will consider the "Internal Observer" (IO) to be a fictitious observer who is *"internal"* to the quantum computer (QC). Only probing by an IO can extract the global truth as a whole from the QC by performing a single internal measurement (U). The IO (Figure-1) is a mathematical abstraction regarding this capability: he/she is the inhabitant of a quantum space where the QC is thought to be immersed (Zizzi, 2005a).

Every elementary cell of the quantum space encodes, by way of the quantum holographic principle (Zizzi, 2000), one qubit of information *("It from qubit")*. Let us suppose that the quantum space has a number of cells equal to the number of qubits of the QC (the state space of the system). Then the two spaces, which are both quantum, are in a one-to-one correspondence. A simple example is the case of a two-level system. In that case, the state space of the system is the state space of one qubit, *i.e.,* the Bloch sphere, and the corresponding quantum space is the fuzzy sphere (Madore, 1992) with two cells.

The theory of quantum gravity (Rovelli, 2004) assumes that quantum space-time has this sort of discrete nature. More specifically, a quantum space consistent with quantum gravity requires quantum units of area and volume that are measurable in terms of the Planck length ($1{,}61 \cdot 10^{-35}$ m). The IO would thus invade the Planck scale; he/she would become part of quantum gravity and thereby "observe" from inside the quantum-computational process.

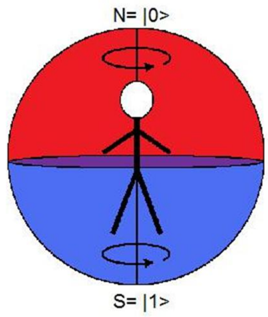

Figure 1. The internal observer

The Truth-Observable, thus apprehended by the IO, coincides with Penrose's mathematical truth (Penrose, 1989; 1994), residing at the Planck scale which in Penrose's theory gives rise to Quantum Mind.

A metalinguistic interpretation casts the IO as a classical external observer who adopts a quantum metalanguage to control the object-language of the QC. The IO in effect hoodwinks the quantum machine (in this case the quantum unconscious) through the employment of quantum metalanguage.

If a psychotherapist could adopt a quantum metalanguage, he/she would be able to find his/her way into and install within the quantum unconscious of the patient a therapeutic bridgehead. The therapist's IO would control, toward constructive ends, the quantum object-language of the patient's unconscious, which is quantum computational. Hopefully, this would make it possible to restore collaborative communication between the patient and the psychotherapist, whose own consciousness also interfaces directly with the external world.

Even granting that such an intervention might be at least theoretically possible, any future concrete implementation would require much additional knowledge not yet at our disposal. However, we suspect that some past and present psychotherapists, although not consciously in possession of explicitly quantum metalinguistic techniques, have already used those techniques without awareness in sporadically successful attempts to communicate with their patients.

Conclusions

We do not know yet how to harness quantum metalanguage as a practical channel for psychotherapy. However, we hope that in the near future it will be possible to use quantum metalanguage, quantum logic, and quantum mechanical concepts generally to facilitate communication between therapist and patient in the context of mental disorders like schizophrenia. Toward that end, scientific research in this field should focus on the study of Quantum Mind and the quantum brain, which are psychiatrically crucial instantiations of quantum logic and quantum physics respectively. In addition, scientists (not only psychiatrists) should directly assay behavioural aspects of thought-disordered subjects and analyse the results from a quantum-paradigmatic viewpoint in order to individualize appropriate quantum technologies for purposes of therapeutic clinical communication. We wish to conclude by expressing our hope that "quantum metalinguistic psycho-technology" will enhance the dignity and safety of schizophrenic patients, whose suffering deserves to be understood at its foundations and accorded the most empathic possible respect.

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