

DNA as Topological Quantum Computer: Part I

Matti Pitkänen¹

Abstract

This is the first part of the article representing a vision about how DNA might act as a topological quantum computer (tqc). Tqc means that the braidings of braid strands define tqc programs and M-matrix (generalization of S-matrix in zero energy ontology) defining the entanglement between states assignable to the end points of strands define the tqc usually coded as unitary time evolution for Schrödinger equation.

Before a representation of the model of tqc general vision about what happens in quantum jump, which at least in formal sense can be regarded as quantum computation, is represented. Included is also a section about modification of thermodynamics required by the possibility of negentropic entanglement. The modification corresponds simply to the replacement $S \rightarrow S - N$ for the entropy in standard thermodynamics. The implications of this replacement are however highly non-trivial. The generalization of the second law allows to understand the thermodynamical aspect of topological quantum computation. One can understand why living matter is so effective entropy producer as compared to inanimate matter and also the characteristic decomposition of living systems to highly negentropic and entropic parts as a consequence of generalized second law. ADP-ATP process of metabolism provides a concrete application for the generalized thermodynamics and allows to see this process as a transfer of negentropic entanglement. Also DNA double strand for which sugar-phosphate backbone consists of XMPs, X= A,T,C,G containing negentropy carrying phosphate bonds can be seen as analogous to conscious brain with DNA strands representing right and left hemispheres.

One can end up to the model of topological quantum computation in the following manner.

1. Darwinian selection for which the standard theory of self-organization provides a model, should apply also to tqc programs. Tqc programs should correspond to asymptotic self-organization patterns selected by dissipation in the presence of metabolic energy feed. The spatial and temporal pattern of the metabolic energy feed characterizes the tqc program - or equivalently - sub-program call.
2. Since braiding characterizes the tqc program, the self-organization pattern should correspond to a hydrodynamical flow or a pattern of magnetic field inducing the braiding. Braid strands must correspond to magnetic flux tubes of the magnetic body of DNA. If each nucleotide is transversal magnetic dipole it gives rise to transversal flux tubes, which can also connect to the genome of another cell. As a matter fact, the flux tubes would correspond to what I call wormhole magnetic fields having pairs of space-time sheets carrying opposite magnetic fluxes.
3. The output of tqc sub-program is probability distribution for the outcomes of state function reduction so that the sub-program must be repeated very many times. It is represented as four-dimensional patterns for various rates (chemical rates, nerve pulse patterns, EEG power distributions,...) having also identification as temporal densities of zero energy states in various scales. By the fractality of TGD Universe there is a hierarchy of tqcs corresponding to p-adic and dark matter hierarchies. Programs (space-time sheets defining coherence regions) call programs in shorter scale. If the self-organizing system has a periodic behavior each tqc module defines a large number of almost copies of itself asymptotically. Generalized EEG could naturally define this periodic pattern and each period of EEG would correspond to an initiation and halting of tqc. This brings in mind the periodically occurring sol-gel phase transition inside cell near the cell membrane. There is also a connection with hologram idea: EEG rhythm corresponds to reference wave and nerve pulse patters to the wave carrying the information and interfering with the reference wave.
4. Fluid flow must induce the braiding which requires that the ends of braid strands must be anchored to the fluid flow. Recalling that lipid mono-layers of the cell membrane are liquid

¹Matti Pitkänen http://tgd.wippiespace-com/public_html. Address: Köydenpunojankatu 2 D 11 10940, Hanko, Finland. Email: matpitka@luukku.com.

crystals and lipids of interior mono-layer have hydrophilic ends pointing towards cell interior, it is easy to guess that DNA nucleotides are connected to lipids by magnetic flux tubes and hydrophilic lipid ends are stuck to the flow.

5. The topology of the braid traversing cell membrane cannot be affected by the hydrodynamical flow. Hence braid strands must be split during tqc. This also induces the desired magnetic isolation from the environment. Halting of tqc reconnects them and make possible the communication of the outcome of tqc.

There are several problems related to the details of the realization.

1. How nucleotides A,T,C,G are coded to the strand color and what this color corresponds to physically? There are two options which could be characterized as fermionic and bosonic.
 - i) Magnetic flux tubes having quark and anti-quark at their ends with u, d and u_c, d_c coding for A,G and T,C. CP conjugation would correspond to conjugation for DNA nucleotides.
 - ii) Wormhole magnetic flux tubes having wormhole contact and its CP conjugate at its ends with wormhole contact carrying quark and anti-quark at its throats. The latter are predicted to appear in all length scales in TGD Universe.
2. How to split the braid strands in a controlled manner? High T_c super conductivity provides a possible mechanism: braid strand can be split only if the supra current flowing through it vanishes. A suitable voltage pulse induces the supra-current and its negative cancels it. The conformation of the lipid controls whether it can follow the flow or not.
3. How magnetic flux tubes can be cut without breaking the conservation of the magnetic flux? The notion of wormhole magnetic field could save the situation now: after the splitting the flux returns back along the second space-time sheet of wormhole magnetic field. An alternative solution is based on reconnection of flux tubes. Since only flux tubes of same color can reconnect this process can induce transfer of color: "color inheritance": when applied at the level of amino-acids this leads to a successful model of protein folding. Reconnection makes possible breaking of flux tube connection for both the ordinary magnetic flux tubes and wormhole magnetic flux tubes.
4. How magnetic flux tubes are realized? The interpretation of flux tubes as correlates of directed attention at molecular level leads to concrete picture. Hydrogen bonds are by their asymmetry natural correlates for a directed attention at molecular level. Also flux tubes between acceptors of hydrogen bonds must be allowed and acceptors can be seen as the subjects of directed attention and donors as objects. Examples of acceptors are aromatic rings of nucleotides, $O =$ atoms of phosphates, etc.. A connection with metabolism is obtained if it is assumed that various phosphates XMP, XDP, XTP , $X = A, T, G, C$ act as fundamental acceptors and plugs in the connection lines. The basic metabolic process $ATP \rightarrow ADP + P_i$ allows an interpretation as a reconnection splitting flux tube connection, and the basic function of phosphorylating enzymes would be to build flux tube connections as also of breathing and photosynthesis.

1 Introduction

Large values of Planck constant makes possible all kinds of quantum computations [47, 41, 48, 50]. What makes topological quantum computation (tqc) [51, 45, 42, 43, 49] so attractive is that the computational operations are very robust and there are hopes that external perturbations do not spoil the quantum coherence in this case. The basic problem is how to create, detect, and control the dark matter with large \hbar . The natural looking strategy would be to assume that living matter, say a system consisting of DNA and cell membranes, performs tqc and to look for consequences.

There are many questions. How the tqc could be performed? Does tqc hypothesis might allow to understand the structure of living cell at a deeper level? What does this hypothesis predict about DNA itself? One of the challenges is to fuse the vision about living system as a conscious hologram with the DNA as tqc vision. The experimental findings of Peter Gariaev [57, 59] might provide a breakthrough in this respect. In particular, the very simple experiment in which one irradiates DNA sample using ordinary light in UV-IR range and photographs the scattered light seems to allow an interpretation as providing a photograph of magnetic flux tubes containing dark matter. If this is really the case, then the bottle neck problem of how to make dark matter visible and how to manipulate it would have been

resolved in principle. The experiment of Gariaev and collaborators [59] also show that the photographs are obtained only in the presence of DNA sample. This leaves open the question whether the magnetic flux tubes associated with instruments are there in absence of DNA and only made visible by DNA or generated by the presence of DNA.

1.1 Basic ideas of tqc

The basic idea of topological quantum computation (tqc) is to code tqc programs to braiding patterns (analogous to linking and knotting). A nice metaphor for tqc is as dance. Dancing pattern in time direction defines the tqc program. This kind of patterns are defined by any objects moving around so that the Universe might be performing topological quantum computation like activities in all scales.

One assigns to the strands of the braid elementary particles. The S-matrix coding for tqc is determined by purely topological consideration as a representation for braiding operation. It is essential that the particles are in anyonic phase: this means in TGD framework that the value of Planck constant differs from its standard value. Tqc as any quantum computation halts in state function reduction which corresponds to the measurement of say spins of the particles involved.

As in the case of ordinary computers one can reduce the hardware to basic gates. The basic 2-gate is represented by a purely topological operation in which two neighboring braid strands are twisted by π . 1-particle gate corresponds to a phase multiplication of the quantum state associated with braid strand. This operation is not purely topological and requires large Planck constant to overcome the effects of thermal noise.

In TGD framework tqc differs somewhat from the ordinary one.

1. Zero energy ontology (ZEO) means that physical states decompose into pairs of positive and negative energy states at the "upper" and "lower" light-like boundaries boundaries of $CD \times CP_2$, where CD denotes causal diamond identified as the intersection of the future and past directed lightcones (in the sequel CD is used for $CD \times CP_2$ in order to make notations more elegant). Positive and negative energy states have opposite values of conserved quantum numbers. The interpretation is as an event, say particle scattering, in positive energy ontology. The time like entanglement coefficients define S-matrix, or rather M-matrix, and this matrix can be interpreted as coding for physical laws in the structure of physical state as quantum superposition of statements "A implies B" with A and B represented as positive and negative energy parts of quantum state. The halting of topological quantum computation would select this kind of statement.
2. The new view about quantum state as essentially 4-D notion implies that the outcome of tqc is expressed as a four-dimensional pattern at space-time sheet rather than as time=constant final state. All kinds of patterns would provide a representation of this kind. In particular, holograms formed by large \hbar photons emitted by Josephson currents, including EEG as a special case, would define particular kind of representation of outcome.

1.2 Identification of hardware of tqc and tqc programs

One challenge is to identify the hardware of tqc and realization of tqc programs.

1. Living cell is an excellent candidate in this respect. The lipid layers of the cell membrane is 2-D liquid crystal and the 2-D motion of lipids would define naturally the braiding if the lipids are connected to DNA nucleotides. This motion might be induced by the self organization patterns of metabolically driven liquid flow in the vicinity of lipid layer both in interior and exterior of cell membrane and thus self-organization patterns of the water flow would define the tqc programs.
2. This identification of braiding implies that tqc as dancing pattern is coded automatically to memory in the sense that lipids connected to nucleotides are like dancers whose feet are connected to the wall of the dancing hall define automatically space-like braiding as the threads connected to their feet get braided. This braiding would define universal memory realized not only as tissue memory but related also to water memory [29].

3. It is natural to require that the genetic code is somehow represented as property of braids strands. This is achieved if strands are "colored" so that A,T,C,G correspond to four different "colors". This leads to the hypothesis that flux tubes assignable to nucleotides are wormhole magnetic flux tubes such that the ends of the two sheets carry quark and antiquark (*resp.* antiquark and quark) quantum numbers. This gives mapping A,T,C,G to u, u_c, d, d_c . These quarks are not ordinary quarks but their scaled variants predicted by the fractal hierarchy of color and electro-weak physics. Chiral selection in living matter could be explained by the hierarchy of weak physics. The findings of topologist Barbara Shipman about mathematical structure of honeybee dance led her to proposed that the color symmetries of quarks are in some mysterious manner involved with honeybee cognition and this model would justify her intuition [39].
4. One should identify the representation of qubit. Ordinary spin is not optimal since the representation of 1-gates would require a modification of direction of magnetic field in turn requiring modification of direction of flux tubes. A more elegant representation is based on quark color which means effectively 3-valued logic: true, false, and undefined, also used in ordinary computers and is natural in a situation in which information is only partial. In this case 1-gates would correspond to color rotations for space-time sheets requiring no rotation of the magnetic field.

In this framework genes define the hardware of tqc rather than genetic programs. This means that the evolution takes place also at the level of tqc programs meaning that strict genetic determinism fails. There are also good reasons to believe that these tqc programs can be inherited to some degree. This could explain the huge differences between us and our cousins in spite of almost the identical genetic codes and explains also cultural evolution and the observation that our children seem to learn more easily those things that we have already learned [60]. It must be added that DNA as tqc paradigm seems to generalizedDNA, lipids, proteins, water molecules,... can have flux tubes connecting them together and this is enough to generate braidings and tqc programs. Even water could be performing simple tqc or at least building memory representations based on braiding of flux tubes connecting water molecules.

1.3 How much tqc resembles ordinary computation?

If God made us to his own image one can ask whether we made computers images of ourselves in some respects. Taking this seriously one ends up asking whether facts familiar to us from ordinary computers and world wide web might have counterparts in DNA as tqc paradigm.

