Article

Quantum Mind in TGD Universe

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Abstract

The basic difficulties and challenges of Quantum Mind program are analyzed. The conclusion is that the recent form of quantum theory is not enough to overcome the challenges posed by the philosophical problems of quantum physics and quantum mind theories, and the puzzles of quantum biology and quantum neuroscience. Certain anomalies of recent day biology giving hints about how quantum theory should be generalized serve as an introduction to the summary of the aspects of quantum TGD especially relevant to the notion of Quantum Mind. These include the notions of many-sheeted space-time and field (magnetic) body, zero energy ontology, the identification dark matter as a hierarchy of phases with large value of Planck constant, and p-adic physics proposed to define physical correlates for cognition and intentionality.

Especially relevant is the number theoretic generalization of Shannon entropy: this entropy is well defined for rational or even algebraic entanglement probabilities and its minimum as a function of the prime defining p-adic norm appearing in the definition of the entropy is negative. Therefore the notion of negentropic entanglement makes sense in the intersection of real and p-adic worlds and is negative: this motivates the proposal that living matter resides in this intersection.

TGD inspired theory of consciousness is introduced as a generalization of quantum measurement theory. The notions of quantum jump and self defining the generalization of the notion of observer are introduced and it is argued that the notion of self reduces to that for quantum jump. Negentropy Maximization Principle reproduces standard quantum measurement theory for ordinary entanglement but respects negentropic entanglement so that the outcome of state function reduction is not random for negentropic entanglement. The new view about the relationship of experienced time and geometric time combined with zero energy ontology is claimed to solve the basic philosophical difficulties of quantum measurement theory and consciousness theory. The identification of the quantum correlates of sensory qualia and Boolean cognition, emotions, cognition and intentionality and self-referentiality of consciousness is discussed.

It should be noted that this article is an updated version of earlier article published in JCER.

1 Introduction

The notion of Quantum Mind [63] has become a respected branch of science during thirty years since Esalem conference. The basic vision is that quantum superposition, quantum entanglement and state function reduction (or some of its interpretational equivalents) are somehow highly relevant for the understanding of consciousness. Whether quantum entanglement or quantum jump or something else is identified as a correlate for consciousness depends on theorist.

The basic objections against Quantum Mind is that standard quantum physics - at least wave mechanics- leaves no room for quantum mind. Decoherence leading to a loss of entanglement is the basic enemy of quantum mind [69]. Experimental work however suggests that macroscopic quantum coherence prevails in cell length scale: the findings about photosynthesis provide an example of this [53]. There is also a growing evidence for macro-entanglement between different brains correlating closely with electromagnetic fields [67, 70].

Of course, the idea that wave mechanics is enough to describe living matter and also the belief that quantum theory - as we know it - is something final are only beliefs. There are many other similar beliefs: the belief on reductionism coded to the statement that everything above intermediate boson length scale is

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understood in recent day physics; the belief that living matter differs from inanimate matter only because it is very complex; the belief that experienced time and the geometric time of physicist are one and the same thing; the pragmatic belief that the problems of quantum measurement theory can be forgotten by saying that quantum theory is just a calculational receipe;...

One could add one further not quite obvious item to the list. Dark matter and dark energy are one of the most notorious problems of recent day physics and it is just a belief that dark matter is nothing but some exotic X-ino having very weak interactions with visible matter and therefore does not have any relevance for the understanding of living matter.

The basic message of this article is that standard quantum theory is not enough if one wants to construct a theory of Quantum Mind. A profound re-evaluation of the belief system underlying the ontology of the recent day quantum physics is needed. My own proposal is following.

- The reductionistic dogma is replaced with fractality meaning infinite hierarcies both at the level of matter and mind. Consciousness is everywhere in a form of self hierarchy so that Quantum Mind involves more than brain. Biological bodies, cells, biomolecules, and even elementary particles correspond to the levels of the self hierarchy. Also higher collective levels are present.

- Topological field structures implied by the new fractal view about space-time - I speak about many-sheeeted space-time- are essential parts of this hierarchy. The notion of field (or magnetic) body is one aspect of the many-sheeted space-time and one could even say that magnetic body is the intentional agent using biological body as a motor instrument and sensory receptor. EEG and its various fractal analogs can be seen as communication and control tools of of the magnetic body in this conceptual framework. The explanation for the strange time delays associated the the passive aspects of consciousness discovered by Libet [61] and the good hopes about understanding of fundamental biorhythms in terms of cyclotron frequencies of biologically important and Josephson frequencies assignable to cell membrane Josephson junctions [5] provide support for this vision. This conforms with the proposals that spin and more generally angular momentum are central for understanding consciousness and living matter [64, 67]. Biological evolution becomes evolution of consciousness and one cannot restrict Quantum Mind to microtubules, brain, or even biological body.

- Self hierarchy has two physical correlates: the hierarchy of p-adic length scales and the hierarchy of Planck constants: both hierarchies have experimental support. A number theoretical miracle occurs: the length scale range 10 nm-2.5 μm involves as many as four Gaussian Mersennes expected to define preferred p-adic length scales since this they do so in the case of elementary particles. The effects of ELF em fields on vertebrate brain [58] and the strange behavior of cell membrane and cell interior suggesting strongly quantal ionic currents [56] provide physical support for both the hierarchy of Planck constants and p-adic length scale hypothesis.

- In TGD Universe zero energy ontology (ZEO) replaces the positive energy ontology of standard physics. The motivation comes both certain philosophical dilemma which is very frustrating for a theoretician, and the crossing symmetry of quantum field theory justifies ZEO. ZEO assigns new macroscopic time scale to each elementary particle. For electron and quarks these time scale coincide with fundamental biological time scales (for instance, the .1 second time scale predicted for electron corresponds to 10 Hz fundamental biorhythm). Elementary particle physics and biology are therefore strongly interrelated in ZEO.

- The identification of quantum jump as moment of consciousness and the notion of self emerge from a generalization of quantum measurement theory to a theory of consciousness. In this framework the experienced time identified as a sequence of quantum jumps and the geometric time of physicist cannot be identified [33, 34, 1].

  The fact that the contents of conscious experience is about a four-dimensional region of space-time implies a new interpretation of memories [22]. Quantum jump replacing the entire geometric future

and past with a new one: Libet's strange findings about active aspects of consciousness [65] forcing in positive energy ontology the conclusion that free will is illusion provide support for this view. The challenge is to understand the arrow of time and why the contents of sensory experience is localized to a rather short time interval of about .1 second: this suggests a rather dramatic radical idea about how the arrow of subjective time emerges as a consequence of Negentropy Maximization Principle [14] defining the basic variational principle of TGD inspired theory of consciousness.

- p-Adic physics extending reality to include also various p-adic levels is highly relevant for the understanding of the difference between living and inanimate matter. Negentropic entanglement is possible for p-adic variant of Shannon entropy making sense if entanglement probabilities are algebraic. One can say that this entanglement is possible in the intersection of real and p-adic worlds in which intentions could transform to actions by quantum jumps replacing p-adic space-time sheets with real ones (this makes sense only in ZEO!). Maybe this is the mathematical and information theoretical quintessence of life.

Before continuing a comment about the notion of consciousness is in order. This notion as also the notion of awareness implicitly codes for the assumption that consciousness is a property of a physical system- something mathematically analogous to mass or charge. The greek world "nous" and finnish word "tajunta" refer to activity rather than property and this meaning is more appropriate in TGD framework. Since it would sound rather artificial to talk about "TGD inspired theory of nous" I will will use the standard term in the sequel although it is misleading. It should be also emphasize that I represent only those aspects of a rather extensive work documented in the books at my homepage, which seem to be especially interesting just now. In the following representation I am forced to leave out all details. They can be found in the books about TGD inspired theory of consciousness at my homepage [32, 4, 20, 9, 3, 11, 12, 27]. I have also summarized TGD inspired theory of consciousness in an issue of JCER [45, 43, 44] but from different view point.

2 What are the problems of quantum mind theories?

In the following I list briefly the basic problems of physics and quantum mind theories using a classification which is rather natural from the point of view of physics.

2.1 Some philosophical problems of quantum physics

- "Monism, dualism, or something else?" is the first basic question. Monism appears as two variants which are mirror images. Materialism has the problem that consciousness becomes something totally reducible to the state of material system so that free will must be an illusion if one believes in the deterministic laws of physics. This is in a sharp contrast to what we directly experience. In the idealistic framework one loses completely physics. The difficulty of dualism- pointed out very clearly by Chalmers [59] - is that it is very difficult to achieve consistency with the basic laws of physics which do not allow free will. It seems that one must have something new allowing to achieve consistency of the determinism of field equations with (partially) free will.

