Macrotemporal quantum coherence, quantum spin glass degeneracy, and number theoretic information concept

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Abstract

The basic objection against quantum consciousness theories is that decoherence times for macroscopic quantum states are quite too short. This argument has been put in quantitative form by Max Tegmark [1]. These counter arguments are however problematic. First of all, the notions of quantum coherence and decoherence are problematic in standard physics framework since the non-determinism of the state function reduction is in conflict with the determinism of Schrödinger equation. The intuitive idea is however that one can estimate the decoherence times as essentially lifetimes of quantum states. Secondly, the estimates for decoherence times are based on standard physics, and it is quite possible that new physics is essential for understanding living matter.

Topological Geometrodynamics (TGD) inspired theory of consciousness leads to a first principle theory of state function reduction free of the logical paradoxes, allows precise definitions for the notions of quantum coherence and decoherence, and predicts a mechanism making the lifetimes of macroscopic bound states much longer than predicted by the standard physics. The basic distinction between TGD and standard physics is quantum spin glass degeneracy, which among other things implies that quantum bound states of, say, two molecules have enormous spin glass degeneracy absent in the free state. This in turn means that the system spends much longer time in bound states than in free states and this implies much longer decoherence time than expected otherwise. The almost degenerate spin glass states differ only by their classical gravitational energy so that gravitation is indeed important.

In the p-adic context one must modify Shannon's definition of entropy by replacing the ordinary logarithm based on p-adic norm. This definition gives rise to a real valued entropy in both real and p-adic contexts if entanglement coefficients are algebraic numbers. For non-algebraic entanglement standard Shannon formula and its p-adic variant must be used and gives rise to non-negative entropy. Unlike Shannon entropy, the p-adic entropies (one for each p) can be also negative so that the entanglement entropy defines a genuine information measure whose sign tells whether the system contains information or dis-information. For the p-adic entropies Negentropy Maximization Principle tends to preserve the quantum coherence. Thus the states with algebraic entanglement can be regarded as bound states, which are not at all fragile like the states with non-algebraic entanglement are. This leads to a purely number-theoretic characterization of life: life corresponds to islands of algebraic numbers in the seas of real and p-adic continua. A more restrictive definition would be based on rational entanglement and even rational entanglement probabilities.

The new views about quantum coherence and information have testable implications at the level of fundamental physics, quantum computation, biology, and consciousness.

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

1 Introduction

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

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

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

Topological Geometrodynamics (TGD, [3, 4]) inspired theory of consciousness [5, 6] leads to a first principle theory of state function reduction and preparation free of the logical paradoxes, allows precise definitions for the notions of quantum coherence and decoherence, and predicts a mechanism making the lifetimes of macroscopic bound states much longer than predicted by the standard physics. The basic distinction between TGD and standard physics is quantum spin glass degeneracy (see the chapter "Quantum theory of self-organization" of [5]), which among other things implies that quantum bound states of, say, two molecules have enormous spin glass degeneracy absent in the free state. This in turn means that the system spends much longer time in bound states than in free states and this implies much longer decoherence time than expected otherwise. The almost degenerate spin glass states differ only by their classical gravitational energy so that gravitation is indeed important. The importance of quantum gravitation is also obvious from the fact that genuine quantum gravitational states are state functionals in the world of classical worlds rather than in the classical 4-D world so that they are expected to represent in some sense higher abstraction level than ordinary quantum states in the hierarchy of consciousness.

This article will cover the following topics.

a) The notion of the many-sheeted space-time and basic ideas of TGD inspired quantum theory of consciousness and biosystems.

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

c) Macrotemporal quantum coherence from the point of view of physics (thermodynamical, energetic and information theoretic aspects) with some comments about the implications for quantum computing.

d) Macrotemporal quantum coherence from the point of view of biology and conscious experience, in particular microtubular model for long term memories.

The illustrations of many-sheeted spacetime, topological field quantization, and of basic concepts of TGD inspired theory of consciousness might help the reader to assimilate the basic notions. See
"Two-dimensional illustrations related to the many-sheeted space-time concept" at *http://www.emergentmind.org/tgdillu/illua.html*, and
"Illustrations related to the many-sheeted space-time concept and the notions of TGD inspired theory of consciousness" at
http://www.emergentmind.org/tgdillu/illuc.html.

2 Background

To make things easier for the reader the basic ideas of TGD inspired theory of consciousness are summarized before the discussion of the macrotemporal quantum coherence.

2.1 The notions of quantum jump and self

The basic notions of TGD inspired theory of consciousness are quantum jump between quantum histories (rather than time=constant snapshots of single quantum history) as moment of consciousness, and the notion of self as sub-system able to remain unentangled in subsequent quantum jumps (see for instance the chapters "Matter, Mind, Quantum" and "Self and Binding" of [5]). There is deep structural analogy with physics: quantum jump is the elementary particle of consciousness and selves are atoms, molecules,.... of consciousness.

