Macro-Temporal Quantum Coherence, Quantum Spin Glass Degeneracy, and Number Theoretic Information Concept

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Abstract

The basic objection against quantum consciousness theories is that de-coherence times for macroscopic quantum states are quite too short, and it indeed seems that standard physics does not allow macro-temporal quantum coherence. In the Universe predicted by Topological Geometro-Dynamics (TGD) situation is different. Many-sheeted space-time and quantum spin glass degeneracy imply that the lifetimes of macroscopic quantum states are much longer than predicted by standard physics. The thermodynamic, energetic, and information theoretic aspects of macro-temporal quantum coherence are discussed with emphasis on the implications of the number theoretic information measures emerging naturally in quantum TGD.

Keywords: macroscopic quantum coherence, de-coherence, spin glass, p-adic numbers, number theoretic entropy, quantum computation.

1 Introduction

The basic objection against quantum consciousness theories is that the de-coherence times for macroscopic quantum states are quite too short. This argument has been put in quantitative form by Mark Tegmark [1].

These counter arguments are however problematic. First of all, the notions of quantum coherence and de-coherence are problematic in standard physics framework since the non-determinism of the state function reduction is in conflict with the determinism of Schrödinger equation. The intuitive idea is however that one can estimate the de-coherence times as essentially lifetimes of quantum states. Secondly, the estimates for de-coherence times are based on standard physics, and it is quite possible that new physics is essential for understanding living matter. The belief that standard physics is enough is based only on the reductionistic dogma.

Penrose and Hameroff [2] have proposed that some future theory of quantum gravitation makes it possible to replace the phenomenological notion of state function reduction with a more fundamental notion which they call Orch OR, that quantum gravitational effects make possible macroscopic quantum states of required long de-coherence time, and that micro-tubules are the systems, where these effects are especially important so that one might even speak about reduction of the consciousness to the micro-tubular level. Penrose and Hameroff have also proposed that micro-tubules could act as quantum computers. The quantum states involved would be quantum superpositions of tubulin conformations and quantum gravitation would somehow make these quantum superpositions stable. Long enduring quantum superpositions of the conformations of (say tubulin) molecules would allow to perform a multi-verse simulation for the conformational behaviour of the molecules and this would certainly have evolutionary value.

Topological Geometrodynamics (TGD, [3, 4]) inspired theory of consciousness [5, 6] leads to a first principle theory of state function reduction and preparation free of the logical paradoxes, allows precise definitions for the notions of quantum coherence and de-coherence, and predicts a mechanism making the lifetimes of macroscopic bound states much longer than predicted by the standard physics. By quantum-classical correspondence the argument can be formulated at space-time level and configuration space (world of classical worlds) level.

a) At the space-time level coherence regions are identifiable as space-time sheets. They indeed are coherence regions for both classical fields and induced spinor fields defining single particle limit of the quantum theory. By quantum criticality of TGD Universe there is no upper bound for neither the spatial or temporal size of the space-time sheet and one obtains a p-adic hierarchy of coherence lengths and de-coherence times. Finiteness of de-coherence time corresponds to the fact that energy flows to the space-time sheet from larger space-time sheet first and then back. Note that in the standard quantum field theory the entire Minkowski space M^4 is the natural identification for the coherence region, and it is difficult to understand how to describe the reduction to a smaller region of M^4.

b) At configuration space level the argument goes as follows. The basic distinction between TGD and standard physics is quantum spin glass degeneracy (see the chapter "Quantum theory of self-organization" of [5]), which among other things implies that quantum bound states of, say, two molecules have enormous spin glass degeneracy absent in the free state. The intuitive expectation is that the system spends much longer time in bound states than in free states and this implies much longer de-coherence time than expected otherwise. One can formulate this argument more rigorously using unitarity conditions implying that forward scattering amplitude for bound states is very large due to the spin glass degeneracy. The almost degenerate spin glass states differ only by their classical gravitational energy so that gravitation is indeed important. The importance of quantum gravitation is also obvious from the fact that genuine quantum gravitational states are state functionals in the world of worlds rather than in world so that they are expected to represent in some sense higher abstraction level than ordinary quantum states in the hierarchy of consciousness.

