Introduction

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1 Basic Ideas of TGD

The basic physical picture behind TGD was formed as a fusion of two rather disparate approaches: namely TGD is as a Poincare invariant theory of gravitation and TGD as a generalization of the old-fashioned string model.

1.1 TGD as a Poincare invariant theory of gravitation

The first approach was born as an attempt to construct a Poincare invariant theory of gravitation. Space-time, rather than being an abstract manifold endowed with a pseudo-Riemannian structure, is regarded as a surface in the 8-dimensional space $H = M^4_+ \times CP_2$, where M^4_+ denotes the interior of the future light cone of the Minkowski space (to be referred as light cone in the sequel) and $CP_2 = SU(3)/U(2)$ is the complex projective space of two complex dimensions [1, 2, 3, 4]. The identification of the space-time as a submanifold [5, 6] of $M^4 \times CP_2$ leads to an exact Poincare invariance and solves the conceptual difficulties related to the definition of the energy-momentum in General Relativity [Misner-Thorne-Wheeler, Logunov *et al*]. The actual choice $H = M^4_+ \times CP_2$ implies the breaking of the Poincare invariance in the cosmological scales but only at the quantum level. It soon however turned out that submanifold geometry, being considerably richer in structure than the abstract manifold geometry, leads to a geometrization of all basic interactions. First, the geometrization of the elementary particle quantum numbers is achieved. The geometry of CP_2 explains electroweak and color quantum numbers. The different H-chiralities of H-spinors correspond to the conserved baryon and lepton numbers. Secondly, the geometrization of the field concept results. The projections of the CP_2 spinor connection, Killing vector fields of CP_2 and of H-metric to four-surface define classical electroweak, color gauge fields and metric in X^4.

1.2 TGD as a generalization of the hadronic string model

The second approach was based on the generalization of the mesonic string model describing mesons as strings with quarks attached to the ends of the string. In the 3-dimensional generalization 3-surfaces correspond to free particles and the boundaries of the 3- surface correspond to partons in the sense that the quantum numbers of the elementary particles reside on the boundaries. Various boundary topologies (number of handles) correspond to various fermion families so that one obtains an explanation for the known elementary particle quantum numbers. This approach leads also to a natural

topological description of the particle reactions as topology changes: for instance, two-particle decay corresponds to a decay of a 3-surface to two disjoint 3-surfaces.

1.3 Fusion of the two approaches via a generalization of the space-time concept

The problem is that the two approaches seem to be mutually exclusive since the orbit of a particle like 3-surface defines 4-dimensional surface, which differs drastically from the topologically trivial macroscopic space-time of General Relativity. The unification of these approaches forces a considerable generalization of the conventional space-time concept. First, the topologically trivial 3-space of General Relativity is replaced with a "topological condensate" containing matter as particle like 3-surfaces "glued" to the topologically trivial background 3-space by connected sum operation. Secondly, the assumption about connectedness of the 3-space is given up. Besides the "topological condensate" there is "vapour phase" that is a "gas" of particle like 3-surfaces (counterpart of the "baby universies" of GRT) and the non-conservation of energy in GRT corresponds to the transfer of energy between the topological condensate and vapour phase.

It clear that TGD leads to a radical generalization of the concept of 3-space. 3-space (or 3-surface) can have boundaries. In elementary particle length scales family replication phenomenon was explained in terms of the topology of 2-dimensional boundary components of the 3-surface. Boundaries are possible even in macroscopic length scales: macroscopic material bodies are identified as 3-surfaces with boundary identified as the outer surface of the macroscopic body. This implies a radical reformulation of condensed matter physics. 3-space need not be connected anymore and free elementary particle corresponds to a 3-surface of finite size. Some of the consequences is the necessity of wormholes of size of order CP_2 size with potential applications to the description of bio-systems as macroscopic quantum systems. Even more: the separations between different disjoint components of 3-surface need not be spacelike, and "association sequences", that is 3-surfaces consisting of time series of extremely strongly (but not totally) correlated 3-surfaces on a classical space-time surface, are possible and even probable and are the basic element in the TGD inspired model of a 'thinking' system.

2 The four threads in the development of quantum TGD

The development of TGD has involved four strongly interacting threads: physics as infinite-dimensional geometry; p-adic physics; TGD inspired theory of consciousness and TGD as a generalized number theory. In the following these four threads are briefly described.

2.1 Quantum TGD as configuration space spinor geometry

A turning point in the attempts to formulate a mathematical theory was reached more than ten years ago. The great insight was "Do not quantize". The basic ingredients to the new approach have served as the basic philosophy for the attempt to construct Quantum TGD since then and are the following ones:

a) Quantum theory for extended particles is free(!), classical(!) field theory for a generalized Schrödinger amplitude in the configuration space $C(H)$ consisting of all possible 3-surfaces in H. "All possible" means that surfaces with arbitrary many disjoint components and with arbitrary internal topology and also singular surfaces topologically intermediate between two different manifold topologies are included. Particle reactions are identified as topology changes [7, 8, 9]. For instance, the decay of a 3-surface to two 3-surfaces corresponds to the decay $A \to B + C$. Classically this corresponds to a path of configuration space leading from 1-particle sector to 2-particle sector. At quantum level this corresponds to the dispersion of the generalized Schrödinger amplitude localized to 1-particle sector to two-particle sector. All coupling constants should result as predictions of the theory since no nonlinearities are introduced.

b) Configuration space is endowed with the metric and spinor structure so that one can define various metric related differential operators, say Dirac operator, appearing in the field equations of the theory.

2.2 p-Adic TGD

The p-adic thread emerged for roughly ten years ago as a dim hunch that p-adic numbers might be important for TGD. Experimentation with p-adic numbers led to the notion of canonical identification mapping reals to p-adics and vice versa. The breakthrough came with the succesful p-adic mass calculations using p-adic thermodynamics for Super-Virasoro representations with the super-Kac-Moody algebra associated with a Lie-group containing

standard model gauge group. Although the details of the calculations have varied from year to year, it was clear that p-adic physics reduces not only the ratio of proton and Planck mass, the great mystery number of physics, but all elementary particle mass scales, to number theory if one assumes that primes near prime powers of two are in a physically favoured position. Why this is the case, became one of the key puzzless and led to a number of arguments with a common gist: evolution is present already at the elementary particle level and the primes allowed by the p-adic length scale hypothesis are the fittest ones.

It became very soon clear that p-adic topology is not something emerging in Planck length scale as often believed, but that there is an infinite hierarchy of p-adic physics characterized by p-adic length scales varying to even cosmological length scales. The idea about the connection of p-adics with cognition motivated already the first attempts to understand the role of the p-adics and inspired 'Universe as Computer' vision but time was not ripe to develop this idea to anything concrete (p-adic numbers are however in a central role in TGD inspired theory of consciousness). It became however obvious that the p-adic length scale hierarchy somehow corresponds to a hierarchy of intelligences and that p-adic prime serves as a kind of intelligence quotient. Ironically, the almost obvious idea about p-adic regions as cognitive regions of space-time providing cognitive representations for real regions had to wait for almost a decade for the access into my consciousness.

There were many interpretational and technical questions crying for a definite answer. What is the relationship of p-adic non-determinism to the classical non-determinism of the basic field equations of TGD? Are the p-adic space-time region genuinely p-adic or does p-adic topology only serve as an effective topology? If p-adic physics is direct image of real physics, how the mapping relating them is constructed so that it respects various symmetries? Is the basic physics p-adic or real (also real TGD seems to be free of divergences) or both? If it is both, how should one glue the physics in different number field together to get *The Physics*? Should one perform p-adicization also at the level of the configuration space of 3-surfaces? Certainly the p-adicization at the level of superconformal representation is necessary for the p-adic mass calculations. Perhaps the most basic and most irritating technical problem was how to precisely define p-adic definite integral which is a crucial element of any variational principle based formulation of the field equations. Here the frustration was not due to the lack of solution but due to the too large number of solutions to the problem, a clear symptom for the sad fact that clever inventions rather than real discoveries might be in question.

Despite these frustrating uncertainties, the number of the applications of the poorly defined p-adic physics growed steadily and the applications turned out to be relatively stable so that it was clear that the solution to these problems must exist. It became only gradually clear that the solution of the problems might require going down to a deeper level than that represented by reals and p-adics.

2.3 TGD as a generalization of physics to a theory consciousness

General coordinate invariance forces the identification of quantum jump as quantum jump between entire deterministic quantum histories rather than time=constant snapshots of single history. The new view about quantum jump forces a generalization of quantum measurement theory such that observer becomes part of the physical system. Thus a general theory of consciousness is unavoidable outcome. This theory leads to a quantitative understanding of the relationship between sensory representations and EEG. The basic elements of the theory are following.

The identification of quantum jump between deterministic quantum histories (configuration space spinor fields) as a moment of consciousness defines microscopic theory of consciousness. Quantum jump involves the steps

$$\Psi_i \rightarrow U\Psi_i \rightarrow \Psi_f \ ,$$

where U is informational "time development" operator, which is unitary like the S-matrix characterizing the unitary time evolution of quantum mechanics. U is however only formally analogous to Schrödinger time evolution of infinite duration although there is *no* real time evolution involved. It is not however clear whether one should regard U-matrix and S-matrix as two different things or not: U-matrix is a completely universal object characterizing the dynamics of evolution by self-organization whereas S-matrix is a highly context dependent concept in wave mechanics and in quantum field theories where it at least formally represents unitary time translation operator at the limit of an infinitely long interaction time. The S-matrix understood in the spirit of superstring models is however something very different and could correspond to U-matrix.

The requirement that quantum jump corresponds to a measurement in the sense of quantum field theories implies that each quantum jump involves localization in zero modes which parametrize also the possible choices of the quantization axes. Thus the selection of the quantization axes performed

by the Cartesian outsider becomes now a part of quantum theory. Together these requirements imply that the final states of quantum jump correspond to quantum superpositions of space-time surfaces which are macroscopically equivalent. Hence the world of conscious experience looks classical. At least formally quantum jump can be interpreted also as a quantum computation in which matrix U represents unitary quantum computation which is however not identifiable as unitary translation in time direction and cannot be 'engineered'.

The concept of self is absolutely essential for the understanding of the macroscopic and macrotemporal aspects of consciousness. Self corresponds to a subsystem able to remain un-entangled under the sequential informational 'time evolutions' U. Exactly vanishing entanglement is practically impossible in ordinary quantum mechanics and it might be that 'vanishing entanglement' in the condition for self-property should be replaced with 'subcritical entanglement'. On the other hand, if space-time decomposes into p-adic and real regions, and if entanglement between regions representing physics in different number fields vanishes, space-time indeed decomposes into selves in a natural manner.

It is assumed that the experiences of the self after the last 'wake-up' sum up to single average experience. This means that subjective memory is identifiable as conscious, immediate short term memory. Selves form an infinite hierarchy with the entire Universe at the top. Self can be also interpreted as mental images: our mental images are selves having mental images and also we represent mental images of a higher level self. A natural hypothesis is that self S experiences the experiences of its subselves as kind of abstracted experience: the experiences of subselves S_i are not experienced as such but represent kind of averages $\langle S_{ij} \rangle$ of sub-subselves S_{ij}. Entanglement between selves, most naturally realized by the formation of join along boundaries bonds between mindlike or material space-time sheets, provides a possible a mechanism for the fusion of selves to larger selves (for instance, the fusion of the mental images representing separate right and left visual fields to single visual field) and forms wholes from parts at the level of mental images.

The third basic element relates TGD inspired theory of conciousness to quantum measurement theory. The assumption that localization occurs in zero modes in each quantum jump implies that the world of conscious experience looks classical. It also implies the state function reduction of the standard quantum measurement theory as the following arguments demonstrate (it took incredibly long time to realize this almost obvious fact!).

a) The standard quantum measurement theory a la von Neumann involves the interaction of brain with the measurement apparatus. If this inter-

action corresponds to entanglement between microscopic degrees of freedom m with the macroscopic effectively classical degrees of freedom M characterizing the reading of the measurement apparatus coded to brain state, then the reduction of this entanglement in quantum jump reproduces standard quantum measurement theory provide the unitary time evolution operator U acts as flow in zero mode degrees of freedom and correlates completely some orthonormal basis of configuration space spinor fields in non-zero modes with the values of the zero modes. The flow property guarantees that the localization is consistent with unitarity: it also means 1-1 mapping of quantum state basis to classical variables (say, spin direction of the electron to its orbit in the external magnetic field).

b) Since zero modes represent classical information about the geometry of space-time surface (shape, size, classical Kähler field,...), they have interpretation as effectively classical degrees of freedom and are the TGD counterpart of the degrees of freedom M representing the reading of the measurement apparatus. The entanglement between quantum fluctuating non-zero modes and zero modes is the TGD counterpart for the $m - M$ entanglement. Therefore the localization in zero modes is equivalent with a quantum jump leading to a final state where the measurement apparatus gives a definite reading.

This simple prediction is of utmost theoretical importance since the black box of the quantum measurement theory is reduced to a fundamental quantum theory. This reduction is implied by the replacement of the notion of a point like particle with particle as a 3-surface. Also the infinite-dimensionality of the zero mode sector of the configuration space of 3-surfaces is absolutely essential. Therefore the reduction is a triumph for quantum TGD and favours TGD against string models.

Standard quantum measurement theory involves also the notion of state preparation which reduces to the notion of self measurement. Each localization in zero modes is followed by a cascade of self measurements leading to a product state. This process is obviously equivalent with the state preparation process. Self measurement is governed by the so called Negentropy Maximization Principle (NMP) stating that the information content of conscious experience is maximized. In the self measurement the density matrix of some subsystem of a given self localized in zero modes (after ordinary quantum measurement) is measured. The self measurement takes place for that subsystem of self for which the reduction of the entanglement entropy is maximal in the measurement. In p-adic context NMP can be regarded as the variational principle defining the dynamics of cognition. In real context self measurement could be seen as a repair mechanism allowing the system

to fight against quantum thermalization by reducing the entanglement for the subsystem for which it is largest (fill the largest hole first in a leaking boat).

The fourth basic element is quantum theory of self-organization based on the identification of quantum jump as the basic step of self-organization. Quantum entanglement gives rise to the generation of long range order and the emergence of longer p-adic length scales corresponds to the emergence of larger and larger coherent dynamical units and generation of a slaving hierarchy. Energy (and quantum entanglement) feed implying entropy feed is a necessary prequisite for quantum self-organization. Zero modes represent fundamental order parameters and localization in zero modes implies that the sequence of quantum jumps can be regarded as hopping in the zero modes so that Haken's classical theory of self organization applies almost as such. Spin glass analogy is a further important element: self-organization of self leads to some characteristic pattern selected by dissipation as some valley of the "energy" landscape. Dissipation can be regarded as the ultimate Darwinian selector of both memes and genes. The mathematically ugly irreversible dissipative dynamics obtained by adding phenomenological dissipation terms to the reversible fundamental dynamical equations derivable from an action principle can be understood as a phenomenological description replacing in a well defined sense the series of reversible quantum histories with its envelope.

The fifth basic element are the concepts of association sequence and cognitive space-time sheet. The huge vacuum degeneracy of the Kähler action suggests strongly that the absolute minimum space-time is not always unique. For instance, a sequence of bifurcations can occur so that a given space-time branch can be fixed only by selecting a finite number of 3-surfaces with timelike(!) separations on the orbit of 3-surface. In case that nondetermism is located to a finite time interval and is microscopic, this sequence of 3-surfaces has interpretation as a simulation of a classical history, a geometric representation of thought. When nondeterminism has long lasting and macroscopic effect one can identify it as volitional nondeterminism associated with our choices. Association sequences relate closely with the cognitive space-time sheets defined as space-time sheets having finite time duration and psychological time can be identified as a temporal center of mass coordinate of the cognitive space-time sheet. The gradual drift of the cognitive space-time sheets to the direction of future force by the geometry of the future lightcone explains the arrow of psychological time. Simplest dimensional estimate gives for the average increment τ of geometric time in quantum jump $\tau \sim 10^4\ CP_2$ times so that $2^{127} - 1 \sim 10^{38}$ quantum jumps

are experienced during secondary p-adic time scale $T_2(k = 127) \simeq 0.1$ seconds which is the duration of physiological moment and predicted to be fundamental time scale of human consciousness.

The sixth basic element adds a physical theory of cognition to this vision. TGD space-time decomposes into regions obeying real and p-adic topologies labelled by primes $p = 2, 3, 5, ...$ p-Adic regions obeys the same field equations as the real regions but are characterized by p-adic nondeterminism since the functions having vanishing p-adic derivative are pseudo constants which are piecewise constant functions. Pseudo constants depend on a finite number of positive pinary digits of arguments just like numerical predictions of any theory always involve decimal cutoff. This means that p-adic space-time regions are obtained by glueing together regions for which integration constants are genuine constants. The natural interpretation of the p-adic regions is as cognitive representations of real physics. p-Adic serve also as correlates for intentionality: the transformation of intention ot action involves quantum in which p-adic space-time regions is transformed to a real one. The freedom of imagination is basically due to the p-adic nondeterminism. p-Adic regions perform mimicry and make possible for the Universe to form cognitive representations about itself.

2.4 TGD as a generalized number theory

Quantum T(opological)D(ynamics) as a classical spinor geometry for infinite-dimensional configuration space, p-adic numbers and quantum TGD, and TGD inspired theory of consciousness, have been for last ten years the basic three strongly interacting threads in the tapestry of quantum TGD. For few yeas ago the discussions with Tony Smith generated a fourth thread which deserves the name 'TGD as a generalized number theory'. Space-time could be regarded locally as a 4-dimensional number field of quaternions imbedded as a surface into 8-dimensional imbedding space identifiable locally as the number field of octonions. The discovery of the hierarchy of infinite primes and their correspondence with a hierarchy defined by a repeatedly second quantized arithmetic quantum field theory gave a further boost for the speculations about TGD as a generalized number theory. The work with Riemann hypothesis led to further ideas.

After the realization that infinite primes can be mapped to polynomials representable as surfaces geometrically, it was clear how TGD might be formulated as a generalized number theory with infinite primes forming the bridge between classical and quantum such that real numbers, p-adic numbers, and various generalizations of p-adics emerge dynamically from alge-

braic physics as various completions of the algebraic extensions of rational quaternions and octonions. Complete algebraic, topological and quaternion-dimensional democracy would characterize the theory.

What is especially satisfying is that p-adic and real regions of the space-time surface emergy automatically as solutions of the field equations. In the space-time regions where the solutions of field equations give rise to in-admissible complex values of the quaternionic coordinate, p-adic solution can exist for some values of the p-adic prime. The characteristic non-determinism of the p-adic differential equations suggests strongly that p-adic regions correspond to 'mind stuff', the regions of space-time where cognitive representations reside. This interpretation implies that p-adic physics is physics of cognition. Since Nature is probably extremely brilliant simulator of Nature, the natural idea is to study the p-adic physics of the cognitive representations to derive information about the real physics. This view encourage by TGD inspired theory of consciousness clarifies difficult interpretational issues and provides a clear interpretation for the predictions of p-adic physics.

3 Quantum Theory

3.1 Basic ideas

The identification of quantum states as configuration space spinor fields means that the construction of quantum TGD reduces to the construction of spinor geometry for the infinite-dimensional configuration space CH of TGD consisting of 3-dimensional surfaces in the 8-dimensional space $M^4_+ \times CP_2$[1]. This means the construction of the metric and spinor structure. Quite general physical requirements lead to the conclusion that the geometry of CH must be so called Kähler geometry[2] allowing complex structure in its tangent space. The construction of the CH metric reduces to that of identifying the so called Kähler function $K(X^3)$ as a functional of 3-surface. The construction of the gamma matrices associated with the spinor structure reduces

[1] For details see the first two parts of [TGD].

[2] Annihilation and creation operators are the quintessence of quantum field theory. Kähler structure in the configuration space of 3-surfaces geometrizes this concept. In Kähler geometry imaginary unit i is geometrically realized as an antisymmetric tensor, so called Kähler form J, whose square is -1, 1 being realized as the metric tensor. Physically Kähler form behaves like sourceless Maxwell field. The simplest example of Kähler geometry is two-dimensional (q,p)- phase space for one-dimensional harmonic oscillator regarded as a complex plane with complex coordinate (z=q+ip).

to the second quantization of free induced spinor fields on space-time surface: anticommuting gamma matrices are superpositions of anticommuting fermionic oscillator operators.

3.1.1 General Coordinate Invariance

The basic physical requirement is 4-dimensional General Coordinate Invariance. This can be realized provided that the Kähler function associates to a given 3-surface X^3 appearing as its argument a unique space-time surface $X^4(X^3)$ for 4-dimensional diffeomorphisms to act on. This space-time surface could be called the classical space-time associated with a given 3-surface. By General Coordinate Invariance the value of $K(X^3)$ must be same as the value of Kähler function for the intersection Y^3 of $X^4(X^3)$ with lightcone boundary. A very convincing guess for the Kähler function $K(Y^3)$ is as the absolute minimum of so called Kähler action in the set of all space-time surfaces going "through" Y^3. A good analogy are the membranes going through a wire: one of them provides the surface with minimum area passing through the wire. In present case possible wires correspond to three-surfaces Y^3 located on lightcone boundary.

3.1.2 Quantum criticality

Kähler action involves only one a priori free parameter, the so called Kähler coupling strength α_K, and the fact that the vacuum functional is precisely analogous to the partition function of a critical system with Kähler coupling strength in the role of temperature suggests that the physical theory corresponds to a critical value of the Kähler coupling strength. An important prediction is the existence of long range quantum correlations in all length scales: this suggests that TGD could provide the mechanisms needed for understanding bio-systems as macroscopic quantum systems.

The identification of the Kähler action as the c-number part of the modified Dirac action resulting from a normal ordering implies that even quantum criticality is a prediction of the theory. This identification allows the critical value of the Kähler coupling strength to depend on the p-adic prime labelling the space-time sheet rather than being a global constant. This picture is supported by the fact that CP_2 type extremals are not fermionic vacua although they are classical vacua: this makes possible an explicit model for elementary particle leading to explicit Feynmann rules for S-matrix.

3.1.3 Various super symmetries

Configuration space geometry is fixed by symmetry considerations and by the requirement of divergence cancellation (recall that the situation is infinite-dimensional!) to a very high degree. Superconformal and supercanonical symmetries associated with the lightcone boundary act as cosmological symmetries and possibly also as good macroscopic symmetries: they act as isometries of the configuration space metric. Quaternion-conformal symmetries in turn act as local super-conformal and super-Kac Moody symmetries in zero modes and dictate the spectrum and interactions of elementary particles. The Kac-Moody group is $P \times SU(3) \times U(2)_{ew}$, where P denotes Poincare group and is identifiable as gauge group of gravitational, strong and electroweak interactions.

TGD as a generalized number theory vision implies that imbedding space is $8n$-dimensional (n-octonion-dimensional) and given by $M^4_+ \times S^{2n-1}$, where S is 4n-dimensional Kähler manifold. $n = 1$ corresponds to the 8-dimensional imbedding space. This is due to the very special conformal properties of the 4-dimensional lightcone boundary (the moment of the big bang) making possible to provide lightcone boundary with Kähler and symplectic structures. The canonical transformations of $\delta M^4_+ \times CP_2^{2n-1}$ act as isometries of the configuration space and canonical Lie-algebra extends to super algebra so that symmetry group is huge even when compared to the symmetries of string models.

Formally the construction of Quantum TGD reduces to the construction of a basis for the classical spinor fields defined in the configuration space. The task is to identify natural basis for these fields, to construct the S-matrix, to derive the elementary particle spectrum and to deduce the quantum field theory limit of TGD.

3.2 Construction of quantum theory

The vision about TGD as a generalized number theory allows to concretize considerably the previous views about quantum TGD and get rid of internal inconsistencies. The superconformal invariance associated with the light cone boundary and quaternion-conformal invariance are quite different things: the first one can be regarded as cosmological symmetry whereas the latter is the symmetry crucial for elementary particle physics. Accordingly, configuration space Dirac equation and super-Virasoro conditions associated with the quaternion-conformal super-Kac-Moody algebra are separate conditions: this realization allows to get rid of some earlier ad hoc constructs

forced by the physically intuition yielded by the p-adic mass calculations and replacing the strictly geometric approach. Unless one is doing quantum cosmology, one can safely forget supercanonical symmetries associated with the lightcone boundary and concentrate on $M^4 \times SO(3,1) \times SU(3) \times U(2)_{ew}$ Super-Kac-Moody algebra acting as gauge symmetries of gravitational, color and electroweak interactions and forming the backbone of p-adic mass calculations.

In cosmological scales the state construction involves the construction of super-canonical representations fixing the state basis at the boundary of configuration space defined by the boundary $\delta M^4_+ \times CP_2$ of the imbedding space. A natural manner to fix the basis for the configuration space spinor fields S in $C(\delta M^4_+ \times CP_2)$ is to require that the basis forms a representation for some Abelian extension of the isometry group of the configuration space.

a) A symplectic $U(1)$ extension of the isometry group induced from the Poisson brackets is constructed.

b) The spinor representations of the symplectic extension are assumed to be constructable in terms of configuration space Dirac opertora. The properties of the CH geometry suggest that configuration space Dirac equation should reduce to Super Virasoro conditions. These conditions say nothing about mass spectrum of elementary particles since cm degrees of freedom represent zero modes not contributing to configuration space metric and Dirac equation.

In practice all that is need is the construction of local physical states as representations of quaternion-conformal super algebra. The only new element is that supergenerators carry fermion number. This means a slight modification of the standard super-algebra structure. In this way one circumvents the Majorana condition forcing the dimension of the imbedding space to $d = 2 \ mod \ 8$. The algebra contains N-S type super generators carrying quark number and Ramond type super generators carrying lepton number. The construction of states as representations of this algebra leads to SKMD equations and yields universal mass formula. SKMD operator contains Kac-Moody central charge as parameter but the requirement that mass squared spectrum is integer valued in natural units, fixes the value of this parameter. Ramond and NS algebras are parts of a larger algebra obtained by combining the two algebras and allowing conformal generators with half odd integer conformal weight: these generators do not however act as geometric transformations and possess quantum numbers of leptoquark. One must pose either NS or Ramond type gauge conditions on the physical states.

