

Introduction to "TGD Inspired Theory of Consciousness"

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Contents

1	Basic Ideas of Topological Geometrodynamics (TGD)	3
1.1	Geometric Vision Very Briefly	3
1.2	Two Visions About TGD as Geometrization of Physics and Their Fusion	6
1.2.1	TGD as a Poincare Invariant Theory of Gravitation	6
1.2.2	TGD as a Generalization of the Hadronic String Model	7
1.2.3	Fusion of the Two Approaches via a Generalization of the Space-Time Concept	7
1.3	Basic Objections	8
1.3.1	Topological Field Quantization	9
1.4	Quantum TGD as Spinor Geometry of World of Classical Worlds	9
1.4.1	World of Classical Worlds	9
1.4.2	Identification of Kähler function	10
1.4.3	WCW spinor fields	10
1.4.4	The role of modified Dirac action	11
1.5	Construction of scattering amplitudes	11
1.5.1	Reduction of particle reactions to space-time topology	11
1.5.2	Construction of the counterparts of S-matrices	12
1.5.3	The notion of M-matrix	12
1.6	TGD as a generalized number theory	13
1.6.1	The Threads in the Development of Quantum TGD	13
1.6.2	Number theoretic vision very briefly	14
1.6.3	p-Adic TGD and fusion of real and p-adic physics to single coherent whole	15
1.6.4	Infinite primes	17
1.7	An explicit formula for $M^8 - H$ duality	17
1.7.1	Holography in H	17
1.7.2	Number theoretic holography in M_c^8	17
1.7.3	Can one find an explicit formula for $M^8 - H$ duality?	18

1.7.4	What could the number theoretic holography mean physically?	19
1.7.5	Twistor lift of the holography	19
1.8	Hierarchy of Planck Constants and Dark Matter Hierarchy	20
1.8.1	Dark Matter as Large \hbar Phases	20
1.8.2	Hierarchy of Planck Constants from the Anomalies of Neuroscience and Biology	21
1.8.3	Dark Matter as a Source of Long Ranged Weak and Color Fields	22
1.9	Twistors in TGD and connection with Veneziano duality	22
1.9.1	Twistor lift at space-time level	22
1.9.2	Twistor lift at the level of scattering amplitudes and connection with Veneziano duality	23
2	TGD As A Generalization Of Physics To A Theory Consciousness	26
2.1	Quantum Jump As A Moment Of Consciousness	26
2.2	Negentropy Maximization Principle (NMP)	28
2.3	The Notion Of Self	28
2.4	Relationship To Quantum Measurement Theory	29
2.5	Selves Self-Organize	30
2.6	Classical Non-Determinism Of Kähler Action	30
2.7	P-Adic Physics As Physics Of Cognition	31
2.8	P-Adic And Dark Matter Hierarchies And Hierarchy Of Selves	32
3	Quantum Biology And Quantum Neuroscience In TGD Universe	33
3.1	Basic Physical Ideas	33
3.2	Brain In TGD Universe	35
3.3	Anomalies	35
4	Bird's Eye of View about the Topics of the Book	36
4.1	The organization of "TGD Inspired Theory of Consciousness"	37
5	Sources	38
6	The contents of the book	38
6.1	PART I: BASIC IDEAS OF TGD INSPIRED THEORY OF CONSCIOUSNESS	38
6.1.1	Matter, Mind, Quantum	38
6.1.2	Negentropy Maximization Principle	40
6.1.3	Self and Binding: Part I	41
6.1.4	Self and Binding: Part II	42
6.1.5	Quantum Model for Sensory Representations	42
6.2	PART II: TIME AND CONSCIOUSNESS	44
6.2.1	Time and Consciousness	44
6.2.2	About the Nature of Time	45
6.2.3	Quantum Model of Memory	46
6.3	PART III: INTELLIGENCE, INFORMATION, AND COGNITION	47
6.3.1	Conscious Information and Intelligence	47
6.3.2	p-Adic Physics as Physics of Cognition and Imagination	49
6.4	PART IV: PARANORMAL PHENOMENA	51
6.4.1	Quantum Model of Paranormal Phenomena	51
6.4.2	TGD Based Model for OBEs	52

1 Basic Ideas of Topological Geometrodynamics (TGD)

Standard model describes rather successfully both electroweak and strong interactions but sees them as totally separate and contains a large number of parameters which it is not able to predict. For about four decades ago unified theories known as Grand Unified Theories (GUTs) trying to understand electroweak interactions and strong interactions as aspects of the same fundamental gauge interaction assignable to a larger symmetry group emerged. Later superstring models trying to unify even gravitation and strong and weak interactions emerged. The shortcomings of both GUTs and superstring models are now well-known. If TGD - whose basic idea emerged towards the end of 1977 - would emerge now it would be seen as an attempt to solve the difficulties of these approaches to unification.

The basic physical picture behind the geometric vision of TGD corresponds to a fusion of two rather disparate approaches: namely TGD as a Poincare invariant theory of gravitation and TGD as a generalization of the old-fashioned string model. After 1995 number theoretic vision started to develop and was initiated by the success of mass calculations based on p-adic thermodynamics. Number theoretic vision involves all number fields and is complementary to the geometric vision: one can say that this duality is analogous to momentum-position duality of wave mechanics. TGD can be also regarded as topological quantum theory in a very general sense as already the attribute "Topological" in "TGD" makes clear. Space-time surfaces as minimal surfaces can be regarded as representatives of homology equivalence classes and p-adic topologies generalize the notion of local topology and apply to the description of correlates of cognition.

1.1 Geometric Vision Very Briefly

T(opological) G(eometro)D(ynamics) is one of the many attempts to find a unified description of basic interactions. The development of the basic ideas of TGD to a relatively stable form took time of about half decade [K1].

The basic vision and its relationship to existing theories is now rather well understood.

1. Space-times are representable as 4-surfaces in the 8-dimensional embedding space $H = M^4 \times CP_2$, where M^4 is 4-dimensional (4-D) Minkowski space and CP_2 is 4-D complex projective space (see Appendix).
2. Induction procedure (a standard procedure in fiber bundle theory, see Appendix) allows to geometrize various fields. Space-time metric characterizing gravitational fields corresponds to the induced metric obtained by projecting the metric tensor of H to the space-time surface. Electroweak gauge potentials are identified as projections of the components of CP_2 spinor connection to the space-time surface, and color gauge potentials as projections of CP_2 Killing vector fields representing color symmetries. Also spinor structure can be induced: induced spinor gamma matrices are projections of gamma matrices of H and induced spinor fields just H spinor fields restricted to space-time surface. Spinor connection is also projected. The interpretation is that distances are measured in embedding space metric and parallel translation using spinor connection of embedding space.

Twistor lift of TGD means that one can lift space-time surfaces in H to 6-D surfaces a analogs of twistor space of space-time surface in the Cartesian product of the twistor spaces of M^4 and CP_2 , which are the only 4-manifolds allowing twistor space with Kähler structure [A7]. The twistor structure would be induced in some sense, and should coincide with that associated with the induced metric. Clearly, the 2-spheres defining the fibers of twistor spaces of M^4 and CP_2 must allow identification: this 2-sphere defines the S^2 fiber of the twistor space of the space-time surface. This poses a constraint on the embedding of the twistor space of space-time surfaces as sub-manifold in the Cartesian product of twistor spaces. The existence of Kähler structure allows to lift 4-D Kähler action to its 6-D counterparts and the 6-D counterpart of twistor space is obtained by its dimensional reduction so that one obtains a sphere bundle. This makes possible twistorialization for all space-time surfaces: in general relativity the general metric does not allow this.

3. A geometrization of quantum numbers is achieved. The isometry group of the geometry of CP_2 codes for the color gauge symmetries of strong interactions. Vierbein group codes

for electroweak symmetries, and explains their breaking in terms of CP_2 geometry so that standard model gauge group results. There are also important deviations from the standard model: color quantum numbers are not spin-like but analogous to orbital angular momentum: this difference is expected to be seen only in CP_2 scale. In contrast to GUTs, quark and lepton numbers are separately conserved and family replication has a topological explanation in terms of topology of the partonic 2-surface carrying fermionic quantum numbers.

M^4 and CP_2 are unique choices for many other reasons. For instance, they are the unique 4-D space-times allowing twistor space with Kähler structure. M^4 light-cone boundary allows a huge extension of 2-D conformal symmetries. M^4 and CP_2 allow quaternionic structures. Therefore standard model symmetries have number theoretic meaning.

4. Induced gauge potentials are expressible in terms of embedding space coordinates and their gradients and general coordinate invariance implies that there are only 4 field-like variables locally. Situation is thus extremely simple mathematically. The objection is that one loses linear superposition of fields. The resolution of the problem comes from the generalization of the concepts of particle and space-time.

Space-time surfaces can be also particle like having thus finite size. In particular, space-time regions with Euclidian signature of the induced metric (temporal and spatial dimensions in the same role) emerge and have interpretation as lines of generalized Feynman diagrams. Particles in space-time can be identified as a topological inhomogeneities in background space-time surface which looks like the space-time of general relativity in long length scales.

One ends up with a generalization of space-time surface to many-sheeted space-time with space-time sheets having extremely small distances of about 10^4 Planck lengths (CP_2 size). As one adds a particle to this kind of structure, it touches various space-time sheets and thus interacts with the associated classical fields. Their effects superpose linearly in good approximation and linear superposition of fields is replaced with that for their effects.

This resolves the basic objection. It also leads to the understanding of how the space-time of general relativity and quantum field theories emerges from TGD space-time as effective space-time when the sheets of many-sheeted space-time are lumped together to form a region of Minkowski space with metric replaced with a metric identified as the sum of empty Minkowski metric and deviations of the metrics of sheets from empty Minkowski metric. Gauge potentials are identified as sums of the induced gauge potentials. TGD is therefore a microscopic theory from which the standard model and general relativity follow as a topological simplification, however forcing a dramatic increase of the number of fundamental field variables.

5. A further objection is that classical weak fields identified as induced gauge fields are long ranged and should cause large parity breaking effects due to weak interactions. These effects are indeed observed but only in living matter. The basic problem is that one has long ranged classical electroweak gauge fields. The resolution of the problem is that the quantum averages of induced weak and color gauge fields vanish due to the fact that color rotations affect both space-time surfaces and induced weak and color fields. Only the averages of electromagnetic fields are nonvanishing. The correlations functions for weak fields are nonvanishing below Compton lengths of weak bosons. In living matter large values of effective Planck constant labelling phases of ordinary matter identified as dark matter make possible long ranged weak fields and color fields.
6. General coordinate invariance requires holography so that space-time surfaces are analogous to Bohr orbits for particles identified as 3-surfaces. Bohr orbit property would be naturally realized by a 4-D generalization of holomorphy of string world sheets and implies that the space-time surfaces are minimal surfaces apart from singularities. This holds true for any action as long as it is general coordinate invariant and constructible in terms of the induced geometry. String world sheets and light-like orbits of partonic 2-surfaces correspond to singularities at which the minimal surface property of the space-time surfaces realizing the preferred extremal property fails. Preferred extremals are not completely deterministic, which implies what I call zero energy ontology (ZEO) meaning that the Bohr orbits are the fundamental objects. This leads to a solution of the basic paradox of quantum measurement

theory. Also the mathematically ill-defined path integral disappears and leaves only the well-defined functional integral over the Bohr orbits.

7. A string model-like picture emerges from TGD and one ends up with a rather concrete view about the topological counterpart of Feynman diagrammatics. The natural stringy action would be given by the string world sheet area, which is present only in the space-time regions with Minkowskian signature. Gravitational constant could be present as a fundamental constant in string action and the ratio $\hbar/G/R^2$ would be determined by quantum criticality conditions. The hierarchy of Planck constants $\hbar_{eff}/\hbar = n$ assigned to dark matter in TGD framework would allow to circumvent the objection that only objects of length of order Planck length are possible since string tension given by $T = 1/\hbar_{eff}G$ apart from numerical factor could be arbitrary small. This would make possible gravitational bound states as partonic 2-surfaces as structures connected by strings and solve the basic problem of superstring theories. This option allows the natural interpretation of M^4 type vacuum extremals with CP_2 projection, which is Lagrange manifold as good approximations for space-time sheets at macroscopic length scales. String area does not contribute to the Kähler function at all.

Whether induced spinor fields associated with Kähler-Dirac action and de-localized inside the entire space-time surface should be allowed remains an open question: super-conformal symmetry strongly suggests their presence. A possible interpretation for the corresponding spinor modes could be in terms of dark matter, sparticles, and hierarchy of Planck constants.

It is perhaps useful to make clear what TGD is not and also what new TGD can give to physics.

1. TGD is *not* just General Relativity made concrete by using embeddings: the 4-surface property is absolutely essential for unifying standard model physics with gravitation and to circumvent the incurable conceptual problems of General Relativity. The many-sheeted space-time of TGD gives rise only at the macroscopic limit to GRT space-time as a slightly curved Minkowski space. TGD is *not* a Kaluza-Klein theory although color gauge potentials are analogous to gauge potentials in these theories.

TGD space-time is 4-D and its dimension is due to completely unique conformal properties of light-cone boundary and 3-D light-like surfaces implying enormous extension of the ordinary conformal symmetries. Light-like 3-surfaces represent orbits of partonic 2-surfaces and carry fundamental fermions at 1-D boundaries of string world sheets. TGD is *not* obtained by performing Poincare gauging of space-time to introduce gravitation and is plagued by profound conceptual problems.

2. TGD is *not* a particular string model although string world sheets emerge in TGD very naturally as loci for spinor modes: their 2-dimensionality makes among other things possible quantum deformation of quantization known to be physically realized in condensed matter, and conjectured in TGD framework to be crucial for understanding the notion of finite measurement resolution. Hierarchy of objects of dimension up to 4 emerge from TGD: this obviously means analogy with branes of super-string models.

TGD is *not* one more item in the collection of string models of quantum gravitation relying on Planck length mystics. Dark matter becomes an essential element of quantum gravitation and quantum coherence in astrophysical scales is predicted just from the assumption that strings connecting partonic 2-surfaces are responsible for gravitational bound states.

TGD is *not* a particular string model although AdS/CFT duality of super-string models generalizes due to the huge extension of conformal symmetries and by the identification of WCW gamma matrices as Noether super-charges of super-symplectic algebra having a natural conformal structure.

3. TGD is *not* a gauge theory. In TGD framework the counterparts of also ordinary gauge symmetries are assigned to super-symplectic algebra (and its Yangian [A1] [?, ?, ?]), which is a generalization of Kac-Moody algebras rather than gauge algebra and suffers a fractal hierarchy of symmetry breakings defining hierarchy of criticalities. TGD is *not* one more quantum field theory like structure based on path integral formalism: path integral is replaced

with functional integral over 3-surfaces, and the notion of classical space-time becomes an exact part of the theory. Quantum theory becomes formally a purely classical theory of WCW spinor fields: only state function reduction is something genuinely quantal.

4. TGD view about spinor fields is *not* the standard one. Spinor fields appear at three levels. Spinor modes of the embedding space are analogs of spinor modes characterizing incoming and outgoing states in quantum field theories. Induced second quantized spinor fields at space-time level are analogs of stringy spinor fields. Their modes are localized by the well-definedness of electro-magnetic charge and by number theoretic arguments at string world sheets. Kähler-Dirac action is fixed by supersymmetry implying that ordinary gamma matrices are replaced by what I call Kähler-Dirac gamma matrices - this something new. WCW spinor fields, which are classical in the sense that they are not second quantized, serve as analogs of fields of string field theory and imply a geometrization of quantum theory.
5. TGD is in some sense an extremely conservative geometrization of entire quantum physics: *no* additional structures such as gauge fields as independent dynamical degrees of freedom are introduced: Kähler geometry and associated spinor structure are enough. "Topological" in TGD should not be understood as an attempt to reduce physics to torsion (see for instance [?]) or something similar. Rather, TGD space-time is topologically non-trivial in all scales and even the visible structures of the everyday world represent non-trivial topology of space-time in the TGD Universe.
6. Twistor space - or rather, a generalization of twistor approach replacing masslessness in 4-D sense with masslessness in 8-D sense and thus allowing description of also massive particles - emerged originally as a technical tool, and its Kähler structure is possible only for $H = M^4 \times CP_2$. It however turned out that much more than a technical tool is in question. What is genuinely new is the infinite-dimensional character of the Kähler geometry making it highly unique, and its generalization to p-adic number fields to describe correlates of cognition. Also the hierarchy of Planck constants $h_{eff} = n \times h$ reduces to the quantum criticality of the TGD Universe and p-adic length scales and Zero Energy Ontology represent something genuinely new.