Macro-temporal coherence has interesting thermodynamics, energetic, and information theoretic implications. In particular, the attempt to gain improved understanding about the information theoretic aspects has led to a new number-theoretical vision about quantum jump. Negentropy Maximization Principle (NMP) is the variational principle governing state preparation process forming part of quantum jump. The formulation of NMP in p-adic context (see the chapter "Negentropy Maximization Principle" of [5]) has led to an identification of three kinds of entanglement entropies S corresponding to systems for which entanglement coefficients reduce to numbers in some finite-dimensional extension of rational numbers, and to systems for which this does not occur and entanglement coefficients are are real or p-adic numbers. For finitely extended rational entanglement entropies S_p, p prime, the ordinary logarithm function $log(x)$ appearing in Shannon entropy can be replaced by the p-based logarithm function $log_p(|x|_p)$ of p-adic norm $|x|_p$ of x. S_p can be non-positive and one can define the entanglement entropy S as $S = Max\{S_p\}$ so that S is negative and thus defines a genuine information measure.

These observations lead to a number theoretical formulation and generalization of quantum TGD and quantum measurement theory so that physics in real and p-adic number fields are unified to single coherent whole. Quantum jump can be seen as a number theoretical necessity and extended rational entanglement can be interpreted as bound state entanglement stable against NMP because of its negative entanglement entropy. This view allows to interpret life as islands of finitely extended rationality in the seas of real and p-adic continua, and macro-temporal quantum coherence as means of generating extended information rich extended rational entanglement crucial for living systems.

In the sequel I will discuss the following topics related to the macroscopic and macro-temporal quantum coherence.

a) How macroscopic and temporal quantum coherence is made possible by the spin glass degeneracy in TGD Universe.

b) Macro-temporal quantum coherence from the point of view of physics (thermodynamical, energetic and information theoretic aspects) with a sketch of the number theoretic vision about quantum jump and NMP and some comments about the implications for quantum computing.

2 Macro-Temporal Quantum Coherence from Spin Glass Degeneracy

At the space-time level the generation of macroscopic quantum coherence is easy to understand if one accepts the identification of the space-time sheets as coherence regions. Quantum criticality and the closely related spin glass degeneracy are essential for the fractal hierarchy of space-time sheets. The problem of understanding macro-temporal and macroscopic quantum coherence at the level of configuration space (of 3-surfaces) is a more tricky challenge although quantum-classical correspondence strongly suggests that this is possible. In the sequel the notion of macro-temporal quantum coherence is discussed in quantum TGD framework and the argument for how quantum spin glass degeneracy implies macro-temporal quantum coherence is developed.

2.1 What Does Quantum Coherence Mean in TGD Universe?

Concerning macro-temporal quantum coherence, the situation in quantum TGD seems at the first glance to be even worse than in standard physics. The problem is that simplest estimate for the increment in psychological time in single quantum jump is about 10^{-39} seconds derived from the idea that single quantum jump represent a kind of elementary particle of consciousness and thus corresponds to CP_2 time of about 10^{-39} seconds. If this time interval defines coherence time one ends up to a definite contradiction with the standard physics. Of course, the average increment of the geometric time during single quantum jump could vary and correspond to the de-coherence time. The idea of quantum jump as an elementary particle of consciousness does not support this assumption.

To understand how this naive conclusion is wrong, one must look more precisely the anatomy of quantum jump. The unitary process $\Psi_i \rightarrow U\Psi_i$, where Ψ_i is a prepared maximally unentangled state produces a maximally entangled multi-verse state. Then follows the state function reduction and after this the state preparation involving a sequence of self measurements and given rise to a new maximally unentangled state Ψ_f containing only bound state entanglement stable against state preparation process.

a) What happens in the state function reduction is a localization in zero modes, which do not contribute to the line element of the configuration space metric. They are non-quantum fluctuating degrees of freedom and TGD counterparts of the macroscopic, classical degrees of freedom. There are however also quantum-fluctuating degrees of freedom and the assumption that zero modes and quantum fluctuating degrees of freedom are correlated like the direction of a pointer of a measurement apparatus and quantum numbers of the quantum system, implies standard quantum measurement theory.

b) Bound state entanglement is assumed to be stable against state function reduction and preparation. Bound state formation has as a geometric correlate formation of join along boundaries bonds between space-time sheets representing free systems. Thus the members of a pair of disjoint space-time sheets are joined to single space-time sheet. Half of the zero modes is transformed to quantum fluctuating degrees of freedom and only overall center of mass zero modes remain zero modes. These new quantum fluctuating degrees of freedom represent macroscopic quantum fluctuating degrees of freedom. In these degrees of freedom localization does not occur since bound states are in question.

