Conscious Information and Intelligence

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Abstract

The notions of information and intelligence are discussed in TGD framework. Definitions for the information measures of the configuration space spinor field and information gain of conscious experience as well as the information theoretic interpretation of Kähler action are discussed in detail the first sections of the chapter.

a) Information content of conscious experience associated with single quantum jump can be defined as the difference of the informations associated with initial and initial quantum histories, which are well defined geometric objects and to which classical information theory applies. One can assign separate information measures to both the state function reduction stage (localization in zero modes) and state preparation stage (cascade of self measurement leading to unentangled state) of the quantum jump. The requirement that information gain of conscious experience reduces to information gains associated with irreducible sub-experiences implies that information measures are local in zero modes.

b) The information content of the conscious experience associated with self is more interesting practically. Since self defines a statistical ensemble, it is straightforward to define entropies associated with the increments of quantum numbers and zero modes defining non-geometric and geometric qualia. These entropies characterize the fuzziness of the quale and are 'negative' information measures. Genuine information measures can be defined as differences of the entropies associated with the asymptotic thermal self (if indeed defined) and self. Also information measures for single quantum jump generalize to the case of self.

c) Information theoretic interpretation of the Kähler function is discussed in detail. With certain hypothesis about the degeneracy of the absolute minima as function of Kähler action, the negative of the Kähler function can be interpreted as an entropy type measure for the information content of the space-time surface. Absolute minimization of the Kähler action can be interpreted as a maximization of the information content of the space-time surface and quantum criticality makes TGD universe maximally interesting and maximizes its intelligence. A concrete prediction is that generation of Kähler electric fields generates cognitive resources: indeed, the presence of strong electric fields is the characteristic feature of living systems.

d) Quantum entanglement between real and p-adic degrees of freedom makes sense if entanglement coefficients are algebraic numbers. In this case one can define entanglement entropy using the p-adic variant of the logarithm. p-Adic entropy can be also negative, and the states for which the entropy is negative are stable against self measurements (NMP) and define macrotemporally quantum coherent states. The number-theoretic entropy serves as an an information measure for cognitive entanglement, and positive entanglement negentropy can be interpreted as a correlate for the experience of understanding. An open question is whether bound states with algebraic entanglement coefficients are sufficiently generic also in the real context to justify the use of the p-adic entanglement negentropy with the value of p fixed uniquely by the requirement that the negentropy is maximal. The number-theoretic definition of information could clearly pave the way towards the understanding of conscious information in the living systems.

Concerning the modelling of conscious intelligence the following aspects are important.

a) Association sequences represent geometric memories, simulations for time development whereas selves represent subjective memories and conscious experience involves always the comparison of geometric and subjective memories telling whether expectations were realized. Quantum theory of self-organization applies also to the evolution of consciousness understood as self-organization in the ensemble of association sequences/selves and implies Darwinian selection also at the level of selves and conscious experiences.

b) TGD Universe is quantum computer in a very general sense and one can understand intelligent system as a quantum computer like system performing one quantum computation per CP_2 time about 10^4 Planck times. Quantum computationalism is shown to reproduce the relevant aspects of computationalism and connectionism without reducing conscious brain to a deterministic machine. Holographic brain is also one of the dominating ideas of neuroscience. TGD based realization of memory allows to reduce hologram idea to its essentials: what matters is that piece of hologram is like a small window giving same information as larger window but in less accurate form. This inspires the concept of neuronal window: each

neuron has small window to the perceptive landscape and is typically specialized to detect particular feature in the landscape. Coherent photons emitted by mindlike space-time sheets and propagating along axonal microtubules serving as wave guides, realize neuronal windows quantum physically. Massless extremals allow rather precise definition for the notion of quantum hologram.

A more refined formulation of these ideas is based on the notion of conscious hologram. Many-sheeted space-time is essentially a fractal Feynmann diagram with lines thicknened to 4-surfaces. The lines are like wave guides carrying laser beams and vertices are like nodes where these laser beams interfere and generate the points of the hologram. The 3-dimensionality of the ordinary hologram generalizes to stereo consciousness resulting in the fusion of mental images associated with various nodes of the conscious hologram. An essential element is the possibility of negative energy space-time sheets analogous to the past directed lines of the Feynmann diagram: negative energy MEs are the crucial element of sensory perception, motor action, and memory.

c) An important element is effective four-dimensionality of brain making possible to understand long term memories, planning and motor activities in a completely new manner. Further important ideas are music metaphor already described and the vision about brain as an associative net. The memetic code, with codewords consisting 126 bit sequences and represented in terms of nerve pulse sequences or membrane oscillations and time varying antineutrino magnetization, is the key essential element of brain as cognitive system. Codewords can be interpreted either as elements of a Boolean algebra or as bits in the binary expansion of an integer in the range $(0, 2^{126})$ so that memetic code makes brain able to assign numbers with qualia. An attractive and testable identification for the memetic codewords is as phonemes of language.

1 Introduction

This chapter is a fusion of two separate chapters, the first one devoted to information measures for conscious experience and second summarizing a quantum model for intelligent systems. This reflects in its own way the fact that the development of the related ideas has not been a linear process and has involved many weird twists typical for a mathematical thinking without strong connection with empiria.

Much of the latest progress relies crucially on the developments in basic quantum TGD occurred during only one year (I am writing this towards the end of January, 2003). In the following I shall summarize different quantum views about information, intelligence and consciousness. Needless to add that all these memes live still their infancy and are only starting their development to social members of the meme society defining TGD inspired theory of consciousness: only time will show which of these friends of mine will survive to the adult age.

1.1 The notions of association sequence and mindlike sheet

"Ontogeny recapitulates phylogeny" metaphor, or better to say quantum-classical correspondence principle, relates the concepts of self and mind-like space-time sheet. Self can be defined as a subsystem able to avoid generation of bound state entanglement with the environment. Self has subjective memory and can be regarded simply as a heap of moments of consciousness occurred after the wakeup. Subjective memory is assumed to be kind of abstraction or sum about experiences associated with moments of consciousness. Self is assumed to experience the experiences of its subselves as somekind of abstractions: this implies infinite hierarchy of selves having increasingly abstract views about world.

Association sequence concept is inspired by the classical nondeterminism of Kähler action. Association sequence is minimal number of spacelike 3-surfaces having timelike separations and

fixing uniquely one of the absolute minima of Kähler action associated with the 3-surface Y^3 at lightcone boundary. Both mind-like and material space-time sheets give rise to association sequences: in case of material space-time sheets the non-determinism involved has macroscopic and long lasting consequences. Association sequences appear in all p-adic length scales. p-Adic slaving hierarchy suggests a mechanism for how the association sequences could form a cognitive hierarchy based on the formation of association sequences of association sequences of....

Quantum non-determinism is expected to be important only in the p-adic length scales of the order of the size of the system whereas in shorter p-adic length scales it should be possible to regard the system as an ensemble of association sequences obeying statistical determinism. Quantum entanglement between the association sequences provides a possible model of association and a model for how wholes are formed from parts at the level of subjective experience. The replication of association sequences in turn makes possible competition and struggle for survival leading to the evolution of cognitive abilities. The interaction of the association sequences with the space-time sheets containing ordinary matter or with lower mind-like space-time sheets gives rise to the cognitive counterparts of the evolutionary pressures.

1.2 Boolean logic and fermions

The connection of fermionic Fock space basis with Boolean algebra was one of the first ideas related to the quantum modelling of intelligent systems. The state basis for the fermionic Fock space has a natural interpretation as Boolean algebra (fermion number $=1/0\leftrightarrow$ yes/no). In this manner ordinary Boolean algebra is extended to vector space spanned by fermionic states. When cognitive fermion pairs are used instead of fermions, fermion number conservation does not pose any constraints and full linear superposition of the Boolean algebra elements is possible. An interesting question is whether one could consider ordinary Boolean logic as some kind of limit for the complex quantum logic and whether our logical mind could have something to do with Boolean algebra. For instance, could primary 'this is true' experiences correspond to Boolean qualia having increments of fermionic quantum numbers as physical correlates.

An alternative, and as it has turned out a more realistic option, corresponds to the identification of the Boolean truth values with spin directions for fermions, anti-neutrinos in case of biosystems. In this case fermion number conservation does not pose any constraints and a the macrosopic realization replaing single spin as a representative of bit with a magnetized ensemble of fermions, makes the realization robust. Both p-adic and real variants of cognitive antineutrinos seems to be needed and p-adic-real entanglement with positive definite number theoretical entanglement entropy gives to the experience of understanding and makes possible cognitive quantum computation like processes.

1.3 Connections with computationalism and hologrammic brain

Classical computationalism dominates cognitive science. The traditional AI models brain as symbol processor whereas connectionism provides a realization for associationism. TGD Universe is quantum computer in a very general sense and one can understand intelligent system as a quantum computer like system performing one quantum computation per CP_2 time about 10^4 Planck times. Macrotemporal quantum coherence binds long sequences of quantum jumps to effetively form a single quantum jump and decoherence times become much longer than CP_2 time. Quantum computationalism is shown to reproduce the relevant aspects of computationalism and connectionism without reducing conscious brain to a deterministic machine.

Holographic brain is also one of the dominating ideas of neuroscience. TGD based realization of memory allows to reduce hologram idea to its essentials: what matters is that piece of hologram is like a small window giving same information as larger window but in less accurate form. This inspires the concept of neuronal window: each neuron has small window to the perceptive landscape

and is typically specialized to detect particular feature in the landscape. Coherent photons emitted by mind-like space-time sheets and propagating along axonal microtubules serving as wave guides, realize neuronal windows quantum physically. The notion of massless extremal (ME) gives a rigorous foundation for the idea that quantum holograms are involved with consciousness. The most advanced and detailed formulation of the hologram idea hitherto is based on the notion of conscious hologram.

1.4 The paradigm of four-dimensional brain

An important element is effective four-dimensionality of brain making possible to understand long term memories, planning and motor activities in a completely new manner. Further important ideas are music metaphor already described and the vision about brain as an associative net such that each neuron represents some sensory quale or 'Boolean quale'. The memetic code, with codons consisting 126 bit sequences, is the key essential element of brain as cognitive system. Codons can be interpreted either as elements of a Boolean algebra or as bits in the binary expansion of an integer in the range $(0, 2^{126})$ so that memetic code makes brain able to assign numbers with qualia. An attractive and testable identification for the memetic codons is as phonemes of language.

The newest development associated with the paradigm of 4-dimensional brain is the realization that brain hemispheres could have different arrows of the geometric time at appropriate p-adic time scales. For instance, negative energy MEs would make possible quantum communications to the direction of the geometric past. The model of non-episodal memory call would involve quantum communication of the question to the geometric past (time-like entanglement and sharing of mental images), and a classical (dissipative) communication of the answer to the geometric future. Negative-positive energy dichotomy could be be realized in an extremely wide range of time scales and to explain, besides the basic mechanism of long term memory, also precisely targeted realization of intentions, sensory-motor dichotomy, and biocycles as dissipation-healing cycles.

1.5 The meanings of sensory, cognitive, symbolic

With my physicist's background I have used the attrivutes sensory, cognitive and symbolic somewhat sloppily and the precise meanings of these become only gradually clear. The classical non-determinism of Kähler action quite generally implies that space-time surfaces are symbolic representations whereas p-adic space-time sheets provide cognitive representations for the subjective existence and also serve as correlates of intentions. For instance, nerve pulse patterns define symbolic real physics representations of the sensory input but do not give rise to sensory qualia which reside at the level of the primary sensory organs (contrary to the expectations raised by various findings of neuro-science). Sensory experience is always a multiverse experience since sensory qualia have quantum jump increments as quantum correlates, and is thus not reducible to the level of space-time.

1.6 Information theoretic interpretation of Kähler action

An important stimulus in the development of ideas was the Jan 30, 1999 issue of New Scientist [23], in which the work of Roy Frieden [21, 22] about information theoretical interpretation of the variational principles of physics was discussed at popular level. The work of Frieden relies on the concept of Fisher information. One can find a precise definition of the Fisher information in Mathematical Handbooks but this definition does not help too much without any further knowledge about Frieden's work. There is also a book available about Frieden's work [22].

Although the article in New Scientist [23] does not give any mathematical details about Frieden's work, it becomes clear that Fisher's theory as such does not apply to TGD frame-

work. Frieden's basic idea seems however extremely attractive. Indeed, TGD inspired theory of consciousness leads to a hypothesis concerning the information theoretic interpretation of the Kähler function.

1. Absolute minimization of Kähler action and maximization of negentropy gain are the two 'great' variational principles of quantum TGD. Both variational principles of TGD have information theoretic interpretation. The negative of the Kähler function for quantum critical universe serves as a classical information measure for the Universe and entanglemement entropy (quantum version of Shannon entropy) tells how interesting potential conscious experience is but does not tell anything about its real information content. As explained in the introduction, one can define much more general information measures of conscious experience.

   It is important to notice that the p-adic version of Kähler action does not make sense nor is needed at all at configuration space level. All that is needed is that the p-adic variants of the field equations stating the absolute minimization of Kähler action are satisfied. At quantum level this means that each quantum jump involves a complete localization in p-adic configuration space degrees of freedom: p-adic physics at the space-time level is completely classical. Cognition has no colors.

2. The negative of the Kähler function for the critical value of the Kähler coupling strength, $-K_{cr}$ is by the absolute minimization of Kähler action non-negative entropy type variable. Hence it could somehow measure the classical information content of the space-time surface. A natural guess is that the information content is essentially due to the presence of the mind-like space-time sheets making it possible to have conscious information about classical time development with contents of separate conscious experiences located in bounded space-time sheets. If this interpretation is correct, the absolute minimization of the Kähler action maximizes the information content of the symbolic representations provided by the space-time surfaces in the superposition defined by the final state of the quantum jumps (zero mode degrees of freedom have same values for all space-time surfaces in the superposition).

3. A new view point to the precise meaning of the quantum criticality emerges. The degeneracy caused by the non-determinism to the configuration space functional integral is characterized by a degeneracy factor N_d assumed to be describable in a good approximation by $N_d \simeq exp(-K_{cr})$ for the critical value of the Kähler coupling strength. The requirement that degeneracy factor and vacuum functional compensate each other fixes, the value of Kähler coupling strength to have the critical value. Thus arbitrarily large negative values of K and arbitrarily large sensory information contents of the space-time surface become possible at quantum criticality. Complexity of the Universe is maximized. Below quantum criticality only configurations for which K is near zero contribute and sensory information content for allowed space-time surface is finite. Above criticality theory becomes ill defined since configuration space integrals diverge. Thus quantum criticality is necessary for maximally intelligent and maximally interesting conscious universe.

4. Altogether this means that absolute minimization of Kähler action and Negentropy Maximization Principle, the basic variational principles of quantum TGD, can be regarded as basic laws for a quantum theory of consciousness: physics reduces to a a theory of consciousness! This is not perhaps so surprising when one realizes that physics is nothing but an attempt to identify lawlike regularities governing the contents of conscious experiences.

1.7 Measures for the information content of conscious experience

The concept of information is expected to be a crucial ingredient of any theory of consciousness. The problem of assigning information measures to conscious experience looks however formidable and it took long time before concrete ideas emerged.

1. The first impulse came from the already mentioned work of Frieden related to the information theoretic interpretation of action principles. Second impulse came from the intensive discussions with Stephen King [35] and other members of *Time* discussion group. The first information measures were assigned with single quantum jump identified as a moment of consciousness. The realization that the quantum jump can be regarded as a TGD counterpart of state function reduction followed by a state preparation realized by an entire cascade of self measurements, made possible further developments related to these information measures along with a more precise formulation of NMP.

2. Already the discovery of the notion of self made it obvious that the information measures associated with single moment of consciousness are not enough, and could be even obsolete as far as macrotemporal aspects of consciousness are considered. Clearly, one should be able to ascribe information measures to selves defined by quantum jump sequences.

   The interpretation of self as a growing statistical ensemble defined by the moments of consciousness implies a deep connection of information theory, statistical physics, and theory of qualia [K3]. It also leads to the identification of concrete information measures associated with the distributions of various quantum number and zero mode increments defined by the sequence of quantum jumps characterizing various primary qualia. Information measures can be identified simply as differences between various kinds of entropies associated with the asymptotic thermal self and 'self now' since self in a thermal state should correspond to a completely fuzzy mental image carrying no information. One cannot deny that these information measures are very practical.

3. The last step of progress (I am writing this paragraph 30th January, 2003) was the realization that p-adic-real cognitive entanglement in the so called quaternion conformal fermionic degrees of freedom makes sense if the entanglement coefficients are algebraic numbers and therefore can be regarded as being common to reals and algebraically extended p-adics. To an algebraic entanglement one can assign a number theoretic entanglement entropy, which can have also negative values, and NMP guarantees that this kind of entanglement is stable under state preparation. In this case sub-self would give rise to an experience of understanding. Algebraic entanglement might be possible also between real systems forming bound states. Needless to say, the possibility to assing genuine positive definite information to selves, could mean a revolution in the understanding of the conscious information processing in the living matter.

1.8 p-Adic physics as physics of cognition and intention

One of the latest newcomers in the bundle of ideas related to intelligent systems is p-adic physics as physics of cognition. p-Adic non-determinism follows from the fact that functions with vanishing derivatives are piecewise constant functions in the p-adic context. More precisely, p-adic pseudo constants depend on the pinary cutoff of their arguments and replace integration constants in p-adic differential equations. In case of field equations this means roughly that the initial data are replaced with initial data given for a discrete set of time values chosen in such a manner that unique solution of field equations results. Solution can be fixed also in a discrete subset of rational points of the imbedding space. Presumably the uniqueness requirement implies some unique pinary cutoff.

Thus the space-time surfaces representing solutions of p-adic field equations are analogous to space-time surfaces consisting of pieces of solutions of the real field equations. Thus p-adic reality is much like the dream reality consisting of rational fragments glued together in illogical manner or pieces of child's drawing of body containing body parts in more or less chaotic order.

The obvious looking interpretation for the solutions of the p-adic field equations is as a geometric correlate of imagination. Plans, intentions, expectations, dreams, and cognition in general are expected to have p-adic space-time sheets as their geometric correlates. This in the sense that p-adic spacetime sheets somehow initiate the real neural processes providing symbolic counterparts for the cognitive representations provided by p-adic spacetime sheets and p-adic fermions. A deep principle seems to be involved: incompleteness is characteristic feature of p-adic physics but the flexibility made possible by this incompleteness is absolutely essential for imagination and cognitive consciousness in general.

p-Adic space-time regions can suffer topological phase transitions to real topology and vice versa in quantum jumps replacing space-time surface with a new one. This process has interpretation as a topological correlate for the mind-matter interaction in the sense of transformation of intention to action and symbolic representation to cognitive representation. Also the notion of p-adic teleportation makes sense: what happens that p-adic massless extremals (MEs) suffer repeated time reflection so that zigzag curve in space-time is generated (p-adic piecewice conservation of energy allows this). This makes possible effectively superluminal communication as well as replication of p-adic cognitive representations. Also time reversed versions of p-adic cognitive representations are generated in this manner. p-Adic cognitive representations could provide the physical correlates for the notions of memes [37] and morphic fields [45].

p-Adic real entanglement makes possible makes possible cognitive measurements and cognitive quantum computation like processes, and provides correlates for the experiences of understanding and confusion.

Although p-adic space-time sheets as such are not conscious, p-adic physics would provide beautiful mathematical realization for the intuitions of Descartes. The formidable challenge is to develop experimental tests for p-adic physics. The basic problem is that we can perceive p-adic reality only as 'thoughts' unlike the 'real' reality which represents itself to us as sensory experiences. Thus it would seem that we should be able generalize the physics of sensory experiences to physics of cognitive experiences. The developments related to the p-adic view about cognition are left to [H8].

1.9 The number theoretic view about information

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

Before continuing I must apologize the lab notebook like character of this chapter. The notion

of information has developed gradually through various side tracks, and I have not yet had time to go all the material through to see which ideas are consistent with each other and which are not. The birth of TGD inspired theory of consciousness has been an enormous explosion of ideas and Darwinian selection must operate for years to eliminate the non-survivors. In any case, one can safely state that the number theoretic view described above is essentially correct, and provides also a deep vision about the role of p-adic numbers in TGD and implying the fusion of physics and information theory with number theory.