1. Can one identify program files as space-like braiding patterns. Can one differentiate between program files and data files?
2. In ordinary computers electromagnetic signalling is in key role. The vision about living matter as conscious holograms suggests that this is the case also now. In particular, the idea that entire biosphere forms a tqc web communicating electromagnetically information and control signals looks natural. Topological light rays (MEs) make possible precisely targeted communications with light velocity without any change in pulse shape. Gariaev's findings [57] that the irradiation of DNA by laser light induces emission of radio wave photons having biological effects on living matter at distances of tens of kilometers supports this kind of picture. Also the model of EEG in which the magnetic body controls the biological body also from astrophysical distances conforms with this picture.
3. The calling of computer programs by simply clicking the icon or typing the name of program followed by return is an extremely economic manner to initiate complex computer programs. This also means that one can construct arbitrarily complex combinations from given basic modules and call this complex by a single name if the modules are able to call each other. This kind of program call mechanism could be realized at the level of tqc by DNA. Since the intronic portion of genome increases with the evolutionary level and is about 98 per cent for humans, one can ask whether introns would contain representations for names of program modules. If so, introns would express themselves electromagnetically by transcribing the nucleotide to a temporal pattern of electromagnetic radiation activating desired subprogram call, presumably the conjugate of intronic

portion as DNA sequence. A hierarchical sequence of subprogram calls proceeding downwards at intronic level and eventually activating the tqc program leading to gene expression is suggestive.

Gariaev [57] has found that laser radiation scattering from given DNA activates only genomes which contain an address coded as temporal pattern for the direction of polarization plane. If flux tubes are super-conducting and there is strong parity breaking (chiral selection) then Faraday rotation for photons traveling through the wormhole flux tube code nucleotide to an angle characterizing the rotation of polarization plane. User id and password would be kind of immune system against externally induced gene expression.

4. Could nerve pulses establish only the connection between receiver and sender neurons as long magnetic flux tubes? Real communication would take place by electromagnetic signals along the flux tube, using topological light ray (ME) attached to flux tube, and by entanglement. Could neural transmitters specify which parts of genomes are in contact and thus serve as a kind of directory address inside the receiving genome?

1.4 Basic predictions of DNA as tqc hypothesis

DNA as tqc hypothesis leads to several testable predictions about DNA itself.

1.4.1 Anomalous em charge

The model for DNA as tqc assigns to flux tubes starting from DNA an anomalous em charge. This means that the total charge of DNA nucleotide using e as unit is $Q = -2 + Q(q)$, where -2 is the charge of phosphate group and $Q(q) = -/+ 2/3, +/- 1/3$ is the electromagnetic charge of quark associated with "upper" sheet of wormhole magnetic flux tube. If the phosphate group is not present one has $Q = Q(q)$. In the presence of phosphate bonds the anomalous charge makes possible the coding of nucleotides to the rotation of angle of polarization plane resulting as photon travels along magnetic flux tube. The anomalous em charge should be visible as an anomalous voltage created by DNA. It would be relatively easy to test this prediction by using various kinds of DNA:s.

1.4.2 Does breaking of matter antimatter and isospin symmetries happen at the level of DNA and mRNA?

The nice feature of the model is that it allows to interpret the slightly broken A-G and T-C symmetries of genetic code with respect to the third nucleotide Z of codon XYZ in terms of the analog of strong isospin symmetry at quark level at wormhole magnetic flux tubes. Also matter-antimatter dichotomy has a chemical analog in the sense that if the letter Y of codon corresponds to quark u, d (antiquark u_c, d_c), the codon codes for hydrophobic (hydrophilic) aminoacid. It is also known that the first letter X of the codon codes for the reaction path leading from a precursor to an aminoacid. These facts play a key role in the model for code of protein folding and catalysis. The basic assumption generalizing base pairing for DNA nucleotides is that wormhole flux tubes can connect an aminoacid inside protein only to molecules (aminoacids, DNA, mRNA, or tRNA) for which Y letter is conjugate to that associated with the aminoacid. This means that the reduction of Planck constant leading to the shortening of the flux tube can bring only these aminoacids together so that only these molecules can find each other in biocatalysis: this would mean kind of code of bio-catalysis.

The fact that matter-antimatter and isospin symmetries are broken in Nature suggests that the same occurs at the level of DNA for quarks and anti-quarks coding for nucleotides. One would expect that genes and other parts of genome differ in the sense that the anomalous em charge, isospin, and net quark number (vanishes for matter antimatter symmetric situation) differ for them. From Wikipedia [58] one learns that there are rules about distribution of nucleotides which cannot be understood on basis of chemistry. The rules could be understood in terms of new physics. Chargaff's rules state that these symmetries hold true in one per cent approximation at the level of entire chromosomes. Szybalski's rules [58] state that they fail for genes. There is also a rule stating that in good approximation both strands contain the same portion of DNA transcribed to mRNA. This implies that at mRNA level the sign of

matter antimatter asymmetry is always the same: this is analogous to the breaking of matter antimatter asymmetry in cosmology (only matter is observed).

It would be interesting to study systematically the breaking of these symmetries for a sufficiently large sample of genes and also other in parts of genome where a compensating symmetry breaking must occur. That the irradiation of DNA by laser light induces emission of radio wave photons having biological effects on living matter at distances of tens of kilometers supports this kind of picture. Also the model of EEG in which magnetic body controls biological body from astrophysical distances conforms with this picture.

The articles published in *Prespacetime Journal*[34] and *Journal of Consciousness Exploration & Research* [35, 36, 37] provide a concise summary about TGD and TGD inspired theory of consciousness and biology and is recommended as a background besides the online books and articles at my homepage.

I have divided the article to two parts. In the first part the basic concepts and ideas behind DNA as tqc hypothesis are described.

1. A brief summary about what happens in quantum jump structurally analogous to quantum computation in zero energy ontology is given and a generalization of thermodynamics to take into account negentropic entanglement crucial for understanding living matter identified as something residing in the intersection of real world describing matter and p-adic worlds describing cognition.
2. In TGD framework the standard positive energy ontology is replaced with zero energy on. This implies that quantum computation in TGD Universe differs from that in standard model world and these differences are summarized. One of the basic differences is temporal non-locality and top down nature of the computation and 4-D character of the ensemble coding for the outcome of the computation statistically.
3. A model for DNA as topological quantum computer is formulated at the general level but details of the model are left to the second part of the article.

2 Basic concepts and ideas

The following represents a brief overall view about the notions of quantum jump, unitary process described by unitary U -matrix between zero energy states having as its orthogonal rows M -matrices between positive and negative energy parts of zero energy states identifiable as counterpart of ordinary S -matrix and of Negentropy Maximization Principle (NMP) governing the dynamics of state function reduction cascade.

2.1 What happens in quantum jump?

Quantum jump involves U process and state function reduction cascade. Negentropy Maximization Principle implies second law for the standard view about state function reduction: second law states that the ensemble entropy increases by the randomness of the outcome of the state function reduction process. When negentropic entanglement possible in what might be called intersection of the real and various p-adic worlds is present the situation is not so clear. Before proceeding to consider the modification of the second law one must define more precisely what U process is.

The simplest view about quantum jump is as a unitary U -process followed by as a cascade of state function reductions proceeding from top to bottom. But what is the top?

1. In positive energy ontology it would be entire Universe. Quantum classical correspondence suggests that one should be able to assign to quantum jump a duration of geometric time. For this proposal this time is most naturally infinite.
2. The vision about fractal hierarchy of selves and quantum jumps together with ZEO suggests a more refined view about quantum jump in which. U -process and subsequence state function reduction cascade could occur independently for disjoint CD s. For a given CD the new sub- CD s (representing mental images of the corresponding self) can be created and old destroyed so that the only constraint would be that only disjoint CD s can perform quantum jumps independently. For this option the duration of geometric time assignable to the quantum jump would naturally correspond to the

temporal distance between the tips of CD : p-adic length scale hypothesis and number theoretical vision suggest that this distance comes as an octave of CP_2 time scale (prime or integer multiple is the more general option). For infinitely large CD this would mean infinite duration. This picture is consistent with the TGD view about how the arrow of subjective time induces the arrow of geometric time [22].

2.2 M-matrix

The unitary U -matrix characterizing the unitary process has as its rows orthogonal M -matrices characterized by in general non-unitarity M -matrices. M -matrix decomposes into a product of positive definite diagonal square roots of density matrix and unitary S -matrix measurement in particle physics experiment. M -matrix represents both the time-like entanglement between positive and negative energy parts of zero energy states with opposite quantum numbers and space-like entanglement for the positive and negative energy states.

2.2.1 Time-like and space-like entanglement in zero energy ontology

M -matrix for each summand is product of Hermitian square root of density matrix and unitary S -matrix multiplied by a square root of probability having interpretation as analog for Boltzmann weight or probability defined by density matrix (note that it is essential to have $Tr(Id) = 1$ for factors of type II_1). If factor of type I_∞ are present situation is more complex. This means that quantum computations are highly universal and M -matrices are characterized by the inclusion $\mathcal{N} \subset \mathcal{M}$ in each summand defining measurement resolution. Hermitian elements of \mathcal{N} act as symmetries of M -matrix. The identification of the reducible entanglement characterized by Boltzmann weight like parameters in terms of thermal equilibrium would allow to interpret quantum theory as square root of thermodynamics.

If the entanglement probabilities defined by S -matrix and assignable to \mathcal{N} rays do not belong to the algebraic extension used then a full state function reduction is prevented by NMP. If the generalized Boltzmann weights are also algebraic then also thermal entanglement is irreducible. In p-adic thermodynamics for Virasoro generator L_0 and using some cutoff for conformal weights the Boltzmann weights are rational numbers expressible using powers of p-adic prime p .

2.2.2 Effects of finite temperature

Usually finite temperature is seen as a problem for quantum computation. In TGD framework the effect of finite temperature is to replace zero energy states formed as pairs of positive and negative energy states with a superposition in which energy varies.

One has an ensemble of space-time sheets which should represent nearly replicas of the quantum computation. There are two cases to be considered.

1. If the thermal entanglement is reducible then each space-time sheet gives outcome corresponding to a well defined energy and one must form an average over these outcomes.
2. If thermal entanglement is irreducible each space-time sheet corresponds to a quantum superposition of space-time sheets, and if the outcome is represented classically as rates and temporal field patterns, it should reflect thermal average of the outcomes as such.

If the degrees of freedom assignable to topological quantum computation do not depend on the energy of the state, thermal width does not affect at all the relevant probabilities. The probabilities are actually affected even in the case of tqc since 1-gates are not purely topological and the effects of temperature in spin degrees of freedom are unavoidable. If T grows the probability distribution for the outcomes flattens and it becomes difficult to select the desired outcome as that appearing with the maximal probability.

2.3 Hyper-finite factors of type II_1 and quantum measurement theory with a finite measurement resolution

The realization that the von Neumann algebra known as hyper-finite factor of type II_1 is tailor made for quantum TGD has led to a considerable progress in the understanding of the mathematical structure

of the theory and these algebras provide a justification for several ideas introduced earlier on basis of physical intuition.

Hyper-finite factor of type II_1 has a canonical realization as an infinite-dimensional Clifford algebra and the obvious guess is that it corresponds to the algebra spanned by the gamma matrices of WCW. Also the local Clifford algebra of the imbedding space $H = M^4 \times CP_2$ in octonionic representation of gamma matrices of H is important and the entire quantum TGD emerges from the associativity or co-associativity conditions for the sub-algebras of this algebra which are local algebras localized to maximal associative or co-associate sub-manifolds of the imbedding space identifiable as space-time surfaces.

The notion of inclusion for hyper-finite factors provides an elegant description for the notion of measurement resolution absent from the standard quantum measurement theory.

1. The included sub-factor creates in zero energy ontology states not distinguishable from the original one and the formally the coset space of factors defining quantum spinor space defines the space of physical states modulo finite measurement resolution.
2. The quantum measurement theory for hyperfinite factors differs from that for factors of type I since it is not possible to localize the state into single ray of state space. Rather, the ray is replaced with the sub-space obtained by the action of the included algebra defining the measurement resolution. The role of complex numbers in standard quantum measurement theory is taken by the non-commutative included algebra so that a non-commutative quantum theory is the outcome.
3. This leads also to the notion of quantum group. For instance, the finite measurement resolution means that the components of spinor do not commute anymore and it is not possible to reduce the state to a precise eigenstate of spin. It is however perform a reduction to an eigenstate of an observable which corresponds to the probability for either spin state.
4. The realization for quantum measurement theory modulo finite measurement resolution is in terms of M -matrices defined in terms of Connes tensor product which essentially means that the included hyper-finite factor N takes the role of complex numbers.

As already explained, the topology of the many-sheeted space-time encourages the generalization of the notion of quantum entanglement in such a manner that unentangled systems can possess entangled sub-systems. One can say that the entanglement between subsystems is not visible in the resolution characterizing selves. This makes possible sharing and fusion of mental images central for TGD inspired theory of consciousness. These concepts find a deeper justification from the quantum measurement theory for hyper-finite factors of type II_1 for which the finite measurement resolution is basic notion.

Also the notions of resolution and monitoring pop up naturally in this framework. p-Adic probabilities relate very naturally to hyper-finite factors of type II_1 and extend the expressive power of the ordinary probability theory. p-Adic thermodynamics with conformal cutoff is very natural for hyper-finite factors of type II_1 and explains p-adic length scale hypothesis $p \simeq 2^k$, k prime characterizing exponentially smaller p-adic length scale.