One can assign to a particle like 3-surface also cm degrees of freedom.

This means that particles are characterized by partial waves in $H = M^4_+ \times CP_2$ so that in the point like limit Kaluza-Klein theory in H results. Color compensation mechanism allows the compensation of the anomalous color associated with color partial waves by the color associated with the monomials of $n = 0$ leptonic and $n = 1/2$ quark like generators of the dynamical Super Virasoro algebras.

In TGD the basic object is U-matrix and it is not clear how closely it corresponds to S-matrix of quantum field theories defined as a unitary time translation operator. U-matrix can be seen at the general level as Glebsch-Gordan coefficients relating free and interacting representations of the quaternion-conformal algebra and superconformal algebra associated with lightcone boundary. Free representation corresponds to the tensor product of super-algebras associated with $\cup_i X^4(Y^3_i)$, Y^3_i are the space-time surfaces associated with the infinite primes labelling the incoming particles whereas interacting representations corresponds to the superalgebras associated with $X^4(\cup_i Y^3_i)$ defined by the infinite integer defined as the product of infinite primes characterizing incoming states. This hypothesis reduces interactions to generalized number theory and gives hopes of making practical calculations someday.

At practical level the construction reduces to the construction of local S-matrix and quaternion-conformal invariance together with the fact that effective one-dimensionality reduces the situation algebraically to that encountered in string models gives good hopes that stringy S-matrix provides an excellent approximation. An open question is whether this S-matrix is approximation to U-matrix or not.

3.3 Construction of S-matrix at high energy limit

It is possible to write Feynmann rules for S-matrix in the approximation that only CP_2 type extremals appear as virtual and real particles. All CP_2 type extremals are locally isometric with CP_2 itself and only the random lightlike curve is dynamical. The classical dynamics is actually isomorphic with stringy dynamics since classical Virasoro conditions are satisfied. Fermions belong to representations of Super-Kac-Moody algebra of $M^4 \times SO(3,1) \times SU(3) \times U(2)_{ew}$. The classical non-determinism of the dynamics implies that Feynmann graph expansion is topologized. This saves from fermionic divergences since the exponent of the momentum generator effecting translation along the lines of Feynmann graph corresponds to that associated with the modified Dirac action and thus to free quantum theory for fermions.

Vertex operators $V(a,b,c)$ are generalizations of the vertex operators of string theory: instead of strings 3-surface inside CP_2 type extremal fuse together. Propagator factors are products of the exponent of Kähler action for CP_2 type extremal proportional to the volume of the CP_2 type extremal, the 'stringy' $1/(L_0 + i\epsilon)$ factor, which in fact comes from the vertices, and translation operator along the geodesic representing cm motion.

The theory has some features characteristic for quantum TGD.

a) One can assume that each quantum jump involves localization in zitterbewegung degrees of freedom. The resulting S-matrix is independent of the choise of the representative for the zitterbewegung orbit as long as the cm motion connects the lines of the vertices. The predictions depend however on an arbitrary function of U of CP_2 coordinates giving rise to a decomposition of CP_2 to 'time slices'. The dependence of the propagator is only through the volume of CP_2 type extremal determined by U whereas coupling constants have more complicated, but presumably very mild dependence on U. The dependence on the function U means that one must average the scattering rates over the allowed spectrum of functions U. This dependence of the fundamental coupling constants on U is in accordance with spin glass analogy and means that fundamental coupling constants are not strictly speaking constants.

b) The volume of the internal line, which is fraction of CP_2 volume determines the value of the exponent of Kähler action and provides thus a supression factor serving as an infrared cutoff. A constraint to the allowed functions U results from the topological condensation of CP_2 in particle like space-time sheet (for instance massless extremal), which implies that CP_2 type extremals cannot extend outside the region with size of order p-adic length scale L_p. The only interpretation is that the information about infrared cutoff length scale is coded into the structure of particle: particle in the box is quite not the same as free particle. This suggests new view about color confinement: quarks and gluons correspond to CP_2 type extremals which cannot exist too long time as free particles and therefore cannot leave hadron. The result also means that even elementary particles are to some degree adaptive systems.

c) The classical non-determinism of the Kähler action, not only makes possible the geometrization of the Feynmann rules, but also allows the interpretation of the S-matrix elements as transition amplitudes from a given vacuum to a new vacuum differing by an addition of a space-time sheet containing zero-energy state with incoming/outgoing states having positive/negative energies. By crossing symmetry this amplitude is indeed equal to S-matrix element. This means that zero energy states represent scatter-

ing events as physical states and obviously correspond to a higher, self-referential level of the physical existence. Entire hierarchy of higher level physical states coding in their structure physical laws at the lower levels of the hierachy is predicted. Thus classical non-determinism makes possible self-referential Universe whereas p-adic non-determinism makes possible cognitive representations.

4 p-Adic aspects of quantum TGD

It took quite a long time to end up with the recent picture how p-adic numbers emerge as a basic aspect of quantum TGD and what p-adicization of TGD might mean. Of course, recent picture need not be the final yet and there are several unsolved problems. In the following the basic properties of the p-adic numbers are described shortly and then it is demonstrated how p-adic numbers might emerge from TGD and how one should formulate p-adic version of quantum TGD formalism.

4.1 p-Adic numbers

Like real numbers, p-adic numbers can be regarded as completions of the rational numbers to a larger number field allowing the generalization of differential calculus. Each prime p defines a p-adic number field allowing the counterparts of the usual arithmetic operations. The basic difference between real and p-adic numbers is that p-adic topology is ultrametric. This means that the distance function $d(x,y)$ (the counterpart of $|x-y|$ in the real context) satisfies the inequality

$$d(x,z) \leq Max\{d(x,y), d(y,z)\} \ ,$$

(Max(a,b) denotes maximum of a and b) rather than the usual triangle inequality

$$d(x,z) \leq d(x,y) + d(y,z) \ .$$

p-Adic numbers have expansion in powers of p analogous to the decimal expansion

$$x = \sum_{n \geq 0} x_n p^n \ ,$$

and the number of terms in the expansion can be infinite so that p-adic number need not be finite as a real number. The norm of the p-adic number (counterpart of $|x|$ for real numbers) is defined as

$$N_p(x = \sum_{n \geq 0} x_n p^n) = p^{-n_0} \ ,$$

and depends only very weakly on p-adic number. The ultrametric distance function can be defined as $d_p(x,y) = N_p(x-y)$.

p-Adic numbers allow the generalization of the differential calculus and of the concept of analytic function $f(x) = \sum f_n x^n$. The basic rules of the p-adic differential calculus are the same as those of the ordinary differential calculus. There is however one important new element: the set of the functions having vanishing p-adic derivative consists of so called pseudo constants, which depend on a finite number of positive pinary digits of x only so that one has

$$f_N(x = \sum_n x_n p^n) = f(x_N = \sum_{n<N} x_n p^n) \ .$$

In the real case only constant functions have vanishing derivative. This implies that p-adic differential equations are non-deterministic.

An essential element is the map of the p-adic numbers to the positive real numbers by the so called canonical identification I:

$$I : \sum x_n p^n \in R_p \rightarrow \sum_n x_n p^{-n} \in R \ .$$

Canonical identification makes it possible to map the predictions of the p-adic physics to real numbers. Canonical identification has inverse, which is single valued for the real numbers having infinite number of pinary digits but two-valued for real numbers having finite number of pinary digits (the reason is that real number with finite number or pinary digits has two equivalent pinary expansions: ($x = 1 = .999999...$ in case of decimal expansion and $x = 1 = 0yyyy...$, $y = p-1$, in case of pinary expansion).

The definition of a definite integral for p-adic numbers is not a trivial problem. The first problem is that p-adic numbers are not well ordered and one cannot define what ordered integration interval $[a,b]$ means p-adically. Canonical identification solves this problem: a is smaller than b if the real counterpart of a under canonical identification is smaller than the real counterpart of b. The second problem is that Riemann sum gives identically vanishing p-adic integral if coordinate increments approach zero at the limit. One can however define the definite integral in terms of the integral function:

$$\int_a^b f(x)dx = F(b) - F(a) \ ; \ \ f(x) = \frac{dF(x)}{dx} \ .$$

Integral function $F(x)$ is obtained using the inverse of the derivation just as in the real context and is unique if p-adic pseudo constants required to reduce to ordinary constants.

One can consider also other possibilities to define p-adic integral. This is not so alarming as it sounds since the idea that p-adic physics is physics of cognitive representations might allow several nonequivalent definitions of definite integral.

a) Especially interesting, and perhaps also practical definition, is based on p-adic Fourier analysis relying on discretization and on the use of Pythagorean phases as counterparts of planewaves. In this case planewaves form a complete and orthogonal set and satisfy the natural physical constraints. For Pythagorean planewaves integral reduces to a sum and ultrametricity implies that the p-adic integral is finite for bounded functions. This property could guarantee UV finiteness of the p-adic QFT limit of TGD.

b) In case of canonical images of real functions, which are not p-adically differentiable, canonical identification makes it possible to induce the division of the p-adic integration interval to subintervals from the corresponding real division and p-adic integral can be calculated from the generalized Riemann sum obtained in this manner. The crucial property of the generalized Riemann sum making possible finite valued integral, is that the p-adic norms of the coordinate increments do not necessarily approach zero even when real coordinate increments do so. This integral need not be equivalent with the direct generalization of real integral and need not work for p-adically differentiable functions, whose real images are not continuous.

c) The so called adelic integration formula defines a promising approach to configuration space integration and might make sense also p-adically.

p-Adic integration makes it possible to define p-adic variational principles: the p-adic counterpart of the action is mapped by the canonical identification to real number and is minimized. The field equations are same as in real case and absolute minimization conditions are interpreted as algebraic conditions on the initial values of configuration space coordinates on lightcone boundary. The solutions of Euler-Lagrange equations are non-deterministic by the existence of the p-adic pseudo constants.

p-Adic fractals are functions $R \to R$ obtained from p-adically analytic functions $f : R_p \to R_p$ as composite functions $f_R = I \circ f \circ I^{-1}$. The last link in the long chain was the realization that the emergence of p-adic fractals in basic quantum TGD is what makes p-adic number fields a basic structural element of quantum TGD.

4.2 How p-adic numbers emerge from quantum TGD?

During last ten years I have developed several arguments suggesting how and why p-adic numbers are an essential part of TGD. Many of the arguments have looked rather convincing but as it seems now, wrong. In the following I represent only the arguments which seem to make sense when one accepts 'TGD as a generalized number theory' vision.

4.2.1 p-Adic physics as physics of cognitive representations

TGD as a generalized number theory vision forces to interpret p-Adic physics as the physics of cognitive representations. This assumption is rather radical since it means that cognition is present already in p-adic length scales in the sense that the p-adic versions of CP_2 type extremals provide cognitive representations for elementary particles. This vision obviously means a concrete realization of the Universe as a Computer idea which was one of the basic sources of inspiration durig the initial states of p-adic TGD.

4.2.2 Vacuum degeneracy of the Kähler action and spin glass analogy

The space of minima of free energy for spin glass is known to have ultrametric topology. p-Adic topology is also ultrametric and this motivated the hypothesis that quantum average space-time, 'topological condensate', defined as a maximum of Kähler function can be obtained by gluing together regions characterized by various values of the p-adic prime p. It must be emphasized that this hypothesis is just a guess and not even correct as such, and it seems that TGD as a generalized number theory vision gives the real justification for the p-adics. A good guess is however that the ultrametric topology of the reduced configuration space consisting of the maxima of the Kähler function is induced from the p-adic norm and that there is a close connection between the two p-adicities. The following arguments tries to make this idea more precise.

The unique feature of the Kähler action is its enormous vacuum degeneracy: any space-time surface, whose CP_2 projection is a so called Legendre manifold (having dimension $D \leq 2$) is vacuum extremal. This is expected to imply a large degeneracy of the absolute minimum space-times: for instance, several absolute minima with the same action are possible for single 3-surface (this forces to a generalization of space-time concept obtained by introducing 'association sequences'). The degeneracy means an obvious analogy with the spin glass phase characterized by 'frustration' implying a

large number of degenerate ground states. In the construction of the configuration space geometry the analogy between quantum TGD and spin glass becomes precise.

Spin glass consists of magnetized regions such that the direction of the magnetization varies randomly in the spatial degrees of freedom but is frozen in time. What is peculiar that, although there are large gradients on the boundaries of the regions with a definite direction of magnetization, no large surface energies are generated. An obvious p-adic explanation suggests itself: p-adic magnetization could be pseudo constant and hence piecewise constant with a vanishing derivative on the boundaries of the magnetized regions so that no p-adic surface energy would be generated.

In the description of the spin glass phase also ultrametricity, which is the basic property of the p-adic topology, emerges in a natural manner. The energy landscape describing the free energy of spin glass as a function of various parameters characterizing spin glass, is fractal like function and there are infinite number of energy minima. In this case there is a standard manner to endow the space of the free energy minima with an ultrametric topology [10].

The counterpart of the energy landscape in TGD can be constructed as follows. The configuration space of TGD (the space of 3-surfaces in H) has fiber-space like structure deriving from the decomposition $CH = \cup_{zeromodes} G/H$. The fiber is the coset space G/H such that G is the group of the canonical transformation of the light cone boundary. In particular, the canonical transformations of CP_2 act in the fiber as isometries. The base space is the infinite-dimensional space of the zero modes characterizing the size and shape as well as the classical Kähler field at the 3-surface.

To calculate S-matrix element, one must form Fock space inner product as a functional of 3-surface X^3 multiplied with the vacuum functional $exp(K)$ and integrate it over the entire configuration space:

$$S_{i\to f} = \int \langle \Psi_f, \Psi_i \rangle (X^3) exp(K(X^3)\sqrt{G} DX^3 \ .$$

The integration over the fiber degrees of freedom reduces to a Gaussian integration around the maxima of the Kähler function with respect to the fiber coordinates. The equally poorly defined Gaussian and metric determinants cancel each other in this integration and one obtains a well defined end result. Canonical transformations are 'almost gauge symmetries' since only classical gravitational fields destroy canonical symmetries acting as $U(1)$ gauge transformations. This means that the action for several canonically related configurations can be degenerate and several maxima are expected for given

values of the zero modes. This means that the subset CH_0 of the configuration space consisting of the maxima of the Kähler function has many sheets parametrized by the zero modes and that generalized catastrophe theory is obtained.

If a localization in the zero modes occurs in the quantum jump, one can circumvent the integration over the zero modes in practice. The exponent for the maximum of the Kähler action is expected to have maxima as a function of the zero modes too. The maxima of $exp(K_{max})$ as function of zero modes define the counterpart of the energy landscape and $exp(K_{max})$ is the counterpart of the energy serving as a height function of the energy landscape. It could quite well be that this height function can be induced from a p-adic norm. If so, the allowed values of p define a decomposition of the space of zero modes to sectors D_p. For 'full' CP_2 type extremals representing virtual gravitons the exponent is indeed proportional to $1/p$ if one takes seriously the argument determining the possible values of the Kähler coupling strength. Thus cognitive p-adicity and spin glass p-adicity would be related to each other. The connection with gravitons is especially interesting since also classical gravitation is closely related to the spin glass degeneracy.

4.3 Various cognitive maps

4.3.1 Canonical identification

The canonical identification $x = \sum_m x_m p^n \in R_p \rightarrow \sum x_n p^{-n} \equiv x_R \in R$ mapping p-adics to reals is the cornerstone of p-adic TGD. The construction of p-adic QFT forces to fix precisely the definition for the inverse of the canonical identification map. The suggested formula for $I : R_p \rightarrow R$ applies, when one maps the predictions of p-adic QFT (probabilities, values of the mass squared, etc...) to reals: in this case the real counterpart of a p-adic number is automatically non-negative.

When real space-time surfaces (absolute minima of Kähler action) are mapped by I^{-1} to their p-adic counterparts, one encounters several problems.

a) The inverse of the canonical identification is two-valued.

b) Canonical identification map is not defined for negative real numbers.

c) Canonical identification is not manifestly General Coordinate Invariant concept

d) The direct canonical image of the space-time surface is not p-adically differentiable. What is needed is smooth surface perhaps satisfying the

p-adic counterparts of the field equations associated with the absolute minimization of the Kähler action.

The correct solution of these problems is provided by the interpretation of p-adic space-time regions as cognitive regions so that canonical identification between real and space-time regions can be regarded as a map defining cognitive representation rather than as two different manners to interpret the same space-time sheet. Thus the map involves always pinary cutoff defining the precision of the representation. Pinary cutoff comes from the requirement that the canonical image with a pinary cutoff can be completed to a p-adic space-time surface which is solution of field equations. Obviously the optimal representation is obtained when pseudoconstants reduce to ordinary constants.

4.3.2 Phase preserving canonical identification

Before the emergence of new view about p-adic physics, the above listed problems forced to consider a modification of the canonical identification map and several options have been considered. The requirement of General Coordinate Invariance finally led to what seemed to be a unique solution to these problems. One must define canonical identification in preferred imbedding space coordinates: if preferred coordinates are not unique, the transformations between the preferred coordinates systems must commute with the modified canonical identification. Although this mapping is not relevant for the definition of fundamental theory, it might make sense if taken as a map defining cognitive representations at the level of Schröndinger amplitudes. In particular, the beautiful mathematical properties of this map and the direct connection with quantum measurement theory, suggest that one should not not keep mind open for possible applications of this map in some future theory of cognition!

The preferred coordinates are Minkowski coordinates $(m^0, m^3, m^1, m^2))$ and complex coordinates of CP_2 transforming linearly under certain Cartan sugroup $U(1) \times U(1)$ determined by the surface Y^3: these coordinates are determined modulo rotations of subgroup $SO(2) \times U(1) \times U(1)$ of Cartan subgroup of $SO(3,1) \times SU(3)$ acting as multiplication by a phase factor in case of $m^1 + im^2$ and CP_2 complex coordinates. Lorentz boosts in Cartan subgroup of $SO(3,1)$ act as multiplication by hyperbolic 'phase factor' in case of the coordinate pair $(m^0, m^3) \equiv a(cosh(\eta), sinh(\eta))$. The mapping commutes with these transformations if the phase factors are mapped as such to their p-adic counterparts, that is without canonical identification. The mapping is only possible for rational complex phase factors: they correspond

to Pythagorean triangles. The coordinate $a = \sqrt{(m^0)^2 - (m^3)^2}$ and moduli of the complex coordinates are mapped using canonical identification.

Since phase preserving canonical identification is discontinuous in phase degrees of freedom, the image of the space-time surface induced by the mapping of H is in the generic case discrete and does not form a subset of any p-adic 4-surface. One can however require that p-adic space-time surface is a smooth completion of a minimal pinary cutoff of the image fixed by the requirement that p-adic counterparts of the field equations guaranteing absolute minimization of the Kähler action are satisfied. The phenomenon of p-adic pseudo constants and non-determinism of Kähler action give good hopes of achieving this. There is a direct connection with quantum measurement theory since the transformations of Cartan algebra commuting with the canonical identification map corresponds to a maximal set of commuting observables in the algebra of the isometry charges.

Although it seems that phase preserving canonical identification might not be useful at the level of imbdeding space, it can be applied to map real spinor fields to their p-adic counterparts. The natural requirement is that the modulus squared is mapped continuously in the cognitive map so that canonical identification is the natural possibility. The phases of eigenstate basis represent typically quantum numbers such as momentum components and spin. Therefore Pythagorean phases are a natural representation of the phase factors and must be mapped as such to their p-adic counterparts. Thus phase preserving canonical identification is natural for spinor fields and Schödinger amplitudes.

4.3.3 How large p-adic space-time sheets can be?

During the development of p-adic TGD two seemingly mutually inconsistent competing identifications of reals and p-adics have caused a lot of painful tension. Canonical identification provides one possible identification map respecting continuity whereas the identification of rationals as points common to p-adics and reals respects algebra of rationals. The resolution of tension comes from the realization that canonical identification is a cognitive representation of external world whereas the identification by common rationals is self-representation.

Canonical identification maps inside out and viceversa. Space-time region having finite size in the real sense can have arbitrarily large size in p-adic sense and vice versa. This raises a rather thought provoking questions. Could the p-adic space-time sheets have cosmological or even infinite size with respect to the real metric but have be p-adically finite? How large

space-time surface is responsible for the p-adic representation of my body? Could the large or even infinite size of the cognitive space-time sheets explain why creatures of a finite physical size can invent the notion of infinity and construct cosmological theories? Could it be that pinary cutoff $O(p^n)$ defining the resolution of a p-adic cognitive representation would define the size of the space-time region needed to realize the cognitive representation? The idea about astrophysical size of the p-adic cognitive space-time sheets providing representation of body and brain is consistent with TGD inspired theory of consciousness, which forces to take very seriously the idea that even human consciousness involves astrophysical length scales.

If canonical identification mediates the connection between the predictions of the p-adic and real physics as the success of the p-adic mass calculations suggest, one can also ask whether there is a kind of a duality between short real length scales and long p-adic length scales and vice versa. The progress of physics to shorter real length scales would be accompanied by the creation of cognitive space-time sheets having progressively larger sizes meaning evolution of consciousness.

4.4 p-Adic length scale hypothesis

p-Adic length scale hypothesis states the existence of a p-adic length scale hierarchy with p-adic length scales given by $L(p) = \sqrt{p}l$, where l is the fundamental p-adic length scale of order CP_2 size R: $l \sim 10^4\sqrt{G}$. The possibility to associate $L(p)$ with a given p can be understood. p-Adic thermodynamics predicts that light particles possess mass squared of order $M^2 \sim 1/p$ and Uncertainty Principle leads directly to the p-adic length scale hypothesis. The second, nontrivial, part of the p-adic length scale hypothesis is that the physically interesting p-adic primes correspond to primes near prime powers of 2, $p \simeq 2^k$, k prime. The possibility that k is a power of prime is not excluded and there is some support for this. There are rather few p-adic primes near prime powers of two and Mersenne primes $M_n = 2^n - 1$ (where n is prime) are especially interesting physically.

The hypothesis is especially interesting above the elementary particle length scales $p > M_{127}$ and has testable implications in nuclear physics, atomic physics and condensed matter length scales. The most convincing support for this hypothesis are provided by the elementary particle mass calculations: if one assumes that the p-adic primes associated with elementary particles are primes near prime powers of two, one can predict lepton and gauge boson masses with accuracy better than one per cent. Also quark masses can be predicted but the calculation of the hadron masses requires

some modelling (CKM matrix, color force, etc...). The existing empirical information about neutrino mass squared differences suggests that the allowed values of k are indeed *powers* of prime rather than primes.

4.5 CP_2 type extremals and elementary particle blackhole analogy

CP_2 type extremals are vacuum extremals having a finite negative action so that one can lower the action of the ordinary vacuum extremals by gluing CP_2 type extremals to them. CP_2 type extremals have one-dimensional M^4_+ projection which is light like random curve. Lightlikeness condition leads to classical Virasoro algebra constraints. For modified Dirac action quaternion-conformal spinors represent the solutions of field equations and contrary to the vacuum extremals, these solutions represent non-vacuum solutions. $M^4 \times SO(3,1) \times SU(3) \times SU(2)_{ew}$ Super-Kac-Moody algebra acts as symmetries and the spectrum of elementary particles is precisely known. The obvious interpretation of the CP_2 type extremals is as a model of elementary particle.

CP_2 extremals are much like blackholes in the sense that they possess elementary particle horizon: this is the surface at which the Euclidian signature of the metric of the CP_2 type extremal changes to the Minkowskian signature of the bacground space-time. One can indeed generalize Bekenstein-Hawking law to a statement saying that the real counterpart of the p-adic entropy predicted by the p-adic thermodynamics is proportional to the surface area of the elementary particle horizon. In particular, for primes $p \sim 2^k$, where k is power of prime, the radius of the elementary particle horizon is itself a p-adic length scale. This suggests a double p-adicization associated with p and k and an additional cognitive degeneracy due to the k-adic non-determinism, and hence also the dominance of the final states of quantum jump for which $p \simeq 2^k$ holds true: there would be simply very many physically equivalent physical states for these values of p.

4.6 p-Adic thermodynamics and particle massivation

The underlying idea of TGD based description of particle massivation is following. Due to the interaction of a topologically condensed 3-surface describing elementary particle with the background space-time, massless ground states are thermally mixed with the excitations with mass of order $m_0 \sim 1/R$ (R is CP_2 length scale, $1/R$ of order 10^{-4} Planck masses) created by the Super Virasoro generators. Instead of energy, the Virasoro genera-

tor L_0 (essentially mass squared) is thermalized. This guarantees Lorentz invariance automatically. p-Adic temperature is quantized by purely number theoretical constraints (Boltzmann weight $exp(-E/kT)$ is replaced with p^{L_0/T_p}, $1/T_p$ integer) and fermions correspond to $T_p = 1$ whereas $T_p = 1/2$ seems to be the only reasonable choice for bosons. That mass squared, rather than energy, is a fundamental quantity at CP_2 length scale is also suggested by a simple dimensional argument (Planck mass squared is proportional to $\hbar$ so that it should correspond to a generator of some Lie-algebra (Virasoro generator L_0!)).

Optimal lowest order predictions for the charged lepton masses are obtained and photon, gluon and graviton appear as essentially massless particles. The calculations support the existence of massless gluons and Z^0 quanta associated with so called massless extremals (MEs). One important prediction is that p-adic thermodynamics cannot explain the masses of the intermediate gauge bosons although the predictions for the fermion masses are excellent. This observation led to the identification of the TGD counterpart of Higgs field whose vacuum expectation provides the dominating contribution to the bosonic masses and only shifts bosonic masses.

4.7 Localization in zero modes and evolution

TGD as a generalized number theory visions suggests that configuration space decomposes into regions D_P characterized by infinite primes P, which are essentially equivalent with reals under canonical identification. Each infinite prime P decomposes in a well-defined sense to finite p-adic primes and an attractive hypothesis is that these primes serve as labels for space-time regions. If U-matrix is rational valued one can interpret U-matrix elements as elements of any p-adic number field or of reals.