2 How to define measures for the information content of consciousness?

In this section my aim is to discuss different views to the problem how to define the information contents of conscious experience rather than advocating any final truth. Of course, just at this moment the statistical information measures associated with self seem to be the most realistic ones to me personally, but during these 24 years of TGD I have learned that it it is better to tolerate all views about the solution of the problem even when their mutual consistency is not obvious.

2.1 How to assign information measures with a moment of consciousness?

The concepts of information, information flow and information gain of conscious experience would seem to have a natural place in theories of consciousness. It seems intuitively obvious that configuration space spinor fields must contain information. Configuration space spinor fields have indeed interpretation as both objective realities and Platonic Ideas, the latter interpretation being suggested strongly by the possibility to interpret fermionic Fock state basis as a Boolean algebra of statements about statements. The basic statements are most naturally statements about space-time geometry since fermionic oscillator operators for X^3 are determined by the second quantized free quantum field theory for the induced spinors on space-time surface $X^4(X^3)$ [H1].

2.1.1 Information gain as difference of informations for initial and final state of quantum jump

The basis idea is that any measure for the information gain of quantum jump is essentially difference of information measures for the initial and final states of the quantum jump. Configuration space spinor field is a well defined geometric object so that the entire machinery of the classical information theory are available. It would be unrealistic to believe that there is only single information measure: rather each type of information is expected to give rise to its own information measure.

To proceed further, notice that quantum jump decomposes to a localization in zero modes representing state function reduction followed by a cascade of self measurements giving rise to state preparation. One can assign information gains both to the localization of zero modes stage and to the state preparation stage. Internal consistency requires that the action of U in zero modes is effectively a flow correlating quantum numbers characterizing configuration spinor to the values of zero modes.

1. If the information gain associated with the quantum jump is defined as the difference of the informations associated with Ψ_i and Ψ_f it vanishes, since these states are localized in zero modes and completely unentangled as outcomes of state preparation process. If this is the correct option, one can assign information measures only to the self defined by the sequence of quantum jumps.

2. An alternative interpretation is that part of the information content of the configuration space spinor field is transformed in the process $U\Psi_i \to \Psi_f$ to conscious information in quantum jump so that the information content of the configuration space spinor field is reduced.

The option 2) is the only sensical one if one wants to assign information gains with single moment of consciousness.

2.1.2 Information measures associated with localization in zero modes and state preparation

As found quantum jump decomposes to a localization in zero modes followed by state preparation. Separate information measures can be associate with these two stages.

1. It is natural to assign this kind of information gain to the localization in zero modes identifiable as information gain associated with the state function reduction. The task is to assign well defined measures of information to the dependence of the configuration space spinor field on zero modes, and identify the information gain of state function reduction as the difference of information measures for $U\Psi_i$ and Ψ_f. The information measures in question ought to be well defined since $U\Psi_i$ is a discrete superposition of states localized in zero modes. For instance, one can assign entanglement entropy to the subsystems defined by quantum fluctuating degrees of freedom and zero modes and this entropy becomes zero in quantum jump: obviously the reduction of entanglement entropy represents simplest measure for information gain.

2. Second class of information measures can be assigned to the sequence of self measurements leading to the final prepared state: during this stage zero modes remain constant. The sum over the total information gains associated with the steps of self measurement cascade seems to be the the proper notion. The total information gain associated with a given step is sum over the information gains associated with various mutually unentangled subsystems performing a self measurement. Entanglement negentropy gains associated with the formulation of NMP are especially natural quantities here.

There are natural constraints on information measures. Since conscious experience decomposes into separate sub-experiences and this decomposition follows closely the decomposition of the space-time surface to p-adic regions characterized by finite values of p-adic prime, one expects that also the information gain of conscious experience has similar decomposition. This indeed turns out to be the case for local information measures expressible as integral of information density

$$i = RX$$

over the configuration space. Here R is the Fock space norm squared of configuration space spinor for given 3-surface Y^3 and X is a measure for local information. X can measure information about the local geometry of configuration space, about configuration space spinor at Y^3 or about the properties of the space-time surface $X^4(Y^3)$. The constraints coming from the formulation of NMP fix essentially uniquely the information gains associated with various irreducible sub-selves.

Examples of especially interesting information measures are entanglement entropy, information measure for the position of Universe (3-surface) in zero modes and information measures giving information about the geometry space-time surface and classical gauge fields defined on it.

2.1.3 The information gains associated with the cascade of self measurements giving rise to state preparation

State function reduction is followed by a sequence of self measurements in quantum fluctuating fiber degrees of freedom ultimately leading to a competely unentangled state (bound states can of

course be entangled and can appear in the product state). It should be possible to assign measures of information also to this cascade of self measurements.

The cascade means decomposition of the system resulting in localization to zero modes to two unentangled subsystems: which pair of subsystems is in question is determined by NMP. The entanglement probabilities defined by the density matrix for either subsystem characterize the probabilities for the outcomes of the self measurement. Both unentangled subsystems resulting in the first step are again subject to self measurements and the process continues until an unentangled state results.

It seems natural to assume that the information measures are associated with the entire cascade and that they are additive in the sense that information gain is sum over the information gains of the steps of the cascade and that a given step contributes by the sum of the information gains associated with unentangled subsystems which are subject to self measurement in a given step of the cascade:

$$\begin{aligned} \Delta N &= \sum_i \Delta N(step\ i)\ , \\ \Delta N(step\ i) &= \sum_{k=1,..,k(i)} \Delta N(system\ k)\ . \end{aligned} \tag{1}$$

2.2 Information measures associated with selves

With the discovery of the notion of self it became clear that information measures associated with single moment of consciousness are not enough to define realistic information measures for selves. The crucial observation in this respect was that the sequence of final states of quantum jump defines a statistical ensemble growing in size quantum jump by quantum jump. If the averages of the increments of zero modes and quantum number increments in quantum jumps are experienced consciously, then the distributions for these increments determine the information content of conscious experience of self. The entropies associated with these distributions characterize the fuzziness of the qualia associated with various quantum number and zero mode increments. Since subselves (mental images) are expected to approach thermal equilibrium asymptotically, it is natural to define information measures associated with these increments as differences of the entropies associated with the asymptotic thermal selves and selves. A word of warning here however relates to the possible problems related to the precise definition of 'thermal self'. Without the notion of thermal self one can only define measures for the lack of information as entropies (which is of course in accordance with the Buddhist notion of Maya).

This approach applies does not necessate the assignment of information measures to the quantum jumps themselves. It is however possible to define also statistical variants of these information measures. Since conscious experience involves an averaging over quantum jumps, it seems natural to consider averages of the information measures associated with the state function reduction and state preparation states over the quantum jump sequence. Again the differences of these measures for self and for asymptotic thermal self would seem to provide the natural information measures. It must be however admitted that it is not at all clear whether these information measures have any practical utility.

2.3 Information measures associated with cognitive representations

p-Adic physics as physics of cognition suggests how to measure the information contents of cognitive representations. The basic hypothesis is that at the fundamental level cognitive representations are provided by the p-adic space-time sheets. One can even say that these space-time sheets mimick the physics of the real space-time sheets representing matter.

One can model these cognitive representations in terms of mappings of real space-time sheets to p-adic space-time sheets. The so called canonical identification is the basic building block of these maps. It maps p-adics and reals to each other continuously but does not respect differentiability. One can define canonical identification with some pinary cutoff and use the inherent non-determinism of the p-adic differential equations to complete the discrete image of the real space-time region to a continuous and differentiable solution of the p-adic counterparts of the field equations associated with the absolute minimization of the Kähler action. Thus p-adic physics simulates real physics.

The so called phase preserving canonical identification is a variant of this map respecting various fundamental symmetries. It must be emphasized that these maps are not fundamental and unique element of quantum TGD as I believed earlier: rather, they are simple models for how intelligent systems build cognitive representations. Especially interesting feature of these maps is that typically inside of system is mapped to outside and viceversa (say, external world to the p-adic world of brain).

The necessary pinary cutoff associated with the cognitive mappings of the real space-time regions to p-adic space-time regions allows to assign unique information measure to the values of the geometric quantities (say imbedding space coordinates as function of space-time coordinates) as the number of pinary digits present in the pinary expansion of the geometric quantity. A natural hypothesis is that the coarse graining characteristic for cognitive experience (world consists of objects) corresponds to the pinary cutoff associated with real-to-p-adics cognitive mappings.

2.4 Information gain related to the localization in zero modes

The simplest local information measure gives information about the position of the classical universe in the zero modes. Only the localization in zero modes is possible since complete localization in configuration space would mean quantum jump to a completely classical world with unique space-time surface rather than quantum superposition of parallel classical space-times and would mean the breaking of basic symmetries. Neither does complete localization make sense mathematically. Since positional information in zero modes measures the deviation of $U\Psi_i$ from the classicality, it relates to the parallel universe aspect of quantum TGD and is very natural from the view point of quantum TGD. For these reasons positional information deserves a detailed discussion.

1. Positional information measure in zero modes relies on Shannon formula giving measure for the information gain associated with a complete localization of configuration space spinor field in zero modes and is the same as used in the kinetic theory of gases based on probability distributions for single particle states. Definition works also in ordinary single particle wave mechanics but has no obvious generalization to quantum field theory context. Note that the positional information gain in zero modes is maximal.

2. Unitarity is consistent with the localization in zero modes only if the action of U is such that it induces effective flow in zero modes such that quantum numbers of the initial state are in one-one correlation with the values of the zero modes in the final state. This assumption about U implies standard state function reduction aspect of quantum measurement. In general U produces discrete superposition of states localized in zero modes and the positional information measure in zero modes becomes discrete. In the simplest case this measure reduces essentially to Shannon entropy defined by the probabilities that localization occurs for various discrete values of zero modes.

3. Without discretization in zero modes positional information measure would contain an infinite part, which does not however depend on the state. Thus, even without localization in zero modes it is possible to compare the information contents of different quantum histories

and the information gain associated with conscious experience is well defined, positive and at least formally finite. A beautiful information theoretic interpretation for the evolution by quantum jumps results. If U acts as a flow the general information gain can be expressed as an average information gain with weighting over the probabilities of various values of zero modes.

4. Since local information measure with respect to zero mdoes is in question, one can assign to each subsystem its own information gain. It is now however obvious whether this picture works in p-adic context.

2.4.1 Definition of the positional information measure in zero modes

If Kähler action were deterministic, configuration space spinor field would be determined once its values on the lightcone boundary are fixed. Thye non-determinism of Kähler action implies that given 3-surface Y^3 on the lightcone boundary corresponds to several absolute minima $X^4(Y^3)$. In fact, it seems that one must introduce infinite number of massless extremals (MEs), whose lightlike boundaries having lightlike M^4_+ projection take mathematically the role of lightcone boundary. It is not yet clear how to formulate the theory consistently using lightlike boundary and the collection of MEs: presumably one must extend the configuration space to include all these MEs. At practical level it is however obvious that MEs located in laboratory become the basic objects.

There is presumably also a discrete non-determinism involved and this forces also a generalization of the concept of 3-surface. The space of 3-surfaces on $X^3 \times CP_2$ is like a many-sheeted like Riemann surface with various sheets corresponding to various absolute minima $X^4(Y^3)$ fixed by choosing some minimal number of 3-surfaces from a particular absolute minimum. The earlier view was that these 'association sequences' provide a geometric representation for thoughts [H1]: the vision about p-adic physics as physics of cognition however suggests that association sequences give for sensory experience the character of multitime snapshot.

Contrary to the original beliefs, the non-determinism of Kähler action implies that it is not possible to reduce everything to the lightcone boundary. Rather, the inner product for the configuration space spinor fields can be expressed using integrals over the spaces of the 3-surfaces Y^3 belonging to $X^3 + \times CP_2$, where the surfaces X^3 denote lightlike projections of MEs to M^4_+ with moment of big bang ($X^3 = \delta M^4_+$) included. There is also a summation over the degenerate branches of $X^4(Y^3)$ for given X^3. Effectively it would seem that each ME defines its own information theory with MEs inside this ME possibly included.

The definition of information to be discussed is used also in the kinetic theory of gases and relies on the idea of the selection of the configuration space point defined by localization of the configuration space spinor field and on Shannon entropy.

1. The probability that 3-surface Y^3 in volume element dV of configuration space is selected is

$$dP \quad = \quad R(Y^3) \times dV \quad , \tag{2}$$

where R is 'modulus squared' for the configuration space spinor field at Y^3, which is essentially the norm of the state of fermionic Fock space.

2. The information about the position of Universe in configuration space associated with the configuration space spinor field is defined as the negative of the Shannon entropy measuring *the information gain in a complete localization of the configuration space spinor field.* Using division into volume elements dV

$$
\begin{aligned}
I &= -\sum_{Y^3} dP \times log(dP) \\
&= -\sum_{Y^3} R \times log(R) \times dV - \sum_{Y^3} R \times dV log(dV) \\
&\rightarrow -\int R \times log(R) \times DX^3 - log(dV)_{|dV \rightarrow 0} \ . \qquad (3)
\end{aligned}
$$

The first part gives, at least formally, a well defined integral over the configuration space. Second term is infinite unless dV becomes effectively discrete. That the information contained by quantum history would be infinite, is not at all surprising. Note however that the infinite term does not depend on state!

3. Since it is only information differences which matter, one could therefore forget the infinite contribution and define information as

$$
I \equiv -\int R \times log(R) \times DX^3 \ . \qquad (4)
$$

This kind of formula of course applies also in ordinary single particle wave mechanics. One should perhaps call I as *available information*. The degeneracy of the absolute minima brings in summation over branches $X^4(X^3)$ but this is only a minor complication and is included in the definition of integral.

The dropping of the infinite background contribution ($log(dV)$) from the definition of information measure implies that the positional information in zero modes is not positive definite anymore. This is of course a questionable feature and contradicts the intuitive view about what information is.

4. If the localization in zero modes occurs and U acts effectively as a flow, then $U\Psi_i$ is localized in the set of discrete points of configuration space. If one replaces R which integral over the quantum fluctuating degrees of freedom, the definition of I reduces to a sum over zero modes

$$
\begin{aligned}
I &= -\sum_{z_i} p_i log(p_i) \ , \\
p_i &= \int_{qf,} R(z_i, qf) dV_{qf} \ . \qquad (5)
\end{aligned}
$$

Here z_i denotes for the discrete values of zero modes in one-one correlation with quantum numbers associated with fiber degrees of freedom (this corresponds to the correlation of quantum numbers with classical variables in state function reduction). qf denotes quantum fluctuating degrees of freedom. This expression is nothing but entanglement entropy for the entanglement between quantum fluctuating degrees of freedom and zero modes. Thus the effective flow property of U in zero modes guarantees both the finiteness and the positivity of the positional information measure.

Note that more general information measures are obtained as averages

$$
\begin{aligned}
I &= -\sum_{z_i} X_i(z_i) p(z_i) log(p(z_i)) \ , \\
p(z_i) &= \int_{qf} R(z_i, qf) dV_{qf} \ , \qquad (6)
\end{aligned}
$$

where X_i is average over fiber degrees of freedom characterizing what kind of information is in question.

The localization in zero modes implies that information for the final state of the quantum jump vanishes so that the positional information gain is maximal possible and equals to the information associated with the state $U\Psi_i$. In the sequel the basic properties of the positional information gain are discussed.

2.4.2 Connection with the information measure defined by Kähler action

One can decompose configuration space spinor field as

$$
\Psi = exp(\frac{K}{2}) f \ , \qquad (7)
$$

where K is Kähler function. This makes it possible to express information in the form

$$
I \equiv - < K > - < log|f|^2 > \ , \qquad (8)
$$

where the first term is expectation value for the negative of the Kähler function. Averaging involves integration over quantum fluctuating degrees of freedom with fixed values of zero modes plus discrete averaging over the zero modes.

What is remarkable that first term is a direct generalization of the purely classical hypothesis that Kähler function gives entropy type measure for the representative resources of the 3-surface measured by the number N_d of the degenerate absolute minima assumed to be proportional to $exp(-K_{cr})$, where K_{cr} is Kähler function at quantum criticality. This suggests that 'ontogeny recapitulates phylogeny' principle is at work also here in the sense that vacuum expectation for the classical measure for representative resources equals to the quantal information of the vacuum state (apart from infinite state dependent term).

2.4.3 Boolean and non-Boolean components of consciousness

Local information measures decompose quite generally into several parts. Kähler function represents vacuum contribution to information, f can in turn decompose to a product of zero mode functional and fermionic part giving an additional bosonic contribution to the information. The purely fermionic Fock space part of the f can be interpreted as the information related to Boolean mind, whereas bosonic contribution has interpretation as the information related to the proto level of consciousness [H1] which includes sensory experiences and emotions.

The original identification of the fermionic contribution was as reflective level of consciousness, "consciousness about consciousness". One the other hand, summation hypothesis telling how self hierarchy gives rise to a hierarchy of abstractions, follows by "Ontogeny recapitulates phylogeny" principle from the geometric model of the abstraction process as a formation of association sequences of association sequences. Hence the natural looking identification of the reflective thought as abstraction favours the identification of the reflective and proto levels of consciousness in terms of self and and its subselves. In case that there are no subselves, only reflective level

is present and would correspond to pure self-awareness without cognitive and sensory content, if latter identification is correct.

The fermionic part of f describes all fermions associated with the 3-surface representing universe: note that in TGD framework elementary bosons are regarded as fermion antifermion bound states in length scale of CP_2 so that all matter in the form of elementary particles corresponds to the reflective contribution to information. If f decomposes into a product of unentangled states then also information reduces to a sum of the informations associated with these subsystems.

2.4.4 Dispersion creates positional information in zero modes

By definition I measures the information gain in the localization of the configuration space spinor field in zero modes. Completely localized configuration space spinor field does not carry (potential) information whereas the delocalized field carries a lot of it.

This picture provides a beautiful information theoretic interpretation for the time evolution by quantum jumps. The action of the operator U implies dispersion from sector D_{p_i} to entire configuration space and generates information (Djinn leaves the bottle!) and localization to the sector D_{p_f} means reduction of information (Djinn fullfills the wish (free will) and returns to a possibly new bottle). Therefore the information gain about classical universe associated with conscious experience is non-negative. Also the measurement of subsystem density matrix generates information and NMP maximizes this information gain.

Positional information in zero modes provides a general insight into the quantum physics of biosystems. Since living systems are known to be very (conscious) information rich systems, time development operator U must generate very large information, which means that the states $U\Psi$ for biosystems are very unclassical having wide distribution in configurations space. Hence the modelling of biosystems treating space-time as a fixed arena of dynamics, need not be a good approximation.

2.5 Combining number theory and information theory

TGD approach to consciousness forces to reconsider also the notion of information itself, and this leads to a new, number-theoretic view about information. This view might have radical implications for quantum computation. The view described in this section represents the latest (December 2002) view about information in TGD framework and is certainly nearest to the truth.

2.5.1 Number theoretic information measures

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

1. At the microtemporal level qualia correspond to the increments of various quantum numbers/zero modes in a quantum jump. Selves can be seen as ensembles of quantum jumps, and one can identify experienced qualia as ensemble averages qualia. Therefore one can assign entropy to a given quale. Usually entropy increases quantum jump by quantum jump and qualia get fuzzy. Formation of macroscopic quantum bound states changes the situation and mental image can stay clear as long as the bound state lasts.

2. The definition of the entropy in p-adic context is based on the notion p-adic logarithm depending on the p-adic norm of the argument x only ($x = p^n r/s$, r and s not divisible by p; $Log_p(x) = log_p(|x|_p) = -n$) [H2]. For rational- and even algebraic number valued probabilities this entropy can be regarded as a real number. The entropy defined in this manner can be negative so that the entanglement can carry genuine positive information. Thus p-adic bound state entanglement giving rise to a fusion of cognitive mental images is a natural correlate for the experience of understanding, and one can assign to heurekas a well

defined amount of information. Rationally entangled p-adic system has a positive information content only if the number of the entangled state pairs is proportional to a positive power of the p-adic prime p.