The great challenge is to construct a mathematical theory around these physically very attractive ideas and I have devoted the last 45 years to the realization of this dream and this has resulted in 26 online books about TGD and nine online books about TGD inspired theory of consciousness and of quantum biology.

A collection of 30 online books is now (August 2023) under preparation. The goal is to minimize overlap between the topics of the books and make the focus of a given book sharper.

1.2 Two Visions About TGD as Geometrization of Physics and Their Fusion

As already mentioned, TGD as a geometrization of physics can be interpreted both as a modification of general relativity and generalization of string models.

1.2.1 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 Minkowski space and $CP_2 = SU(3)/U(2)$ is the complex projective space of two complex dimensions [A3, A6, A2, A5].

The identification of the space-time as a sub-manifold [A4, A9] 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.

It soon however turned out that sub-manifold 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 electro-weak 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 electro-weak, color gauge fields and metric in X^4 .

The choice of H is unique from the condition that TGD has standard model symmetries. Also number theoretical vision selects $H = M^4 \times CP_2$ uniquely. M^4 and CP_2 are also unique spaces allowing twistor space with Kähler structure.

1.2.2 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.

This decay vertex does not however correspond to a direct generalization of trouser vertex of string models. Indeed, the important difference between TGD and string models is that the analogs of string world sheet diagrams do not describe particle decays but the propagation of particles via different routes. Particle reactions are described by generalized Feynman diagrams for which 3-D light-like surface describing particle propagating join along their ends at vertices. As 4-manifolds the space-time surfaces are therefore singular like Feynman diagrams as 1-manifolds.

Quite recently, it has turned out that fermionic strings inside space-time surfaces define an exact part of quantum TGD and that this is essential for understanding gravitation in long length scales. Also the analog of AdS/CFT duality emerges in that the Kähler metric can be defined either in terms of Kähler function identifiable as Kähler action assignable to Euclidian space-time regions or Kähler action + string action assignable to Minkowskian regions.

The recent view about construction of scattering amplitudes is very “stringy”. By strong form of holography string world sheets and partonic 2-surfaces provide the data needed to construct scattering amplitudes. Space-time surfaces are however needed to realize quantum-classical correspondence necessary to understand the classical correlates of quantum measurement. There is a huge generalization of the duality symmetry of hadronic string models.

The proposal is that scattering amplitudes can be regarded as sequences of computational operations for the Yangian of super-symplectic algebra. Product and co-product define the basic vertices and realized geometrically as partonic 2-surfaces and algebraically as multiplication for the elements of Yangian identified as super-symplectic Noether charges assignable to strings. Any computational sequences connecting given collections of algebraic objects at the opposite boundaries of causal diamond (CD) produce identical scattering amplitudes.

1.2.3 Fusion of the Two Approaches via a Generalization of the Space-Time Concept

The problem is that the two approaches to TGD 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 could be “vapor phase” that is a “gas” of particle like 3-surfaces and string like objects (counterpart of the “baby universes” of GRT) and the non-conservation of energy in GRT corresponds to the transfer of energy between different sheets of the space-time and possible existence vapour phase.

. What one obtains is what I have christened as many-sheeted space-time (see **Fig.** <http://tgdtheory.fi/appfigures/manysheeted.jpg> or **Fig. ??** in the appendix of this book). One particular aspect is topological field quantization meaning that various classical fields assignable to a physical system correspond to space-time sheets representing the classical fields to that particular system. One can speak of the field body of a particular physical system. Field body consists of topological light rays, and electric and magnetic flux quanta. In Maxwell's theory the physical system does not possess this kind of field identity. The notion of the magnetic body is one of the key players in TGD inspired theory of consciousness and quantum biology. The existence of monopole flux tubes requiring no current as a source of the magnetic field makes it possible to understand the existence of magnetic fields in cosmological and astrophysical scales.

This picture became more detailed with the advent of zero energy ontology (ZEO). The basic notion of ZEO is causal diamond (CD) identified as the Cartesian product of CP_2 and of the intersection of future and past directed light-cones and having scale coming as an integer multiple of CP_2 size is fundamental. CDs form a fractal hierarchy and zero energy states decompose to products of positive and negative energy parts assignable to the opposite boundaries of CD defining the ends of the space-time surface. The counterpart of zero energy state in positive energy ontology is the pair of initial and final states of a physical event, say particle reaction.

At space-time level ZEO means that 3-surfaces are pairs of space-like 3-surfaces at the opposite light-like boundaries of CD. Since the extremals of Kähler action connect these, one can say that by holography the basic dynamical objects are the space-time surface connecting these 3-surfaces and identifiable as analogs of Bohr orbits. This changes totally the vision about notions like self-organization: self-organization by quantum jumps does not take for a 3-D system but for the entire 4-D field pattern associated with it.

General Coordinate Invariance (GCI) allows to identify the basic dynamical objects as space-like 3-surfaces at the ends of space-time surface at boundaries of CD: this means that space-time surface is analogous to Bohr orbit. An alternative identification of the lines of generalized Feynman diagrams is as light-like 3-surfaces at which the signature of the induced metric changes from Minkowskian to Euclidian. Also the Euclidian 4-D regions can have a similar interpretation. The requirement that the two interpretations are equivalent, leads to a strong form of General Coordinate Invariance. The outcome is effective 2-dimensionality stating that the partonic 2-surfaces identified as intersections of the space-like ends of space-time surface and light-like wormhole throats are the fundamental objects. That only effective 2-dimensionality is in question is due to the effects caused by the failure of strict determinism of Kähler action. In finite length scale resolution these effects can be neglected below UV cutoff and above IR cutoff. One can also speak about a strong form of holography.

The understanding of the super symplectic invariance leads to the proposal that super symplectic algebra and other Kac-Moody type algebras labelled by non-negative multiples of basic conformal weights allow a hierarchy of symmetry breakings in which the analog of gauge symmetry breaks down to a genuine dynamical symmetry. This gives rise to fractal hierarchies of algebras and symmetry breakings. This breaking can occur also for ordinary conformal algebras if one restricts the conformal weights to be non-negative integers.

1.3 Basic Objections

Objections are the most powerful tool in theory building. The strongest objection against TGD is the observation that all classical gauge fields are expressible in terms of four embedding space coordinates only- essentially CP_2 coordinates. The linear superposition of classical gauge fields taking place independently for all gauge fields is lost. This would be a catastrophe without many-sheeted space-time. Instead of gauge fields, only the effects such as gauge forces are superposed. Particles topologically condense to several space-time sheets simultaneously and experience the sum of gauge forces. This transforms the weakness to extreme economy: in a typical unified theory the number of primary field variables is countered in hundreds if not thousands, now it is just four.

Second objection is that TGD space-time is quite too simple as compared to GRT space-time due to the embeddability to 8-D embedding space. One can also argue that Poincare invariant theory of gravitation cannot be consistent with General Relativity. The above interpretation makes it possible to understand the relationship to GRT space-time and how the Equivalence Principle

(EP) follows from Poincare invariance of TGD. The interpretation of GRT space-time is as effective space-time obtained by replacing many-sheeted space-time with Minkowski space with effective metric determined as a sum of Minkowski metric and sum over the deviations of the induced metrics of the space-time sheets from Minkowski metric. Poincare invariance strongly suggests classical EP for the GRT limit in long length scales at least. One can also consider other kinds of limits such as the analog of GRT limit for Euclidian space-time regions assignable to elementary particles. In this case deformations of CP_2 metric define a natural starting point and CP_2 indeed defines a gravitational instanton with a very large cosmological constant in Einstein-Maxwell theory. Also gauge potentials of the standard model correspond classically to superpositions of induced gauge potentials over space-time sheets.

1.3.1 Topological Field Quantization

Topological field quantization distinguishes between TGD based and more standard - say Maxwellian - notion of field. In Maxwell's fields created by separate systems superpose and one cannot tell which part of field comes from which system except theoretically. In TGD these fields correspond to different space-time sheets and only their effects on test particle superpose. Hence physical systems have well-defined field identifies - field bodies - in particular magnetic bodies.

The notion of magnetic body carrying dark matter with non-standard large value of Planck constant has become central concept in TGD inspired theory of consciousness and living matter, and by starting from various anomalies of biology one ends up to a rather detailed view about the role of magnetic body as intentional agent receiving sensory input from the biological body and controlling it using EEG and its various scaled up variants as a communication tool. Among other things this leads to models for cell membrane, nerve pulse, and EEG.

1.4 Quantum TGD as Spinor Geometry of World of Classical Worlds

A turning point in the attempts to formulate a mathematical theory was reached after seven years from the birth of TGD. 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 have been the following ones.

1.4.1 World of Classical Worlds

The notion of WCW reduces the interacting quantum theory to a theory of free WCW spinor fields.

1. Quantum theory for extended particles is free(!), classical(!) field theory for a generalized Schrödinger amplitude identified as WCW spinor in the configuration space CH ("world of classical worlds", WCW) 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.
2. 4-D general coordinate invariance forces holography and replaces the ill-defined path integral over all space-time surfaces with a discrete sum over 4-D analogs of Bohr orbits for particles identified as 3-surfaces. Holography means that basic objects are these analogs of Bohr orbits. Since there is no quantization at the level of WCW, one has an analog of wave mechanics with point-like particles replaced with 4-D Bohr orbits.
3. One must geometrize WCW as the space of Bohr orbits. In an infinite-dimensional situation the existence of geometry requires maximal symmetries already in the case of loop spaces. Physics is unique from its mathematical existence.

WCW is endowed with metric and spinor structure so that one can define various metric related differential operators, say Dirac operators, appearing in the field equations of the theory ¹

¹There are four kinds of Dirac operators in TGD. The geometrization of quantum theory requires Kähler metric definable either in terms of Kähler function identified as a the bosonic action for Euclidian space-time regions

1.4.2 Identification of Kähler function

The evolution of these basic ideas has been rather slow but has gradually led to a rather beautiful vision. One of the key problems has been the definition of Kähler function. Kähler function is Kähler action for a preferred extremal assignable to a given 3-surface but what this preferred extremal is? The obvious first guess was as absolute minimum of Kähler action but could not be proven to be right or wrong. One big step in the progress was boosted by the idea that TGD should reduce to almost topological QFT in which braids would replace 3-surfaces in finite measurement resolution, which could be inherent property of the theory itself and imply discretization at partonic 2-surfaces with discrete points carrying fermion number.

It took long time to realize that there is no discretization in 4-D sense - this would lead to difficulties with basic symmetries. Rather, the discretization occurs for the parameters characterizing co-dimension 2 objects representing the information about space-time surface so that they belong to some algebraic extension of rationals. These 2-surfaces - string world sheets and partonic 2-surfaces - are genuine physical objects rather than a computational approximation. Physics itself approximates itself, one might say! This is of course nothing but strong form of holography.

1. TGD as almost topological QFT vision suggests that Kähler action for preferred extremals reduces to Chern-Simons term assigned with space-like 3-surfaces at the ends of space-time (recall the notion of causal diamond (CD)) and with the light-like 3-surfaces at which the signature of the induced metric changes from Minkowskian to Euclidian. Minkowskian and Euclidian regions would give at wormhole throats the same contribution apart from coefficients and in Minkowskian regions the $\sqrt{g_4}$ factor coming from metric would be imaginary so that one would obtain sum of real term identifiable as Kähler function and imaginary term identifiable as the ordinary Minkowskian action giving rise to interference effects and stationary phase approximation central in both classical and quantum field theory.

Imaginary contribution - the presence of which I realized only after 33 years of TGD - could also have topological interpretation as a Morse function. On physical side the emergence of Euclidian space-time regions is something completely new and leads to a dramatic modification of the ideas about black hole interior.

2. The way to achieve the reduction to Chern-Simons terms is simple. The vanishing of Coulomb contribution to Kähler action is required and is true for all known extremals if one makes a general ansatz about the form of classical conserved currents. The so called weak form of electric-magnetic duality defines a boundary condition reducing the resulting 3-D terms to Chern-Simons terms. In this way almost topological QFT results. But only "almost" since the Lagrange multiplier term forcing electric-magnetic duality implies that Chern-Simons action for preferred extremals depends on metric.

1.4.3 WCW spinor fields

Classical WCW spinor fields are analogous to Schrödinger amplitudes and the construction of WCW Kähler geometry reduces to the second quantization of free spinor fields of H .

1. The WCW metric is given by anticommutators of WCW gamma matrices which also have interpretation as supercharges assignable to the generators of WCW isometries and allowing expression as non-conserved Noether charges. Holography implies zero energy ontology (ZEO) meaning that zero energy states are superpositions of Bohr orbits connecting boundaries of causal diamond (CD). CDs form a fractal hierarchy and their space forming the spine of WCW is finite-dimensional and can be geometrized. The alternative interpretation is as a superposition of pairs of ordinary 3-D fermionic states assignable to the ends of the space-time surfaces.

2. There are several Dirac operators. WCW Dirac operator D_{WCW} appears in Super-symplectic gauge conditions analogous to Super Virasoro conditions. The algebraic variant of the H

or as anti-commutators for WCW gamma matrices identified as conformal Noether super-charges associated with the second quantized modified Dirac action consisting of string world sheet term and possibly also modified Dirac action in Minkowskian space-time regions. These two possible definitions reflect a duality analogous to AdS/CFT duality.

Dirac operator D_H appears in fermionic correlation functions: this is due to the fact that free fermions appearing as building bricks of WCW gamma matrices are modes of D_H . The modes of D_H define the ground states of super-symplectic representations. There is also the modified Dirac operator D_{X^4} acting on the induced spinors at space-time surfaces and it is dictated by symmetry one the action fixing the space-time surfaces as Bohr orbits is fixed. D_H is needed since it determines the expressions of WCW gamma matrices as Noether charges assignable to 3-surfaces at the ends of WCW.

1.4.4 The role of modified Dirac action

1. By quantum classical correspondence, the construction of WCW spinor structure in sectors assignable to CDs reduces to the second quantization of the induced spinor fields of H . The basic action is so called modified Dirac action in which gamma matrices are replaced with the modified gamma matrices defined as contractions of the canonical momentum currents of the bosonic action defining the space-time surfaces with the embedding space gamma matrices. In this way one achieves super-conformal symmetry and conservation of fermionic currents among other things and a consistent Dirac equation.

Modified Dirac action is needed to define WCW gamma matrices as super charges assignable to WCW isometry generators identified as generators of symplectic transformations and by holography are needed only at the 3-surface at the boundaries of WCW. It is important to notice that the modified Dirac equation does not determine propagators since induced spinor fields are obtained from free second quantized spinor fields of H . This means enormous simplification and makes the theory calculable.

2. An important interpretational problem relates to the notion of the induced spinor connection. The presence of classical W boson fields is in conflict with the classical conservation of em charge since the coupling to classical W fields changes em charge.

One way out of the problem is the fact that the quantum averages of weak and gluon fields vanish unlike the quantum average of the em field. This leads to a rather precise understanding of electroweak symmetry breaking as being due the fact that color symmetries rotate space-time surfaces and also affect the induced weak fields.