Both state function reduction and state preparation stages leave this bound state entanglement intact, and in these degrees of freedom the system behaves effectively as a quantum coherent system. One can say that a sequence of quantum jumps binds to form a single long-lasting quantum jump effectively. This is in complete accordance with the fractality of consciousness. Quantum jumps represent moments of consciousness which are elementary particles of consciousness and in macro-temporal quantum coherent state these elementary particles bind to form atoms, molecules, etc. of consciousness.

c) The properties of the bound state plus its interaction with the environment allow to estimate the typical duration of the bound state. This time takes the role of coherence time. This suggests a connection with the standard approach to quantum computation.

2.2 Many-Sheeted Space-Time, Topological Field Quantization, and Spin Glass Degeneracy

Many-sheeted space-time allows to understand topologically the generation of structures. Even the macroscopic objects of every-day world correspond to space-time sheets. The replacement of point like particles with 3-surfaces of arbitrarily large size implies the crucial non-locality at space-time level. Concerning the understanding of bio-superconductivity, the basic observation is that those space-time sheets, which are much larger than atomic space-time sheets, contain very low densities of ordinary particles (since most of the particle like structures contained by them are space-time sheets containing... containing the ordinary particles) so that the temperature can be extremely low and macroscopic quantum phases are possible.

Topological field quantization, which is implied both by topological reasons and by the absolute minimization of the Kähler action, implies that space-time surfaces are counterparts of Bohr orbits and have complex topology. This means that topologically relatively featureless linear Maxwell fields are replaced by extremely complex topological structure, which can be regarded as kind of a generalized Feynman diagram obtained by thickening the lines to four-dimensional space-time sheets.

Quantum-classical correspondence has been a basic guideline in the construction of the theory and states that classical space-time physics provides classical correlates for various quantum aspects of physical system leads to the view that the topological field quanta accompanying a given material system provide a representation for its quantum structure, kind of a manual.

The topological self-referentiality generalizes further to the idea that the inherent non-determinism of the p-adic dynamics makes possible space-time representation of quantum jump sequences and classical non-determinism of Kähler action the non-determinism inherent to the linguistic representations for the contents of consciousness of self. This in turn implies feedback loop to the configuration space (of 3-surfaces) level: configuration space spinor fields can represent (not faithfully) quantum jump sequences and thus the contents of consciousness associated with a sequence of quantum jumps (self), so that the ability to become conscious about being conscious about something can be understood.

One can also speak about 'field body' (or actually hierarchy of them) as being associated with the material system. This field body, which is much larger than the material system, serves as a sensory canvas at which sensory representations are realized and could also perform motor control. This means radical modification of the neuro-science view about brain as the sole seat of consciousness (see the chapters "Time, Space-Time and Consciousness" and "Magnetic Sensory Canvas Hypothesis" of []cbook2).

The basic variational principle underlying quantum TGD states that the space-time surface associated with a given 3-surface is absolute minimum of so called Kähler action, which is essentially Maxwell action for a Maxwell field, which is obtained by projecting CP_2 Kähler form to space-time surface. Thus primary dynamical variables are CP_2 coordinates rather than vector potential. This implies huge vacuum degeneracy: any space-time surface having CP_2 projection, which is Legendre manifold, that is at most a 2-dimensional surface of CP_2 having vanishing induced Kähler form, is a vacuum extremal. New vacua are obtained by the canonical transformations of CP_2 acting as $U(1)$ gauge transformations on Kähler gauge potential. This symmetry is also approximate for non-vacuum extremals and broken only by classical gravitation represented by the induced metric.

Physically this means spin glass degeneracy: the geometric $U(1)$ gauge invariance ceases to be gauge invariance (nothing to do with ordinary gauge invariance) and implies huge almost-degeneracy of physical states. Gravitational energy distinguishes between these almost physically equivalent states. The standard manner to visualize the situation is by using the notion of the energy landscape. Spin glass energy landscape (now energy corresponds to Kähler function) is a fractal structure containing valleys inside valleys inside... This symmetry is responsible for a very large class of phenomena distinguishing between TGD and standard physics and also makes possible macro-temporal quantum coherence.