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

4. The modified definition of entropy would have deep implications. For the ordinary definition of the entropy NMP [H2] states that real entanglement is minimized in the state preparation process. For the number theoretic definition of entanglement entropy NMP stabilizes the entanglement with positive information content. The fragility of quantum coherence is the basic problem of quantum computation and the good news would be that Nature itself (according to TGD) tends to stabilize quantum coherence if entanglement is rational/algebraic.

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

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

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

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

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

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

The view about the crucial role of rational and algebraic numbers as far as intelligent life is considered, could have been guessed on very general grounds from the analogy with the orbits of a dynamical system. Rational numbers allow a predictable periodic decimal/pinary expansion and are analogous to one-dimensional periodic orbits. Algebraic numbers are related to rationals by a finite number of algebraic operations and are intermediate between periodic and chaotic orbits allowing an interpretation as an element in an algebraic extension of any p-adic number field. The projections of the orbit to various coordinate directions of the algebraic extension represent now periodic orbits. The decimal/pinary expansions of transcendentals are un-predictable being

analogous to chaotic orbits. The special role of rational and algebraic numbers was realized already by Pythagoras, and the fact that the ratios for the frequencies of the musical scale are rationals supports the special nature of rational and algebraic numbers. The special nature of the Golden Mean, which involves $\sqrt{5}$, conforms the view that algebraic numbers rather than only rationals are essential for life.

2. Other options

There are also other options besides the maximally conservative option.

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

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

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

2.5.3 Quantum computation and quantum problem solving in TGD Universe

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

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

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

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

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

2.5.4 Information concept at space-time level

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

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

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

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

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

2) Define the information as sum

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

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

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

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

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

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

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

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

$$S = -\sum_p S_p = I \quad .$$

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

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

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

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

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

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

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

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

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

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

Seeing the prime factorization might be also possible via a direct sensory perception. Oliver Sacks tells in his book 'The man who mistook his wife for a hat' [44] about twins, John and Michael, who had a mysterious ability to 'see' large numbers and their prime factorizations despite the fact that their intelligence quotient was about 60 and they did not have any idea about the notions of integer and prime. For instance, matchbox was dropped from the table and its contents were spread along the floor. Both twins shouted immediately '111!'. Then John mumbled '37', Michael repeated it and John said '37' third time. Obviously this was their sensory representation for the decomposition $111 = 3 \times 37$ of number 111 to a product of primes! The explanation of these strange feats suggested in [H3] is a less general idea about physical representation of the factorization. The proposed mechanism could indeed explain prime factorization as a sensory perception involving no algorithmic cognition at all.

3 Information theoretic interpretation of quantum TGD

Frieden's hypothesis [21, 22, 23] that the action principles of physics have information theoretic interpretation inspired the idea that Kähler action has information theoretic interpretation. It must be emphasized that this section represents kind of an archeological layer in the development of TGD based view about information, and I have not yet tried to relate it to the latest (December 2002) TGD based view about information described in the previous section.

3.1 Information theoretic interpretation of action in Frieden's theory

Frieden [21, 22, 23] introduces two kinds of information concepts. Fisher information, usually denoted by I, is defined as the information which can extracted from a physical phenomenon by measurements of a specific type. Information J is defined as the information contained by the phenomenon and in general $J - I \geq 0$ holds true.

The action defining the dynamical equations of a physical theory decomposes into a difference $I - J$, where J is the total information contained by the state and I is the available information. I and J depend on what is measured. Minimization of $I - J$ for position measurement leads to classical Newton's equations.

In classical mechanics J corresponds typically to the integral of potential energy V and I corresponds to the integral of kinetic energy I, in accordance with the decomposition

$$S = \int L dt, \quad L = T - V \ .$$

Maxwell action is obtained by considering position measurement in presence of charge. For Maxwell action

$$S = \int (B^2 - E^2) d^4x \ ,$$

the entire integral of B^2 corresponds to I whereas total information J is non-vanishing only provided there is coupling to external currents.

This interpretation does not look promising from the point of view of TGD.

1. The total information J is identically zero whereas absolute minimization of Kähler action implies that the available information I is negative. It is difficult to assign physical meaning to negative available information.

2. Frieden's approach puts position measurement in a special role and the idea that every measurement type defines its own physical law, looks peculiar. A more natural interpretation for the Kähler function would be a measure for some kind of classical information associated with the space-time surface.

3. Frieden's interpretation has no connection with the TGD inspired ideas about symbolic and cognitive representations.

3.2 Kähler function is unique from the requirement that temporally localized conscious experience is possible

The properties of the Kähler action are unique from the requirement that the information given by conscious experience is maximized. The crucial property of the Kähler action is its vacuum degeneracy, which implies classical non-determinism and makes possible mindlike space-time sheets. As a consequence, it becomes possible to have time localized conscious information about quantum histories and sensory experience becomes possible (note that cognition is possible already by the inherent non-determinism of the p-adic field equations). Also the arrow of the psychological time is generated. Thus the requirement that temporally localized conscious experience is possible, selects Kähler action uniquely.

Some of the consequences are matter-mind decomposition for the space-time surfaces resulting as a decomposition to mind-like and material space-time sheets. Similar decomposition applies at the level of the configuration space spinors. Spin glass analogy and the notion of infinite primes,... are also consequences of the classical non-determinism.

Note that this argument is a strong argument in favour of the information theoretic interpretation but does not involve the assumption about $I - J$ decomposition of the Kähler function. Furthermore, whatever the information theoretic interpretation of the Kähler function is, it must be consistent with this interpretation. An attractive guess is that the negative of the Kähler function could be identified as a measure for the amount of potential information contained by the classical space-time surface. It seems that this information must be symbolic information rather than cognitive since real mind-like sheets seem to be geometric correlates of symbolic rather than cognitive representations.

3.3 Information theoretic interpretation of Kähler function

The $I - J$ decomposition of the Kähler function in the manner suggested by Frieden's theory does not make sense in TGD context. On the other hand, the formal similarity of the vacuum functional with thermodynamical partition function suggests the interpretation of the vacuum functional as an exponent for the negative of some kind of entropy type variable so that the negative of the Kähler function would correspond to entropy.

The exponent $exp(-K_{cr})$ of the negative of Kähler function, for a suitable choice of the value α_{cr} of the Kähler coupling strength, should somehow measure the number of some kind of microstates. A natural identification of the 'microstates' is as a degeneracy caused by the classical non-determinism of the Kähler action, which implies that configuration space integration over 3-surfaces Y^3 at the light cone boundary involves summation over all possible association sequences going through the same 3-surface Y^3 on the light-cone boundary and having the same value of the Kähler function. This summation brings in a degeneracy factor, which will be referred to as N_d.

An educated guess is that the degeneracy factor N_d is in a good approximation proportional to the exponent of the negative of the Kähler function, when Kähler coupling strength has critical value α_{cr}:

$$N_d \simeq exp(-K_{cr}) \ . \tag{9}$$

Note that α_{cr} depends on the sector D_p of the configuration space since Kähler coupling strength depends on p-adic length scale in a logarithmic manner typically predicted by $U(1)$ gauge theories. This hypothesis allows to answer to the basic questions related to the definition of the Kähler function.

1. Why absolute minimization of Kähler action?

The first consequence of the hypothesis is that absolute minimization of the Kähler action maximizes some kind of information. This is achieved by generation of Kähler electric fields necessarily accompanied by mind-like space-time sheets, whose contribution to N_d compensates the negative Kähler action. Perhaps this could partially explain why electric fields, in particular those associated with the cell membranes, are so important in biosystems. The construction of conscious systems artificially perhaps possible some day could thus involve construction of Kähler electric fields.

2. Why quantum criticality?

This hypothesis throws also new light to the precise mechanism of the quantum criticality. At quantum criticality the degeneracy factor N_d in the functional integral over the configuration space compensates the exponent of the negative Kähler function even when its value is infinite! Below quantum criticality the probabilities for 3-surfaces having negative Kähler function suffer exponential cutoff so that only the 3-surfaces for which the value of Kähler function per volume vanishes, are important. The resulting universe is obviously much less interesting than quantum critical universe, which maximizes complexity. Also the maximum for the total information content of the quantum jump is always finite for subcritical universe unlike for quantum critical universe. Above quantum criticality the degeneracy dominates over vacuum functional and configuration space integral of the vacuum functional diverges so that the theory becomes mathematically ill defined. Therefore quantum critical universe possesses maximal complexity and is as interesting and intelligent as universe can be! Note that quantum criticality was already earlier realized to be crucial for consciousness since it makes possible long range quantum correlations and hence arbitrarily large macroscopic quantum systems.

It deserves to be noticed that the proposed estimate for the value of the degeneracy factor N_d gives for the TGD inspired theory of consciousness a status of a quantitative theory. Once the value

of the Kähler function is known, then also the representational (symbolic representations seem to be in question) capacities associated with the 3-surface are known. A reasonable guess is that this criterion makes sense also for finite space-time regions. The fact that $\alpha_K(p)$ decreases with p-adic length scale means that the degeneracy increases exponentially as the function of $1/\alpha_K(p)$. This is just what p-adic evolution suggests: the larger the value of p, the larger the typical space-time surface and the larger the degeneracy since new modes emerge, when p increases.

In [E5, E6] arguments leading to the determination of the precise value of the Kähler coupling strength was proposed. The argument reduced the problem to the guess about the general form of the partition function for an arithmetic quantum field theory: the bosonic part of the partition function was assumed to be expressible in terms of Euler Zeta function.

The interpretation of this partition function was as a fictitious partition function emerging in the calculation of the fermionic determinant associated with the functional integral defined by the induced spinor fields. It is however possible to interpret this partition function also as a real partition function providing a statistical description of the degrees of freedom related to symbolic representations provided by the mind-like space-time sheets. If this interpretation is correct, then the connection between infinite primes and symbolic representations provides support for the arithmetic quantum field theory based ansatz for the partition function. An open question is whether these two interpretations are actually mutually compatible.

3.4 The role of electric fields in living matter

Absolute minimization of Kähler action is achieved by generating strong Kähler electric fields, or essentially equivalently, strong electric or Z^0 electric fields. The generation of magnetic fields has opposite effect as is clear from $B^2 - E^2$ decomposition of the Maxwell action. The proposed information theoretic interpretation of the Kähler function implies that the generation of the Kähler electric fields generates resources of symbolic information. An attractive, considerably stronger, hypothesis is that in a good approximation the negative of the total Kähler action in a given space-time volume of Minkowski space gives the symbolic information resources contained in this volume. Amazingly, strong electric fields are known to be vital for the functioning of the living systems. Needless to say, there is no obvious explanation for this in standard physics context.

1. Classical electric fields are in a fundamental role in biochemistry and living biosystems are typically electrets containing regions of spontaneous electric polarization. Fröhlich [33] proposed that oriented electric dipoles form macroscopic quantum systems with polarization density serving as a macroscopic order parameter. Several theories of consciousness share this hypothesis. Experimentally this hypothesis has not been verified. TGD suggests much more profound role for the unique di-electric properties of the biosystems: the presence of strong electric dipole fields is a necessary prequisite for cognition and life and could even force the emergence of life. Strong electric fields imply also the presence of the charged wormhole BE condensates: the surface density of the charged wormholes on the boundary is essentially equal to the normal component of the electric field so that wormholes are in some sense 'square root' of the dipole condensate of Fröhlich! Wormholes make also possible pure vacuum polarization type dipole fields: in this case the magnitudes of the em field at the two space-time sheets involved are same whereas the directions of the fields are opposite. It has been already suggested that the splitting of Z^0 wormhole contacts creates cognitive neutrino pairs. Also microtubules carry strong longitudinal electric fields.

2. One of the basic mysteries of cell biology is the rest potential of the living cell. Living cell membranes carry huge electric fields: something like 10^7 Volts per meter. The electric part of the Maxwell action gives a rough upper bound for the symbolic information resources of an axon:

$$-K \sim \frac{1}{16\pi \times \alpha_K} \times E_K^2 \times Vol \times T \ .$$

One obtains order of magnitude estimate for the Kähler electric field across membrane as $E_K \sim V/d$, where V membrane potential of order $V \sim .1$ Volts and $d \sim 10^{-8}$ meters is the thickness of the axonal membrane. $Vol = 2\pi \times R \times d \times L$ is the volume of the axonal portion of neuronal membrane. The radius and length of the axonal membrane can be taken to be $R \sim 10^{-6}$ meters and $L \sim 10^{-6}$ meters respectively. For definiteness one can take the lifetime of the cell membrane to be $T \sim 1$ year ($\alpha_K \sim 1/137$ denotes Kähler coupling strength) In this manner one finds an upper bound

$$-K \sim 10^{21} \ \text{bits}$$

for the symbolic information resources of the axonal membrane. This is huge amount of information. Of course, only a small fraction of it contributes to single conscious experience since the dispersion of the configuration space spinor field in the 'mindlike' degrees of freedom is never complete and single quantum jump reduces only a small amount of the total sensory degeneracy.

3. Also EEG oscillations, which have emerged at rather late stage of evolution, give a sizable contribution to Kähler action. The amplitude of EEG is roughly one per cent of the membrane potential so that the fractional change of sensory information resources is about 10^{-2} per cent. Since the value of the Kähler action per space-time volume is huge, this however means a huge increase of the symbolic information resources. The slower the EEG rhythm, the larger the amplitude of EEG, which suggests increased cognition. Meditative states of consciousness are indeed associated with slow EEG rhytms. Note that neural activity and hence presumably also neural contribution to consciousness, is small in meditative states.

4. Epileptic seizures involve anomalously large electric fields in some brain regions. Perhaps epilepsy is the price paid for anomalously high information content of sensory experience (recall the characters of Dostojevksi's novels having their epileptic attacks!). Epilepsy has always been the professional disease of prophets: perhaps precognition necessitates exceptionally strong electric fields!

3.5 Generation of artificial life by generating strong electric fields?

The observation that the generation of strong electric fields is necessarily accompanied by cognition might be the counterpart of the $E = mc^2$ formula in consciousness theories and make possible the construction of artificial life. Also the symbiosis of living systems with electronic systems containing strong electric fields could be considered. Nanotechonology could be perhaps used to build strong electric fields in short length scales. Of course, even ordinary computers might have some conscious intelligence, not for the reasons proposed by AI people, but because their circuits contain electric fields.

One could consider the possibility of testing TGD inspired theory of consciousness by studying whether the presence of strong electric fields could lead to any phenomena characteristic for life. The total Maxwell action for these systems gives a precise estimate for their representative resources. In [I5] an explanation of $1/f$ noise [24, 20, 28] based on quantum criticality and quantum control of the behaviour of material space-time sheets performed by mind-like space-time sheets, will be proposed. If this explanation is correct, $1/f$ noise serves as a signature for the presence of the mind-like space-time sheets. Electronic circuits are characterized by $1/f$ noise as a rule, which indeed suggests that some kind of primitive cognition is present. One testable prediction is that

the generation of electric fields should increase the intensity of $1/f$ noise. The simplest, but not the only possible, explanation for the effect of anesthetics is that their presence reduces electric fields of, say, microtubules and cell membranes. One could also test the effect of anesthetics on $1/f$ noise appearing in biosystems.

4 Association sequences and selves

The concepts of association sequence and self are fundamental in TGD inspired physics based model for symbolic and cognitive consciousness and "ontogeny recapitulates phylogeny" metaphor relates them closely to each other.

4.1 Association sequences and classical non-determinism

Quite generally, the non-determinism of Kähler action corresponds to that of symbolic representations (say language) and p-adic non-determinism to that of intention, cognitive representations, and imagination. Imagination indeed involves maps of cognitive representations to symbolic representations provided by say nerve pulse patterns.

Association sequences are related to the classical non-determinism forcing the generalization of the concept of 3-surface by allowing sequences of 3-surfaces with time like separations. There is extremely tight correlation between the 3-surfaces of the sequence and typically only a finite number of new degrees of freedom labeled by a finite number of binary digits results in this manner. In case that non-determinism corresponds to N subsequent bifurcations in the time-development of the system, the number of the association sequences is 2^N.

Association sequences can be interpreted as symbolic simulations of classical time development and the associated conscious experiences correspond to multitime snapshots of time evolution, in which the individual snapshots are however experienced subjectively as simultaneous events. Mind-like space-time sheets, almost vacuum space-time surfaces with finite time duration, are especially promising candidates for association sequences since in this case the enormous vacuum degeneracy of the Kähler action suggests strongly classical non-determinism for the dynamics determined by the absolute minimization of Kähler action. But also material space-time sheets having infinite duration can behave non-deterministically and correspond thus to association sequences, which can consists of infinite number of 3-surfaces.

"Ontogeny recapitulates phylogeny" metaphor allows to identify association sequences associated with the mind-like space-time sheets as the geometric counterparts of selves. Whereas self can be regarded as a heap of moments of consciousness occurred after the wake-up, association sequence can be regarded as a sequence of snaphots about classical time evolution. Quantum non-determinism at the level of self corresponds to classical non-determinism at the level of the association sequence. Whereas selves give rise to subjective memory about previous moments of consciousness, association sequences give rise to geometric memory making possible simulations of the geometric past and future, which are reliable in the limit that the effect of quantum jumps is negligible.

4.2 Association sequences of association sequences and model for abstraction

Also association sequences of association sequences of ... can be formed. An attractive interpretation is as formation of abstractions and an entire hierarchy of abstractions is possible. At the level of selves this corresponds to the formation of selves from subselves and summation hypothesis states that the experience of self is sum over the abstracted experiences of its subselves. Association sequences of associations sequences of ... can be regarded as a geometric realization for

the self hierarchy. This interpretetation is consistent with the identification of the reflective and proto levels of consciousness as contributions of self and its subselves to conscious experiences. The difficulty of consciously forming higher level abstractions such as experiencing what it is to have an experience of having experience of having experience of red can be understood if subselves are represented as abstractions providing average experiences about subselves of subselves. Effectively subsub...selves represent unconscious mind.

One could also consider the identification of the reflective level of the consciousness as represented by the fermionic Fock space whose state basis has interpretation as Boolean algebra. This interpretation is however not favoured by "onthogeny recapitulates phylogeny" metaphor: it seems that fermions provide only a representation for Boolean mind. Fermionic state basis can also be regarded as a finite field $G(2, N)$ having 2^N elements as also do have association sequences associated with N multi-furcations. In case of closed space-time surfaces one could perhaps even speak about supersymmetry relating the Boolean algebra defined by cognitive fermion pairs and mindlike space-time sheets.

4.3 Products of association sequences

It is possible to form products of association sequences by combining association sequences associated with two weakly interacting subsystems. Association sequences of association sequences can be formed by taking association sequence at p-adic level p and by gluing to each 3-surface associated with this sequence a 3-surface at level $p_1 < p$. This operation gives rise to $N(p_1)^{N(p)}$ association sequences and could be interpreted as a geometric model for abstraction process. Obviously the process yields fractal like structure when repeated several times. An attractive possibility is that this kind of process gives rise to cognitive and sensory hierarchies and realization of the Slaving Hierachy of Haken at the level of conscious experience. This picture could also provide a geometric model for the formation of language such that phonemes, words, sentences, etc correspond to a hierarchy of mind-like space-time sheets with increasing value of p-adic prime.

At the level of selves product of association sequences corresponds to parallel selves belonging to the same level of hierarchy and having no direct access to each other's experiences. Right and left halves of brain of split brain patient are a possible example of this kind of situation. Formation of join along boundaries bonds between space-time surfaces defining two association sequences in the product makes possible generation of quantum entanglement between corresponding selves and formation of single self and disappearance of composite selves. Formation of wholes from parts at the level of mental images presumably corresponds to this process. Conscious association $A \leftrightarrow B$ might be formed when the entanglement between selves disappears in quantum jump.

4.4 Replication of association sequences

The replication of association sequences provides a possible manner for a quantum state to construct representations for some aspects of its time development via quantum jumps and hence to remember something about its previous quantum states by re-experiencing some aspects of previous quantum jumps. Replication provides also a manner to produce entangled association sequences just like the decay of a particle to two particles produces entangled particle pair. Replication could play same role in the cognitive and sensory evolution of individual as it plays in the ordinary evolution. The replication at the level of selves would correspond to replication of memes, ideas. Language is a mechanism of meme replication, which is much more advanced than mere copying. What happens is that standardized sound patters generate standardized self-organized self-cascades giving rise to generation of selves followed by the generation of subselves followed by.... Note that the decomposition of particles to... elementary particles at the level of matter corresponds to the decomposition of processes to.... elementary processes consisting of sequences of

quantum jumps at the level of subjective existence. For instance, DNA molecules could represent elementary selves in biosystems.