- "Reductionism or not?" is second key question. For me personally the realization that reductionism is a mere dogma was a painful process although it was from the beginning clear that TGD based view about space-time forces to challenge this belief. It was especially painful to take seriously the fact that even the reduction of chemical bond to wave mechanics alone is nothing but a belief since it it is not yet testable by perfoming numerical calculations. Gradually I became conscious about the many non-existing bridges of reductionism: the bridge from quarks and gluons to hadrons; the brigde from nucleons to nuclei; the bridge from atoms to molecules; the bridges from inorganic chemistry to organic chemistry to biochemistry: all these bridges are just figments of wishful thinking

and implications of the reductionistic dogma rather than support for it. Also the widely accepted argument about living matter as something which is just complex fails to be distinguishable from a rhetoric trick.

- "Determinism or not?" is the third question. Also here it took time to realize that the belief that free will is an illusion does not reflect the reality but our limited tools for describing it. The physicists of previous centuries did not have any conceptual and mathematical tools to describe free will without giving up the idea about laws of physics. Most importantly, they did not know anything about quantum non-determinism. Perhaps it is some kind of cognitive inertia that physicists have been ready to give up even the very notion of objective reality instead of accepting the fact that non-determinism is real and concluding that one should find an ontology consistent with both quantum non-determinism and Schrödinger equation.

- The notion of time is highly problematic.

  - The relationship between experienced time and the geometric time of physicist is poorly understood. Subjective time is irreversible and has only recent moment and past, geometric time is reversible and spans entire eternity. The assignment of experienced time with a 3-D wave front shifting in the direction of geometric time direction is in conflict with Lorentz symmetry and general coordinate invariance, which do not allow to identify a unique time coordinate as the subjective time. The natural basic object in general relativity is 4-dimensional space-time region, not time=constant snapshot.
  - In physics conceptual difficulties are encountered already in the phenomenological description of dissipation by adding to the reversible field equations phenomenological dissipation terms. Rather remarkably, the quantum mechanical formulas for the reaction rates in terms used to calculated dissipation coefficients involve integral over entire space-time so that quantum events have at least formally an infinite duration. Finite duration is certainly necessary by Uncertainty Principle. Somehow quantum jump seems to involve entire geometric eternity: as if it would take place between two geometric eternities.
  - There is also the problem of initial state. If the dynamics is deterministic and conservation laws hold, only a single solution of field equations is realized in classical physics and theoretical physics becomes useless waste of time since it cannot be tested. If quantum non-determinism is allowed, conservation laws still restrict the physical states to those having fixed net values. "What was the initial state at the moment of Big Bang?" is the question which cannot be aswered in the framework of physics alone and one ends up doing metaphysics. Indeed, the recent crisis of M-theory- meant to be the final jewel in the crown of materialistic and reductionistic science- has led to the landscape problem, and many colleagues have given up the hope that ultimate theory could predict anything so that anthropic principle would be the only manner to connect theory with experiment.

2.2 Basic philosophical problems of quantum mind theories

At least the following problems could be seen as basic philosophical problems of quantum mind theories.

- What are the quantum correlates for consciousness? Entanglement has been proposed as a correlate of consciousness. For instance, in the orchestrated reduction approach of Hameroff and Penrose the period of consciousness ends with a state function reduction and quantum gravitation is believed to play a fundamental role in the understanding of consciousness. The believer in free will could see state function reduction or its generalization as as a natural quantum correlate for a moment of consciousness. The basic objection is that the randomness of state function reduction does not allow genuine goal directed free will. One could also argue that state function reduction generates

entropy at least at the level of ensemble whereas intentional action should do just the opposite. Here one must however remember that entropy generation at the level of aspect need not mean entropy generation at the level of the member of ensemble.

- How the determinism of field equations and Schrödinger equation can be consistent with the non-determinism of the state function reduction? This question must be answered unless one is ready to give up the notion of objective reality completely or to believe in multiverse interpretation. These manners to circumvent the basic problem do not however leave much room for quantum consciousness theorizing. The closely related question about the relationship between experienced time and time of physicist has been already mentioned.

- What is the quantum correlate for the notion of self? The quantum notion of self should be a generalization of the notion of observer which in quantum measurement theory still remains a structureless outsider.

- What conscious information is? Can one give it a mathematical measure? Can one measure physically the amount of conscious information? Unfortunately the recent day physics can only provide measure for dis-information as Shannon entropy and the best that subsystem can achieve is no information at all if this picture is accepted.

- There is a bundle of questions about the quantum correlates of various aspects of conscious experience. For instance, what is the quantum correlate of mental image, and what are the quantum correlates of cognition and intentionality, Boolean mind, sensory qualia, memory, and of emotions?

- An especially challenging question relates to the quantum correlate for the self referentiality of consciousness making possible reflective levels of consciousness. What it means physically to be conscious about what one is (or perhaps only "was") conscious? Jack Sarfatti was well aware about this problem and in his dualistic approach talked about feedback loop but still used a trick in which one divides various fields to matter-like and mind-like.

2.3 Basic problems of quantum biology and quantum neuroscience

The basic problems of quantum biology and neuroscience are closely related unless one is ready to believe that consciousness reduces to one particular function assignable to some particular part of brain ("consciousness module"). This kind of assignment can be imagined in engineerish neuroscience identifying brain as electric circuitry but does not have much sense in quantum mind approach.

The first list of first principle questions includes at least the following ones.

- What distinguishes between living and dead matter is certainly the fundamental question. In standard biology based on materialistic philosophy one tries to reduce the distinction to a list of properties which as such can be possessed by inanimate matter. Ability to replicate, to process information, to communicate, to form representations about the external world, the ability to self-organize to increasingly complex configurations, intentional behavior, ability to co-operate,.... could be properties of this kind. Up to self-organization the reduction seems plausible. It is easy to model self-organization (by say cell automatons) but it this dynamics is like the dynamics of traffic rules and neither classical nor quantum dynamics resembles it. Intentional behavior is impossible to understand in classical physics unless one claims that it is a mere illusion. This is the case also in quantum physics as we understand it since the randomness of the outcome of state function reduction seems to be in conflict with intentional behavior. Here one must however keep in mind that the individual subsystem performing a state function reduction could quite well experience it as an intentional action. In any case, standard view about state function reduction makes it difficult to co-operative behavior.

- What distinguishes between biochemistry and organic chemistry? For instance, how biomolecules can find themselves in the dense soup of biomolecules and how can one understand the effectiveness of bio-catalysts? One might think that these problems are well-understood since we have learned what happens in DNA replication, transcription, and translation and we know the complex reaction pathways. The dynamics involved is very much like the symbolic dynamics of society (one can predict the day of practizing professional from knowing his profession but not from the knowledge of initial data of every possible elementary particle in his body). But what makes the soup of biomolecules a molecular society obeying a dynamics based on symbols? The description of biochemistry in terms of kinematics allows to construct complex reaction pathways based on the idea that each step of the reaction pathway requires a key which fits to a lock of a room containing a key to the lock to the next room [57] but can one really deduce this kind of kinematics from standard quantum theory?

- Both biology and neuroscience characterizes subsystems of biological systems and brain in terms of functions they possess and one should also understand whether and how the quantum counterparts of functions emerge. The identification of various functions as time evolution of standard self-organization patterns is certainly a part of the answer. But what self-organization means? Conscious information is certainly the key notion but is the existing quantum theory able to characterize it?

- At the level of brain one of the key questions concerns EEG. Since EEG correlates strongly with the contents of consciousness it is difficult to believe that it is random side product of neural activity. What is then the real role of neuronal activity and EEG and its variants? Why EEG is needed? Signaling related to communication and control is what comes first in mind. But why this kind of signaling would be needed. Brain sends (receives) information but who receives (sends) it?

- How macroscopic quantum coherence is achieved allowing quantum super-positions in long time scales? How stable quantum entanglement is achieved? These are difficult problems if one wants to understand quantum mind without generalizing quantum theory itself. Planck constant is simply too small so that dissipation rates are too high and coherence times and lengths are too short. Should physicists adopt a humbler attitude and consider seriously the possibility that the existing physics is not enough and try to learn from biology instead of saying that living systems are just complex?

2.4 Could anomalies help?

Anomalies are the best way to end up with a discovery of something new. Of course, living matter as such is a gigantic anomaly but this does not help much. One should pick up the anomalies which are in sharp conflict with the existing physics and give a clear hint about what is wrong with our cherished assumptions.

- In quantum mind approach EEG should be a quantal phenomenon since it correlates with consciousness. From the basic formula $E = hf$ of quantum mechanics the energies of EEG photons are however ridiculously small as compared to the thermal energy at physiological temperatures. The strange quantal looking effects of ELF photons on vertebrate (why just vertebrate?!) brain at frequencies which correspond to cyclotron frequencies of biologically important ions such as Ca^{++} are however an experimental fact (see for instance [58]). The effects of magnetic field patterns on brain studied by Persinger and collaborators represent also an example of this kind of strange effects [66]. The strange findings about the behavior of cell membrane [56] suggest that ionic currents do not dissipate much. The recently discovered burning of water when irradiated by radiowave photons [**?**, **?**] suggests that energetically these photons behave like photons of visible light. The recent findings about photosynthesis [53] suggest quantum coherence in cellular length scale.