If U-matrix is not rational and if sub-U-matrix for the transitions leading to D_P has values in some algebraic extension of R_P, one must generalize the notion of unitarity by allowing U-matrix to be a 'sum' of sub-U-matrices belonging to algebraic extensions of different infinite-p p-adic number fields R_P. This is possible if one assumes that localization in D_P occurs in each quantum jump. In fact, the localization in zero modes hypothesis implies localization into D_P. The localization in zero modes is forced by the requirement that quantum jump corresponds to a quantum measurement in the QFT sense of the word.

This picture suggest that the subjective time development is a sequence of quantum jumps such that single quantum jump decomposes to the following steps.

a) Unitary transformation U, acts on the initial state localized in some sector D_{P_1} of CH and leads to dispersion in CH.

b) Quantum jump implying a localization to some sector D_{P_2} occurs. Thus time development corresponds to a sequence .... $\rightarrow P_1 \rightarrow P_2$... of infinite primes and simple geometric argument suggests that P increases in the long run. One can interpret the increase of P as evolution inducing the increase of finite p-adic primes which in well-defined sense compose P.

5 TGD inspired theory of consciousness very briefly

For reader's benefit the basic concepts and ideas of TGD inspired theory of consciousness are summarized briefly below.

5.1 Moment of consciousness as quantum jump between quantum histories

The identification of quantum jump as a moment of consciousness defines what might be called microscopic theory of consciousness. To grow flesh around this skeleton, one must formulate precisely what happens in quantum jump and the development of the theory has been largely due to the increased understanding of the quantum jump concept. The basic assumption is that any quantum jump corresponds to a quantum measurements for the density matrix of some subsystem (possibly decomposing to unetangled subsystems). It is however far from obvious what the notion of quantum measurement means when quantum states are quantum histories: in particular, the precise definition of the subsystem concept has turned out to be a difficult challenge. The requirement that allowed quantum measurements are local operations in zero modes, forces localization in zero modes in each quantum jump. This in turn implies that the world of conscious experience looks classical.

To sum-up the recent picture about quantum jump: TGD Universe is quantum computer in extremely general sense of the word. Every quantum jump involves unitary informational "time development" U (quantum computation) and quantum jump involving localization in zero modes (halting of the computation). Quantum computation lasts infinitely long time but this time has nothing to do with the subjectively experienced time, which is basically measured by the number of quantum jumps occurred after the wake-up of self. Besides informational and subjective time developments, there is geometric time development of the space-time surface determined by the absolute minimization of Kähler action. These three time developments fuse to single "holy trinity" of informational, subjective and geometric time

evolutions. This "holy trinity" corresponds to the "holy trinity" of matter in the sense of res extensa identified as 3-surfaces, ideas identified as quantum histories/objective realities (logos=cosmos) and to the world of subjective experiences defined by the quantum jump sequences for selves.

5.2 Information gain of conscious experience

One cannot write any formula for the contents of conscious experience. This does not make impossible to assign well-defined information measures for the contents of conscious experience associated with single quantum jump. The idea is simple: interpret conscious systems as "information eaters" in the sense that information gain in conscious experience is difference for the information measures for the initial and final states $U\Psi_i$ and Ψ_f respectively. Since one can write formula for the quantum histories, it is possible to assign well defined information measures to them.

In real context these information measures would be however typically infinite. A crucial role is played by the unique pinary cutoff associated with any mapping of a real geometric object to its p-adic counterpart and the fact that the real counterpart of p-adic integer n is finite even in the case that n is infinite as ordinary integer. p-Adicization and pinary cutoff suggest a universal manner to characterize the finite mental abilities of self caused by its finite size (information gains are bounded by $p \times log(p)$). One could perhaps call the p-adic image of reality with pinary cutoff as "personal p-adicity" of self characterized by p-adic prime p. The assumption that information measures are local with respect to configuration space together with the fact that configuration space spinors are analogous to ordinary single particle Schrödinger amplitudes, makes it possible to assign unique measure to a given type of information.

5.3 TGD predicts standard quantum measurement theory

TGD inspired theory of conciousness and standard quantum measurement theory are closely related. The assumption that localization occurs in zero modes in each quantum jump implies that the world of conscious experience looks classical. It also implies standard quantum measurement theory as the following arguments demonstrate (it took incredibly long time to realize this almost obvious fact!).

i) The standard quantum measurement theory a la von Neumann involves the interaction of brain with the measurement apparatus. If this interaction corresponds to entanglement between microscopic degrees of freedom

m with the macroscopic effectively classical degrees of freedom M characterizing the reading of the measurement apparatus coded to brain state, then the reduction of this entanglement in quantum jump reproduces standard quantum measurement theory provide the unitary time evolution operator U acts as flow in zero mode degrees of freedom and correlates completely some orthonormal basis of configuration space spinor fields in non-zero modes with the values of the zero modes. The flow property guarantees that the localization is consistent with unitarity: it also means 1-1 mapping of quantum state basis to classical variables (say, spin direction of the electron to its orbit in the external magnetic field).

ii) Since zero modes represent classical information about the geometry of space-time surface (shape, size, classical Kähler field,...), they have interpretation as effectively classical degrees of freedom and are the TGD counterpart of the degrees of freedom M representing the reading of the measurement apparatus. The entanglement between quantum fluctuating non-zero modes and zero modes is the TGD counterpart for the $m - M$ entanglement. Therefore the localization in zero modes is equivalent with a quantum jump leading to a final state where the measurement apparatus gives a definite reading.

This simple prediction is of utmost theoretical importance since the black box of the quantum measurement theory is reduced to a fundamental quantum theory. This reduction is implied by the replacement of the notion of a point like particle with particle as a 3-surface. Also the infinite-dimensionality of the zero mode sector of the configuration space of 3-surfaces is absolutely essential. Therefore the reduction is a triumph for quantum TGD and favours TGD against string models.

5.4 Negentropy Maximization Principle

Standard quantum measurement theory follow from the hypothesis that localization in zero modes occurs in each quantum jump and that the 'time development' operator U acts effectively as flow in zero modes in preferred basis for incoming states. TGD inspired theory of consciousness however encourages the generalization of quantum measurement theory by introducing the notion of self measurement occurring in quantum fluctuating degrees of freedom and following ordinary quantum measurement and meaning the measurement of the density matrix for some subsystem of self. Self measurement occurs again and again until the resulting state is a completely unentangled state. Obviously the cascade of self measurements is equivalent with state preparation process.

The so called Negentropy Maximization Principle in principle tells which kind of pair of unentangled subsystem defines the self measurement. The conscious experience itself is associated with the entire unentangled subsystem (self). NMP says is that the entanglement entropy reduction associated with the conscious experience is as large as it can be in a given quantum state: in this sense we live in the best possible world. Self measurement provides a fundamental self repair mechanism and allows quantum system to fight against thermalization according to the principle 'If you are in a leaking boat it is best to fill in the largest hole first'. NMP is the basic variational principle of cognition in p-adic context.

It must be emphasized that self measurement reduces entropy and thus corresponds to a tendency opposite to that described by second law or thermodynamics which in turn reflects directly the non-determinism of Kähler action.

The precise formulation NMP involves delicate issues. In the standard physics context NMP does not make sense whereas in the TGD context an elegant formulation with sensical predictions is possible. In particular, NMP reduces to a local principle since universe decomposes to unentangled subsystems corresponding to space-time sheets in different number fields: in standard physics context the only self would be entire Universe. The definition of the negentropy concept in the p-adic framework involves quite interesting delicacies: for instance, entanglement with a vanishing entanglement entropy is possible. The definition of the notion of subsystem is highly nontrivial in TGD context. The principle of quantum holography comes in rescue here and suggest strongly that the lightlike boundaries of massless extremals (MEs) are universal candidates for geometric correlates of subsystems.

5.5 The notions of self and subjective memory

Self is identified as a subsystem able to remain p-adically unentangled during informational time evolutions U associated with the sequential quantum jumps. Or putting it differently: self is a subsystem behaving like its own sub-Universe p-adically (with respect to NMP). This concept of self makes sense in quantum TGD framework since the map mapping real system to its p-adic counterpart is characterized by a unique pinary cutoff and maps subcritical real entanglement to a vanishing p-adic entanglement. Note that the requirement that U does not generate real entanglement does not make sense. The hypothesis that the experiences of self associated with the quantum jumps occurred after the wake-up sum up to single experience, implies

that self can have memories about earlier moments of consciousness. Therefore self becomes extended object with respect to subjective time and has a well defined "personal history". If the temporal binding of experiences involves kind of averaging (possible weighted such that the most recent experience has largest weight), quantum statistical determinism makes the total experience defined by the heap of the experiences associated with individual quantum jumps reliable. Subjective memory has natural identification as short term memory, which is fraction of second for sensory experiences.

There are two kinds of selves: irreducible selves having no subselves and reducible selves possessing subselves. Irreducible self has no mental images and the identification of the irreducibility as "whole-body" consciousness or pure awareness is attractive. Reducible selves correspond to ordinary consciousness. New self can "wake-up" in two manners.

a) In a given quantum jump irreducible self generates two mutually unentangled subsystems providing two new candidates for subselves. The subsystem giving rise to a new subself candidate must generate so large an entanglement that NMP allows the quantum jump reducing p-adic entanglement to zero. Whether a new subself is actually created depends on whether the self candidate is able to remain p-adically unentangled in the next step $\Psi_i \to U\Psi_i$.

b) The alternative possibility is that self wakes up spontaneously, when informational "time development" operator U generates vanishing p-adic entanglement. Sufficiently intelligent self could hence apply two strategies to wake-up sub-selves.

5.6 Summation hypothesis and binding of experiences

Subsystem X possessing self behaves essentially as a separate p-adic sub-Universe with respect to NMP. If one postulates that the conscious experiences of subsystems X_i of an unentangled subsystem X integrate with the self experience of X to single experience, one obtains filtered hierarchy of conscious experiences with increasingly richer contents and at the top of the hierarchy is entire universe, God, enjoying eternal self-consciousness since it cannot get entangled with any larger system.

An attractive hypothesis is that the experience of self is abstraction in the sense that the experiences of subselves X_{ij} of X_i are abstracted to average experiences $\langle X_{ij} \rangle$ experienced as mental images. This implies that the experiences of sub-sub-...selves of X are effectively unconcious to X. This hierarchy obviously has extremely far-reaching consequences. The averaging involved with the temporal binding implies that experiences of individual

selves are reliable and abstraction brings in the possibility of quantum statistical determinism at the level of ensembles.

5.7 Binding of experiencers by entanglement

The binding of experiencers is also possible. The binding of selves by quantum entanglement however destroys the component selves. This process naturally corresponds to the formation of wholes from their parts at the level of mental images, say the formation of word from letters represented as subselves. Entanglement mechanism could also provide also a a mechanism of "enlightment". This mechanism might make possible communication between selves belonging to different levels of the self hierarchy (this kind of communication could occur during sleep). "Ontogeny recapitulates phylogeny" metaphor suggests that the generation of entanglement corresponds geometrically to the formation of join along boundaries bonds between space-time sheets associated with the two entangled selves.

5.8 Mindlike and material space-time sheets

In TGD space-time surfaces decompose into real and p-adic regions. p-Adic regions are identified as cognitive representations for real regions. The basic motivation for this identification is the inherent non-determinism of the p-adic field equations making possible imagination and simulation.

The classical non-determinism of Kähler action makes possible also real space-time sheets of finite temporal duration. These space-time sheets are identified as mindlike space-time sheets serving as geometric correlates of sensory experience. Thus matter-mind duality is realized geometrically although space-time as such is not conscious. The notion of mindlike space-time sheets (referred to as cognitive space-time sheets in earlier writings) has turned out to be crucial for the understanding of cognition and sensory experience.

Mindlike space-time sheets provide a simulation of geometric history and explain the intentional aspects of consciousness (planning, expectations, desires,...), the localization of contents to finite time interval, and give rise to what might be called "geometric memory". Each quantum jump involves naturally comparison of the expected time development provided by "geometric memory" and the actual subjective time development stored in subjective memory. This comparison should give rise to those emotions involving comparison of some kind.

One can understand the arrow of psychological time very simply. The

center of mass time coordinate for a given mindlike space-time sheet is zero mode so that each quantum jump involves localization to a superposition of space-time surfaces for which the values of the psychological time for all mindlike space-time sheets involved are identical. Since there is much more room in the future of a given point of the future lightcone than in its past, mindlike space-time sheets are expected to gradually drift in the direction of future so that the arrow of psychological time results.

5.9 The notion of association sequence

The notion of association sequence is closely related to the notion of mindlike space-time sheet. The origin of association sequence concept is the enormous vacuum degeneracy of the Kähler action, which implies classical non-determinism in the sense that the absolute minimum for a given spacelike 3-surface is not unique. In order to get rid of this non-determinism one must generalize the concept of 3-surface. Also association sequences, that is 3-surfaces consisting of sequences of disjoint 3-surfaces with timelike(!) separations, must be allowed. In the p-adic quantum field theory limit this phenomenon has a nice description: the integration constants appearing in the absolute minima of the p-adic effective action are piecewise constant functions depending on a finite number of pinary digits: system behaves like a spin glass also in the time direction.

It is useful to distinguish between volitional non-determiminism for which the effects are macroscopic and long lasting and the non-determinism with microscopic and shortlasting consequences. The contents of the conscious experience (locus of the non-determinism of the quantum jump) are located around a more or less unique value of the geometric time (or several values in case of geometric memories!). A working hypothesis worth of studying is that sensory experiences correspond to real and cognition to p-adic association sequences.

Association sequences of association sequences are also possible and average spatial and temporal distances ΔL and ΔT between fundamental building blocks of the association sequence give measures for the temporal and spatial resolutions of the cognitive or sensory representation provided by the association sequence. For volitional non-determinism various degenerate absolute minima can be identified as various alternatives of macroscopic volitional acts and quantum entanglement between particle like states and the branches of the classical multifurcation makes possible volitional acts.

5.10 p-Adic–real phase transitions as a transformation of thought to action and of sensory input to cognition

Basic hypothesis is that sensory experiences resp. thoughts have real resp. p-adic space-time sheets as their geometric correlates. A fundamental model for the transformation of thought into action is as a p-adic-to-real phase transition for the topology of a mindlike space-time sheet induced by quantum jump. TGD as a generalized number theory vision suggests that this kind of phase transition can be induced by a variation of the parameters in the polynomial $P(p, q)$ of two quaternionic imbedding space coordinates defining the space-time surface changing a p-adic root to a real one or viceversa. The reverse of this phase transition corresponds to the transformation of sensory experiences to cognition.

In principle it is enough that very simple and possibly standardized p-adic–real transformations occur at some level, say neuronal level or at the level of topological field quanta of em field ("massless extremals"). The reason is that simple transformations can serve as symbols inducing macrocopic action in an initial value sensitive system (single push of button can induce nuclear war). The commands given using written or spoken language are typical examples of the emergence of this kind symbol function.

5.11 Fermions and Boolean mind

The state basis of the Fock space generated by N fermionic creation operators is isomorphic with the Boolean algebra consisting of 2^N possible statements about N basic statements, leads to the idea that many fermion states give representation for what might be called Boolean maind.

Combining the concept of association sequence with the fermionic realization of Boolean algebra and requiring that fermionic states exist in finite time interval defined by the duration of mindlike space-time sheets and that time like entanglement is possible for many-fermion states, one ends up with a rather concrete model for Boolean consciousness at the level of brain. The model relies on the unique properties of condensed matter neutrinos: the energy of condensed matter neutrinos is negative so that cognitive neutrino pairs have can have nearly vanishing net energy so that their generation is energetically easy. Antineutrino temporal sequences of varying Z^0 magnetization for antineutrinos at the cell membrane space-time sheet are ideal for represesenting 126 bit memetic codons.

The so called Combinatorial Hierarchy provides a simple model for abstraction process explaining basic numbers of the genetic code and predicting

an entire hierarchy of 'genetic codes'. The identification of the next level of the hierarchy as a 'memetic code' when combined with the p-adic length scale hypothesis leads to the prediction that the duration of the memetic codeword should be .1 seconds, often taken to be the duration of psychological moment. The number of binary digits in the memetic codeword is 126, which means that single bit corresponds to a time scale of one millisecond: this is slightly below the time scale of nerve pulse and it might be that cell membrane oscillations induced by Z^0 oscillations correspond to memetic codons.

5.12 Quantum theory of self-organization

The hypothesis that configuration space decomposes into sectors D_p such that the effective topology in D_p is p-adic, is crucial for the understanding of the p-adic aspects of quantum TGD. Mathematical consistency requires that each quantum jump involves localization in some sector D_p: this is also implied by the localization in zero modes. Evolution as can be regarded as a gradual statistical increase of the p-adic prime characterizing D_p. Simple arguments suggest that one must allow also infinite primes. Infinite primes decompose into finite primes in a well defined sense and "Ontogeny recapitulates phylogeny" metaphor suggests that this decomposition corresponds to the decomposition of the space-time surface to cognitive and matter like space-time sheets both of which are characterized by finite p-adic primes. This decomposition makes evolution local: the increase of the finite prime characterizing finite space-time regions favours the increase of the infinite prime.

Conscious self is the basic concept of TGD inspired theory of consciousness and the concept of self-organization gets quite new meaning in TGD framework. Inside each self NMP dictates to which kind of subsystem-complement decomposition given quantum jump gives rise and thus dictates what kind of state preparation occurs during the cascade of self measurements.

Quantum jump is the basic step of self-organization. The requirement that quantum jump corresponds to quantum measurement, implies that quantum jump involves localization in so called zero modes identifiable as the order parameters characterizing the shape and size and Kähler field structure of the space-time surface. This means that the evolution in zero modes is effectively classical and modellable using dissipative classical dynamics, and Haken"s classical theory of self organization generalizes almost as such: also TGD version of spontaneous symmetry breaking follows automatically. One

can also understand why the world of conscious experience is classical.

Self-organization of selves in the "energy" landscape of quantum spin glass throws considerable insight to the basic mysteries of the living matter. Darwinian selection of both genes and memes can be understood as resulting from dissipation allowing very few asymptotic self-organization patterns located near the bottoms of the deep valleys of spin glass "energy" landscape. For instance, protein folding can be understood as resulting from the self-organization of protein self leading to the bottom of a deep valley of spin glass landscape. Also the formation of long term memories can be understood using this paradigm.

In case of bound states quantum entanglement makes possible the formation of long range quantum correlations and the emergence of longer and longer p-adic length scales can be regarded as the counterpart for the emergence of dynamical units of increasing size. The feed of quantum entanglement (entropy) is the necessary prequisite of self-organization replacing self-organized units (selves) with larger ones. Both the passive (sensory experiences) and active aspects of consciousness (reaction to sensory perception) are in essential role in biological self-organization.

6 Bio-systems as macroscopic quantum systems

TGD Universe [TGD] can be regarded as a quantum counterpart of a critical thermodynamical system: the so called Kähler coupling strength is the only a priori free parameter of quantum TGD and is mathematically completely analogous to temperature. The requirement that Kähler coupling strength is analogous to critical temperature, makes the theory unique. Criticality implies long range quantum correlations in all length scales and could provide a first principle explanation for the ability of the bio-systems to act as macroscopic quantum systems. The task is to identify the mechanisms realizing the predicted long range quantum correlations.

6.1 Topological field quantization

Topological field quantization [TGD] is one of the basic differences between TGD and ordinary quantum field theories. In TGD space-time is regarded as a surface of the 8-dimensional space $H = M^4_+ \times CP_2$ and classical gauge fields are induced from the curvature of the CP_2 spinors connection. The compactness of CP_2 implies that the imbedding of a given gauge field typically fails on 3-dimensional surfaces and this implies many-sheeted space-time structure with different sheets having finite M^4_+-projection and outer

boundary. At the boundaries the gauge fluxes flow from the smaller sheet to a larger one via tiny wormholes with size determined by CP_2 size.

A lower bound for the size of the topological field quantum is given by the p-adic length scale. p-Adic length scale hypothesis leads to a prediction of a series of preferred length scales: the length scales should correspond to primes $p \simeq 2^m$, m prime or possibly a power of prime and it seems possible to identify these length scales in bio-systems. This gives for the many-sheeted space-time concept a status of a quantitative hypothesis.

Topological field quantization[3] implies that various notions of quantum field theory have rather precise classical analogies. Topological field quantization provides the correspondence between the abstract Fock space description of elementary particles and the description of the elementary particles as concrete geometric objects detected in the laboratory. In standard quantum field theory this kind of correspondence is lacking since classical fields are regarded as a phenomenological concept only. Topological field quanta define regions of coherence for the classical fields and classical coherence is the prequisite of the quantum coherence.

The energies and other classical charges of the topological field quanta are quantized by the absolute minimization of the Kähler action making classical space-time surfaces the counterparts of the Bohr orbits. Feynmann diagrams become classical space-time surfaces with lines thickened to 4-manifolds. For instance, "massless extremals" representing topologically quantized classical radiation fields are the classical counterparts of gravitinos and photons. Topologically quantized non-radiative nearby fields give rise to various geometric structures such as magnetic and electric flux tubes.

The virtual particles of quantum field theory have also classical counterparts. In particular, the virtual particles of quantum field theory can have negative energies: this is true also for the TGD counterparts of the virtual particles. The fundamental difference between TGD and GRT is that in TGD the sign of energy depends on the time orientation of the space-time sheet: this is due to the fact that in TGD energy current is vector field rather than part of tensor field. Therefore space-time sheets with negative energies are possible. This could have quite dramatic technological consequences: consider only the possibility of generating energy from vacuum and classical signalling backwards in time along negative energy space-time sheets[4]. Also bio-ystems might have invented negative energy space-time sheets: in fact,

[3]See the chapter "Macroscopic quantum phenomena and CP_2 geometry" of [TGD].

[4]See the chapter "Anomalies explainable by TGD based space-time concept" of [padTGD].

so called "massless extremals" provide an ideal manner to generate coherent motions as recoil effects caused by the creation of negative energy massless extremals[5]. An interesting possibility is that quantum entanglement has the formation of the join along boundaries bonds as its geometric correlate.

Topological field quanta could serve as templates for the formation of the bio-structures. Thus topologically quantized classical electromagnetic fields could be equally important for the functioning of the living systems as the structures formed by the visible bio-matter and the visible part of bio-system might represent only a dip of an ice berg.

The hierarchical structure of the many-sheeted space-time has very concrete implications for the understanding of bio-systems and one ends up with a rather concrete picture for how energy, electromagnetic fields and information are transferred from one space-time sheet to another. Almost empty space-time sheets, containing only classical electromagnetic fields at their interior and wormholes on their boundaries, could provide an excellent physical realization for the cognitive and sensory representations of the external world: various space-time sheets would be mimicking each other's behaviour!

6.2 Formation of the join along boundaries bonds

In many critical systems criticality can be understood purely geometrically in terms of the concept of bond. The crucial factor is the probability for a bond to exist between subsystems. If the probability is larger than the critical probability, the system freezes by forming a single connected structure. Below criticality very few bonds exist and the system is in a liquid like state. At criticality arbitrarily large connected subsystems can exist and the shape and size of subystem becomes dynamical. This phase is obviously the most interesting one biologically.

Join along boundaries bonds [TGD,padTGD] connecting the outer boundaries of the topological field quanta provide a geometric realization of the quantum criticality in quantum TGD in the sense that the formation of join along boundaries bonds is a necessary condition for the formation of larger quantum systems from smaller topological field quanta. Geometrically it corresponds simply to the touching of the two 3-surfaces. Join along boundaries bonds appear in all length scales. Non-biological examples are the color flux tubes connecting the 3-surfaces with subhadronic size connecting valence quarks, the bonds connecting nucleons in nuclei to form clusters and

[5]See the chapter "Quantum control and coordination in bio-systems".

the chemical bonds between atoms.

In biological length scales the proteins connecting different lipid layers of the cell membrane and cell interior and exterior, the MAPs (micotubule associated proteins) joining microtubules, the gap junctions connecting coherently firing groups of neurons and cells belonging to the epithelial cell sheets, are good examples of join along boundaries bonds. The dynamical nature of the join along boundaries condensates at criticality could provide a quantum level explanation for the ability of the bio-systems to change their size, shape and topology.

Join along boundaries bonds serve also as Josephson junctions connecting space-time sheets representing different levels of the self-hierarchy. Josephson currents in turn provide a means of quantum control.

6.3 Wormhole Bose Einstein condensates

6.3.1 How wormholes emerge?

The gauge and gravitational fluxes at the boundary of a given space-time sheet must go somewhere by gauge flux conservation. This forces the existence of a larger space-time sheet and of tiny wormholes connecting the two space-time sheets and feeding the gauge fluxes from the smaller sheet to the larger one. Wormholes (# contacts) are elementary particle like objects (actually deformed pieces of so called CP_2 type extremals) having size of order CP_2 size about 10^4 Planck lengths and, being sources and sinks of gauge field lines, wormhole throats effectively like classical charges, the charges of throats at the two space-time sheets being of opposite sign. Hence wormholes look like dipoles and couple to the difference of the classical gauge potentials associated with the two space-time sheets. Also the coupling to the difference of the gauge potentials serving as order parameters for the coherent states of photons is possible.

6.3.2 Wormhole BE condensate

Since wormholes can be regarded as very light particles, with the inertial mass determined by the p-adic length scale associated with the space-time sheet in question, they suffer BE condensation, and the resulting structure is a macroscopic quantum system. Since wormholes mediate an interaction between subsystem and the external world (the two space-time sheets in question), wormhole super conductivity is an excellent candidate for a universal model of a nervous system. The coupling of the wormhole BE condensate to the geometry of the boundary of the space-time sheet in turn could make

possible the quantum control of the size and shape of 3-surface. The usual master-slave relationship between background space-time and fields could be reversed in bio-systems. This is expected to happen in macromolecular and microtubular length scales as well as during the growth of multicellular organism. Furthermore, the transfer of energy and classical electromagnetic between different space-time sheets can take place only via the coupling of ordinary matter with the wormhole BE condensates, which in turn couple to the geometry of the boundary of space-time sheet in a unique manner. Thus wormhole BE condensates should provide a royal road to the understanding of energy and information transfer in bio-systems if TGD is a correct theory.