4.5 What is the typical time span for association sequences?

One can wonder what is the typical time span of for the association sequences at level p. p-Adic length scale hypothesis suggests that the characteristic spatial length scale is just $L(p)$ and that the corresponding time scale is by dimensional analytic argument determined $T \sim L/v$, where v is the typical velocity of information transfer in the system. In elementary particle length scales v can be identified as light velocity whereas in many particle systems the most natural guess for v is as some typical signal velocity from the requirement that a connection with the classical picture of information processing and transfer must exist. For instance, in brain the velocity of nerve pulse progation about $v \sim 10^{-6}c$ would give that for p-adic length scale corresponding to the size of brain of order .1 meters, the duration of association sequences is of order 10^{-3} seconds so that the time non-locality of conscious experience would be rather short. Of course, also longer association sequences are possible since also the next level of the abstraction hierarchy is realized partially.

Taking "ontogeny recapitulates phylogeny" metaphor to its extreme one could argue that the duration of association sequences associated with our selves is same as that of subjective memory identifiable as short range memory and thus of order of few seconds. On the other hand, our ability to plan in time scale of order lifetime suggests that we have access to much longer association sequences: this could be however due to a temporary entanglement with higher level selves having also much longer subjective memories. Even our body could give rise to a mind-like space-time sheet with a duration of order our lifetime.

4.6 Quantum entanglement and association sequences

The role of quantum entanglement is crucial for the TGD inspired theory of consciousness. Quantum entanglement, unless it is bound state entanglement, is reduced in quantum jumps in fermionic degrees of freedom and fiber degrees of freedom of the configuration space. The localization occurring in zero implies that bound state entanglement in zero modes is not possible. The fermionic oscillator operators for leptons and quark like spinors represent fermionic degrees of freedom (note that also elementary bosons can be regarded as fermion-antifermion composites in TGD). The simplest fiber degrees of freedom correspond to the rotational and color rotational degrees of freedom associated with the space-time sheets and also mind-like sheets have these degrees of freedom. In fact, it might be possible to identify the quantum correlates of the various qualia associated with vision in terms of cm degrees of freedom for mindlike space-time sheets.

Bound state quantum entanglement between association sequences might be an important mechanism of symbolic thought.

1. Quantum entanglement for the association sequences suggest a manner to realize associations $a \leftrightarrow b$. Association sequences a and b could correspond to single instances of a more general bundle of associations $A \leftrightarrow B$.

2. An interesting possibility is that this kind of entangled superpositions of associations could be regarded as theorems $A \rightarrow B$. At fermionic level quantum entanglement could give metalevel statements of type $P(a) \rightarrow P(b)$ stating that statement $P(a)$ implies statement $P(b)$. There is however a problem associated with the direction of the arrow of implication: does a imply b or vice versa? The fact that the logical implication seems to be very closely related to the arrow of time suggests that implication is realized by quantum entanglement in time direction between parts of the association sequence. Ordinary entanglement in spatial directions would give rise to ordinary non-directed associations. One could however argue that

logical causation cannot be represented as association since geometric time does not possess inherent arrow. This does not exclude the possibility that various rules about behaviour of external world could not be coded into associations represented as quantum entanglement between association sequences associated with mind-like space-time sheets.

5 Logic and fermions

The state basis for the fermionic Fock space has a natural interpretation as a Boolean algebra (fermion number =1/0↔ yes/no). In this manner ordinary Boolean algebra is extended to vector space spanned by fermionic states. When cognitive fermion pairs are used instead of fermions, fermion number conservation does not pose any constraints and full linear superposition of the Boolean algebra elements is possible. An interesting question is whether one could consider ordinary Boolean logic as some kind of limit for the complex quantum logic.

The simplest TGD based model for thinking systems leads to the result that thoughts correspond to quantum states in discrete spaces. The reason is that slightly non-deterministic classical time evolution means a finite number of multi-furcations. These additional dynamical degrees of freedom correspond to N-element set labelling the different time evolutions associated with given initial values. This suggests that a suitably defined *binary* Hilbert space having Z_2 rather than complex numbers as a coefficient field could provide a simple quantum model for a thinking system. This raises the following question.

What would a quantum field theory in discrete space and with the field of complex numbers replaced with binary numbers Z_2 (0,1/Yes,No) look like?

The answer is following.

1. The state basis of the quantum field theory defined in N-element set is nothing but a Boolean algebra consisting of 2^N elements: all possible statements about the N elements interpreted as propositions! Bosons and fermions are one and the same thing and behave like fermions since occupation number can have only the values 0 and 1.

2. The requirement that triangle equality for the inner product is satisfied, does not allow linear superposition and one must choose some orthogonal basis for the space. The absence of quantum superposition means that theory is completely classical. Thus it seems that Boolean QFT is completely classical and the transition from classical mechanics to quantum theory could be regarded as a transition from binary QFT to complex QFT or from a binary logic to complex logic.

3. Quantization means construction of statements about statements: the simplest model for an abstraction process one can imagine! One can of course continue this quantization: second, third, etc., quantization is possible and this corresponds to a construction of statements about statements about..... Hence a direct connection with the ideas about genetic code emerges.

4. Also the state basis in the Fock space of the ordinary fermions has interpretation as a Boolean algebra, all possible statements about some propositions (particle with a definite spin component is at point x).

5.1 The state basis of fermionic Fock space as Boolean algebra

The state basis of a fermionic Fock space can be interpreted as a basis of a Boolean algebra. In quantum TGD all elementary particles are constructed using fermionic oscillators operators.

This suggests that entire quantum field theory is actually a representation of Boolean algebra and N-fermion states have interpretation as statements about basic propositions labelled by the indices labelling fermionic oscillator operators. In particular, configuration space spinor structure is constructed in terms of the fermionic oscillator operators for the second quantized spinor fields on space-time and this suggests a deep connection between spinor geometry and logic. Perhaps one could say that quantum logic is C-valued in the sense that all complex superpositions of a statement and its negation are possible.

In Boolean algebra one can select the maximum number of 2^{N-1} mutually consistent statements as axioms. An interesting possibility is that only these mutually consistent statements are physically realized so that the number of states is reduced by a factor of one half. Amusingly, in the ordinary fermionic field theory the states created by a finite number of oscillator operators are the counterparts of the mutually consistent statements, their negations would correspond to a vacuum state obtained as an infinite product of all creation operators annihilated by creation operators. The states created by annihilation operators from this states are not allowed in QFT since they would have infinite energy.

One can identify the complex valued linear space of fermions as a generalization of Boolean algebra to complex Hilbert space. Cognitive fermion pairs could provide realization for this space as pairs of fermion and antifermion belonging to different space-time sheets and representing logical statement and its negation: the automatic presence of negation is rather natural from the point of view of consciousness theory. The splitting of the wormhole contacts connecting the space-time sheets gives rise to annihilation process generating fermion and antifermion pair (fermionic quantum numbers reside on the boundary components of the split wormhole contact). In this manner one avoids problems related to fermion number conservation encountered otherwise in physical realization of the fermionic logic. Alternative possibility is to assume fixed number of fermions and associate truth values with the direction of spin.

5.2 Boolean algebra as Boolean QFT

Boolean algebra $B(N)$ is generated by all possible yes/no statements about N propositions. It consists of sequences of N binary digits of form $(...,1,0,0,..,1)$ having value of 0 or 1. Addition is with respect to Z_2 so that $1+1=0$. Boolean algebra is Z_2 linear space and the elementwise multiplication of the binary digits in the string makes it algebra. $(0,0,0,..)$ and $(1,1,....,)$ are zero and unit elements of the algebra.

Geometrically Boolean algebra $B(N)$ corresponds to all possible subsets of an N-element set. Sum corresponds to a symmetric difference (take the union of sets and throw away the common elements). Multiplication corresponds to the intersection of the sets. Entire set represents unit element and empty set zero. Empty set is not physically realizable, or equivalently, the zero element of the Boolean algebra does not correspond to a physical state in the Z_2 Hilbert space defined by the Boolean algebra.

Quantum field theory in N-element set formed by the basic propositions (analogous to 3-space in QFT) means associating to each element of the N-element set creation and annihilation operators and postulating standard commutation relations with them:

$$[a^\dagger(i), a(j)] = 1 \quad .$$

One can also consider fermions that is anticommutation relations but since -1=1 in Boolean algebra, they are equivalent with the bosonic commutation relations so that Boolean bosons and fermions are one and the same thing in the Boolean QFT.

The states of this QFT are constructed in the usual manner. The only difference is the occupation numbers are Z_2 valued and are either one or zero just as in the case of fermions. Thus Boolean particles are fermions always. Since N creation operators are involved one obtains a space

generated by 2^N states. The proposition and its negation correspond to the states created by, say I oscillator operators and the dual of this state created by the remaining $N - I$ oscillators operators. Statement corresponds to I particles and its negation to I holes in the dual ground state containing all N oscillator operators.

Thus the state basis is nothing but the Boolean algebra associated with the N element set! Thus the state basis of Z_2 valued quantum field theory in the set of N propositions is nothing but the formation of all possible statements about these statements: a model for abstraction process. One can apply this process to the $2^N - 1$ element set and by continuing this process get a sequence of second quantizations as a sequence of abstractions.

The assumption of unrestricted linear superposition in Z_2 Hilbert space leads to difficulties with Schwartz and triangle inequalities. The physical interpretation of the theory requires that inner product satisfies Schwartz inequality

$$|(x, y)| \leq |x||y| \quad .$$

Linear superposition allows states, say y, with zero norm since any superposition of even number of orthonormal states has zero norm in Z_2. The norm of the inner product of one of the basis states appearing in zero norm state, call it x, with the zero norm state y equals to one and is not smaller than the product of the norm of the basis state and state with vanishing norm: one obtains $1 < 0$, which does not make sense if inner product is interpreted as real number (as a Z_2 valued number one could perhaps say $1 = -1 < 0$). One ends up to difficulties also with the triangle inequality: $|x+y| \leq |x|+|y|$ if x and y are zero norm states with single common element of orthonormal basis so that one has $|x + y| = 1$.

The only possible manner to save Schwartz and triangle inequalities is to assume that linear superposition is not allowed for Z_2 Hilbert space. This in turn means that situation is completely classical! If the set generating Boolean algebra consists of entire 3-space, this means that every state is gauge equivalent with an N-particle state of completely localized particles. This in turn implies that Boolean QFT should be more or less equivalent with classical mechanics and one could understand the transition from classical physics to quantum physics as the replacement of Z_2 with complex numbers C as the coefficient field of the state space.

One can change state basis by unitary transformations. Unitary matrices are obtained from orthogonal Z_2 valued unit vectors possessing entries equal to 1 or 0. Any unitary matrix corresponds to a matrix representing the permutation of 2^N elements of the basis of the Boolean algebra. Time development operator in this quantum field theory is always defined for a *finite* time interval only (the length of the 'chronon' is fixed naturally in p-adic QFT) and represents a permutation of this basis. In particular, a nonlinear transformation of the oscillator operators in general occurs. All unitary transformations are permutations, which do *not* lead to state basis involving superpositions of the basic states. This is in accordance with the observation that Boolean QFT is completely classical.

5.3 Boolean mind and neutrinos

Very low energy neutrino physics a la TGD differs from that predicted by standard model dramatically because TGD predicts the presence of classical Z^0 fields coupling to neutrinos. Even more classical Z^0 fields become important above cell length scale since this length scale corresponds to the Compton length of neutrinos.

Ordinary fermions cannot reside on mindlike space-time sheets unless they are created as pairs with vanishing total quantum numbers (in particular energy!): this is possible only if the second spacetime sheet has negative time orientation. Exotic, possibly dark, neutrinos are however exceptional [M6, J7]. Exotic neutrinos are an ideal tool of cognition since they do not couple to electromagnetic interactions and, having couplings only to the classical weak fields. TGD based

model of condensed matter predicts that the classical Z^0 binding energy of the exotic neutrino with condensed matter makes neutrino energy in condensed matter negative and large [F9, M6].

From this it is still a long way to precise models and one can make only educated guesses.

1. Cognitive neutrino pairs could reside in the defect regions of neutrino super conductor which is superconductor of type I having complicated stripe like defect regions near criticality. TGD based model for the interaction of neutrinos with condensed matter predicts that the thickness of the defect regions is of order 10^{-8} meters. Hence cell membranes are excellent candidates for the defect regions. One indeed ends up to a detailed quantitative model of cognition and memetic code by combining this idea with the observation about magnetic and Z^0 magnetic transitions as a fundamental element of our consciousness [M6].

2. Also chromosomes (having same thickness as cell membranes) could be identified as defect regions of neutrino super conductor. Very simple model for the abstraction process as a hierarchy of Boolean statements about Boolean statements about... starting from two basic statements explains the basic numbers of the genetic code [L1]. It is difficult to believe that this could be mere accident. Cognitive neutrino pairs indeed allow to construct a model of a many-sheeted DNA realizing gene level Boolean mind and possibly explaining the mystery of introns [31] and the role of cognitive neutrino pairs is very similar to that in cell membrane cognition. One possibility is that cell membrane cognition assigns quantitative measures and names to conscious experiences as the integers defined by the sequences of the cognitive neutrino pairs whereas DNA cognition represents conscious beliefs: thus DNA would store information about both material and cognitive basic structure [L1, M6, L2].

5.4 Combinatorial Hierarchy as a hierarchy of 'genetic codes'

The simplest model for abstraction process is based on the process in which one forms first all possible Boolean statements about N basic statements, 2^N alltogether. If one drops one of the statements one has $M_N = 2^N - 1$ statements: M_N is Mersenne number. The motivation for the dropping of one statement might be that in set theoretical realization one of the statements corresponds to empty set and is not realizable. Alternatively, in the realization based on many-fermion states, vacuum state could correspond to this kind of state. One can form also statements about statements: the first level of abstraction. This leads to $M_{M_N} = 2^{M_N} - 1$ many-fermion states. Construction is especially intersting if the numbers $M(M_N)$ are primes, so called Mersenne primes. Indeed, in some cases one obtains hierarchies of Mersenne primes by repeating the construction as long as it works.

The so called Combinatorial Hierarchy, shown already earlier to provide an explanation for the numbers of the Genetic Code, emerges as the most notable hierarchy. The Combinatorial Hierarchy [16] consists of the Mersenne numbers $2, M(1) = 3, 7$,$127, 2^{127} - 1, ..$ constructed using the rule $M(n+1) = M_{M(n)} = 2^{M(n)} - 1$. The explicitely listed ones are known to be primes. Combinatorial Hierarchy emerges from a model of abstraction process as subsequent transitions from level to metalevel by forming Boolean statements about Boolean statements of level n and dropping one statement away and starting from $n = 2$ basic statements. Combinatorial Hierarchy results also by constructing the sets of all subsets with empty set excluded starting from two element set.

The set of statements at level n can be given a structure of Finite Field $G(M(n), 1)$ if $M(n)$ is prime. The multiplicative groups $Z_{M(n)-1}$ form a nested hierarchy and the coset spaces $Z_{k_n} \equiv Z_{M(n+1)-1}/Z_{M(n)-1}$ are cyclic groups. Combinatorial Hierarchy based model of Genetic Code explains the number of DNA:s and aminoacids and the representation of words of the GC as triplets of 4 different codons. Aminoacids correspond to $k_{n=3} = 21$ axioms of a formal system defined by $n = 3$ level of Combinatorial Hierarchy having a unique imbedding as the group $Z_{k_n} \subset Z_{M(n)-1}$

$= Z_{126}$ and DNA:s correspond to the set $X_{N(DNA)} \subset Z_{M(n)-1}$ of $N(DNA) = (M(n)+1)/2 = 64$ mutually consistent statements at level n regarded as special cases of general theorems. GC corresponds to the mapping $x \to x^{k_{n-1}} = x^6$ in $Z_{M(n)-1}$ mapping DNA type statements to aminoacid type statements. The numbers of DNA:s coding single aminoacid are reproduced in a symmetry breaking mechanism involving the finite groups $Z_{p_{n-1}}$ and Z_{k_n} and symmetry breaking is in a well defined sense minimal. The infinite hierarchy of possible genetic codes suggests the possibility of an infinite hierarchy of increasingly complicated lifeforms or forms of intelligence.

5.5 Boolean mind and memetic code

For quite a long time it has been clear that neutrino and antineutrinos might providea a realization of Boolean mind and the memetic code. There are actually several candidates for this kind of realizations.

1. The first model of memetic codon is based on *geometro-temporal* sequences of cognitive neutrino pairs having nearly vanishing energy. The classical non-determinism of Kähler action is absolutely essential prequisite. The intuitive idea is that cognition involves multilocality with respect to the geometric time. Rigidity and robustness requires that identical memetic codons must form analog of magnetized phase and that conscious experience results in spin flips of cognitive antineutrino sequences so that all pairs of the final state point to the direction of the external Z^0 magnetic field. This model emerged long before the notion of self. The model requires that cognitive antineutrino pairs annhilate and are created regularly in time scale of millisecond and this assumption is obviously quite strong.

2. A more conventional model emerged after the notion of self and a general vision about cognitive/symbolic representations in terms of spin glass type phases with bits 1/0 represented as spin blocks with opposite directions of magnetizations. The phase transition reversing the direction of magnetization to that of an external magnetic field gives rise to a conscious experience about the second value of the bit. Only $2^N - 1$ bit sequences give rise to a conscious experience so that Mersenne primes emerge naturally. The model relies on *subjecto-temporal* sequences of Z^0 magnetization directions (true/false) of a block of antineutrinos at the cell membrane space-time sheet. In this model the approximate vanishing of net energy for neutrino-antineutrino pairs in biomatter only facilitates the generation of anti-neutrino phases. Also spatial sequences of Z^0 magnetized antineutrino blocks could define memetic codons.

The hypothesis that memetic code corresponds to the next level of the Combinatorial Hierarchy characterized by Mersenne prime M_{127}, when combined with p-adic length scale hypothesis, leads to a prediction of .1 seconds for the duration of the 'wake-up' period of subself corresponding to the codon of the memetic code. Bits are expressed as separate mental images if they correspond to sub-selves, otherwise they are experienced as a "clump" and presumably only the number of bits matters so that a reduction to something akin to 64 bit genetic code results at the level of conscious experience.

The memetic codon consists of 126 bits with two possible spin directions corresponding to the two values of Boolean statement. This implies that 1/1260 seconds should be the duration of single bit: this time scale is indeed fundamental for nerve pulse activity but nerve pulses tend to have somewhat longer duration: a more natural realization seems to be in terms of membrane oscillations. Both hearing and vision have .1 second time scale as fundamental time scale.

One can understand the number 126 as related to the total number of separately experienced frequencies in the interval $20 - 20000$ Hz spanning 10 octaves. $10 \times 12 = 120$ is not far from 126: here 12 corresponds to 12 tones of basic music scale. Also speech has 10 Hz frequency as

fundamental frequency. In visual primary cortex replicating triplets, 4-,5- and 6-plets of spikes with highly regular intervals between spikes have been detected. The triplets are accompanied by ghost doublets. This would suggest a coding of some features of visual experience to reverberating mental images. The time scale for various patterns is .1 seconds. Thus there is some support for the realization of at least a degenerate version of the memetic code in terms of nerve pulse patterns but the realization using membrane oscillations seems to be a more plausible option and it is known that sounds are coded to electric oscillations in ear.

The simplest assumption is that memetic code is a newcomer and involved only with the logical thought: this would explain the completely exceptional characteristics of human brain. One can test the hypothesis about cognitive neutrino pairs: the presence of very intensive Z^0 magnetic fields could generate neutrino pairs and spontaneously magnetize cognitive antineutrinos and make conscious thought impossible. Rapid magnetic pulses could be accompanied by rapid Z^0 magnetic pulses. An interesting possibility is that the magnetic pulses associated with nerve pulses involve also Z^0 magnetic field with changes the direction of the spin of the cognitive neutrino pair. This mechanism would code nerve pulse patterns to patterns of cognitive neutrino pairs such that nerve pulse would mean change of the direction of the spins in the temporal sequence of cognitive neutrino pairs.