Is standard quantum theory able to explain these findings? Should one challenge the belief that Planck constant is just a conversion factor between units which can be put equal one with a suitable choice of units? Could Planck constant have a spectrum of discrete values? This would explain the strange findings since by $E = hf$ relation low frequencies could correspond to high energies and dissipation rates -in the first guess inversely proportional to $\hbar$- could be very small. Large values of Planck constant would also increase the spatial and time scales of quantum coherence and might solve the basic technical problem of quantum consciousness theories.

- Also biophotons [54] correlate with the state of living system but are poorly understood in the existing theoretical framework.

- Libet's findings about strange time delays associated with the passive aspects of consciousness serve also as a hint. Our sensory data has age which is a fraction of second and corresponds to a photon wavelength $\lambda = cT$ to a length scale, which is of order of Earth size. As if sensory data would be communicated somewhere. Where?

- Cyclotron frequencies of biologically important ions in a magnetic field .2 Gauss (smaller than the nominal value of .5 Gauss of the Earth's magnetic field) are involved with the effects of ELF radiation on vertebrate brain. Also Schumann resonances are reported to have effects on brain. Are some kind of magnetic field structures involved? Earth's magnetic field and perhaps also the magnetic field patterns associated with biological system itself with $B = 2B_E/5$ for one important level in the hierarchy? As noticed in [67], the cyclotron energy scale of electron in pT range is in EEG range and pT range indeed characterizes the magnetic field associated with brain activity. Do also these magnetic structures carry Cooper pairs of electrons?

- ADP-ATP machinery is the core of energy metabolism and its description involves the problematic notion of high energy phosphate bond [52]. Does this notion really reduce to standard quantum theory?

- The chiral selection of biomolecules in living matter [51, 55] means a large parity breaking. This is a complete mystery in standard model which predicts extremely small parity breaking effects. Therefore chiral selection is extremely valuable anomaly helping to guess what kind of new physics might be involved with living matter. Somehow it seems that the parity breaking effects which are large in electro-weak scale appear in immensely zoomed up scales (scaling factors of order 10^{10} would be involved)

3 Some aspects of quantum TGD

In the following I summarize very briefly those basic notions of TGD which are especially relevant for TGD inspired consciousness theory and quantum biology. The representation will be practically formula free. The article series published in Prespacetime Journal [37, 38, 41, 42, 39, 36, 40, 46] describes the mathematical theory behind TGD. The seven books about TGD [35, 23, 17, 15, 29, 24, 28] provide a detailed summary about the recent state of TGD.

3.1 New space-time concept

The physical motivation for TGD was what I have christened the energy problem of General Relativity. The notion of energy is ill-defined because the basic symmetries of empty space-time are lost in the presence of gravity. The way out is based on assumption that space-times are imbeddable as 4-surfaces to certain 8-dimensional space by replacing the points of 4-D empty Minkowski space with 4-D very small internal space. This space -call it S- is unique from the requirement that the theory has the symmetries

of standard model: $S = CP_2$, where CP_2 is complex projective space with 4 real dimensions [46], is the unique choice.

The replacement of the abstract manifold geometry of general relativity with the geometry of surfaces brings the shape of surface as seen from the perspective of 8-D space-time and this means additional degrees of freedom giving excellent hopes of realizng the dream of Einstein about geometrization of fundamental interactions.

The work with the generic solutions of the field equations assignable to almost any general coordinate invariant variational principle led soon to the realization that the space-time in this framework is much more richer than in general relativity.

1. Space-time decomposes into space-time sheets with finite size: this lead to the identification of physical objects that we perceive around us as space-time sheets. For instance, the outer boundary of the table is where that particular space-time sheet ends. Besides sheets also string like objects and elementary particle like objects appear so that TGD can be regarded also as a generalization of string models obtained by replacing strings with 3-D surfaces.

2. Elementary particles are identified as topological inhomogenities glued to these space-time sheets. In this conceptual framework material structures and shapes are not due to some mysterious substance in slightly curved space-time but reduce to space-time topology just as energy- momentum currents reduce to space-time curvature in general relativity.

3. Also the view about classical fields changes. One can assign to each material system a field identity since electromagnetic and other fields decompose to topological field quanta. Examples are magnetic and electric flux tubes and flux sheets and topological light rays representing light propagating along tube like structure without dispersion and dissipation making em ideal tool for communications [18]. One can speak about field body or magnetic body of the system.

Field body indeed becomes the key notion distinguishing TGD inspired model of quantum biology from competitors. The magnetic body inherits from the biological body an onionlike fractal structure. Each part of the magnetic body can be seen as an intentional agent using the corresponding part of the biological body as a motor instrument and sensory receptor. The size scale of the magnetic body is in general much larger than that of biological body. Cyclotron frequency identified as frequency of photons able to exist as oscillations at magnetic body gives an estimate for the size of the magnetic body corresponding to a particular magnetic field strength. For 10 Hz frequency the size scale is of order Earth size. In this framework a fractal generalization of EEG and its variants provides a communication and control tool for magnetic body. The findings of Libet about time delays associated with the passive aspects and meaning that sensory data is a fraction of second old [61] could be understood as delays due to the finite velocity of light: it takes finite time for the signal to propagate from biological body to the magnetic body.

This obviously means a profound modification of the views about what we are. The identification with the biological body could be understood as an illusion: a child looking a movie assimilates completely with the hero. There is a rich variety of illusions related to this identification of observer with the region of space from which the dominating contribution to consciousness comes from.

3.2 Zero energy ontology

In standard ontology of quantum physics physical states are assumed to have positive energy. In zero energy ontology physical states decompose to pairs of positive and negative energy states such that all net values of the conserved quantum numbers vanish. The interpretation of these states in ordinary ontology would be as transitions between initial and final states, physical events. By quantum classical correspondences zero energy states must have space-time and imbedding space correlates.

1. Positive and negative energy parts reside at future and past light-like boundaries of causal diamond (CD) defined as intersection of future and past directed light-cones and visualizable as double cone. The analog of CD in cosmology is big bang followed by big crunch. CDs for a fractal hierarchy containing CDs within CDs. Disjoint CDs are possible and CDs can also intersect.

2. p-Adic length scale hypothesis [**?**] motivates the hypothesis that the temporal distances between the tips of the intersecting light-cones come as octaves $T = 2^n T_0$ of a fundamental time scale T_0 defined by CP_2 size R as $T_0 = R/c$. One prediction is that in the case of electron this time scale is .1 seconds defining the fundamental biorhythm. Also in the case u and d quarks the time scales correspond to biologically important time scales given by 10 ms for u quark and by and 2.5 ms for d quark [2]. This means a direct coupling between microscopic and macroscopic scales.

Zero energy ontology conforms with the crossing symmetry of quantum field theories meaning that the final states of the quantum scattering event are effectively negative energy states. As long as one can restrict the consideration to either positive or negative energy part of the state ZEO is consistent with positive energy ontology. This is the case when the observer characterized by a particular CD studies the physics in the time scale of much larger CD containing observer's CD as a sub-CD. When the time scale sub-CD of the studied system is much shorter that the time scale of sub-CD characterizing the observer, the interpretation of states associated with sub-CD is in terms of quantum fluctuations.

ZEO solves the problem of initial state since in principle any zero energy state is obtained from any other state by a sequence of quantum jumps without breaking of conservation laws. The fact that energy is not conserved in general relativity based cosmologies can be also understood since each CD is characterized by its own conserved quantities. As a matter fact, one must be speak about average values of conserved quantities since one can have a quantum superposition of zero energy states with the quantum numbers of the positive energy part varying over some range.

For thermodynamical states this is indeed the case and this leads to the idea that quantum theory in ZEO can be regarded as a "complex square root" of thermodynamics obtained as a product of positive diagonal square root of density matrix and unitary S-matrix. M-matrix defines time-like entanglement coefficients between positive and negative energy parts of the zero energy state and replaces S-matrix as the fundamental observable. In standard quantum measurement theory this time-like entanglement would be reduced in quantum measurement and regenerated in the next quantum jump if one accepts Negentropy Maximization Principle (NMP) [14] as the fundamental variational principle. Various M-matrices define the rows of the unitary U matrix characterizing the unitary process part of quantum jump. From the point of view of consciousness theory the importance of ZEO is that conservation laws in principle pose no restrictions for the new realities created in quantum jumps: free will is maximal.

3.3 The hierarchy of Planck constants

The motivations for the hierarchy of Planck constants come from both astrophysics and biology. The biological motivations have been already discussed. In astrophysics the observation of Nottale [50] that planetary orbits in solar system seem to correspond to Bohr orbits with a gigantic gravitational Planck constant motivated the proposal that Planck constant might not be constant after all [25, 19].

This led to the introduction of the quantization of Planck constant as an independent postulate. It has however turned that quantized Planck constant in effective sense could emerge from the basic structure of TGD alone. Canonical momentum densities and time derivatives of the imbedding space coordinates are the field theory analogs of momenta and velocities in classical mechanics. The extreme non-linearity and vacuum degeneracy of Kähler action imply that the correspondence between canonical momentum densities and time derivatives of the imbedding space coordinates is 1-to-many: for vacuum extremals themselves 1-to-infinite.