6.3.3 Possible applications of wormhole concept

Wormhole concept has several potential applications.

a) An interesting possibility is that various bio-structures act as weakly coupled wormhole super conductors. For instance, the lipid layers of the cell membrane are identified as coupled wormhole super conductors. Join along boundaries bonds connecting the lipid layers/cell interior and exterior could serve as Josephson junctions. Also the boundaries of the interior and exterior of the cell and microtubule could form weakly coupled wormhole super conductors connected by Josephson junctions.

b) Wormholes could be important also in DNA and molecular length scales and perhaps provide even DNA with a rudimentary nervous system. This idea gets support from the successful model of the so called Comorosan effect[6]. What happens in Comorosan effect is that for certain frequencies and irradiation times quantized in multiples of 5 seconds, the interaction of a laser light with the bio-matter enhances the entzyme substrate interaction. There are many peculiar selection rules involved, which can be explained if substrate and entzyme molecules form a pair of wormhole super conductors coupled by Josephson junctions. The wormhole super currents flowing in the coupled molecular wormhole super conductors affect the reaction rates and the interaction with the laser laser light affects these currents.

c) The transfer of a chemical energy and charge over macroscopic distances is a mystery from the view point of standard physics. One possibility is that the energy of the liberated photons could be absorbed by the charged wormholes and generate propagating soliton like deformations on the boundary of the protein space-time sheet. The electrons dropped from the atomic space-time sheet to the protein space-time sheet could be trapped in the

[6]See the chapter "Wormhole magnetic fields".

regions of enhanced positive wormhole charge density associated with the propagating deformation and this would make possible the charge transfer.

d) The transfer of the classical electromagnetic fields from a larger space-time sheet to a smaller one must involve the rearrangement of the wormhole charge densities or even creation of wormhole pairs serving as sources of the electric field at the smaller space-time sheet. It might be that this process can occur only through a quantum jump replacing the old quantum average effective space-time with a new one and giving to a net increase of the wormhole density. According to TGD inspired theory of consciousness this would mean that a moment of consciousness is involved with this quantum jump. From this it is clear that the presence of the external electromagnetic fields can generate or destroy wormhole BE condensates and have a profound influence on living systems. This is in accordance with the ideas of [Fröhlich] about the fundamental importance of electric dipoles in bio-systems: it however seems that macroscopic quantum systems would be created, not by the dipoles, but by the charged wormholes serving as sources of the dipole fields.

e) Wormholes are characterized by a complex order parameter and since 3-space according to TGD is very complicated topologically, the phase increments of the order parameter around closed loops (integer multiples of 2π) can carry important biological information. For instance, the conservation of these integers along a cylindrical structure, which branches, gives important selection rules for growth. The book of Winfree [Winfree] contains a rather interesting example about these selection rules (left and right hand leg have opposite winding numbers and if one tries implant a left handed leg in place of a lost right handed leg, two additional right handed legs grow!).

6.4 Coherent light and gravitons

The concept of the induced gauge field differs from the ordinary gauge field concept in that even in the absence of the matter purely classical field configurations having non-vanishing gauge currents as their sources are possible. Also Einstein tensor can be nontrivial in the absence of the ordinary matter and its negative plays the role of energy momentum tensor of vacuum. Each Fourier component of the gauge current/Einstein tensor serves as a source of coherent photons/gravitons. The mechanism has no counterpart in ordinary QED.

The so called massless extremals describing nonlinear waves propagating with light velocity and carrying non-vanishing gauge currents and Einstein tensor are especially interesting candidates for the sources of coherent light and gravitons. The direction of the propagation of the wave defines a pre-

ferred direction in case of the massless extremals and makes linear geometric structures especially interesting as possible candidates for sources of coherent photons: in fact, the lightlikeness of the vacuum current maximizes the efficiency of these quantum antennae since the photon emission occurs in a resonant like manner. There is a natural interaction between coherent light and photons, which should be important in bio-systems (making possible the absorption of coherent photons in efficient manner).

Linear structures are indeed frequently encountered in bio-systems. Examples are DNA, proteins, microtubules and various filamentary structures. Microtubules provide an attractive candidate for a source of coherent photons and coherent photons could give a means for the intercellular communication [Albrecht-Buehler]. The identification of bio-photons [Popp] as coherent light generated by DNA:s is suggestive.

6.5 Ionic super conductors and many-sheeted ionic flow equilibrium

The observations about the special effects of ELF em fields on brain appearing at cyclotron frequencies of ions Na^+, Cl^-, K^+, Ca^{++} on brain in field .2 Gauss near to that of Earth's magnetic field (with nominal value of .5 Gauss) were made already at 1983 [11]. These experiments suggest strongly that these ions/their Cooper pairs form are confined at magnetic flux quanta having this magnitude but not identifiable as magnetic field of Earth (as I erratically believed until 2006) and form bound states with macroscopic size of order cell size and extremely small binding energy corresponding to frequency of order 10 Hz. This is certainly not possible in the standard physics framework but can be understood as resulting from the dropping of ions and electrons from the atomic space-time sheet to the space-time sheet of the cell where the density of the matter is very low. The extremely low rate of energy transfer between various space-time sheets and self measurements governed by Negentropy Maximization Principle allowing the system to fight against thermalization, should allow non-atomic space-time sheets to stay in a superconducting state.

The fact that multiples of the cyclotron frequencies correspond directly to the most important frequencies of EEG suggests very strongly that these frequencies are crucial for the understanding of the sensory representations. Furthermore, the $n = 3$ multiple of proton cyclotron frequency in $B_=.2$ Gauss is 900 Hz and corresponds to the millisecond time scale of the nerve pulse, perhaps not an accident. There is very cold, dry and silent in the cellular space-time sheets and this makes possible macroscopic quantum

phases formed by Cooper pairs of Na^+, Cl^-, K^+ ions, proton and electron as well as well as Ca^{++} ions. Also other ions, even molecular ions, are possible but these ions are especially important for the generation of EEG.

Also electron Cooper pairs of high T_c electronic super conductor as well as Cooper pairs of neutrino super conductor are important. Besides magnetic cyclotron frequencies Z^0 magnetic cyclotron frequencies and wormhole cyclotron frequencies make sense: Z^0 currents for ions indeed induce automatically also ionic currents. Also neutrino Cooper pairs are possible and wormhole super conductivity is possible for wormholes located on the boundaries of the space-time sheets. These macroscopic quantum phases characterized by cyclotron frequencies provide the hardware for consciousness in TGD framework.

The dynamical hierarchy of Josephson currents and supracurrents flowing between the space-time sheets belonging to different levels of the self hierarchy, leads to a general quantitative model of quantum control and quantum realization of master-slave hierarchy. Many-sheeted ionic flow equilibrium allows the amplification of extremely low ionic densities at superconducting magnetic flux tube structures to get amplified to much higher ionic densities at atomic space-time sheets. Massless extremals (MEs) interact with superconducing ions at magnetic flux tubes via magnetic induction changing supra currents, by acting as Josephson junctions, by inducing supra current leakage betweent space-time sheets at different levels of the hierarchy, by inducing magnetic phase transitions, etc...

Some outcomes are a model of EEG and nerve pulse predicting correctly the important EEG frequencies and time scale of nerve pulse, quantum mechanism of synchronous firing, and quantum model of comparison circuits. Perhaps the most important prediction is that our magnetic body serves as the sensory magnetic canvas where sensory representations are realized and by Uncertainty Principle having the size of order Earth. We are much more than our neurons if TGD is correct!

6.6 Identification of mindlike space-time sheets as massless extremals

The so called 'massless extremals' (MEs) are basic solutions of field equations associated with Kähler action (see chapter "Quantum antenna hypothesis"). MEs describe propagation of one-dimensional nondispersive wave with light velocity and are accompanied by lightlike vacuum current generating coherent photons and gravitons. Since the vacuum current behaves in a non-deterministic manner at given point of ME, it is ideal for the coding

of classical information. MEs can appear also as pairs of space-time sheets such that the two space-time sheets have opposite time orientations and hence also energies so that the net energy of ME pair vanishes. MEs define a fractal hierarchy starting from elementary particle length scales and extending up to cosmic length scales. MEs have lightlike boundaries carrying supercanonical

One can assign to the lightlike boundaries of MEs representations of superconformal and supercanonical algebras. Supercanonical symmetry is thus transformed from a cosmological symmetry to an ordinary macroscopic symmetry. Apart from small gravitational effects, supercanonical degrees of freedom commute with the translational degrees of freedom. Physical states associated with MEs correspond to Bose-Einstein condensates of collinear photons and gravitons (these degrees of freedom correspond to quaternion conformal degrees of freedom explaining elementary particle quantum numbers) having an additional supercanonical degeneracy. Supercanonical states can be interpreted as quantum holograms storing quantum information to the lightlike boundary of ME, which is thus analogous to the moment of big bang at the cosmological level.

The energies of BE condensed photons and gravitons come as multiples of $E = \pi/L$, where L is the length L of ME. p-Adic length scales $L_p(n) = p^{n/2}L_p$ for $p \simeq 2^k$, k power of prime, define a preferred set of lengths for MEs, and this means quantization of the fundamental transition frequencies involved with the transitions of photonic and gravitonic BE condensates as multiples of $f(p,n) = \pi/L_p(n)$. Rather amazingly, in ELF range these frequencies correspond to resonant EEG frequencies!

The supercanonical degrees of freedom commute with Poincare algebra apart from gravitational effects which means a gigantic almost-degeneracy of states. This means that supercanonical states can provide huge entanglement negentropy resources crucial for quantum computation and communication type operations as well as for cognitive representations. Thus supercanonical representations can be interpreted as quantum level articulation for the statement that TGD Universe is quantum critical quantum spin glass. Supercanonical representations clearly provide an excellent candidate for an infinite hierarchy of life forms. These lifeforms are labelled by three integers (k,m,n): physically interesting primes correspond to $p \simeq 2^{k^m}$, whereas k prime and m and n are integers. Perhaps it is these lifeforms which make mindlike space-time sheets living creatures and these lifeforms emerge already in elementary particle length scales and become increasingly complex when the p-adic length scale increases. If so, life could be regarded as a symbiosis of these lifeforms with lower level lifeforms associated with

superconducting magnetic flux tubes.

These lifeforms ('mind') interact with each other, superconducting magnetic flux tubes and ordinary matter via coherent light and gravitons and the classical gauge fields associated with MEs. MEs indeed act as receiving and sending quantum antennae and the lightlike classical vacuum currents associated with MEs allow to understand the classical aspects of dynamical quantum holograms and of quantum communications made possible by MEs.

MEs can act as junctions inducing the leakage of supra currents between space-time sheets belonging to different levels of the p-adic hierarchy. MEs can also serve as Josephson junctions between magnetic flux tubes. MEs interact with superconducting magnetic flux tube circuitry also by magnetic induction analogous to the interaction of brain's magnetic fields with SQUIDs. MEs can induce also magnetic quantum transitions. These interaction mechanisms could explain the observed intensity windows in the interaction of ELF em fields with bio-matter [12].

The natural identification of MEs as building blocks of cognitive structures leads to a rather concrete model for long term memory and forces the hypothesis that MEs define an infinite hierarchy of electromagnetic life forms living in symbiosis with each other and bio-matter. The model allows to understand EEG as a direct physical correlate of mindlike space-times sheets (MEs) associated with ELF selves and provides a general vision about the electromagnetic organization of brain as sensory and motor organ of higher level self. MEs corresponding to entire frequency spectrum from UV to ULF are involved. In particular, RF (radiofrequency) and MW (microwave) MEs representing our mental images are crucial for the model. MEs are also crucial in the model of qualia. MEs are present also below cellular length scales and even at molecular level.

The model of qualia (see the chapter "Spectroscopy of consciousness" of [cbook2] leads to rather detailed view about the sizes of the hierarchy of various MEs defining what might be called our electromagnetic body. It took long time to answer the question whether we should identify ourselves with the self associated with brain; with the entire body; with ELF ME having size at least of order Earth circumference; with ULF ME having size of order order light years from the fact that we have long term memories in time scale of lifetime; or with self having literally infinite size. In light of the fact that the supercanonical representations associated with MEs correspond to higher abstraction level than ordinary quantum states, the last two options seem to be more plausible than the first three: the illusion that we are nothing but our physical bodies is created by the fact that during

wake-up state sensory input is about the region surrounding our body.

7 Contents of the book

7.1 PART I: Overview of TGD

An overview of TGD and p-adic TGD is given with special emphasis on the applications to bio-systems.

7.1.1 Overall view about TGD

This chapter provides a bird's eye view about TGD in its 25^{th} birthday with the hope that this kind of summary might make it easier to follow the more technical representation provided by sub-sequent chapters. The geometrization of fundamental interactions assuming that space-times are representable as 4-surfaces of $H = M^4_+ \times CP_2$ is wherefrom everything began. The two manners to understand TGD is TGD as a Poincare invariant theory of gravitation obtained by fusing special and general relativities, and TGD as a generalization of string model obtained my replacing 1-dimensional strings with 3-surfaces. The fusion of these approaches leads to the notion of the many-sheeted space-time.

The evolution of quantum TGD involves four threads which have become more and more entangled with each other. The first great vision was the reduction of the entire quantum physics (apart from quantum jump) to the geometry of classical spinor fields of the infinite-dimensional space of 3-surfaces in H, the great idea being that infinite-dimensional Kähler geometric existence and thus physics is unique from the requirement that it is free of infinities. The outcome is geometrization and generalization of the known structures of the quantum field theory and of string models.

The second thread is p-adic physics. p-Adic physics was initiated by more or less accidental observations about reduction of basic mass scale ratios to the ratios of square roots of Mersenne primes and leading to the p-adic thermodynamics explaining elementary particle mass scales and masses with an unexpected success. p-Adic physics turned eventually to be the physics of cognition and intentionality. Consciousness theory based ideas have led to a generalization of the notion of number obtained by gluing real numbers and various p-adic number fields along common rationals to a more general structure and implies that many-sheeted space-time contains also p-adic space-time sheets serving as space-time correlates of cognition and intentionality. The hypothesis that real and p-adic physics can be regarded as

algebraic continuation of rational number based physics provides extremely strong constraints on the general structure of quantum TGD.

TGD inspired theory of consciousness can be seen as a generalization of quantum measurement theory replacing the notion of observer as an outsider with the notion of self. The detailed analysis of what happens in quantum jump have brought considerable understanding about the basic structure of quantum TGD itself. It seems that even quantum jump itself could be seen as a number theoretical necessity in the sense that state function reduction and state preparation by self measurements are necessary in order to reduce the generalized quantum state which is a formal superposition over components in different number fields to a state which contains only rational or finitely-extended rational entanglement identifiable as bound state entanglement. The number theoretical information measures generalizing Shannon entropy (always non-negative) are one of the important outcomes of consciousness theory combined with p-adic physics.

Physics as a generalized number theory is the fourth thread. The key idea is that the notion of divisibility could make sense also for literally infinite numbers and perhaps make them useful from the point of view of physicist. The great surprise was that the construction of infinite primes corresponds to the repeated quantization of a super-symmetric arithmetic quantum field theory. This led to the vision about physics as a generalized number theory involving infinite primes, integers, rationals and reals, as well as their quaternionic and octonionic counterparts. A further generalization is based on the generalization of the number concept already mentioned. Space-time surfaces could be regarded in this framework as concrete representations for infinite primes and integers, whereas the dimensions 8 and 4 for imbedding space and space-time surface could be seen as reflecting the dimensions of octonions and quaternions. Also the dimension 2 emerges naturally as the maximal dimension of commutative sub-number field and relates to the ordinary conformal invariance central also for string models.

This chapter represents a overall view of classical TGD, a discussion of the p-adic concepts, a summary of the ideas generated by TGD inspired theory of consciousness, and the vision about physics as a generalized number theory. Also the construction of configuration space geometry and spinor structure, and of S-matrix are also described at the level of general principles.

7.1.2 p-Adic Numbers and Generalization of Number Concept

In this chapter the general TGD inspired mathematical ideas related to p-adic numbers are discussed. The extensions of the p-adic numbers including extensions containing transcendentals, the correspondences between p-adic and real numbers, p-adic differential and integral calculus, andp-adic symmetries and Fourier analysis belong the topics of the chapter.

The basic hypothesis is that p-adic space-time regions correspond to cognitive representations for the real physics appearing already at the elementary particle level. The interpretation of the p-adic physics as a physics of cognition is justified by the inherent p-adic non-determinism of the p-adic differential equations making possible the extreme flexibility of imagination.

p-Adic canonical identification and the identification of reals and p-adics by common rationals are the two basic identification maps between p-adics and reals and can be interpreted as two basic types of cognitive maps. The concept of p-adic fractality is defined and p-adic fractality is the basic property of the cognitive maps mapping real world to the p-adic internal world. Canonical identification is not general coordinate invariant and at the fundamental level it is applied only to map p-adic probabilities and predictions of p-adic thermodynamics to real numbers. The correspondence via common rationals is general coordinate invariant correspondence when general coordinate transformations are restricted to rational or extended rational maps: this has interpretation in terms of fundamental length scale unit provided by CP_2 length.

A natural outcome is the generalization of the notion of number. Different number fields form a book like structure with number fields and their extensions representing the pages of the book glued together along common rationals representing the rim of the book. This generalization forces also the generalization of the manifold concept: both imbedding space and configuration space are obtained as union of copies corresponding to various number fields glued together along common points, in particular rational ones. Space-time surfaces decompose naturally to real and p-adic space-time sheets. In this framework the fusion of real and various p-adic physics reduces more or less to to an algebraic continuation of rational number based physics to various number fields and their extensions.

p-Adic differential calculus obeys the same rules as real one and an interesting outcome are p-adic fractals involving canonical identification. Perhaps the most crucial ingredient concerning the practical formulation of the p-adic physics is the concept of the p-adic valued definite integral. Quite generally, all general coordinate invariant definitions are based on algebraic

continuation by common rationals. Integral functions can be defined using just the rules of ordinary calculus and the ordering of the integration limits is provided by the correspondence via common rationals. Residy calculus generalizes to p-adic context and also free Gaussian functional integral generalizes to p-adic context and is expected to play key role in quantum TGD at configuration space level.

The special features of p-adic Lie-groups are briefly discussed: the most important of them being an infinite fractal hierarchy of nested groups. Various versions of the p-adic Fourier analysis are proposed: ordinary Fourier analysis generalizes naturally only if finite-dimensional extensions of p-adic numbers are allowed and this has interpretation in terms of p-adic length scale cutoff. Also p-adic Fourier analysis provides a possible definition of the definite integral in the p-adic context by using algebraic continuation.

7.1.3 Fusion of p-Adic and Real Variants of Quantum TGD to a More General Theory

The mathematical aspects of p-adicization of quantum TGD are discussed. In a well-defined sense Nature itself performs the p-adicization and p-adic physics can be regarded as physics of cognitive regions of space-time which in turn provide representations of real space-time regions. Cognitive representations presumably involve the p-adicization of the geometry at the level of the space-time and imbedding space by a mapping of a real space time region to a p-adic one. One can differentiate between two kinds of maps: the identification induced by the common rationals of real and p-adic space time region and the representations of the external real world to internal p-adic world induced by a canonical identification type maps.

Only the identification by common rationals respects general coordinate invariance, and it leads to a generalization of the number concept. Different number fields form a book like structure with number fields and their extensions representing the pages of the book glued together along common rationals representing the rim of the book. This generalization forces also the generalization of the manifold concept: both imbedding space and configuration space are obtained as union of copies corresponding to various number fields glued together along common points, in particular rational ones. Space-time surfaces decompose naturally to real and p-adic space-time sheets. In this framework the fusion of real and various p-adic physics reduces more or less to to an algebraic continuation of rational number based physics to various number fields and their extensions.

The program makes sense only if also extensions containing transcen-

dentals are allowed: the p-dimensional extension containing powers of e is perhaps the most important transcendental extension involved. Entire cognitive hierarchy of extension emerges and the dimension of extension can be regarded as a measure for the cognitive resolution and the higher the dimension the shorter the length scale of resolution. Cognitive resolution provides also number theoretical counterpart for the notion of length scale cutoff unavoidable in quantum field theories: now the length scale cutoffs are part of the physics of cognition rather than reflecting the practical limitations of theory building.

There is a lot of p-adicizing to do.

a) The p-adic variant of classical TGD must be constructed. Field equations make indeed sense also in the p-adic context. The strongest assumption is that real space time sheets have the same functional form as real space-time sheet so that there is non-uniqueness only due to the hierarchy of dimensions of extensions.

b) Probability theory must be generalized. Canonical identification playing central role in p-adic mass calculations using p-adic thermodynamics maps genuinely p-adic probabilities to their real counterparts. p-Adic entropy can be defined and one can distinguish between three kinds of entropies: real entropy, p-adic entropy mapped to its real counterpart by canonical identification, and number theoretical entropies applying when probabilities are in finite-dimensional extension of rationals. Number theoretic entropies can be negative and provide genuine information measures, and it turns that bound states should correspond in TGD framework to entanglement coefficients which belong to a finite-dimensional extension of rationals and have negative number theoretic entanglement entropy. These information measures generalize by quantum-classical correspondence to space-time level.

c) p-Adic quantum mechanics must be constructed. p-Adic unitarity differs in some respects from its real counterpart: in particular, p-adic cohomology allows unitary S-matrices $S = 1 + T$ such that T is hermitian and nilpotent matrix. p-Adic quantum measurement theory based on Negentropy Maximization Principle (NMP) leads to the notion of monitoring, which might have relevance for the physics of cognition.

d) Generalized quantum mechanics results as fusion of quantum mechanics in various number fields using algebraic continuation from the field of rational as a basic guiding principle. It seems possible to generalize the notion of unitary process in such a manner that unitary matrix leads from rational Hilbert space H_Q to a formal superposition of states in all Hilbert spaces H_F, where F runs over number fields. If this is accepted, state

function reduction is a pure number theoretical necessity and involves a reduction to a particular number field followed by state function reduction and state preparation leading ultimately to a state containing only entanglement which is rational or finitely-extended rational and because of its negative number theoretic entanglement entropy identifiable as bound state entanglement stable against NMP.

e) Generalization of the configuration space and related concepts is also necessary and again gluing along common rationals and algebraic continuation is the basic guide line also now. Configuration space is a union of symmetric spaces and this allows an algebraic construction of the configuration space Kähler metric and spinor structure, whose definition reduces to the super canonical algebra defined by the function basis at the light cone boundary. Hence the algebraic continuation is relatively straightforward. Even configuration space functional integral could allow algebraic continuation. The reason is that symmetric space structure together with Duistermaat Hecke theorem suggests strongly that configuration space integration with the constraints posed by infinite-dimensional symmetries on physical states is effectively equivalent to Gaussian functional integration in free field theory around the unique maximum of Kähler function using contravariant configuration space metric as a propagator. Algebraic continuation is possible for a subset of rational valued zero modes if Kähler action and Kähler function are rational functions of configuration space coordinates for rational values of zero modes.

7.1.4 p-Adic Numbers and TGD: Physical Ideas

The most important p-adic concepts and ideas are p-adic fractality, spin glass analogy, p-adic length scale hypothesis, p-adic realization of the Slaving Principle, p-adic criticality, and the non-determinism of the p-adic differential equations justifying the interpretation of the p-adic space-time regions as cognitive representations. These ideas are discussed in this chapter in a more concrete level than in previous chapters in the hope that this might help the reader to assimilate the material more easily. Some of the considerations might be a little bit out of date since the chapter is written much earlier than the preceding chapters.

a) The criticality of quantum TGD and the need to generalize conformal invariance to the 4-dimensional context were the original motivations of the p-adic approach. It however turned out that quaternion conformal invariance, rather than p-adic conformal invariance for the space-time surface regarded as an algebraic extension of p-adics, is the correct manner to real-

ize conformal invariance. In TGD as a generalized number theory approach p-adic space-time regions emerge completely naturally and have interpretation as cognitive representations of the real physics. If this occurs already at the level of elementary particles, one can understand p-adic physics as a model for a cognitive model about physics provided by Nature itself. The basic motivation for this assumption is the p-adic non-determinism of the p-adic field equations making them ideal for the simulation purposes. The p-adic–real phase transitions are the second basic concept allowing to understand how intention is transformed to action and vice versa: the occurrence of this process even at elementary particle level explains why p-adic length scale hypothesis works. This picture is consistent with the idea about evolution occurring already at the level of elementary particles and allowing the survival of the systems with largest cognitive resources.

b) Spin glass analogy, which was the original motivation for p-adicization before the discovery that p-adic regions of space-time emerge automatically from TGD as a generalized number theory approach, is discussed at configuration space level. The basic idea is that the maximum (several of them are possible) of the exponential of the Kähler function with respect to the fiber degrees of freedom as function of zero modes is p-adic fractal. This together with spin glass analogy suggest p-adic ultra-metricity of the reduced configuration space CH_{red}, the TGD counterpart of the energy landscape.

c) Slaving Principle states that there exists a hierarchy of dynamics with increasing characteristic length (time) scales and the dynamical variables of a given length scale obey dynamics, where the dynamical variables of the longer length (time) scale serve as "masters" that is effectively as external parameters or integration constants. The dynamics of the "slave" corresponds to a rapid adaptation to the conditions posed by the "master". p-Adic length scale hypothesis allows a concrete quantification of this principle predicting a hierarchy of preferred length, time, energy and frequency scales.

d) Critical systems are fractals and the natural guess is that p-adic topology serves also as an effective topology of real space-time sheets in some length scale range and that real non-determinism of Kähler action mimics p-adic non-determinism for some value of prime p. This motivates some qualitative p-adic ideas about criticality.

e) The properties of the CP_2 type extremals providing TGD based model for elementary particles and topological sum contacts, are discussed in detail. CP_2 type extremals are for TGD what black holes are for General Relativity. Black hole elementary particle analogy is discussed in detail and the generalization of the Hawking-Bekenstein formula is shown to lead to

a prediction for the radius of the elementary particle horizon and to a justification for the p-adic length scale hypothesis. A deeper justification for the p-adic length scale hypothesis comes from the assumption that systems with maximal cognitive resources are winners in the fight for survival even in elementary particle length scales.

f) Quantum criticality allows the dependence of the Kähler coupling strength on zero modes. The assumptions that this dependence is only through the p-adic prime and that gravitational coupling constant does not depend on the p-adic length scale, fix completely the evolution of the Kähler coupling strength as a function of the p-adic length scale. One can understand the coupling constant evolution also at the level of infinite p-adic primes and a precise numerical prediction for the value of the Kähler coupling strength results.