5.6 How nerve pulse patterns and membrane oscillations could be coded to Boolean statements?

The representation of Boolean mind based on the identification of the antineutrino Z^0 magnetization direction with the value of the Boolean statement seems to be the most realistic one found hitherto. This option also allows to identify a mechanism coding membrane oscillations and perhaps even nerve pulse patterns to Boolean statements.

1. Antineutrinos reside in the strong Z^0 magnetic field associated with the cell membrane and having the direction of the axon. The presence/absence of nerve pulse corresponds to true/false statement in accordance with neuro science intuition. Nerve pulse flips the spins of antineutrinos in the block representing single bit of the codon and in this manner changes the direction of Z^0 magnetization. Nerve pulse must induce a magnetic pulse orthogonal to the original magnetic field inducing with a high probability a quantum jumps changing the direction of antineutrino spin.

2. Since the spin of the antineutrino signifies Boolean statement, the change of the spin direction of the cognitive neutrino pair should correspond to a transition between harmonic oscillator states (n, up) and $(n+1, down)$ of the cognitive antineutrino in the strong Z^0 magnetic field in the direction of axon. This transition should be induced by the generation of nerve pulse.

3. It seems that the transition must occur as a quantum jump induced by a harmonic perturbation of the Z^0 magnetic field changing the direction of spin. Harmonic perturbation causes transition only if its frequency is equal to the difference of energies for the initial and final states so that the angular frequency of the perturbation must be equal to the difference $\omega = E(n+1, down) - E(n+1, up)$ of the antineutrino energies so that resonant transition is in question. If the transition rate is sufficiently large the transition occurs with high enough probability. There are two options.

   i) The model of nerve pulse is based on Z^0 MEs propagating along axon with an effective phase velocity equal to the conduction velocity (see the [M2]). Z^0 MEs acting as the clock, whose "tick" corresponds to the duration of the bit of the memetic codon, could be also responsible for the well-known neuronal synchronization in the millisecond time scale. The magnetic field pulse carried by Z^0 ME could change the direction of the Z^0 magnetization

of the antineutrinos of a single bit of the memetic codon since it causes a torque (classically the torque caused by the magnetic field on spin is proportional to the cross product $S \times B$) in a correct direction.

ii) There is also another option. Rather remarkably, or one could say almost miraculously, for muonic and tau neutrinos the(n, up)-$(n+1, down)$ transition frequency corresponds to the duration defined by the duration of nerve pulse for a reasonable value of the axonal Z^0 magnetic field. Thus the Z^0 ionic currents associated with nerve pulse could generate Z^0 magnetic field having correspond basic frequency in its Fourier expansion [L1]. This perturbation would be induced by the Z^0 ionic currents associated accompanying nerve pulse (note that all nuclei are completely ionized Z^0 ions: this is essential also for the model of nerve pulse generation).

6 Quantum computationalism

TGD Universe can be formally regarded as infinite quantum computer like structure in the sense that each quantum jump involves the unitary process U analogous to a Schrödinger evolution lasting infinite time and is followed by state function reduction and state preparation process. Therefore TGD suggests what might be called quantum computationalism. Universe would be performing huge quantum computation and the computation like processes performed by us or by our brains would be only a ridiculously small portion of this computation. Of course, this must be taken as a rough metaphor, the quintessence of the conscious quantum computation like processes could be quite different from the essence of the ordinary quantum computation.

The average increment of the psychological time in quantum jump is rather small: the simplest guess suggest that the average quantum of psychological time is or order 'CP_2 time', about 10^4 Planck times. This means that the relation of the information processing performed by biosystems to quantum jump would be the same as the relationship of macroscopic physics to physics in CP_2 scale about 10^4 Planck length scales. This would however mean an extremely short decoherence time in an obvious conflict with the experimental facts. Macrotemporal quantum coherence, which corresponds to the formation of bound states, however effectively fuses a sequence of quantum jumps to a single quantum jump so that the decoherence occurring otherwise in CP_2 time scale can be circumvented.

The notion of self is absolutely crucial for TGD approach to consciousness and makes possible to understand consciousness in macroscopic time scales. A very natural notion is that of cascades of selves within selves generated spontaneously or by quantum jumps. This implies a connection with the basic conceptual structure of computationalism. The cascades have natural modular structure, which is quintessential for the understanding of the symbol processing performed by brain. A very attractive hypothesis is that selves within selves are conscious counterparts of computational agents or more or less equivalently, of the subroutines of computer program. Selves can perform two kinds of quantum jumps and a natural identification of these modes is as computational and sensory (input) modes. Subjective memory takes automatically care of ouput in the sense that the subjective history of subself is experienced as an abstracted memory by self.

Communication between selves could occur as it does between human beings. Also 'mass media' at neuronal level seem to be possible and would make possible the concept of global workspace. Quantum jumps can be regarded hopping in the space of zero modes identifiable as fundamental order parameters and Haken's theory of feature recognition generalizes. Quantum entanglement in turn provides elegant realization of association concept so that the basic ideas of connectionism emerge naturally from quantum computationalism. There are also drastic differences with between TGD and computationalism, basically implied by the different concept of psychological time which

implies that cognition has holistic aspect also with respect to time. Thoughts are definitely not deterministic computations and living systems are definitely not robots.

6.1 Computationalism and connectionism

Computational approach to cognition [42] is the dominating approach in cognititive and neuro sciences and has had undeniable successes. Computationalism is often identified as traditional AI based on the concept of truth preserving manipulation of symbols according to some fixed rules of the formal system. This approach indeed explains nicely computational aspects of mind. Combinatorial explosion is the basic failure of the approach at practical level. Connectionism relies on the concept of association and associative neural net provides a quantitative model for how brain learns. Connectionism is often regarded as a variant of the computationalism and it is believed that neural nets provide models for unconscious parallel information processing whereas conscious information processing is best modelled by hierarchical program like structures. The general philosophical shortcomings of these approaches are obvious: they cannot provide any insights to the problem how meaning, understanding, emotions and volition, which are factors crucially important for the functioning of conscious brain, arise. This has even led some advocates of this approach [42] to believe that human brain, being computer basically, is simply uncapable of understanding the problem of consciousness! This would probably be the case if human beings were robots: fortunately we are not!

6.1.1 Traditional AI approach

In the traditional AI approach brain is modelled as a complicated computer. Computation is realized using rigid algorithms, which are hierarchical structures consisting of subprograms. Using more abstract terminology, the basic concepts are symbols and agents, 'demons'. Symbols are inputs for 'demons', subroutines of program manipulating symbols and creating new outputs as symbols. One could however interpret also agents themselves as symbols. The concept of global work-space [36] realizes the intuition that short-term memory is available to many users. Also the concepts of belief and desire can be formulated without referring to consciousness. Beliefs are inscriptions about the world and desires are identified as goals. For instance, problem solving means simply making trials with the aim of minimizing the difference between goal and result of trial. The concept of representation is central. It is known that brain realizes several types of representations [42]. Visual mosaic like representations, phonological representations in short-term memory consisting of few phonemes (say remembering phone number for some time), grammatical language like representations with hierarchical structures and 'mentalese', which is the most abstract representation type summarizing in very implicit manner the essentials of, say, mathematical model.

Computationalism explains nicely the general features of language by providing a representation for the hierarchical structure of language. One can also easily think brain as a population of (possibly) conscious demons. Some demons receive sensory input, some demons process it and the ouputs of some demons are realized as motor outputs. It seems that this approach models quite satisfactorily those aspects of cognition, which can be realized as purely mechanical truth preserving symbol manipulation modellable universally by Turing machine. The best proof for the claim that computers have catched something about the basic structure of cognition is that computers are already now able to beat chess champions. The weak point of the computationalism is its extreme rigidity: minor input error or programming error and program fails to work. Combinatorial explosion is second shortcoming. For instance, all possible melodies formed from finite number of musical notes with finite number of durations for each and lasting the typical length of musical piece is immense. In computer chess combinatorial explosion makes the simple-minded trial and

error approach completely unpractical and the only possible manner to proceed is to teach the computer by mechanizing the human intuitions about good chess.

6.1.2 Connectionism and neural nets

Connectionism provides a modern version of associationism proposed by British philosophers Locke, Hume, Hartley, Berkeley and Mills. Behaviorism was the first purely mechanistic version of this approach but was quite too simplistic to work. Associationism consists of two laws. The first law states that the ideas which are often experienced together get associated: when one is activated also the other one gets activated. Second law states that similar ideas activate each other. Connectionism tries to realize these two aspects of associationism mathematically and construct practical realizations for associative thinking. Typical application would be feature recognition and machines learing automatically from their inputs some predetermined tasks.

Neural nets provide a mathematical model for the concept of association and associative learning. The simplest model for learning simply associates unique self-organized state of a dissipative neural net to the state of the external world represented as an external force driving the neural net. Dissipation realizes also the second law: if input is sufficiently similar to the standard input generating given standard output, the standard output is indeed generated. Also Haken's model for feature recognition realizes second law as a feature recognition based on nonequilibrium thermodynamics. Features correspond to equilibrium states of a nonlinear dissipative system (free energy minima for order parameters). If input creates initial output belonging to the attractor of the feature, dissipative dynamics takes care that the asymptotic output is feature.

Associative net can be regarded as a many-layered structure, in which the states of some nodes correlate strongly with the states of some other nodes. The state of node is characterized by a component of vector, whose components give the values of the amplitude in the nodes. For a given input the net rapidly achieves equilibrium in which the associations created by the input are determined by those nodes in which the amplitude is large. The equilibrium states of neural nets with coupling to external are identified as representations for stable mental states representing some states of the external world.

The flexibility of the neural nets is the strength of connectionism. Also combinatorial explosion can be avoided. Neural nets might indeed model lower level cognition which is mostly unconscious to us. The absence of the hierarchical structures means the loss of 'expressive power' essential for higher cognition and leads to the problems decribed in [42].

1. Connectionistic approach is not able to distinguish between individual and class: what is created from the inputs is some kind of average individual: neural network can learn to recognize human face but not a particular human face or to recognize particular human face but not to make abstraction about what human face looks like.

2. Second problem is so called compositionality: the ability of the representation to be build out of parts and represent the meaning of the whole deriving from the meanings of parts. A related problem are the difficulties in the identification of the meaning of linguistic expressions. For instance, the meanings of the expressions consisting of words 'the child', 'ate' and 'the slug' depend on the order in which the words are represented and connectionism is not able to distinguish between 'the child ate the slug' and 'the slug ate the child'. The natural ordering of symbols provided by hierarchical tree solves this problem in AI approach. Simple neural network learns easily to recognize picture containing horse but if the picture contains two horses, network fails completely!

3. The third problem is a combination of these two. An example from [42] illustrates this. Network can learn to sum 1 and 3 to 4. When it learns to sum 2 and 2 to 4 it can lose the already learned ability. Second example: consider the exression 'Every forty five seconds

some-one in the United States sustains a head injury'. Human brain can easily realize the meaning of this sentence which suggests that quantification occurs in brain and human brain transforms the sentence either to expression "Every forty-five seconds {there exists an X[who gets injured]}" instead of "There exists an X{who every forty-five seconds[gets injured]}"

4. What multiplies human thoughts is recursion. We can take proposition and give it a role in another prosition and so on. In this manner a combinatorial explosion of propositions is generated. To get propositions-inside-propositions network, one could add a new layer of connections but this solution is clumsy and non-economical. The addition of a new level of abstraction would mean a new network containing additional level. In computationalism the solution of the problem is much more elegant. Each proposition is represented in long term memory once. One can of course combine computationalism and connectivism and use simple neural networks as basic modules of computer program like modular structure.

5. Neural net models, which realize connectionistic philosophy in practice, have serious problems in modelling long term memory. If its is assumed that long term memories are coded into the matrices defining output of the node in terms of its inputs, which are modified during learning process, the unavoidable conclusion is that new memories destroy the old ones. Childhood memories seem however to be the most stable ones.

6.2 How connectionism emerges from TGD framework?

6.2.1 Brain as an associative net in TGD

TGD leads to a variant of connectionism which differs from the standard version in some crucial respects. Brain as a quantum self-organizing system moving in spin glass energy landscape generalizes the neural net realization of connectionism. The plasticity of the neural substrate corresponds directly to the spin glass property and the notion of frustration fundamental for spin glass type systems is guaranteed by the inhibitory/excitatory nature of nerve pulses. Neural net becomes dynamical rather than being a fixed structure. One can view brain as system moving in the space of neural nets and perceiving and affecting its own position in this abstract space.

Brain can be regarded as a conscious associative net developing by quantum self-organization to asymptotic self-organization patterns which correspond to recognized features, learned habits, skills $\cdots$: dissipation can be said to serve as fundamental Darwinian selector in this process. By music metaphor each neuron, when it fires, generates a characteristic neuronal experience possibly contributing to our conscious experience: only the intensity of this experience depends on the nerve pulse pattern. The firing of a neuron gives rise to a conscious neuronal association $A \to B$.

This would suggest that brain is like a conscious music instrument, or rather, entire orchestra, played by the nerve pulse patterns and our experiences corresponds to the sound patterns created by this orchestra. It has turned out that this view is probably quite not correct. Brain and body are much more. The music is at the level of sensory organs as sensory qualia, and neural activity cognizes, that is analyses the sensory music to notes and represents the notes. This view, which is certainly not possible in the standard neuroscience framework and surprisingly close to what a layman knowing nothing about neuroscience would think spontaneously, makes sense in TGD framework if one assumes that entanglement between brain and sensory organs binds sensory qualia with the cognitive associations generated by the sensory input. This view also allows to understand elegantly the differences between sensory experience, dreaming, hallucinations, and imagination. An essential element is the feedback from brain to sensory organs enabling "qualifacation" during dreaming and hallucinations. This feedback is also active during the ordinary wake-up consciousness.

Spin glass energy landscape is four-dimensional in a well defined sense and the identification of the long term memories as geometric memories solves the basic paradox of the neural net models

of memory. One can also understand how brain knows that the mental image represents memory and why repetition and reverberation of nerve pulse patterns in neural circuits leads to learning and why emotional experiences are easily remembered.

6.2.2 Feature recognition

The first law of associationism states that similar ideas tend to induce each other. For instance, a part of familiar face in the visual field induces a memory about the entire face. In computational approach feature recognitition is believed to involve unconscious low level parallel processing. Haken [25] has proposed an elegant model of feature recognition based on non-equilibrium thermodynamics. The features to be recognized represent the minima of the potential depending on order parameteres and the presence of dissipative terms implies that system ends up to potential minimum representing feature.

Haken's theory generalizes to TGD context almost as such. Dissipative time evolution is replaced with quantum self-organization by quantum jumps and in each step entire macroscopic space-time surface is replace by a new one. The zero mode degrees of freedom of the configuration space are identifiable as fundamental order parameters and each quantum jump involves complete localization in continuous zero modes. The localization in discrete zero modes characterizing cognitively degenerate space-time surfaces need not be complete: what is needed is localization to a subset of space-time sheets for which the eigenvalues of the p-adic density matrix are degenerate. This means that the time evolution by quantum jumps corresponds to hopping in the space of zero modes, which leads to that part of zero mode sector, where configuration space spinor field has largest value. The maxima of Kähler function are excellent candidates for the attractors of the quantum self-organization process.

A more concrete brain level model of feature detection based on the realization of the self-hierarchy as a hierarchy of Josephson currents frequency-modulating each other perhaps helps to clarify the abstract general ideas about conscious feature detection.

1. The feature to be detected is represented as a reference supra current flowing in a neural circuit and weakly coupled to a parallel neural circuit representing the input. When the supra currents are identical, constructive interference of the Josephson currents flowing between the two circuits occurs and induces large modulation of the rest potentials of neurons of the circuit and leads to a synchronous generation of nerve pulses. Synchronous neural firing can start under rather wide limits depending on the alertness of the neural circuit (how near to the threshold value resting potential is) controlled by the modulating Josephson currents also.

2. Synchronous neural firing wakes-up subself which starts to self-organize and develops into an asymptotic pattern representing a mental image about the detected feature. The final state depends only weakly on the initial state of the neural circuit representing self so that genuine feature detection is in question. For instance, some minimal number of neurons firing in the neural circuit leads to given final state pattern so that the constructive interference of the Josephson currents need not be maximal.

3. The self-organization parterns in neural circuits define a population of sub-selves defining cognitive mental images, features. These sub-selves wake-up and fall asleep (even periodically during their lifetime (after images)). Falling asleep occurs, when the sub-system generates a bound state entanglement with some other sub-system, and wake-up by a reduction of the bound state entanglement.

4. Self-organizating neural circuit starts to approach the maximum of 'subsystem' Kähler function (recall that approximate representability of Kähler function as a sum of subsystem

Kähler functions is probably possible) is accompanied by the wake-up of subself. This corresponds to the motion of neural circuit in its spin glass energy landscape induced by various neural transmitters inducing short term or long term changes in the synaptic contacts. Thus self-organization induces also a generalized motor action shifting the position of the neural circuit in the spin glass energy landscape.

5. Feature detection involves kind of *Eureka!* experience. Perhaps the subself representing the mental image about recgonized object remains for some time irreducible and hence does not possess any subselves (and is in 'enlightened' state). This could be the situation for some time until subselves are generated during self-organization and lead to the analysis of of the recognized feature.

It seems that the presence of an algebraic p-adic-real entanglement with a positive entanglement negentropy a is a physical correlate for the experience of understanding and Eureka experience. Real bound state entanglement can give rise to experiences like seeing beauty, feeling truth, and feeling love. Thus both p-adic and real physics, cognitive and symbolic representations, must be involved. Cognitive representations realized in terms of p-adic cognitive neutrinos are generated from the real physics based symbolic representations. The entanglement between cognitive and symbolic would give rise to the Eureka experience. The need to separate cognitive and symbolic representations from each other is highly non-trivial implication.

6.2.3 Learning of associations

The second law of associationism states that ideas experienced simultaneously tend to form associations. TGD suggests two mechanisms for realizing associative learning.

1. The purely quantal mechanism realizes associations in terms of quantum entanglement. This mechanism would be extremely elegant because super position principle allows huge capacity of forming associations. Quantum entanglement however seems to associate parts to form wholes with the ensuing loss of conscious information about parts rather than giving rise to conscious associations $A \to B$. One could say that the association in question is spatial rather than temporal. Note also that quantum entanglement lacks the directional character of association. It seems that this mechanism is essential for associating various cognitive features at the level of brain with sensory qualia at the level of sensory organs.

2. In second mechanism the classical neural net type realization is replaced by a process in which subself wakes up another sub-self. A process in which presynaptic neuron wakes up postsynaptic neuron and the mental images of these neurons form the association, could indeed serve as building blocks of our associations.

It has turned out that these mechanisms are actually not mutually exclusive, and that both are involved with the association mechanism. The TGD based notion of sub-system, relying on the topological non-triviality of the many-sheeted space-time, makes possible for separate selves (unentangled systems) to share mental images via the entanglement of their sub-selves. Topologically this corresponds to the following situation. Two selves (say sensory mental image and cognitive mental image) are realized as disjoint space-time sheets S_i, $i = 1, 2$ and their sub-selves as smaller space-time sheets S_{ij} glued by wormhole contacts to the space-time sheets S_i. When sub-self space-time sheets S_{1j} and S_{2k} are connected by join along boundaries bonds, the fusion and sharing of these mental images occurs.

The neural network model for the formation of associations relies on the idea that some states of the neural net are in a correspondence with the states of the external world. Also the states of different layers of neural net have natural mutual correspondence. Association basically creates

one-one map. In neural net models the interaction with external world occurs via driving force and dissipation leads to asymptotic states, which can be interpreted as association of net-states with the states of the external world. The problem of the neural network models is how the learning process could be realized in living brain. In particular, how two simultaneous ideas represented by the substates of neural net get associated with each other. This seems to require that the presence of two active nodes present in the net tends to strengthen their mutual coupling. There is a lot of empirical supports for this and neural transmitter action is an essential element of this process. In TGD framework this process corresponds to the gradual movement of neurons and brain in their spin glass energy landscape induced by neural transmitter action.