2.4 NMP and biology

The notion of self is crucial for the understanding of bio-systems and consciousness. It seems that the negentropic entanglement is the decisive element of life and that one can say that in metaphorical sense life resides in the intersection of real and p-adic worlds.

2.4.1 Generalization of the notion of information

TGD inspired theory of consciousness, in particular the formulation of Negentropy Maximization Principle (NMP) in p-adic context, has forced to rethink the notion of the information concept. In TGD state preparation process is realized as a sequence of self measurements and state preparation for next quantum jump is state reduction for the previous quantum jump. In zero energy ontology one can interpret the state preparation for positive and negative energy parts of the state as reduction and preparation in the sense of standard physics. Each self measurement means a decomposition of the sub-system involved to

two unentangled parts unless the system is bound state. The decomposition is fixed highly uniquely from the requirement that the reduction of the entanglement entropy is maximal.

Bound state entanglement is stable against self measurement simply because energy conservation prevents the decay to a pair of free (uncorrelated) subsystems. The generalized definition of entanglement entropy allows to assign a negative value of entanglement entropy to rational and algebraic entanglement, so that this kind of entanglement would actually carry information, in fact conscious information (experience of understanding). This kind of entanglement cannot be reduced in state function reduction. Macro-temporal quantum coherence could correspond to a generation of either bound state entanglement or negentropic entanglement, and is indeed crucial for ability to have long lasting non-entropic mental images. Generation of negentropic entanglement would involve experience about expansion of consciousness and that of bound states entanglement a loss of consciousness.

The mathematical models for quantum computers typically operate with systems for which entanglement probabilities are identical. Also rational numbers are involved. Does this mean that negentropic entanglement makes possible quantum computation? This does not seem to be the case. State function reduction with random outcomes is a central element of quantum computation which suggests that quantum computation must be based on entropic entanglement with large enough value of \hbar to overcome the restrictions caused by the interactions with the external world. The negentropic entanglement in turn would relate to conscious information processing involving experience of understanding represented by negentropic entanglement. Negentropic entanglement would make possible conscious cellular automaton type information processing much closer to that carried out by ordinary computers and this information processing might be equally important in living systems.

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

Rational and even algebraic entanglement coefficients make sense in the intersection of real and p-adic worlds, which suggests that life and conscious intelligence reside in the intersection of the real and p-adic worlds. This would mean that the mathematical expressions for the space-time surfaces (or at least 3-surfaces or partonic 2-surfaces and their 4-D tangent planes) make sense in both real and p-adic sense for some primes p . Same would apply to the expressions defining quantum states. In particular, entanglement probabilities would be rationals or algebraic numbers so that entanglement can be negentropic and the formation of bound states in the intersection of real and p-adic worlds generates information and is thus favored by NMP.

The identification of intentionality as the basic aspect of life seems to be consistent with this idea.

1. The proposed realization of the intentional action has been as a transformation of p-adic space-time sheet to a real one. Also transformations of real space-time sheets to p-adic space-time sheets identifiable as cognitions are possible. Algebraic entanglement is a prerequisite for the realization of intentions in this manner. Essentially a leakage between p-adic and real worlds is in question and makes sense only in zero energy ontology. The reason is that various quantum numbers in real and p-adic sectors are not in general comparable in positive energy ontology so that conservation laws would be broken or even cease to make sense.
2. The transformation of intention to action can occur if the partonic 2-surfaces and their 4-D tangent space-distributions are representable using rational functions with rational (or even algebraic) coefficients in preferred coordinates for the imbedding space dictated by symmetry considerations. Intentional systems must live in the intersection of real and p-adic worlds.
3. For the minimal option life would be also effectively 2-dimensional phenomenon and essentially a boundary phenomenon as also number theoretical criticality suggests. There are good reasons to expect that only the data from the intersection of real and p-adic partonic two-surfaces appears in U -matrix so that only the data from rational and some algebraic points of the partonic 2-surface dictate U -matrix. This means discretization at parton level and something which might be called number theoretic quantum field theory should emerge as a description of intentional action.

A good guess is that algebraic entanglement is essential for quantum computation, which therefore might correspond to a conscious process. Hence cognition could be seen as a quantum computation like

process, a more appropriate term being quantum problem solving [27]. Living-dead dichotomy could correspond to rational-irrational or to algebraic-transcendental dichotomy: this at least when life is interpreted as intelligent life. Life would in a well defined sense correspond to islands of rationality/algebraicity in the seas of real and p-adic continua. Life as a critical phenomenon in the number theoretical sense would be one aspect of quantum criticality of TGD Universe besides the criticality of the space-time dynamics and the criticality with respect to phase transitions changing the value of Planck constant and other more familiar criticalities. How closely these criticalities relate remains an open question [26].

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.

That only algebraic extensions are possible is of course only a working hypothesis. Also finite-dimensional extensions of p-adic numbers involving transcendentals are possible and might in fact be necessary. Consider for instance the extension containing e, e^2, \dots, e^{p-1} as units (e^p is ordinary p-adic number). Infinite number of analogous finite-dimensional extensions can be constructed by taking a function of integer variable such that $f(p)$ exists both p-adically and as a real transcendental number. The powers of $f(p)^{1/n}$ for a fixed value of n define a finite-dimensional transcendental extension of p-adic numbers if the roots do not exist p-adically.

Numbers like $\log(p)$ and π cannot belong to a finite-dimensional extension of p-adic numbers [21]. One cannot of course take any strong attitude concerning the possibility of infinite-dimensional extensions of p-adic numbers but the working hypothesis has been that they are absent. The phases $\exp(i2\pi/n)$ define finite dimensional extensions allowing to replace the notion of angle in finite measurement resolution with the corresponding phase factors in finite measurement. The functions $\exp(i2\pi q/n)$, where q is arbitrary p-adic integers define in a natural manner the physical counterparts of plane waves and angular momentum eigenstates not allowing an identification as ordinary p-adic exponential functions. They are clearly strictly periodic functions of q with a finite value set. If n is divisible by a power of p , these functions are continuous since the values of the function for q and $q + kp^n$ are identical for large enough values of n . This condition is essential and means in the case of plane waves that the size scale of a system (say one-dimensional box) is multiple of a power of p .

2.4.3 Evolution and second law

Evolution has many facets in TGD framework.

1. A natural characterization of evolution is in terms of p-adic topology relating naturally to cognition. p-Adic primes near powers of two are favored if *CDs* have the proposed discrete size spectrum. From the point of view of self this would be essentially cosmic expansion in discrete jumps. *CDs* and can be characterized by powers of 2 and if partonic 2-surfaces correspond to effective p-adic p-adic topology characterized by a power of two, one obtains the commensurability of the secondary p-adic time scale of particle and that of *CD* in good approximation.
2. The notion of infinite primes motivates the hypothesis that the many-sheeted structure of space-time can be coded by infinite primes[20]. The number of primes larger than given infinite prime P is infinitely larger than the number of primes than P . The infinite prime P characterizing the entire universe decomposes in a well defined manner to finite primes and p-adic evolution at the level of entire universe is implied by local p-adic evolution at the level of selves. Therefore maximum entanglement negentropy gain for p-adic self increases at least as $\log(p)$ with p in the long run.

This kind of relationship might hold true for real selves of p-adic physics is physics of cognitive representations of real physics as suggested by the success of p-adic mass calculations. Thus it should be possible to assign definite p-adic prime to each partonic 2-surface.

3. A further aspect of evolution relates to the hierarchy of Planck constants implying that at dark matter levels rational or at least integer multiples of the favored p-adic time scales are realized. The latter option is favored by the idea that the book like structure with pages consisting of many-sheeted coverings of CD and CP_2 , and correlates with the emergence of algebraic extensions of p-adic numbers defined by the roots $\exp(i2\pi/n)$ of unity. For the latter option evolution by quantum jumps would automatically imply the drifting of the partonic 2-surfaces to the pages of books labelled by increasing values of Planck constant. For more general option one might argue that drifting to pages with small values of Planck constant is also possible. This would give kind of antizooms of long length scale physics to short scales. Both kind of temporal zooms could be crucial for conscious intelligence building scaled models about time evolution in various scales.
4. The generation of negentropic entanglement between different number fields would of course be the fundamental aspect of evolution. It would give rise to increasingly complex and negentropic sensory perceptions and cognitive representations based on conscious rules coded by negentropic entanglement. This would justify the association concept as it used in neuro-science. Negentropic entanglement could be also crucial for the basic mechanism of metabolism and make possible conscious co-operation even in nano-scales.

Just for fun one can play also with numbers.

1. The highest dark matter level associated with self corresponds to its geometric duration which can be arbitrarily long: the typical duration of the memory span gives an idea about the level of dark matter hierarchy involved if one assumes that the time scale .1 seconds assignable to electrons is the fundamental time scale. If the time scale T of human life cycle corresponds to a secondary p-adic time scale then $T = 100$ years gives the rough estimate $r \equiv \hbar/\hbar_0 = 2^{33}$ if this time scale corresponds to that for dark electron. The corresponding primary p-adic time length scale corresponds to $k = 160$ and is 2.2×10^{-7} meters.
2. If human time scale -taken to be $T = 100$ years- corresponds to primary p-adic time scale of electron, one must have roughly $r = 2^{97}$.

I have already discussed the second law in TGD framework and it seems that its applies only when the time scale of perception is longer than the time scale characterizing the level of the p-adic and dark matter hierarchy. Second law as it is usually stated can be seen as an unavoidable implication of the materialistic ontology.

2.4.4 Stable entanglement and quantum metabolism as different sides of the same coin

The notion of binding has two meanings. Binding as a formation of bound state and binding as a fusion of mental images to larger ones essential for the functioning of brain and regarded as one the big problems of consciousness theory.

Only bound state entanglement and negentropic entanglement are stable against the state reduction process. Hence the fusion of the mental images implies the formation of a bound entropic state- in this case the two interpretations of binding are equivalent- or a negentropic state, which need not be bound state.

1. In the case of negentropic entanglement bound state need not be formed and the interesting possibility is that the negentropic entanglement could give rise to stable states without binding energy. This could allow to understand the mysterious high energy phosphate bond to which metabolic energy is assigned in ATP molecule containing three phosphates and liberated as ATP decays to ADP and phosphate molecule. Negentropic entanglement could also explain the stability of DNA and other highly charged biopolymers. In this framework the liberation of metabolic (negentropic) energy would involve dropping of electrons to a larger space-time sheets accompanying the process $ATP \rightarrow ADP + P_i$. A detailed model of this process is discussed in [29].

2. The formation of bound state entanglement is expected to involve a liberation of the binding energy and this energy might be a usable energy. This process could perhaps be coined as quantum metabolism and one could say that quantum metabolism and formation of bound states are different sides of the same coin. It is known that an intense neural activity, although it is accompanied by an enhanced blood flow to the region surrounding the neural activity, does not involve an enhanced oxidative metabolism [73] (that is $ATP \rightarrow ADP$ process and its reversal). A possible explanation is that quantum metabolism accompanying the binding is involved. Note that the bound state is sooner or later destroyed by the thermal noise so that this mechanism would in a rather clever manner utilize thermal energy by applying what might be called buy now–pay later principle.

If these interpretations are correct, there would be two modes of metabolism corresponding to two different kinds of fusion of mental images.

2.5 Generalization of thermodynamics allowing negentropic entanglement and a model for conscious information processing

The possibility of negentropic entanglement in TGD framework means that the second law of thermodynamics must be modified. The most obvious modification means only the replacement $S \rightarrow S - N$, where S is thermodynamical entropy and N the negentropy associated with negentropic entanglement. Hence the basic formulas of thermodynamics remain formally as such. The generalization leads to a thermodynamical model for how conscious information is generated and how metabolism relates to this. One can also understand why living matter is so effective entropy producer as compared to inanimate matter and the characteristic decomposition of living systems to highly negentropic and entropic parts.

2.5.1 Modification of thermodynamics to take into account negentropic entanglement

What does the presence of the negentropic entanglement mean from the point of view of thermodynamics? There are two obvious options to consider. The optimistic option is just the standard thermodynamics saying nothing about negentropy generation. The pessimistic option is that the generation of negentropy must be accompanied by a generation of at least the same amount of entropy: the good news is that this entropy can be carried by different system and it is possible to have genuinely negentropic systems. The following consideration is restricted to the pessimistic option which seems to be more realistic view about the world we live in.

1. One must generalize the basic expression for energy differential

$$dE = TdS - dW \rightarrow T(dS - dN) - dW . \quad (2.1)$$

This means that there are two kinds of energies given out by the system. The useful work dW and negentropic energy TdN . For steam engine only dW is present. For ideal system only negentropic energy would be present.