One can also consider a stronger condition. If one requires that the spinor modes have well-defined em charge, one must assume that the modes in the generic situation are localized at 2-D surfaces - string world sheets or perhaps also partonic 2-surfaces - at which classical W boson fields vanish. Covariantly constant right handed neutrinos generating super-symmetries forms an exception. The vanishing of the Z^0 field is possible for Kähler-Dirac action and should hold true at least above weak length scales. This implies that the string model in 4-D space-time becomes part of TGD. Without these conditions classical weak fields can vanish above weak scale only for the GRT limit of TGD for which gauge potentials are sums over those for space-time sheets.

The localization would simplify the mathematics enormously and one can solve exactly the Kähler-Dirac equation for the modes of the induced spinor field just like in super string models.

At the light-like 3-surfaces the signature of the induced metric changes from Euclidian to Minkowskian so that $\sqrt{g_4}$ vanishes. One can pose the condition that the algebraic analog of the massless Dirac equation is satisfied by the modes of the modified-Dirac action assignable to the Chern-Simons-Kähler action.

1.5 Construction of scattering amplitudes

1.5.1 Reduction of particle reactions to space-time topology

Particle reactions are identified as topology changes [A8, A10, A11]. For instance, the decay of a 3-surface to two 3-surfaces corresponds to the decay $A \rightarrow B+C$. Classically this corresponds to a path of WCW 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.

During years this naïve and very rough vision has of course developed a lot and is not anymore quite equivalent with the original insight. In particular, the space-time correlates of Feynman graphs have emerged from theory as Euclidian space-time regions and the strong form of General Coordinate Invariance has led to a rather detailed and in many respects un-expected visions. This picture forces to give up the idea about smooth space-time surfaces and replace space-time surface with a generalization of Feynman diagram in which vertices represent the failure of manifold property. I have also introduced the word “world of classical worlds” (WCW) instead of rather formal “configuration space”. I hope that “WCW” does not induce despair in the reader having tendency to think about the technicalities involved!

1.5.2 Construction of the counterparts of S-matrices

What does one mean with the counterpart of S-matrix in the TGD framework has been a long standing problem. The development of ZEO based quantum measurement theory has led to a rough overall view of the situation.

1. There are two kinds of state function reductions (SFRs). ”Small” SFRs (SSFRs) following the TGD counterpart of a unitary time evolution defines a sequence of SFRs, which is analogous to a sequence of repeated quantum measurements associated with the Zeno effect. In wave mechanics nothing happens in these measurements. In quantum optics these measurements correspond to weak measurements. In TGD SSFR affects the zero energy state but leaves the 3-D state at the passive boundary of CD unaffected.
2. In TGD framework each SSFR is preceded by a counterpart of a unitary time evolution, which means dispersion in the space of CDs and unitary time evolution in fermionic degrees of freedom such that the passive boundary of CDs and 3-D states at it are unaffected but a superposition of CDs with varying active boundaries in the space of CDs is formed. In SSFR a localization in the space of CDs occurs such that the active is fixed. In a statistical sense the size of the CD increases and the increasing distance between the tips of the CD gives rise to the arrow of geometric time.
3. Also ”big” SFRs (BSFRs) can occur and they correspond to ordinary SFRs. In BSFR the roles of the active and passive boundary are changed and this means that the arrow of time is changed. Big SFR occurs when the SSFR corresponds to a quantum measurement, which does not commute with the operators, which define the states at the passive boundary of CD as their eigenstates. This means a radical deviation from standard quantum measurement theory and has predictions in all scales.
4. One can assign the counterpart of S-matrix to the unitary time evolution between two subsequent SSFRs and also to the counterpart of S-matrix associated with BSFR. At least in the latter case the dimension of the state space can increase since at least BSFRs lead to the increase of the dimension of algebraic extension of rationals assignable to the space-time surface by $M^8 - H$ duality. Unitarity is therefore replaced with isometry.
5. I have also considered the possibility that unitary S-matrix could be replaced in the fermionic degrees of freedom with Kähler metric of the state space satisfying analogs of unitarity conditions but it seems that this is un-necessary and also too outlandish an idea.

1.5.3 The notion of M-matrix

1. The most ambitious dream is that zero energy states correspond to a complete solution basis for the Dirac operators associated with WCWs associated with the spaces of CDs with fixed passive boundary: this would define an S-matrix assignable to SFR. Also the analog of S-matrix for the localizations of the states to the active boundary assignable to the BSFR changing the state at the passive boundary of CD is needed.

2. If one allows entanglement between positive and energy parts of the zero energy state but assumes that the states at the passive boundary are fixed, one must introduce the counterpart of the density matrix, or rather its square root. This classical free field theory would dictate what I have called M-matrices defined between positive and negative energy parts of zero energy states which form orthonormal rows of what I call U-matrix as a matrix defined between zero energy states. A given M-matrix in turn would decompose to a product of a hermitian square root of density matrix and unitary S-matrix.
3. M-matrix would define time-like entanglement coefficients between positive and negative energy parts of zero energy states (all net quantum numbers vanish for them) and can be regarded as a hermitian square root of density matrix multiplied by a unitary S-matrix. Quantum theory would be in a well-defined sense a square root of thermodynamics. The orthogonality and hermiticity of the M-matrices commuting with S-matrix means that they span infinite-dimensional Lie algebras acting as symmetries of the S-matrix. Therefore quantum TGD would reduce to group theory in a well-defined sense.
4. In fact the Lie algebra of Hermitian M-matrices extends to Kac-Moody type algebra obtained by multiplying hermitian square roots of density matrices with powers of the S-matrix. Also the analog of Yangian algebra involving only non-negative powers of S-matrix is possible and would correspond to a hierarchy of CDs with the temporal distances between tips coming as integer multiples of the CP_2 time.

The M-matrices associated with CDs are obtained by a discrete scaling from the minimal CD and characterized by integer n are naturally proportional to a representation matrix of scaling: $S(n) = S^n$, where S is unitary S-matrix associated with the minimal CD [K13]. This conforms with the idea about unitary time evolution as exponent of Hamiltonian discretized to integer power of S and represented as scaling with respect to the logarithm of the proper time distance between the tips of CD.

5. I have also considered the notion of U-matrix. U-matrix elements between M-matrices for various CDs are proportional to the inner products $Tr[S^{-n_1} \circ H^i H^j \circ S^{n_2} \lambda]$, where λ represents unitarily the discrete Lorentz boost relating the moduli of the active boundary of CD and H^i form an orthonormal basis of Hermitian square roots of density matrices. \circ tells that S acts at the active boundary of CD only. I have proposed a general representation for the U-matrix, reducing its construction to that of the S-matrix.

1.6 TGD as a generalized number theory

Quantum T(opological)D(ynamics) as a classical spinor geometry for infinite-dimensional configuration space (“world of classical worlds”, WCW), 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. The fourth thread deserves the name “TGD as a generalized number theory”. It involves three separate threads: the fusion of real and various p-adic physics to a single coherent whole by requiring number theoretic universality discussed already, the formulation of quantum TGD in terms of complexified counterparts of classical number fields, and the notion of infinite prime. Note that one can identify subrings such as hyper-quaternions and hyper-octonions as sub-spaces of complexified classical number fields with Minkowskian signature of the metric defined by the complexified inner product.

1.6.1 The Threads in the Development of Quantum TGD

The development of TGD has involved several strongly interacting threads: physics as infinite-dimensional geometry; TGD as a generalized number theory, the hierarchy of Planck constants interpreted in terms of dark matter hierarchy, and TGD inspired theory of consciousness. In the following these threads are briefly described.

1. Quantum T(opological) G(eometro)D(ynamics) as a classical spinor geometry for infinite-dimensional WCW, p-adic numbers and quantum TGD, and TGD inspired theory of consciousness and of quantum biology have been for last decade of the second millenium the basic three strongly interacting threads in the tapestry of quantum TGD.

2. The discussions with Tony Smith initiated a fourth thread which deserves the name “TGD as a generalized number theory”. The basic observation was that classical number fields might allow a deeper formulation of quantum TGD. The work with Riemann hypothesis made time ripe for realization that the notion of infinite primes could provide, not only a reformulation, but a deep generalization of quantum TGD. This led to a thorough and rather fruitful revision of the basic views about what the final form and physical content of quantum TGD might be. Together with the vision about the fusion of p-adic and real physics to a larger coherent structure these sub-threads fused to the “physics as generalized number theory” thread.
3. A further thread emerged from the realization that by quantum classical correspondence TGD predicts an infinite hierarchy of macroscopic quantum systems with increasing sizes, that it is not at all clear whether standard quantum mechanics can accommodate this hierarchy, and that a dynamical quantized Planck constant might be necessary and strongly suggested by the failure of strict determinism for the fundamental variational principle. The identification of hierarchy of Planck constants labelling phases of dark matter would be natural. This also led to a solution of a long standing puzzle: what is the proper interpretation of the predicted fractal hierarchy of long ranged classical electro-weak and color gauge fields. Quantum classical correspondences allows only single answer: there is infinite hierarchy of p-adically scaled up variants of standard model physics and for each of them also dark hierarchy. Thus TGD Universe would be fractal in very abstract and deep sense.

The chronology based identification of the threads is quite natural but not logical and it is much more logical to see p-adic physics, the ideas related to classical number fields, and infinite primes as sub-threads of a thread which might be called “physics as a generalized number theory”. In the following I adopt this view. This reduces the number of threads to three corresponding to geometric, number theoretic and topological views of physics.

TGD forces the generalization of physics to a quantum theory of consciousness, and TGD as a generalized number theory vision leads naturally to the emergence of p-adic physics as physics of cognitive representations.

1.6.2 Number theoretic vision very briefly

Number theoretic vision about quantum TGD involves notions like adelic physics, $M^8 - H$ duality and number theoretic universality. A short review of the basic ideas that have developed during years is in order.

1. The physical interpretation of M^8 is as an analog of momentum space and $M^8 - H$ duality is analogous to momentum-position duality of ordinary wave mechanics.
2. Adelic physics means that all classical number fields, all p-adic number fields and their extensions induced by extensions of rationals and defining adeles, and also finite number fields are basic mathematical building bricks of physics.

The complexification of M^8 , identified as complexified octonions, would provide a realization of this picture and $M^8 - H$ duality would map the algebraic physics in M^8 to the ordinary physics in $M^4 \times CP_2$ described in terms of partial differential equations.

3. Negentropy Maximization Principle (NMP) states that the conscious information assignable with cognition representable measured in terms of p-adic negentropy increases in statistical sense.

NMP is mathematically completely analogous to the second law of thermodynamics and number theoretic evolution as an unavoidable statistical increase of the dimension of the algebraic extension of rationals characterizing a given space-time region implies it. There is no paradox involved: the p-adic negentropy measures the conscious information assignable to the entanglement of two systems regarded as a conscious entity whereas ordinary entropy measures the lack of information about the quantum state of either entangled system.

4. Number theoretical universality requires that space-time surfaces or at least their $M^8 - H$ duals in M_c^8 are defined for both reals and various p-adic number fields. This is true if they are

defined by polynomials with integer coefficients as surfaces in M^8 obeying number theoretic holography realized as associativity of the normal space of 4-D surface using as holographic data 3-surfaces at mass shells identified in terms of roots of a polynomial. A physically motivated additional condition is that the coefficients of the polynomials are smaller than their degrees.

5. Galois confinement is a key piece of the number theoretic vision. It states that the momenta of physical states are algebraic integers in the extensions of rationals assignable to the space-time region considered. These numbers are in general complex and are not consistent with particle in box quantization. The proposal is that physical states satisfy Galois confinement being thus Galois singlets and having therefore total momenta, whose components are ordinary integers, when momentum unit defined by the scale of causal diamond (CD) is used.
6. The notion of p-adic prime was introduced in p-adic mass calculations that started the developments around 1995. p-Adic length scale hypothesis states that p-adic primes near powers of 2 have a special physical role (as possibly also the powers of other small primes such as $p = 3$).

The proposal is that p-adic primes correspond to ramified primes assignable to the extension and identified as divisors of the polynomial defined by the products of the root differences for the roots of the polynomial defining space-time space and having interpretation as values of, in general complex, virtual mass squared.

1.6.3 p-Adic TGD and fusion of real and p-adic physics to single coherent whole

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 successful 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 favored position. Why this is the case, became one of the key puzzles 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.

In string model context one tries to reduce the physics to Planck scale. The price is the inability to say anything about physics in long length scales. In TGD p-adic physics takes care of this shortcoming by predicting the physics also in long length scales.

There were many interpretational and technical questions crying for a definite answer.

1. 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 WCW? Certainly the p-adicization at the level of super-conformal representation is necessary for the p-adic mass calculations.

2. 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. Quite recently I however learned that the problem of making sense about p-adic integration has been for decades central problem in the frontier of mathematics and a lot of profound work has been done along same intuitive lines as I have proceeded in TGD framework. The basic idea is certainly the notion of algebraic continuation from the world of rationals belonging to the intersection of real world and various p-adic worlds.

Despite various uncertainties, the number of the applications of the poorly defined p-adic physics has grown 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.

The key challenge is to fuse various p-adic physics and real physics to single larger structure. This has inspired a proposal for a generalization of the notion of number field by fusing real numbers and various p-adic number fields and their extensions along rationals and possible common algebraic numbers. This leads to a generalization of the notions of embedding space and space-time concept and one can speak about real and p-adic space-time sheets. One can talk about adelic space-time, embedding space, and WCW.

The corresponds of real 4-surfaces with the p-adic ones is induced by number theoretical discretization using points of 4-surfaces $Y^4 \subset M_c^8$ identifiable as 8-momenta, whose components are assumed to be algebraic integers in an extension of rationals defined by the extension of rationals associated with a polynomial P with integer coefficients smaller than the degree of P . These points define a cognitive representation, which is universal in the sense that it exists also in the algebraic extensions of p-adic numbers. The points of the cognitive representations associated with the mass shells with mass squared values identified as roots of P are enough since $M^8 - H$ duality can be used at both M^8 and H sides and also in the p-adic context. The mass shells are special in that they allow for Minkowski coordinates very large cognitive representations unlike the interiors of the 4-surfaces determined by holography by using the data defined by the 3-surfaces at the mass shells. The higher the dimension of the algebraic extension associated with P , the better the accuracy of the cognitive representation.

Adelization providing number theoretical universality reduces to algebraic continuation for the amplitudes from this intersection of reality and various p-adicities - analogous to a back of a book - to various number fields. There are no problems with symmetries but canonical identification is needed: various group invariant of the amplitude are mapped by canonical identification to various p-adic number fields. This is nothing but a generalization of the mapping of the p-adic mass squared to its real counterpart in p-adic mass calculations.

This leads to surprisingly detailed predictions and far reaching conjectures. For instance, the number theoretic generalization of entropy concept allows negentropic entanglement central for the applications to living matter (see **Fig.** <http://tgdtheory.fi/appfigures/cat.jpg> or **Fig. ??** in the appendix of this book). One can also understand how preferred p-adic primes could emerge as so called ramified primes of algebraic extension of rationals in question and characterizing string world sheets and partonic 2-surfaces. Preferred p-adic primes would be ramified primes for extensions for which the number of p-adic continuations of two-surfaces to space-time surfaces (imaginings) allowing also real continuation (realization of imagination) would be especially large. These ramifications would be winners in the fight for number theoretical survival. Also a generalization of p-adic length scale hypothesis emerges from NMP [K12].

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 a 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 encouraged by TGD inspired theory of consciousness clarifies difficult interpretational issues and provides a clear interpretation for the predictions of p-adic physics.

1.6.4 Infinite primes

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.

After the realization that infinite primes can be mapped to polynomials possibly 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 algebraic physics as various completions of the algebraic extensions of complexified quaternions and octonions. Complete algebraic, topological and dimensional democracy would characterize the theory.