2.3 Spin Glass Degeneracy and Classical Gravitation Stabilize Bound State Entanglement

This picture gives connection with the standard physics view but does not yet explain why de-coherence times are so long. New physics is required to explain why the life times of bound states are much long er than predicted by the standard physics. Spin glass degeneracy provides this physics. There are two arguments: probabilistic argument based on intuition and the more rigorous argument based on unitarity.

2.3.1 Probabilistic Argument

The probabilistic argument goes as follows.

a) Suppose that spin glass degeneracy gives rise to a huge number of almost degenerate bound states for which only the classical gravitational energy is different, and that for non-bound states this degeneracy is much smaller. The dominant part of the binding energy is of course something else than gravitational. If this is the case, the number of the bound states is so large as compared to the number of unbound states that the branching ratio for the decay to unbound state is very small. This means that the time spent in bound states is much longer than the time spend in free states and this means that de-coherence time is much longer than without spin glass degeneracy.

b) If the join along boundaries bonds are sufficiently near to vacuum extremals, they indeed allow immense spin glass degeneracy with slightly different gravitational interaction energies and the desired situation can be achieved.

2.3.2 The Argument Based on Unitarity

A more refined argument is based on unitarity of S-matrix. The S-matrix can be written as sum of unit matrix and reaction matrix T: $S = 1 + iT$.

a) The unitarity conditions $SS^\dagger = 1$ read in terms of T-matrix as

$$i(T - T^\dagger) = TT^\dagger \ . \tag{1}$$

For diagonal elements one has

$$2 \times Im(T_{mm}) = \sum_r |T_{mr}|^2 \geq 0 \ . \tag{2}$$

What is essential that the right hand side is non-negative and closely related to the total rate of transitions. If this rate is high also the imaginary part at the left hand side of the equation is large and therefore also the rate for the diagonal transition. For instance, in the case of low energy strong interactions this implies that the total reaction rates are high but transitions occur mostly in the forward direction. In this case the mere large number of final many-hadron states implies that most transitions occur in the forward direction.

In the recent case one must consider both free states and bound states. Let us use capitals M, N as labels for bound states and small letters m, n as labels for free states.

a) The diagonal unitarity conditions can be written for both of these states as

$$\begin{aligned} 2Im(T_{mm}) &= \sum_r |T_{mr}|^2 + \sum_R |T_{mR}|^2 \geq 0 \ , \\ 2Im(T_{MM}) &= \sum_R |T_{MR}|^2 + \sum_r |T_{Mr}|^2 \geq 0 \ . \end{aligned} \tag{3}$$

In both cases there is a large number of the degenerate states involved at the right hand side so that one expects that the right hand side has a large value. For bound states the number of degenerate states is much higher due to the additional degeneracy brought in by the join along boundaries bonds. Thus the lifetime and de-coherence time should be considerably longer than expected on basis of standard physics.

b) For the non-diagonal transitions from bound states to free states one has

$$i(T_{Mm} - \overline{T}_{mM}) = \sum_r T_{Mr}\overline{T}_{mr} + \sum_R T_{MR}\overline{T}_{mR} \ . \tag{4}$$

The right hand side is not positive definite and since a large number of amplitudes between widely different free and bound states are involved, one expects that a destructive interference occurs. This is consistent with a small value of the non-diagonal amplitudes T_{Mm} and with the long lifetime of bound states.

c) What happens for non-diagonal transitions between degenerate states? The unitarity conditions read as

$$\begin{aligned} i(T_{mn} - \overline{T}_{nm}) &= \sum_r T_{mr}\overline{T}_{nr} + \sum_r T_{mR}\overline{T}_{nR} \ , \\ i(T_{MN} - \overline{T}_{NM}) &= \sum_R T_{MR}\overline{T}_{NR} + \sum_r T_{Mr}\overline{T}_{Nr} \ . \end{aligned} \tag{5}$$

The right hand side is not anymore positive definite and there is a very large number of summands present. Hence a destructive interference could occur and the amplitude would be very strongly restricted in the forward direction. This need not however be true in the case of degenerate states since they are expected to be very similar to each other.

d) One can indeed play with the idealization that the transition amplitudes between degenerate states are identical $T_{MN} = T$ and that the amplitudes T_{Mr} are independent of M and given by $T_{Mr} = T_r$.