A convenient technical manner to treat the situation is to replace imbedding space with its n-fold singular covering. Canonical momentum densities to which conserved quantities are proportional would

be same at the sheets corresponding to different values of the time derivatives. At each sheet of the covering Planck constant is effectively $\hbar = n\hbar_0$. This splitting to multisheeted structure can be seen as a phase transition reducing the densities of various charges by factor $1/n$ and making it possible to have perturbative phase at each sheet (gauge coupling strengths are proportional to $1/\hbar$ and scaled down by $1/n$). The connection with fractional quantum Hall effect [49] is almost obvious. At the more detailed level one finds that the spectrum of Planck constants would be given by $\hbar = n_a n_b \hbar_0$.

This has many profound implications, which are wellcome from Quantum Mind perspective.

1. Quantum coherence and quantum superposition become possible in arbitrary long length scales. One can speak about zoomed up variants of elementary particles and zoomed up sizes make it possible to satisfy the overlap condition for quantum length parameters used as a criterion for the presence of macroscopic quantum phases. In the case of quantum gravitation the length scale involved are astrophysical. This would conform with Penrose's intuition that quantum gravity is fundamental for the understanding of consciousness and also with the idea that consciousness cannot be localized to brain.

2. Photons with given frequency can in principle have arbitrarily high energies by $E = hf$ formula, and this would explain the strange anomalies associated with the interaction of ELF em fields with living matter [58]. Quite generally the cyclotron frequencies which correspond to energies much below the thermal energy for ordinary value of Planck constant could correspond to energies above thermal threshold.

3. The value of Planck constant is a natural characterizer of the evolutionary level and biological evolution would mean a gradual increase of the largest Planck constant in the hierarchy characterizing given quantum system. Evolutionary leaps would have interpretation as phase transitions increasing the maximal value of Planck constant for evolving species. The space-time correlate would be the increase of both the number and the size of the sheets of the covering associated with the system so that its complexity would increase.

4. The phase transitions changing Planck constant change also the length of the magnetic flux tubes. The natural conjecture is that biomolecules form a kind of Indra's net connected by the flux tubes and $\hbar$ changing phase transitions are at the core of the quantum bio-dynamics. The contraction of the magnetic flux tube connecting distant biomolecules would force them near to each other making possible for the bio-catalysis to proceed. This mechanism could be central for DNA replication and other basic biological processes. Magnetic Indra's net could be also responsible for the coherence of gel phase and the phase transitions affecting flux tube lengths could induce the contractions and expansions of the intracellular gel phase. The reconnection of flux tubes would allow the restructing of the signal pathways between biomolecules and other subsystems and would be also involved with ADP-ATP transformation inducing a transfer of negentropic entanglement [7]. The braiding of the magnetic flux tubes could make possible topological quantum computation like processes and analog of computer memory realized in terms of braiding patterns[6].

5. p-Adic length scale hypothesis and hierarchy of Planck constants suggest entire hierarchy of zoomed up copies of standard model physics with range of weak interactions and color forces scaling like $\hbar$. This is not conflict with the known physics for the simple reason that we know very little about dark matter (partly because we might be making misleading assumptions about its nature).

   Dark matter would make possible the large parity breaking effects manifested as chiral selection of bio-molecules [51]. What is required is that classical Z^0 and W fields responsible for parity breaking effects are present in cellular length scale. If the value of Planck constant is so large that weak scale is some biological length scale, weak fields are effectively massless below this scale and large parity breaking effects become possible.

For the solutions of field equations which are almost vacuum extremals Z^0 field is non-vanishing and proportional to electromagnetic field. The hypothesis that cell membrane corresponds to a space-time sheet near a vacuum extremal (this corresponds to criticality very natural if the cell membrane is to serve as an ideal sensory receptor) leads to a rather successful model for cell membrane as sensory receptor with lipids representing the pixels of sensory qualia chart. The surprising prediction is that bio-photons [54] and bundles of EEG photons can be identified as different decay products of dark photons with energies of visible photons. Also the peak frequencies of sensitivity for photoreceptors are predicted correctly [21].

3.4 p-Adic physics and number theoretic universality

p-Adic physics [31, 15] has become gradually a key piece of TGD inspired biophysics. Basic quantitative predictions relate to p-adic length scale hypothesis and to the notion of number theoretic entropy. Basic ontological ideas are that life resides in the intersection of real and p-adic worlds and that p-adic space-time sheets serve as correlates for cognition and intentionality.

3.4.1 p-Adic number fields

p-Adic number fields Q_p [48] -one for each prime p- are analogous to reals in the sense that one can speak about p-adic continuum and that also p-adic numbers are obtained as completions of the field of rational numbers. One can say that rational numbers belong to the intersection of real and p-adic numbers. p-Adic number field Q_p allows also an infinite number of its algebraic extensions. Also transcendental extensions are possible. For reals the only extension is complex numbers.

p-Adic topology defining the notions of nearness and continuity differs dramatically from the real topology. An integer which is infinite as a real number can be completely well defined and finite as a p-adic number. In particular, powers p^n of prime p have p-adic norm (magnitude) equal to p^{-n} in Q_p so that at the limit of very large n real magnitude becomes infinite and p-adic magnitude vanishes.

p-Adic topology is rough since p-adic distance $d(x,y) = d(x-y)$ depends on the lowest pinary digit of $x-y$ only and is analogous to the distance between real points when approximated by taking into account only the lowest digit in the decimal expansion of $x-y$. A possible interpretation is in terms of a finite measurement resolution and resolution of sensory perception. p-Adic topology looks somewhat strange. For instance, p-adic spherical surface is not infinitely thin but has a finite thickness and p-adic surfaces possess no boundary in the topological sense. Ultrametricity is the technical term characterizing the basic properties of p-adic topology and is coded by the inequality $d(x-y) \leq Min\{d(x), d(y)\}$. p-Adic topology brings in mind the decomposition of perceptive field to objects.

3.4.2 Physical and biological motivations for p-adic number fields

The physical motivations for p-adic physics came from the observation that p-adic thermodynamics - not for energy but infinitesimal scaling generator of so called super-conformal algebra [47] acting as symmetries of quantum TGD [23]- predicts elementary particle mass scales and also masses correctly under very general assumptions [15]. In particular, the ratio of proton mass to Planck mass, the basic mystery number of physics, is predicted correctly. The basic assumption is that the preferred primes characterizing the p-adic number fields involved are near powers of two: $p \simeq 2^k$, k positive integer. Those nearest to power of two correspond to Mersenne primes $M_n = 2^n - 1$. One can also consider complex primes known as Gaussian primes, in particular Gaussian Mersennes $M_{G,n} = (1+i)^n - 1$.

It turns out that Mersennes and Gaussian Mersennes are in a preferred position physically in TGD based world order. What is especially interesting that the length scale range 10 nm-2.5 μ assignable to DNA contains as many as 4 Gaussian Mersennes corresponding to $n = 151, 157, 163, 167$ [21]. This number theoretical miracle supports the view that p-adic physics is especially important for the understanding of living matter.

p-Adic length scale hypothesis suggests the identification of metabolic energy currencies as energy quanta liberated as particle drops from space-time sheet to a larger one. These energy quanta correspond to increrements of zero point kinetic energy. Metabolic energy currencies would be completely universal and exist already during the prebiotic era so that metabolic machinery would build up around this pre-existing structure. A simple (and also rough) model based on p-adic length scale hypothesis allows to estimate the increments of zero point kinetic energy. The quantum corresponding to about .5 eV has place in this hierarchy for which basic energies (those for which larger space-time sheet is very large) come as octaves of basic energy quantum [2, 10]. These energy quanta do not have interpretation in terms of molecular transitions and there exist anamalous lines of radiation from interstellar space both in IR, visible, and UV region [2].

3.4.3 p-Adic physics as correlate for cognition and intentionality

The philosophical for p-adic numbers fields come from the question about the possible physical correlates of cognition and intention [16]. Cognition forms representations of the external world which have finite cognitive resolution and the decomposition of the perceptive field to objects is an essential element of these representations. Therefore p-adic space-time sheets could be seen as candidates of thought bubbles, the mind stuff of Descartes. One can also consider p-adic space-time sheets as correlates of intentions. The quantum jump in which p-adic space-time sheet is replaced with a real one could serve as a quantum correlate of intentional action. This process is forbidden by conservation laws in standard ontology: one cannot even compare real and p-adic variants of the conserved quantities like energy in the general case. In zero energy ontology the net values of conserved quantities for zero energy states vanish so that conservation laws allow these transitions.

3.4.4 Life as something in the intersection of real and p-adic worlds

Rational numbers belong to the intersection of real and p-adic continua. An obvious generalization of this statement applies to real manifolds and their p-adic variants. When extensions of p-adic numbers are allowed, also some algebraic numbers can belong to the intersection of p-adic and real worlds. The notion of intersection of real and p-adic worlds has actually two meanings.