7.1.5 About the possible role of p-adic numbers in bio-systems

The identification of some p-adic length scales predicted by the p-adic length scale hypothesis as biologically relevant length scales is suggested. p-Adic ultrametricity, the non-determinism of the p-adic differential equations, the special features of the p-adic dynamical flows, the delicacies of the p-adic probabity concept and the special features of p-adic entanglement are also discussed briefly and possible implications for bio-systems are pointed out. Also ideas, which are only marginally consistent with the interpretation of p-adic physics as physics of cognition, are discussed.

In particular, some speculations about possible role of so called exotic representations of quaternion conformal algebra are included. These speculations rely heavily on the assumption that canonical correspondence between p-adic and real masses holds true in full generality. The prediction is the existence of a hierarchy of p-adic states for which p-adic masses have having extremely small real counterparts whereas the corresponding real states have super-astronomical masses. These strange states have huge degeneracies and the original speculation was that they are crucial for the understanding of biological life. Later however came the realization that the states of the supercanonical representations associated with the lightlike boundaries of massless extremals (MEs) have also gigantic almost-degeneracies. In particular, there is no need to assume the highly questionable p-adic–real correspondence at the level of masses for them. Therefore the cautious conclusion is that biology can do without the exotic quaternion conformal representations.

7.2 PART II: TGD inspired theory of consciousness

This part of the book describes overall view about TGD inspired theory of consciousness.

7.2.1 Matter, Mind, Quantum

The chapter is devoted to the TGD inspired theory of consciousness, which can be also regarded as a generalization of quantum measurement theory. The basic elements of the theory are following.

a) Physical realities correspond to quantum histories, configuration space spinor fields, which can be regarded as generalized Schrödinger amplitudes in the world of classical worlds identified as space-time surfaces. The quantum jump between deterministic quantum histories is identified as a moment of consciousness. Quantum jump begins with the step $\Psi_i \rightarrow U\Psi_i$, where U is informational "time development" operator defining S-matrix. There is actually no real time development involved. The requirement that quantum jump involves a state function reduction in the sense of quantum field theories implies that the unitary time development is followed by a localization in zero modes: $U\Psi_i \rightarrow \Psi_{f_0}$. Hence Ψ_{f_0} corresponds to a quantum superposition of space-time surfaces which are perceptively equivalent, and the world of conscious experience looks classical in space-time degrees of freedom.

The localization in zero modes is followed by a cascade of self measurements $\Psi_{f_0} \rightarrow ....\Psi_f$ leading to a minimimally entangled product state: this sequence affects the state only in quantum fluctuating degrees of freedom. Only bound state entanglement is stable against self measurements. This process is equivalent with the state preparation process. Self measurement is governed by the so called Negentropy Maximization Principle (NMP) stating that the information content of conscious experience is maximized. In the self measurement the density matrix of some subsystem of a given subsystem is measured. The self measurement takes place for that subsystem of self for which the reduction of the entanglement entropy is maximal in the measurement.

Also p-adic-real (or cognitive) entanglement makes sense if entanglement coefficients are algebraic numbers. In this case a number theoretical definition of the entanglement entropy is possible. The number-theoretical entanglement entropy can be also negative, and in this case self measurement cannot reduce entanglement. A very attractive identification for the cognitive entanglement with positive entanglement negentropy is as a correlate

for the experience of understanding.

b) The concept of self is absolutely essential for the understanding of the macroscopic aspects of consciousness. Self corresponds to a subsystem able to not generate bound state entanglement during quantum jumps. It is assumed that the experiences of the self after the last 'wake-up' sum to single average experience. This means subjective memory identifiable as a conscious short term memory. Selves form infinite hierarchy with entire Universe, God, at the top.

A natural hypothesis is that self X experiences the experiences of its subselves as kind of abstracted experience: the experiences of subselves X_i are not experienced as such but represent kind of averages $\langle X_{ij} \rangle$ of sub-subselves X_{ij}. Entanglement between selves, most naturally realized by the formation of join along boundaries bonds between the space-time sheets, provides a mechanism building wholes from parts at the level of mental images represented by subselves. The fusion of mental images gives rise to what might be called stereo consciousness (stereo vision is the basic example of this). The notion of sub-system motivated by the many-sheeted space-time concept allows the sub-selves of un-entangled selves to entangle. This makes possible fusion and telepathic sharing of mental images. Self can be regarded as a statistical ensemble consisting of quantum jumps and various qualia are identified as statistical averages for the increments of quantum numbers and zero modes over the sequence of the quantum jumps defining self.

c) The quantum theory of self-organization is based on the identification of quantum jump as the basic iterative step of self-organization. Quantum entanglement gives rise to the generation of long range order and the emergence of longer p-adic length scales corresponds to the emergence of larger and larger coherent dynamical units and generation of slaving hierarchy. Zero modes represent fundamental order parameters and localization in zero modes implies that the sequence of quantum jumps can be regarded as hopping in the zero modes so that Haken's classical theory of self organization applies almost as such. The possibility of the reversal of the arrow of geometric time (negative energy space-time sheets) below p-adic time scales means that the second law of thermodynamics is broken below p-adic time scale with respect to the geometric time although it still holds true with respect to subjective time. There are good reasons to expect that the temporal reversal of the arrow of geometric time in various p-adic time scales is a crucial element in the function of living matter and identifiable as a universal healing mechanism.

d) p-Adic physics provides the physics cognition and intentionality. TGD

space-time decomposes into regions obeying real and p-adic topologies labelled by primes $p = 2, 3, 5, ...$ p-Adic space-time regions obey the same field equations as the real regions but are characterized by p-adic non-determinism since the functions having vanishing p-adic derivative are pseudo constants which are piecewise constant functions. Pseudo constants depend on a finite number of positive pinary digits of arguments just like numerical predictions of any theory always involve decimal cutoff. This means that p-adic space-time regions are obtained by glueing together regions for which integration constants are genuine constants. The natural interpretation of the p-adic regions is as cognitive representations of real physics. p-Adic spacetime sheets are also correlates of intentionality and the transformation of p-adic space-time sheet to a real one in the quantum jump has interpretation as a transformation of intention to action. The freedom of imagination is basically due to the p-adic non-determinism. p-Adic regions perform mimicry and make possible for the Universe to form cognitive representations about itself. Real resp. p-adic space-time sheets are interpreted as symbolic resp. cognitive space-time correlates for conscious experience.

e) Quantum-classical correspondence is absolutely essential for the interpretation of the theory and understanding of how psychological time emerges. The classical non-determinism of Kähler action makes it possible to interpret space-time surfaces as symbolic representations for the contents of consciousness (not faithful). In particlar, the concepts of association sequence and mindlike space-time sheet are made possible by the classical non-determinism. Association sequences relate closely with the mindlike space-time sheets defined as space-time sheets having finite time duration and psychological time can be identified as a temporal center of mass coordinate of the mindlike space-time sheet. The gradual drift of the mindlike space-time sheets to the direction of future force by the geometry of the future lightcone explains the arrow of psychological time. Simplest dimensional estimate gives for the average increment τ of geometric time in quantum jump $\tau \sim 10^4\ CP_2$ times so that $2^{127} - 1 \sim 10^{38}$ quantum jumps are experienced during secondary p-adic time scale $T_2(k = 127) \simeq 0.1$ seconds which is the duration of physiological moment and predicted to be fundamental time scale of human consciousness. Psychological time can be also interpreted as a temporal coordinate for the front of a p-adic-to-real phase transition proceeding to the direction of the geometric future and representing the transformation of intentions to actions.

f) The new view about space-time is crucial for the understanding of brain consciousness. Bio-systems are identified as macroscopic quantum systems and the quantum criticality of TGD Universe predicts the exis-

tence of quantum systems in all length scales and fractality. The notion of many-sheeted space-time provides several mechanisms making bio-systems macroscopic quantum systems. The generation of bound state entanglement makes possible macrotemporal quantum coherence implying that decoherence time increases from CP_2 time to a macrotemporal time interval. An essential prequisite of the macrotemporal quantum coherence is the quantum spin glass degeneracy of TGD Universe and classical gravitation is essentially involved with the mechanism. Macrotemporal quantum coherence implies a genuine breaking of the second law of thermodynamics since dissipation is effectively absent in quantum coherent degrees of freedom, and processes analogous to quantum computation become possible in the time scales relevant to human consciousness. From the point of view of consciousness this means that a sequence of moments of consciousness effectively integrates to a single moment of consciousness of macrotemporal duration, and that various qualia defined as subjectotemporal averages for the increments of quantum numbers and zero modes stay sharp.

Topological field quantization forces to assign to any material system also a field body, in particular magnetic and Z^0 magnetic bodies. The notion of the magnetic body plays a pivotal role in the understanding of how sensory representations, long term memories, and motor actions are realized. Living organisms become in TGD Universe essentially objects of astrophysical size.

The fractal hierarchy of massless extremals (MEs) represents genuinely quantum gravitational states at a more abstract level of existence than ordinary quantum states. MEs interacting with fractal hierarchy of magnetic flux tube structures in many-sheeted ionic flow equilibrium with ordinary bio-matter at the atomic space-time sheets provide the hardware of bio-consciousness. The sign of energy depends in TGD Universe on the time orientation of the space-time sheet. Negative energy MEs serve as space-time correlates for bound state entanglement, and allow to understand an amazing variety of phenomena related to consciousness and biocontrol. The models of long term memory, sensory experience, and motor actions rely crucially on negative energy MEs serving as quantum entanglers and positive energy MEs serving as tools of precisely targeted classical communications.

7.2.2 Negentropy Maximization Principle

In TGD Universe the moments of consciousness are associated with quantum jumps between quantum histories. The localization in zero modes guarantees that the world of conscious experience looks classical. Together with the assumption that the unitary operator U acts effectively as a flow in zero

modes, this implies standard quantum measurement theory with zero modes playing the role of macroscopic effectively classical variables and quantum fluctuating degrees of freedom correspond to quantum degrees of freedom. Contrary to original belief there is however no need to assume that this localization occurs in each quantum jump and might also be governed by Negentropy Maximization Principle, whose formulation is the basic topic of this chapter.

The localization in zero modes (state function reduction) is assumed be followed by a sequence of self measurements in quantum fluctuating degrees of freedom. Self measurement is repeated again and again and eventually leads to a product state: only bound state entanglement is stable against this process. Obviously the process is equivalent with state preparation. Negentropy Maximization Principle provides the dynamical law governing state preparation and, as is has turned out, also state function reduction.

a) Consider a given unentangled system S. The basic assumption is that the density matrix of the subsystem of S, or equivalently, of its complement, is the fundamental observable measured in self measurement. NMP applies separately inside each system of this kind and states that for given system the quantum measurement occurs for that subsystem-complement pair for which the reduction of the entanglement entropy in self measurement is largest.

b) The original belief was that self measurement leads to an un-entangled state. It is however possible to assign a negative entanglement entropy to an entanglement characterized by entanglement probabilities in finite extension of rationals. Thus NMP allows also a reduction to this kind of state. The natural interpretation of this kind of state is as a bound state. The density matrix must be unit matrix for the outcome if one requires that a measurement of density matrix is in question.

There are important technicalities involved with the formulation of NMP.

a) The definition of sub-system concept remains a highly nontrivial challenge for TGD. The reason is the classical non-determinism of Kähler action. A 3-surface acting as a causal determinant of Kähler action is the most general definition of the sub-system at space-time level. Causal determinants can can be light like surfaces $X_l^3 \subset H$ (elementary particle horizons) or space-like 3-surfaces inside light like 7-surfaces $X_l^3 \times CP_2 \subset M_+^4 \times CP_2$ analogous to the boundary $\delta M_+^4 \times CP_2$ of H. The reason is that these surface act as quantum holograms and representations of super-canonical and quaternion conformal algebras.

b) The many-sheeted space-time concept forces to modify the naive definition of subsystem as a tensor factor: two un-entangled systems can have

sub-systems, which are entangled. The length scale dependent notion of subsystem allows to see this kind of entanglement as an entanglement invisible in the length scale resolution of the un-entangled systems.

c) Concerning the precise definition of negentropy there are three cases to be discussed.

i) In the situation in which entanglement probabilities reduce to a finite extension of rationals (discrete number field) a purely number theoretic definition of the entanglement entropy is possible using a p-adic variant of logarithm with argument replaced by its p-adic norm. Entanglement entropy can be defined as the maximally negative entanglement entropy S_p resulting in this manner: this assigns a unique p-adic prime p to the entanglement. The resulting real-valued entanglement entropy is negative and the entanglement is stable against self measurements and NMP. This negentropic entanglement could be identified as a correlate for the experience of understanding.

ii) In the second case entanglement probabilities are genuinely real or p-adic numbers. For real entanglement Shannon entropy works. The modification of p-based logarithm preserving the additivity of negentropy allows to define in p-adic case a p-adic valued entanglement entropy, which can be mapped to a non-negative real number by canonical identification.

d) The highly non-trivial observation is that the entanglement between systems belonging to different number fields is possible provided the states are orthonormalized. Furthermore, entanglement coefficients can belong to any number field. This means that the character of entanglement does not depend at all on the character of the entangled systems and is thus a typical category theoretic notion (relationship or "arrow" in the slang of category theory).

These findings lead to the idea state function reduction and preparation are number theoretic necessities. Unitary process U creates a formal superposition of states with entanglements in various number fields. State function reduction and preparation realized as a sequence of self measurements reduce the entanglement to a finitely extended rational entanglement interpreted as an information carrying bound state entanglement. Quantum jump can therefore be regarded as an elementary act of cognition in which unitary process is followed by analysis yielding as an outcome bound state entanglement giving rise to an experience of understanding. State function reduction and preparation can also occur in quantum parallel manner in various scales. This view modifies dramatically the interpretation of what de-coherence means. De-coherence removes only the entropic non-bound entanglement and preserves and even generates bound state entanglement.

This obviously forces totally new view about second law of thermodynamics.

There are good reasons to expect that finitely extended rational entanglement is a basic characteristic of living and intelligent systems and crucial for the understanding of the information theoretic aspects of life. Negentropic bound state entanglement due to the quantum spin glass degeneracy provides mechanisms of macro-temporal quantum coherence making possible quantum computation type processes. The possibility of quantum parallel dissipation also forces to generalize quantum computation paradigm so that quantum parallel classical computations become possible.

7.2.3 Self and Binding

The quantum notion of self solved some long standing problems of TGD inspired theory of consciousness and led to a breakthrough in quantum theory of consciousness. Self is identified as a sub-system able to not generate bound state entanglement during quantum jumps. Generation of bound state entanglement leads to a loss of consciousness.

Subjective memory is assumed to correspond to an average of conscious experiences of quantum jumps occurred after the last wake-up of self. This leads to the identification of qualia as averages of the increments of quantum numbers and zero modes in the ensemble of quantum jumps defining self. Summation hypothesis states that self X experiences the experiences of its subselves as abstracted experiences, averages X_{ij} about sub-subselves X_{ij}. Subselves of un-entangled selves can entangle (this is due to the many-sheeted sub-system concept) and this allows fusion and sharing of mental images.

Selves are called irreducible if they possess no subselves, otherwise reducible. Subselves correspond to mental images so that irreducible subselves possess no mental images and are in a state of pure self-awareness: it is not clear whether this kind of states are possible in practice. When the subselves of self fuse to single subself, a state of "one-ness" results. This mode of consciousness can be identified as "whole-body" consciousness and differs from ordinary consciousness during which self has large number of mental images. These modes could naturally explain emotional/holistic and rational modes of mind. These two modes could make it possible to understand various dichotomies like brain/left brain, emotional/analytic, religous/rational, Eastern/Western,...

One could understand linear cognitive processes like thinking and language as self cascades in which self decomposes into subselves, which in turn decompose into subselves, which ... and self hierarchy implies connec-

tion with computationalism. Quantum entanglement provides a mechanism leading also to formation of irreducible wholes at the level of mental images.

In TGD framework it is not at all obvious that the highest levels of our personal self hierarchy should correspond to the size of the physical body. Various empirical facts, in particular the observations related to the special effects of excitations of geomagnetic fields and ELF em fields in EEG frequency range on brain, inspire the hypothesis that our selves correspond to topological field quanta of em fields associated with EEG frequencies and thus by Uncertainty Principle have size scale of Earth. This leads to a rather radical modification of the brain centered views about consciousness, and one can quite seriously consider the questions like what physical death means from the point of view of consciousness: it could be that electromagnetic part of self hierarchy could survive after the physical death as a 'soul'.

7.2.4 Time and consciousness

In moments of consciousness as quantum jumps between quantum histories picture the basic challenge is to explain how psychological time arises: why the contents of at least sensory experiences are concentrated around definite value of geometric time and what is the origin of the arrow of psychological time. It has become gradually clear that TGD cannot reproduce the common sense conception of time and that one can only require that the generalized view is consistent with our restricted conscious experiences and shows our position in the hierarchy of consciousness.

The long sought-for solution to the puzzle of psychological time and its arrow was surprisingly simple. Psychological time corresponds to center of mass coordinate for mindlike space-time sheet and is zero mode so that its value is precisely defined for each state of quantum jump by the localization in zero modes associated with quantum jump. The geometry of future lightcone in turn implies the gradual drift of the mindlike space-time sheet to the direction of the future.

Much later came the realization that this picture leads to several paradoxes unless one assumes that psychological time labels the zone of volition corresponding to a p-adic-to-real phase transition proceeding towards the geometric future. Furthermore, the value of the psychological time must be assumed to be common for the selves at the same level of the self hierarchy, perhaps for the entire bio-sphere. This gives very strong first principle support for the view that entire bio-sphere is conscious being and gives justification for very speculative ideas such as sensory representations realized on the magnetic sensory canvas having size much larger than the physical

body. Rather concrete vision about the character of consciousness after the physical death emerges and throws light to various religious concepts (saints and sinners, heaven and hell).

The concept of self led to the understanding of the subjective memory as an average over experiences of self experienced after its "wake-up". Subjective memories are always about past. Geometric memories are predictions for the future/past assuming that no quantum jumps would occur after/had occurred before the one giving rise to the geometric memory. Pre-cognitions can be seen as geometric memories about future. Intentions are p-adic variants of precognitions. It seems that long term memories must correspond to geometric memories: this hypothesis, when combined with the spin glass model of brain, the notion of quantum self-organization, and some key aspects of many-sheeted physics, allows to understand the basic aspects of the long term memory and avoids the basic difficulties of the neural net models.

"Ontogeny recapitulates phylogeny" principle suggests that the structure of the many-sheeted space-time represents the structure of the cosmology of consciousness. This heuristic principle together with the concept of self, the hypothesis that also infinite primes are present in the topological condensate and association sequence concept, leads to a Grand Scenario for the cosmology of consciousness. There is no need to assume that different irreducible sub-experiences associated with given moment of consciousness correspond to a common value of the psychological time. Most naturally, the values of psychological time extending from zero to strictly infinite values of time and beyond(!) are present. This means that cosmology of consciousness has fractal like structure: there are subcosmologies which know nothing about each other's existence except in quantum jumps involving entanglement with larger space-time sheets: in this case the conscious experience could be regarded as a religious or mystic experience. Both future and past civilizations participate in each quantum jump. The allowance of infinite primes suggested strongly by various arguments, means that conscious intelligences which are God like as compared to us, participate in each quantum jump.

An especially important general consequence is the paradigm of 4-dimensional brain.

a) This paradigm trivializes the problem of long term memory. The desire to remember would be quantum communicated from the geometric now to the geometric past by sharing of mental images made possible by time-like quantum entanglement of sub-selves. In the case of episodal memories the sharing of mental images gives already rise to the memory. For non-episodal memories the memory is communicated classically to the geometric future. An essential element of the mechanism are negative energy MEs ("massless

extremals") which are ideal for generating time-like quantum entanglement with the geometric past. Positive energy MEs are in turn involved with classical communications.

b) Second consequence is a model of cognition relying on the concept of cognitive neutrino pair: cognitive neutrino pair has almost vanishing total energy and consists of neutrino and antineutrino residing at different space-time sheets. The cornerstone of the model is the negative energy of the condensed matter neutrinos deriving from the classical Z^0 interaction with nuclear Z^0 charges. Thus one can say that TGD predicts that $k = 169$ space-time sheet ($L(169) \simeq 5$ microns) is the length scale in which cognitive consciousness emerges.

Quantum jumps between quantum histories concept explains the peculiar time delays of consciousness revealed in the experiments relating to active and passive roles of consciousness [13, 14] and the causal anomalies revealed by the experiments of Radin and Bierman [15]. TGD predicts "tribar effect" as a general signature for the quantum jump between quantum histories concept.

7.2.5 Quantum model for sensory representations

One of the toughest challenges of quantum theories of consciousness is to understand how sensory representations are constructed at quantum level. It became as a surprise that the vision about sensory representation which resulted from a long lasting thought experimentation is actually very much what the original, fifteen year old, experience about myself as a computer sitting at its own terminal, when taken very literally in some aspects, actually suggests. This vision adds to the standard view about brain an additional layer responsible for the sensory representations and brings in the quantum level of control so that nerve pulse patterns are only part of the control loop. In fact, it has turned out that the same basic theory applies to both geometric memories, precognition, sensory perception, and motor actions.

a) As far as our consciousness is considered, primary sensory organs are the seats of sensory qualia and brain only constructs cognitive and symbolic representations. Various objections against this hypothesis can be circumvented by assuming that sensory organs entangle with the brain and by the mirror mechanism of the long term memory. The question how imagination differs from the sensory experience becomes trivial, and dreams and hallucinations can be understood as resulting via the back-projection of the imagined mental images to the primary sensory organs.

b) Libet's findings about passive aspects of consciousness lead to the view

that sensory percept can be regarded as a geometric memory in time scale of .5 seconds involving entanglement with the geometric past mediated by negative energy MEs. Libet's experiments about the active aspects of consciousness in turn lead to realization that motor actions and sensory perceptions are in a well-defined sense time-reversals of each other: pre-cognition is a definite aspect of motor action. One can say that motor action at the level of negative energy MEs is initiated from the level of muscles rather than brain and motor imagination is just a motor action starting from some level higher than muscles. The transformation of a p-adic ME to negative energy ME realizes the transformation of intention to action in a precisely targeted manner and the emission of negative energy makes possible extreme flexibility by buy now-let others pay mechanism of remote metabolism. This process is the basic step initiating motor action, neural activity leading to imagery, and active memory recall. This picture also explains why geometric memories occur more or less spontaneously whereas precognition is a rare phenomenon (pre-cognizer must *receive* negative energy MEs).

c) In TGD framework one can assign to any material structure a magnetic body having much large size. The closed flux loops composing magnetic bodies allow an elegant realization of the long term memories in terms of negative and positive energy MEs. A stronger hypothesis is that various magnetic bodies define sensory canvases at which various sensory representations are realized. Motor action can be seen as a geometric time reversal of sensory perception. Cortex can be seen as a collection of pre-existing symbolic and cognitive features possibly entangled with sensory mental images at sensory organs, and activated when they appear in the perceptive field or form a part of motor action. The basic task of the central nervous system is to identify these features from the sensory input. The mental images associated with various parts of the physical body are entangled with the points of the corresponding magnetic bodies representing objects of the perceptive field by sharing of mental images and in this manner define attributes of these objects. There is an entire hierarchy of representations corresponding to the hierarchy of magnetic bodies, and also sensory perception involves active selections by entangling a sequences of mental images defining paths along the tree-like structure defined by the hierarchy of magnetic bodies beginning from the personal magnetic body and ending at the roots defined by magnetic bodies of sensory organs. This explains phenomena like sensory rivalry.

d) The decomposition of the perceptive field to objects is one of the basic aspects of sensory experiencing and TGD provides a mechanism generating these objects as mindlike space-time sheets: the boundaries of these

objects correspond to regions of strong Kähler electric field whose strength is assumed to correlate with the intensity of the neural input. It might be that even the objects of perceptive field or thoughts could be regarded as features.

e) The computational activities associated with the construction of the sensory representations (say estimating distances and directions of the objects of perceptive field) and virtual sensory representations representing the goals of motor action are presumably realized as iterated processes in which virtual sensory inputs characterizing the expected experiences are compared with the real world sensory input. In a similar manner the goal of the motor action is compared with the sensory representation resulting from effect of a virtual motor action on the representation of the recent state of world and body. This comparison does not necessarily require sensory representation at any level of the self hierarchy and could be based on comparison circuits defined by parallel supra currents in which the inputs which are sufficiently near to each other generate constructive interference giving rise to a large Josephson current.

7.2.6 Quantum model for memory

The neural realization of long term memories has remained to a high extent a mystery in the framework of the standard brain science. The TGD based quantum model for memory have developed gradually from the basic realization that in TGD framework the identification of quantum states as quantum histories makes it un-necessary to store information about the geometric past to the geometric now. This has deep implications.

a) It is possible to separate genuine geometric memory recall from apparent memory recalls such as feature recognition, associations, and implicit and procedural memories. There are no memory storages in brain and only memory representations abstracting the essential aspects of experience are needed.

b) The models of long term memory based on the assumption that information about the geometric past is stored in the recent state of the system predict that the new memories should mask the old ones. It is however known that childhood memories are the stablest ones. In TGD framework this ceases to be a problem.

Mirror mechanism provides a very general mechanism of long term memory. To remember something at a temporal distance T in the geometric past is to look at a mirror at a distance $cT/2$. If the mirror is quantum mirror only a timelike entanglement (allowed by the non-determinism of Kähler

action) of the mental image of the geometric past with a mental image in brain now is needed. The un-necessity to communicate memories classically implies extreme generality of the mechanism: all kinds of memories: sensory, cognitive, verbal,.... can be recalled in this manner. Even the mechanism of memory recall by cue can be generalized since the notion of tele association makes in principle sense.