In this case T-matrix would have the form $T = t \times X$, where X is a matrix for which all elements are equal to one. t can be written as $|t|exp(i\phi)$. T-matrix is maximally degenerate and the diagonalized form T^D of T-matrix has only a single non-vanishing element equal to Nt, N the number of degenerate states. t must satisfy the unitarity condition $|t| = 2 \times sin(\phi)/N$. S-matrix would reduce to an almost unit matrix for the diagonalized bound states.

What about the stability of the bound states in this case? The decay amplitudes for bound states corresponding to the vanishing eigen values of T are given by $T^D(M,r) = \sum c_M T_{Mr} = \sum_M c_M \times T_r = 0$ by the orthogonality of these states with the state with a non-vanishing eigen value. Thus the lifetimes of all bound states expect the one with the non-vanishing eigen value of T are infinitely long in this idealization.

2.3.3 Color Confinement and Spin Glass Degeneracy

This mechanism has applications also outside consciousness theory. For instance, one can understand color confinement. When quarks form color bound states, their space-time sheets are connected by color flux tubes (this is the aspect of confinement which goes outside QCD). Also color flux tubes possess huge spin glass degeneracy. Free quark states do not possess this degeneracy since join along boundaries bonds are absent. Thus the time spent in free states in which color flux tubes are absent is negligible compared with the time time spent in color bound states so that the states consisting of free quarks are unobservable.

A more precise phrasing of this idea relies on unitarity conditions and the assumptions $T_{MN} \simeq T$ and $T_{Mr} \simeq T_r$. Here capital subscripts refer to degenerate hadronic states and small letter subscripts to free many-quark states. In this idealization hadronic degenerate states are stable against decay to free many-quark states with only single exception. The exceptional state should act as a doorway making possible the transition to quark-gluon plasma phase.

3 Basic Implications

In the sequel the physical aspects of the macro-temporal quantum coherence are discussed.

3.1 Thermodynamical Aspects

During macro-temporal quantum coherence dissipation is absent in the quantum coherent degrees of freedom. This implies the breaking of the second law of thermodynamics in time scales shorter than the duration of bound states in the sense that entropy does not grow. [It is also possible that the geometric arrow of psychological time is reversed at the space-time sheets having negative time orientation: in this case second law holds true with respect to subjective time but corresponds to a decrease of entropy with respect to the geometric time of the external observer.]

p-Adic length scale hypothesis suggests a hierarchy of time scales for bound state lifetimes so that a hierarchical structure for the breaking of the second law is predicted. At space-time sheet characterized by p-adic prime p the second law would be broken below the time scale $T_p = L_p/c$, $L_p = \sqrt{p} \times l_0$, where l_0 is essentially CP_2 length scale about 10^4 Planck lengths. Breaking could also occur only below n-ary p-adic time scales $T_p(n) = p^{(n-1)/2} L_p$.

Quite recently it has been found that second law is indeed broken below .1 seconds for certain systems [7]. This time scale corresponds to the secondary p-adic time scale $T_p(2)$ associated with the Mersenne prime $M_{127} = 2^{127} - 1$ defining the p-adic length scale of electron. This time scale is fundamental in the TGD based model of living system and corresponds to the time scale of alpha band and the time resolution of the sensory experience (duration of sensory mental images). The reversal of the arrow of geometric time below p-adic time scale might be fundamental aspect of living systems and this point will be discussed later in more detail.

3.2 Energetic Aspects

The generation of quantum bound state involves liberation of the binding energy as a usable energy. This might provide a new kind of metabolic mechanism in which co-operation by the formation of macroscopic quantum bound states allows a liberation of metabolic energy. The energy bill must be paid sooner or later, and the energy feed from environment takes care of this by destroying the bound state in average time defined by the duration of the bound state. The fact that oxidative metabolism is anomalously low during the neuronal synchrony [8] supports the view that neuronal synchrony might give rise to bound-state entangled multineuron states. This mechanism is quite general and even ordinary metabolism could be based on this mechanism as will be proposed later. Also the bound state entanglement between different organisms might be possible and liberate energy. Thus the notion of 'synergy' might be much more than a mere metaphor.

3.3 Information Theoretic Aspects

TGD framework forces to reconsider also the notion of information itself, and the new number-theoretic view about information might have radical implications for quantum computation.