The infinite primes at the first level of hierarchy, which represent analogs of bound states, can be mapped to irreducible polynomials, which in turn characterize the algebraic extensions of rationals defining a hierarchy of algebraic physics continuable to real and p-adic number fields. The products of infinite primes in turn define more general algebraic extensions of rationals. The interesting question concerns the physical interpretation of the higher levels in the hierarchy of infinite primes and integers mappable to polynomials of $n > 1$ variables.

1.7 An explicit formula for $M^8 - H$ duality

$M^8 - H$ duality is a generalization of momentum-position duality relating the number theoretic and geometric views of physics in TGD and, despite that it still involves poorly understood aspects, it has become a fundamental building block of TGD. One has 4-D surfaces $Y^4 \subset M_c^8$, where M_c^8 is complexified M^8 having interpretation as an analog of complex momentum space and 4-D spacetime surfaces $X^4 \subset H = M^4 \times CP_2$. M_c^8 , equivalently E_c^8 , can be regarded as complexified octonions. M_c^8 has a subspace M_c^4 containing M^4 .

Comment: One should be very cautious with the meaning of "complex". Complexified octonions involve a complex imaginary unit i commuting with the octonionic imaginary units I_k . i is assumed to also appear as an imaginary unit also in complex algebraic numbers defined by the roots of polynomials P defining holographic data in M_c^8 .

In the following $M^8 - H$ duality and its twistor lift are discussed and an explicit formula for the dualities are deduced. Also possible variants of the duality are discussed.

1.7.1 Holography in H

$X^4 \subset H$ satisfies holography and is analogous to the Bohr orbit of a particle identified as a 3-surface. The proposal is that holography reduces to a 4-D generalization of holomorphy so that X^4 is a simultaneous zero of two functions of complex CP_2 coordinates and of what I have called Hamilton-Jacobi coordinates of M^4 with a generalized Kähler structure.

The simplest choice of the Hamilton-Jacobi coordinates is defined by the decomposition $M^4 = M^2 \times E^2$, where M^2 is endowed with hypercomplex structure defined by light-like coordinates (u, v) , which are analogous to z and \bar{z} . Any analytic map $u \rightarrow f(u)$ defines a new set of light-like coordinates and corresponds to a solution of the massless d'Alembert equation in M^2 . E^2 has some complex coordinates with imaginary unit defined by i .

The conjecture is that also more general Hamilton-Jacobi structures for which the tangent space decomposition is local are possible. Therefore one would have $M^4 = M^2(x) \times E^2(x)$. These would correspond to non-equivalent complex and Kähler structures of M^4 analogous to those possessed by 2-D Riemann surfaces and parametrized by moduli space.

1.7.2 Number theoretic holography in M_c^8

$Y^4 \subset M_c^8$ satisfies number theoretic holography defining dynamics, which should reduce to associativity in some sense. The Euclidian complexified normal space $N^4(y)$ at a given point y of Y^4 is required to be associative, i.e. quaternionic. Besides this, $N^4(i)$ contains a preferred complex Euclidian 2-D subspace $Y^2(y)$. Also the spaces $Y^2(x)$ define an integrable distribution. I have assumed that $Y^2(x)$ can depend on the point y of Y^4 .

These assumptions imply that the normal space $N(y)$ of Y^4 can be parameterized by a point of $CP_2 = SU(3)/U(2)$. This distribution is always integrable unlike quaternionic tangent space

distributions. $M^8 - H$ duality assigns to the normal space $N(y)$ a point of CP_2 . M_c^4 point y is mapped to a point $x \in M^4 \subset M^4 \times CP_2$ defined by the real part of its inversion (conformal transformation): this formula involves effective Planck constant for dimensional reasons.

The 3-D holographic data, which partially fixes 4-surfaces Y^4 is partially determined by a polynomial P with real integer coefficients smaller than the degree of P . The roots define mass squared values which are in general complex algebraic numbers and define complex analogs of mass shells in $M_c^4 \subset M_c^8$, which are analogs of hyperbolic spaces H^3 . The 3-surfaces at these mass shells define 3-D holographic data continued to a surface Y^4 by requiring that the normal space of Y^4 is associative, i.e. quaternionic. These 3-surfaces are not completely fixed but an interesting conjecture is that they correspond to fundamental domains of tessellations of H^3 .

What does the complexity of the mass shells mean? The simplest interpretation is that the space-like M^4 coordinates (3-momentum components) are real whereas the time-like coordinate (energy) is complex and determined by the mass shell condition. One would have $Re^2(E) - Im(E)^2 - p^2 = Re(m^2)$ and $2Re(E)Im(E) = Im(m^2)$. The condition for the real parts gives H^3 when $\sqrt{Re^2(E) - Im(E)^2}$ is taken as a time coordinate. The second condition allows to solve $Im(E)$ in terms of $Re(E)$ so that the first condition reduces to an equation of mass shell when $\sqrt{(Re(E)^2 - Im(E)^2)}$, expressed in terms of $Re(E)$, is taken as new energy coordinate $E_{eff} = \sqrt{(Re(E)^2 - Im(E)^2)}$. Is this deformation of H^3 in imaginary time direction equivalent with a region of the hyperbolic 3-space H^3 ?

One can look at the formula in more detail. Mass shell condition gives $Re^2(E) - Im(E)^2 - p^2 = Re(m^2)$ and $2Re(E)Im(E) = Im(m^2)$. The condition for the real parts gives H^3 , when $\sqrt{Re^2(E) - Im(E)^2}$ is taken as an effective energy. The second condition allows to solve $Im(E)$ in terms of $Re(E)$ so that the first condition reduces to a dispersion relation for $Re(E)^2$.

$$Re(E)^2 = \frac{1}{2}(Re(m^2) - Im(m^2) + p^2)(1 \pm \sqrt{1 + \frac{2Im(m^2)^2}{(Re(m^2) - Im(m^2) + p^2)^2}}). \quad (1.1)$$

Only the positive root gives a non-tachyonic result for $Re(m^2) - Im(m^2) > 0$. For real roots with $Im(m^2) = 0$ and at the high momentum limit the formula coincides with the standard formula. For $Re(m^2) = Im(m^2)$ one obtains $Re(E)^2 \rightarrow Im(m^2)/\sqrt{2}$ at the low momentum limit $p^2 \rightarrow 0$. Energy does not depend on momentum at all: the situation resembles that for plasma waves.

1.7.3 Can one find an explicit formula for $M^8 - H$ duality?

The dream is an explicit formula for the $M^8 - H$ duality mapping $Y^4 \subset M_c^8$ to $X^4 \subset H$. This formula should be consistent with the assumption that the generalized holomorphy holds true for X^4 .

The following proposal is a more detailed variant of the earlier proposal for which Y^4 is determined by a map g of $M_c^4 \rightarrow SU(3)_c \subset G_{2,c}$, where $G_{2,c}$ is the complexified automorphism group of octonions and $SU(3)_c$ is interpreted as a complexified color group.

This map defines a trivial $SU(3)_c$ gauge field. The real part of g however defines a non-trivial real color gauge field by the non-linearity of the non-abelian gauge field with respect to the gauge potential. The quadratic terms involving the imaginary part of the gauge potential give an additional condition to the real part in the complex situation and cancel it. If only the real part of g contributes, this contribution would be absent and the gauge field is non-vanishing.

How could the automorphism $g(x) \subset SU(3) \subset G_2$ give rise to $M^8 - H$ duality?

1. The interpretation is that $g(y)$ at given point y of Y^4 relates the normal space at y to a fixed quaternionic/associative normal space at point y_0 , which corresponds is fixed by some subgroup $U(2)_0 \subset SU(3)$. The automorphism property of g guarantees that the normal space is quaternionic/associative at y . This simplifies the construction dramatically.
2. The quaternionic normal sub-space (which has Euclidian signature) contains a complex sub-space which corresponds to a point of sphere $S^2 = SO(3)/O(2)$, where $SO(3)$ is the quaternionic automorphism group. The interpretation could be in terms of a selection of spin quantization axes. The local choice of the preferred complex plane would not be unique

and is analogous to the possibility of having non-trivial Hamilton Jacobi structures in M^4 characterized by the choice of $M^2(x)$ and equivalently its normal subspace $E^2(x)$.

These two structures are independent apart from dependencies forced by the number theoretic dynamics. Hamilton-Jacobi structure means a selection of the quantization axis of spin and energy by fixing a distribution of light-like tangent vectors of M^4 and the choice of the quaternionic normal sub-space fixes a choice of preferred quaternionic imaginary unit defining a quantization axis of the weak isospin.

3. The real part $Re(g(y))$ defines a point of $SU(3)$ and the bundle projection $SU(3) \rightarrow CP_2$ in turn defines a point of $CP_2 = SU(3)/U(2)$. Hence one can assign to g a point of CP_2 as $M^8 - H$ duality requires and deduce an explicit formula for the point. This means a realization of the dream.
4. The construction requires a fixing of a quaternionic normal space N_0 at y_0 containing a preferred complex subspace at a single point of Y^4 plus a selection of the function g . If M^4 coordinates are possible for Y^4 , the first guess is that g as a function of complexified M^4 coordinates obeys generalized holomorphy with respect to complexified M^4 coordinates in the same sense and in the case of X^4 . This might guarantee that the $M^8 - H$ image of Y^4 satisfies the generalized holomorphy.
5. Also space-time surfaces X^4 with M^4 projection having a dimension smaller than 4 are allowed. I have proposed that they might correspond to singular cases for the above formula: a kind of blow-up would be involved. One can also consider a more general definition of Y^4 allowing it to have a M^4 projection with dimension smaller than 4 (say cosmic strings). Could one have implicit equations for the surface Y^4 in terms of the complex coordinates of $SU(3)_c$ and M^4 ? Could this give for instance cosmic strings with a 2-D M^4 projection and CP_2 type extremals with 4-D CP_2 projection and 1-D light-like M^4 projection?

1.7.4 What could the number theoretic holography mean physically?

What could be physical meaning of the number theoretic holography? The condition that has been assumed is that the CP_2 coordinates at the mass shells of $M_c^4 \subset M_c^8$ mapped to mass shells H^3 of $M^4 \subset M^4 \times CP_2$ are constant at the H^3 . This is true if the $g(y)$ defines the same CP_2 point for a given component X_i^3 of the 3-surface at a given mass shell. g is therefore fixed apart from a local $U(2)$ transformation leaving the CP_2 point invariant. A stronger condition would be that the CP_2 point is the same for each component of X_i^3 and even at each mass shell but this condition seems to be unnecessarily strong.

Comment: One can criticize this condition as too strong and one can consider giving up this condition. The motivation for this condition is that the number of algebraic points at the 3-surfaces associated with H^3 explodes since the coordinates associated with normal directions vanish. Kind of cognitive explosion would be in question.

$SU(3)$ corresponds to a subgroup of G_2 and one can wonder what the fixing of this subgroup could mean physically. G_2 is 14-D and the coset space $G_2/SU(3)$ is 6-D and a good guess is that it is just the 6-D twistor space $SU(3)/U(1) \times U(1)$ of CP_2 : at least the isometries are the same. The fixing of the $SU(3)$ subgroup means fixing of a CP_2 twistor. Physically this means the fixing of the quantization axis of color isospin and hypercharge.

1.7.5 Twistor lift of the holography

What is interesting is that by replacing $SU(3)$ with G_2 , one obtains an explicit formula from the generalization of $M^8 - H$ duality to that for the twistorial lift of TGD!

One can also consider a twistorial generalization of the above proposal for the number theoretic holography by allowing local G_2 automorphisms interpreted as local choices of the color quantization axis. G_2 elements would be fixed apart from a local $SU(3)$ transformation at the components of 3-surfaces at mass shells. The choice of the color quantization axes for a connected 3-surface at a given mass shell would be the same everywhere. This choice is indeed very natural physically since 3-surface corresponds to a particle.

Is this proposal consistent with the boundary condition of the number theoretical holography mean in the case of 4-surfaces in M_c^8 and $M^4 \times CP_2$?

1. The selection of $SU(3) \subset G_2$ for ordinary $M^8 - H$ duality means that the $G_{2,c}$ gauge field vanishes everywhere and the choice of color quantization axis is the same at all points of the 4-surface. The fixing of the CP_2 point to be constant at H^3 implies that the color gauge field at $H^3 \subset M_c^8$ and its image $H^3 \subset H$ vanish. One would have color confinement at the mass shells H_i^3 , where the observations are made. Is this condition too strong?
2. The constancy of the G_2 element at mass shells makes sense physically and means a fixed color quantization axis. The selection of a fixed $SU(3) \subset G_2$ for entire space-time surface is in conflict with the non-constancy of G_2 element unless G_2 element differs at different points of 4-surface only by a multiplication of a local $SU(3)_0$ element, that is local $SU(3)$ transformation. This kind of variation of the G_2 element would mean a fixed color group but varying choice of color quantization axis.
3. Could one consider the possibility that the local $G_{2,c}$ element is free and defines the twistor lift of $M^8 - H$ duality as something more fundamental than the ordinary $M^8 - H$ duality based on $SU(3)_c$. This duality would make sense only at the mass shells so that only the spaces $H^3 \times CP_2$ assignable to mass shells would make sense physically? In the interior CP_2 would be replaced with the twistor space $SU(3)/U(1) \times U(1)$. Color gauge fields would be non-vanishing at the mass shells but outside the mass shells one would have G_2 gauge fields. There is also a physical objection against the G_2 option. The 14-D Lie algebra representation of G_2 acts on the imaginary octonions which decompose with respect to the color group to $1 \oplus 3 \oplus \bar{3}$. The automorphism property requires that 1 can be transformed to 3 or $\bar{3}$ to themselves: this requires that the decomposition contains $3 \oplus \bar{3}$. Furthermore, it must be possible to transform 3 and $\bar{3}$ to themselves, which requires the presence of 8. This leaves only the decomposition $8 \oplus 3 \oplus \bar{3}$. G_2 gluons would both color octet and triplets. In the TDG framework the only conceivable interpretation would be in terms of ordinary gluons and leptoquark-like gluons. This does not fit with the basic vision of TGD.

The choice of twistor as a selection of quantization axes should make sense also in the M^4 degrees of freedom. M^4 twistor corresponds to a choice of light-like direction at a given point of M^4 . The spatial component of the light-like vector fixes the spin quantization axis. Its choice together with the light-likeness fixes the time direction and therefore the rest system and energy quantization axis. Light-like vector fixes also the choice of M^2 and of E^2 as its orthogonal complement. Therefore the fixing of M^4 twistor as a point of $SU(4)/SU(3) \times U(1)$ corresponds to a choice of the spin quantization axis and the time-like axis defining the rest system in which the energy is measured. This choice would naturally correspond to the Hamilton-Jacobi structure fixing the decompositions $M^2(x) \times E^2(x)$. At a given mass shell the choice of the quantization axis would be constant for a given X_i^3 .

1.8 Hierarchy of Planck Constants and Dark Matter Hierarchy

By quantum classical correspondence space-time sheets can be identified as quantum coherence regions. Hence the fact that they have all possible size scales more or less unavoidably implies that Planck constant must be quantized and have arbitrarily large values. If one accepts this then also the idea about dark matter as a macroscopic quantum phase characterized by an arbitrarily large value of Planck constant emerges naturally as does also the interpretation for the long ranged classical electro-weak and color fields predicted by TGD. Rather seldom the evolution of ideas follows simple linear logic, and this was the case also now. In any case, this vision represents the fifth, relatively new thread in the evolution of TGD and the ideas involved are still evolving.

1.8.1 Dark Matter as Large \hbar Phases

D. Da Rocha and Laurent Nottale [E1] have proposed that Schrödinger equation with Planck constant \hbar replaced with what might be called gravitational Planck constant $\hbar_{gr} = \frac{GmM}{v_0}$ ($\hbar = c = 1$). v_0 is a velocity parameter having the value $v_0 = 144.7 \pm .7$ km/s giving $v_0/c = 4.6 \times 10^{-4}$. This is rather near to the peak orbital velocity of stars in galactic halos. Also subharmonics and harmonics of v_0 seem to appear. The support for the hypothesis coming from empirical data is impressive.