The basic objections against this over-simplified picture is that there is no guarantee that the reflected ME returns to the brain and that there is no control over the time span of long term memories. The notion of magnetic body allows a more realistic formulation. Brain or the personal magnetic body generates spontaneously negative energy MEs with all fundamental frequencies. These MEs can be also curved and are parallel to the closed flux tubes defining the personal magnetic body and connect geometric now with the brain of the geometric past: multiple reflections are probably required to achieve this. The length of the closed magnetic loop defines the time span of the corresponding long term memory. The sharing of mental images by timelike entanglement allows to communicate the desire to remember to the geometric past, and gives rise to the memory recall in the case of episodal memories. In the case of non-episodal/declarative memories the memory is communicated from the brain of the geometric past by classical communications using positive positive energy MEs which propagate with an effective phase velocity much lower than light velocity along closed magnetic flux tubes and generate in the receiving end symbolic representation of the memory.

Macrotemporal quantum coherence is further important piece of the model. The understanding of how macrotemporal quantum coherence is made possible by the spin glass degeneracy led to a concrete realization of the mirror model and also provided a connection with the ideas of Hameroff and Penrose. When a bound state is formed the zero modes of the bound state entangled subsystems become quantum fluctuating degrees of freedom. This means that state function reduction and state preparation cease to occur in these degrees of freedom. The bound state is in a kind of long-lasting multiverse state, or state of 'oneness' experientially, and the sequence of quantum jumps defined by the duration of the bound state behaves effectively as a single quantum jump. Macrotemporal quantum coherence making possible supercomputer like activities becomes possible.

The spin glass degeneracy associated with the join along boundaries bonds (the space-time correlates for the bound state formation) lengthens the lifetimes of the bound states dramatically and solves thus the basic objections against quantum consciousness. The spin glass degeneracy is due to

classical gravitational energy of the system. The quantum jumps between different classical gravitational configurations involve the emission of gravitational (equivalently Z^0) MEs and the intention to remember is realized as a transformation of p-adic ME to negative energy gravitational ME. The fact that classical gravitational fields couple to classical gauge fields with a coupling which is about 10^8 stronger than the ordinary gravitational coupling, could play an important role too. Water clusters and macromolecules with sizes in the range of cell membrane thickness and cell size are good candidates for generating gravitonic MEs responsible for all geometric memories. Also classical Z^0 interaction might be involved since gravitonic MEs can be regarded also as Z^0 MEs.

A rather detailed neuro level model of long term memory is developed and the model conforms nicely with the basic facts known about the relationship of hippocampus and long term memory.

7.2.7 Conscious information and intelligence

In this chapter the notions of information and intelligence are discussed in TGD framework. The discussion reflects the chronological development of ideas towards increasing realism. 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.

7.2.8 p-Adic physics as physics of cognition and intention

TGD as a generalized number theory vision forces the interpretation of the p-adic physics as a physics of cognitive representations so that matter-mind dichotomy corresponds to real–p-adic dichotomy at the level of the geometric correlates of mind. This interpretation has far reaching implications for

both TGD inspired theory of consciousness and for the general world view provided by TGD. Cognition is predicted to be present in all length scales and the success of the p-adic physics in elementary particle length scales forces to conclude that cognition and intention are present even at this level. In this chapter these implications are studied from the point of view of cognitive consciousness.

p-Adic space-time sheets are identified as the counterparts of cognitive representations: one could also assign them with memes, morphic fields, or analogous notions used by parapsychologists. The possibility to identify the inherent non-determinism of the p-adic field equations as the non-determinism of imagination makes this identification so attractive. The 'phase transition' of a p-adic space-time sheet to a real space-time sheet taking place in quantum jump between quantum histories corresponds to the transformation of a thought into action or sensory experience (during dreams and hallucinations) whereas the reverse transformation corresponds to the transformation of the sensory input into cognition. One possible view is that p-adic memes are everywhere waiting for their materialization by p-adic-to-real phase transition and that biological systems are only a special class of cognitive systems. The identification of the psychological time as the value of the geometric time associated with the front of volition (identified as p-adic-to-real phase transition) proceeding towards geometric future has very strong implications and allows to consider even questions like 'What after physical death?'.

p-Adic teleportation for the massless extremals (MEs) is a basic mechanism making in principle possible the replication and transmission of memes with an effective velocity which can be superluminal. Time reversed cognition is a basic implication of the teleportation mechanism. Basic cognitive functions are dicussed in this this conceptual framework. Time reverse reference waves generate time reversed holograms, which suggests an extremely general and simple model of healing using the phase conjugate of the reference wave inducing the 'disease program' hologram and thus forcing the program to run backwards. DNA strand and its conjugate strand have interpretation as represention of a command and its time reversal coded to holograms by MEs scanning DNA like reading head and coding nucleotide sequence to a lightlike vacuum current.

The realization of p-adic–real phase transitions at brain level is suggested: the appearence of the millisecond rhytm behind neuronal synchronization would correspond to p-adic-to-real transition for MEs carrying classical Z^0 fields.

The obvious question is how to test p-adic physics empirically. First of

all, thinking is p-adic sensory experiencing. Hence the reduction of theories–experimental science dichotomy to p-adic–real dichotomy seems natural: just like experimental science is an extension of everyday real sensory experience, theories represent an extension of everyday p-adic sensory experience (common sense thinking). Thus the basic test is how well p-adic physics based theories describe cognition. Secondly, the p-adic models for physical systems are strictly speaking models for cognitive models for real physics. The successes of these highly predictive models (consider only p-adic elementary particle mass calculations involving only very few integer valued parameters) supports the vision about p-adic physics as physics of cognition. p-Adic–real phase transitions as models for how thought is transformed to action and sensory input to thought provide a further testing ground for the new paradigm.

p-Adic–real phase transitions as models for how thought is transformed to action and sensory input to thought provide a further testing ground for the new paradigm. This forces the allowance of finite-dimensional extensions of p-adic numbers involving real transcendentals like π and e. The outcome is a series of number theoretical conjectures and a considerable generalization of the previously developed insights about how to understand and prove Riemann hypothesis. The zeros of Riemann Zeta can be identified as a universal number theoretically quantized spectrum of scaling momenta characterizing various conformally invariant critical systems.

7.2.9 Quantum model for paranormal phenomena

The general quantum model for bio-systems leads to a general model for electromagnetic bio-control which applies to a very wide variety of hard-to-understand bio-chemical phenomena such as molecular recognition mechanisms, water memory, and homeopathy and leads to a generalization of genetic code explaining the mystery of introns. The same model generalizes to a model of paranormal phenomena such as psychokinesis, remote sensing, remote healing, telepathy, communications with deceased, and instrumental transcommunications.

a) Magnetic mirrors (ME-magnetic flux tube pairs) connecting the sender and receiver make possible a universal mechanism for the transfer of intent and action. p-Adic MEs represent the transfer of a mere intent and real MEs represent a transfer of action. p-Adic ME can be transformed to real ME either by receiver or some higher level magnetic self.

b) The transfer of intent gives rise to mechanism of remote interaction which can act both endo- and exogenously. Magnetic mirrors characterized

by their fundamental frequencies make possible bridges between sender and receiver (say healer and healee) and allow a resonant interaction in which healer can initiate various control commands acting as 4-dimensional templates represented as holograms. Also smaller MEs can be send along the MEs serving as bridges (this is like throwing balls with light velocity!).

c) The ME-magnetic flux tube pair connecting sender and receiver acts as a reference wave which can initiate an arbitrarily complex hologram representing biological program. Sender has the ability to generate and amplify the frequencies which induce holograms representing the control commands. In particular, sender can initiate complex biological programs without knowing anything about their functioning.

d) Magnetic mirrors make possible also feedback and this feedback could make possible learning. For instance, in psychokinesis (especially so in micro PK), this learning would be crucial and analogous to that what occurs when we learn to drive a car. In healing this kind of feedback might help to find the healing frequency by trial and error.

e) It is quite possible that also multibrained and -bodied higher level magnetic selves actively participate in the process. This makes possible coherent amplification effects (TEM, prayer groups) and also makes available information resources of all brains involved with the group. This could for instance explain the ability of a remote viewer to see an object on basis of data which need not have any meaning for her. Fast amplitude modulation of alpha waves introducing higher harmonics to the carrier wave is a good candidate for mediating communication between brains and higher level multibrained selves. Mesoscopic 'features' in brain involve precisely this kind of amplitude modulation and might represent just this kind of messages. Interestingly, also speech is produced by fast amplitude modulation of 10 Hz basic vibration frequency of speech organs.

7.3 PART III: More mathematical aspects of consciousness theory

7.3.1 Infinite primes and consciousness

p-Adic unitarity implies that each quantum jump involves unitarity evolution U followed by a quantum jump to some sector D_p of the configuration space labelled by a p-adic prime. Simple arguments show that the p-adic prime characterizing the 3-surface representing the entire universe increases in statistical sense. This leads to a peculiar paradox: if the number of quantum jumps already occurred is infinite, this prime is most naturally infinite.

On the other hand, if one assumes that only finite number of quantum jumps have occurred, one encounters the problem of understanding why the initial quantum history was what it was. The estimate $a \sim L_p$ gives infinite value for the time parameter a in accordance with ordinary S-matrix theory, in which $a \to \infty$ is regarded as an idealization. Furthermore, since the size of the 3-surface representing the entire Universe is infinite, p-adic length scale hypothesis suggest also that the p-adic prime associated with the entire universe is infinite.

These arguments motivate the attempt to construct a theory of infinite primes and to extend quantum TGD so that also infinite primes are possible. Rather surprisingly, one can construct infinite primes by repeating a procedure analogous to a repeated quantization of a super symmetric quantum field theory. Furthermore, the representation of infinite prime defines what can be regarded as an analog of subsystem-complement decomposition and one can indeed identify the decomposition of space-time surface to p-adic regions and to subsystem and its complement with corresponding decomposition of infinite prime to primes at lower level of infinity: at the basic level are finite primes for which one cannot find any formula. One consequence is that the definition of the subsystem appearing in the formulation of NMP is fixed by the infinite p-adic prime itself.

Some rather natural requirements lead to a unique generalization for the concepts of integer, rational and real. Somewhat surprisingly, infinite integers and reals can be regarded as infinite-dimensional vector spaces with integer and real valued coefficients respectively and one cannot exclude the possibility that the tangent space for the configuration space of 3-surfaces could be regarded as the space of generalized octonions! Also the question, whether TGD universe is able to discover the laws of physics and consciousness is pondered in the light of the notions of self and subjective and geometric memory; the concept of generalized real and the concept of generalized lexicon and its seems that TGD Universe might do it!

7.3.2 Category theory, quantum TGD and TGD inspired theory of consciousness

Category theory has been proposed as a new approach to the deep problems of modern physics, in particular quantization of General Relativity. Category theory might provide the desired systematic approach to fuse together the bundles of general ideas related to the construction of quantum TGD proper. Category theory might also have natural applications in the general theory of consciousness and the theory of cognitive representations.

a) The ontology of quantum TGD and TGD inspired theory of consciousness based on the trinity of geometric, objective and subjective existences could be expressed elegantly using the language of the category theory. Quantum classical correspondence might allow a mathematical formulation in terms of structure respecting functors mapping the categories associated with the three kinds of existences to each other.

b) Cognition is categorizing and category theory suggests itself as a tool for understanding cognition and self hierarchies and the abstraction processes involved with conscious experience.

c) Categories possess inherent generalized logic based on set theoretic inclusion which in TGD framework is naturally replaced with topological condensation: the outcome is quantum variants for the notions of sieve, topos, and logic. This suggests the possibility of geometrizing the logic of both geometric, objective and subjective existences and perhaps understand why ordinary consciousness experiences the world through Boolean logic and Zen consciousness experiences universe through three-valued logic. Also the right-wrong logic of moral rules and beautiful-ugly logic of aesthetics seem to be too naive and might be replaced with a more general quantum logic.

7.3.3 Topological Quantum Computation in TGD Universe

Topological quantum computation (TQC) is one of the most promising approaches to quantum computation. The coding of logical qubits to the entanglement of topological quantum numbers promises to solve the de-coherence problem whereas the S-matrices of topological field theories (modular functors) providing unitary representations for braids provide a realization of quantum computer programs with gates represented as simple braiding operations. Because of their effective 2-dimensionality anyon systems are the best candidates for realizing the representations of braid groups.

TGD allows several new insights related to quantum computation. TGD predicts new information measures as number theoretical negative valued entanglement entropies defined for systems having extended rational entanglement and characterizes bound state entanglement as bound state entanglement. Negentropy Maximization Principle and p-adic length scale hierarchy of space-time sheets encourage to believe that Universe itself might do its best to resolve the de-coherence problem. The new view about quantum jump suggests strongly the notion of quantum parallel dissipation so that thermalization in shorter length scales would guarantee coherence in longer length scales. The possibility of negative energies and communications to geometric future in turn might trivialize the problems caused by

long computation times: computation could be iterated again and again by turning the computer on in the geometric past and TGD inspired theory of consciousness predicts that something like this occurs routinely in living matter.

The absolute minimization of Kähler action is the basic variational principle of classical TGD and predicts extremely complex but non-chaotic magnetic flux tube structures, which can get knotted and linked. The dimension of CP_2 projection for these structures is $D = 3$. These structures are the corner stone of TGD inspired theory of living matter and provide the braid structures needed by TQC.

Anyons are the key actors of TQC and TGD leads to detailed model of anyons as systems consisting of track of a periodically moving charged particle realized as a flux tube containing the particle inside it. This track would be a space-time correlate for the outcome of dissipative processes producing the asymptotic self-organization pattern. These tracks in general carry vacuum Kähler charge which is topologized when the CP_2 projection of space-time sheet is $D = 3$. This explains charge fractionization predicted to occur also for other charged particles. When a system approaches chaos periodic orbits become slightly aperiodic and the correlate is flux tube which rotates N times before closing. This gives rise to Z_N valued topological quantum number crucial for TQC using anyons ($N = 4$ holds true in this case). Non-Abelian anyons are needed by TQC, and the existence of long range classical electro-weak fields predicted by TGD is an essential prerequisite of non-Abelianity.

Negative energies and zero energy states are of crucial importance of TQC in TGD. The possibility of phase conjugation for fermions would resolve the puzzle of matter-antimatter asymmetry in an elegant manner. Anti-fermions would be present but have negative energies. Quite generally, it is possible to interpret scattering as a creation of pair of positive and negative energy states, the latter representing the final state. One can characterize precisely the deviations of this Eastern world view with respect to the Western world view assuming an objective reality with a positive definite energy and understand why the Western illusion apparently works. In the case of TQC the initial *resp.* final state of braided anyon system would correspond to positive *resp.* negative energy state.

The light-like boundaries of magnetic flux tubes are ideal for TQC. The point is that 3-dimensional light-like quantum states can be interpreted as representations for the time evolution of a two-dimensional system and thus represented self-reflective states being "about something". The light-likeness (no geometric time flow) is a space-time correlate for the ceasing of subjec-

tive time flow during macro-temporal quantum coherence. The S-matrices of TQC can be coded to these light-like states such that each elementary braid operation corresponds to positive energy anyons near the boundary of the magnetic flux tube A and negative energy anyons with opposite topological charges residing near the boundary of flux tube B and connected by braided threads representing the quantum gate. Light-like boundaries also force Chern-Simons action as the only possible general coordinate invariant action since the vanishing of the metric determinant does not allow any other candidate. Chern-Simons action indeed defines the modular functor for braid coding for a TQC program.

The comparison of the concrete model for TQC in terms of magnetic flux tubes with the structure of DNA gives tantalizing hints that DNA double strand is a topological quantum computer. Strand *resp.* conjugate strand would carry positive *resp.* negative energy anyon systems. The knotting and linking of DNA double strand would code for 2-gates realized as a unique maximally entangling Yang-Baxter matrix R for 2-state system. The pairs A-T, T-A, C-G, G-C in active state would code for the four braid operations of 3-braid group in 1-qubit Temperley Lieb representation associated with quantum group $SL(2)_q$. On basis of this picture one can identify N-O hydrogen bonds between DNA strands as structural correlates of 3-braids responsible for the nontrivial 1-gates whereas N-N hydrogen bonds would be correlates for the return gates acting as identity gates. Depending on whether the nucleotide is active or not it codes for nontrivial 1-gate or for identity gate so that DNA strand can program itself or be programmed dynamically.

7.3.4 Intentionality, Cognition, and Physics as Number theory

In this chapter a braid of ideas inspired by the work with topological quantum computation and ideas about mathematical cognition is discussed.

a) The first bundle of ideas relates to quantum TGD and emerged when I learned about braid groups and type II_1 factors of von Neumann algebras. The connection with infinite-dimensional Clifford algebra of configuration space led to the idea about the realization of quantum geometry at the level of configuration space without non-commutative coordinates. Classical quantum correspondence led to very concrete view about how join along boundaries bonds defining braids serve as correlates for quantum bound state formation and bound state entanglement. Even a physicist's "proof" of four-color theorem emerges as an outcome.

The non-integer quantization of dimensions for effective II_1 tensor factors

implies quantization of Planck constant: the values of h are given $h(n) = [2log(2)/log(r)] \times h$, where r is the dimension of the effective II_1 tensor factor. The spectrum of r contains continuum $r \geq 4$ and discrete spectrum $r = B_n = 4cos^2(\pi/n)$ $(n \geq 3)$ below it. B_n is so called Beraha number. The interpretation in terms of discrete bound states and continuum of unbound states is a suggestive, and in fact a sensible, interpretation. For $n = 3$ with $r = 1$ Planck constant becomes infinite and this corresponds to extremely quantal regime. Planck constant would approach zero at the limit $r \to \infty$. TGD approach mildly suggests that $r \geq 4$ is not possible.

b) Physics as a generalized number theory is the most ambitious dream inspired by TGD approach. The dimensions 4 and 8 for space-time and imbedding space led for years ago to the idea that space-time surface is in some sense maximal associative (that is quaternionic) sub-manifold of octonionic space. The problem was to understand why the compactification of octonion space to $H = M^4_+ \times CP_2$ does mean and here the observation that CP_2 parameterizes different quaternionic planes in the space of octonions is crucial.

c) The idea about p-adic physics as physics of cognition and intentionality inspired the generalization of a number concept so that reals and various extensions of p-adic numbers are glued together along common rationals and form a book like structure with the rim of book being represented by rationals. This in turn inspired the vision that p-adicization of physics should correspond to an algebraic continuation of rational physics to various number fields.

d) p-Adic continuation leads typically to the need of finite-dimensional extensions of p-adic numbers and also transcendental extensions are needed (e^p is ordinary p-adic number and defines finite-dimensional transcendental extension). This inspired the idea that the evolution of mathematical consciousness corresponds to the gradual increase of both p and dimension of extension of p-adics and inspired various number theoretical conjectures relating different transcendentals to each other. The first form of these conjectures turned out to be wrong but in this chapter the conjectures are already much more realistic being minimal conjectures guaranteing the universality of physics.

The p-adication problem led to quite unexpected developments in the understanding of space-time correlates of mathematical cognition. The challenge is to locate the Platonia of mathematical ideas at space-time level, that is to identify space-time correlates of algebraic structures, manipulations and equations. The arguments evolved in the following manner.

a) The p-adicization of the vacuum functional defined as an exponent

of Kähler function requires that the exponent proportional to the inverse of Kähler coupling constant converges for most primes p. The observation that this is highly improbable led the question whether infinite primes might be of help in the problem. The notion of infinite primes, integers and rationals generalized to complex, quaternionic and octonionic case was one of the first deep ideas inspired by TGD inspired theory of consciousness. The basic observation was that infinite primes correspond to quantum states of an arithmetic quantum field theory second quantized repeatedly.

The key observation was that the multiplication of inverse Kähler coupling strength with a power of quantity $Y = X/(1+X)$, where X is defined as product of all finite primes, and by powers of more general quantities $Y(n/m) = (n/m)X/Q(n/m)$ (n is integer and m square free integer), where $\Pi(n/m)$ is infinite rational solves the algebraic continuation problem. In real sense the numbers Y are units but p-adically their p-adic norm is $1/p$ for all primes except those dividing n and m.

b) The unit-in-real-sense property means that these numbers define an infinite-dimensional extension of rational numbers differing from ordinary rationals in no manner in the real context. The conclusion is that in TGD Universe space-time and imbedding space points are like the monads of Leibniz having infinitely complex structure. Since infinite primes, and their complex, quaternionic, and octonionic counterparts can represent quantum states of entire Universe, Universe is an algebraic hologram in the strongest sense that one can imagine.

c) Since this structure is not visible at the level of real number based physics, the interpretation is as space-time correlate for mathematical cognition. The free algebra generated by products and sums of infinite primes can be seen as the Mother of All Algebraic Structures allowing representation of any smaller structure. In particular, quantum states and quantum entanglement is representable and all kinds of algebraic rules can be represented using entanglement of the algebra elements representing algebra elements.

d) The paths of points in space-time define paths in this algebra and p-adic continuity for all primes implies the conservation of topological energy encountered in arithmetic quantum field theories and implying that the ordinary rational defined by the algebra element is a constant of motion. These paths are correlates for algebraic manipulations forming themselves an algebra with respect to local multiplication (analogous to gauge group multiplication).

A hierarchy of paths (paths of $d = 1$ objects, $d = 2$ and $d = 3$ objects) defining $d-$dimensional surfaces giving rise to analogs of local gauge algebras result. In TGD Universe the maximal dimension of this kind of structure

is $d = 4$. This probably has some deep algebraic meaning. At classical level these structures have interpretation as abstractions of the rules obeyed by algebraic manipulations using a collection of examples defined by a pile of d-dimensional manipulation sequences. The algebraic manipulations correspond to Feynmann diagram like structures with algebra and co-algebra operations having particle fusion and creation as their physical analogs.

7.3.5 Was von Neumann right after all?

The work with TGD inspired model for quantum computation led to the realization that von Neumann algebras, in particular hyper-finite factors of type II_1 could provide the mathematics needed to develop a more explicit view about the construction of S-matrix. In this chapter I will discuss various aspects of type II_1 factors and their physical interpretation in TGD framework.

1. Philosophical ideas behind von Neumann algebras

The goal of von Neumann was to generalize the algebra of quantum mechanical observables. The basic ideas behind the von Neumann algebra are dictated by physics. The algebra elements allow Hermitian conjugation and observables correspond to Hermitian operators. A measurable function of operator belongs to the algebra.

The predictions of quantum theory are expressible in terms of traces of observables. The highly non-trivial requirement of von Neumann was that identical a priori probabilities for a detection of states of infinite state system must make sense. Since quantum mechanical expectation values are expressible in terms of operator traces, this requires that unit operator has unit trace.

For finite-dimensional case it is easy to build observables out of minimal projections to 1-dimensional eigen spaces of observables. For infinite-dimensional case the probably of projection to 1-dimensional sub-space vanishes if each state is equally probable. The notion of observable must thus be modified by excluding 1-dimensional minimal projections, and allow only projections for which the trace would be infinite using the straightforward generalization of the matrix algebra trace as dimension of the projection.

The definitions of adopted by von Neumann allow more general algebras than algebras of II_1 for with traces are not larger than one. Type I_n algebras correspond to finite-dimensional matrix algebras with finite traces whereas I_∞ does not allow bounded traces. For algebras of type III traces are always infinite and the notion of trace becomes useless.

2. von Neumann, Dirac, and Feynman

The association of algebras of type I with the standard quantum mechanics allowed to unify matrix mechanism with wave mechanics. Because of the finiteness of traces von Neumann regarded the factors of type II_1 as fundamental and factors of type III as pathological. The highly pragmatic and successful approach of Dirac based on the notion of delta function, plus the emergence of Feynman graphs and functional integral meant that von Neumann approach was forgotten to a large extent.

Algebras of type II_1 have emerged only much later in conformal and topological quantum field theories allowing to deduce invariants of knots, links and 3-manifolds. Also algebraic structures known as bi-algebras, Hopf algebras, and ribbon algebras to type II_1 factors. In topological quantum computation based on braids and corresponding topological S-matrices they play an especially important role.

3. Factors of type II_1 and quantum TGD

There are good reasons to believe that hyper-finite (ideal for numerical approximations) von Neumann algebras of type II_1 are of a direct relevance for TGD.

Equivalence of generalized loop diagrams with tree diagrams.

The work with bi-algebras led to the proposal that the generalized Feynman diagrams of TGD at space-time level satisfy a generalization of the duality of old-fashioned string models. Generalized Feynman diagrams containing loops are equivalent with tree diagrams so that they could be interpreted as representing computations or analytic continuations. This symmetry can be formulated as a condition on algebraic structures generalizing bi-algebras. The new element is the possibility of vacuum lines having natural counterpart at the level of bi-algebras and braid diagrams. At space-time level they correspond to vacuum extremals.

Inclusions of hyper-finite II_1 factors as a basic framework to formulate quantum TGD.