2.1.1 Quantum jump as a moment of consciousness

Each quantum jump replaces the solution of field equations (universe) with a new one. Quantum jump involves three steps:
a) The unitary time development U giving rise to the S-matrix summarizing quantum physics as it is understood by particle physicist,
b) the counterpart of state function reduction,
c) and state preparation involving a sequence of self measurements.

U can be said to generate multiverse, quantum superposition of potentialities, a state of oneness in which everything is entangled with everything. State function reduction and preparation in turn mean gradual decomposition of universe to maximally disentangled subsystems interpretable as conscious analysis. Thus oneness and separation are both basic aspects of consciousness. The sequence of quantum jumps defines subjective time whereas geometric (or physicist's) time corresponds to the fourth spatial coordinate. The distinction between these times allows to resolve the basic paradoxes of modern physics and philosophy of mind.

2.1.2 Self

Self is by definition a sub-system able to remain unentangled in subsequent quantum jumps. Only bound state entanglement is stable in quantum jump and selves correspond to regions of the space-time surface having local topology in a given number field (real or p-adic number fields labelled by primes). p-Adic regions are interpreted as physical (non-conscious) correlates for imagination, intention and cognition whereas real regions correspond to matter. The unitary operator U could in principle generate entanglement also between p-adic and real regions (rational entanglement coefficients make sense in any number field), which is destroyed in the state function reduction step. This might be crucial for the generation of cognitive maps assigning to the states of matter (say reading of physical measurement apparatus) cognitive states (say mental image about the reading of the measurement apparatus).

The contents of consciousness of self are determined as the average over the quantum jumps occurred after it was created (the real or p-adic space-time region corresponding to self appeared in quantum jump). Selves can have sub-selves and self experiences them as mental images. Self can represent a mental image of a higher level self. Self experiences only the average of its sub-sub-selves. Thus statistical averaging is involved in both subjecto-temporal sense and spatially and is of central importance in the theory of qualia. This suggests that the foundations of, not only quantum measurement theory, but also statistical physics, reduce to the theory of consciousness. Quantum entanglement between sub-selves means fusion of mental images. The simplest assumption is that entangling self loses its consciousness.

The sharing of mental images by quantum entanglement is purely TGD based prediction. What happens is rather paradoxic: the subselves of unentangled selves bound state entangle so that the resulting fused mental image is shared by both selves. This is not possible if one applies the standard notion of quantum mechanical sub-system as a tensor factor. The p-adic hierarchy of space-time sheets forces to generalize the notion of sub-system (note that also real space-time sheets are characterized by p-adic prime determining the size scale).

Smaller space-time sheets glued to larger space-time sheets by wormhole contacts having size of order CP_2 length of about 10^4 Planck lengths and having Euclidian signature of the induced metric (imbedding space $H = M^4_+ \times CP_2$, where space-time surfaces "live", is obtained by replacing each point of the future lightcone M^4_+ with the 4-dimensional complex projective space CP_2). This implies the presence of elementary particle horizons at which metric around wormhole contacts changes its signature from Minkowskian to Euclidian. At these 3-dimensional surfaces the induced metric is degenerate so that these surfaces are effectively 2-dimensional and allow conformal invariance crucial for the construction of the quantum theory. The analogy with black hole horizon is obvious. Black holes cannot be described as tensor factors of the entire universe and the same holds true for topologically condensed space-time sheets. The reason is that the elementary particle horizon, which from the view point of the imbedding space has one time-like direction, becomes a causal determinant for the field equations. One must just postulate a hierarchy of systems labelled by p-adic primes and allow entanglement between sub-systems of unentangled systems. In terms of length scale thinking of quantum field theories, one can say that the entanglement between sub-systems is not visible in the p-adic length and time scales of the systems themselves.

2.1.3 General view about psychological time and intentionality

A natural resolution of the problems related to the preferred role of single moment of time for conscious experience is based on the idea that biological growth and self-organization is a 4-dimensional phase transition proceeding in the direction of the geometric future quantum jump by quantum jump. And, in particular, that the dominating contribution to the conscious experience comes from the front of the phase transition where the volition is.

What is then this fundamental phase transition giving rise to what we call life? The front of phase transition corresponds naturally to volitional consciousness. Volition as a transformation of intention to action in TGD universe corresponds to the p-adic-to-real phase transitions of space-time sheets taking place in quantum jumps (for more detailed arguments see the chapter "Time and consciousness" of [5]). Thus the natural conclusion is that p-adic-to-real phase transition is the fundamental phase transition guiding the biological self-organization.

At least the selves at the same level of the self hierarchy possess the same value of psychological time. It might even be that the entire living biosphere (with magnetosphere included) could be seen as a phase transition front proceeding to the direction of the geometric future. This conclusion is of utmost importance since it leaves no other possibility that to accept that even biosphere defines conscious self and we correspond to only single level in the self hierarchy. In particular, the notion of collective consciousness is more or less 'a must' in this framework. A more detailed discussion of the notion of time can be found in the chapter "Time and consciousness" of [5].