In TGD framwork the formation of association $A \to B$ would mean that the stimulus A alone can generate B. This means that the subself representing mental image A tends to wake up the subself representing mental image B. At the neuronal level this simply means that the firing presynaptic neuron excites postsynaptic neuron so that it also fires: the long term changes of the synaptic connection promotes this ability. At the level of our mental images the waking up process must involve nerve pulse transmission from neural circuit representing subself A to the neural circuit representing subself B. Josephson current model suggests that during learning period, when A and B are experienced simultaneously, they are mapped to reference currents in feature recognition network $A + B$. Later when only A serves as input, part A of the circuit $A + B$ begins to fire when it receives A as input. If the synaptic connections between circuits A and B have been strenghtened during learing period, the firing spreads out to B and also B wakes up. This in turn leads to the self-organization process generating experience $A + B$.

Many associations are bi-directional: for instance, symbols for real world objects are bi-directional associations. In TGD framework one can model the generation of the bi-directional associations in classical sense along following lines. Denote by A and B the symbols to be associated: A and B correspond to subselves of say self X. Neural net philosophy suggests that A and B should co-operate to keep each other in wake-up state (alive!): self-organization by quantum jumps could lead to this kind of co-operation. This is achieved if sensory experiences stimulate automatically co-operative self-populations, whose members tend to keep each other awake. This model is consistent with the fact that associations do not involve conscious thought. For instance, A could generate nerve pulse patterns waking up B and vice versa. Note that at the next level of the self hierarchy this could be regarded as a formation of self-association $X \to X$ possibly giving rise to a stable short term memory and also as survival of self X guaranteed by co-operation of subselves.

6.3 Computationalism and TGD

Computationalism in strong sense (brains as deterministic machines) does not emerge from TGD. The basic reason is that the time concept is totally different from that of computationalism. One can say that quantum jumps select between different time evolutions and the overall-important modular structures result from self cascades.

6.3.1 How computationalism and TGD approach differ?

A good example is provided by vision discussed in [42]. Vision builds representation or description of the world from sensory data. Since inverse optics is not possible, implicit assumptions about the structure of the external world are necessary. Typically illusions rely on the breaking of these implicit assumptions. Illusions are not always undesirable. Two-dimensional pictures are an example of an illusion making possible visual communication! Auto-stereograms [42] consisting of diffuse soup of points are a particularly striking example of illusion: looking the picture for a sufficient time, one can experience a dramatic reshapening of the experience: beautiful 3-dimensional picture emerges from the chaos. Auto-stereograms support the hypothesis that vision involves

computational activities or quantum counterparts of them. This process can be seen as a school example about how brain adds to a pure sensory input symbolic and cognitive representations.

In TGD universe brain does not probably deduce the representation of the world from picture by a straightforward computation. Certainly the data and implicit or learned assumptions about the world appear as an input in some sense. Some kind of iterated guessing based on implicit assumptions seems to involved: guess is made and compared with the actual picture. Quantum self-organization indeed makes possible the iteration, being in itself an iterative process. Guesses are very probably based on the existing abstract data about possible configurations of the world. The paradigm of 4-dimensional brain allowing to realized long term memoryes as geometric memories could be crucial in this respect. One can wonder whether the implicit assumptions might also develop from temporal entanglements with larger selves (during sleep) giving rise to information about world in longer length and time scales.

Control of motion is second good example of what might happen. There is no deterministic program proceeding with respect to geometric time and selecting what happens next and creating the quantum history step by step. Rather, the entire pattern of motion is selected by the creation of the main program self by quantum jump. The subsequent quantum jumps occur in the cascade proceeding in top-to-bottom type manner to shorter spatial and temporal scales. Thus the main program corresponds to, say the pattern of large scale motion, and sub-programs correspond to the details of the motion. What is new as compared to computationalism is that the program is created while it runs.

At the level of CNS anatomy sensory perceptions and motor actions loook mirror images of each other. TGD suggests that they could be mirror images at much deeper level. Motor actions would be time reversal of sensory perception in appropriate time scales for MEs (topological light rays, "massless extremals") and routinely involve breaking of the second law in this p-adic time scales. This assumption implies that motor action results like a painting starting from a rough sketch. Dissipation and its time reversal automatically perform Darwinian selection leading quantum jump by quantum jump to the final motor action. No detailed planning is needed. Motor imagination is motor action starting from some level above the muscles and motor skills can be learned by imagining them.

6.3.2 Real selves as symbols

The ability to think in terms of symbols is certainly one of the key features of intelligence. The hierarchical structure of selves within selves and the possibility of cascades creating selves within selves allows to interpret subselves of self as conscious representations for symbols, at least under certain additional conditions. The condition seems to be that symbol subself and the primary subself representing the real object must be able to wake-up each other bi-directionally. Symbol self and 'real self' could also belong to different levels of the hierarchy. For instance, single neuron could serve as a representative of neuron group in the sense that neuron and neuron group can wake-up each other. Perhaps Grandma neuron serves as a symbol for a complicated experience of entire neuron group. Linguistic associations would certainly be subselves representing this kind of representative function very effectively. This kind of symbol neurons would correspond to leaders at the level of human society. Indeed, words can generate actions and word selves are excellent candidates for the leaders of the neuronal society!

Selves allow also other interpretations. In very general sense they can be identified as agents or 'demons' in the sense of computationalism. Agents can be also regarded as counterparts of submodules of main program. The call of subroutine from main program could be regarded as a wake-up of subprogram self. The main program forms automatically abstraction of the entire subjective history of subprogram self. The input data of submodules realized as subselves is most naturally realized as sensory input. For instance, neurons are expected to have chemical

senses making communication between neuronal selves possible [K3]. Nerve pulses provide obvious candidate for a communication mode.

The concept of global workspace [36] is one of the basic concepts used in the modelling of cognition and short term memory. The model visualizes short term memory as a global workspace, kind of common blackboard seen by various agents. The agents in turn can add write data to the global work space. Communication via global workspace is clearly analogous to mass media. Communication via global work space could be realized as chemical communication. Hormonal system could be an example of mass media operating at the level of our conscious experience. A surprisingly large volume of brain is free of neurons and glial cells and there is experimental evidence for chemical communication occurring via this free volume [27]. In TGD framework global work space could be also realized in terms of coherent photons if selves act as quantum antennas able to receive and send messages: this would be very much like mass media in neuronal and subneuronal length scales.

6.3.3 Wholes and parts, classes and individuals

Wholes contra parts and classes contra invividuals are basic concepts of computationalism and should allow representation as quantum level concepts. Also in TGD framework these concepts emerge naturally. The subselves X_i of self X are individuals and a natural hypothesis is that X experiences X_i as separate subselves. The self Y at the next level of hierarchy containing X in turn experiences the set $\{X_i\}$ of subselves of X as an average $\langle X_i \rangle$, typical representative of class X. For instance, if subselves of X represent different faces, then Y forms abstraction about the concept of face.

'Whole' is a concept different from class. A good example of 'whole' is letter F formed from smaller F:s. Whole is something more than a sum of invididuals and the problem is to understand how this whole is represented at quantum level. A very natural hypothesis is that the whole formed by subselves is formed by quantum entanglement between subselves leading to the disappearance of the invidual subselves. When entanglement is destroyed, subselves or some of them are experienced as separate: this mechanism could also be regarded as a quantum mechanism for the formation of associations. Sensory experiences would wake up sensory selves involving sensory organ and parts of brain giving rise to different representations of sensory data and the analysis of sensory experience would involve the decomposition of these selves to subselves.

Our body consciousness provides testing ground these ideas. Contrary to the basic dogma of neuroscience, in TGD framework the fundamental representation of the body is formed by the body itself as is clear also on basis of the concept of self. Of course, representations at the level of brain are also involved and make possible the analysis of the body experience. We do not however experience our bodies as a huge number of separate cells. The explanation is that our subselves correspond to structures that are much larger than cell. Various parts of our body could obviously correspond to the subselves of our self. The fact that we recognize all parts of our body as such suggests that our self is at least as large as our body or perhaps even larger. Interestingly, in some brain disorders patient does not admit that some part of body, say left side of the body, belongs to them. This would suggest that the self of these persons is reduced to the self of the other side of the body rather than that of entire body.

6.3.4 Predictions and memories

The paradigm of 4-dimensional brain (and of 4-dimensional body and even of 4-dimensional Universe!) differentiates between TGD based computationalism and classical computationalism. One of the most important predictions is the possibility of two kinds of memories: geometric 'memory' generating simulations of past and future and subjective memory making it possible to have genuine memories about previous moments of consciousness. The comparison of the predictions with

what actually happened seems to be basic activity of conscious mind. The fundamental realizations of both subjective and geometric memory elegantly circumvent the memory storage problems encountered in the computationalistic approach and multiplied by the combinatorial explosion.

These basic memory types allow several realizations. The identification of immediate short term memories as subjective memories is very natural. Geometric memories seem to be the only reasonable candidate for long term memories. Procedural memories relying on association of say nerve pulse patterns with experiences are possible.

Self at a given level of hierarchy forms automatically abstractions about the wake-up periods of the lower level selves. This makes possible to form abstractions about the time development of subselves and to gain wisdom given by experience. Long term memories involve both the formation of abstractions as some kind of time averages and detailed information. This is difficult to realize in the neural network approach.

6.3.5 Boolean logic and logical deductions

One can easily invent models of logical reasoning but probably the most realistic model is based on representing the premises of the logical deduction using Boolean statements realized in terms of cognitive (that is p-adic) neutrinos. These cognitive representations are transformed by p-adic-to-real transition to symbolic ones, and generate a neural activity representing the logical deduction which is basically realized using learned associations. The outcome is represented again in terms of cognitive neutrinos. Thus only the inputs and outputs of the deduction process are represented in terms of cognitive neutrinos (this must be so since the experience of understanding requires p-adic-real entanglement with a positive entanglement negentropy). This model involves minimum amount of p-adic physics, is essentially isomorphic with the model of imagination, and is consistent with neuro-science facts.

An interesting possibility is that many particle states of cognitive neutrino pairs providing representation of logical thoughts could replicate. This might be possible. If the macroscopic phase determined by cognitive neutrino pairs is compeletely fixed by the structure of mindlike space-time sheets then the replication of the material space-time sheet and mind-like space-time sheet would lead to the replication of thought. DNA replication seems to occur in too short length length scale to be associated with this process. Cell replication could however quite well involve replication of thoughts. Cell replication does not seem to occur at the level of brain. Presumably nerve pulses generating standardized patters of cognitive neutrino pairs have replaced direct decay of cell as a more effective manner to replicate thoughts and eventually even communicate them.

6.3.6 Beliefs and desires

Computational approach does not have much to say about emotions. Beliefs and desires are however concepts allowing symbolic (one might say computational) representation: this of course does not explain what gives for belief or desire its emotional content.

Beliefs could be very generally regarded as basic axioms of formal system from which various deductions by truth preserving symbol manipulations are obtained. The mathematical model behind numerical calculation is a nontrivial example of this kind of belief system. Desires can be realized in computational science in terms of goals assigned with the initial state. For instance, the desire of the problem solver is to solve the problem that is get from initial state to the desired final state by applying fixed rules. Initial state could correspond to the assumptions of a theorem and final state to the theorem itself. If it is possible to solve the problem at the level of symbolic representation, the solution of problem can be mapped to the real world. Beliefs and desires could easily be represented symbolically in terms of neural activity using associations. A Boolean representation of beliefs could be in terms of logical statements using cognitive neutrinos or real neutrinos.

It is not so easy to understand what gives rise to the conscious experience of belief or desire. The geometric time development can be regarded as a prediction of future (and past) whereas "reality" corresponds to the subjective time development. The belief about what happens in the future is a special belief and could be seen as 'memories' with respect to the geometric time: seeing to the future. Intention would be the p-adic counterpart of this kind of belief, seeing to the p-adic future. A wide class of emotions could result from the comparison of the predicted and real. That predicted and real coincide, could correspond to nearly identical sub-selves able to form a bound state accompanied by a a period of macrotemporal quantum coherence and a positive emotion like understanding.

The fundamental desire of the subself is to stay conscious, to survive. Cognitive, symbolic, and Boolean representations would give for the desire of the mental images of the conscious world model to survive an interpretation as a higher level desire. Also beliefs might be determined to a large extend by the desire of the sub-selves to survive: giving up a belief means death of the corresponding mental images and unpleasant mental images are a threat for mental images defining the self model. We tend to have beliefs which do not threat our ego.

6.3.7 Simple model for problem solving

Problem solving is certainly quite high level cognitive skill. A good test for the proposed scenario is how simple conscious problem solving could proceed. The basic desire of problem solver is to achieve the goal given the initial state. Problem solver makes trials and when goal and achieved state are sufficiently near to each other problem can be said to be solved. The model for this activity could be roughly like follows:

1. Goal is represented as a physical state of some subsystem and the basic problem is how problem solver can compare the result of trial with the goal. It seems that all conscious comparisons must reduce at fundamental level to the comparisons of geometric and subjective time developments of some subself. Thus it seems that problem solver self must directly experiences whether the goal was achieved by experiencing how much the hoped for geometric time development and subjective time development generated by the trial resembled each other.

2. This approach as such is not practical. Standard computationalism would the comparison of the result of a trial to the goal necessitates circuit which carries out comparisons. This kind of circuit is easy to realize. For intance, Josephson junctions could physically realize the difference between the result of trial and goal as the phase difference between weakly coupled superconductors. To know whether the trial was succesful, problem solver must compare the desire represented by a binary digit one in geometric memory with the result of comparison represented by a binary digit having one one or zero in subjective memory. For instance, limbic brain could be the seat of these binary digits and comparison could occur there.

3. Problem-solver subself generates solution trials. Most naturally this involves quantum jump leading to decomposition of problem solver self to two subsystems. This decomposition represents the trial. Good problem solver must be able to generate very many different trials: this means that entangelment entropy is almost constant function of subself generated in quantum jump.

4. Problem solver self performs the comparison. When output is 'No' problem-solver self generates a new trial. System must have a *Eeureka!* experience, when the problem is solved. This is achieved if 'problem solver' self is 'enlightened' when it receives ouput 'yes' from the comparison circuit. This means that problem-solver selves begins to make quantum jumps reducing matter-mind entanglement and does not generate trials anymore. Note that the

Eureka requires a generation of p-adic-real entanglement with positive entanglement negentropy.

5. The trials could be representable as p-adic space-time sheets defining the initial states of the symbolic representation defining the world model and realized as patterns of neural activity based on association mechanism. Their transformation to real ones would initiate the simulation. Also this process is very similar to that behing logical reasoning and imagination.

There is no need to add that in reality problem solving is much more complicated procedure! The above model could however provide insight about the conscious experiences related to the problem solving.

6.4 How brain builds the model of the external world?

What we experience is not completely determined by the sensory data: a lot of computation like processes at the level of cortex is involved. In TGD generation of symbolic representations would perhaps be more appropriate term. The phenomenon of illusions, most importantly, our ability to see planar pictures as 3-dimensional, shows that this computation involves a model of external world based on definite assumptions [42]. Stereo vision [42] is a good example of a sensory experience involving a lot of cognitive processing at the level of cortex. Depth cannot be experienced directly and the deduction of the actual positions for the points of the visual field must involve large amount of cognitive processing carried out in cortex. At the level of conscious experience the fusion of right and left visual fields to single visual field seems to be responsible for the emergence of the 3-D visual experience.

That complicated information processing is involved is demonstrated by autostereograms, in which a chaotic set of points experienced as a planar picture organizes to a beautiful 3-dimensional picture after intensive concentration (all subject persons are not able to see the 3-dimensional picture). It is known that stereo vision develops in age of few months at the same time when some cortical neurons specialize to receive input from only single eye instead of superposing the inputs from both eyes. Brain is also able to estimate the state of motion of objects of visual field from sensory data and this must involve a lot of computation. The fact that some people cannot experience motion in the visual field provides a support for the claim that this experience is a result of a complicated neuronal processing. At first, the computational aspects of the conscious experience would seem to be in conflict with the idea that sensory organs are the primary sensory experiencers. The situation is however not so simple as the closer examination of the computational aspects of the visual experience demonstrates. The basic point is that brain quantum entangles to the sensory representation various symbolic and cognitive representations giving meaning to what is sensed.

6.4.1 TGD based view about construction of sensory representations

The motion of eye or head does not induce the sensation that the world is moving although the sensory image moves around the cortex. Rather, brain acts like a (possibly moving) canvas at which the sensory input is projected and monitored by an external observer. This very simple observation is a strong objection against the idea that the ultimate sensory and cognitive representations reside inside brain, and leads to the view that the magnetic flux tube structures associated with the primary and secondary sensory organs define a hierarchy of sensory and symbolic representations outside brain. Magnetic flux tube structures would serve as the sensory canvas to which sensory images are projected from brain and possibly from sensory organs and even neurons. MEs serve as projectors and place coding by magnetic transition frequency associated with ME wakes-up sensory subselves at various positions of magnetic flux tubes having varying thickness and associate thus

various sensory qualia and even more complex attributes to the objects of the perceptive field. Thus the experiencer would the complex containing so called material body and hierarchy of field bodies.

EEG MEs correspond to our level in this hierarchy of projections. The simplest possibility is that the sizes of these sensory selves are of the order of EEG ME sizes ($L(EEG) = c/f(EEG)$) and thus can be of the order of Earth size! Thus the ultimate sensory representations are magnetic gigants in TGD and diametrical opposites of the neurophysiological dwarfs of standard neuroscience populating also TGD brain.

The known strange effects of large scale perturbations of Earth's magnetic field on consciousness (say, statistics about the effects of magnetic storms in mental state and tectonic activity inducing UFO experiences) provide a rich palette of anomalies supporting this view. The conservation of magnetic flux makes the magnetic flux tube structures of Earth size very stable: thus physical death presumably means only that our magnetic body redirects its attention to something more interesting. Near death experiences discussed in more detail in [I3] indeed support this view. Of course, this view about human consciousness is not new, it is shared by all spiritual practices. What is new is the concrete physical model realizing this view physically.

It would seem that the generation of the visual experience involves some kind of iterative computational process laeding to an optimal conscious sensory representation of the external world. This process must involve a model of the external world, which is improved iteratively. Each computational step must provide an estimate for the various positional coordinates of the object and features associated with it and a subsequent comparison of the real sensory data with the virtual sensory data yielded by the model world. The virtual world sensory input yielded by this model is compared with the real world sensory input in comparison circuit and when virtual and real inputs are sufficiently near each other synchronous neural firing leading to a wake-up of sensory subself and conscious recognition of the object of the perceptive field occurs. This could also involve intermediate cognitive, symbolic, and sensory representations not conscious to us who see only the final product of this process. In case of vision the model suggests that both eyes yield actually stereovision separately in ordinary circumstances. This might be the case: one must hold second eye closed for sufficiently long time before the picture gradually flattens.

This quasi-computational process is cognitive process involving imagined sensory, motor and Boolean representations ('this is true' experiences) realized. If the primary qualia are at the level of sensory organs it is easy to understand why imagination lacks the sensory qualia. Only during dreams and hallucinations would the back-projection to the sensory organs occur and "qualiafy" the symbolic representations generated by imagination. Imagination involves p-adic-to-real phase transitions transforming p-adic space-time sheets to the initial value nerve pulse patterns serving as symbolic representations and initiating an associative simulation. The genuinely p-adic aspect of imagination would be thus analogous to the free choice of initial values in a computer simulation. If motor actions is a geometric time reversal of sensory perception in relevant p-adic time scales, motor actions are initiated at some level above muscles and proceed to higher levels so that there is no danger that real motor actions are generated. Dissipation and its time reversal implying a Darwinian selection of mental images are probably the basic tools of imagination and problem solving: second law becomes an ally rather than an enemy. Problem solving and motor actions quite generally start from a rough sketch and there is no need for rigid and bureucratic program structures as in case of AI. Program develops as it runs.

There are several information sources at use when cortex deduces the positional coordinates for the objects of the perceptive field. In case of vision the decomposition of the right and left visual fields to objects is an essential element of the approach. For instance, simple estimate for the distance of object results from the comparison of the positions of the images of object in the retina. If illumination is constant, the comparison of the intensities of the reflected light coming from various planar pieces of the surface representing object gives estimate for the normal direction

of the planar piece. Also the fact, that some points of the object are not seen simultaneously by right and left eye can be used as a constraint. In case of autostereograms there is no decomposition into objects and the problem is to identify, which points of the right eye and left eye correspond to same point of the external world: the color of the points is obvious clue. Also long term memories about objects seen earlier are obviously involved.