Nottale and Da Rocha believe that their Schrödinger equation results from a fractal hydrodynamics. Many-sheeted space-time however suggests that astrophysical systems are at some levels of the hierarchy of space-time sheets macroscopic quantum systems. The space-time sheets in question would carry dark matter.

Nottale's hypothesis would predict a gigantic value of h_{gr} . Equivalence Principle and the independence of gravitational Compton length on mass m implies however that one can restrict the values of mass m to masses of microscopic objects so that h_{gr} would be much smaller. Large h_{gr} could provide a solution of the black hole collapse (IR catastrophe) problem encountered at the classical level. The resolution of the problem inspired by TGD inspired theory of living matter is that it is the dark matter at larger space-time sheets which is quantum coherent in the required time scale [K22].

It is natural to assign the values of Planck constants postulated by Nottale to the space-time sheets mediating gravitational interaction and identifiable as magnetic flux tubes (quanta) possibly carrying monopole flux and identifiable as remnants of cosmic string phase of primordial cosmology. The magnetic energy of these flux quanta would correspond to dark energy and magnetic tension would give rise to negative "pressure" forcing accelerate cosmological expansion. This leads to a rather detailed vision about the evolution of stars and galaxies identified as bubbles of ordinary and dark matter inside magnetic flux tubes identifiable as dark energy.

Certain experimental findings suggest the identification $h_{eff} = n \times h_{gr}$. The large value of h_{gr} can be seen as a way to reduce the string tension of fermionic strings so that gravitational (in fact all!) bound states can be described in terms of strings connecting the partonic 2-surfaces defining particles (analogous to AdS/CFT description). The values $h_{eff}/h = n$ can be interpreted in terms of a hierarchy of breakings of super-conformal symmetry in which the super-conformal generators act as gauge symmetries only for a sub-algebras with conformal weights coming as multiples of n . Macroscopic quantum coherence in astrophysical scales is implied. If also Kähler-Dirac action is present, part of the interior degrees of freedom associated with the Kähler-Dirac part of conformal algebra become physical. A possible is that fermionic oscillator operators generate super-symmetries and sparticles correspond almost by definition to dark matter with $h_{eff}/h = n > 1$. One implication would be that at least part if not all gravitons would be dark and be observed only through their decays to ordinary high frequency graviton ($E = hf_{high} = h_{eff}f_{low}$) of bunch of n low energy gravitons.

1.8.2 Hierarchy of Planck Constants from the Anomalies of Neuroscience and Biology

The quantal ELF effects of ELF em fields on vertebrate brain have been known since seventies. ELF em fields at frequencies identifiable as cyclotron frequencies in magnetic field whose intensity is about 2/5 times that of Earth for biologically important ions have physiological effects and affect also behavior. What is intriguing that the effects are found only in vertebrates (to my best knowledge). The energies for the photons of ELF em fields are extremely low - about 10^{-10} times lower than thermal energy at physiological temperatures- so that quantal effects are impossible in the framework of standard quantum theory. The values of Planck constant would be in these situations large but not gigantic.

This inspired the hypothesis that these photons correspond to so large a value of Planck constant that the energy of photons is above the thermal energy. The proposed interpretation was as dark photons and the general hypothesis was that dark matter corresponds to ordinary matter with non-standard value of Planck constant. If only particles with the same value of Planck constant can appear in the same vertex of Feynman diagram, the phases with different value of Planck constant are dark relative to each other. The phase transitions changing Planck constant can however make possible interactions between phases with different Planck constant but these interactions do not manifest themselves in particle physics. Also the interactions mediated by classical fields should be possible. Dark matter would not be so dark as we have used to believe.

The hypothesis $h_{eff} = h_{gr}$ - at least for microscopic particles - implies that cyclotron energies of charged particles do not depend on the mass of the particle and their spectrum is thus universal although corresponding frequencies depend on mass. In bio-applications this spectrum would correspond to the energy spectrum of bio-photons assumed to result from dark photons by h_{eff} reducing phase transition and the energies of bio-photons would be in visible and UV range

associated with the excitations of bio-molecules.

Also the anomalies of biology (see for instance [K18, K19, K17]) support the view that dark matter might be a key player in living matter.

1.8.3 Dark Matter as a Source of Long Ranged Weak and Color Fields

Long ranged classical electro-weak and color gauge fields are unavoidable in TGD framework. The smallness of the parity breaking effects in hadronic, nuclear, and atomic length scales does not however seem to allow long ranged electro-weak gauge fields. The problem disappears if long range classical electro-weak gauge fields are identified as space-time correlates for massless gauge fields created by dark matter. Also scaled up variants of ordinary electro-weak particle spectra are possible. The identification explains chiral selection in living matter and unbroken $U(2)_{ew}$ invariance and free color in bio length scales become characteristics of living matter and of bio-chemistry and bio-nuclear physics.

The recent view about the solutions of Kähler- Dirac action assumes that the modes have a well-defined em charge and this implies that localization of the modes to 2-D surfaces (right-handed neutrino is an exception). Classical W boson fields vanish at these surfaces and also classical Z^0 field can vanish. The latter would guarantee the absence of large parity breaking effects above intermediate boson scale scaling like h_{eff} .

1.9 Twistors in TGD and connection with Veneziano duality

The twistorialization of TGD has two aspects. The attempt to generalize twistor Grassmannian approach emerged first. It was however followed by the realization that also the twistor lift of TGD at classical space-time level is needed. It turned out that the progress in the understanding of the classical twistor lift has been much faster - probably this is due to my rather limited technical QFT skills.

1.9.1 Twistor lift at space-time level

8-dimensional generalization of ordinary twistors is highly attractive approach to TGD [K28]. The reason is that M^4 and CP_2 are completely exceptional in the sense that they are the only 4-D manifolds allowing twistor space with Kähler structure [A7]. The twistor space of $M^4 \times CP_2$ is Cartesian product of those of M^4 and CP_2 . The obvious idea is that space-time surfaces allowing twistor structure if they are orientable are representable as surfaces in H such that the properly induced twistor structure co-incides with the twistor structure defined by the induced metric.

In fact, it is enough to generalize the induction of spinor structure to that of twistor structure so that the induced twistor structure need not be identical with the ordinary twistor structure possibly assignable to the space-time surface. The induction procedure reduces to a dimensional reduction of 6-D Kähler action giving rise to 6-D surfaces having bundle structure with twistor sphere as fiber and space-time as base. The twistor sphere of this bundle is imbedded as sphere in the product of twistor spheres of twistor spaces of M^4 and CP_2 .

This condition would define the dynamics, and the original conjecture was that this dynamics is equivalent with the identification of space-time surfaces as preferred extremals of Kähler action. The dynamics of space-time surfaces would be lifted to the dynamics of twistor spaces, which are sphere bundles over space-time surfaces. What is remarkable that the powerful machinery of complex analysis becomes available.

It however turned out that twistor lift of TGD is much more than a mere technical tool. First of all, the dimensionally reduction of 6-D Kähler action contained besides 4-D Kähler action also a volume term having interpretation in terms of cosmological constant. This need not bring anything new, since all known extremals of Kähler action with non-vanishing induced Kähler form are minimal surfaces. There is however a large number of embeddings of twistor sphere of space-time surface to the product of twistor spheres. Cosmological constant has spectrum and depends on length scale, and the proposal is that coupling constant evolution reduces to that for cosmological constant playing the role of cutoff length. That cosmological constant could transform from a mere nuisance to a key element of fundamental physics was something totally new and unexpected.

1. The twistor lift of TGD at space-time level forces to replace 4-D Kähler action with 6-D dimensionally reduced Kähler action for 6-D surface in the 12-D Cartesian product of 6-D twistor spaces of M^4 and CP_2 . The 6-D surface has bundle structure with twistor sphere as fiber and space-time surface as base.

Twistor structure is obtained by inducing the twistor structure of 12-D twistor space using dimensional reduction. The dimensionally reduced 6-D Kähler action is sum of 4-D Kähler action and volume term having interpretation in terms of a dynamical cosmological constant depending on the size scale of space-time surface (or of causal diamond CD in zero energy ontology (ZEO)) and determined by the representation of twistor sphere of space-time surface in the Cartesian product of the twistor spheres of M^4 and CP_2 .

2. The preferred extremal property as a representation of quantum criticality would naturally correspond to minimal surface property meaning that the space-time surface is separately an extremal of both Kähler action and volume term almost everywhere so that there is no coupling between them. This is the case for all known extremals of Kähler action with non-vanishing induced Kähler form.

Minimal surface property could however fail at 2-D string world sheets, their boundaries and perhaps also at partonic 2-surfaces. The failure is realized in minimal sense if the 3-surface has 1-D edges/folds (strings) and 4-surface 2-D edges/folds (string world sheets) at which some partial derivatives of the embedding space coordinates are discontinuous but canonical momentum densities for the entire action are continuous.

There would be no flow of canonical momentum between interior and string world sheet and minimal surface equations would be satisfied for the string world sheet, whose 4-D counterpart in twistor bundle is determined by the analog of 4-D Kähler action. These conditions allow the transfer of canonical momenta between Kähler- and volume degrees of freedom at string world sheets. These no-flow conditions could hold true at least asymptotically (near the boundaries of CD).

$M^8 - H$ duality suggests that string world sheets (partonic 2-surfaces) correspond to images of complex 2-sub-manifolds of M^8 (having tangent (normal) space which is complex 2-plane of octonionic M^8).

3. Cosmological constant would depend on p-adic length scales and one ends up to a concrete model for the evolution of cosmological constant as a function of p-adic length scale and other number theoretic parameters (such as Planck constant as the order of Galois group): this conforms with the earlier picture.

Inflation is replaced with its TGD counterpart in which the thickening of cosmic strings to flux tubes leads to a transformation of Kähler magnetic energy to ordinary and dark matter. Since the increase of volume increases volume energy, this leads rapidly to energy minimum at some flux tube thickness. The reduction of cosmological constant by a phase transition however leads to a new expansion phase. These jerks would replace smooth cosmic expansion of GRT. The discrete coupling constant evolution predicted by the number theoretical vision could be understood as being induced by that of cosmological constant taking the role of cutoff parameter in QFT picture [L2].

1.9.2 Twistor lift at the level of scattering amplitudes and connection with Veneziano duality

The classical part of twistor lift of TGD is rather well-understood. Concerning the twistorialization at the level of scattering amplitudes the situation is much more difficult conceptually - I already mentioned my limited QFT skills.

1. From the classical picture described above it is clear that one should construct the 8-D twistorial counterpart of theory involving space-time surfaces, string world sheets and their boundaries, plus partonic 2-surfaces and that this should lead to concrete expressions for the scattering amplitudes.

The light-like boundaries of string world sheets as carriers of fermion numbers would correspond to twistors as they appear in twistor Grassmann approach and define the analog for the massless sector of string theories. The attempts to understand twistorialization have been restricted to this sector.

2. The beautiful basic prediction would be that particles massless in 8-D sense can be massive in 4-D sense. Also the infrared cutoff problematic in twistor approach emerges naturally and reduces basically to the dynamical cosmological constant provided by classical twistor lift.

One can assign 4-momentum both to the spinor harmonics of the embedding space representing ground states of super-conformal representations and to light-like boundaries of string world sheets at the orbits of partonic 2-surfaces. The two four-momenta should be identical by quantum classical correspondence: this could be seen as a concretization of Equivalence Principle. Also a connection with string model emerges.

3. As far as symmetries are considered, the picture looks rather clear. Ordinary twistor Grassmannian approach boils down to the construction of scattering amplitudes in terms of Yangian invariants for conformal group of M^4 . Therefore a generalization of super-symplectic symmetries to their Yangian counterpart seems necessary. These symmetries would be gigantic but how to deduce their implications?
4. The notion of positive Grassmannian is central in the twistor approach to the scattering amplitudes in $calN = 4$ SUSYs. TGD provides a possible generalization and number theoretic interpretation of this notion. TGD generalizes the observation that scattering amplitudes in twistor Grassmann approach correspond to representations for permutations. Since 2-vertex is the only fermionic vertex in TGD, OZI rules for fermions generalizes, and scattering amplitudes are representations for braidings.

Braid interpretation encourages the conjecture that non-planar diagrams can be reduced to ordinary ones by a procedure analogous to the construction of braid (knot) invariants by gradual un-braiding (un-knotting).

This is however not the only vision about a solution of non-planarity. Quantum criticality provides different view leading to a totally unexpected connection with string models, actually with the Veneziano duality, which was the starting point of dual resonance model in turn leading via dual resonance models to super string models.

1. Quantum criticality in TGD framework means that coupling constant evolution is discrete in the sense that coupling constants are piecewise constant functions of length scale replaced by dynamical cosmological constant. Loop corrections would vanish identically and the recursion formulas for the scattering amplitudes (allowing only planar diagrams) deduced in twistor Grassmann would involve no loop corrections. In particular, cuts would be replaced by sequences of poles mimicking them like sequences of point charge mimic line charges. In momentum discretization this picture follows automatically.
2. This would make sense in finite measurement resolution realized in number theoretical vision by number-theoretic discretization of the space-time surface (cognitive representation) as points with coordinates in the extension of rationals defining the adèle [L1]. Similar discretization would take place for momenta. Loops would vanish at the level of discretization but what would happen at the possibly existing continuum limit: does the sequence of poles integrate to cuts? Or is representation as sum of resonances something much deeper?
3. Maybe it is! The basic idea of behind the original Veneziano amplitudes (see <http://tinyurl.com/yyhwvbqb>) was Veneziano duality. This 4-particle amplitude was generalized by Yoshiro Nambu, Holber-Beck Nielsen, and Leonard Susskind to N-particle amplitude (see <http://tinyurl.com/yyvkv7as>) based on string picture, and the resulting model was called dual resonance model. The model was forgotten as QCD emerged. Later came superstring models and led to M-theory. Now it has become clear that something went wrong, and it seems that one must return to the roots. Could the return to the roots mean a careful reconsideration of the dual resonance model?
4. Recall that Veneziano duality (1968) was deduced by assuming that scattering amplitude can be described as sum over s-channel resonances or t-channel Regge exchanges and Veneziano duality stated that hadronic scattering amplitudes have representation as sums over s- or t-channel resonance poles identified as excitations of strings. The sum over exchanges defined by t-channel resonances indeed reduces at larger values of s to Regge form.

The resonances had zero width, which was not consistent with unitarity. Further, there were no counterparts for the *sum* of s-, t-, and u-channel diagrams with continuous cuts

in the kinematical regions encountered in QFT approach. What puts bells ringing is the u-channel diagrams would be non-planar and non-planarity is the problem of twistor Grassmann approach.

5. Veneziano duality is true only for s- and t- channels but not been s- and u-channel. Stringy description makes t-channel and s-channel pictures equivalent. Could it be that in fundamental description u-channels diagrams cannot be distinguished from s-channel diagrams or t-channel diagrams? Could the stringy representation of the scattering diagrams make u-channel twist somehow trivial if handles of string world sheet representing stringy loops in turn representing the analog of non-planarity of Feynman diagrams are absent? The permutation of external momenta for tree diagram in absence of loops in planar representation would be a twist of π in the representation of planar diagram as string world sheet and would not change the topology of the string world sheet and would not involve non-trivial world sheet topology.

For string world sheets loops would correspond to handles. The presence of handle would give an edge with a loop at the level of 3-surface (self energy correction in QFT). Handles are not allowed if the induced metric for the string world sheet has Minkowskian signature. If the stringy counterparts of loops are absent, also the loops in scattering amplitudes should be absent.