The real-to p-adic transition can occur in situations in which there is an energy feed providing the energy for the materialized real systems. Systems with a small or vanishing rest mass are favoured.

a) Cognitive neutrino pairs of almost zero energy are the first candidate in this respect since the neutrinos at $k = 169$ space-time sheet have negative Z^0 interacting energies (because of their lightness) (see the chapter "Genes and Memes" of [6]). It however seems that configuration space spin degrees of freedom (that is fermionic degrees of freedom), in particular cognitive neutrinos are related to the cognition rather than intention. In this case p-adic-to-real transformation corresponds to the transformation of cognitive representation to a symbolic one. Symbolic representation could of course induce some physical effect: for instance, the symbolic representation in terms of real neutrinos could induce a nerve pulse pattern.

b) p-Adic-to-real phase transition could also occur for massless extremals (MEs) and perhaps also for the flux tubes of the magnetic fields. MEs are ideal for communication and control purposes and thus taylor-made for the realization of intentions. Besides MEs TGD counterparts of Teslas's scalar waves propagating with light velocity and representing pulses of electric field in the direction of propagation (see the chapter "Anomalies explainable by the many-sheeted space-time concept" of [4] are good candidates in this respect. Also wormhole magnetic fields consisting of pairs of magnetic flux tubes with opposite time orientations and having vanishing net energies must be considered (see the chapter "Wormhole magnetic fields" of [5]). Similar pairs of MEs are also possible.

To concretize the picture it is good to ask how intentions could be realized at the atomic level. Obviously the intentions of atom are very simple: make a transition to another energy level. These transitions involve the emission of photon, which can be also a negative energy virtual photon. Clearly, the generation of a p-adic ME is the most natural candidate for the space-time correlate of the atomic intention. If atomic transition occurs, it can provide the energy to transform p-adic ME to real one but the energy can also come from some other source. The p-adic-to-real transition is expected to occur with a considerable probability only if the p-adic ME resembles real ME sufficiently: for instance, p-adic and real ME could go through the same rational points in an appropriate p-adic resolution. In the presence of a real ME with fundamental frequency equal to the atomic transition frequency the probability for the atom to emit radiation in the direction of ME is enhanced so that intention is realized without conflict with the quantum statistical determinism. Intention only modifies quantums statistical probabilities by modifying the system.

MEs and Tesla's scalar wave pulses are not only ideal communication lines but also ideal control tools since they can form temporary bridges between space-time sheets making possible the leakage of ions between them. The leakage implies recoil effect and MEs and scalar wave pulses can act as switches inducing a coherent locomotion in direction of ME as a recoil effect. The findings of Modanese and Podkletnov [7] discussed in the chapter "Anomalies explainable by the many-sheeted space-time concept" of [4]) provide a support this mechanism. Z^0 MEs can also act as Josephson junctions between cell interior and exterior and induce nerve pulse sequences in turn allowing to control motor actions (see the chapter "Quantum model for EEG and nerve pulse" of [6]).

It is important to notice that p-adic intentionality does not mean randomness. A complete localization in p-adic configuration space ("world of classical worlds") degrees of freedom must occur in each quantum jump. Hence each quantum jump leads to a state in which p-adic spacetime sheets are completely fixed (whereas real spacetime sheets are fixed only modulo a resolution defined by an appropriate p-adic lengths scale). It is however not possible to say that the localization occurs with some probability to a given configuration of p-adic space-time sheets. System can freely intend arbitrarily many times in the same manner. Thus p-Adic MEs (and less probably magnetic fields and wormhole magnetic fields) might represent a plan for the evolution of the biological system, and induce biological self-organization of matter around the resulting electromagnetic hologram like templates.

2.2 Many-sheeted space-time, topological field quantization, and spin glass degeneracy

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

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

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

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

One can also speak about 'field body' (or actually hierarchy of them) as being associated with the material system. This field body, which is much larger than the material system, serves as a sensory canvas at which sensory representations are realized and could also perform motor control. This means radical modification of the neuro-science view about brain as the sole seat of consciousness (see the chapters "Magnetic sensory canvas hypothesis" and "Magnetospheric sensory representations" of [6]).

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

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

3 Macrotemporal quantum coherence from spin glass degeneracy

In the sequel the notion of macrotemporal quantum coherence is defined in TGD framework and the argument for how quantum spin glass degeneracy implies macrotemporal quantum coherence is developed.

3.1 What does quantum coherence mean in TGD Universe?

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

To understand how th naive conclusion is wrong, one must look more precisely the anatomy of quantum jump. The unitary process $\Psi_i \rightarrow U\Psi_i$, where Ψ_i is a prepared maximally unentangled state, corresponds to the quantum computation producing maximally entangled multiverse state. Then follows the state function reduction and after this the state preparation involving a sequence of self measurements and given rise to a new maximally unentangled state Ψ_f.