1. The intersection could consist of the rational and possibly some algebraic points in the intersection of real and p-adic partonic 2-surfaces at the ends of CD. This set is in general discrete. The interpretation could be as discrete cognitive representations.

2. The intersection could also have a more abstract meaning. For instance, the surfaces defined by rational functions with rational coefficients have a well-defined meaning in both real and p-adic context and could be interpreted as belonging to this intersection. There is strong temptation to assume that intentions are transformed to actions only in this intersection. One could say that life resides in the intersection of real and p-adic worlds in this abstract sense.

Additional support for the idea comes from the observation that Shannon entropy $S = -\sum p_n log(p_n)$ allows a p-adic generalization if the probabilities are rational numbers by replacing $log(p_n)$ with $-log(|p_n|_p)$, where $|x|_p$ is p-adic norm. Also algebraic numbers in some extension of p-adic numbers can be allowed. The unexpected property of the number theoretic Shannon entropy is that it can be negative and its unique minimum value as a function of the p-adic prime p it is always negative. Entropy transforms to information!

In the case of number theoretic entanglement entropy there is a natural interpretation for this. Number theoretic entanglement entropy would measure the information carried by the entanglement whereas ordinary entanglement entropy would characterize the uncertainty about the state of either entangled system. For instance, for p maximally entangled states both ordinary entanglement entropy and number theoretic entanglement negentropy are maximal with respect to R_p norm. Entanglement carries maximal

information. The information would be about the relationship between the systems, a rule. Schrödinger cat would be dead enough to know that it is better to not open the bottle completely.

Negentropy Maximization Principle [14] coding the basic rules of quantum measurement theory implies that negentropic entanglement can be stable against the effects of quantum jumps unlike entropic entanglement. Therefore living matter could be distinguished from inanimate matter also by negentropic entanglement possible in the intersection of real and p-adic worlds. In consciousness theory negentropic entanglement could be seen as a correlate for the experience of understanding or any other positively colored experience, say love.

Negentropically entangled states are stable but binding energy and effective loss of relative translational degrees of freedom is not responsible for the stability. Therefore bound states are not in question. The distinction between negentropic and bound state entanglement could be compared to the difference between unhappy and happy marriage. The first one is a social jail but in the latter case both parties are free to leave but do not want to. The special characterics of negentropic entanglement raise the question whether the problematic notion of high energy phosphate bond citeHEP central for metabolism could be understood in terms of negentropic entanglement. This would also allow an information theoretic interpretation of metabolism since the transfer of metabolic energy would mean a transfer of negentropy [7].

4 Consciousness theory as extension of quantum measurement theory

TGD inspired theory of consciousness [13] could be seen as a generalization of quantum measurement theory. The notions of quantum jump and self self are the key notions. Negentropy Maximization Principle (NMP) [14] is the basic dynamical principle. NMP is mirror image for the second law of thermodynamics and states that the amount of conscious information gain in quantum jump is maximal. NMP reproduces standard quantum measurement theory for entropic entanglement and is in this case consistent with the second law since the non-determinism of state function reductions implies the increase of ensemble entropy.

4.1 Quantum jumps as moment of consciousness

The starting point of TGD inspired theory of consciousness was the identification of quantum jump as a moment of consciousness [13].

1. Quantum jump has a complex anatomy which however simplifies in ZEO. Quantum jump involves unitary time evolution leading from a state resulting in state function reduction to a quantum superposition of states: one could speak of multiverse. This step is described by the counterpart of the unitary process of Penrose and is coded by a unitary matrix U in the state space formed by zero energy states. U is therefore not identifiable directly as S-matrix of quantum field theories but contains as its rows all possible M-matrices which are what particle physicist tries to measure in laboratory. State function reduction and state preparation can be assigned to the opposite light-like boundaries of CD.

   A good metaphor is Djinn in the bottle. In U-process bottle is opened and Djinn comes out and creates a quantum superposition of all possible worlds. The wish of the observer is fulfilled and leads to a state function reduction. Actually there is an entire cascade of state function reductions starting from the level of the entire universe which splits the entangelement sub-systems already obtained in a step-wise manner to pairs un-entangled sub-systems. The splitting for a given sub-system occurs only if it is consisent with NMP.

   For the ordinary definition of entanglement entropy the process would lead to a completely unentangled situation. If the number theoretic entanglement entropy making sense for rational (and even

algebraic) entanglement probabilities is allowed, the process stops unless the reduction of entanglement reduces the entanglement entropy. Therefore the number theoretic entanglement possible in the intersection of real and p-adic worlds can be stable and living systems are able to preserve their coherence.

2. Since the reduction cascade proceeds from top to bottom, one can speak about fractal formed by quantum jumps within quantum jumps. One cannot assign to the steps of this sequence any duration of geometric time. One can however associate to it an experienced duration and it is very tempting to assume that the experienced duration increases as one climbs up in the self hierarchy.

3. Quantum jump replaces the quantum superposition of classical histories (space-time surfaces, classical worlds) with a new one whereas ordinary state function reduction would do this for time=constant snapshot of Schrödinger evolution. Quantum jump does not spoil the determinism of classical dynamics or of Dirac equation since it occurs entirely outside space-time and Hilbert space. In quantum jump both the geometric future and past (defined only within measurement resolution) are replaced with new ones. The mysterious finding of Libet [65] that intentional action is preceded by neural activity can be interpreted in this framework without giving up the notion of free will. This raises a fascinating question about time scales in which the geometric past can be affected in quantum jump. Also memories stored in the geometric past can be affected in quantum jumps and the fact that memories are highly unstable suggest that the time scale is measured in years.

   It must be added that the notion of classical determinism in its standard form fails due to the special properties of Kähler action (vacuum degeneracy mathematically analogous to a gauge degeneracy but physically analogous to 4-D spin glass degeneracy). This failure provides a space-time correlate for the non-determinism of the quantum jump sequence.

4.2 The notion of self

The notion of self is second basic notion introduced originally as a notion independent from quantum jump. It however seems that the notion of self could be reduced to that of quantum jump.

1. The notion of self can be seen as a generalization of the notion of observer. The natural first guess inspired by the standard notion of entanglement entropy was that self is a subsystem able to remain unentangled during a sequence of quantum jumps. Self would be a system able to preserve its quantum identity. In the case of negentropic entanglement a more natural interpretation is that expansion of consciousness rather than loss of it is experienced as self entangles with second system negentropically. Only entropic entanglement would lead to a loss of consciousness. Second condition would be that self is stable against splitting to unentangled subsystems. This criterion is satisfied if self corresponds to a system for which the entanglement between its subsystems is negentropic.

   Self experiences its sub-selves as mental images and even we would represent mental images of some higher collective self. Everything would be conscious but consciousness could be lost. The flow of consciousness for a given self could be due to the quantum jump sequences performed by its sub-selves giving rise to mental images.

2. The fractal structure of quantum jump suggests that the notions of self and quantum jump are one and same thing. The fractal hierarchy of quantum jumps would correspond to fractal hierarchy of selves. This fractal hierarchy is very much analogous and closely related to the hierarchy formed by physical systems extending from elementary particle level to arbitrary long astrophysical scales. The hierarchy of Planck constants and NMP with number theoretic entanglement entropy predicts that particle like entities are possible in all length scales.

3. By quantum classical correspondence self has also space-time correlates.One can visualize subself as a space-time sheet "glued" by topological sum to the space-time sheet of self. Subsystem is not

described as a tensor factor as in the standard description of subsystems. Also subselves of selves can entangle negentropically and this gives rise to a sharing of mental images about which stereo vision would be basic example. Quite generally, one could speak of stereo consciousness. Also the experiences of sensed presence [67] could be understood as a sharing of mental images between brain hemispheres which are not themselves entangled. This is possible also between different brains. In the normal situation brain hemispheres are entangled.

4. At the level of 8-dimensional imbedding space the natural correlate of self would be CD (causal diamond). At the level of space-time the correlate would be space-time sheet or light-like 3-surface. The contents of consciousness of self would be determined by the space-time sheets in the interior of CD. Without further restrictions the experience of self would be essentially four-dimensional. Memories would be like sensory experiences except that they would be about the geometric past and for some reason are not usually colored by sensory qualia. As already noticed, .1 second time scale defining the duration of moment for sensory experience corresponds to that of electron's CD which suggests that Cooper pairs of electrons are essential for the sensory qualia.

4.3 How experienced time and the geometric time of physicist relate to each other?

The relationship between experienced time and time of physicis is one of the basic puzzles of modern physics. In the proposed framework they are certainly two different things and the challenge is to understand why the correlation between them is so strong that it has led to their identification. One can imagine several alternative views explaining this correlation [33, 34, 1] and it is better to keep mind open.

4.3.1 Basic questions

The flow of subjective time corresponds to quantum jump sequences for sub-selves of self having interpretation as mental images. If mind is completely empty of mental images subjectively experienced time ceases to exists. This leaves however several questions to be answered.