3.3.1 Number Theoretic Information Measures

The attempts to formulate Negentropy Maximization Principle in for p-adic physics had led to new views about the notion of information.

a) The definition of the entropy in p-adic context is based on the notion p-adic logarithm depending on the p-adic norm of the argument x only ($x = p^n r/s$, r and s not divisible by p; $Log_p(x) = log_p(|x|_p) = -n$: see the chapter "Negentropy Maximization Principle" of [5]). In p-adic context the ordinary Shannon formula for information is replaced by

$$S_p = -\sum_n p_n log_p(|p_n|_p) \ , \tag{6}$$

where the integer valued p-based logarithm is regarded as a p-adic number. p-Adic valued entanglement entropy S_p can be mapped to a real number continuously by canonical identification $x = \sum_n x_n p^n \rightarrow \sum_n x_n p^{-n} = x_R$.

$$S_p = (S_p)_R \times log(p) \ . \tag{7}$$

The resulting entropy is always non-negative but vanishes if entanglement probabilities have p-adic norm equal to one.

b) For rational- and even algebraic number valued and even finite-dimensional extensions of R_p containing transcendentals S_p be regarded as a real number and there is no need to perform canonical identification map. The entropy defined in this manner can be negative so that the entanglement can carry genuine positive information. The problem is how to fix the value of the prime p used to define S_p and the only reasonable criterion is maximization of information so that entanglement entropy is always negative and can be identified as a measure for information content. Note that for p-adic system the prime p corresponding to maximal S_p need not be same as the p-adic prime q characterizing the system.

c) One can distinguish between two kinds of entanglements: extended rational entanglement with positive information content and entanglement which does not reduce to extended rational entanglement which can be real or p-adic valued and for which entanglement entropy is always non-negative. The tentative interpretation of the extended rational entanglement is as bound state entanglement whereas genuinely real and p-adic entanglement can be interpreted as unbound entanglement, which is reduced in the state function reduction and preparation process so that only extended rational entanglement remains.

d) Extended rational entanglement is possible even between states defined in different number fields assuming that they are orthonormalized (1 and 0 are common to all number fields). $R-R_p$ and $R_{p_1}-R_{p_2}$, $p_1 \neq p_2$ entanglement is indeed necessary algebraic (and rational unless one allows an algebraic extension of p-adic numbers, which is however forced by the diagonalization of the density matrix in the general case). For $R_{p_1}-R_{p_2}$ entanglement there are two natural entropies S_{p_1} and S_{p_2}. One can define the total entropy uniquely as the sum $S = S_{p_1} + S_{p_2}$: similar definition applies to $R-R_p$ case. Extended rational entanglement could be called cognitive, and it would be natural to assign a positive or negative information with cognitive entanglement. Cognition could be seen as a quantum computation like process, more appropriate term being quantum problem solving. In particular, bound state entanglement between p-adic states giving rise to a fusion of cognitive mental images is a natural correlate for the experience of understanding, and one can assign to eurekas a well defined amount of information.

e) The modified definition of entropy applying in case of extended rational entanglement has deep implications. For the ordinary definition of the entropy NMP (see the chapter "Negentropy Maximization Principle" of [5]) states that real entanglement is minimized in the state preparation process. Finitely extended rational entanglement has positive information content and is therefore stable against NMP. The fragility of quantum coherence is the basic problem of quantum computation and the good news would be that Nature itself (according to TGD) tends to stabilize quantum coherence.

3.3.2 Is Quantum Jump a Number Theoretic Necessity?

The existence of three kinds of information measures suggests that quantum jump and Negentropy Maximization Principle might be number theoretic necessities.

a) In the chapter "Fusion of p-Adic and Real Variants of Quantum TGD to a More General Theory" of [3] a formulation of quantum TGD based on the generalization of the number concept obtained by replacing real numbers R by a structure obtained by gluing real numbers and all p-adic number fields R_p and their finite-dimensional extensions along rational numbers common for all of them. Gluing occurs also along algebraic numbers common to any two number fields in the union. The generalized notion of number leads to a generalization of manifold concept and allows to formulate the notion of many-sheeted space-time time having both real and p-adic space-time sheets in a more rigorous manner. p-Adic space-time sheets are interpreted as correlates for intentions and cognition and the transformation of intention to action is identified as a quantum jump in which p-adic space-time sheet becomes real.