2. What happens to the second law? The pessimistic guess is that generation of negentropy requires a generation of at least same amount of entropy so that one would have

$$\Delta S - \Delta N \geq 0 . \quad (2.2)$$

Here S can be interpreted as a sum of two terms. The first part corresponds to the ensemble entropy generated by the randomness of ordinary quantum jumps, and second part to the entropy assignable as maximal entanglement entropy assignable to the decompositions of bound state to two parts. N corresponds to maximal negentropy for the decompositions of negentropic sub-system to pairs. One can criticize these definitions and a possible modification of could be as as the average for the entanglement entropies over this kind of decompositions.

3. Quite generally, Clausius inequality allowing to deduce extremization conditions for various thermodynamical potentials generalizes to

$$T_0(\Delta S - \Delta N) - \Delta E - P_0\Delta V \geq 0 . \quad (2.3)$$

where T_0 and P_0 and temperature and pressure of heat bath. Living systems would be entropy producers and this seems to conform with what we see around us.

For instance, for a system in constant volume one would have

$$\Delta S - \Delta N - \frac{\Delta E}{T} \geq 0 . \quad (2.4)$$

so that systems developing negentropy would also generate thermodynamics entropy. For a system in heat bath one has $T = T_0$ and Clausius inequality gives

$$\Delta F = -\Delta W \quad (2.5)$$

stating that increase of free energy at constant temperature requires work done on the system ($dW < 0$): otherwise $\Delta F \leq 0$ holds true.

By using the variable $S - N$ instead of S all formulas reduce formally to standard thermodynamics except that S can be negative.

2.5.2 The analog of Carnot cycle as a simple model for information processing in living matter

Carnot engine transforms heat to work. Costa de Beauregard [52] has proposed a modification of Carnot engine as a model for information processing. One can consider Carnot engine and its information theoretic analog in this framework.

1. The basic equation for Carnot engine is

$$dW = dQ_{in} - dQ_{out} \geq 0 . \quad (2.6)$$

Optimal efficiency corresponds to $dS_{out} = dS_{in}$.

2. The information theoretic analog of Carnot engine proposed by Beauregard does not perform work and one would have

$$dW = 0 , \quad (2.7)$$

and

$$dN = dS_{out} - dS_{in} \geq 0 . \quad (2.8)$$

The interpretation would be that incoming entropy flow leaves the computer in a state of higher entropy and the difference corresponds to information dN feeded to say printer. The increase of entropy would have interpretation in terms of erasing of data from computer memory.

The problematic aspect of the model is that it requires $T_{in} > T_{out}$ in order to have $dN > 0$. For living systems one has however typically $T_{in} < T_{out}$. Already for $T_{in} = T_{out}$ the situation trivializes since one has

$$dN = 0 \tag{2.9}$$

by $dW = 0$ and $dS = dQ/T$.

3. In the recent case however a more general condition

$$T_{in}d(S_{in} - N_{in}) - T_{out}d(S_{out} - N_{out}) \geq 0 \tag{2.10}$$

holds true and allows to generate conscious information provided it is compensated by thermodynamical entropy. Note that the temperature of the environment can be even lower than the temperatures of the system.

It is also possible to transform information to work as the expression for the differential $dF = -SdT - TdN - dW$ of the generalized free energy $E = E - TS$ shows. The increase of dW for the work done by the system is compensated by the reduction of information dN so that system loses negentropy in the process keeping dF constant. The loss of negentropy could be interpreted in terms of a loss of metabolic energy which corresponds to negentropic entanglement for AMP, ADP, and ATP molecules.

2.5.3 Basic biological implications

Some clarifying comments about biological implications are in order.

1. There is no need to restrict the consideration to equilibrium systems. First of all, the environment and living system are in general at different temperatures and temperature difference is typically of wrong sign for the model of Beauregard to work in this context. Beauregard's model is of course a model for computation, not for the generation of negentropic mental images. Maybe cognitive machine might be proper term for what the modified model could describe.
2. Quite generally, self-organization requires a feed of energy to the system so that one has flow equilibrium. In the case of living system this feed of energy is metabolic energy associated with the negentropic entanglement transferred to the system in the ATP-ADP process. Self-organization driven by negentropic entanglement leads to standardized negentropic mental images automatically as asymptotic self-organization patterns in 4-D sense (CDs within CDs within ... : CD denotes causal diamond defined as cartesian product to the intersection of the future and past directed light-cones with CP_2 , which is the key notion in zero energy ontology).
3. No explicit assumptions about computational aspects of the process has been made. Just a generation of conscious information identified in terms of negentropic entanglement is assumed. The basic character quantum jump as U -process followed by the cascade of state function reductions represents a fractal hierarchy of what can be seen as quantum computations and are distinguished from classical computations in that the process proceeds from top to bottom rather than being a local process. The result of computation is represented using statistical ensembles defined by sub- CDs at various levels of the hierarchy and is in principle communicable by classical fields (say EEG patterns in the case of brain) to higher levels of self hierarchy which in turn can induce the same distributions so that communication of the objective aspects of the experience with the mediation of "medium" is possible. The presence of the "medium" seems unavoidable. Magnetic body would be this medium in TGD inspired biology.

Living matter involves also another aspect made possible by the generalized second law obtained by the replacement $S \rightarrow S - N$. Subsystem can have also negative net entropy and split to two highly negentropic and entropic pieces. In the extreme situation this is nothing but excretion, which is absolutely essential element of being alive but sometimes forgotten from the lists of properties distinguishing living matter from inanimate matter. It is not at all clear whether this is possible for standard non-equilibrium systems defining information as a reduction of disorder. At all levels of the fractal hierarchy division into negentropic and entropic subsystems is expected.

This picture seems to be in accordance with basic chemistry of energy metabolism.

1. The process creating both negentropy and entropy would be standardized in living matter and mean a generation of high energy phosphate bonds assignable to AMP, ADP, and ATP containing 1, 2, and 3 phosphates respectively besides the sugar residue. Sugar residue is basic nutrient and would provide the stored metabolic energy transformed to the negentropic energy of the high energy phosphate bonds if the proposed view is correct. Also other DNA nucleotides such as G can appear besides A but in metabolism A has a preferred role.
2. The basic metabolic cycle provides ADP with an additional phosphate energizing it to ATP and the reverse process transfers the metabolic energy and also negentropic entanglement to the acceptor molecule. Also ADP can provide metabolic energy by transforming to AMP when ATP is not available in sufficient amounts. That the catabolism of AMP creates urea excreted out of the system fits with the general picture. The catabolism for nutrients would create the entropy compensating for the negentropy of the high energy phosphate bonds.
3. The backbone of DNA is made of sugar and phosphate residues and corresponds to a sequence of XMP , $X = A, T, C, G$ with each XMP presumably containing single high energy phosphate bond serving as a storage or potential source of negentropy. This conforms with the view that DNA carries conscious information.

Negentropic and entropic entanglement are assumed to generate mental images with opposite emotional colors. This connects information processing with emotions. From neuroscience point of view this is not a news: peptides are molecules of emotions on one hand and molecules of information on the other hand [76]. The well-known specialization of the left and right hand sides of the amygdala to experience positive and negatively colored emotions could be seen as one instance of this connection and representing also an example about fractal negentropic-entropic differentiation.

3 How quantum computation in TGD Universe differs from standard quantum computation?

Many problems of quantum computation in standard sense might relate to a wrong view about quantum theory. If TGD Universe is the physical universe, the situation would improve in many respects. There is the new fractal view about quantum jump and observer as "self"; there is p-adic length scale hierarchy and hierarchy of Planck constants as well as self hierarchy; there is a new view about entanglement and the possibility of irreducible entanglement carrying genuine information and making possible quantum superposition of fractal quantum computations and quantum parallel dissipation; there is zero energy ontology, the notion of M -matrix allowing to understand quantum theory as a square root of thermodynamics, the notion of measurement resolution allowing to identify M -matrix in terms of Connes tensor product; there is also the notion of magnetic body providing one promising realization for braids in tqc, etc... This section gives a short summary of these aspects of TGD.

There is also a second motivation for this section. Quantum TGD and TGD inspired theory of consciousness involve quite a bundle of new ideas and the continual checking of internal consistency by writing it through again and again is of utmost importance. This section can be also seen as this kind of checking. I can only represent apologies to the benevolent reader: this is a work in rapid progress.

3.1 General ideas related to topological quantum computation

Topological computation relies heavily on the representation of tqc program as a braiding. There are many kinds of braidings. Number theoretic braids are defined by the orbits of minima of vacuum expectation of Higgs at lightlike partonic 3-surfaces (and also at space-like 3-surfaces). There are braidings defined by Kähler gauge potential (possibly equivalent with number theoretic ones) and by Kähler magnetic field. Magnetic flux tubes and partonic 2-surfaces interpreted as strands of define braidings whose strands are not infinitely thin. A very concrete and very complex time-like braiding is defined by the motions of people at the surface of globe: perhaps this sometimes purposeless-looking fuss has a deeper purpose: maybe those at the higher levels of dark matter hierarchy are using us to carry out complex topological quantum computations!

3.1.1 General vision about quantum computation

In TGD Universe the hierarchy of Planck constants gives excellent prerequisites for all kinds of quantum computations. The general vision about quantum computation (tqc) would result as a special case and would look like follows.

1. Time-like entanglement between positive and negative energy parts of zero energy states would define the analogs of qc-programs. Space-like quantum entanglement between ends of strands whose motion defines time-like braids would provide a representation of q-information.
2. Both time- and space-like quantum entanglement would correspond to Connes tensor product expressing the finiteness of the measurement resolution between the states defined at ends of space-like braids whose orbits define time like braiding. The characterization of the measurement resolution would thus define both possible q-data and tq-programs as representations for "laws of physics".
3. The braiding between DNA strands with each nucleotide defining one strand transversal to DNA realized in terms of magnetic flux tubes was my first bet for the representation of space-like braiding in living matter. It turned out that the braiding is more naturally defined by flux tubes connecting nucleotides to the lipids of nuclear-, cell-, and endoplasmic membranes. Also braidings between other microtubules and axonal membrane can be considered. The conjectured hierarchy of genomes giving rise to quantum coherent gene expressions in various scales would correspond to computational hierarchy.

3.1.2 About the relation between space-like and time-like number theoretic braidings

The relationship between space- and time-like braidings is interesting and there might be some connections also to 4-D topological gauge theories suggested by geometric Langlands program discussed in the previous posting and also in [16].

1. The braidings along light-like surfaces modify space-like braiding if the moving ends of the space-like braids at partonic 3-surfaces define time-like braids. From tqc point of view the interpretation would be that tqc program is written to memory represented as the modification of space-like braiding in 1-1 correspondence with the time-like braiding.
2. The orbits of space-like braids define codimension two sub-manifolds of 4-D space-time surface and can become knotted. Presumably time-like braiding gives rise to a non-trivial "2-braid". Could also the "2-braiding" based on this knotting be of importance? Do 2-connections of n-category theorists emerge somehow as auxiliary tools? Could 2-knotting bring additional structure into the topological QFT defined by 1-braidings and Chern-Simons action?
3. The strands of dynamically evolving braids could in principle go through each other so that time evolution can transform braid to a new one also in this manner. This is especially clear from standard representation of knots by their planar projections. The points where intersection occurs correspond to self-intersection points of 2-surface as a sub-manifold of space-time surface. Topological QFT:s are also used to classify intersection numbers of 2-dimensional surfaces understood as homological equivalence classes. Now these intersection points would be associated with "braid cobordism".

3.1.3 Quantum computation as quantum superposition of classical computations?

It is often said that quantum computation is quantum super-position of classical computations. In standard path integral picture this does not make sense since between initial and final states represented by classical fields one has quantum superposition over *all* classical field configurations representing classical computations in very abstract sense. The metaphor is as good as the perturbation theory around the minimum of the classical action is as an approximation.

In TGD framework the classical space-time surface is a preferred extremal of Kähler action so that apart from effects caused by the failure of complete determinism, the metaphor makes sense precisely. Besides this there is of course the computation associated with the spin like degrees of freedom in which one has entanglement and which one cannot describe in this manner.

For tqc a particular classical computation would reduce to the time evolution of braids and would be coded by 2-knot. Classical computation would be coded to the manipulation of the braid. Note that the branching of strands of generalized number theoretical braids has interpretation as classical communication.

3.1.4 The identification of topological quantum states

Quantum states of tqc should correspond to topologically robust degrees of freedom separating neatly from non-topological ones.

1. The generalization of the imbedding space inspired by the hierarchy of Planck constants suggests an identification of this kind of states as elements of the group algebra of discrete subgroup of $SO(3)$ associated with the group defining covering of M^4 or CP_2 or both in large \hbar sector. One would have wave functions in the discrete space defined by the homotopy group of the covering transforming according to the representations of the group. This is by definition something robust and separated from non-topological degrees of freedom (standard model quantum numbers). There would be also a direct connection with anyons.
2. An especially interesting group is dodecahedral group corresponding to the minimal quantum phase $q = \exp(2\pi/5)$ (Golden Mean) allowing a universal topological quantum computation: this group corresponds to Dynkin diagram for E_8 by the ALE correspondence. Interestingly, neuronal synapses involve clathrin molecules [70] associated with microtubule ends possessing dodecahedral symmetry.