This argument applies only inside the Minkowskian space-time regions. If string world sheets are present also in Euclidian regions, they might have handles and loop corrections could emerge in this manner. In TGD framework strings (string world sheets) are identified to 1-D edges/folds of 3-surface at which minimal surface property and topological QFT property fails (minimal surfaces as calibrations). Could the interpretation of edge/fold as discontinuity of some partial derivatives exclude loopy edges: perhaps the branching points would be too singular?

A reduction to a sum over s-channel resonances is what the vanishing of loops would suggest. Could the presence of string world sheets make possible the vanishing of continuous cuts even at the continuum limit so that continuum cuts would emerge only in the approximation as the density of resonances is high enough?

The replacement of continuous cut with a sum of *infinitely* narrow resonances is certainly an approximation. Could it be that the stringy representation as a sum of resonances with *finite* width is an essential aspect of quantum physics allowing to get rid of infinities necessarily accompanying loops? Consider now the arguments against this idea.

1. How to get rid of the problems with unitarity caused by the zero width of resonances? Could *finite* resonance widths make unitarity possible? Ordinary twistor Grassmannian approach predicts that the virtual momenta are light-like but complex: obviously, the imaginary part of the energy in rest frame would have interpretation as resonance width.

In TGD framework this generalizes for 8-D momenta. By quantum-classical correspondence (QCC) the classical Noether charges are equal to the eigenvalues of the fermionic charges in Cartan algebra (maximal set of mutually commuting observables) and classical TGD indeed predicts complex momenta (Kähler coupling strength is naturally complex). QCC thus supports this proposal.

2. Sum over resonances/exchanges picture is in conflict with QFT picture about scattering of particles. Could *finite* resonance widths due to the complex momenta give rise to the QFT type scattering amplitudes as one develops the amplitudes in Taylor series with respect to the resonance width? Unitarity condition indeed gives the first estimate for the resonance width. QFT amplitudes should emerge in an approximation obtained by replacing the discrete set of finite width resonances with a cut as the distance between poles is shorter than the resolution for mass squared.

In superstring models string tension has single very large value and one cannot obtain QFT type behavior at low energies (for instance, scattering amplitudes in hadronic string model are concentrated in forward direction). TGD however predicts an entire hierarchy of p-adic length scales with varying string tension. The hierarchy of mass scales corresponding roughly to the lengths and thickness of magnetic flux tubes as thickened cosmic strings and characterized by the value of cosmological constant predicted by twistor lift of TGD. Could this give rise

to continuous QCT type cuts at the limit when measurement resolution cannot distinguish between resonances?

The dominating term in the sum over sums of resonances in t -channel gives near forward direction approximately the lowest mass resonance for strings with the smallest string tension. This gives the behavior $1/(t - m_{min}^2)$, where m_{min} corresponds to the longest mass scale involved (the largest space-time sheet involved), approximating the $1/t$ -behavior of massless theories. This also brings in IR cutoff, the lack of which is a problem of gauge theories. This should give rise to continuous QFT type cuts at the limit when measurement resolution cannot distinguish between resonances.

2 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. The basic idea is that quantum jump can be identified as momentum of consciousness. Thus a general theory of consciousness is unavoidable outcome. This theory is developed in detail in the books [K27, K3, K16, K2, K7, K9, K11, K23, K26].

It is good to list first the basic challenges of TGD inspired theory of consciousness. The challenges can be formulated as questions. Reader can decide how satisfactory the answered proposed by TGD are.

1. What does one mean with quantum jump? Can one overcome the basic problem of the standard quantum measurement theory, that which forcing Bohr to give up totally the idea about objective reality?
2. How do the experienced time and geometric time relate in this framework? How the arrow of subjective time translates to that of geometric time?
3. How to define conscious information? Is it conserved or even increased during time evolution as biological evolution suggests? How does this increase relate to second law implied basically by the randomness of state function reduction?
4. Conscious entities/selves/observers seem to exist. If they are real how do they emerge?

2.1 Quantum Jump As A Moment Of Consciousness

The identification of quantum jump between deterministic quantum histories (WCW 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 formally analogous to Schrödinger time evolution of infinite duration. The time evolution can however interpreted as a sequence of discrete scalings and Lorentz boosts of causal diamond (CD) and the time corresponds to the change of the proper time distance between between the tips of CD.

In TGD framework S-matrix is generalized to a triplet of U-, M-, and S-matrices. M-matrix is a hermitian square root of density matrix between positive and negative energy states multiplied by universal S-matrix depending on the scale of CD only. The square roots of projection operators form an orthonormal basis. U -matrix and S -matrix are completely universal objects characterizing the dynamics of evolution by self-organization.

The M-matrices associated with CDs are obtained by a discrete scaling from the minimal CD and characterized by integer n are naturally proportional to S^n , where S is the S-matrix associated with the minimal CD. This conforms with the idea about unitary time evolution as exponent of Hamiltonian discretized to integer power of S .

U-matrix elements between M-matrices for various CDs are proportional to the inner products $Tr[S^{-n_1} \circ H^i H^j \circ S^{n_2} \lambda]$, where λ represents unitarily the discrete Lorentz boost relating the moduli of the active boundary of CD and H^i form an orthonormal basis of Hermitian square roots of density matrices. \circ tells that S acts at the active boundary of CD only. It turns out possible to construct a general representation for the U-matrix reducing its construction to that of S-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 parameterize 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”.

In ZEO U -matrix should correspond to zero energy states to each other and M matrices defining the rows of U matrix should be assignable to a fixed CD. Zero energy states should have wave function in the moduli space of CDs such that the second boundary of every CD would belong to a boundary of fixed light-cone but second boundary would be free with possible constraint that the distance between the tips of CD is multiple of CP_2 time.

Zero energy states of ZEO correspond in positive energy ontology to physical events and break time reversal invariance. This because either the positive or negative energy part of the state is reduced/equivalently prepared whereas the second end of CD corresponds to a superposition of (negative/positive energy) states with varying particle numbers and single particle quantum numbers just as in ordinary particle physics experiment.

The first state function reduction at given boundary of CD must change the roles of the ends of CDs. This reduction can be followed by a sequence of reductions to the same boundary of CD and not changing the boundary nor the parts of zero energy states associated with it but changing the states at the second end and also quantum distribution of the second boundary in the moduli space of CDs. In standard measurement theory the follow-up reductions would not affect the state at all.

The understanding of how the arrow of time and experience about its flow emerge have been the most difficult problem of TGD inspired theory of consciousness and I have considered several proposals during years having the geometry of future light-cone as the geometric core element.

1. The basic objection is that the arrow of geometric time alternates at embedding space level but we know that arrow of time looks the same in the part of the Universe we live. Possible exceptions however exist, for instance phase conjugate laser beams seem to obey opposite arrow of time. Also biological phenomena might involve non-standard arrow of time at some levels. This led Fantappie [J1] to introduce the notion of syntropy. This suggests that the arrow of time depends on the size scale of CD and of space-time sheet.
2. It took some time to realize that the solution of the problem is trivial in ZEO. In the ordinary quantum measurement theory one must assume that state function reduction can occur repeatedly: the assumption is that nothing happens to the state during repeated reductions. The outcome is Zeno effect: the watched pot does not boil.

In TGD framework situation is different. Repeated state function reduction leaves the already reduced parts of zero energy state invariant but can change the part of states at the opposite boundary. One must allow a delocalization of the second boundary of CDs and one assumes that the second tip has quantized distance to the fixed one coming as multiple of CP_2 time. Also Lorentz boosts leaving the second CD boundary invariant must be allowed. One must therefore introduce a wave function in the moduli space of CDs with second boundary forming part of fixed light-cone boundary ($\delta M_{\pm}^4 \times CP_2$).

3. The sequence of state function reductions on a fixed boundary of CD leads to the increase of the average temporal distance between the tips of CDs and this gives rise to the experience about flow of time as shifting of contents of perception towards future if the change is what contributes to conscious experience and gives rise to a fixed arrow of time.
4. Contrary to original working hypothesis, state function reduction in the usual sense does not solely determine the ordinary conscious experience. It can however contribute to conscious

experience and the act of free will is a good candidate in this respect. TGD view about realization of intentional action assumes that intentional actions involve negative energy signals propagating backwards in geometric time. This would mean that at some level of CD hierarchy the arrow of geometric time indeed changes and the reduction start to occur at opposite boundary of CD at some level of length scale hierarchy.

2.2 Negentropy Maximization Principle (NMP)

Information is the basic aspect of consciousness and this motivates the introduction of Negentropy Maximization Principle (NMP) [K12] as the fundamental variational principle of consciousness theory. The amount of negentropy of zero energy state should increase in each quantum jump. The ordinary entanglement entropy is also non-negative so that negentropy could be at best zero. Since p-adic physics is assumed to be a correlate of cognition, it is natural to generalize Shannon entropy to its number theoretic variant by replacing the probabilities appearing as arguments of logarithms of probabilities with their p-adic norms. This gives negentropy which can be positive so that NMP can generate entanglement.

Consistency with quantum measurement theory allows only negentropic density matrices proportional to unit matrix and negentropy has the largest positive value for the largest power of prime factor of the dimension of density matrix. Entanglement matrix proportional to unitary matrix familiar from quantum computation corresponds to unit density matrix and large $h_{eff} = n \times h$ states are excellent candidates for forming negentropic entanglement (see **Fig.** <http://tgdtheory.fi/appfigures/cat.jpg> or **Fig. ??** in the appendix of this book).

The interpretation of negentropic entanglement is as a rule. The instances of the rule correspond to the pairs appearing in the superposition and the larger the number of pairs is, the higher the abstraction level of the rule is. NMP is not in conflict with the second law since negentropy in the sense of NMP is not single particle property. Ordinary quantum jumps indeed generate entropy at the level of ensemble as also quantum jumps for states for which the density matrix is direct sum of unit matrices with various dimensions.

NMP forces the negentropic entanglement resources of the Universe to grow and thus implies evolution. I have coined the name “Akashic records” for these resources forming something analogous to library. It has turned out that the only viable option is that negentropic entanglement is experienced directly.

2.3 The Notion Of Self

The concept of self seems to be absolutely essential for the understanding of the macroscopic and macro-temporal aspects of consciousness and would be counterpart for observer in quantum measurement theory.

1. The original view was that self corresponds to a subsystem able to remain un-entangled under the sequential informational “time evolutions” U . It is however unclear how it could be possible to avoid generation of entanglement.
2. In ZEO the situation changes. Self corresponds to a sequence of quantum jumps for which the parts of zero energy states at either boundary of CD remain unchanged. Therefore one can say that self defined in terms of parts of states assignable to this boundary remains unaffected as sub-system and does not generate entanglement. At the other boundary changes occur and give rise to the experience of time flow and arrow of time since the average temporal distance between the tips of CD tends to increase.

When the reductions begin to occur at the opposite boundary of CD, self “falls asleep”: symmetry suggests that new self living in opposite direction of geometric time is generated. Also in biological the change of time direction at some level of hierarchy might take place.

3. It looks natural to assume 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 sub-selves as kind of abstracted

experience: the experiences of sub-selves S_i are not experienced as such but represent kind of averages $\langle S_{ij} \rangle$ of sub-sub-selves S_{ij} . Entanglement between selves, most naturally realized by the formation of flux tube bonds between cognitive 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.

4. Self corresponds in neuro science to self model defining a model for organism and for the external world. Information or negentropy seems to be necessary for understanding self. Negentropically entangled states - Akashic records - are excellent candidates for selves and would thus correspond to dark matter in TGD sense since the number of states in superposition corresponds to the integer n defining h_{eff} . It is enough that self is potentially conscious: this could mean that its conscious experience about self is generated only in interaction free measurement. Repeated state function reductions to given boundary of CD is second possibility. This would assign irreversibility and definite arrow of time and experience of time flow with self.
5. CDs would serve as embedding space correlates of selves and quantum jumps would be followed by cascades of state function reductions beginning from given CD and proceeding downwards to the smaller scales (smaller CDs). At space-time level space-time sheets in given p-adic length scale would be the natural correlates of selves. One ends also ends up with concrete ideas about how the localization of the contents of sensory experience and cognition to the “upper” (changing) boundary of CD could take place. One cannot exclude the possibility that state function reduction cascades could also take place in parallel branches of the quantum state.

2.4 Relationship To Quantum Measurement Theory

TGD based quantum measurement has several new elements. Negentropic entanglement and hierarchy of Planck constants, NMP, the prediction that state function reduction can take place to both boundaries of CD implying that the arrow of geometric time can change (this is expected to occur in microscopic scales whether the arrow of time is not established), and the possibility to understand the flow and arrow of geometric time.

1. 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 WCW 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).
2. The assumption that localization occurs in zero modes in each quantum jump implies that the world of conscious experience looks classical. It is also consistent with 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!).
3. 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 WCW of 3-surfaces is absolutely essential. Therefore the reduction is a triumph for quantum TGD and favors TGD against string models.

Standard quantum measurement theory involves also the notion of state preparation which reduces to the notion of self measurement. In ZEO state preparation corresponds at some level of the self hierarchy to the a state function reduction to boundary opposite than before. In biology sensory perception and motor action would correspond to state function reduction sequences at opposite boundaries of CDs at some levels of the hierarchy.

Self measurement is governed by 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).

2.5 Selves Self-Organize

The fourth basic element is quantum theory of self-organization based on the identification of quantum jump as the basic step of self-organization [K21]. 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 prerequisite 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.

ZEO brings in important additional element to the theory of self-organization. The maxima of Kähler function corresponds to the most probable 3-surfaces. Kähler function receives contributions only from the Euclidian regions ("lines" of generalized Feynman diagrams) whereas the contribution to vacuum functional from Minkowskian regions is exponent of imaginary action so that saddle points with stationary phase are in question in these regions. In ZEO 3-surfaces are replaced by pairs of 3-surfaces at opposite boundaries of CD. The maxima actually correspond to temporal patterns of classical fields connecting these 3-surfaces: this means that self-organization is four spatiotemporal rather than spatial patterns - a crucial distinction from the usual view allowing to understand the evolution of behavioral patterns quantally. In biology this allows to understand temporal evolutions of organisms as the most probable self-organization patterns having as correlates the evolutions of the magnetic body of the system.

2.6 Classical Non-Determinism Of Kähler Action

A further basic element is non-determinism of Kähler action. This led to the concepts of association sequence and cognitive space-time sheet, which are not wrong notions but replaced by new ones.

1. The huge vacuum degeneracy of the Kähler action suggests strongly that the preferred 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 time like(!) separations on the orbit of 3-surface. Quantum classical correspondence suggest an alternative

formulation. Space-time surface decomposes into maximal deterministic regions and their temporal sequences have interpretation a space-time correlate for a sequence of quantum states defined by the initial (or final) states of quantum jumps. This is consistent with the fact that the variational principle selects preferred extremals of Kähler action as generalized Bohr orbits.

2. In the case that non-determinism 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 correlate for contents of consciousness. When non-determinism has long lasting and macroscopic effect one can identify it as volitional non-determinism associated with our choices. Association sequences relate closely with the cognitive space-time sheets defined as space-time sheets having finite time duration.

Later a more detailed view about non-determinism in the framework of ZEO has emerged and quantum criticality is here the basic notion. The space-time surface connecting two 3-surfaces at the ends of CD is not unique. Conformal transformations which act trivially at the ends of space-time surface generate a continuum of new extremals with the same value of Kähler action and classical conserved quantities. The number n of conformal equivalence classes is finite and defines the value of h_{eff} (see **Fig.** <http://tgdtheory.fi/appfigures/planckhierarchy.jpg> or **Fig. ??** in the appendix of this book). There exists a hierarchy of breakdowns of conformal symmetry labelled by n . The fractal hierarchy of CDs gives rise to fractal hierarchy of non-determinisms of this kind.