The basic facts about von Neumann factors of II_1 suggest a more concrete view about the general mathematical framework needed.

a) The effective 2-dimensionality of the construction of quantum states and configuration space geometry in quantum TGD framework makes hyper-finite factors of type II_1 very natural as operator algebras of the state space. Indeed, the elements of conformal algebras are labelled by discrete numbers and also the modes of induced spinor fields are labelled by discrete label, which guarantees that the tangent space of the configuration space is a separable Hilbert space and Clifford algebra is thus a hyper-finite type II_1 factor. The same holds true also at the level of configuration space degrees

of freedom so that bosonic degrees of freedom correspond to a factor of type I_∞ unless super-symmetry reduces it to a factor of type II_1.

b) Four-momenta relate to the positions of tips of future and past directed light cones appearing naturally in the construction of S-matrix. In fact, configuration space of 3-surfaces can be regarded as union of big-bang/big crunch type configuration spaces obtained as a union of light-cones with parameterized by the positions of their tips. The algebras of observables associated with bounded regions of M^4 are hyper-finite and of type III_1. The algebras of observables in the space spanned by the tips of these light-cones are not needed in the construction of S-matrix so that there are good hopes of avoiding infinities coming from infinite traces.

c) Many-sheeted space-time concept forces to refine the notion of sub-system. Jones inclusions $\mathcal{N} \subset \mathcal{M}$ for factors of type II_1 define in a generic manner imbedding interacting sub-systems to a universal II_1 factor which now corresponds naturally to infinite Clifford algebra of the tangent space of configuration space of 3-surfaces and contains interaction as $\mathcal{M} : \mathcal{N}$-dimensional analog of tensor factor. Topological condensation of space-time sheet to a larger space-time sheet, formation of bound states by the generation of join along boundaries bonds, interaction vertices in which space-time surface branches like a line of Feynman diagram: all these situations could be described by Jones inclusion characterized by the Jones index $\mathcal{M} : \mathcal{N}$ assigning to the inclusion also a minimal conformal field theory and conformal theory with k=1 Kac Moody for $\mathcal{M} : \mathcal{N} = 4$. $\mathcal{M} : \mathcal{N}$=4 option need not be realized physically as quantum field theory but as string like theory whereas the limit $D = 4 - \epsilon \to 4$ could correspond to $\mathcal{M} : \mathcal{N} \to 4$ limit. An entire hierarchy of conformal field theories is thus predicted besides quantum field theory.

d) von Neumann's somewhat artificial idea about identical a priori probabilities for states could replaced with the finiteness requirement of quantum theory. Indeed, it is traces which produce the infinities of quantum field theories. That $\mathcal{M} : \mathcal{N} = 4$ option is not realized physically as quantum field theory (it would rather correspond to string model type theory characterized by a Kac-Moody algebra instead of quantum group), could correspond to the fact that dimensional regularization works only in $D = 4 - \epsilon$. Dimensional regularization with space-time dimension $D = 4 - \epsilon \to 4$ could be interpreted as the limit $\mathcal{M} : \mathcal{N} \to 4$. $\mathcal{M}$ as an $\mathcal{M} : \mathcal{N}$-dimensional $\mathcal{N}$-module would provide a concrete model for a quantum space with non-integral dimension as well as its Clifford algebra. An entire sequence of regularized theories corresponding to the allowed values of $\mathcal{M} : \mathcal{N}$ would be predicted.

Generalized Feynman diagrams are realized at the level of $\mathcal{M}$ as

quantum space-time surfaces.

The key idea is that generalized Feynman diagrams realized in terms of space-time sheets have counterparts at the level of $\mathcal{M}$ identifiable as the Clifford algebra associated with the entire space-time surface X^4. 4-D Feynman diagram as part of space-time surface is mapped to its $\beta = \mathcal{M} : \mathcal{N} \leq$ 4-dimensional quantum counterpart.

a) von Neumann algebras allow a universal unitary automorphism $A \rightarrow \Delta^{it} A \Delta^{-it}$ fixed apart from inner automorphisms, and the time evolution of partonic 2-surfaces defining 3-D light-like causal determinant corresponds to the automorphism $\mathcal{N}_i \rightarrow \Delta^{it} \mathcal{N}_i \Delta^{-it}$ performing a time dependent unitary rotation for $\mathcal{N}_i$ along the line. At configuration space level however the sum over allowed values of t appear and should gives rise to the TGD counterpart of propagator as the analog of the stringy propagator $\int_0^t exp(iL_0 t)dt$. Number theoretical constraints from p-adicization suggest a quantization of t as $t = \sum_i n_i y_i > 0$, where $z_i = 1/2 + y_i$ are non-trivial zeros of Riemann Zeta.

b) At space-time level the "ends" of orbits of partonic 2-surfaces coincide at vertices so that also their images $\mathcal{N}_i \subset \mathcal{M}$ also coincide. The condition $\mathcal{N}_i = \mathcal{N}_j = ... = \mathcal{N}$, where the sub-factors $\mathcal{N}$ at different vertices differ only by automorphism, poses stringent conditions on the values t_i and Bohr quantization at the level of $\mathcal{M}$ results. Vertices can be obtained as a vacuum expectations of of the operators creating the states associated with the incoming lines (crossing symmetry is automatic).

c) The equivalence of loop diagrams with tree diagrams would be due to the possibility to move the ends of the internal lines along the lines of the diagram so that only diagrams containing 3-vertices and self energy loops remain. Self energy loops are trivial if the product associated with fusion vertex and co-product associated with annihilation compensate each other. The possibility to assign quantum group or Kac Moody group to the diagram gives good hopes of realizing product and co-product. Octonionic triality would be an essential prerequisite for transforming N-vertices to 3-vertices. The equivalence allows to develop an argument proving the unitarity of S-matrix.

d) A formulation using category theoretical language suggests itself. The category of space sheets has as the most important arrow topological condensation via the formation of wormhole contacts. This category is mapped to the category of II_1 sub-factors of configurations space Clifford algebra having inclusion as the basic arrow. Space-time sheets are mapped to the category of Feynman diagrams in $\mathcal{M}$ with lines defined by unitary rotations of $\mathcal{N}_i$ induced by Δ^{it}.

e) The hierarchy of imbeddings for type II_1 factors generalizes to the hierarchy of generalized Feynman diagrams in which the particles of given level correspond to Feynman diagrams of the previous level. These Feynman diagrams provide representations for the projections of S-matrix to subspaces of incoming and outgoing states providing a hierarchy of self representations about the system. The vertices for the interactions of these Feynman diagrams reduce to the interactions at the lowest level apart from the automorphisms $\Delta_{\mathcal{M}_n}$ defining free propagation. The interpretation is as an infinite cognitive hierarchy realizing theory about the material world as cognitive quantum states. This hierarchy corresponds to states with vanishing conserved net quantum numbers but having non-vanishing "gravitational" charges identifiable as classical charges. A fascinating possibility is that dark matter corresponds to thoughts!

Is $\hbar$ dynamical?

The work with topological quantum computation inspired the hypothesis that $\hbar$ might be dynamical, and that its values might relate in a simple manner to the logarithms of Beraha numbers giving Jones indices $\mathcal{M} : \mathcal{N}$. The model for the evolution of $\hbar$ implied that $\hbar$ is infinite for the minimal value $\mathcal{M} : \mathcal{N} = 1$ of Jones index.

The construction of a model explaining the strange finding that planetary orbits seem to correspond to a gigantic value of "gravitational" Planck constant led to the hypothesis that when the system gets non-perturbative so that the perturbative expansion in terms of parameter $k = alphaQ_1Q_2$ ceases to converge, a phase transition increasing the value of $\hbar$ to $\hbar_s = k \times \hbar/v_0$, where $v_0 = 4.8 \times 10^{-4}$ is the ratio of Planck length to CP_2 length, occurs. This involves also a transition to a macroscopic quantum phase since Compton lengths and times increase dramatically. Dark matter would correspond to ordinary matter with large value of $\hbar$, which is conformally confined in the sense the sum of complex super-canonical conformal weights (related in a simple manner to the complex zeros of Riemann Zeta) is real for the many-particle state behaving like a single quantum coherent unit.

The value of $\hbar$ for $\mathcal{M} : \mathcal{N}$=1 is large but not infinite, and thus in conflict with the original original proposal. A more refined suggestion is that the evolution of $\hbar$ as a function of $\mathcal{M} : \mathcal{N} = 4cos^2(\pi/n)$ can be interpreted as a renormalization group evolution for the phase resolution. The earlier identification is replaced by a linear renormalization group equation for $1/\hbar$ allowing as its solutions the earlier solution plus an arbitrary integration constant. Hence $1/\hbar$ can approach to a finite value $1/\hbar(3) = v_0/k \times \hbar(n \to \infty)$ at the limit $n \to 3$. The evolution equation gives a concrete view about how various charges should be imbedded in Jones inclusion to the larger

algebra so that the value of $\hbar$ appearing in commutators evolves in the required manner.

The dependence of $\hbar$ on the parameters of interacting systems means that it is associated with the interface of the interacting systems. Instead of being an absolute constant of nature $\hbar$ becomes something characterizing the interaction between two systems, the "position" of II_1 factor $\mathcal{N}$ inside $\mathcal{M}$. The interface could correspond to wormhole contacts, join along boundaries bond, light-like causal determinant, etc... This property of $\hbar$ is consistent with the fact that vacuum functional expressible as an exponent of Kähler action does not depend at all on $\hbar$.

7.4 PART IV: Bio-systems as macroscopic quantum systems

7.4.1 Quantum theory of self-organization

Quantum theory of self-organization based on the idea that quantum jump serves as the basic step of self-organization, is represented. The notion of self and the identification of self as the fundamental statistical ensemble gives totally new meaning for the concept of self-organization as a generation of hierarchies of selves. Zero modes of the configuration space geometry, whose existence derives from the generalization of point like particle to 3-surface, provide universal, nonlocal order parameters and the emergence of the new level of self-organization occurs through phase transition like process as also in Haken's theory. The fact that quantum jumps involve localization in zero modes means that the sequence of quantum jumps means hopping in zero modes characterizing the classical aspects of the space-time geometry. The quantum version of Haken's theory of self-organization is proposed and is almost identical with Haken's theory. Spin glass analogy means that "energy" landscape has fractal valleys inside valleys structure: this structure is important for understanding long term memories. A crucially important aspect of the quantum self-organization is the Darwinian selection of very few asymptotic self-organization pattterns by dissipation which explains the selection of both genes and memes: this selection provides royal road to the understanding of various miraculous feats performed by living matter.

The comparison with Rupert Sheldrake's concepts of morphic field and morphic resonance leads to interesting ideas about how learning at the level of species could occur quantum-mechanically. For instance, the phenomenon of bio-feedback suggests that self could quite generally effectively act as morphic field for its subselves. If entanglement occurs mostly between subsystems having same value of p-adic prime one could understand the "alike

likes alike" rule of Sheldrake at the quantum level.

7.4.2 Dark Nuclear Physics and Living Matter

The unavoidable presence of classical long ranged weak (and also color) gauge fields in TGD Universe has been a continual source of worries for more than two decades. The basic question has been whether Z^0 charges of elementary particles are screened in electro-weak length scale or not. The hypothesis has been that the charges are feeded to larger space-time sheets in this length scale rather than screened by vacuum charges so that an effective screening results in electro-weak length scale.

A more promising approach inspired by the TGD based view about dark matter assumes that weak charges are indeed screened for ordinary matter in electro-weak length scale but that dark electro-weak bosons correspond to much longer symmetry breaking length scale.

The large value of $\hbar$ in dark matter phase implies that Compton lengths and -times are scaled up. In particular, the sizes of nucleons and nuclei become of order atom size so that dark nuclear physics would have direct relevance for condensed matter physics. It becomes impossible to make a reductionistic separation between nuclear physics and condensed matter physics and chemistry anymore.

1. The notion of dark matter

In this chapter the earlier ideas about dark matter as an explanation of various anomalies are abstracted into a coherent theoretical framework. General considerations lead to the conclusion that only space-time sheets characterized by the same real or complex p-adic prime and same value of $\hbar$ interact quantum coherently, and that elementary particles are characterized by the p-adic primes characterizing the space-time sheets at which they feed their gauge charges. Hence the notion of darkness is only relative and there exists an infinite number of relatively dark space-time sheets.

The simplest form of dark matter corresponds to real conformal weights but large value of $\hbar$. In the electromagnetic large $\hbar$ phase corresponding to $k = 113$ strong and weak physics are standard but the height of the Coulomb wall of nuclei is reduced dramatically since the size of nuclei increases by a factor of order 2^{11}. This is enough to explain cold fusion anomalies and selection rules and also the anomalous physics of water.

Elementary particles can also have complex conformal weights such that the conformal weight of the entire system is real. The hypothesis that given particle has a fixed complex conformal weight characterized by the complex

zero of Riemann Zeta allows natural hierarchy for these phases and implies no apparent breakings of Fermi statistics. Weak bosons with complex conformal weights are assumed to correspond to Gaussian Mersennes instead of real Mersennes and Gaussian Mersennes corresponding to k=113 (nuclear length scale),151,157,163,167 (biologically important length scales possibly related to the coiling hierarchy of DNA) define the most interesting examples allowing large parity breaking effects and non-standard weak nuclear physics.

For each, in general complex, conformal weight an entire hierarchy of dark matters with increasing values of $\hbar$ is predicted ("dark dark" matter structures consisting of conformally confined dark matter structures, etc...). This hierarchy has an interpretation in terms of the hierarchy of infinite primes constructible by a repeated second quantization of a supersymmetric arithmetic quantum field theory.

2. What dark nucleons are?

The basic hypothesis is that nucleons can make a phase transition to dark phase in which the electromagnetic size of both quarks and nucleons is measured in Angstroms. Proton condensates with large $\hbar$ might be crucial for understanding the properties of water and perhaps even the properties of ordinary condensed matter.

A further phase transition $k = 89 \rightarrow 113$ of weak bosons to Gaussian Mersenne phase with complex conformal weights would have dramatic effects on the weak decay rates of resulting nuclei. If also $\hbar$ is large, one could understand the large parity breaking effects in living matter.

TGD based model for nuclei as nuclear strings relies on the notions of dark valence quark with large $\hbar$ and light exotic quark for which weak space-time sheet is dark and corresponds to $k = 113$ and p-adic length scale of order atomic size. Exotic quark and anti-quark appear at the ends of color bonds connecting nucleons to form a nuclear string. Color bonds can be also charged.

The simplest model for dark nucleons turns out to be the one in which valence quarks, which are dark in QCD sense but not in nuclear physics sense, are transformed to doubly dark quarks and correspond to p-adic length scale $L(151) \simeq 10$ nm whereas exotic quarks have always dark weak space-time sheet with atomic size. This leads to a model of partially dark condensed matter based on the assumption that nuclei can form super-nuclei, which are string like structures containing ordinary nuclei as highly knotted and linked portions separated by color bonds having length of order interatomic distance. If internuclear color bonds are em charged, they are also weakly

charged, and the repulsive weak force between exotic quark and anti-quark, which must be actually strong by criticality condition, compensates the internuclear color force in equilibrium.

3. Anomalous properties of water and dark nuclear physics

The transparency of water to visible light inspired originally the idea that water is partially dark matter. Second crucial empirical input was the $H_{1.5}O$ chemical formula supported by neutron and electron scattering in attosecond time scale, which happens to correspond to the electromagnetic size of dark proton. This leads to the hypothesis that one fourth of protons combine to form neutron strings with positively charged color bonds between neutrons. Double darkness of the valence quarks explains why the neutrons are dark with respect to nuclear strong interactions and thus not seen in neutron scattering, whereas the transformation to neutrons explains why they are not seen in electron scattering.

The crucial property of water is the presence of molecular clusters. Tedrahedral clusters allow an interpretation in terms of magic Z=8 protonic dark nuclei. The icosahedral clusters consisting of 20 tedrahedral clusters in turn have interpretation as magic dark dark nuclei: the presence of the dark dark matter explains large portion of the anomalies associated with water and explains the unique role of water in biology. In living matter also higher levels of dark matter hierarchy are predicted to be present. The observed nuclear transmutation suggest that also light weak bosons are present.

4. Implications of the partial darkness of condensed matter

The model for partially dark condensed matter deriving from nuclear physics allows to understand the low compressibility of the condensed matter as being due to the repulsive weak force between exotic quarks, explains large parity breaking effects in living matter, and suggests a profound modification of the notion of chemical bond having most important implications for biochemistry and understanding of bio-chemical evolution.

7.4.3 Biological realization of the self hierarchy

Self-hierarchy is the basic prediction of the TGD inspired theory of consciousness and the biological realization of the self-hierarchy is the basic theme of this chapter. Space-time sheets, in particular mind like space-time sheets having finite temporal duration and providing cognitive representation of the material world, are geometrical correlates of selves and biological self hierarchy reduces geometrically and topologically to the hierarchy of

space-time sheets. Crucially involved is the notion of the topological field quantization, which among other things implies that photons have as their classical geometrical correlates so called topological field quanta. One interpretation for the topological field quanta of em field is as classical/quantal coherence regions of classical/quantum em field and electromagnetic (em) fields and their topological field quanta are expected to be especially important in bio-systems. One can assign vacuum quantum numbers to topological field quanta and these quantum numbers are expected to be carriers of a biologically relevant information.

In principle the self hierarchy starts already at elementary particle level but the atomic length scale serves as a natural length scale for length scale at which biological relevant part of the self-hierarchy starts.

a) The assumption that various bio-molecules are selves allows to understand the miraculous abilities of living systems as outcome of quantum self-organization process in which dissipation selects very limited repertoire of self-organization patterns identifiable as survivors in Darwinian selection. For instance, one can understand protein folding and DNA replication as self-organization processes.

b) The fact that bio-systems are liquid crystals, makes them ideal for the realization of the self hierarchy. The reason is that liquid crystals have ability to self-organize to very complicated structures and are ideal for communication purposes: for instance, mechanical signals can be coded to electric signals and vice versa. Liquid crystals are also electrets: the presence of electric fields is indeed an important prerequisite of cognition in TGD as discussed in the chapter "Information and consciousness". In fact, one could identify various bio-structures such as micro-tubuli, cell organelles and cells as generic outcomes of the self-organization of the liquid crystals. An especially important level of the self hierarchy is provided by collagen networks which could give rise to what might be called 'body consciousness'. Central nervous system is only one, although very important level in the self hierarchy, and TGD approach allows to understand why this is the case.

c) p-Adic length scale hypothesis allows quantitative grasp to the structure of the self hierarchy and one can build general picture about how various p-adic length scales emerged during the evolution. In particular, one can identify various p-adic length scales associated with the brain.

d) One level of the self hierarchy corresponds to the topological field quanta of ELF em fields associated with EEG. ELF (extremely low frequency) em fields are known to have dramatic effects on living matter and brain and the origin of these effects is poorly understood. A simple argument based on Uncertainty Principle leads to the conclusion that ELF photons

in 10 Hz frequency range correspond to topological field quanta of size of entire Earth. This leads to a rather dramatic conclusion that our biological body is only a tip of an iceberg and we are much more than our neurons. The most important levels in our personal self hierarchy contains levels are of size of Earth! Support for this picture come from the quantitative success of the scenario: one can immediately understand various important neuro time scales in terms of the cyclotron frequencies of various charged particles in $B = 2/5B_E = .2$ Gauss.

e) Each bio-structure is accompanied by a topologically quantized magnetic field defining corresponding magnetic body and these magnetic bodies form a hierarchy. Magnetic bodies could serve as intentional agents, as templates for the formation of various biological control circuits crucial for homeostasis and biological information processing, define the basic structure making possible metabolism with universal metabolic energy currencies, and could even define what might be called Nature's own bio-laboratory.

f) The magnetic flux structures associated with body could be of crucial importance for understanding human consciousness. For instance, eyes generate magnetic fields. Also brain, in particular pineal gland (the 'third eye' of mystics and the seat of soul for Descartes), contains magnetic materials. Corresponding magnetic transition frequencies correspond to time scales relevant for the self narrative in human time scales. Perhaps these higher levels of magnetic self hierarchy could relate with NDE experiences and represent structures surviving in physical death.

7.4.4 Quantum control and coordination in bio-systems: part I

The basic dynamical aspects of the biological system relate to coordination and control. Coordination is involved with almost automatic and predictable activities involving no volition whereas control involves volition and non-predictability. A basic examples of coordination and control are EEG and nerve pulse respectively. Various motor activities are good examples of a control involving macroscopic changes of the shape of the organ. The great challenge is to identify the quantum correlates of coordination and control.

The vision about living matter as consisting of a fractal hierarchy of MEs controlling a fractal hierarchy super-conducting magnetic flux tube structures in turn controlling ordinary matter at atomic space-time sheets via many-sheeted ionic flow equilibrium provides a very promising approach for modelling living matter. MEs interact with magnetic superconductors via magnetic induction by inducing supra-currents, by acting as Josephson junctions between magnetic flux tubes, and by inducing magnetic transi-

tions.

The fact that TGD predicts infinite hierarchy of dark matters defining scaled down copies of color and electro-weak physics generalizes this picture dramatically and means that dark matter becomes the quintessential component of living systems. The predicted spectrum for the values of Planck constant conforms with quantum criticality since Kähler function does not depend on $\hbar$ and long range fluctuations at quantum criticality can be also interpreted as fluctuations in the value of $\hbar$ appearing only in the construction of quantum states and making possible macroscopic quantum coherence.

TGD suggests strongly that the formation of join the along boundaries bonds between the space-time sheets possibly representing different levels of the self hierarchy could be the basic mechanism of control and coordination. The interpretation as a prerequisite for bio-feedback, understood in very general sense, is very suggestive. The presence of join along boundaries bonds makes possible transfer of various charge particles between space-time sheets in question and the resulting system is very similar to two weakly coupled super conductors connected by Josephson junctions. This suggests that that super currents and Josephson currents between the space-time sheets are crucial for the coordination, which could be identified as deterministic quantum time development without quantum jumps.

Any harmonic perturbation with some magnetic transition frequency can induce magnetic quantum transitions and even magnetic quantum phase transitions. An attractive identification for this process is as basic tool of quantum control tool so that the resonance frequency appears as control parameter 'waking up' subself at its critical value. Critical frequencies correspond to the magnetic and Z^0 magnetic cyclotron frequencies in the model of super conductor relying on the presence of weak magnetic or Z^0 magnetic field (magnetic field guarantees effective one-dimensionality of the super conductor and implies finite gap energy in TGD framework). Cyclotron frequency hypothesis has had rather dramatic success and leads to a rather detailed picture about brain as a macroscopic quantum system.

7.4.5 Quantum control and coordination in bio-systems: part II

The topics of this chapter are related to the implications of absolute minimization of Kähler action for the understanding of bio-systems, to the TGD counterparts of scalar waves of Tesla and the realization of the time mirror mechanism mechanism, to 1/f noise as a signature of quantum criticality, and to the role of ELF fields in living systems.

1. Absolute minimization of Kähler action

Absolute minimization of Kähler action yields a non-deterministic dynamics mimicking the dissipative dynamics of the quantum jump sequence. This dynamics leads to asymptotic field patterns for which dissipation represented by a non-vanishing Lorentz 4-force is absent. The vanishing is guaranteed by the topologization of the Kähler current so that it becomes proportional to instanton current. When Kähler electric field is absent, magnetic field reduces to what is known as Beltrami field. Beltrami fields are known to be extremely complex but highly organized structures. The natural conjecture is that topologically quantized many-sheeted magnetic and Z^0 magnetic Beltrami fields and their generalizations serve as templates for the helical molecules populating living matter, and explain both chirality selection, the complex linking and knotting of DNA and protein molecules, and even the extremely complex and self-organized dynamics of biological systems at the molecular level.

2. Tesla's scale waves and time mirror mechanism

TGD allows scalar wave pulses represented as space-time sheets propagating with velocity of light and carrying longitudinal electric field. These solutions exist certainly as vacuum extremals and, as it seems, also as solutions of field equation which do not represent asymptotic self-organization patterns but kind of transits analogous to longitudinal virtual photons.

Many-sheeted space-time makes possible many-sheeted lasers since cold space-time sheets can contain Bose-Einstein condensates of ions and their Cooper pairs. If the system contains population inverted many-sheeted laser for which the increment of zero point kinetic energy corresponds to the energy of photons associated with negative energy MEs, the absorption of negative energy photons gives rise to a phase transition like dropping of particles to larger space-time sheet by the induced emission mechanism, and the control signal represented by negative energy MEs can be amplified if a critical number of particles drops to the larger space-time sheet. This control mechanism allows an instantaneous motor control in which intention is transformed to a desire represented by negative energy MEs and generates in geometric past a reaction representing the desired response, say neuronal activity giving rise to motor action. This process probably involves entire hierarchy of magnetic selves realizing their intentions as desires communicated to lower level magnetic selves and the lowest level corresponds to the regions of brain responsible for liberating metabolic energy.

3. Quantum criticality and $1/f$ noise

Criticality is one prerequisite of control: the controlled system must be initial value sensitive, that is critical, in some degrees of freedom. TGD universe is indeed quantum critical and the universality of $1/f$ noise serves as an empirical support for this. It is indeed known that $1/f$ noise is related to criticality but the problem is that critical systems are by definition unstable. This has led to the paradigm of self-organized criticality in which system is assumed to self-organize into a critical state. Since TGD Universe is quantum critical, this questionable assumption is not needed. The only coupling parameter of TGD is analogous to critical temperature and as a fundamental coupling constant is not subject to external perturbations.

4. The role of ELF fields in bio-control

Some evidence for the hypothesis that higher levels of the biological self hierarchy control biological body using fields at ELF frequencies (EEG frequencies are in ELF range) is discussed. The basic inputs are topological field quantization, the idea of memetic code and the observations about the effects of ELF em fields to brain suggesting that the higher levels of our self hierarchy correspond to em selves with sizes of order wavelength of photons generated by EEG currents and thus realized as topological field quanta having size of order of Earth.

7.4.6 Bio-systems as superconductors: part I

In this chapter the description of super-conductivity in many-sheeted space-time is discussed. The notion of many-sheeted space-time alone provides strong motivation for this and I have developed various ideas about high T_c super-conductivity in parallel with ideas about living matter as a macroscopic quantum system. A further motivation and a hope for more quantitative modelling comes from the discovery of various non-orthodox superconductors including high T_c superconductors, heavy fermion super-conductors and ferromagnetic superconductors. The standard BCS theory does not work for these super-conductors and the mechanism for the formation of Cooper pairs is not understood. There is experimental evidence that quantum criticality is a key feature of many non-orthodox super-conductors. TGD provides a conceptual framework and bundle of ideas making it possible to develop models for non-orthodox superconductors.

1. Quantum criticality, hierarchy of dark matters, and dynamical $\hbar$

Quantum criticality is the basic characteristic of TGD Universe and quantum critical superconductors provide an excellent test bed to develop

the ideas related to quantum criticality into a more concrete form.

The hypothesis that $\hbar$ is dynamical possessing quantized spectrum adds further content to the notion of quantum criticality. Phases with different values of $\hbar$ behave like dark matter with respect to each other in the sense that they do not have direct interactions. In large $\hbar$ phases various quantum time and length scales are scaled up which means macroscopic and macro-temporal quantum coherence.

The great idea is that the transition to large $\hbar$ phase occurs when perturbation theory based on the expansion in terms of gauge coupling constant ceases to converge: Mother Nature would take care of the problems of theoretician. The transition to large $\hbar$ phase obviously reduces gauge coupling strength α so that higher orders in perturbation theory are reduced whereas the lowest order "classical" predictions remain unchanged. A possible quantitative formulation of the criterion is that maximal 2-particle gauge interaction strength parameterized as $Q_1Q_2\alpha$ satisfies the condition $Q_1Q_2\alpha \simeq 1$.