3.1.5 Some questions

A conjecture inspired by the inclusions of HFFs is that these states can be also regarded as representations of various gauge groups which TGD dynamics is conjectured to be able to mimic so that one might have connection with non-Abelian Chern-Simons theories where topological S-matrix is constructed in terms of path integral over connections: these connections would be only an auxiliary tool in TGD framework.

1. Do these additional degrees of freedom give only rise to topological variants of gauge- and conformal field theories? Note that if the earlier conjecture that entire dynamics of these theories could be mimicked, it would be best to perform tqc at quantum criticality where either M^4 or CP_2 dynamical degrees of freedom or both disappear.
2. Could it be advantageous to perform tqc near quantum criticality? For instance, could one construct magnetic braidings in the visible sector near q-criticality using existing technology and then induce phase transition changing Planck constant by varying some parameter, say temperature.

3.2 Fractal hierarchies

Fractal hierarchies are the essence of TGD. There is hierarchy of space-time sheets labelled by preferred p-adic primes. There is hierarchy of Planck constants reflecting a book like structure of the generalized imbedding space and identified in terms of a hierarchy of dark matters. These hierarchies correspond at the level of conscious experience to a hierarchy of conscious entities - selves: self experiences its sub-selves as mental images.

Fractal hierarchies mean completely new element in the model for quantum computation. The decomposition of quantum computation to a fractal hierarchy of quantum computations is one implication of this hierarchy and means that each quantum computation proceeds from longer to shorter time scales $T_n = T_0 2^{-n}$ as a cascade like process such that at each level there is a large number of quantum computations performed with various values of input parameters defined by the output at previous level. Under some additional assumptions to be discussed later this hierarchy involves at a given level a large number of replicas of a given sub-module of tqc so that the output of single fractal sub-module gives automatically probabilities for various outcomes as required.

3.3 Irreducible entanglement and possibility of quantum parallel quantum computation

The basic distinction from standard measurement theory is irreducible entanglement not reduced in quantum jump.

3.3.1 NMP and the possibility of irreducible entanglement

Negentropy Maximization Principle (NMP) states that entanglement entropy is minimized in quantum jump. For standard Shannon entropy this would lead to a final state which corresponds to a ray of state space. If entanglement probabilities are rational - or even algebraic - one can replace Shannon entropy with its number theoretic counterpart in which p-adic norm of probability replaces the probability in the argument of logarithm: $\log(p_n) \rightarrow \log(|p_n|_p)$. This entropy can have negative values. It is not quite clear whether prime p should be chosen to maximize the number theoretic negentropy or whether p is the p-adic prime characterizing the light-like partonic 3-surface in question.

Obviously NMP favors generation of irreducible entanglement which however can be reduced in U process. Irreducible entanglement is something completely new and the proposed interpretation is in terms of experience of various kinds of conscious experiences with positive content such as understanding.

Quantum superposition of unitarily evolving quantum states generalizes to a quantum superposition of quantum jump sequences defining dissipative time evolutions. Dissipating quarks inside quantum coherent hadrons would provide a basic example of this kind of situation.

3.3.2 Quantum parallel quantum computations and conscious experience

The combination of quantum parallel quantum jump sequences with the fractal hierarchies of scales implies the possibility of quantum parallel quantum computations. In ordinary quantum computation halting selects single computation but in the recent case arbitrarily large number of computations can be carried out simultaneously at various branches of entangled state. The probability distribution for the outcomes is obtained using only single computation.

One would have quantum superposition of space-time sheets (assignable to the maxima of Kähler function) each representing classically the outcome of a particular computation. Each branch would correspond to its own conscious experience but the entire system would correspond to a self experiencing consciously the outcome of computation as intuitive and holistic understanding, and abstraction. Emotions and emotional intellect could correspond to this kind of non-symbolic representation for the outcome of computation as analogs for collective parameters like temperature and pressure.

3.3.3 Delicacies

There are several delicacies involved.

1. The above argument works for factors of type I. For HFFs of type II_1 the finite measurement resolution characterized in terms of the inclusion $\mathcal{N} \subset \mathcal{M}$ mean is that state function reduction takes place to \mathcal{N} -ray. There are good reasons to expect that the notion of number theoretic entanglement negentropy generalizes also to this case. Note that the entanglement associated with \mathcal{N} is below measurement resolution.

2. In TGD inspired theory of consciousness irreducible entanglement makes possible sharing and fusion of mental images. At space-time level the space-time sheets corresponding to selves are disjoint but the space-time sheets topologically condensed at them are joined typically by what I call join along boundaries bonds identifiable as braid strands (magnetic flux quanta). In topological computation with finite measurement resolution this kind of entanglement with environment would be below the natural resolution and would not be a problem.
3. State function reduction means quantum jump to an eigen state of density matrix. Suppose that density matrix has rational elements. Number theoretic vision forces to ask whether the quantum jump to eigen state is possible if the eigenvalues of ρ do not belong to the algebraic extension of rationals and p-adic numbers used. If not, then one would have number theoretically irreducible entanglement depending on the algebraic extension used. If the eigenvalues actually define the extension there would be no restrictions: this option is definitely simpler.
4. Fuzzy quantum logic [18] brings also complications. What happens in the case of quantum spinors that spin ceases to be observable and one cannot reduce the state to spin up or spin down. Rather, one can measure only the eigenvalues for the probability operator for spin up (and thus for spin down) so that one has fuzzy quantum logic characterized by quantum phase. Inclusions of HFFs are characterized by quantum phases and a possible interpretation is that the quantum parallelism related to the finite measurement resolution could give rise to fuzzy qubits. Also the number theoretic quantum parallelism implied by number theoretic NMP could effectively make probabilities as operators. The probabilities for various outcomes would correspond to outcomes of quantum parallel state function reductions.

3.4 Possible problems related to quantum computation

At least following problems are encountered in quantum computation.

1. How to preserve quantum coherence for a long enough time so that unitary evolution can be achieved?
2. The outcome of calculation is always probability distribution: for instance, the output with maximum probability can correspond to the result of computation. The problem is how to replicate the computation to achieve the desired accuracy. Or more precisely, how to produce replicas of the hardware of quantum computer defined in terms of classical physics?
3. How to isolate the quantum computer from the external world during computation and despite this feed in the inputs and extract the outputs?

3.4.1 The notion of coherence region in TGD framework

In standard framework one can speak about coherence in two senses. At the level of Schrödinger amplitudes one speaks about coherence region inside which it makes sense to speak about Schrödinger time evolution. This notion is rather defined.

In TGD framework coherence region is identifiable as a region inside which the modified Dirac equation holds true. Strictly speaking, this region corresponds to a light-like partonic 3-surface whereas 4-D space-time sheet corresponds to coherence region for classical fields. p-Adic length scale hierarchy and hierarchy of Planck constants means that arbitrarily large coherence regions are possible.

The precise definition for the notion of coherence region and the presence of scale hierarchies imply that the coherence in the case of single quantum computation is not a problem in TGD framework. Decoherence time or coherence time correspond to the temporal span of space-time sheet and a hierarchy coming in powers of two for a given value of Planck constant is predicted by basic quantum TGD. p-Adic length scale hypothesis and favored values of Planck constant would naturally reflect this fundamental fractal hierarchy.

3.4.2 De-coherence of density matrix and replicas of tqc

Second phenomenological description boils down to the assumption that non-diagonal elements of the density matrix in some preferred basis (involving spatial localization of particles) approach to zero. The existence of more or less faithful replicas of space-time sheet in given scale allows to identify the counterpart of this notion in TGD context. De-coherence would mean a loss of information in the averaging of M -matrix and density matrix associated with these space-time sheets.

Topological computations are probabilistic. This means that one has a collection of space-time sheets such that each space-time sheet corresponds to more or less the same tqc and therefore the same M -matrix. If M is too random (in the limits allowed by Connes tensor product), the analog of generalized phase information represented by its "phase" - S -matrix - is useless.

In order to avoid de-coherence in this sense, the space-time sheets must be approximate copies of each other. Almost copies are expected to result by dissipation leading to asymptotic self-organization patterns depending only weakly on initial conditions and having also space-time correlates. Obviously, the role of dissipation in eliminating effects of de-coherence in tqc would be something new. The enormous symmetries of M -matrix, the uniqueness of S -matrix for given resolution and parameters characterizing braiding, fractality, and generalized Bohr orbit property of space-time sheets, plus dissipation give good hopes that almost replicas can be obtained.

3.4.3 Isolation and representations of the outcome of tqc

The interaction with environment makes quantum computation difficult. In the case of topological quantum computation this interaction corresponds to the formation of braid strands connecting the computing space-time sheet with space-time sheets in environment. The environment is four-dimensional in TGD framework and an isolation in time direction might be required. The space-time sheets responsible for replicas of tqc should not be connected by light-like braid strands having time-like projections in M^4 .

Length scale hierarchy coming in powers of two and finite measurement resolution might help considerably. Finite measurement resolution means that those strands which connect space-time sheets topologically condensed to the space-time sheets in question do not induce entanglement visible at this level and should not affect tqc in the resolution used.

Hence only the elimination of strands responsible for tqc at given level and connecting computing space-time sheet to space-time sheets at same level in environment is necessary and would require magnetic isolation. Note that super-conductivity might provide this kind of isolation. This kind of elimination could involve the same mechanism as the initiation of tqc which cuts the braid strands so the initiation and isolation might be more or less the same thing.

Strands reconnect after the halting of tqc and would make possible the communication of the outcome of computation along strands by using say em currents in turn generating generalized EEG, nerve pulse patterns, gene expression, etc... halting and initiation could be more or less synonymous with isolation and communication of the outcome of tqc.

3.4.4 How to express the outcome of quantum computation?

The outcome of quantum computation is basically a representation of probabilities for the outcome of tqc. There are two representations for the outcome of tqc. Symbolic representation which quite generally is in terms of probability distributions represented in terms "classical space-time" physics. The rates for various processes having basically interpretation as geometro-temporal densities would represent the probabilities just as in the case of particle physics experiment. For tqc in living matter this would correspond to gene expression, neural firing, EEG patterns,...

A representation as a conscious experience is another (and actually the ultimate) representation of the outcome. It need not have any symbolic counterpart since it is felt. Intuition, emotions and emotional intelligence would naturally relate to this kind of representation made possible by irreducible entanglement. This representation would be based on fuzzy qubits and would mean that the outcome would be true or false only with certain probability. This unreliability would be felt consciously.

The proposed model of tqc combined with basic facts about theta waves [75, 74] to be discussed in the subsection about the role of supra currents in tqc suggests that EEG rhythm (say theta rhythm) and

correlated firing patterns correspond to the isolation at the first half period of tqc and random firing at second half period to the sub-sequent tqc:s at shorter time scales coming as negative powers of 2. The fractal hierarchy of time scales would correspond to a hierarchy of frequency scales for generalized EEG and power spectra at these scales would give information about the outcome of tqc. Synchronization would be obviously an essential element in this picture and could be understood in terms of classical dynamics which defines space-time surface as a generalized Bohr orbit.

Tqc would be analogous to the generation of a dynamical hologram or "conscious hologram" [31]. EEG rhythm would correspond to reference wave generated by magnetic body as control and coordination signal and the contributions of spikes to EEG generated by neurons would correspond to the incoming wave interfering with the reference wave.

3.4.5 How data is feeded into submodules of tqc?

Scale hierarchy obviously gives tqc a fractal modular structure and the question is how data is feeded to submodules at shorter length scales. There are certainly interactions between different levels of scale hierarchy. The general ideas about master-slave hierarchy assigned with self-organization support the hypothesis that these interactions are directed from longer to shorter scales and have interpretation as a specialization of input data to tqc sub-modules represented by smaller space-time sheets of hierarchy. The call of submodule would occur when the tqc of the calling module halts and the result of computation is expressed as a 4-D pattern. The lower level module would start only after the halting of tqc (with respect to subjective time at least) and the durations of resulting tqc's would come as $T_n = 2^{-n}T_0$ that geometric series of tqc's would become possible. There would be entire family of tqc's at lower level corresponding to different values of input parameters from calling module.

One of the ideas assigned to hyper-computation [44] is that one can have infinite series of computations with durations coming as negative powers of 2 (Zeno paradox obviously inspires this idea). In TGD framework there can be however only a finite series of these tqc's since CP_2 time scale poses a lower bound for the duration of tqc. One might of course ask whether the spectrum of Planck constant could help in this respect.

3.4.6 The role of dissipation and energy feed

Dissipation plays key role in the theory of self-organizing systems [46]. Its role is to serve as a Darwinian selector. Without an external energy feed the outcome is a situation in which all organized motions disappear. In presence of energy feed highly unique self-organization patterns depending only very weakly on the initial conditions emerge.

In the case of tqc one function of dissipation would be to drive the braidings to static standard configurations, and perhaps even effectively eliminate fluctuations in non-topological degrees of freedom. Note that magnetic fields are important for 1-gates. Magnetic flux conservation however saves magnetic fields from dissipation.