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

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

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

c) The properties of the bound state plus its interaction with the environment allow to estimate the typical duration of the bound state. This time takes the role of coherence time. This suggests a connection with the standard approach to quantum computation. Fractality of consciousness suggests that one can effectively treat long quantum jump sequence of a bound state as a single quantum jump (just like one can treat molecules as pointlike particles in a reasonable approximation) so that Hamiltonian description should be a good approximation.

3.2 Spin glass degeneracy and classical gravitation stabilize irreducible bound state entanglement

This picture gives connection with the standard physics view but does not yet explain why decoherence times are so long. New physics is required to explain why the life times of bound states are much longer than predicted by the standard physics. Spin glass degeneracy provides this physics.

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

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

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

The Hamiltonian time evolution would more or less correspond to a unitary operator resulting as a product of the actions of the unitary operators U associated with the quantum jumps of the sequence. The interpretation is as a length/time scale dependent time development operator obtained by integrating over the spin glass degrees of freedom. This is natural since spin glass degrees of freedom represent hidden degrees of freedom and degenerate bound states are identified as one and the same bound state in the standard physics context. Discretized time development emerges automatically in this framework. The Schrödinger equation at the infinitesimal level does not make sense but this is of course not a practical problem. One could say that the sequence of quantum jumps defining the conscious experience of self is able to simulate the unitary time evolution associated with single quantum history.

4 Basic implications

In the sequel the physical aspects of the macrotemporal quantum coherence are discussed.

4.1 Thermodynamical aspects

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

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

Quite recently it has been found that second law is indeed broken below .1 seconds for certain systems [8]. This time scale corresponds to the secondary p-adic time scale $T_p(2)$ associated with the Mersenne prime $M_{127} = 2^{127} - 1$ defining the p-adic length scale of electron. This time scale is fundamental in the TGD based model of living system and corresponds to the time scale of alpha band and the time resolution of the sensory experience (duration of sensory mental images). The reversal of the arrow of geometric time below p-adic time scale might be fundamental aspect of living systems and this point will be discussed later in more detail.

4.2 Energetic aspects

The generation of quantum bound state involves liberation of the binding energy as a usable energy. This might provide a new kind of metabolic mechanism in which co-operation by the formation of macroscopic quantum bound states allows a liberation of metabolic energy. The energy bill must be paid sooner or later, and the energy feed from environment takes care of this by destroying the bound state in average time defined by the duration of the bound state. The fact that oxidative metabolism is anomalously low during the neuronal synchrony [9] supports the view that neuronal synchrony might give rise to bound-state entangled multineuron states. This mechanism is quite general and even ordinary metabolism could be based on this mechanism as will be proposed later. Also the bound state entanglement between different organisms might be possible and liberate energy. Thus the notion of 'synergy' might be much more than a mere metaphor.

4.3 Information theoretic aspects

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

4.3.1 Number theoretic information measures

The notion of information in TGD framework differs in some respects from the standard notion.

a) The definition of the entropy in p-adic context is based on the notion p-adic logarithm depending on the p-adic norm of the argument x only ($x = p^n r/s$, r and s not divisible by p; $Log_p(x) = log_p(|x|_p) = -n$) (see the chapter "Negentropy Maximization Principle" of [5]). For rational- and even algebraic number valued probabilities this entropy can be regarded as a real number. The entropy defined in this manner can be negative so that the entanglement can carry genuine positive information. Thus p-adic bound state entanglement giving rise to a fusion of cognitive mental images is a natural correlate for the experience of understanding, and one can assign to eurekas a well defined amount of information. Rationally entangled p-adic system has a positive information content only if the number of the entangled state pairs is proportional to a positive power of the p-adic prime p.

b) This kind of definition of entropy works also in the real-rational and even real-algebraic cases and makes always sense for finite real world ensembles and for entanglement between real (p-adic) systems. Entanglement probabilities are indeed algebraic numbers for both rational and algebraic entanglement coefficients. Here the problem is how to fix the value of the prime p and the only reasonable criterion is maximization of information.

c) The modified definition of entropy would have deep implications. For the ordinary definition of the entropy NMP (see the chapter "Negentropy Maximization Principle" of [5]) states that real entanglement is minimized in the state preparation process. For the number theoretic definition of entanglement entropy NMP stabilizes the entanglement with positive information content. The fragility of quantum coherence is the basic problem of quantum computation and the good news would be that Nature itself (according to TGD) tends to stabilize quantum coherence if entanglement is rational/algebraic.

4.3.2 Life as islands of rational/algebraic numbers in the seas of real and p-adic continua?

The possibility to define entropy differently for rational/algebraic entanglement raises the question about which kind of systems can possess this kind of entanglement. There are several options.