b) The dramatic differences between real and p-adic topologies (the limit p^n, $n \rightarrow \infty$ has vanishing p-adic norm and infinite real norm!) imply that p-adic space-time sheets have infinite size in real sense and cognition is predicted to be an essentially cosmic phenomenon (see the chapter "Time, Space-Time, and Consciousness" of [6]). Furthermore, the failure of real statistics for intentional systems allows to measure whether the system is intentional and what is the value of p characterizing the system. In a series of N measurements during fixed time interval T the change of the time increment $\Delta T = T/N$ by changing the value of N is predicted to alter dramatically the frequencies of various outcomes if interpreted as real numbers whereas the change is predicted to be small if they are interpreted as p-adic numbers for a proper choice of p (see the chapter "Time, Space-Time, and Consciousness" of [6]).

c) One also ends up to a generalization of quantum mechanics and the notion of quantum jump (see the chapter "Fusion of p-Adic and Real Variants of Quantum TGD to a More General Theory" of [3]. Unitary time evolution generates a formal superposition of states which belong to all possible number fields, and state function reduction and preparation take care of the reduction of the state to a definite number field followed by a reduction to a finite-dimensional extension of rational numbers occurs. The reduction of entanglement to discrete entanglement conforms with the idea that quantum jump is cognitive process and that discreteness is basic aspect of cognition. Negentropy Maximization Principle governs the process leading to a state containing only finitely extended rational entanglement interpreted as bound state entanglement and having negative entanglement entropy.

3.3.3 Life as Islands of Finitely Extended Rational Numbers in the Seas of Real and P-Adic Continua?

If quantum jump is indeed number theoretic necessity, the generation of macro-temporal quantum coherence means generation of states with extended rational entanglement. Macro-temporal quantum coherence is basic aspect of life and consciousness and one could therefore say that life corresponds to an island of extended rationality in the seas of real and p-adic continua. One could also see evolution of cognition as gradual emergence of extensions of p-adic number fields (in particular, p-adic space-time sheets) of increasing value of p and increasing algebraic dimension.

The view about the crucial role of rational and finitely extended numbers as far as intelligent life is considered, could have been guessed on very general grounds from the analogy with the orbits of a dynamical system. Rational numbers allow a predictable periodic decimal/pinary expansion and are analogous to one-dimensional periodic orbits. Algebraic numbers are related to rationals by a finite number of algebraic operations and are intermediate between periodic and chaotic orbits allowing an interpretation as an element in an algebraic extension of any p-adic number field. The projections of the orbit to various coordinate directions of the algebraic extension represent now periodic orbits. The decimal/pinary expansions of transcendentals are un-predictable being analogous to chaotic orbits. The special role of rational and algebraic numbers was realized already by Pythagoras, and the fact that the ratios for the frequencies of the musical scale are rationals supports the special nature of rational and algebraic numbers. The special nature of the Golden Mean, which involves $\sqrt{5}$, conforms the view that also algebraic numbers rather besides rationals are essential for life.

Note however that also finite-dimensional extensions of p-adic numbers involving transcendentals are possible (say the extension containing $e, e^2, .., e^{p-1}$ as units (e^p is ordinary p-adic number). Thus one could see the discovery of transcendentals as an emergence of transcendentals like e and π to the finite-dimensional algebraic extension associated with p-adic space-time sheets serving as correlates for mathematical cognition. Finite extension inspires the conjecture that ratios like e/π, $log(p)/\pi$ (p any prime), and $log(\Phi)/\pi$ are rational numbers (see the chapter "Time, Space-Time, and Consciousness" of [6]).

3.3.4 Quantum Computation and Quantum Problem Solving in TGD Universe

Macro-temporal quantum coherence makes also quantum computation like processes possible since a sequence of quantum jumps effectively binds to a single quantum jump with a duration, which corresponds to the lifetime of the bound state. Quantum computation like process starts, when the quantum bound state is generated and halts when it decays. Spin glass degeneracy increases the duration of the quantum computation to time scales which are sensible for human consciousness. In case of cognitive quantum computation like processes the quantum coherence is stabilized by NMP.

a) Spin glass degeneracy provides the needed huge number of degrees of freedom making quantum computations very effective. These degrees of freedom are associated with the join along boundaries bonds and are essentially gravitational so that a connection with Penrose-Hameroff hypothesis emerges.