1. Why the contents of conscious of self comes from a finite space-time region looks like an easy question. If the contents of consciousness for subselves representing mental images is localized to the sub-CDs with indeed have defined temporal position inside CD assigned with the self the contents of consciousness is indeed from a finite space-time volume. This implies a new view about memory. There is no need to store again and again memories to the "brain now" since the communications with the geometric past by negative energy signals and also time-like negentropic quantum entanglement allow the sharing of the mental images of the geometric past.

2. There are also more difficult questions. Subjective time has arrow and has only the recent and possibly also past. The subjective past could in principle reduce to subjective now if conscious experience is about 4-D space-time region so that memories would be always geometric memories. How these properties of subjective time are transferred to apparent properties of geometric time? How the arrow of geometric time is induced? How it is possible that the locus for the contents of conscious experience shifts or at least seems to be shifted quantum jump by quantum jump to the direction of geometric future? Why the sensory mental images are located in a narrow time interval of about .1 seconds in the usual states of consciousness (not that sensory memories are possible: scent memories and phantom pain in leg could be seen as examples of vivid sensory memory)?

Just to make illustrate how many different aspects are involved and in the hope that various constraings would allow to select among many alternatives that one can imagine (and have imagined!), let us first try to list basic questions in the framework provided by ZEO.

1. ZEO forces the arrow of geometric time to become a property of zero energy states. What does this mean concretely? Could the observed arrow of time reduce solely to this arrow?

2. Do sub-CD:s drift in preferred time direction inside CD? Or do space-time sheets drift inside CD to preferred direction. Or is there a a phase transition proceeding in the direction of geometric time of CD associated with the entire CD and inducing state function reduction for sub-CDs: it would not matter what is boundary of sub-CD is selected if sub-CD would be effectively point-like. The quantum arrow of time for zero energy state should force preferred direction of this phase transition.

3. Does the U process as a cascade proceeding from long scales of CDs to short ones involve explicitly the arrow of geometrc time. For instance, could state function reduction cascade for sub-CDs with a given scale correspond to a process analogous to burning proceeding towards geometric future? Or could a phase transition transforming p-adic space-time sheets to real ones as a realization of intentional action proceed in this manner?

4. Do space-time sheets possess an arrow of geometric time coming from the failure of strict determinism (shock waves in hydrodynamics) and giving space-time correlate for the quantum arrow of time? In hydrodynamics second law allows to select between alternative developments in multi-furcation. Could second law or NMP be involved also now?

5. What is the role of the fractal hierarchy of CD? Also entanglement between sub-CDs carrying zero energy states is possible. Could the state function reductions occurring for sub-CDs give rise to the experience of flow of time at the level of CD. Do these quantum jumps occur for some reason ina time ordered manner (light-cone proper time defines a unique Lorentz invariant time ordering). Could the entanglement anatomy of zero energy states force this automatically? The process would be analogous to burning.

6. Suppose that the idea about time flip-flop meaning that unitary process reduces to a base change between basis with opposite arrows of geometric time. Doesn't this imply that the arrow of geometric time changes its direction alternately or is there a manner to avoid this conclusion?

7. State function reduction involves a reduction of entanglement between quantum variables and classical variables represented by zero modes in TGD Universe. Does this reduction play a kay role in the generation of the arrow of time. What is the role of negentropic entanglement? For instance, could it be that the generation of negentropic entanglement at second end of the CD stabilizes the states with respect to state function reduction leading to counterpart of Orch OR?

8. The geometry of light-cone has intrinsic arrow of time. The question is how this arrow induces the arrow of experienced geometric arrow of time with minimal assumption (from structure of zero energy states).

9. The localization of sensory experience to short time interval does not define so strong constraint as one might think since if sensory mental images correspond to small enough sub-CDs, the localization inside sub-CD is enough. For CD itself the localization to either boundary looks naturl since state function reduction takes place at the boundary.

4.3.2 First trial

Possible answers to these questions could rely on NMP if understood as a sufficiently general principle. Suppose that NMP translates to the statement that selves are eager to gain conscious information. The mere assumption that selves are curious leaves a lot of room for alternatives and one can imagine several models. Note also that geometric time can correspond to the local time assignable to space-time sheet or to the cosmic time assignable to the CD or to 8-D imbedding space.

1. The space-time in the geometric future above the "upper" light-like boundary of CD represents the unknown where the news come from. Negentropic self has to some extent free will and can perform quantum jumps inducing effectively the shift of the quantum superposition of the space-time surfaces towards geometric past. The news come from the future and represent sensory input and induce subselves as mental images. The population of sensory subselves would tend to be created near the "upper" boundary of CD. This would induce a breaking of time reversal invariance and spontanous arrow of geometric time. Self would be like a person in movie theater. Self would not move anywhere, space-time surfaces -the film- would move with respect to self.

2. One can consider also alternative view analogous to the standard view if one assumes that the CDs representing subselves can shift towards geometric future in the sequence of quantum jumps. Suppose that U process creates a quantum superposition over temporal positions of CD and that temporal localization takes place during the state function reduction process. Also now the strong form of NMP could force a drift of the sub-self population towards unkown defining the geometric future. The geometric time would be assignable to the larger CD. Also the first option allows drifting of subselves to the upper boundary of CS as a consequence of strong form of NMP.

One might hope that spontaneous breaking of time reversal invariance alone could explain the induced arrow of geometric time so that the arrow of time would not be a result of intentional action. Following options represent attempts to understand the arrow of cosmic time as something analogous to diffusion in half-space.

1. Self is a subself of larger self and the corresponding CD could induce a breaking of time reversal invariance since the proper time coordinate for CD has only positive values so that a diffusion and even drift towards geomeric future could result. If subself is nearer to the lower boundary of the larger CD it tends to diffuse upwards and vice versa. In the middle of the larger CD, where the analog of cosmic expansion changes to contraction geometric time would stop.

2. Second option is based on the observation that the size scale of given CD must increase on the average during quantum jump sequence. These events correspond to phase transitions increasing the size scale of CD by a factor of two and could serve as correlate for cosmic expansion. When one fixes either tip of CD, the second tip moves towards future with respect to it in discrete phase transition like steps. This discrete time evolution might define a quantum correlate for the flow of cosmic time at imbedding space level [26].

More detailed discussions of the problem can be found in [1]. In any case, it must be admitted that something important piece of understanding is still lacking. The following represents one of the many attempts to identify this piece and relies on single new input: zero energy states possess quantum arrow of time.

4.3.3 Second trial

ZEO allows to assign to zero energy states an arrow of time naturally since one can require that states have well defined single particle quantum numbers at either upper or lower boundary of CD. Also the spontaneous change of the arrow of geometric time is possible. The simplest possible description for U-process is that U-matrix relates to each other these two kinds of states and state function reductions occur alternately at upper and lower boundaries of CD meaning reduction to single particle states with well defined quantum numbers. The localization of sensory experience to short time interval could also correspond to mental images with size scale of CD being about .1 seconds so that the assumption that localization inside CD to either boundary takes place is not absolutely necessary.

It is unclear whether this identification of the unitary process allows a generation of a universal arrow of geometric time. It would seem that the arrow of time as a property of zero energy states must

alternate for the proposed mechanism. But is this really the case? To answer this question one must try to understand how the observer concludes that there is geometric arrow of time.

1. This situation could correspond to single arrow of geometric time for a conscious entity if it resides permanently at either boundary of CD: does this mean a sleep-awake cycle of consciousness as a basic attribute of conscious experience? The hierarchy of CDs allows however to think that the scale in which the arrow of time as deduced from cosmology alternates in time scale of lifetime of the Universe so that unique arrow of time would be observed. In time scales shorter than that assignable to the CD of observer the arrow of time would vary periodically (generalized sleep-wake cycle).

2. Does the time flip-flop between upper and lower boundaries of CD really give rise to a variation of perceived arrow of geometric time? Suppose that quantum arrow of time has a direct counterpart in the time evolution of preferred extremals (dissipative processes). The direction of classical dissipation changes as the quantum arrow of time changes. Space-time evolution with a fixed geometric arrow of time would be effectively folded forth and back.

   If this were the case, it seems that self has no means of detecting this change in the classical dynamics of preferred extremals assignable to its own CD. This if only the information about space-time sheet is used. The only manner to detect the change of the arrow of time would by looking the classical dynamics of larger CDs.

   If the arrow for the larger C remains the same when the arrow of geometric time for CD changes, self could detect the change of its own geometric arrow of time. For instance, self would experience dissipation inside its own CD to take place in opposite direction compared to that in larger scales. Here one however encounters a problem since in living systems the dissipation indeed could take place in wrong direction: this has even inspired the introduction of the notion of syntropy [62, 60]. Self should however observe that the clocks defined by larger scale system run in wrong direction. But if the single half-period in the reduction cycle corresponds to life-cycle then also this is possible only after what we would call biological death!