2.7 P-Adic Physics As Physics Of Cognition

A further 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 $p = 2, 3, 5, \dots$ p-Adic 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 binary 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 gluing together regions for which integration constants are genuine constants. The natural interpretation of the p-adic regions is as cognitive representations of real physics. The freedom of imagination is due to the p-adic non-determinism. p-Adic regions perform mimicry and make possible for the Universe to form cognitive representations about itself. p-Adic physics space-time sheets serve also as correlates for intentional action.

A more precise formulation of this vision requires a generalization of the number concept obtained by fusing reals and p-adic number fields along common rationals (in the case of algebraic extensions among common algebraic numbers). This picture is discussed in [K25]. The application this notion at the level of the embedding space implies that embedding space has a book like structure with various variants of the embedding space glued together along common rationals (algebraics, see **Fig.** <http://tgdtheory.fi/appfigures/book.jpg> or **Fig. ??** in the appendix of this book). The implication is that genuinely p-adic numbers (non-rationals) are strictly infinite as real numbers so that most points of p-adic space-time sheets are at real infinity, outside the cosmos, and that the projection to the real embedding space is discrete set of rationals (algebraics). Hence cognition and intentionality are almost completely outside the real cosmos and touch it at a discrete set of points only.

This view implies also that purely local p-adic physics codes for the p-adic fractality characterizing long range real physics and provides an explanation for p-adic length scale hypothesis stating that the primes $p \simeq 2^k$, k integer are especially interesting. It also explains the long range correlations and short term chaos characterizing intentional behavior and explains why the physical realizations of cognition are always discrete (say in the case of numerical computations). Furthermore, a concrete quantum model for how intentions are transformed to actions emerges.

The discrete real projections of p-adic space-time sheets serve also space-time correlate for a logical thought. It is very natural to assign to p-adic binary digits a p -valued logic but as such this kind of logic does not have any reasonable identification. p-Adic length scale hypothesis suggest that the $p = 2^k - n$ binary digits represent a Boolean logic B^k with k elementary statements (the

points of the k -element set in the set theoretic realization) with n taboos which are constrained to be identically true.

2.8 P-Adic And Dark Matter Hierarchies And Hierarchy Of Selves

Dark matter hierarchy assigned to a spectrum of Planck constant having arbitrarily large values brings additional elements to the TGD inspired theory of consciousness.

1. Macroscopic quantum coherence can be understood since a particle with a given mass can in principle appear as arbitrarily large scaled up copies (Compton length scales as \hbar). The phase transition to this kind of phase implies that space-time sheets of particles overlap and this makes possible macroscopic quantum coherence.
2. The space-time sheets with large Planck constant can be in thermal equilibrium with ordinary ones without the loss of quantum coherence. For instance, the cyclotron energy scale associated with EEG turns out to be above thermal energy at room temperature for the level of dark matter hierarchy corresponding to magnetic flux quanta of the Earth's magnetic field with the size scale of Earth and a successful quantitative model for EEG results [K6].

Dark matter hierarchy leads to detailed quantitative view about quantum biology with several testable predictions [K6]. The general prediction is that Universe is a kind of inverted Mandelbrot fractal for which each bird's eye of view reveals new structures in long length and time scales representing scaled down copies of standard physics and their dark variants. These structures would correspond to higher levels in self hierarchy. This prediction is consistent with the belief that 75 per cent of matter in the universe is dark.

1. *Living matter and dark matter*

Living matter as ordinary matter quantum controlled by the dark matter hierarchy has turned out to be a particularly successful idea. The hypothesis has led to models for EEG predicting correctly the band structure and even individual resonance bands and also generalizing the notion of EEG [K6]. Also a generalization of the notion of genetic code emerges resolving the paradoxes related to the standard dogma [K10, K6]. A particularly fascinating implication is the possibility to identify great leaps in evolution as phase transitions in which new higher level of dark matter emerges [K6].

It seems safe to conclude that the dark matter hierarchy with levels labelled by the values of Planck constants explains the macroscopic and macro-temporal quantum coherence naturally. That this explanation is consistent with the explanation based on spin glass degeneracy is suggested by following observations. First, the argument supporting spin glass degeneracy as an explanation of the macro-temporal quantum coherence does not involve the value of \hbar at all. Secondly, the failure of the perturbation theory assumed to lead to the increase of Planck constant and formation of macroscopic quantum phases could be precisely due to the emergence of a large number of new degrees of freedom due to spin glass degeneracy. Thirdly, the phase transition increasing Planck constant has concrete topological interpretation in terms of many-sheeted space-time consistent with the spin glass degeneracy.

2. *Dark matter hierarchy and the notion of self*

The vision about dark matter hierarchy leads to a more refined view about self hierarchy and hierarchy of moments of consciousness [K5, K6]. The larger the value of Planck constant, the longer the life-time of self measured as the increase of the average distance between tips of CDs appearing in the quantum superposition during the period of repeated reductions not affecting the part of the zero energy state at the other boundary of CD- Quantum jumps form also a hierarchy with respect to p-adic and dark hierarchies and the geometric durations of quantum jumps scale like \hbar .

The fact that we can remember phone numbers with 5 to 9 digits supports the view that self experience subselves as separate mental images. Averaging over experiences of sub-selves of sub-self would however occur.

3. *The time span of long term memories as signature for the level of dark matter hierarchy*

The basic question is what time scale can one assign to the geometric duration of quantum jump measured naturally as the size scale of the space-time region about which quantum jump gives conscious information. This scale is naturally the size scale in which the non-determinism of quantum jump is localized. During years I have made several guesses about this time scales but zero energy ontology and the vision about fractal hierarchy of quantum jumps within quantum jumps leads to a unique identification.

CD as an embedding space correlate of self defines the time scale τ for the space-time region about which the consciousness experience is about. The temporal distances between the tips of CD as come as integer multiples of CP_2 length scales and for prime multiples correspond to what I have christened as secondary p-adic time scales. A reasonable guess is that secondary p-adic time scales are selected during evolution and the primes near powers of two are especially favored. For electron, which corresponds to Mersenne prime $M_{127} = 2^{127} - 1$ this scale corresponds to .1 seconds defining the fundamental time scale of living matter via 10 Hz biorhythm (alpha rhythm). The unexpected prediction is that all elementary particles correspond to time scales possibly relevant to living matter.

Dark matter hierarchy brings additional finesse. For the higher levels of dark matter hierarchy τ is scaled up by \hbar/\hbar_0 . One could understand evolutionary leaps as the emergence of higher levels at the level of individual organism making possible intentionality and memory in the time scale defined τ .

Higher levels of dark matter hierarchy provide a neat quantitative view about self hierarchy and its evolution. Various levels of dark matter hierarchy would naturally correspond to higher levels in the hierarchy of consciousness and the typical duration of life cycle would give an idea about the level in question. The level would determine also the time span of long term memories as discussed in [K6]. The emergence of these levels must have meant evolutionary leap since long term memory is also accompanied by ability to anticipate future in the same time scale. This picture would suggest that the basic difference between us and our cousins is not at the level of genome as it is usually understood but at the level of the hierarchy of magnetic bodies [K10, K6]. In fact, higher levels of dark matter hierarchy motivate the introduction of the notions of super-genome and hyper-genome. The genomes of entire organ can join to form super-genome expressing genes coherently. Hyper-genomes would result from the fusion of genomes of different organisms and collective levels of consciousness would express themselves via hyper-genome and make possible social rules and moral.

3 Quantum Biology And Quantum Neuroscience In TGD Universe

Quantum biology - rather than only quantum brain - is an essential element of Quantum Mind in TGD Universe. Cells, biomolecules, and even elementary particles are conscious entities and the biological evolution is evolution of consciousness so that it would be very artificial to restrict the discussion to brain, neurons, or microtubules.

3.1 Basic Physical Ideas

The following list gives the basic elements of TGD inspired quantum biology.

1. Many-sheeted space-time allows the interpretation of the structures of macroscopic world around us in terms of space-time topology. Magnetic/field body acts as intentional agent using biological body as a sensory receptor and motor instrument and controlling biological body and inheriting its hierarchical fractal structure. Fractal hierarchy of EEGs and its variants can be seen as communication and control tools of magnetic body. Also collective levels of consciousness have a natural interpretation in terms of magnetic body. Magnetic body makes also possible entanglement in macroscopic length scales. The braiding of magnetic flux tubes makes possible topological quantum computations and provides a universal mechanism of memory. One can also understand the real function of various information molecules and corresponding receptors by interpreting the receptors as addresses in quantum computer

memory and information molecules as ends of flux tubes which attach to these receptors to form a connection in quantum web.

2. Magnetic body carrying dark matter and forming an onion-like structure with layers characterized by large values of Planck constant is the key concept of TGD inspired view about Quantum Mind to biology. Magnetic body is identified as intentional agent using biological body as sensory receptor and motor instrument. EEG and its fractal variants are identified as a communication and control tool of the magnetic body and a fractal hierarchy of analogs of EEG is predicted. Living system is identified as a kind of Indra's net with biomolecules representing the nodes of the net and magnetic flux tubes connections between them.

The reconnection of magnetic flux tubes and phase transitions changing Planck constant and therefore the lengths of the magnetic flux tubes are identified as basic mechanisms behind DNA replication and analogous processes and also behind the phase transitions associated with the gel phase in cell interior. The braiding of magnetic flux makes possible universal memory representation recording the motions of the basic units connected by flux tubes. Braiding also defines topological quantum computer programs updated continually by the flows of the basic units. The model of DNA as topological quantum computer is discussed as an application. In zero energy ontology the braiding actually generalize to 2-braiding for string world sheets in 4-D space-time and brings in new elements.

3. Zero energy ontology (ZEO) makes possible the proposed p-adic description of intentions and cognitions and their transformations to action. Time mirror mechanism (see **Fig.** <http://tgdtheory.fi/appfigures/timemirror.jpg> or **Fig. ??** in the appendix of the book) based on sending of negative energy signal to geometric past would apply to both long term memory recall, remote metabolism, and realization of intentional acting as an activity beginning in the geometric past in accordance with the findings of Libet. ZEO gives a precise content to the notion of negative energy signal in terms of zero energy state for which the arrow of geometric time is opposite to the standard one.

The associated notion of causal diamond (CD) is essential element and assigns to elementary particles new fundamental time scales which are macroscopic: for electron the time scale is .1 seconds, the fundamental biorhythm. An essentially new element is time-like entanglement which allows to understand among other things the quantum counterparts of Boolean functions in terms of time-like entanglement in fermionic degrees of freedom.

4. The assignment of dark matter with a hierarchy of Planck constants gives rise to a hierarchy of macroscopic quantum phases making possible macroscopic and macrotemporal quantum coherence and allowing to understand evolution as a gradual increase of Planck constant. The model for dark nucleons leads to a surprising conclusion: the states of nucleons correspond to DNA, RNA, tRNA, and amino-acids in a natural manner and vertebrate genetic code as correspondence between DNA and amino-acids emerges naturally. This suggests that genetic code is realized at the level of dark hadron physics and living matter in the usual sense provides a secondary representation for it.

The hierarchy of Planck constants emerges from basic TGD under rather general assumptions. The key element is the huge vacuum degeneracy which implies that preferred non-vacuum extremals of Kähler action form a 4-D spin glass phase. The basic implications following from the extreme non-linearity of Kähler action is that normal derivatives of embedding space coordinates at 3-D light-like orbits of partonic 2-surfaces and at space-like 3-surfaces at ends of CDs are many-valued functions of canonical momentum densities: this is one of the reasons that forced to develop physics as an infinite-D Kähler geometry vision instead of trying to develop path integral formalism or canonical quantization. A convenient manner to treat the situation is to introduce local many-sheeted covering of embedding space such that the sheets are completely degenerate at partonic 2-surfaces. This leads in natural manner to the hierarchy of Planck constants as effective hierarchy hierarchy and integer multiples of Planck constants emerge naturally.

5. p-Adic physics can be identified as physics of cognition and intentionality. The hierarchy of p-adic length scales predicts a hierarchy of universal metabolic quanta as increments of zero point kinetic energies. Negentropic entanglement (see **Fig.** <http://tgdtheory.fi/appfigures/cat.jpg> or **Fig. ??** in the appendix of this book) possible for number theoretic

entanglement entropy makes sense for rational (and even algebraic) entanglement and leads to the identification of life as something residing in the intersection of real and p-adic worlds. NMP respects negentropic entanglement and the attractive idea is that the experience of understanding and positively colored emotions relate to negentropic entanglement.

6. Living matter as conscious hologram is one of the basic ideas of TGD inspired biology and consciousness theory. The basic objection against TGD is that the interference of classical fields is impossible in the standard sense for the reason that classical fields are not primary dynamical variables in TGD Universe. The resolution is based on the observation that only the interference of the effects caused by these fields can be observed experimentally and that many-sheeted space-time allows to realize the summation of effects in terms of multiple topological condensations of particles to several parallel space-time sheets. One concrete implication is fractality of qualia. Qualia appear in very wide range of scales: our qualia could in fact be those of magnetic body. The proposed mechanism for the generation of qualia realizes the fractality idea.

3.2 Brain In TGD Universe

Brain cognizes and one should find physical correlates for cognition. Also the precise role of brain in information processing and its relationship to metabolism should be understood. Here magnetic body brings as a third player to the couple formed by environment and organism.

1. An attractive idea is that the negentropic entanglement can be assigned with magnetic flux tubes somehow and that ATP serves as a correlate for negentropic entanglement. This leads to a rather detailed ideas about the role of phosphate bond and provides interpretation for the fact that the number of valence bonds tend to be maximized in living matter. In a loose sense one could even call ATP a consciousness molecule. The latest view encourages to consider the possibility that negentropic entanglement with what might be called Mother Gaia is what is transferred in metabolism.
2. The view about the function of brain differs from the standard view. The simplest option is that brain is a builder of symbolic representations building percepts and giving them names rather than the seat of primary qualia relevant to our conscious experience. Sensory organs would carry our primary qualia and brain would build sensory percepts as standardized mental images by using virtual sensory input to the sensory organs. The new view about time is absolutely essential for circumventing the objections against this vision. The prediction is that also neuronal and even cell membranes define sensory maps with primary qualia assignable to the lipids serving as pixels of the sensory screen. These qualia would not however represent our qualia but lower level qualia. At this moment it is not possible to choose between these two options.
3. The role of EEG and its various counterparts at fractally scaled frequency ranges is to make possible communications to the various onion-like layers of the magnetic body and the control by magnetic body. Dark matter at these layers could be seen as the intentional agent and sensory perceiver.

3.3 Anomalies

Various anomalies of living matter have been in vital role in the development of not only TGD view about living matter but also TGD itself.

1. TGD approach to living matter was strongly motivated by the findings about strange behavior of cell membrane and of cellular water, and gel behavior of cytoplasm. Also the findings about effects of ELF em fields on vertebrate brain were decisive and led to the proposal of the hierarchy of Planck constants found later to emerge naturally from the non-determinism of Kähler action. Rather satisfactorily, the other manner to introduce the hierarchy of Planck constants is in terms of gravitational Planck constant: at least in microscopic scales the equivalence of these approaches makes sense and leads to highly non-trivial predictions. The basic testable prediction is that dark photons have cyclotron frequencies inversely proportional to their masses but universal energy spectrum in visible and UV range which corresponds

to the transition energies for biomolecules so that they are ideal for biocontrol at the level of both magnetic bodies and at the level of biochemistry.

2. Water is in key role in living matter and also in TGD inspired view about living matter. The anomalies of water lead to a model for dark nuclei as dark proton strings with the surprising prediction that DNA, RNA, amino-acids and even tRNA are in one-one correspondence with the resulting 3-quark states and that vertebrate genetic code emerges naturally. This leads to a vision about water as primordial life form still playing a vital role in living organisms. The model of water memory and homeopathy in turn generalizes to a vision about how immune system might have evolved.
3. Metabolic energy is necessary for conscious information processing in living matter. This suggests that metabolism should be basically transfer of negentropic entanglement from nutrients to the organism. ATP could be seen as a molecule of consciousness in this picture and high energy phosphate bond would make possible the transfer of negentropy.