External energy feed is needed in order to generate new braidings. For the proposed model of cellular tqc the flow of intracellular water induces the braiding and requires energy feed. Also now dissipation would drive this flow to standard patterns coding for tqc programs. Metabolic energy would be also needed in order to control whether lipids can flow or not by generating cis type unsaturated bonds. Obviously, energy flows defining self organization patterns would define tqc programs.

3.4.7 Is it possible to realize arbitrary tqc?

The 4-D spin glass degeneracy of TGD Universe due to the enormous vacuum degeneracy of Kähler action gives good hopes that the classical dynamics for braidings allows to realize every possible tqc program. As a consequence, space-time sheets decompose to maximal non-deterministic regions representing basic modules of tqc. Similar decomposition takes place at the level of light-like partonic 3-surfaces and means decomposition to 3-D regions inside which conformal invariance eliminates light-like direction as dynamical degree of freedom so that the dynamics is effectively that of 2-dimensional object. Since these 3-D regions behave as independent units as far as longitudinal conformal invariance is considered, one can say that light-like 3-surfaces are 3-dimensional in discretized sense. In fact, for 2-D regions standard conformal

invariance implies similar effective reduction to 1-dimensional dynamics realized in terms of a net of strings and means that 2-dimensionality is realized only in discretized sense.

4 DNA as topological quantum computer

Braids [38] code for topological quantum computation. One can imagine many possible identifications of braids but this is not essential for what follows. What is highly non-trivial is that the motion of the ends of strands defines both time-like and space-like braidings with latter defining in a well-defined sense a written version of the tqc program, kind of log file. The manipulation of braids is a central element of tqc and if DNA really performs tqc, the biological unit modifying braidings should be easy to identify. An obvious signature is the 2-dimensional character of this unit.

4.1 Conjugate DNA as performer of tqc and lipids as quantum dancers

In this section the considerations are restricted to DNA as tqc. It is however quite possible that also RNA and other biomolecules could be involved with tqc like process.

4.1.1 Sharing of labor

The braid strands must begin from DNA double strands. Precisely which part of DNA does perform tqc? Genes? Introns[72]? Or could it be conjugate DNA which performs tqc? The function of conjugate DNA has indeed remained a mystery and sharing of labor suggests itself.

Conjugate DNA would do tqc and DNA would "print" the outcome of tqc in terms of RNA yielding amino-acids in the case of exons. RNA could be the outcome in the case of introns. The experience about computers and the general vision provided by TGD suggests that introns could express the outcome of tqc also electromagnetically in terms of standardized field patterns. Also speech would be a form of gene expression. The quantum states braid would entangle with characteristic gene expressions. This hypothesis will be taken as starting point in the following considerations.

4.1.2 Cell membranes as modifiers of braidings defining tqc programs?

The manipulation of braid strands transversal to DNA must take place at 2-D surface. The ends of the space-like braid are dancers whose dancing pattern defines the time-like braid, the running of classical tqc program. Space-like braid represents memory storage and tqc program is automatically written to memory during the tqc. The inner membrane of the nuclear envelope and cell membrane with entire endoplasmic reticulum included are good candidates for dancing hall. The 2-surfaces containing the ends of the hydrophobic ends of lipids could be the parquets and lipids the dancers. This picture seems to make sense.

1. Consider first the anatomy of membranes. Cell membrane [65] and membranes of nuclear envelope [71] consist of 2 lipid [63] layers whose hydrophobic ends point towards interior. There is no water here nor any direct perturbations from the environment or interior milieu of cell. Nuclear envelope consists of two membranes having between them an empty volume of thickness 20-40 nm. The inner membrane consists of two lipid layers like ordinary cell membrane and outer membrane is connected continuously to endoplasmic reticulum [61], which forms a highly folded cell membrane. Many biologists believe that cell nucleus is a prokaryote, which began to live in symbiosis with a prokaryote defining the cell membrane.
2. What makes dancing possible is that the phospholipid layers of the cell membrane are liquid crystals [55]: the lipids can move freely in the horizontal direction but not vertically. "Phospho" could relate closely to the metabolic energy needs of dancers. If these lipids are self-organized around braid strands, their dancing patterns along the membrane surface would be an ideal manner to modify braidings since the lipids would have standard positions in a lattice. This would be like dancing on a chessboard. Note that the internal structure of lipid does not matter in this picture since it is braid color dictated by DNA nucleotide which matters. As a matter fact, living matter is full

of self-organizing liquid crystals and one can wonder whether the deeper purpose of their life be running and simultaneous documentation of tqc programs?

3. Ordinary computers have an operating system [54]: a collection of standard programs - the system - and similar situation should prevail now. The "printing" of outputs of tqc would represent example of this kind of standard program. This tqc program should not receive any input from the environment of the nucleus and should therefore correspond to braid strands connecting conjugate strand with strand. Braid strands would go only through the inner nuclear membrane and return back and would not be affected much since the volume between inner and outer nuclear membranes is empty. This assumption looks ad hoc but it will be found that the requirement that these programs are inherited as such in the cell replication necessitates this kind of structure (see the section "Cell replication and tqc").
4. The braid strands starting from the conjugate DNA could traverse several time through the highly folded endoplasmic reticulum but without leaving cell interior and return back to nucleus and modify tqc by intracellular input. Braid strands could also traverse the cell membrane and thus receive information about the exterior of cell. Both of these tqc programs could be present also in prokaryotes [66] but the braid strands would always return back to the DNA, which can be also in another cell. In multicellulars (eukaryotes [67]) braid strands could continue to another cell and give rise to "social" tqc programs performed by the multicellular organisms. Note that the topological character of braiding does not require isolation of braiding from environment. It might be however advantageous to have some kind of sensory receptors amplifying sensory input to standardized re-braiding patterns. Various receptors in cell membrane would serve this purpose.
5. Braid strands can end up at the parquet defined by ends of the inner phospholipid layer: their distance of inner and outer parquet is few nanometers. They could also extend further.
 - i) If one is interested in connecting cell nucleus to the membrane of another cell, the simpler option is the formation of hole defined by a protein attached to cell membrane. In this case only the environment of the second cell affects the braiding assignable to the first cell nucleus.
 - ii) The bi-layered structure of the cell membrane could be essential for the build-up of more complex tqc programs since the strands arriving at two nearby hydrophobic 2-surfaces could combine to form longer strands. The formation of longer strands could mean the fusion of the two nearby hydrophobic two-surfaces in the region considered. In fact, tqc would begin with the cutting of the strands so that non-trivial braiding could be generated via lipid dance and tqc would halt when strands would recombine and define a modified braiding. This would allow to connect cell nucleus and cell membrane to a larger tqc unit and cells to multicellular tqc units so that the modification of tqc programs by feeding the information from the exteriors of cells - essential for the survival of multicellulars - would become possible.

4.1.3 Gene expression and other basic genetic functions from tqc point of view

It is useful to try to imagine how gene expression might relate to the halting of tqc. There are of course myriads of alternatives for detailed realizations, and one can only play with thoughts to build a reasonable guess about what might happen.

1. *Qubits for transcription factors and other regulators*

Genetics is consistent with the hypothesis that genes correspond to those tqc moduli whose outputs determine whether genes are expressed or not. The naive first guess would be that the value of single qubit determines whether the gene *is* expressed or not. Next guess replaces "is" with "can be".

Indeed, gene expression involves promoters, enhancers and silencers [62]. Promoters are portions of the genome near genes and recognized by proteins known as transcription factors [68]. Transcription factors bind to the promoter and recruit RNA polymerase, an enzyme that synthesizes RNA. In prokaryotes RNA polymerase itself acts as the transcription factor. For eukaryotes situation is more complex: at least seven transcription factors are involved with the recruitment of the RNA polymerase II catalyzing

the transcription of the messenger RNA. There are also transcription factors for transcription factors and transcription factor for the transcription factor itself.

The implication is that several qubits must have value "Yes" for the actual expression to occur since several transcription factors are involved with the expression of the gene in general. In the simplest situation this would mean that the computation halts to a measurement of single qubit for subset of genes including at least those coding for transcription factors and other regulators of gene expression.

2. Intron-exon qubit

Genes would have very many final states since each nucleotide is expected to correspond to at least single qubit. Without further measurements that state of nucleotides would remain highly entangled for each gene. Also these other qubits are expected to become increasingly important during evolution.

For instance, eukaryotic gene expression involves a transcription of RNA and splicing out of pieces of RNA which are not translated to amino-acids (introns). Also the notion of gene is known to become increasingly dynamical during the evolution of eukaryotes so that the expressive power of genome increases. A single qubit associated with each codon telling whether it is spliced out or not would allow maximal flexibility. Tqc would define what genes are and the expressive power of genes would be due to the evolution of tqc programs: very much like in the case of ordinary computers. Stopping sign codon and starting codon would automatically tell where the gene begins and ends if the corresponding qubit is "Yes". In this picture the old fashioned static genes of prokaryotes without splicings would correspond to tqc programs for which the portions of genome with a given value of splicing qubit are connected.

3. What about braids between DNA, RNA, tRNA and amino-acids

This simplified picture might have created the impression that amino-acids are quantum outsiders obeying classical bio-chemistry. For instance, transcription factors would in this picture end up to the promoter by a random process and "Print" would only increase the density of the transcription factor. If DNA is able to perform tqc, it would however seem very strange if it would be happy with this rather dull realization of other central functions of the genetic apparatus.

One can indeed consider besides the braids connecting DNA and its conjugate - crucial for the success of replication - also braids connecting DNA to mRNA and other forms of RNA, mRNA to tRNA, and tRNA to amino-acids. These braids would provide the topological realization of the genetic code and would increase dramatically the precision and effectiveness of the transcription and translation if these processes correspond to quantum transitions at the level of dark matter leading more or less deterministically to the desired outcome at the level of visible matter be it formation of DNA doublet strand, of DNA-mRNA association, of mRNA-tRNA association or tRNA-amino-acid association.

For instance, a temporary reduction of the value of Planck constant for these braids would contract these to such a small size that these associations would result with a high probability. The increase of Planck constant for braids could in turn induce the transfer of mRNA from the nucleus, the opening of DNA double strand during transcription and mitosis.

Also DNA-amino-acid braids might be possible in some special cases. The braiding between regions of DNA at which proteins bind could be a completely general phenomenon. In particular, the promoter region of gene could be connected by braids to the transcription factors of the gene and the halting of tqc computation to printing command could induce the reduction of Planck constant for these braids inducing the binding of the transcription factor binds to the promoter region. In a similar manner, the region of DNA at which RNA polymerase binds could be connected by braid strands to the RNA polymerase.

4.1.4 How braid color is represented?

If braid strands carry 4-color (A,T,C,G) then also lipid strands should carry this kind of 4-color. The lipids whose hydrophobic ends can be joined to form longer strand should have same color. This color need not be chemical in TGD Universe.

Only braid strands of the same color can be connected as tqc halts. This poses strong restrictions on the model.

1. Do braid strands appear as patches possessing same color?

Color conservation is achieved if the two lipid layers decompose in a similar manner into regions of fixed color and the 2-D flow is restricted inside this kind of region at both layers. A four-colored map of cell membrane would be in question! Liquid crystal structure [65] applies only up to length scale of $L(151) = 10$ nm and this suggests that lipid layer decomposes into structural units of size $L(151)$ defining also cell membrane thickness. These regions might correspond to minimal regions of fixed color containing $N \sim 10^2$ lipids.

The controversial notion of lipid raft [69] was inspired by the immiscibility of ordered and disordered liquid phases in a liquid model of membrane. The organization to connected regions of particular phase could be a phenomenon analogous to a separation of phases in percolation. Many cell functions implicate the existence of lipid rafts. The size of lipid rafts has remained open and could be anywhere between 1 and 1000 nm. Also the time scale for the existence of a lipid raft is unknown. A line tension between different regions is predicted in hydrodynamical model but not observed. If the decomposition into ordered and disordered phases is time independent, ordered phases could correspond to those involved with tqc and possess a fixed color. If disordered phases contain no braid strands the mixing of different colors is avoided. The problem with this option is that it restricts dramatically the possible braidings.

If one takes this option seriously, the challenge is to make patches and patch color (A,T,C,G) visible. Perhaps one could try to mark regions of portions of lipid layer by some marker to find whether the lipid layer decomposes to non-mixing regions.

Quantum criticality suggests that that the patches of lipid layer have a fractal structure corresponding to a hierarchy of tqc program modules. The hydrodynamics would be thus fractal: patches containing patches... moving with respect to each other would correspond to braids containing braids containing ... such that sub-braids behave as braid strands. In principle this is also a testable prediction.

2. Does braid color corresponds to some chemical property?

The conserved braid color is not necessary for the model but would imply genetic coding of the tqc hardware so that sexual reproduction would induce an evolution of tqc hardware. Braid color would also make the coupling of foreign DNA to the tqc performed by the organism difficult and realize an immune system at the level of quantum information processing.