1. Only the entanglement between different number fields is rational/algebraic

This option is maximally conservative and would bring nothing new into the real physics. $R - R_p$ and $R_{p_1} - R_{p_2}$, $p_1 \neq p_2$ entanglement is indeed necessary algebraic (and rational unless one allows an algebraic extension of p-adic numbers, which is however forced by the diagonalization of the density matrix in the general case). For $R_{p_1} - R_{p_2}$ entanglement there are two natural entropies S_{p_1} and S_{p_2}. One can define the total entropy uniquely as the sum $S = S_{p_1} + S_{p_2}$: similar definition applies to $R - R_p$ case. This definition generalizes to the situation when more than two systems belonging to different number fields are entangled.

This kind of entanglement could be called cognitive, and it would be natural to assign a positive or negative information with cognitive entanglement. Cognition could be seen as a quantum computation like process, more approriate term being quantum problem solving. Intelligent life would metaphorically reside at the rational/algebraic intersection of reals and p-adics/algebraic extensions of p-adics. Quantum-classical correspondence suggests that life is a boundary phenomenon at the space-time level: real and p-adic space-time sheets, action and intention, meet along common rational/algebraic points at the boundaries of the real space-time sheets so that these regions are indeed space-time correlates for the presence of cognitive entanglement.

Since intentionality (and thus p-adicity) is an essential aspect of life, one could say that living-dead dichotomy corresponds to rational-irrational or to algebraic-transcendental dichotomy. Life would in a well defined sense correspond to islands of rationality/algebraicity in the seas of real and p-adic continua.

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

2. Other options

There are also other options besides the maximally conservative option.

a) Physics could be quite generally rational/algebraic at Hilbert space level. This would mean that the state space has algebraic numbers as coefficient field. In this case everything would be living. A milder constraint is that $R_p - R_p$ entanglement is always algebraic. For non-algebraic $R_p - R_p$ entanglement the entanglement entropy is p-adic valued and must be mapped to real number by canonical identificiation $x = \sum x_n p^n \rightarrow \sum x_n p^{-n}$: the resulting entropy is non-negative. If only algebraic $R_p - R_p$ entanglement is allowed, one can use $I = -S_p$ as an information measure.

b) Bound state entanglement is rational/algebraic. If this view is correct, one is led to ask whether life corresponds to rational or algebraic entanglement. The algebraic option would maximize the size of the living sector of the state space. Rational numbers are common for reals and all p-adics: in algebraic case this holds true only if one introduces algebraic extensions of p-adics. This might make rationals preferred.

The objection against both options is that in the case of algebraic $R - R$ entanglement it is not clear which prime p should define the information measure. The only reasonable looking criterion fixing the value of p is the maximation of information. One could also argue that information is associated with only cognitive entanglement which by definition is between different number fields. Also the hypothesis that all entanglement/bound state entanglement is always algebraic, might pose too strong restrictions on quantum dynamics. For instance, S-matrix elements would be rational- or algebraic number valued.

4.3.3 Quantum computation and quantum problem solving in TGD Universe

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

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

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

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

d) It might be more appropriate to talk about conscious problem solving instead of quantum computation. In this framework the periods of macrotemporal quantum coherence replace the unitary time evolutions at the gates of the quantum computer as the basic information processing units and entanglement bridges between selves act as basic quantum communication units with the sharing of mental images providing a communication mode not possible in standard quantum mechanics.

4.3.4 Information concept at space-time level

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

1. How to assign an information measure to a space-time sheet

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

Obviously the primes dividing N define natural candidates for the information measures but the problem is which criterion selects one of them. There are three options.

1) Require that the information measure corresponds to the prime p for which S_p is smallest. Obviously p must divide N.

2) Define the information as sum

$$I = -\sum_{p|N} S_p \quad ,$$

(here $p|N$ means that p divides N) so that all contributions are positive.

3) Include all primes dividing N or m_i in $p_i = m_i/N$:

$$I = -\sum_{p|N \ or \ p|m_i} S_p \quad ,$$

In this case also negative contributions are present. This defition is actually equivalent with a definition

$$I = -\sum_{p} S_p \quad ,$$

in which the summation appears over all primes. One could say that the information decomposes into different kinds of informations labelled by primes.

What is interesting is that, the ordinary Shannon entropy S for rational probabilities can be expressed as a sum of all p-adic entropies using the adelic decomposition $|x| = \prod_p |x|_p^{-1}$:

$$S = -\sum_{p} S_p = I \quad .$$

The sum of real and p-adic entropies vanishes. Real dis-information and the p-adic information would compensate each other completely. Whether the adelic formula for information theory might have some deeper interpretation remains open.