Suppose that one just for a moment accepts this picture in absence of anything better. One can argue that there must exist concrete correlates for the flow of time experienced by self in terms of quantum dynamics of sub-selves. One should understand what the fractal hierarchy of selves really means at the level of conscious experience and of its physical correlates. Several mechanisms at space-time level for the generation of arrow of time have been discussed but the really satisfactory mechanism remains to be identified.

Is there a phase transition proceeding in the direction of geometric time of CD associated with the entire CD and inducing state function reduction for sub-CDs: it would not matter what is boundary of sub-CD is selected if sub-CD would be effectively point-like. The quantum arrow of time for zero energy state should force preferred direction of this phase transition.

1. Could it be that this phase transition like process corresponds to a sequence of state function reductions for sub-CDs of given size proceeding to the future. Could the fractal structure of zero energy states give rise to this structure? Ordinary Feynman diagrams would describe only single level in this hierarchy and state function reductions selecting subset of diagrams with given incoming and outgoing states are not possible. Suppose that zero energy states satisfy in very symbolic sense the recursion relation

$$\Psi_n = \Psi_{n,0} + \sum_{0<k<n} \Psi_{n-k} \circ \Psi_k \quad .$$

   Here n corresponds to the size scale of CD. $\Psi_{n,0}$ corresponds an irreducible contribution corresponding to the ordinary Feynman diagrams for which no state function reduction in intermediate

states is possible: this would be like dropping out subset of Feynman diagrams. The second term corresponds to splitting two two sub-CDs and is possible only in ZEO. We of course do physics in various scales without formal theoretical justification. For instance, we calculate QCD type process we can restrict the consideration to corresponding time scales. The decomposition would express this fact as a law of physics.

For these lower level contributions similar equation can be applied and one repeat the recursion down to the lowest level. $\circ$ symbolizes entanglement between the zero energy states Ψ_{n-k} and Ψ_k.

2. Suppose that at the first step state function reduction has led to prepared states at -say- upper end (corresponding to Ψ_k). This is nothing but the basic assumption about zero energy states. At the next step the reduction reduces the entanglement between Ψ_{n-k} and Ψ_k: essentially the sum defining an element for a product AB of matrices reduces to a product of two elements: $\sum_j A_{ij}B_{jk} \to A_{ij}B_{jk}$. Time ordering of the reductions is unavoidable at this level since sub-CDs are in question. This process would continue fractally downwards to shorter scales. Complete time ordering results if the reduction for Ψ_k proceeds to the short scales first and only then for Ψ_{n-k}. Othwerwise reduction sequences would occur for sub-CDs at different temporal positions simultaneously.

3. There is also entanglement with zero modes at each level but it seems that this entanglement is not relevant for this argument reducing the arrow to recursive property of states and to the factorization of two entangled zero energy states at given level of recursion.

4. This view about unitary process would explain the arrow of geometric time, explain why self experiences lower level state functions as time flow, and would also allow to understand the localization of sensory and various other kinds of experiences and also intentional action to short time interval.

4.4 Quantum correlates of for various aspects of conscious experience

The identification of quantum correlates of cognition and intentionality, of sensory qualia, Boolean mind, and of emotions [8] represents one challenge for Quantum Mind theories. As already explained, p-adic physics, the vision about life as something residing in the intersection of real and p-adic worlds, and the notion of number theoretic entropy provide a plausible starting point when one tries to say something about the geometric and quantum correlates of cognition and intentionality. Zero energy ontology makes possible the transitions transforming p-adic zero energy states to their real counterparts and having interpretation in terms of intentional action.

1. Quantum numbers characterize quantum states. Therefore the increments ΔQ of quantum numbers for a subsystem should characterize quantum jumps and it is attractive to assign classify fundamental qualia in terms of quantum number increments. "The increments of quantum numbers for a subsystem representing self" looks innocent but what it really means is surprisingly difficult to make precise. The following attempt relies on ZEO.

   (a) For the positive energy part of state located at "lower" boundary of CD self - subsystem S - and environment E are un-entangled. At the "upper" boundary there is entanglement between S and E, and it should be able to assign qualia as quantum number increments to this entanglement.

   (b) Consider increments of color quantum numbers identified in terms of visual colors as an example. In the positive energy state color quantum numbers for an unentangled subsystem S vanish by color confinement. In negative energy state they can be non-vanishing for S but vanish for $S \otimes E$. The experienced qualia for S are determined as quantum averages of color quantum numbers in the entangled state and expressible in terms of the sub-system density matrix. One can indeed assign to the zero energy state increments ΔQ_{ZEO} of color quantum numbers as difference of color quantum numbers for S at "upper" and "lower" boundaries of C. These increments characterize zero energy state rather than quantum jump.

(c) In state function reduction the entanglement at upper boundary is reduced if the entanglement is entropic whereas negentropic entanglement can be stable. Quale is experienced sensorily as long as quantum jumps preserve negentropic entanglement. When entanglement is eventually reduced, thee experience can be only a memory about the experienced quale. The increments ΔQ of color quantum numbers in quantum jump can be identified as $\Delta Q = \Delta Q_{ZEO}$. Hence this notion is indeed well-defined.

(d) This interpretation allows to assign to the quantum jump also space-time evolution changing the quantum numbers in the same manner as they change in quantum jump. This is what quantum-classical correspondence indeed requires.

One application is the identification of basic colors in terms of color quantum number increments of quantum states [8]. This identification makes sense if one accepts the fractal hierarchy of QCD like dynamics allowed by p-adic length scale hierarchy and by the hierarchy of Planck constants. The original concrete model was provided by the capacitor model of sensory qualia in which a large number of particles which same quantum numbers flows to a subsystem during quantum jump inducing the analog of di-electric breakdown (note the analogy with nerve pulse). Bose-Einstein condensation provides one possible realization. In this case one can say that the quantum numbers of the particle in question represent the basic quale which is amplified.

The above picture forces to modify this view by replacing a color capacitor with a fixed size with that of a variable size corresponding to the size of system S and $S \otimes E$: the second plate of capacitor either in S or environment. The flow of charges associated with the transition generating quale still makes sense and generates strong color polarization in the scale $S \otimes E$. In the model the increase of the size of the color capacitor means a formation of flux tubes between the sensory receptor and environment such that net color is non-vanishing only for these flux tubes. In state function reduction reducing entanglement the flux tubes are split and S become color neutral but can represent a memory about the quale as negentropic color neutral entanglement in the scale of S: some sub-system of S can now experience the color quale. This suggests a holographic memory in which quale eventually is represented in very small scale in terms of negentropic entanglement.

The argument involves assumption about color confinement. In the case of qualia assignable to electromagnetic charges, spin, etc... similar assumption makes sense. Even in case of momentum and angular momentum this assumption makes sense and means that subsystem in the state of experiencing momentum or angular momentum increment as quale is in a real accelerated motion in the scale of CD. As a matter fact, the vanishing of quantum numbers of S in absence of entanglement might not be necessary for the interpretation.

2. One could also speak about Boolean qualia and fermions provide possible correlates for them. The 2^N many-fermion states of fermionic Fock space for N fermionic qubits define a basis of Boolean algebra. The entangled pairs of fermionic states associated with the positive and negative energy parts of zero energy states define quantal Boolean functions as sums over entangled pairs of many fermion states. Negentropic entanglement could define a representation of a rule with entangled pairs representing various instances of the rule. Time-like entanglement would define a representation for a "law of physics" and M-matrices would be fundamental representations of this kind. The increments of the fermionic quantum numbers could define Boolean qualia and one can imagine Boolean capacitor mechanism allowing to amplify a given Boolean statement.

One should be also able to say something about the quantum correlates of emotions. Here the notion of negentropic entanglement might be the key concept.

1. Emotions have a quale like character. For instance, psychological pleasure and pain resemble their physiological counterparts- and quite generally there is a tendency to assign to emotions the attributes of sensory experience. It would be attractive to assign this positive/negative dichotomy to

the increase/reduction of entanglement negentropy. Emotion would represent Boolean bit as the sign of negentropy increment. The destruction of generation of negentropic entanglement would therefore be the core element of emotional quale. The character of entanglement involved would determine whether the emotion corresponds to pleasure or pain, joy or sorrow, pride or shame.

In the case of physiological pain or pleasure it is easy to imagine that the cause of pain destroys/creates negentropic entanglement. Pain and pleasure at this level relates directly to what happens to metabolism. This is easy to understand if the basic function of energy metabolism is to transfer negentropic entanglement. For higher level emotions the negentropy reduction or increase could be produced artificially to give an emotional content for something regarded as important.

2. Very often emotions are characterized by good-bad/right-wrong dichotomy characterizable by single binary digit. Perhaps emotions provide a representation of a high level summary about large amounts information, a kind of Boolean function of very many qubits. The function of neural transmitters can be often interpreted in terms of reward or punishment. Information and emotions seem to be closely related: peptides are often regarded as both information molecules and molecules of emotion [68]. This can be understood if the function of information molecule is to induce emotional response representing the information.