The conservation of braid color poses however considerable problems. The concentration of braid strands of the same color to patches would guarantee the conservation but would restrict the possible braiding dramatically. A more attractive option is that the strands of same color find each other automatically by energy minimization after the halting of tqc. Electromagnetic Coulomb interaction would be the most natural candidate for the interaction in question. Braid color would define a faithful genetic code at the level of nucleotides. It would induce long range correlation between properties of DNA strand and the dynamics of cell immediately after the halting of tqc.

The idea that color could be a chemical property of phospholipids does not seem plausible. The lipid asymmetry of the inner and outer monolayers excludes the assignment of color to the hydrophilic groups PS, PI, PE, PCh. Fatty acids have $N = 14, \dots, 24$ carbon atoms and $N = 16$ and 18 are the most common cases so that one could consider the possibility that the 4 most common feet pairs could correspond to the resulting combinations. It is however extremely difficult to understand how long range correlation between DNA nucleotide and fatty acid pair could be created.

3. Does braid color correspond to neutral quark pairs?

It seems that the color should be a property of the braid strand. In TGD inspired model of high T_c super-conductivity [24] wormhole contacts having u and \bar{d} and d and \bar{u} quarks at the two wormhole throats feed electron's gauge flux to larger space-time sheet. The long range correlation between electrons of Cooper pairs is created by color confinement for an appropriate scaled up variant of chromo-dynamics which are allowed by TGD. Hence the neutral pairs of colored quarks whose members are located the ends of braid strand acting like color flux tube connecting the nucleotide to the lipid could code DNA color to QCD color.

For the pairs $u\bar{d}$ with net em charge the quark and anti-quark have the same sign of em charge and tend to repel each other. Hence the minimization of electro-magnetic Coulomb energy favors the neutral configurations $w\bar{u}$, $d\bar{d}$ and $u\bar{u}$, and $d\bar{d}$ coding for A,T,C,G in some order.

After the halting of tqc only these pairs would form with a high probability. The reconnection of the

strands would mean a formation of a short color flux tube between the strands and the annihilation of quark pair to gluon. Note that single braid strand would connect DNA color and its conjugate rather than identical colors so that braid strands connecting two DNA strands (conjugate strands) should always traverse through an even (odd) number of cell membranes. The only plausible looking option is that nucleotides A,T,G,C are mapped to pairs of quark and anti-quarks at the ends of braid strand. Symmetries pose constraints on this coding.

1. By the basic assumptions charge conjugation must correspond to DNA conjugation so that one A and T would be coded to quark pair, say $q\bar{q}$ and its conjugate $\bar{q}q$. Same for C and G.
2. An additional aesthetically appealing working hypothesis is that *both* A and G with the same number of aromatic cycles (three) correspond to $q\bar{q}$ (or its conjugate).

This would leave four options:

$$\begin{aligned}
 (A, G) &\rightarrow (u\bar{u}, d\bar{d}) \quad , \quad (T, C) \rightarrow (\bar{u}u, \bar{d}d) \quad , \\
 (A, G) &\rightarrow (d\bar{d}, u\bar{u}) \quad , \quad (T, C) \rightarrow (\bar{d}d, \bar{u}u) \quad , \\
 (T, C) &\rightarrow (u\bar{u}, d\bar{d}) \quad , \quad (A, G) \rightarrow (\bar{u}u, \bar{d}d) \quad , \\
 (T, C) &\rightarrow (d\bar{d}, u\bar{u}) \quad , \quad (A, G) \rightarrow (\bar{d}d, \bar{u}u) \quad .
 \end{aligned}
 \tag{4.1}$$

It is an experimental problem to deduce which of these correspondences - if any - is realized.

4.1.5 Some general predictions

During tqc the lipids of the two lipid layers should define independent units of lipid hydrodynamics whereas after halting of tqc they should behave as single dynamical unit. Later it will be found that these two phases should correspond to high T_c superconductivity for electrons (Cooper pairs would bind the lipid pair to form single unit) and its absence. This prediction is testable.

The differentiation of cells should directly correspond to the formation of a mapping of a particular part of genome to cell membrane. For neurons the gene expression is maximal which conforms with the fact that neurons can have very large size. Axon might be also part of the map. Stem cells represent the opposite extreme and in this case minimum amount of genome should be mapped to cell membrane. The prediction is that the evolution of cell should be reflected in the evolution of the genome-membrane map.

4.1.6 Quantitative test for the proposal

There is a simple quantitative test for the proposal. A hierarchy of tqc programs is predicted, which means that the number of lipids in the nuclear inner membrane should be larger or at least of the same order of magnitude that the number of nucleotides. For definiteness take the radius of the lipid molecule to be about 5 Angstroms (probably somewhat too large) and the radius of the nuclear membrane about $2.5 \mu\text{m}$.

For our own species the total length of DNA strand is about one meter and there are 30 nucleotides per 10 nm. This gives 6.3×10^7 nucleotides: the number of intronic nucleotides is only by few per cent smaller. The total number of lipids in the nuclear inner membrane is roughly 10^8 . The number of lipids is roughly twice the number nucleotides. The number of lipids in the membrane of a large neuron of radius of order 10^{-4} meters is about 10^{11} . The fact that the cell membrane is highly convoluted increases the number of lipids available. Folding would make possible to combine several modules in sequence by the proposed connections between hydrophobic surfaces.

4.2 How quantum states are realized?

Quantum states should be assigned to the ends of the braid strands and therefore to the nucleotides of DNA and conjugate DNA. The states should correspond to many-particle states of anyons and fractional electrons and quarks and anti-quarks are the basic candidates.

4.2.1 Anyons represent quantum states

The multi-sheeted character of space-time surface as a 4-surface in a book like structure having as pages covering spaces of the imbedding space (very roughly, see the appendix) would imply additional degrees of freedom corresponding to the group algebra of the group $G \supset Z_n$ defining the covering. Especially interesting groups are tetra-hedral, octahedral, and icosahedral groups whose action does not map any plane to itself. Group algebra would give rise to $n(G)$ quantum states. If electrons are labeled by elements of group algebra this gives $2^{n(G)}$ -fold additional degeneracy corresponding to many-electron states at sheets of covering. The vacuum state would be excluded so that $2^{n(G)} - 1$ states would result. If only Cooper pairs are allowed one would have $m_n = 2^{n(G)-1} - 1$ states.

This picture suggests the fractionization of some fermionic charges such as em charge, spin, and fermion number. This aspect is discussed in detail in the Appendix. Single fermion state would be replaced by a set of states with fractional quantum numbers and one would have an analogy with the full electronic shell of atom in the sense that a state containing maximum number of anyonic fermions with the same spin direction would have the quantum numbers of the ordinary fermion.

One can consider two alternative options.

1. The fractionization of charges inspired the idea that catalytic hot spots correspond to "half" hydrogen bonds containing dark fractionally charged electron meaning that the Fermi sea for electronic anyons is not completely filled [25]. The formation of hydrogen bond would mean a fusion of "half hydrogen bond" and its conjugate having by definition a compensating fractional charges guaranteeing that the net em charge and electron number of the resulting state are those of the ordinary electron pair and the state is stable as an analog of the full electron shell. Half hydrogen bonds would assign to bio-molecules "names" as sequences of half hydrogen bonds and only molecules whose "names" are conjugates of each other would form stable hydrogen bonded pairs. Therefore symbolic dynamics would enter the biology via bio-catalysis. Concerning quantum computation the problem is that the full shell assigned to hydrogen bond corresponds to only single state and cannot carry information.
2. The assignment of braids and fractionally charged anyonic quarks and anti-quarks would realize very similar symbolic dynamics. One cannot exclude the possibility that leptonic charges fractionize to same values as quark charges.

This suggest the following picture.

1. One could assign the fractional quantum numbers to the quarks and anti-quarks at the ends of the flux tubes defining the braid strands. This hypothesis is consistent with the correspondence between nucleotides and quarks and assigns anyonic quantum states to the ends of the braid. Wormhole magnetic fields would distinguish between matter in vivo and in vitro. This option is certainly favored by Occam's razor in TGD Universe.
2. Hydrogen bonds connect the DNA strands which suggests that fractionally charged quantum states at the ends of braids might be assignable to the ends of hydrogen bonds. The model for plasma electrolysis of Kanarev [17] leads to a proposal that new physics is involved with hydrogen bonds. The presence of fractionally charged particles at the ends of bond might provide alternative explanation for the electrostatic properties of hydrogen bonds usually explained in terms of a modification electronic charge distribution by donor-acceptor mechanism. There would exist entire hierarchy of hydrogen bonds corresponding to the increasing values of Planck constant. DNA and even hydrogen bonds associated with water might correspond to a larger value of Planck constant for mammals than for bacteria.
3. The model for protein folding code [28] leads to a cautious conclusion that flux tubes are prerequisites for the formation of hydrogen bonds although not identifiable with them. The model predicts also the existence of long flux tubes between acceptors of hydrogen bonds (such as $O =$, and aromatic rings assignable to DNA nucleotides, amino-acid backbone, phosphates, XYP , $X = A, T, G, C$, $Y = M, D, T$). This hypothesis would allow detailed identification of places to which quantum states are assigned.

4.2.2 Hierarchy of genetic codes defined by Mersenne primes

The model for the hierarchy of genetic codes inspires the question whether the favored values of $n(G) - 1$ correspond to Mersenne primes [40]. The table below lists the lowest hierarchies. Most of them are short.

$$\begin{array}{lll}
 \{M_n\} & \{n(G)\} & \\
 & \{n_b\} & \\
 \{2, 7, 127, 2^{127} - 1, ?\} & \{4, 8, 128, 2^{127}, ?\} & \{2, 6, 126, 2^{126}, ?\} \\
 \{5, 31, 2^{31} - 1\} & \{6, 32, 2^{31}\} & \{4, 30, 2^{30}\} \\
 \{13, 2^{13} - 1\} & \{14, 2^{13}\} & \{12, 2^{12}\} \\
 \{17, 2^{17} - 1\} & \{18, 2^{17}\} & \{16, 2^{16}\} \\
 \{19, 2^{19} - 1\} & \{20, 2^{19}\} & \{18, 2^{18}\} \\
 \{61, 2^{61} - 1\} & \{62, 2^{61}\} & \{60, 2^{60}\} \\
 \{89, 2^{89} - 1\} & \{90, 2^{89}\} & \{88, 2^{88}\} \\
 \{107, 2^{107} - 1\} & \{108, 2^{107}\} & \{106, 2^{106}\}
 \end{array} \tag{4.2}$$

The number of states assignable to M_n is $M_n = 2^n - 1$ which does not correspond to full n bits: the reason is that one of the states is not physically realizable. 2^{n-1} states have interpretation as maximal number of mutually consistent statements and to $n_b = n - 1$ bits. The table above lists the values of n_b for Mersenne primes.

Notice that micro-tubules decompose into 13 parallel helices consisting of 13 tubulin dimers. Could these helices with the conformation of the last tubulin dimer serving as a kind of parity bit realize M_{13} code?

There would be a nice connection with the basic phenomenology of ordinary computers. The value of the integer $n - 1$ associated with Mersenne primes would be analogous to the number of bits of the basic information unit of processor. During the evolution of PCs it has evolved from 8 to 32 and is also power of 2.

4.3 The role of high T_c superconductivity in tqc

A simple model for braid strands leads to the understanding of how high T_c super conductivity assigned with cell membrane [32] could relate to tqc. The most plausible identification of braid strands is as magnetic or wormhole magnetic flux tubes consisting of pairs of flux tubes connected by wormhole contacts whose throats carry fermion and anti-fermion such that their rotational motion at least partially generates the antiparallel magnetic fluxes at the two sheets of flux tube. The latter option is favored by the model of tqc but one must of course keep mind open for variants of the model involving only ordinary flux tubes. Both kinds of flux tubes can carry charged particles such as protons, electrons, and biologically important ions as dark matter with large Planck constant and the model for nerve pulse and EEG indeed relies on this assumption [33].

4.3.1 Currents at space-like braid strands

If space-like braid strands are identified as idealized structures obtained from 3-D tube like structures by replacing them with 1-D strands, one can regard the braiding as a purely geometrical knotting of braid strands.

The simplest realization of the braid strand as magnetic flux tube would be as a hollow cylindrical surface connecting conjugate DNA nucleotide to cell membrane and going through 5- and/or 6- cycles associated with the sugar backbone of conjugate DNA nucleotides. The free electron pairs associated with the aromatic cycles would carry the current creating the magnetic field needed.

For wormhole magnetic flux one would have pair of this kind of hollow cylinders connected by wormhole contacts and carrying opposite magnetic fluxes. In this case the currents created by wormhole contacts would give rise to the antiparallel magnetic fluxes at the space-time sheets of wormhole contact and could serve as controllers of tqc. I have indeed proposed long time ago that so called wormhole Bose-Einstein condensates might be fundamental for the quantum control in living matter [23]. In this case the presence of supra currents at either sheet would generate asymmetry between the magnetic fluxes.