2. How to assign p-adic prime or primes to a real space-time sheet?

A long-standing problem of quantum TGD is how to associate to a given *real* (not only p-adic) space-time sheet a unique p-adic prime (or possibly several of them) as required by the p-adic length scale hypothesis.

a) One could achieve this by requiring that for this prime the negentropy associated with the ensemble is maximal. The simplest hypothesis is that a real space-time sheet consisting of N deterministic pieces corresponds to the p-adic prime defining the largest factor of N.

b) One could also consider a more general possibility. If N contains p^n as a factor, then the real fractality above n-ary p-adic length scale $L_p(n) = p^{(n-1)/2}L_p$ corresponds to smoothness in the p-adic topology. This option is more attractive since it predicts that the fundamental p-adic length scale L_p for a given p can be effectively replaced by any integer multiple NL_p, such that N is not divisible by p. There is indeed a considerable evidence for small p p-adicity in long length scales. For instance, genetic code and the appearence of binary pairs like cell membrane consisting of liquid layers suggests 2-adicity in nano length scales. This view means that the fractal structure of a given real space-time sheet represents both an integer N and its decomposition to prime factors physically. This would also mean that one can assign several p-adic information measures to the real space-time sheet. This obviously conforms with the physics as a generalized number theory vision.

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

d) The hypothesis that the prime factorization of N determines the effective p-adic topologies associated with the real space-time sheet inspires the hypothesis that the rational (or algebraic) p-adic-real entanglement necessary for cognitive quantum measurements is probable/possible only for the p-adic primes dividing N.

3. Does classical space-time physics represent factorization of integers?

Quantum-classical correspondence suggests that quantum computation processes might have counterparts at the level of space-time. An especially interesting process of this kind is the factorization of integers to prime factors. The classical cryptography relies on the fact that the factorization of large integers to prime factors is a very slow process using classical computation: the time needed to factor 100 digit number using modern computer would take more than the recent age of the universe. For quantum computers the factorization is achieved very rapidly using the famous Shor's algorithm. Does the factorization process indeed have a space-time counterpart?

Suppose that one can map the integer N to be factored to a real space-time sheet with N deterministic pieces. If one can measure the powers $p_i^{n_i}$ of primes p_i for which the fractality above the appropriate p-adic length scale looks smoothness in the p-adic topology, it is possible to deduce the factorization of N by direct physical measurements of the p-adic length scales characterizing the representative space-time sheet (say from the resonance frequencies of the radiation associated with the space-time sheet). If only the p-adic topology corresponding to the largest prime p_1 is realized in this manner, one can deduce first it, and repeat the process for N/p_1^n, and so on, until the full factorization is achieved. A possible test is to generate resonant radiation in a wave guide of having length which is an integer multiple of the fundamental p-adic length scale and to see whether frequencies which correspond to the factors of N appear spontaneously.

Seeing the prime factorization might be also possible via a direct sensory perception. Oliver Sacks tells in his book 'The man who mistook his wife for a hat' [10] about twins, John and Michael, who had a mysterious ability to 'see' large numbers and their prime factorizations despite the fact that their intelligence quotient was about 60 and they did not have any idea about the notions of integer and prime. For instance, matchbox was dropped from the table and its contents were spread along the floor. Both twins shouted immediately '111!'. Then John mumbled '37', Michael repeated it and John said '37' third time. Obviously this was their sensory representation for the decomposition $111 = 3 \times 37$ of number 111 to a product of primes! The explanation of these strange feats suggested in the chapter "Self and Binding" of [5] is a less general idea about physical representation of the factorization. The proposed mechanism could indeed explain prime factorization as a sensory perception involving no algorithmic cognition at all.

5 Macrotemporal quantum coherence, consciousness, and biology

This section is devoted to a brief discussion of the aspects of macrotemporal quantum coherence related to consciousness and biology.

5.1 Macrotemporal quantum coherence and states of "oneness"

Selves can be regarded as ensembles of quantum jumps with contents of conscious experience determined by qualia identified as statistical averages over increments of quantum numbers *resp.* zero modes over quantum jumps (non-geometric *resp.* geometric qualia such as colors *resp.* geometric shape. In general selves, and in particular sub-selves representing mental images of self become fuzzy during ageing since the entropies associated with the distributions of quantum number/zero mode increments increase with the increasing size. Macrotemporal quantum coherence allows to avoid this problem and mental image stays sharp as long as the bound state lasts.

The formation of quantum bound states corresponds to the fusion of mental images (subselves) to form large mental images and in the ideal situation all mental images fuse to single mental image. The fusion of the right and left visual fields to a single visual field giving rise to stereo vision is basic example of this process. Quite generally, the fusion of more or less identical mental images gives rise to a 'stereo-consciousness'. Synchronous neuronal firing is the physical correlate for the fusion of mental images and is made possible by the formation of join along boundaries bonds. In case that the mental images are too different this kind of fusion is not useful, and at least in the case of vision, sensory rivalry selects either of the visual images as a conscious percept [9].