3. Comparison to a standard -be it moral rule, expected or desired behavior, or something else- is rather often an essential aspect of emotion. Comparison can in principle be represented as a quantal Boolean function involving the standard (say moral rule) represented in terms of negentropic entanglement. If the Boolean instance compared with the rule corresponds to an instance allowed by the rule, positive emotion results. Otherwise the emotion is negatively colored. One might also think that there is expectation for the result of comparison. If the outcome differs from expected-which corresponds to a flip of bit, positive or negative emotion results but could do so as a secondary representation. The above argument suggests that the outcome of comparison does not represent the emotion as such but there is a neural circuitry encoding the outcome to reward or punishment.

4.5 Self referentiality of conscious experience

Self referentiality of consciousness is one of its most mysterious looking aspects. In a loose formulation one could say that system is able to be conscious what it *is* conscious of. This formulation however leads to an infinite hierarchy of reflective levels and therefore to a paradox. One can however milden the formulation by saying that self-referential system is able to be conscious about what it *was* conscious of (with respect to subjective time of course!)

In this formulation quantum classical correspondence gives hopes about the understanding of self-referentiality. Quantum classical correspondence means in TGD framework that not only quantum states but also quantum jump sequences have space-time correlates. The failure of classical determinism for Kähler action in standard sense of the word is responsible for this and relates directly to the basic properties distinguishing TGD Universe from that of standard model. This allows to imagine that quantum jump leading from a superposition of space-time surfaces to a new one also gives rise to a representation of the conscious experiences which preceded the last quantum jump at the level of space-time geometry. Reductio ad absurdum would transform to evolution of consciousness able to add to the existing hierarchy a new reflective level in each quantum jump.

I have proposed several correlates for the self-referentiality of consciousness. Many-sheeted space-time would provide the physical representation.

4.5.1 Many-sheeted space-time and self-referentiality

The fractal hiearchy of magnetic flux tubes giving rise to braids, which in turn make possible topological quantum computation would be a rather realization of this representation, A possible concrete physical

realization of self-referentiality is suggested by DNA as quantum computer model [6]. One assumes that DNA nucleotides and lipids are connected by magnetic flux tubes. Since the lipid layer of the cell membrane is 2-dimensional liquid crystal, the lipids are in continual hydrodynamical motion and this means in time direction entanglement of the orbits. The events in nearby environment and also nerve pulses affect this flow. This braiding in time direction defines a topological quantum computation. This motion entangles also the flux tubes connecting the lipids to DNA nucleotides so that when the topological quantum computation halts it becomes stored into memory as space-like entanglement. In TGD framework also the time-like braiding provides a space-time representation of the quantum computation which also gives to a conscious experience at some level of the hierarchy.

4.5.2 Infinite primes and self-referentiality

The hierarchy of infinite primes (and of integers and rationals) [30] was the first mathematical notion stimulated by TGD inspired theory of consciousness. The construction recipe is equivalent with a repeated second quantization of a super-symmetric arithmetic quantum field theory with bosons and fermions labeled by primes such that the many-particle states of previous level become the elementary particles of new level. At a given level there are free many particles states plus counterparts of many particle states. There is strong structural analogy with polynomial primes. For polynomials with rational coefficients free many-particle states would correspond to products of first order polynomials and bound states to irreducible polynomials with non-rational roots.

The hierarchy of space-time sheets with many particle states of space-time sheet becoming elementary particles at the next level of hierarchy. For instance, the description of proton as an elementary fermion would be in a well defined sense exact in TGD Universe. Also the hierarchy of n:th order logics are possible correlates for this hierarchy.

This construction leads also to a number theoretic generalization of space-time point since a given real number has infinitely rich number theoretical structure not visible at the level of the real norm of the number a due to the existence of real units expressible in terms of ratios of infinite integers. This number theoretical anatomy suggest a kind of number theoretical Brahman=Atman identity stating that the set consisting of number theoretic variants of single point of the imbedding space (equivalent in real sense) is able to represent the points of WCW or maybe even quantum states assignable to causal diamond. One could also speak about algebraic holography.

The correspondence between the quantum states defined by WCW spinor fields and wave functions in the infinite-dimensional discrete space of hyper-octonionic units can be made more concrete [30]. These wave functions must transforming irreducibly under discrete subgroup SU(3) of octonion automorpisms transforming ordinary hyper-octonionic prime to a new hyper-octonionic prime. SU(3) has interpretation as color group. One can assign standard model quantum numbers to these wave functions and prime property in principle fixes the spectrum of possible quantum states- in particular the spectrum of masses. Therefore the extremely esoteric looking notion of infinite prime might turn out to be very practical calculational tool.

4.5.3 Quantum Mathematics and self referentiality of consciousness

In Quantum Mathematics numbers are replaced with Hilbert spaces and the dimension of Hilbert space - in appropriately. generalized sense - characterizes the number.

1. This suggests a generalization of calculus for Hilbert spaces. Mathematical objects which are defined for numbers in various number fields become well defined when these numbers are replaced with Hilbert spaces. One can speak of the Hilbert space analogs of algebraic numbers, transcendentals, p-adic numbers and their extensions. Anything having as a building brick rationals, algebraic numbers, real or p-adic numbers or finite fields generalizes. Even the notions like matrix group, algebras, and ring generalize. Also the notion of manifold generalizes as well as the notion of calculus.

2. The Hilbert space in associated with the element of number field characterizes its number theoretic anatomy and therefore could be a correlate of cognition. The crucial step in the generalization of this process to the level of the Hibert space representing points. Points of Hilbert spaces can be replaced with Hilbert spaces and process can be repeated ad infinitum. This suggests that the self-referentiality at the deepest level corresponds to this fractal view about space-time based on assignment of quantum dynamics to numbers. Also a connection with the hierarchy of n:th order logics. A close relationship to infinite primes would not be surprising since in both cases one an infinite hierarchy of processes analogous to second quantization is involved. A natural question is whether many-sheeted space-time provides a dynamical representation in terms of space-time sheets for the number theoretic anatomy so that kind of Brahman=Atman identity or algebraic holography would hold true. This correspondence could be see as a cognitive representation of external world and one could also see the external world as symbolic representation of the world of cognition.

3. A connection with generalized Feynman diagrams and hierarchy of Planck constants is suggestive and the idea was originally inspired by the observation that the two vertices of generalized Feynman diagrams identifiable as generalizations of the basic stringy 3-vertex for closed strings and basic 3-vertex for Feynman diagrams correspond naturally to direct sum and tensor product in turn having natural correspondence with + and $\times$ of the usual arithmetics. This correspondence motivates the introduction of co-operations of direct sum and tensor product meaning that quantum dynamics is brought into the game through these vertices. This suggests that Quantum Mathematics is actually Quantum dynamics in which generalized Feynman diagrams define sequences of arithmetic or even more general algebraic operations.

   If so, the basic structures of Quantum Mechanics (QM) might reduce to fundamental mathematical and metamathematical structures, and that one even consider the possibility that Quantum Mechanics reduces to Quantum Mathematics with mathematician included or expressing it in a concise manner: QM=QM!

The fractal character of the Quantum Mathematics is what makes it a good candidate for understanding the self-referentiality of consciousness. The replacement of the Hilbert space with the direct sum of Hilbert spaces defined by its points would be the basic step and could be repeated endlessly corresponding to a hierarchy of statements about statements or hierarchy of n^{th} order logics. The construction of infinite primes leads to a similar structure.

What about the step leading to a deeper level in hierarchy and involving the replacement of each point of Hilbert space with Hilbert space characterizing it number theoretically? What could it correspond at the level of states?

1. Suppose that state function reduction selects one point for each Hilbert space $x_n \times p^n$. The key step is to replace this direct sum of points of these Hilbert spaces with direct sum of Hilbert spaces defined by the points of these Hilbert spaces. After this one would select point from this very big Hilbert space. Could this point be in some sense the image of the Hilbert space state at previous level? Should one imbed Hilbert space $x_n \times p^n$ isometrically to the Hilbert space defined by the preferred state $x_n \times p^n$ so that one would have a realization of holography: part would represent the whole at the new level. It seems that there is a canonical manner to achieve this. The interpretation as the analog of second quantization suggest the identification of the imbedding map as the identification of the many particle states of previous level as single particle states of the new level.

2. Could topological condensation be the counterpart of this process in many-sheeted spacetime of TGD? The states of previous level would be assigned to the space-time sheets topologically condensed to a larger space-time sheet representing the new level and the many-particle states of previous level would be the elementary particles of the new level.

3. If this vision is correct, second quantization performed by theoreticians would not be a mere theoretical operation but a fundamental physical process necessary for cognition! The above proposed

unitary imbedding would imbed the states of the previous level as single particle states to the new level. It would seem that the process of second quantization, which is indeed very much like self-reference, is completely independent from state function reduction and unitary process. This picture would conform with the fact that in TGD Universe the theory about the Universe is the Universe and mathematician is in the quantum jumps between different solutions of this theory.

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