There are two extreme options for both kinds of magnetic fields. For B-option magnetic field is parallel to the strand and vector potential rotates around it. For A-option vector potential is parallel to the strand and magnetic field rotates around it. The general case corresponds to the hybrid of these options and involves helical magnetic field, vector potential, and current.

1. For B-option current flowing around the cylindrical tube in the transversal direction would generate the magnetic field. The splitting of the flux tube would require that magnetic flux vanishes requiring that the current should go to zero in the process. This would make possible selection of a part of DNA strand participating to tqc.
2. For A-option the magnetic field lines of the braid would rotate around the cylinder. This kind of field is created by a current in the direction of cylinder. In the beginning of tqc the strand would split and the current of electron pairs would stop flowing and the magnetic field would disappear. Also now the initiation of computation would require stopping of the current and should be made selectively at DNA.

The control of the tqc should rely on currents of electron pairs (perhaps Cooper pairs) associated with the braid strands. Supra currents would have quantized values and they are therefore very attractive candidates. The (supra) currents could also bind lipids to pairs so that they would define single dynamical unit in 2-D hydrodynamical flow. One can also think that Cooper pairs with electrons assignable to different members of lipid pair bind it to a single dynamical unit.

4.3.2 Do supra currents generate magnetic fields?

Energetic considerations favor the possibility that supra currents create the magnetic fields associated with the braid strands defined by magnetic flux tubes. In the case of wormhole magnetic flux tubes supra currents could generate additional magnetic fields present only at the second sheet of the flux tube.

Supra current would be created by a voltage pulse ΔV , which gives rise to a constant supra current after it has ceased. Supra current would be destroyed by a voltage pulse of opposite sign. Therefore voltage pulses could define an elegant fundamental control mechanism allowing to select the parts of genome participating to tqc. This kind of voltage pulse could be collectively initiated at cell membrane or at DNA. Note that constant voltage gives rise to an oscillating supra current.

Josephson current through the cell membrane would be also responsible for dark Josephson radiation determining that part of EEG which corresponds to the correlate of neuronal activity [32]. Note that TGD predicts a fractal hierarchy of EEGs and that ordinary EEG is only one level in this hierarchy. The pulse initiating or stopping tqc would correspond in EEG to a phase shift by a constant amount

$$\Delta\Phi = Ze\Delta VT/\hbar ,$$

where T is the duration of pulse and ΔV its magnitude.

The contribution of Josephson current to EEG responsible for beta and theta bands interpreted as satellites of alpha band should be absent during tqc and only EEG rhythm would be present. The periods dominated by EEG rhythm should be observed as EEG correlates for problem solving situations (say mouse in a maze) presumably involving tqc. The dominance of slow EEG rhythms during sleep and meditation would have interpretation in terms of tqc.

4.3.3 Topological considerations

The existence of supra current requires that the flow allows for a complex phase $\exp(i\Psi)$ such that supra current is proportional to $\nabla\Psi$. This requires integrability in the sense that one can assign to the flow lines of A or B (combination of them in the case of A-B braid) a coordinate variable Ψ varying along the flow lines. In the case of a general vector field X this requires $\nabla\Psi = \Phi X$ giving $\nabla \times X = -\nabla\Phi/\Phi$ as an integrability condition. This condition defines what is known as Beltrami flow [19].

The perturbation of the flux tube, which spoils integrability in a region covering the entire cross section of flux tube means either the loss of super-conductivity or the disappearance of the net supra current. In the case of the A-braid, the topological mechanism causing this is the increase in the dimension of the CP_2 projection of the flux tube so that it becomes 3-D [19], where I have also considered the possibility

that 3-D character of CP_2 projection is what transforms the living matter to a spin glass type phase in which very complex self-organization patterns emerge. This would conform with the idea that in tqc takes place in this phase.

4.3.4 Fractal memory storage and tqc

If Josephson current through cell membrane ceases during tqc, tqc manifests itself as the presence of only EEG rhythm characterized by an appropriate cyclotron frequency. Synchronous neuron firing might therefore relate to tqc. The original idea that a phase shift of EEG is induced by the voltage initiating tqc - although wrong - was however useful in that it inspired the question whether the initiation of tqc could have something to do with what is known as a place coding by phase shifts performed by hippocampal pyramidal cells [75, 74]. The playing with this idea provides important insights about the construction of quantum memories and demonstrates the amazing explanatory power of the paradigm once again.

The model also makes explicit important conceptual differences between tqc a la TGD and in the ordinary sense of word in particular those related to different view about the relation between subjective and geometric time.

1. In TGD tqc corresponds to the unitary process U taking place following by a state function reduction and preparation. It replaces configuration space ("world of classical worlds") spinor field with a new one. Configuration space spinor field represent generalization of time evolution of Schrödinger equation so that a quantum jump occurs between entire time evolutions. Ordinary tqc corresponds to Hamiltonian time development starting at time $t = 0$ and halting at $t = T$ to a state function reduction.
2. In TGD the expression of the result of tqc is essentially 4-D pattern of gene expression (spiking pattern in the recent case). In usual tqc it would be 3-D pattern emerging as the computation halts at time t . Each moment of consciousness can be seen as a process in which a kind of 4-D statue is carved by starting from a rough sketch and proceeding to shorter details and building fractally scaled down variants of the basic pattern. Our life cycle would be a particular example of this process and would be repeated again and again but of course not as an exact copy of the previous one.

1. Empirical findings

The place coding by phase shifts was discovered by O'Reefe and Recce [75]. In [74] Y. Yamaguchi describes the vision in which memory formation by so called theta phase coding is essential for the emergence of intelligence. It is known that hippocampal pyramidal cells have "place property" being activated at specific "place field" position defined by an environment consisting of recognizable objects serving as landmarks. The temporal change of the percept is accompanied by a sequence of place unit activities. The theta cells exhibit change in firing phase distributions relative to the theta rhythm and the relative phase with respect to theta phase gradually increases as the rat traverses the place field. In a cell population the temporal sequence is transformed into a phase shift sequence of firing spikes of individual cells within each theta cycle.

Thus a temporal sequence of percepts is transformed into a phase shift sequence of individual spikes of neurons within each theta cycle along linear array of neurons effectively representing time axis. Essentially a time compressed representation of the original events is created bringing in mind temporal hologram. Each event (object or activity in perceptive field) is represented by a firing of one particular neuron at time τ_n measured from the beginning of the theta cycle. τ_n is obtained by scaling down the real time value t_n of the event. Note that there is some upper bound for the total duration of memory if scaling factor is constant.

This scaling down - story telling - seems to be a fundamental aspect of memory. Our memories can even abstract the entire life history to a handful of important events represented as a story lasting only few seconds. This scaling down is thought to be important not only for the representation of the contextual information but also for the memory storage in the hippocampus. Yamaguchi and collaborators have also found that the gradual phase shift occurs at half theta cycle whereas firings at the other half cycle show no correlation [74]. One should also find an interpretation for this.

2. TGD based interpretation of findings

How this picture relates to TGD based 4-D view about memory in which primary memories are stored in the brain of the geometric past?

1. The simplest option is the initiation of tqc like process in the beginning of each theta cycle of period T and having geometric duration $T/2$. The transition $T \rightarrow T/2$ conforms nicely with the fundamental hierarchy of time scales coming as powers defining the hierarchy of measurement resolutions and associated with inclusions of hyperfinite factors of type II_1 [18]. That firing is random at second half of cycle could simply mean that no tqc is performed and that the second half is used to code the actual events of "geometric now".
2. In accordance with the vision about the hierarchy of Planck constants defining a hierarchy of time scales of long term memories and of planned action, the scaled down variants of memories would be obtained by down-wards scaling of Planck constant for the dark space-time sheet representing the original memory. In principle a scaling by any factor $1/n$ (actually by any rational) is possible and would imply the scaling down of the geometric time span of tqc and of light-like braids. One would have tqc's inside tqc's and braids within braids (flux quanta within flux quanta). The coding of the memories to braidings would be an automatic process as almost so also the formation of their zoomed down variants.
3. A mapping of the time evolution defining memory to a linear array of neurons would take place. This can be understood if the scaled down variant (scaled down value of \hbar) of the space-time sheet representing original memory is parallel to the linear neuron array and contains at scaled down time value t_n a stimulus forcing n^{th} neuron to fire. The 4-D character of the expression of the outcome of tqc allows to achieve this automatically without complex program structure.

To sum up, it seems that the scaling of Planck constant of time like braids provides a further fundamental mechanism not present in standard tqc allowing to build fractally scaled down variants of not only memories but tqc's in general. The ability to simulate in shorter time scale is a certainly very important prerequisite of intelligent and planned behavior. This ability has also a space-like counterpart: it will be found that the scaling of Planck constant associated with space-like braids connecting bio-molecules might play a fundamental role in DNA replication, control of transcription by proteins, and translation of mRNA to proteins. A further suggestive conclusion is that the period T associated with a given EEG rhythm defines a sequence of tqc's having geometric span $T/2$ each: the rest of the period would be used to perceive the environment of the geometric now. The fractal hierarchy of EEGs would mean that there are tqc's within tqc's in a very wide range of time scales.

4.4 Codes and tqc

TGD suggests the existence of several (genetic) codes besides 3-codon code [30, 29]. The experience from ordinary computers and the fact that genes in general do not correspond to $3n$ nucleotides encourages to take this idea more seriously. The use of different codes would allow to tell what kind of information a given piece of DNA strand represents. DNA strand would be like a drawing of building containing figures (3-code) and various kinds of text (other codes). A simple drawing for the building would become a complex manual containing mostly text as the evolution proceeds: for humans 96 per cent of code would correspond to introns perhaps obeying some other code.

The hierarchy of genetic codes is obtained by starting from n basic statements and going to the meta level by forming all possible statements about them (higher order logics) and throwing away one which is not physically realizable (it would correspond to empty set in the set theoretic realization). This allows $2^n - 1$ statements and one can select 2^{n-1} mutually consistent statements (half of the full set of statements) and say that these are true and give kind of axiomatics about world. The remaining statements are false. DNA would realize only the true statements.

The hierarchy of Mersenne primes $M_n = 2^n - 1$ with $M_{n(next)} = M_{M_n}$ starting from $n = 2$ with $M_2 = 3$ gives rise to 1-code with 4 codons, 3-code with 64 codons, and $3 \times 21 = 63$ -code with 2^{126} codons [30] realized as sequences of 63 nucleotides (the length of 63-codon is about $2L(151)$, roughly twice the

cell membrane thickness. It is not known whether this Combinatorial Hierarchy continues ad infinitum. Hilbert conjectured that this is the case.

In the model of pre-biotic evolution also 2-codons appear and 3-code is formed as the fusion of 1- and 2-codes. The problem is that 2-code is not predicted by the basic Combinatorial Hierarchy associated with $n = 2$.

There are however also other Mersenne hierarchies and the next hierarchy allows the realization of the 2-code. This Combinatorial Hierarchy begins from Fermat prime $n = 2^k + 1 = 5$ with $M_5 = 2^5 - 1 = 31$ gives rise to a code with 16 codons realized as 2-codons (2 nucleotides). Second level corresponds to Mersenne prime $M_{31} = 2^{31} - 1$ and a code with $2^{30=15 \times 2}$ codons realized by sequences of 15 3-codons containing 45 nucleotides. This corresponds to DNA length of 15 nm, or length scale $3L(149)$, where $L(149) = 5$ nm defines the thickness of the lipid layer of cell membrane. $L(151) = 10$ nm corresponds to 3 full 2π twists for DNA double strand. The model for 3-code as fusion of 1- and 2-codes suggests that also this hierarchy - which probably does not continue further - is realized.

There are also further short Combinatorial hierarchies corresponding to Mersenne primes [40].

1. $n = 13$ defines Mersenne prime M_{13} . The code would have $2^{12=6 \times 2}$ codons representable as sequences of 6 nucleotides or 2 3-codons. This code might be associated with microtubuli.
2. The Fermat prime $17 = 2^4 + 1$ defines Mersenne prime M_{17} and the code would have $2^{16=8 \times 2}$ codons representable as sequences of 8 nucleotides.
3. $n = 19$ defines Mersenne prime M_{19} and code would have $2^{18=9 \times 2}$ codons representable as sequences of 9 nucleotides or three DNA codons.
4. The next Mersennes are M_{31} belonging to $n = 5$ hierarchy, M_{61} with $2^{60=30 \times 2}$ codons represented by 30-codons. This corresponds to DNA length $L(151) = 10$ nm (cell membrane thickness). M_{89} (44-codons), M_{107} (53-codons) and M_{127} (belonging to the basic hierarchy) are the next Mersennes. Next Mersenne corresponds to M_{521} (260-codon) and to completely super-astrophysical p-adic length scale and might not be present in the hierarchy.

This hierarchy is realized at the level of elementary particle physics and might appear also at the level of DNA. The 1-, 2-, 3-, 6-, 8-, and 9-codons would define lowest Combinatorial Hierarchies.

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