An interesting question is what kind of conscious experience this process corresponds. A natural guess is that the fusion of mental images to single mental images gives rise to a mystic experience of 'one-ness'. In p-adic context rational bound state entanglement can have negative p-adic entanglement entropy under rather natural definition of entanglement entropy. Perhaps the fusion of p-adic mental images representing cognitive mental images gives rise to the experience of understanding. As found, the definition of entanglement entropy used in p-adic-rational context applies as such in real-rational context. Thus also sensory mental images could carry positive information.

Bound state entanglement for mental images means sharing and fusion of mental images and this kind of mechanism could be crucial for the formation of social structures and establishment of common value systems and moral rules.

The experience of love might be the conscious experience associated with the sharing of mental images. TGD predicts also the possibility of bound state quantum entanglement even in astrophysical length scales and sharing of mental images provides a basic mechanism of remote mental interactions by making remote system effectively a part of the system. The realization of sensory representations at the magnetic body and probably also at magnetosphere is based on this kind of remote mental interaction. Rather paradoxicly, paranormal phenomena would be completely normal.

5.2 Macrotemporal quantum coherence and biology

The formation of bound states is a generic mechanism for generating new quantum fluctuating degrees of freedom and could make possible quantum computation like processes and multiverse states of consciousness containing large amounts of conscious information. At the macro-level sexual organism could be a basic example of a multi-verse state of one-ness generated by the formation of a macroscopic quantum bound state of partners. Neuro-scientists are used to talk about rewards and punishments, and one might argue that life involves kind of sexual or spiritual pleasure as a reward for the formation of bound states at all levels of hierarchy. Spiritual experiences would represent the most abstract experiences of this kind involving the formation of bound states of the field bodies by MEs serving as field bridges.

Some examples are in order.

a) The binding of molecules by lock and key mechanism is a fundamental process in living matter and could generate large number of quantum fluctuating degrees of freedom and generate conscious intelligence. This could explain why long linear macro-molecules are so important for life. From the viewpoint of classical chemistry it is not obvious why DNA is arranged into long chromosomes rather than separate short threads. In TGD universe the reason why would be that for chromosomes the number of quantum fluctuating degrees of freedom and thus the amount of conscious intelligence is maximized.

b) The binding of the information molecules to receptors is a universal control mechanism in the living matter. In TGD universe information molecule would initiate genuine quantum information processing lasting for the lifetime of the information molecule-receptor complex. In particular, neurotransmitters could induce molecular states of one-ness in the receptor-neurotransmitter complex or perhaps even in larger-sized structures. If neurotransmitters have join along boundaries bonds to other neurons mediated by magnetic flux tube structures or MEs, they could act as conscious quantum links in quantum web and induce quantum computation like processes involving distant neurons just as the links in the web induce classical computations involving distance computers.

c) One could see information molecules and receptors as representatives of opposite molecular sexes: information molecules would be active quantum binders free to move from flower to flower whereas receptors would be the passive party attached to some structure. The binding of the information molecule to the receptor would be the molecular analog of the sexual intercourse. Usually the receptors are bound to larger structures such as cell membrane and also the zero modes for some parts of these larger structures could become quantum fluctuating in the process.

d) As found, the new number-theoretic definition of entropy is very attractive from the point of view of consciousness theory also in the real context. An especially interesting biological application of the number-theoretic entropy would be to the genetic code: in this case the number of bases is proportional to at least $p = 3$. Does the number N of DNA triplets of gene or of information bearing fragments of gene have a tendency to be proportional to powers of some relatively large primes? Could one order the genes hierarchically by the prime number decomposition of the number N so that large primes would correspond to high level bio-control and small primes to low level bio-control? Could the prime number decomposition of N define natural decompositions of gene to sub-modules of the biological program defined by the gene? For instance, $N = 10 = 2 \times 5$ would correspond to 5 (2) sub-modules consisting of 2 (5) DNA triplets.

5.3 Macrotemporal quantum coherence and long term memory

The energies liberated in the transitions between spin glass states should correspond to gravitational binding energies. MEs would be the space-time correlates for the radiation emitted in these transitions. These MEs could be electromagnetically neutral and carrying only classical Z^0 fields and gravitational fields (it is a matter of taste whether one speaks of Z^0 or gravitational MEs). It turns out that these transitions could realize the mirror mechanism of long term memories.

5.3.1 Mirror mechanism of long term memories and gravitonic topological light rays

To remember what happened (more precisely, happens subjectively now) in the geometric past at a temporal distance of one year is to look at a quantum mirror at a distance of one half light year. To have an intention is to look at a p-adic quantum mirror which is in the geometric future.