b) Bio-systems would be especially attractive candidates for performers of conscious quantum computation like processes. The binding of molecules by lock and key mechanism is a basic process in living matter and the binding of information molecules to receptors is a special case of this process. All these processes would involve new physics not taken into account in the standard physics based biochemistry.

c) The possibility of cognitive quantum computation like information processing forces generalize the standard quantum computer paradigm also because ordinary quantum computers represent only the lowest, 2-adic level of the p-adic intelligence. Qubits must be replaced by qupits since for algebraic $R-R_p$ entanglement two-state systems are naturally replaced with p-state systems and for $R_{p_1}-R_{p_2}$ entanglement with $p_1 \times p_2$ state systems. For primes of order say $p \simeq 2^{167}$ (the size of small bacterium) this means about 167 bits, which means gigantic quantum computational resources. The secondary p-adic time scale $T_2(127) \simeq .1$ seconds basic bit-like unit corresponds to $M_{127} = 2^{127} - 1$ M_{127}-qupits making about 254 bits.

d) The number theoretic formulation of state function reduction and preparation encourages to think that there is an entire hierarchy of these processes labelled by p-adic length and time scales and that these processes occur in quantum parallel manner in different p-adic length and time scales. This would allow to understand why it is possible to describe hadrons as genuine quantum systems in long scales whereas perturbative QCD describes hadrons as dissipative systems using kinetic equations in short scales. This forces to ask whether quantum parallel dissipative computations each of them very similar to ordinary classical computation could be possible. If so then the strengths of classical and quantum computation might be combined.

3.3.5 Information Concept at Space-Time Level

Quantum-classical correspondence suggests that the notion of information is well defined also at the space-time level. The non-determinism of Kähler action and p-adic non-determinism plus algebraic information measures suggest a natural approach tot the problem of defining the information concept. This approach provides also a new light to the problem of assigning a p-adic prime to a given real space-time sheet.

In the presence of the classical non-determinism of Kähler action and p-adic non-determinism one can indeed define ensembles, and therefore also probability distributions and entropies. For a given space-time sheet the natural ensemble consists of the deterministic pieces of the space-time sheet regarded as different states of the same system. The probability for the occurrence of a given value of observable is of the general form $p_i = m_i/N$, $m_i < N$, where N is the number of deterministic pieces and S_p is always negative, when p divides N. The natural manner to define the entropy is as S_p for a value of p making S_p maximally negative. This value of p could be also identified as the prime characterizing the space-time sheet.

Intuitively it seems obvious that there must be a physical mechanism selecting one prime amongst all possible primes which characterizes the information measure associated with the ensemble of the deterministic pieces associated with the real space-time sheet. Conscious information requires the presence of cognition: the real space-time sheet must be entangled with a p-adic space-time sheet. Quantum-classical correspondence means that the cognitive entanglement of the real system with p-adic system has as a space-time correlate join along boundaries bond connecting the real and p-adic space-time sheet and glued to the boundary of the real space-time sheet along common rational points. One could argue that the p-adic join along boundaries bonds are most probable when the p-adic prime is such that it defines an effective p-adic topology for the real space-time sheet. This would mean that the prime-power factors of N define preferred p-adic length scales to the real space-time sheet.

The hypothesis that the prime factorization of N determines the effective p-adic topologies associated with the real space-time sheet inspires a further hypothesis that the finitely extended rational entanglement between real and p-adic systems necessary for cognitive quantum measurements is probable/possible only for the p-adic primes dividing N.

4 Conclusion

Quantum spin glass degeneracy is a basic characteristic of TGD Universe, and makes possible macro-temporal quantum coherence by increasing the lifetime of bound states. The fusion of real physics and its p-adic variants to single generalized physics using generalized notion of number allows to understand state function reduction and preparation as number theoretic necessities and finitely extended rational entanglement can be interpreted as bound state entanglement possessing positive information content. The most significant implications relate to TGD inspired theory of consciousness. In particular, to the understanding of evolution of cognition as a process in which p-adic primes characterizing systems increase and the dimensions of extensions of p-adic number fields increase. Life can be seen as an island of extended rationality in the seas of real and p-adic continua. The possibility of quantum parallel dissipative processes suggests a generalization of quantum computation paradigm.

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