In the simple situation that the visual world consists of simple objects, no comparison of the model world with the real world is needed provided that cortex is able to perform some simple arithmetics (which is not at all obvious!). In the general situation experience is yielded by the iterative computation like process (actually a rather long sequence of quantum computations if single quantum computation lasts about 10^4 Planck times).

6.4.2 A possible model for the computational aspects of sensory experience

The mind-like space-time sheets in the regions of cortex and various brain nuclei could see each other in the illumination provided by the Bose-Einstein condensed photons propagating along axonal (possibly also microtubular) wave guides. This would make possible comparison circuits in which inputs from two different areas of brain to area of brain are compared. The comparison circuit based on Josephson currents is ideal for this purpose. In case that inputs are identical, synchronous neural activity results. The comparison of the images could be crucial in realizing the iterative evaluation of the computational aspects of sensory experience. This iterative comparison process need not be conscious to us.

From our point of view brain seems to generate only symbolic representations. Cortex might however also generate virtual world sensory experiences at lower levels of the self hierarchy and not conscious to us. These could be compared with the genuine sensory input in (say) thalamus and convergent iteration would lead to a resonant firing and conscious experience of recognition. This would explain the observed adaptive resonance phenomenon in which thalamo-cortical feedback loop directs conscious attention to those aspects of sensory percept which agree with the expectation. Direction of attention would mean generation of a sensory subself representing the recognized part of perceptive field. Novelty detection could occur at higher information processing level and could be based on inhibitory projections from feature detectors to the novelty detecting neural circuit.

Just to concretize the idea, one could imagine the following rough scenario for how the comparison involving neuronal sensory qualia (not ours) could proceed.

1. Neurons in some parts of brain, most naturally in the thalamus, have neural window to the primary sensory organ radiating coherent light propagating along microtubular waveguides to thalamus. Besides vision and perhaps even hearing, neurons would also have chemical senses and receptor-transmitter complexes would define different qualia. Different sensory modalities feed different regions of thalamus with difference wavelengths characterizing the sensory modality so that the neuronal window based on coherent light might be used by all sensory modalities to achieve this comparison. This is consistent with the fact that microtubuli are present in all axons. There is an intensive feedback from cortex to thalamus and this feedback could quite generally be related to the cognitive representations generated in cortex and communicated to thalamus for comparison. The results of the comparison are sent back to the cortex coded in nerve pulse patterns and change the properties of the model world to give a better fit.

2. The imagery model world consisting of neuronal mindlike space-time sheets in cortex represents the results of a cortical computation. Mind-like space-time sheets radiate coherent light with the intensity determined by the model of the external world specifying the intensity of the reflected light from a particular object. The simplest possibility is that the representation consists of mind-like space-time sheets whose size and shape are deduced from the size

and shape of the objects and from the estimated values of the height function. Only the active cortical neurons send coherent light along microtubules to thalamus. The result of the comparison is coded to nerve pulse pattern and sent back to cortex to make possible next trial.

6.4.3 Connection with the observations of Barbara Shipman

There is also an interesting connection with the model the model of Barbra Shipman for the dance of honeybee [17, 18, 19].

1. The model relies on the puzzling observation that the manifold $F_3 = SU(3)/U(1) \times U(1)$ parametrizing different choices of color quantum numbers seems to be involved with the dance [K3]. In TGD framework color rotations do not leave classical Z^0 and em fields invariant although induced Kähler field is color invariant. For instance, in a color rotation a pure Z^0 ME is in general transformed to a ME carrying a lightlike vacuum em current generating a hologram possibly acting as a biological control command. This suggests an explanation for the observations of Shipman and also that the canonical coordinates (P_i, Q_i) for the 6-dimensional symplectic space F_3 play crucial role in the construction of sensory representation. In fact, in Shipman's model the Hamiltonians associated with color isospin and hypercharge take the role of planar coordinates for the dance floor at which the dance of honeybee takes place. More generally, it might be possible to represent the position of the object of a perceptive field using some coordinates of F_3. The optimal situation would be that both the velocity and position would be coded to a point of F_3 so that CP_2 orientation of space-time sheet would represent position for an object of a perceptive field.

2. If this view is correct, the values of the positional coordinates and the velocity of the object of the perceptive field should correlate with the CP_2 orientation of the active neuron and/or ME(s) associated with it. First of all, the level of hologrammic activity for ME measured by the strength of the lightlike em current depends on its CP_2 orientation. Secondly, different CP_2 orientations correspond to slightly different values of the membrane potential and could be directly mapped to the degree of alertness of neuron. For instance, if a moving object of the perceptive field is in nearby space and moves towards the perceiver, the (P_i, Q_i) values could be such that the resting potential is lowered and nearer to the critical value for firing. Also the lightlike em currents associated with MEs would be stronger in this kind of situation.

7 Holographic brain and quantum TGD

Brain as a hologram paradigm states that one cannot locate the information in brain in any specific region. There is indeed considerable empirical support for this hypothesis [38, 43, 40].

7.1 Evidence for holographic brain

The first empirical motivations for holographic brain came from the experiments of Lashley [38] with rats. Psychologist Karl Lashley started 1920 lifelong study of the effect of brain vaults in memory. Lashley studied the behaviour of rats in mazes and found that the reduction of the brain tissue did not destroy the visual memory of rats totally, only the intensity of the memory was weakened. This led to the introduction of the terms mass action and equipotentiality. Mass action says that the intensity of the memory depends on the amount of the brain tissue present and equipotentiality says that each neuron carries the memory traces. The experiments of Lashley lead to the idea that the memory storage mechanism in brain is nonlocal and hologram like.

In 1948 physicists Dennis Gabor discovered the idea of optical hologram and within twenty years the same principles had been applied to brain. What hologram stores is the information about both amplitude and phase of incoming light wave, quantum mechanically identifiable as the order parameter characterizing coherent light. What makes holographic information storage so attractive is its extreme robustness and flexibility: a small piece of hologram carries same information as entire hologram, albeit in blurred form. Philip Westlake [48] was one of the first mathematicians to argue that hologram priciple matches with what brain does with the information. Karl Pribram [43] and colleagues have done a lot of experimental work with monkeys using the holographic theory to see in detail how the theory makes it possible for brains to remember. The book 'Shuffle brain' [Pietch] popularizes in an enjoyable manner the idea of holographic brain and the work Pietch with salamanders. The experimental work of Pietch provides rather convincing experimental support for the idea of holographic data storage [40]. The experiments of Pietch with salamanders involved the cutting the brain of the salamander to pieces, shuffling the pieces randomly and putting them back together: no detectable changes in the behaviour of salamander occurred as a result of this operation! It is hard to imagine a computer which would function after this kind of treatment.

Holographic data storage is extremely flexible and stable. Since brains have developed in jungle rather than in safe computer laboratory, these properties make the idea of holographic brain much more attractive than the paradigm of computer brain. Also transformations between sensory modalities are easily realized. For instance, acoustic holograms can be transformed to optic holograms. One can however also invent objections against holographic data and memory storage.

1. The creation of hologram is based on the interference of a reference beam of light with the beam of light reflected from the object. The reading of the hologram is done by using reference beam to regenerate the original picture. It is however not clear whether this kind of mechanism is possible to realize at the level of brain. Furthermore, in reality it is the real beam which stimulates memory recall rather than the hypothetical refence beam! It seems that comparison of reference pattern representing the expected experience with input is what happens in brain rather than illumination of holograms.

2. In order to have holographic memory, it should be possible to code very many holograms simultaneously to single hologram. Multiple holograms are indeed possible [40]. One must however admit that the idea about storing large number of temporal events to same multiple hologram does not look very attractive. The identification of the long term memory as geometric memory solves these problems in TGD framwork so that hologram idea could survive as a a restricted principle determining how the experience is generated.

3. The structure of the human brain suggests that data representation is not completely hologram like. For instance, the various phonemes are recognized by well defined regions located in linguistic areas of the brain like potatoes in the field. The differences between right and left brain are a challenge for the hologram idea in its simplest form. One must however notice that it is brain functions that are localized whereas data storage could quite well be hologram like. Of course, it could quite well be that brain decomposes into regions in which data represented as a hologram is different: for instance, different sensory modalities seem to use different regions of brain. In particular, the existence of various sensory homunculi in brain is consistent with the holographic data representation.

7.2 Three explanations for the hologram like properties of brain

The fact is that brain seems to be extremely flexible and this does not fit nicely with the idea that brain is some kind of extremely complicated electronic circuit. Hologram like data storage in which each neuron is like a part of hologram provides only one explanation for the empirical data.

The common feature of TGD based explanations is that conscious experience is not so strongly dependent on the neurophysiogical state of the neural substrate as the vision about brain as a computer would suggest.

1. Quantum self-organization implies that systems self-organize to dynamical patterns which do not depend very much on the initial state. For sufficiently simple brains, whose presence is not absolutely crucial for the 'household' activities of the organism, this could be all that is needed. For instance, the ability of a lizard to generate a new head supports this view. Salamanders are simple creatures and the mere quantum self-organization without recourse to hologram memory could explain the results of the experiments of Pietch.

2. TGD based model of conscious brain relies on self hierarchy realized in terms of various Josephson currents forming a master-slave hierarchy. Josephson currents do not depend very strongly on the material substrate of brain. Josephson currents and associated supra currents allow also basic wave like phenomena like interference crucial for hologram model. Comparison circuits formed by weakly coupled super conductors and constructive interference of Josephson currents provide a quantum model of brain which resembles hologram model but also differs from it in certain crucial aspects. In particular, reference ray is replaced by reference current representing expected experience. Also comparison circuits in which parallel supra currents of same intensity flow in coupled superconductors, are possible. In this case large Josephson net current is generated by constructive interference of Josephson currents when the phases of supra currents differ by a constant phase.

3. It might be that brain is indeed hologram like in some sense although reference rays are probably not involved. In TGD framework it seems to be possible to abstract from the hologram idea its essentials, namely the fact that a piece of hologram is like a small window. This makes it possible to circumvent the most obvious objections against the idea.

   i) The essential feature of the hologram is that a small piece of a hologram acts like a window. The visual experience is not changed much even when one perceives through a small window. Hence one could give up the assumption that brain prepares holograms. Rather, one could consider the possibility that neurons see part of the same sensory scene through neuronal windows. Seing would be made possible by some field like quantity whose values would be determined by its sources in the same nonlocal manner as electromagnetic field is determined by its sources. Sources could be either objects of the external world or of model world generated by sensory experience, constisting perhaps of mind-like space-time sheets. Massless fields are especially attractive alternative since the form of the wave is preserved during propagation. Hence coherent photons generated by so called massless extremals [J4] assumed to be associated with the linear structures like microtubules contained inside every axon, are especially promising as a tool of neuronal vision.

   ii) TGD framework provides extremely general mechanisms of subjective and geometric memory corresponding to actual memories and expectations for what will happen and possibly happened. In principle it is possible to avoid memory storage completely. The experiments of Lashley could be understood by assuming only that the sensory data are experienced through neuronal windows. Thus there is no need to store memories in multiple holograms and even holograms are un-necessary. All boils down to the idea of neural window and TGD based quantum model of memory.

   iii) The existence of sensory homunculi is not in conflict with the holographic data representation. What happens is that single neuron sees part of the perceptive landscape through a window. Each neuron could be specialized to particular task, such as recognizing whether particular feature is present in the the sensory landscape. This would involve simple compar-

ison circuit making possible feature recognition perhaps involving neuronal wake-up. Feature recognition could rely basically on the generalization of Haken's theory [I1].

7.3 From holographic brain to neuronal window?

7.3.1 The notion of neural window

All sensory experiences should reduce to representations generated by zero modes, in particular zero modes characterizing classical Kähler field, which can reduce to pure electromagnetic (vision?) or Z^0 field (auditory experience?). If the primary or secondary stimuli generate Kähler electric fields proportional to the gradient of the intensity one can understand the generation of the objects of the perceptive field. If the gradient is strong, as it is on the boundary of the image of the object, the conservation of the Kähler electric flux forces the generation of mind-like space-time sheet at which part of the flux goes. Thus secondary sensory organ would automatically create representation for the objects of the perceptive field as mindlike space-time sheets, which in turn could give rise to selves representing objects of the perceptive field as mental images.

The idea that parts of brain automatically form a model for the objects of the external world as mind-like space-time sheets suggests an interesting connection with the holographic model of brain [40] and with micro-tubules as quantum antenna hypothesis [J4].

1. If mind-like space-time sheets are massless extremals, they act as quantum antennae and generate coherent photons. Axons contain microtubules and this leads to ask whether these axons could serve as wave guides for the coherent light generated by the mind-like space-time sheets representing the objects of the external world. Also the vacuum currents associated with these microtubular massless extremals could code the intensity of the coherent light emitted by the mind-like space-time sheets. If either of these guesses is correct, axons provide neurons with a direct sensory window to the representation of the external world formed by the mind-like space-time sheets residing at sensory organs. Coherent photons would also give rise to neuronal lingua franca realized as a direct neuronal/microtubular vision.

2. Sensory window would be in question in a rather literal sense. The fact that a piece of hologram provides the representation given by the entire hologram, albeit in a somewhat blurred form, is essentially equivalent with the possibility to see through a small window. Therefore the idea about neuronal window is in accord with the holographic model of brain [43, 40], which is based on the idea that all neurons receive more or less the same sensory input, analogous to the visual experience generated by a piece of hologram. Clearly, coherent photons would serve as kind of mass media at the level of brain.

3. What is interesting is that the decomposition of the neuronal vision to a large number of different views represented by small groups of light sensitive neurons could even help to build monocular stereoscopic vision since much more information would be used about the visual field.

4. Music metaphor provides a considerable restriction to the neuronal window idea. The Bose-Einstein condensed photons should correspond to single frequency equal to some cyclotron frequency. Thus it would seem that the sensory input of single neutron is yes/no type. The neuronal window however makes however still sense for neuronal groups: in this case the input would be determined by light and dark pixels. Various nuclei or brain could thus have neuronal windows to cortex and other nuclei of brain.

7.3.2 Neural window and imagery

Mental imagery is something which is difficult to understand in the framework of the standard neuro science. There are empirical results suggesting that mental images correspond to patterns of activity inside cortex, which are three-dimensional and continuous so that neural activation provides a concrete recognizable image about object [42]. Rather remarkably, also imaginative thought resembles very much visual imagery as is clear from the fact that language is full of visual metaphors [42]. It is also known that imagery uses same regions of cortex as real sensory experience and the problem is to understand why there is genuine sensory experience involved with imagery.

In the framework of the standard neuroscience the obvious question is why the pattern of the imagery activity is not accompanied by a direct sensory experience. Also the boundary between direct sensory experience and imagination is sometimes problematic: for instance, in the state between sleep and awake, sensory images often enter into mind. During dreams one can have sensory images and eidetic memory is essentially sensory memory. I have a personal experience about extended state of consciousness, or rather whole-body consciousness (this experience actually made me consciousness theoretician!). During this state I could see my thoughts as vivid visual images and had also peculiar odour and taste experiences also reported to occur during mystic experiences. Could the correct interpretation be that thalamus, cortex and sensory organs temporarily formed a larger self during this experience?

If one accepts that sensory qualia are at the level of sensory organs and neural activity only builds symbolic and cognitive representations, it is easy to understand the difference between imagination and sensory perception. Sensory imagination is sensory perception without sensory qualia. Quantum entanglement between sensory organs and cortex and TGD based view about long term memory resolves the obvious objections against this view.

This does not exlude the possibility that neurons have chemical senses and even see and hear. Neurons would not only contribute to our experience. Neurons able to perceive sensorily would be probably much more effective information processors than neurons which are blind and deaf. Therefore the notion of neuronal window could be useful metaphor in the modelling the neuronal basis of the mental imagery. For instance, the understanding of processes like rotation of an imagined object of visual field provides an exciting challenge. The rotation of mind-like space-time sheet should induce the rotation of the region containing nerve pulse activity. Neuronal window idea suggest that the imagined rotation of the object involves virtual sensory experience generated in the somatosensory- auditory-visual association region of the neocortex (note that only humans have these associatin regions). This region would be able to form representations of the basic objects of the perceptive field and manipulate them. The imagined rotation of the object could occur here and would be observed by the primary sensory regions.

Sensory perceptions involve a lot of computation like processing at the level of cortex (consider stereo vision as an example), which can be naturally identified as imagination yielding successive models for the external world as consisting of familiar objects. Both the imagined world represented by the mind-like space-time sheets inside cortex and the mindlike space-time sheets in the sensory organ could be seen by the secondary sensory organs in thalamus and compared to see whether the imagined world yields the same sensory input as the real world. The result of the comparison would be fed back to cortex as a nerve pulse pattern serving as a feedback modifying the model.

7.3.3 Neuronal window and blind sight

The phenomenon of blind sight [46] suggests that there is kind of a Zombi within us [39], which can see but that this vision does not give rise to a conscious vision. Typically persons who have blind sight can grasp the object of the visual field once they have been told that it contains the object. The Zombi within us seems to be much more rapid and reliable than the conscious 'I' in its responses but it seems to be much less flexible. It also seems that Zombi within us cannot

be cheated by illusions unlike conscious 'I', which suggests that much less theorizing and pattern recognition is involved. Rapid responses of Zombies within us are certainly consistent with the fact that cortical processing is not involved. Nonflexibility would be the price paid for the reliability and absence of higher level cognitive processing.

One can imagine many models for Zombi within us and probably there are many of them (and they are actually not Zombies at all!).

1. Thalamus projects sensory data to amygdala which is often called brain inside brain, or emotional brain. Amygdala would thus have neuronal window to to thalamus and could give rise to unconscious-to-us mental activity responsible also for the blind sight. Also the sensory perception at the level of retinae might be enough if one assumes that primary sensory qualia are at the level of sensory organs.

2. Formation of the symbolic representations for the objects of the perceptive field could occur also in the thalamic nuclei.

3. The decomposition of the perceptive field to objects could occur for the first time already at the level of retina and the coherent light from the mind-like space-time sheets provides a representation of the visual field seen by neurons of thalamus, whose regions serve as secondary secondary organs identifiable Zombies within us (Zombies only from our view point!).

7.4 Possible evidence for the neuronal window idea

To find whether the neuronal window based on coherent light hypothesis could make sense, it would be important to eliminate the effects of the higher level information processing. This requires the study of simple organisms having primitive sense of vision. There is indeed experimental support for identifying the coherent states of photons as associated with vision. It is known that some monocellulars possess elementary vision based on the microtubules [30]. The emergence of the multicellulars during the Cambrian explosion was preceded by the appearance of the microtubules. If the emergence of the microtubules meant the emergence of the visual consciousness in the length scale of the cell, then the formation of the multicellulars as cell societies can be understood as a natural consequence.

The length distribution of the microtubules in the rods and cones of the eye is concentrated in the region of the visible wavelengths. The coherent light in question could be identifiable as bio-photons of Popp [34]. The architecture of retina is 'wrong' from the engineering point of view. The ganglial axons feeding sensory input to brain are in front of the retina. This is in accordance with the TGD based model of vision in which the photons of incoming light Bose-Einstein condense on the ganglial axons and amplify the signal to the thalamus.

A further piece of evidence comes from the work of Callahan about the sense of smell of insects [32]. Many insects, such as moths and ants, are known to be attracted by light, say candles and electric lamps and Callahan took as his challenge to understand what is involved. Callahan discovered that insect's olfaction is not based on chemistry (alone) but to a maser like emission of infrared light generated by various molecules such as pheromones, scent molecules and many other biomolecules. Insects see rather than smell the sources of the infrared light. The sensillae of the insects serve as receiving antennas and amplify the incoming infrared radiation. Callahan also observed that the oscillation of insect antennae induce maser like emission from scent/etc. molecules by creating an oscillating emf. Thus sensory experiencing seems to involve active participation from the part of insect. In any case, the results of Callahan suggest that coherent light could be important also in our neuronal sensory experiencing.