MEs (topological light rays) with fundamental frequencies with a time scale measured using year as a natural unit are needed in the mirror model of long term memories. The gravitational transitions between a huge number of almost degenerate spin glass states could be coded to the fundamental frequencies of MEs. In particular, structures with sizes slightly above cell membrane thickness, such as microtubules, could generate these MEs as a topological correlate for graviton emission with frequency (length) of ME equal to the increment of the gravitational binding energy in quantum jump involved. Thus there would be a direct correlation with long term memories and microtubules: microtubule conformations could code for long term memories.

The mirror mechanism of long term memory allows a beautiful interpretation in terms of topological correlates for virtual graviton exchange with vacuum.

a) The light reflected in mirror corresponds to topological light rays assignable to gravitons and is reflected from the curved vacuum. Topological counterpart of virtual graviton is emitted by (say) a tubulin, reflected by the vacuum, and finally absorbed by the tubulin. Curved vacuum acts as a mirror for gravitons and self can see the self of the geometric past in this mirror.

b) Why gravitons are the only possibility in time scale of years is simply that they interact so weakly that they can propagate light years before absorbed by curved vacuum. Note however that Z^0 MEs interact classically with the matter and this interaction is especially strong in cellular length scales and presumably makes possible the reflection of the ME from the vacuum. Time scales come out correctly and microtubules are known to be crucial for long term memories (Altzheimer's disease involves changes at the microtubular level).

c) One could interpret the low energy topological graviton rays responsible for long term memory as a particular kind of $1/f$ noise accompanying all critical systems, in particular TGD Universe, which can be regarded as a quantum critical quantum spin glass. Gravitonic $1/f$ noise would be emitted in the transitions between almost degenerate spin glass states and would be kind of analog for gravitational brehmstrahlung.

If this view is correct, the time scales of long term memory at DNA level would correspond to very long time scales characterizing consciousness at the level of species. This in fact conforms with the role of DNA as a species memory. As a matter fact, the gravitational binding energy associated with $L(139) \sim .1$ nm (atomic physics) corresponds to the age of the universe: perhaps this explains why Schröedinger equation applies to the description of atom. $1/R$ dependence of the gravitational interaction energy would explain why very short length scales code biological information about very long time scales rather than vice versa.

5.3.2 Order of magnitude estimate for gravitational binding energies

A rough order of magnitude estimate for the gravitational binding energy for a cubic blob of water (that is living matter) having size given by p-adic length scale $L(k)$ is

$$E_{gr}(cubic,k) \sim \frac{GM^2}{L(k)} = G\rho^2 L^5(k) \sim \frac{Gm_p^2}{L(137)} \frac{L^5(k)}{L^5(137)} \simeq 2^{-127} 2^{5/2(k-137)} \frac{1}{L(137)} \quad .$$

Gravitational binding energy is larger than the p-adic energy $2\pi/L(k)$ for $L(k = 179) \simeq .169$ mm. In the range $L(163) = 640$ nm and $L(167) = 2.56$ μm gravitational binding frequency varies between 1 Hz and 1 kHz, that is over EEG range up to the maximal frequency of nerve pulses. If the binding energy gives estimate for the lifetime of the gravitationally bound states, this might fit nicely with EEG energies in typical cell length scales!

For $k = 157$ and $k = 151$ (the range from cell 10 nm-80 nm, microtubules are at the lower end of this range) the gravitational binding frequency corresponds to a time scale of 8.5 hours and 32 years respectively so that the time scales relevant for life are spanned by the Gaussian Mersennes. What sounds paradoxic is that short length scales would correspond to long time scales but this indeed follows from the inverse square law for the gravitational force.

One can perform a similar estimate for linear structures. Parametrizing the microtubular transversal area to be $d = x^2L^2(151)$, $L(151) = 10$ nm, one has

$$E_{gr}(lin,k) = x^5 \times E_{gr}(cubic,151)\frac{L(k)}{L(151)} \quad .$$

This gives for $L(k) \sim 1$ meter, the frequency of $.1 \times x^5$ Hz. The time scale varies between $10/x^5$ seconds and $32/x^5$ years and certainly covers the time scale for human long term memories. Of course, this rough estimate involves numerical factor which can increase the upper bound. One must also remember that the change of the classical gravitational energy for spin glass transitions is in question and this energy is smaller than binding energy itself so that actual time scales are considereably longer.

Together with the known facts about the correlations of microtubuli with long term memories this leads to the idea that microtubuli represent long term memories. What is so beautiful in this idea is that there is no need for long term static storage of memories since memory is represented in the geometric past. The instantaneous configurations of the microtubuli define the memories and they are allowed to change in quite rapid time scales. The two conformations of tubulin dimers are ideal for representing declarative memories as bit sequences and microtubuli provide huge information storage capacities. One can also understand why sensory pathways tend to maximize their length. The loss of long term memories at old age respects the oldest memories and this naturally corresponds to the degeneation of the long microtubuli first with shortest microtubuli being the most stable ones. In the chapter "Quantum model of memory" of [5] the model for long term memories is developed in detail.

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