A further hypothesis is that in the transition to large $\hbar$ phase the scaling $\hbar \to n\hbar/v_0$, where n is integer and $v_0 \simeq 2^{-11}$ is expressible in terms of the ratio of Planck length to CP_2 length scale.

The only coupling constant strength of theory is Kähler coupling constant g_K^2 which appears in the definition of the Kähler function K characterizing the geometry of the configuration space of 3-surfaces (the "world of classical worlds"). The exponent of K defines vacuum functional analogous to the exponent of Hamiltonian in thermodynamics. The allowed values of g_K^2, which are analogous to critical temperatures, are determined by quantum criticality requirement and labelled by p-adic primes. $\hbar$ appears in the commutation and anticommutation relations of various superconformal algebras but not in the vacuum functional. For a given p-adic length scale space-time sheets with all allowed values of $\hbar$ are therefore possible. Hence the spectrum of quantum critical fluctuations could in the ideal case correspond to the spectrum of $\hbar$ coding for the scaled up values of Compton lengths and other quantal lengths and times. If so, large $\hbar$ phases could be crucial for understanding of quantum critical superconductors, in particular high T_c superconductors.

TGD actually predicts an infinite hierarchy of phases behaving like dark or partially dark matter with respect to the ordinary matter and the value of $\hbar$ is only one characterizer of these phases. These phases, especially so large $\hbar$ phase, seem to be essential for the understanding of even ordinary hadronic, nuclear and condensed matter physics. This strengthens the motivations for finding whether dark matter might be involved with quantum critical super-conductivity.

2. Many-sheeted space-time concept and ideas about macroscopic quantum phases

Many-sheeted space-time leads to obvious ideas concerning the realization of macroscopic quantum phases.

a) The dropping of particles to larger space-time sheets is a highly attractive mechanism of super-conductivity. If space-time sheets are thermally isolated, the larger space-time sheets could be at extremely low temperature and super-conducting.

b) The possibility of large $\hbar$ phases allows to give up the assumption that space-time sheets characterized by different p-adic length scales are thermally isolated. The scaled up versions of a given space-time sheet corresponding to a hierarchy of values of $\hbar$ are possible such that the scale of kinetic energy and magnetic interaction energy remain same for all these space-time sheets. For instance, for scaled up variants of space-time sheet having size scale characterized by $L(151) = 10$ nm (cell membrane thickness) the critical temperature for superconductivity could be higher than room temperature.

c) The idea that wormhole contacts can form macroscopic quantum phases and that the interaction of ordinary charge carriers with the wormhole contacts feeding their gauge fluxes to larger space-time sheets could be responsible for the formation of Cooper pairs, have been around for a decade. The realization that wormhole contacts can be regarded as parton-antiparton pairs with parton and antiparton assignable to the light-like causal horizons accompanying wormhole contacts, opens the doors for more concrete models. The simplest idea is that em charged Cooper pairs can be modelled as a pair of charged particles at a space-time sheet X^4_c topologically condensed to the background space-time sheet Y^4 of condensed matter system. The Coulombic binding energy of charges particles with the quarks and antiquarks assignable to the wormhole throats feeding the em gauge flux to Y^4 could be responsible for the energy gap.

d) Quantum classical correspondence has turned out be a very powerful idea generator. For instance, one can ask what are the space-time correlates for various notions of condensed matter such as phonons, BCS Cooper pairs, holes, etc... For instance, TGD predicts the existence of negative energy space-time sheets so that ordinary particles can and must exist in negative energy states (in cosmological scales the density of inertial energy is predicted to vanish). The question is whether holes could have quite concrete representation as negative energy space-time sheets carrying negative energy particles and whether the notion of Cooper pair of holes could have

this kind of space-time correlate.

3. Model for high T_c superconductivity

These general ideas lead to a concrete model for high T_c superconductors as quantum critical superconductors allowing to understand the characteristic spectral lines as characteristics of the Cooper pair. The model for quantum critical electronic Cooper pairs generalizes to Cooper pairs of fermionic ions and for sufficiently large $\hbar$ stability criteria, in particular thermal stability conditions, can be satisfied in a given length scale. Also high T_c superfluidity based on dropping of bosonic atoms to Cooper pair space-time sheets where they form Bose-Einstein condensate is possible and part of copper atoms are predicted to be dark matter.

At qualitative level the model explains various strange features of high T_c superconductors such as the existence of pseudogap: this is due to the fact that two kinds of super-conductivities corresponding to BCS type large $\hbar$ supra currents at interior and boundary supra currents carried by wormholy Cooper pairs. At quantitative level the model predicts correctly the four poorly understood photon absorption lines and allows to understand the critical doping ratio. The current carrying structures have structure similar to that of axon including the double layered structure of cell membrane and also the size scales are predicted to be same so that the idea that axons are high T_c superconductors is highly suggestive.

4. Empirical evidence for high T_c superconductivity in bio-systems

The evidence for super-conductivity in bio-systems. DNA should be insulator but under some circumstances it becomes conductor and perhaps even high T_c quantum critical super-conductor. Also evidence for Josephson effect has been reported. The so called ORMEs patented by Hudson are claimed to behave like superconductors: unfortunately the academic world has not taken these claims seriously enough to test them. The claimed properties of ORMEs conform with high quantum critical T_c super-conductivity and superfluidity. The strange findings about the strange quantal behavior of ionic currents through cell membranes suggest the presence of ionic supra currents.

7.4.7 Bio-systems as superconductors: part II

The general model for quantum control and coordination relies crucially on the existence of a hierarchy of superconductors associated with the self hierarchy (self defined as a quantum system able to avoid bound state entangle-

ment with environment) controlling the ionic densities at atomic space-time sheets via many-sheeted ionic flow equilibrium and being quantum controlled with the mediation of the fractal hierarchy of MEs.

1. General mechanisms for superconductivity

The many-sheeted space-time concept provides a very general mechanism of superconductivity based on the 'dropping' of charged particles from atomic space-time sheets to larger space-time sheets. The first guess was that larger space-time sheets are very dry, cool and silent so that the necessary conditions for the formation of high T_c macroscopic quantum phases are met.

The possibility of large hbar quantum coherent phases makes however the assumption about thermal isolation between space-time sheets un-necessary. At larger space-time sheet the interactions of the charged particles with classical em fields generated by various wormhole contacts feeding gauge fluxes to and from the space-time sheet in question give rise to the necessary gap energy. The simplest model for Cooper pair is space-time sheet containing charged particles having attractive Coulombic interaction with the quarks and antiquarks associated with the throats of the wormhole contacts.

A crucial element is quantum criticality predicting that superconductivity appears at the fluctuating boundaries of competing ordinary and large $\hbar$ phases for nuclei. This assumption predicts several anomalous phenomena such as cold fusion and nuclear transmutations. Also high T_c superfluidity of bosonic atoms dropped to space-time sheets of electronic Cooper pairs becomes possible besides ionic super conductivity. Even dark neutrino superconductivity can be considered below the weak length scale of scaled down weak bosons.

Magnetic and Z^0 magnetic flux tubes and walls are especially interesting candidates for supra current carries. In this case the Cooper pairs must have spin one and this is indeed possible for wormholy Cooper pairs. The fact that the critical magnetic (Z^0 magnetic) fields can be very weak or large values of $\hbar$ is in accordance with the idea that various almost topological quantum numbers characterizing induced magnetic fields provide a storage mechanism of bio-information.

This mechanism is extremely general and works for electrons, protons, ions, charged molecules and even exotic neutrinos so that an entire zoo of high T_c bio-superconductors, super-fluids and Bose-Einstein condensates is predicted. Of course, there are restrictions due to the critical temperature and it seems that only electron, neutrino, and proton Cooper pairs are possible at room temperature.

a) The experimental data about the effects of ELF em fields at cyclotron frequencies of various ions in Earth's magnetic field on bio-systems provide support for this scenario. Most remarkably, the cyclotron frequencies of biologically important ions correspond to the important frequencies of EEG and the time scale of nerve pulse corresponds to $n = 3$ multiple of proton cyclotron frequency so that a direct quantitative contact with brain consciousness results.

b) Electronic super conductors are of type II with defect regions being typically cylindrical: DNA sequences, proteins, microtubules,... could provide examples of the defect regions. One ends up also with a model of high T_c super conductors in which the interaction of the electrons with wormhole BE condensate gives rise to Cooper pairs. The model explains elegantly the basic peculiar features of the high T_c superconductors.

c) Long ranged Z^0 force due to anomalous weak isospin of nuclei and Z^0 charged wormholes make possible also Z^0 ionic superconductivity and even dark neutrino super conductivity. For instance, Z^0 ionic superconductivity is crucial in the model for the quantum correlate of hearing: audible frequencies are mapped to Z^0 cyclotron frequencies. Dark neutrino super conductors are of type I in the interesting length scale range and defect regions are stripe like. Besides cell and endoplasma membranes, epithelial sheets consisting of two cell layers and some larger structures in cortex could correspond to regions of this kind and the interpretation as a physical realization of cognitive hierarchy suggests itself.

2. Superconductivity at magnetic flux quanta in astrophysical length scales

Magnetic flux tubes with magnetic field $B = 2B_E/5 = .2$ Gauss, where B_E denotes the nominal value of the Earth's magnetic field, are crucial for the TGD based model of bio-superconductivity. Since the models of auroras assume that the magnetic flux lines act effectively as conducting wires, the natural hypothesis is that superconductivity is an astrophysical phenomenon. This leads to a model of auroras explaining the latest findings and providing further insights to the superconductivity and the manner how it breaks down. Critical temperature is the temperature at which the join along boundaries bonds making possible the leakage of the supra currents to the non-superconducting space-time sheets become possible and can be gigantic as compared to the temperature at the superconducting space-time sheets.

3. Fractal hierarchy of EEGs

There are three contributions to EEG besides neural noise: Schumann frequencies, cyclotron frequencies, and the frequencies associated with Josephson junctions determined by the sum of the constant voltage and voltage perturbation determined by the superposition of cyclotron frequencies. Cyclotron contribution can be interpreted as a control signal from a magnetic body in question labelled by k_d and affects both the ions at the flux sheets traversing DNA and the Josephson junction. The coherent state of photons generated by Josephson current corresponds to a reaction to this signal received by the magnetic body as a feedback. Schumann frequencies can be assigned to the control by magnetic body of Earth and correlate with the collective aspects of consciousness.

The analysis of the Josephson current leads to the conclusion that the frequencies in the coherent state of photons are in general sums and differences of Josephson frequency and harmonics of cyclotron frequencies. For small amplitudes this implies that alpha band to which the cyclotron frequencies most biologically important bosonic ions corresponds has as satellites theta and beta bands. Higher harmonics correspond to gamma and higher bands having also satellites. For large amplitudes EEG becomes chaotic which is indeed the property of beta band during say intense concentration or anxiety. The findings of Nunez about narrow 1-2 Hz wide bands at 3,5,7 Hz and 13,15,17 Hz confirm with the prediction of satellite bands and fix the Josephson frequency to 5 Hz. This picture explains the general characteristics of EEG in wake-up state qualitatively and quantitatively.

In order to understand the characteristics during various stages of deep sleep one must assume that the cyclotron frequency scale of ions is scaled down by a factor of 1/2. One explanation is that right *resp.* left brain hemisphere corresponds to $Z = 2$ *resp.* $Z = 1$ quantization condition $Z \int BdS = n\hbar$ for the magnetic flux. $Z = 2$ case allows only doubly charged bosonic ions at magnetic flux sheets. $Z = 1$ case also also singly charged ions be their bosons or fermions and for this option magnetic field is scaled down by a factor of 1/2. The alternative explanation is that during sleep only Bose-Einstein condensates of singly charged exotic ions resulting when color bond inside nucleus becomes charged are present. This reduces the scale of cyclotron frequencies by a factor 1/2 and leaves only theta and delta bands. During stage 4 sleep only only DNA cyclotron frequencies in delta band are around 1 Hz and just above the thermal threshold are predicted to be present. For $k_d = 3$ and magnetic field scaled up by λ and flux tube area scaled down by λ^{-2} DNA frequencies are scaled up to kHz for $Z = 2$ flux quantization and might define neuronal synchronization frequencies.

4. The effects of ELF em fields on brain

The experimental data about the effects of ELF em fields at cyclotron frequencies of various ions on vertebrate brains provide a test bench for the fractal hierarchy of EEGs. As a matter fact, it was the attempt to explain these effects, which eventually led to the discovery of the fractal hierarchy of EEGs and ZEGs.

The reported effects occur for harmonics of cyclotron frequencies of biologically important ions in $B = .2$ Gauss (Earth's magnetic field has nominal value .5 Gauss). They occur only in amplitude windows. The first one is around 10^{-7} V/m and second corresponds to the range $1 - 10$ V/m: the amplitudes of EEG waves are in the range 5-10 V/m. The effects are present only in the temperature interval 36-37 C.

The temperature interval has interpretation in terms of quantum criticality of high T_c superconductivity (both interior and boundary super currents are possible in this interval). Amplitude windows correspond to resonant EEG bands if the voltage perturbations contribute to the voltages over Josephson junctions and are thus coded to EEG. That the effects occur only for cyclotron frequencies and in the amplitude windows can be understood if there is AND gate involved. The voltage signal affects the interior of the cell nucleus opening communication line to the magnetic body if a harmonic of cyclotron frequency is in question. The signal affects also the Josephson junction which sends a signal to magnetic body if the voltage of the perturbation is large enough and corresponds to a frequency in the resonance band of EEG. The response of the magnetic body affects nucleus only if the communication line is open. This AND gate eliminates very effectively the effects of neural noise.

7.4.8 Biosystems as Superconductors: Part III

This chapter is devoted to further applications of the theory of high T_c superconductors as quantum critical superconductors involving dark matter hierarchy and large values of $\hbar$. The theory is applied to explain the strange findings about ionic currents through cell membrane, exotic neutrino superconductivity and the notion of cognitive neutrino pair are discussed, and the possibility that superconductivity and Bose-Einstein condensates are involved with atmospheric phenomena is considered.

1. Strange behavior of cellular water and quantal ionic currents through cell membrane

The fact that cellular water does not leak out of cell in a centrifugal force

suggests that some fraction of water inside cell is in different phase. One explanation is that the nuclei of water inside cell are in doubly dark phase whereas electrons are in singly dark phase (having Compton length of 5 nm and perhaps directly "visible" using day technology!) as indeed predicted by the model of high Tc superconductivity. This conceptual framework could explain various findings challenging the notions of ionic pumps.

The empirical findings challenging the notions of ionic pumps and channels, nicely summarized by G. Pollack in his book, provide a strong support for the notions of many-sheeted space-time and ionic super-conductivity.

a) The selectivity of the cell membrane implies that channels cannot be simple sieves and there must be complex information processing involved.

b) The needed number of pumps specialized to particular ions is astronomical and the first question is where to put all these channels and pumps. On the other hand, if the cell constructs the pump or channel specialized to a given molecule only when needed, how does it know what the pump looks like if it has never seen the molecule? The needed metabolic energy to achieve all the pumping and channelling is huge. Strangely enough, pumping does not stop when cell metabolism stops.

c) One can also wonder why the ionic currents through cell membrane look quantal and are same through cell membrane and silicon rubber membrane.

These observations suggest strongly the presence non-dissipative ionic currents and quantum self-organization. The TGD based explanation would be in terms of high T_c electronic and possibly even ionic superconductivity associated with cell membrane made possible by the large $\hbar$ phase for nuclei and electrons in the interior of cell. It however seems that thermal stability conditions allow only protonic Cooper pairs in the model of ionic Cooper pairs based on direct generalization of the model of high T_c electronic super conductivity. This does not however mean that quantal ionic currents would be absent. This empirical input also supports a view about homeostasis as a many-sheeted ionic flow equilibrium controlled by larger space-time sheets with the mediation of massless extremals (MEs) serving as space-time correlates for Bose-Einstein condensates of massless bosons (also of scaled down dark electro-weak bosons and gluons).

In the proposed picture one can understand how extremely low densities of ions and their supra currents can control much higher ion densities at the atomic space-time sheets. The liquid crystal nature of the bio-matter is crucial for the model. This vision allows also much better understanding of the effects of ELF em fields on bio-matter. Also the effects of homeopathic remedies and acupuncture known to crucially involve electromagnetic fre-

quency signatures of chemicals can be understood if homeostasis is based on many-sheeted ionic flow equilibrium.

2. Dark Z^0 magnetic fields and cognition

Similar arguments as in the em case apply in the scale L_w=.2 μm for Z^0 magnetic transitions with scale about 10^4 eV much above the thermal energy scale. The hierarchy of length scales is now L_w=.2 μm, .4 mm, .8 m,.... L_w=.4 mm, possibly characterizing mm sized cortical modules, corresponds roughly to a frequency scale 40/A Hz, A atomic weight. The thermal stability supports the earlier idea that Z^0 force, dark neutrino superconductivity, $\nu\overline{\nu}$ wormhole contacts, and ZEG relate to cognition which must be thermally insulated whereas electromagnetic interactions would relate to sensory perception which could be highly sensitive even to temperature differences.

3. Dark neutrino super conductivity

Neutrinos play a key role in TGD based model for cognition and hearing and it is interesting to see whether this model survives the radically different interpretation of long ranged weak fields forcing to introduce large $\hbar$ variants of $k = 113$ weak bosons. The notion of cognitive neutrino pair generalizes elegantly to $\nu\overline{\nu}$ wormhole contact such that ν is dark neutrino coupling to exotic light weak bosons. The model for quantum critical electronic superconductivity discussed in previous chapter generalizes in a rather straightforward manner and together with its electronic counterpart correctly predicts and provides interpretation for the fundamental biological length scales.

A strong deviation from the previous picture is that one must however assume that the neutrinos which are most relevant for cognition correspond to $k = 127$ and mass of order .5 MeV. Quantum model of hearing, which is one of the quantitative victories of TGD inspired theory of consciousness, is not affected appreciably if one requires that the Gaussian Mersennes $k = 167, 163, 157$ label scaled down copies of charged leptons with $k = 113$ defining the mass scales of exotic weak bosons. Neutrino mass scale should be much lower than .5 eV mass of exotic electron (the metabolic energy quantum by the way) rather than .5 MeV mass scale.

The large neutrino mass scale could be understood as effective mass scale if the neutrino space-time sheets are connected by color magnetic flux tubes with $k = 127$ quarks at their ends in the same manner as nucleons form nuclear strings in TGD based model of nucleus. Also leptomesons, which have been identified as pion like bound states of color octet leptons and explain the anomalous production of electron pairs in the scattering of heavy nuclei just above Coulomb wall, could be understood as exotic

$k = 167$ lepton space-time sheets connected together by color bonds having $k = 127$ quarks at their ends. There would be quark-antiquark pair per lepton making possible color octet state.

4. Atmospheric phenomena and superconductivity

There is a considerable evidence that various electromagnetic time scales associated with the atmospheric phenomena correspond to those associated with brain functioning. If magnetic sensory canvas hypothesis holds true, this is just what is expected. In this section these phenomena are considered in more detail with the aim being to build as concrete as possible vision about the dynamics involving the dark matter Bose-Einstein condensates at super-conducting magnetic and Z^0 magnetic flux quanta.

Tornadoes and hurricanes provide the first example of self-organizing systems for which Bose-Einstein condensates of dark matter at magnetic and Z^0 magnetic flux quanta might be of relevance. Auroras represent a second phenomenon possibly involving supra currents of Cooper pairs and of exotic ions. Lightnings, sprites and elves might also involve higher levels of dark matter hierarchy. p-Adic length scale hypothesis and the hierarchy of Planck constants provide a strong grasp to these far from well-understood phenomena and allow to build rather detailed models for them as well as to gain concrete understanding about how dark matter hierarchy manifests itself in the electromagnetic phenomena at the level of atmosphere.

7.4.9 Quantum antenna hypothesis

So called massless extremals are non-vacuum extremals of both Kähler action and the EYM action serving as effective action of the theory. These extremals have cylindrical geometry and are carriers of purely classical vacuum currents and Einstein tensor, which are both light like. These vacuum currents generate coherent states of photons and gravitons with frequences coming as multiples of the basic frequency determined by the length of the microtubule. It is proposed that microtubules and other linear structures could act as quantum antennae so that coherent light is for brain same as radiowaves for us. Massless extremals associated with axonal microtubules or axons themselves could serve as waveguides for the photons of coherent light and realize the notion of neural window abstracted from the paradigm of holographic brain. Vacuum currents could be also behind the ability of the bio-systems to form representations of the external world.

There is indeed evidence for the quantum antenna hypothesis: some monocellulars are known to possess primitive microtubular vision, bio-photons

of Popp could could be generated by massless extremals and the observations of Callahan support the view that odor perception of insects relies on maserlike emissions by the odour molecules. The coherent light emitted in sonoluminescence could be generated by lightlike vacuum currents associated with regions with size given roughly by the diameter of microtubule when vapour-to-liquid phase transition occurs at the final stage of the bubble collapse. Also the observed direct transformation of kinetic energy of fluid motion to chemical energy could involve generation of massless extremals.

The lightlike boundaries of MEs have the same miraculous conformal properties as the boundary of future lightcone and MEs also allow holography in the sense of quantum gravity and string models and there are good hopes to generalize the construction of the configuration space geometry and quantum TGD to take into account the classical non-determinism of Kähler action. MEs provide a justification for the intuition that the supercanonical and superconformal symmetries of the lightcone boundary $\delta M^4_+ \times CP_2$, which are cosmological symmetries, generalize to approximate macroscopic symmetries acting on the lightlike boundaries of the space-time sheets inside future lightcone and broken only by quantum gravity. Supercanonical symmetries almost-commute with Poincare symmetries and the gigantic almost-degenerate supercanonical multiplets defined by genuinely quantum gravitational state functionals in the 'world of worlds' correspond in a well-defined sense to higher abstraction level expected to be crucial for understanding consciousness. MEs are also taylor-made for quantum holography and teleportation. Quantum holography conceptualization inspires much more detailed views about how bio-systems process information and how this information becomes conscious.

7.4.10 Wormhole magnetic fields

It is argued that two purely TGD based concepts: topological field quantization and wormhole BE condensate are fundamental for the understanding of biosystems.

1. Basic concepts

Quantum classical correspondence suggests that gauge charges and p-adic coupling constant should have space-time counterparts. The first problem is to define precisely the concepts like classical gauge charge, gauge flux, topological condensation and evaporation. The crucial ingredients in the model are so called CP_2 type extremals. The realization that # contacts (topological sum contacts and $\#_B$ contacts (join along boundaries bonds)

are accompanied by causal horizons which carry quantum numbers and allow identification as partons leads to a solution of this problem.

The partons associated with topologically condensed CP_2 type extremals carry elementary particle vacuum numbers whereas the parton pairs associated with # contacts connecting two space-time sheets with Minkowskian signature of induced metric define parton pairs. These parton pairs do not correspond to ordinary elementary particles. Gauge fluxes through # contacts can be identified as gauge charges of the partons. Gauge fluxes between space-time sheets can be transferred through # and $\#_B$ contacts concentrated near the boundaries of the smaller space-time sheet.

2. Model for topologically quantized magnetic fields

Topological field quantization replaces classical magnetic fields with bundles of flux tubes parallel to the field lines; flux tubes are cylindrical 3-surfaces with outer boundary. In particular, *"wormhole magnetic fields"* having charged wormholes situated at the boundaries of the flux tubes as their sources, are possible and are vacuum configurations in the sense that they do not contain ordinary matter at all. Since wormholes are very light particles, they suffer BE condensation, and the resulting structure is macroscopic quantum system.

If the space-time sheets associated with the wormhole magnetic field have opposite time orientation, the structure can have vanishing net energy and is thus an ideal candidate for a mindlike space-time sheet (or pair of these). These structures can be glued to the boundary of material space-time sheet and they form a cognitive local representation for the classical fields at the material space-time sheets by a direct mimicry! Thus wormhole magnetic fields and more general structures of the same kind could realize quantum physicist's version about the computer scientist's dream about universe consisting of Turing machines emulating each other.

3. Models for Comorosan effect, phantom DNA effect, and homeopathy

It is shown that the concept of wormhole magnetic field leads to a rather detailed understanding of *Comorosan effect* and *phantom DNA effect*. Homeopathy could be explained in terms of the mindlike space-time sheets mimicking the properties of the drug and left to the solution in the repeated dilution of the drug. Wormhole magnetic fields provide a quantum mechanism of control from distance, say of the control of the behavior of cell organelles by cell nucleus as well as a model for the memory of bio-system in terms of integer valued winding numbers identifiable as quantized momenta of wormhole supra currents. Wormhole magnetic fields can also represent

defects of electron and neutrino super conductors and serve as a templates for the topological condensation of ordinary matter. The fact that wormhole flux tubes are *hollow* cylinders, is in nice accordance with this idea (microtubules, axonal membranes, etc. are hollow cylinders).

4. TGD inspired model for psychokinesis

A model of psychokinesis (PK) based on the concept of wormhole magnetic field is proposed. The basic philosophy is that PK is not just some isolated exotic phenomenon but only a special case of the voluntary control of bodily motions, which we all routinely perform. The only difference is that the range of voluntary control extends over the boundaries of the body in case of PK. The conclusion is that PK phenomena must involve classical long range fields, which give for bio-systems spatial extension larger than what is visible (that is hands with which to grasp on external object!). According to TGD inspired theory of consciousness, cell, and even DNA can be conscious, and perform choices. Thus the model should also provide understanding about small scale bio-control such as the (possibly voluntary!) control of the motion of cell organelles performed by cell nucleus. There is also alternative approach to the understanding of psychokinesis based on the possibility of creation of space-time sheets having negative time orientation and negative classical energy density and one could consider the possibility that poltergeist effects could involve this mechanism. Many-sheeted space-time concept makes possible also psychokinesis based on levitation: what is needed that subsystem is able to topologically condense to a sufficiently large space-time sheet carrying very weak gravitational fields.

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