The infrared light emissions from pheromones mediate sexual messages in case of insects. Quite remarkably, pheromones are known to mediate sexual and social signals also in case of many

mammals. For instance, certain chemical messages from a female mouse can make male mouse to mate immediately while certain chemical messages from other males make him agrresive. Many mammals, for instance rodents, are known to possess vomeronasal organs, small cigar like sacks containing neurons and having length of order few millimeters [41], giving rise to an accessory olfactory system, which is known to have much more primitive structure and to work in different way than the ordinary olfactory system. It is also known that this systems bypasses cerebral cortex in rodents. There is evidence that even humans have the ability to sniff certain chemicals mediating social and sexual signals without being aware of it and there is already now an entire perfurme industry based on this evidence. The chemicals giving rise to sexual attraction are probably pheromones. The fact that pheromones mediate sexual signals in case of both insects and mammals, is hardly an accident and suggests that the sensory mechanism must be the same and be based on the infrared emissions by phreromones. If the response is at neuronal level and if the cortex is not involved, one could understand why these messages are not experienced consciously. One could test this hypothesis by finding whether coherent infared radiation at frequencies emitted by pheromones can affect the behaviour of higher mammals including humans.

There is a further peculiar co-incidence: the cascade of transduction events occurring in the absorption of photon in retina is repeated in a remarkably similar way in olfactory receptor cells, which respond to odours whereas the receptor cells that respond to sound use a very different system [41]. Could this mean that also the experience of odour primarily involves the detection of (also) infrared light so that humans would not basically differ from insects or that olfactory system has evolved from the receptor neurons originally sensing infrared light? This would conform with the idea that the Kähler field generated in ear corresponds to classical Z^0 field, which does not generate coherent photons but couples with neutrinos. One must however notice that the resemblances between visual and linguistic imagery suggest that some part of ear generates cognitive representation based on coherent light and experienced by the secondary sensory organs in the thalamus.

7.5 Massless extremals as quantum holograms

It took long time to really understand what MEs really and along with this understanding came the vision about precisely how MEs could act as holograms and what biological functions these holograms could correspond to. It indeed seems that massless extremals (MEs) are perhaps the most fundamental solutions of the field equations as far as TGD inspired theory of consciousness is considered. What is important is that MEs play both the roles of quantum gravitational holograms [26] and dynamical holograms [29].

The hologram principle of quantum gravitational theories roughly states that the quantum theory in space-time with boundary reduces to a conformal quantum field theory at the boundary. If Kähler action were deterministic, precisely this would happen. The construction of the configuration space geometry relies crucially on the assumption that the complications due to the non-determinism of Kähler action do not radically modify the picture resulting assuming complete determinism.

It has indeed turned out that the basic construction in which everything to the lightlike boundary of M^4_+ (moment of big bang) acting as a hologram in quantum gravitational sense and defining conformal quantum theory, generalizes. The basic construction survives as a template of a more general construction in which also the lightlike boundaries of MEs having always lightlike M^4_+ projection are taken into account besides δM^4_+ as surfaces at which initial values can be prescribed arbitrarily. This brings in also time effectively absent in a strictly deterministic theory. The quantum gravitational hologram defined by δM^4_+ is replaced by a fractal structure formed by δM^4_+ and Russian doll hierarchy of the lightlike boundaries of MEs inside MEs. The supercanonical and superconformal invariances of the lightlike boundaries generalize in an elegant manner on basis of

the basic properties of MEs.

There are good reasons to expect that the lightlike selves defined by the boundaries of MEs are fundamental in TGD inspired theory of consciousness. The supercanonical quantum states associated with the lightlike boundaries are genuine quantum gravitational states defined by configuration space spinor fields, whose dependence on configuration space fiber degrees of freedom does not reduce to mere vacuum functional, and therefore do not possess any quantum field theoretic counterparts. They are state functionals in the world of worlds, so to say, and therefore should represent highest level in the hierarchy of quantum control in living systems.

MEs carry lightlike vacuum currents. In passive state these currents are Z^0 currents whereas in active state, obtained by a color $SU(3)$ rotation, the current is electromagnetic and generates coherent state of photons. One can say that the lightlike current provides a dynamical variant of the diffraction grating defined by the ordinary static hologram. This leads to a model of living matter in which the coherent states of ordinary photons and colored configuration space photons act as control commands. Their phase conjugates (time reversals) in turn correspond to the time reversed commands. What is especially beautiful is that simple reference wave can activate arbitrarily complex hologram acting as a control command. This provides new visions about healing by time reversed reference waves forcing the biological program responsible for an illness like cancer to run backwards in time. One can also construct a general theory of sensory representations based on MEs [H4]. To sum up, it seems that the hologram principle is they key element of brain and biological functioning but in a sense somewhat different from what it was believed to be by the pioneers.

7.6 The notion of conscious hologram

The notion of conscious hologram is the last step in the development of ideas related to bioholograms. The basic challenge is to generalize the notion of the ordinary hologram to that of a *conscious* hologram, about which bio-holograms would be examples. The notion of quantum gravitational hologram is defined at the level of geometric, purely physical existence whereas conscious holograms exist at the level of subjective existence defined by the sequence of quantum jumps and giving rise to the self hierarchy. Of course, these two notions of hologram must be closely related.

The notion of conscious hologram combines the saint and sinner aspects of consciousness to single concept: macrotemporal quantum coherence due to the generation of bound state entanglement and giving rise to co-operation on one hand, and the dissipative self-organization giving rise to Darwinian selection and competition on the other hand.

In nutshell, the notion of conscious hologram follows from the topological field quantization. Classical fields and matter form a Feynmann diagram like structure consisting of lines representing matter (say charged particles) and bosons (say photons). The matter lines are replaced by space-time sheets representing matter (elementary particles, atoms, molecules,...), and virtual bosons are replaced by topological light rays ("mass-less extremals", MEs). Also magnetic flux tubes appear and together with MEs they serve as correlates for bound state quantum entanglement.

The classical fields associated with MEs interfere only at the nodes, where they meet, and one has a hologram like structure with nodes interpreted as the points of a hologram. Thus one avoids the loss of information caused by the interference of all signals everywhere. This aspect is crucial for understanding the role of em fields in living matter and brain. The MEs corresponding to 'real photons' are like laser beams entering the hologram and possibly reflected from it. What is new that the nodes can be connected by 'virtual photon' MEs also analogous to laser beams. Hence also 'self-holograms' with no laser beam from external world are possible (brain without sensory input).

The hologram has a fractal structure: there are space-time sheets at space-time sheets and high frequency MEs propagating effectively as mass-less particles inside low frequency MEs serving as

quantum entangling bridges of even astrophysical length. The particle like high frequency MEs induce 'bridges' between magnetic flux tubes and atomic space-time sheets at the receiving end. This makes possible the leakage of supra currents from magnetic flux tubes to atomic space-time sheets analogous to the exposure of film producing hologram. The leakage induces dissipation, self-organization, and primitive metabolism as a cyclic flow of ionic currents between the two space-time sheets, and thus a Darwinian selection of the self-organization patterns results. Under certain conditions the leakage followed by dropping back to the larger space-time sheet can also give rise to a many-sheeted laser. The low frequency MEs are responsible for the bound state entanglement, macroscopic quantum coherence and co-operation whereas high frequency MEs are responsible for self-organization and competion.

The 3-D vision associated with ordinary holograms generalizes to stereo consciousness resulting in the fusion of mental images associated with the points of conscious hologram [K4].

8 Four-dimensional fractal brain as an associative net

The identification of brain as 4-dimensional fractal associative net seems to provide a promising paradigm for the understanding of brain functioning. The associative net structure and mere real physics considerations are certainly not all that is needed. p-Adic physics as physics of cognition means that fundamental cognitive representations correspond to p-adic space-time regions, and, needless to say, in this respect huge amount of work remains to be done in order to build connections between theory and observations. In the following only the real physics aspects of brain as an associative net are considered.

8.1 Brain as an associative net

The notion of associative net suggests a general paradigm making it possible to understand brain functioning. The subjective time development of an associative net consists of experiences representing associations $A \to B$. In case of brain associative net is a network of neurons. "A$\to$ B" association is made possible because the emission of synaptic vesicles implies that postsynaptic and presynaptic neuronal space-time sheets form a connected space-time sheet. A is represented by the various presynaptic inputs and B corresponds to the output of the postsynaptic neuron. A and B can correspond to various sensory qualia or Boolean statements represented in terms of memes which in turn decompose into sequences of codons consisting of 126 binary digits and represented in terms of cognitive neutrino-antineutrino sequences. Memetic codons could also have interpretation as binary representations of integers providing quantitative measures for qualities. In Boolean case associations are experienced as logical implications "If A then B" is true. A and B can represented arbitrarily complicated statements composed of elementary statements. Neuron receives the conclusions of postsynaptic neuron as premises and feeds its own conclusion as premises to its own postsynaptic neuron.

Self-organization by quantum jumps selects gradually the allowed "A $\to$ B" correspondences as asymptotic self- organization patterns. Quantum self-organization and quantum statistical determinism suggest a natural Darwinian selection of the memes caused by the dissipation inside self and completely analogous to protein folding. The correspondences $A \to B$ would be determined by chemical macro variables characterizing the state of the neuron and chemical transmitters would play a crucial part in the learning of the responses. Syncronization is necessary for the function of the network. Emotional control can modify the associations "A$\to$ B" in long time scale (conditioning and desensitization): for instance, some conditions belonging to premises A of Boolean association drop away or B can change.

8.2 4-dimensional fractal brain

One needs two additional principles in order to have vision about brain a la TGD.

1. Brain is 4-dimensional in well-defined and very restricted sense. This follows from the classical non-determinism of Kähler action. Self-organization by quantum jumps replaces the classical space-time surface repeatedly with a new one and the final result represents classically the activity as it would be detected by a compeletely mechanical instrument. One can say that the classical time development describing say sensory experience, long term memory, motor activity or logical thought is gradually refined by starting from a rough sketch and making successively finer corrections iteratively. The process is like making a painting stating from a rough scetch. The four-dimensionality of the brain and difference between subjective and geometric time is absolutely essential element.

2. Fractality is second element. The successive refinement process proceeds from long to short time and spatial lenght scales. Thus large and slow neural circuits correspond to rough sketches and small and rapid circuits to small details. Small circuits are simultaneously active (in sense of subjective time) in the entire space-time region defining the duration of the activity. Thus again the 4-dimensionality of brain is crucial.

The notion of associative net suggests a very general view about how brain functions and gives rise to conscious experiences. Brain itself is a huge associative circuit but decomposes into more or less autonomous subcircuits.

8.3 Sensory experiences, logical thinking, associations and simulations

The notion of associative net allows readily to understand what happens in sensory experiencing, logical thinking, formation of associations and imagination

1. Sensory representations are formed by an iterative process involving comparison which takes also care about the computation of unknown data such as distances of the objects of the perceptive field. For instance, various cortico-thalamic loops could be related this process. The updating of the zero modes of the sensory inputs from sensory organs is performed in the thalamic neurons receiving real sensory input from the sensory organ and expected sensory input from cortex. An automatic comparison process possibly realized at quantum level in terms of two weakly coupled super conductors is in question [I4, I5]. This process involves also the concentration of attention to specific features of the sensory experience.

2. Neuronal input represents in general case several sensory modalities and conscious output single sensory modality or 'Boolean quale' represented by memetic codon. Thus associative circuits can represent the formation of associations in associative regions of brain. Note however that pre- and postsynaptic neurons in principle represent always an association at the neural level and neuronal associations are basic building blocks of 'our' associations involving entire groups of neurons and entire neural circuits. Also the formation of associations is very probably an iterative process.

3. The circuits of the associative net provide an ideal realization for predictive simulations of type $A \to B \to ....$ in terms of various kinds of sensory qualia. This makes possible imagination. The difference with respect to the standard neural net is that conscious neuron represents some sensory modality or Boolean modality: this makes the simulation "real" and assigns meaning to nerve pulse patterns: note that the generation of meaning is basic problem of the neural net models of consciousness. This kind of simulation circuits are expected to be related with frontal lobes and to be crucial for the planning of the future activities. Motor

circuit involving basal ganglia, thalamus and prefrontal cortex is also a possible example of this kind of circuit. Again iteration bringing in more and more details to the motor plan is involved.

4. Logical deductions do not differ from simultation in an essential manner: the only difference is the replacement of the temporal causation by logical causations. In case of logical deductions premises and conclusions are coded to memetic codons represented by cognitive neutrino pairs. Much of our logical thinking might be actually habitual and almost deterministic deduction sequences associated with circular loops and unconscious to us. Logical consistency is thus not guaranteed and, unless the brain of a ideal mathematician is not in question, and results only from the logical consistency of the external world.

8.4 Formation of long term memories

Associative circuit give rise to learning of long term memories. Short term memories correspond to reverberating nerve pulse patterns in closed circuits giving rise to a repetition of the same component of experience again and again. In Boolean case periodic association sequences represented by closed loops $A \to B \to ...A$ correspond to tautologies. Reverberating memories are remembered with high probability if long term memories are realized as geometric memories. The reason is that there is high probability for a randomly generated cognitive space-time sheet in geometric past to reside on the region occupied by a reverbarating loop. Repetition is the manner to learn. It is rather plausible that Nature has discovered effective learning in this manner and there are indeed circuits associated with long term learning.

A quite recent finding in neuroscience is that during the learning of spatial tasks hippocampus and some other parts of brain generate long spike sequences. Typical interval between spikes varies between 1-2 milliseconds. This would mean that a sequence of 126 spikes would correspond to .1-.25 seconds which is of the same order of magnitude as the duration of our self identified as the duration of immediate sensory memory. Also long term memories are constructed as kind of artworks or charicatures.

8.5 Planning and realization of motor programs

Associative circuits are associated with planning and realization of the motor programs.

1. Motor activity is the reverse of sensory experiencing in a well-defined sense. The imagined motion of the object in the working memory representing perceptive field is transformed to the motion of the real world counterpart of the object so that motor organs are like puppets bound to axonal strings and moved by the little man in the brain. The perceptive field, where imagined motion occurs is located in the frontal cortex with primary motor cortex excluded. Several copies of the perceptive field providing different representation of the perceptive field are probably involved as 'working memories'. These working memories are formed by topographical maps between different parts of brain.

2. Planning of the motor action is almost motor action: the only difference is that the last stage when nerve pulse patterns characterizing the motion are fed to motor organs is not performed. Plan is essentially four-dimensional pattern of nerve pulse activity.

3. The ability to realize plan seems to require that it is memorized: this would require that the performance of the motor activity is repeatedly imagined and finally allowed to occur. Thus the nerve pulse activity representing plan becomes a periodical nerve pulse pattern and the actual motion starts when the coupling to primary organs is turned on. As a matter fact, 4-dimensional brain allows to give up the assumption about reverberation. Also the activation

of a motor plan in the geometric past could be possible! This would be consistent with the results of the experiments of Libet about active aspects of consciousness: what was observed that neural activity started before the conscious decision to raise index finger. The relevant time scale would be of the order of second. Of course, an interesting question is whether adult person could initiate in the geometric childhood a motor action affecting dramatically the geometric present, say leading to traffic accident! This possibility would seem to lead to paradoxal looking consequences.

4. Learning of a motor skill presumably means that motor plans very rapidly self-organize to their final shapes. Learned skills correspond to motor plans which are winners in the Darwinian selection associated with self-organization.

5. The realization of the motor plan requires initial value sensitivity and muscles indeed provide an excellent example of an initial value sensitive system in which single nerve pulse generates macroscopic motion.

Motor action is planned and performed as a four-dimensional pattern. Construction of the motor plan means that *four-dimensinal* virtual perceptive landscape is gradually deformed into the desired shape. Motor activity can be seen as a fractal top-down process analogous to the construction of a space-time fractal: fractal classical determinism of Kähler action is absolutely crucial for this and $1/f$ noise [I5] is one of the consequences of the fractality. The non-determinism of the p-adic differential equations is very probably a direct correlate of the classical non-determinism of the Kähler action.

Macroscopic motor activity starts from a rough 4-dimensional sketch of motion which is gradually refined to the final artwork and possibly memorized to represent a reverbarating structure. The sketch and its various refinements are represented at the virtual perceptive landscape of the premotor cortex. More concretely:

1. First a large quantum jump realizing in rough sense the motor action occurs (for instance, hand grasps the object): this corresponds to certain classical time development starting in geometric past on new space-time surface. This stage corresponds to the activation of slow and large neural circuits with time scale characterizing the entire motion. This is like construction of the first sketch of a 4-dimensional fractal representing motor plan.

2. After this a cascade of smaller scale quantum jumps adding details to the motor plan occur: this is like adding further details to a four-dimensional fractal. The neural circuits involved are smaller and faster. Addition of details takes places in the entire time interval T of the geometric time associated with the full motion. This involves multitime moments of consciousness so that also neural circuits are active in the geometric interval defined by T.

8.6 Language

Memetic codons represented as temporal sequences of 126 binary digits should be the basic building blocks of the linguistic consciousness. The value of single binary digit is represented at the neural level by the presence/absence of nerve pulse and at the level of cognitive consciousness by the direction of the spin of the cognitive antineutrino. Boolean interpretation is not necessary: the interpretation of the sequences of 126 bit as integers providing quantitative measures for, say the intensities of the sensory experiences, is also possible. The proposed quantum models for the quantum correlate of hearing and for Boolean mind [K3, L1, H8] suggest that sound frequencies are mapped to Z^0 magnetic cyclotron frequencies of ions whereas thinking corresponds to Z^0 magnetic cyclotron frequency which is above the range of the audible sound frequencies. This supports the idea that memetic codons are as such experienced as some kind of internal speech and also that

only certain brain regions allow Boolean mind: the generation of cognitive neutrino pairs indeed requires strong axonal Z^0 magnetic fields which could be present only in the postsynaptic axons of the associative regions of cortex.

The differences between right and left brain suggest that the output axons in the associative regions of left brain represent information using cognitive neutrino pairs whereas the corresponding axons in the right brain hemisphere could represent information in terms of Z^0 cyclotron frequency varying above the audible frequency range (left brain talks and right brain sings!). If audible frequencies are involved, Josephson frequencies must be sufficiently far from cyclotron frequencies so that right brain imagines of hearing the thoughts rather than actually hears them. Unless higher harmonics of the cyclotron frequency are used (which is quite possible!), this requires parallel mode of representation since music metaphor suggests that the Z^0 cyclotron frequency of the axon is not variable.

Language circuits would be involved with the translation of the Boolean statements to linguistic expressions coded eventually to motor activities yielding speech. This process is only special case of a motor activity and thought as an internal speech is like a motor plan. Language represents one possible realization of the memetic code analogous to the translation of DNA sequences to proteins. It is instructive to look what contraints the memetic code poses on the general structure of language. The first empirical fact is that the meaning of the linguistic experience is insensitive to the local variations in the speed of speech. In particular, the repetion of a phoneme is usually interpreted as providing no additional purely linquistic information. On the other hand, the linguistic meaning of speech is determined by its purely local structure.

These facts are consistent with the hypothesis that phonemes are the basic codons of speech having fixed duration and that a repeated phoneme has the same linguistic meaning as single phoneme. This supports the identification of the phonemes as representations of the memetic codons: phoneme would thus represent single linguistic subself. By the previous estimate the duration of the memetic codon should have duration in the range $.1 - .25$ seconds. A more precise estimate comes from the detailed model for the physical realization of the memetic code and from the model of nerve pulse [L1, M2]: the resulting estimate for the duration of the memetic codon is about .14 seconds. The facts that a frequency $f \sim 10$ Hz represents the fundamental frequency associated with speech organs and that 20 Hz frequency represents the lower limit for the audible frequencies are consistent with the identification of the phonemes as linguistic images of the memetic codons.

Note that cognitive neutrino pairs of duration of order one millisecond are not experienced as separate components of conscious experience if time averaging is involved with temporal binding. This is consistent with the fact that language does not contain any smaller consciously experienced constituents than phonemes. Not that speech represents (very-!) many-to one expression of the menetic code (faithful coding would require language with 2^{126} different phonemes: this gives good idea about the present evolutional level of human culture!). Genetic code is not unique and some cell organelles, such as mitochondria, possess their own genetic code. Various languages could correspond to different translations of the memetic code to nerve pulse patterns in turn coded to motor activities representing expressions of language. The Mersenne prime $2^{127} - 1$ could be clearly re-christened to be the number of Babel!

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