4 Bird's Eye of View about the Topics of the Book

This book tries to give an overall view about TGD inspired theory of consciousness as it stands now. In nutshell TGD based view about consciousness relies following ideas and concepts.

1. The basic notions TGD inspired theory of consciousness are quantum jump identified as a moment of consciousness, self identified as sequence of quantum jumps analogous to bound state of particles, self hierarchy with sub-selves experienced by self as mental images, and sharing and fusion of mental images by quantum entanglement.
2. Dark matter hierarchy, the levels of which are labeled by increasing quantized value of Planck constant, suggests that the geometric durations for the moments of consciousness form defined as the scale of the space-time volume from which conscious experience is about, form an increasing hierarchy so that the highest level associated with a given self would correspond to single moment of consciousness. This would actually eliminate the notion of self and self hierarchy would correspond to a fractal hierarchy of quantum jumps.
3. The anatomy of quantum jumps must be consistent with the notions of state preparation, state function reduction, and unitary evolution and this leads to a detailed view what quantum jump means for quantum states of the Universe identified as classical spinor fields in configuration space, the "world of classical worlds". The zero modes of the configuration space geometry which do not contribute to its metric and thus do not quantum fluctuate, correspond to classical observables. A direct connection with quantum measurement theory emerges.
4. Negentropy Maximization Principle (NMP) defines the basic variational principle of TGD inspired theory of consciousness. NMP states that the negentropy gain in quantum jump is maximal. The allowance of a number theoretic variant of Shannon entropy making sense for rational or algebraic entanglement probabilities implies that quantum jump can also generate or increase the amount of entanglement. A possible interpretation is in terms of bound state entanglement to which conscious information can be assigned.
5. A natural characterization of the fundamental qualia is in terms of quantum number increments associated with the quantum jump. The classical non-determinism of Kähler action (in the usual sense of the world) means that the contents of the conscious experience of a given self comes from a 4-dimensional space-time region rather than representing 3-D snapshot of space-time. This together with the new view about energy and time (negative energies and communications to the geometric past are predicted) leads to a new vision about memory, intentional action, and also metabolism.
6. p-Adic physics as physics of cognition is a genuinely new element as compared to the existing theories of consciousness and forces to give up the view that cognition is localized in the sense of real physics. Indeed, p-adic space-time sheets representing intentions have literally infinite size since most p-adic integers, in particular those which are infinitesimally small, have infinitely large as real numbers. Cognition would quite literally see the real cosmos from outside. The transformations of p-adic space-time sheets to real ones in quantum jump define an attractive view about what happens when intention transforms to an action and is

consistent with TGD based view about energy (also negative inertial energies are possible and the density of inertial energy vanishes in cosmological length scales). The discrete rational projection of p-adic space-time sheets to the real embedding space is excellent candidate for the realization of cognitive representations at the level of space-time since p-adic numbers define very naturally a generalization of binary logic and for primes satisfying p-adic length scale hypothesis the resulting logic has also Boolean interpretation as a logic in which certain number of statements are taboos so that the number of allowed statements is reduced from 2^k to $p = 2^k - n$.

7. The new view about the relationship between experienced and geometric time inspires a general model of memory, intentional action, and metabolism. In this model time mirror mechanism meaning communications with geometric past using negative energy (phase conjugate photons) is in central role. Also time-like entanglement plays a key role in the model of memories. A precise conceptualization for this vision is provided by zero energy ontology in which M-matrix generalizes S-matrix. M-matrix is identifiable as the “square” root of density matrix defines time like entanglement coefficients between positive and negative energy parts of the zero energy state located at past and future boundaries of the causal diamond defined by the intersection of future and past directed light-cones.

4.1 The organization of “TGD Inspired Theory of Consciousness”

The topics of the book are organized in the following manner.

1. In the 1st part of the book TGD inspired theory of consciousness is discussed at general level. There are three summarizing chapters give a view about how ideas have evolved. Besides this there are chapters devoted to Negentropy Maximization Principle (NMP), to a detailed exposition of the notion of self, and to a model of sensory representations.
The views about what NMP really states have fluctuated during years and in the recent number theoretical vision NMP follows as almost trivial consequence and applies only in statistical sense. What is however essential that any system pair can experience what can called quantum measurement of the density matrix describing their mutual entanglement.
In zero energy ontology (ZEO) second important aspect is that there are two kinds of quantum measurements: “big” state function reductions which correspond to state function reductions in the ordinary sense - in these the arrow of time is changed - and “small” state function reductions which would correspond to so called weak measurements. ZEO energy ontology can be said to lift quantum measurement theory to a theory of consciousness by making observer a part of the physical system.
2. 2nd part of the book contains three chapters about the relationship between experienced and geometric time. The first one is more than decade old. The second one - inspired by zero energy ontology and written quite recently - provides a rather detailed vision about how the arrow of geometric time correlating with the arrow of experienced time and the localization of the contents of sensory experience to a narrow time interval emerge. The chapter explaining TGD based view about long term memory is also included.
3. The 3rd part of the book summarizes roughly decade old view about intelligence and cognition. p-Adic physics as physics of cognition and intentionality and many-fermion states as representations of Boolean statements are the key notions. In zero energy ontology also quantal versions of logical rules $A \rightarrow B$ realized as quantum variants of Boolean functions emerge at the fundamental level.
A chapter about the role of dark matter hierarchy, in particular about topological quantum computation as a universal information processing tool, and a chapter about adelic physics as a mathematical description of physics of both sensory experience and cognition, would be needed to make the picture correspond to the recent understanding.
4. The 4th part is devoted to remote mental interactions. The theoretical motivation for taking remote mental interactions seriously is that exactly the same mechanisms which are involved with the interaction between magnetic body and biological body apply also to remote mental interactions in TGD Universe. One could also understand why these phenomena are rare: a kind of immune system making it impossible for foreign magnetic bodies to control and

communicate with the biological body possessed by a particular magnetic body would be a highly probable (but perhaps not unavoidable) outcome of evolutionary process.

5 Sources

The eight online books about TGD [K30, K29, K20, K15, K4, K14, K8, K24] and nine online books about TGD inspired theory of consciousness and quantum biology [K27, K3, K16, K2, K7, K9, K11, K23, K26] are warmly recommended for the reader willing to get overall view about what is involved.

My homepage (<http://tinyurl.com/ybv8dt4n>) contains a lot of material about TGD. In particular, a TGD glossary at <http://tinyurl.com/yd6jf3o7>.

I have published articles about TGD and its applications to consciousness and living matter in *Journal of Non-Locality* (<http://tinyurl.com/ycyrxj4o> founded by Lian Sidorov and in *Prespacetime Journal* (<http://tinyurl.com/ycvktjhn>), *Journal of Consciousness Research and Exploration* (<http://tinyurl.com/yba4f672>), and *DNA Decipher Journal* (<http://tinyurl.com/y9z52khg>), all of them founded by Huping Hu. One can find the list about the articles published at <http://tinyurl.com/ybv8dt4n>. I am grateful for these far-sighted people for providing a communication channel, whose importance one cannot overestimate.

6 The contents of the book

6.1 PART I: BASIC IDEAS OF TGD INSPIRED THEORY OF CONSCIOUSNESS

6.1.1 Matter, Mind, Quantum

This chapter is devoted to the TGD inspired theory of consciousness. TGD inspired theory of consciousness could be seen as a generalization of quantum measurement theory to make observer, which in standard quantum measurement theory remains an outsider, a genuine part of physical system subject to laws of quantum physics. The basic notions are quantum jump identified as moment of consciousness and the notion of self: zero energy ontology (ZEO) is essential for the notion of self. Negentropy Maximization Principle (NMP) defines the dynamics of consciousness and as a special case reproduces standard quantum measurement theory.

1. *Quantum jump as moment of consciousness*

TGD suggests that the quantum jump between quantum histories could identified as moment of consciousness and could therefore be for consciousness theory what elementary particle is for physics.

This means that subjective time evolution corresponds to the sequence of quantum jumps $\Psi_i \rightarrow U\Psi_i \rightarrow \Psi_f$ consisting of unitary process followed by state function process. In zero energy ontology (ZEO) U defines a unitary matrix between zero energy states and is naturally assignable to intentional actions whereas the ordinary S-matrix telling what happens in particle physics experiment (for instance) generalizes to M-matrix defining time-like entanglement between positive and negative energy parts of zero energy states. One might say that U process corresponds to a fundamental act of creation creating a quantum superposition of possibilities and the remaining steps generalizing state function reduction process select between them.

2. *Negentropy Maximization Principle and the notion of self*

U -process is followed by a cascade of state function reductions. Negentropy Maximization Principle (NMP) states that in a given quantum state the entangled subsystem-complement pair with largest entanglement entropy can perform the quantum jump. More precisely: the reduction of the entanglement entropy in the quantum jump is as large as possible. This selects the pair in question and in case of ordinary entanglement entropy leads the selected pair to a product state. The interpretation of the reduction of the entanglement entropy as conscious information gain makes sense. The sequence of state function reductions decomposes at first step the entire system to two parts in such a manner that the reduction entanglement entropy is maximal. This process

repeats itself for subsystems. If the subsystem in question cannot be divided into a pair of entangled free system the process stops since energy conservation does not allow it to occur (binding energy) or the resulting entanglement is negentropic for all sub-system-complement divisions.

The original definition of self was as a subsystem able to remain unentangled under state function reductions associated with subsequent quantum jumps. Everything is consciousness but consciousness can be lost. Second aspect of self was assumed to be the integration of subsequent quantum jumps to coherent whole giving rise to the experienced flow of time.

What is the precise identification of self allowing to understand both of these aspects turned out to be difficult problem. I became aware the solution of the problem in terms of ZEO only quite recently (2014). Self indeed corresponds to a sequence of quantum jumps integrating to single unit, but these quantum jumps correspond to state function reductions to a fixed boundary of causal diamond (CD) leaving the corresponding parts of zero energy states invariant. In positive energy ontology these repeated state function reductions would have no effect on the state but in TGD framework there occurs a change for the second boundary and gives rise to the experienced flow of time and its arrow and gives rise to self. The first quantum jump to the opposite boundary corresponds to the act of free will or wake-up of self.

p-Adic physics as correlate for cognition and intention leads to the notion of negentropic entanglement possible in the intersection of real and p-adic worlds involves experience about expansion of consciousness. Consistency with standard quantum measurement theory forces negentropic entanglement to correspond to density matrix proportional to unit matrix. Unitary entanglement typical for quantum computing systems gives rise to unitary entanglement.

The first state function reduction - wake-up of self- at given boundary of CD is a hierarchical cascade proceeding from long to short scales. The reduction process can stop also if the self in question allows only decompositions to pairs systems with negentropic entanglement. This does not require that that the system forms a bound state for any pair of subsystems so that the systems decomposing it can be free (no binding energy). This defines a new kind of bound state not describable as a jail defined by the bottom of a potential well. Subsystems are free but remain correlated by negentropic entanglement.

Ordinary state function reductions imply dissipation crucial for self organization and quantum jump could be regarded as the basic step of an iteration like process leading to the asymptotic self-organization patterns. One could regard dissipation as a Darwinian selector as in standard theories of self-organization. NMP predicts that self organization and hence presumably also fractalization can occur inside selves. NMP would favor the generation of negentropic entanglement. This notion is highly attractive since it could allow to understand how quantum self-organization generates larger coherent structures. Note that state function reduction for negentropic entanglement is highly deterministic since the number of degenerate states with same negative entanglement entropy is expected to be small. This could allow to understand how living matter is able to develop almost deterministic cellular automaton like behaviors. In ZEO this self-organization is for 4-D spatio-temporal patterns since 3-surfaces are pairs of space-like surfaces at the boundaries of CD and maxima of Kähler function are selected in the process. These temporal patterns correspond to behaviors and functions in living matter.

The chapter is devoted to the discussion of detailed implications of these general ideas. The topics to be discussed include following basic questions.

1. How the general structure for the contents of consciousness of self are determined? The basic assumption is that self hierarchy in which subselves define mental images of self is responsible for the general structure of conscious experience. ZEO allows to derive the space-time correlates of selves.
2. How the physical realization of the hardware of consciousness differs from that assumed in neuroscience? Here the notion of magnetic body as intentional agent using biological body as motor instrument and sensory receptor is central.
3. What is the precise relationship between the geometric time of physicist and subjective time identified in terms of a sequence of quantum jumps? ZEO gives the most convincing answer to this question found hitherto.
4. What can one say about various types of conscious experience in the proposed framework. This includes p-adic description of cognition and intentional action, model for sensory

experience and sensory qualia, model for Boolean mind in terms of fermions, a model for directed attention, ideas about emotions, and also a general interpretation for altered states of consciousness based on the special features of negentropic entanglement.

5. Can one provide solutions to the paradoxes of quantum physics, theories of consciousness, and logic in the proposed conceptual framework?

The discussion differs considerably from the earlier one. The reason is that the developments occurred during period 2005-2010 (ZEO, hierarchy of Planck constants assigned to dark matter, hyper-finite factors of type II_1 , the implications of the number theoretical negentropies) are introduced from the beginning to the formulation of the theory rather than as additions to the existing text so that the representation is more coherent and the number of internal inconsistencies is minimized. The latest progress relates to the understanding of the notions of psychological time and self (2012-2014).

6.1.2 Negentropy Maximization Principle

In TGD Universe the moments of consciousness are associated with quantum jumps between quantum histories. The proposal is that the dynamics of consciousness is governed by Negentropy Maximization Principle (NMP), which states the information content of conscious experience is maximal. The formulation of NMP is the basic topic of this chapter.

NMP codes for the dynamics of standard state function reduction and states that the state function reduction process following U -process gives rise to a maximal reduction of entanglement entropy at each step. In the generic case this implies at each step a decomposition of the system to unique unentangled subsystems and the process repeats itself for these subsystems. The process stops when the resulting subsystem cannot be decomposed to a pair of free systems since energy conservation makes the reduction of entanglement kinematically impossible in the case of bound states. The natural assumption is that self loses consciousness when it entangles via bound state entanglement.

There is an important exception to this vision based on ordinary Shannon entropy. There exists an infinite hierarchy of number theoretical entropies making sense for rational or even algebraic entanglement probabilities. In this case the entanglement negentropy can be negative so that NMP favors the generation of negentropic entanglement (NE), which is not bound state entanglement in standard sense since the condition that state function reduction leads to an eigenstate of density matrix requires the final state density matrix to be a projection operator.

NE might serve as a correlate for emotions like love and experience of understanding. The reduction of ordinary entanglement entropy to random final state implies second law at the level of ensemble. For the generation of NE the outcome of the reduction is not random: the prediction is that second law is not a universal truth holding true in all scales. Since number theoretic entropies are natural in the intersection of real and p -adic worlds, this suggests that life resides in this intersection. The existence effectively bound states with no binding energy might have important implications for the understanding the stability of basic bio-polymers and the key aspects of metabolism. A natural assumption is that self experiences expansion of consciousness as it entangles in this manner. Quite generally, an infinite self hierarchy with the entire Universe at the top is predicted.

There are two options to consider. Strong form of NMP, which would demand maximal negentropy gain: this would not allow morally responsible free will if ethics is defined in terms of evolution as increase of NE resources. Weak form of NMP would allow self to choose also lower-dimensional sub-space of the projector defining the final state sub-space for strong form of NMP. Weak form turns out to have several highly desirable consequences: it favours dimensions of final state space coming as powers of prime, and in particular dimensions which are primes near powers of prime: as a special case, p -adic length scale hypothesis follows. Weak form of NMP allows also quantum computations, which halt unlike strong form of NMP.

Besides number theoretic negentropies there are also other new elements as compared to the earlier formulation of NMP.

1. ZEO modifies dramatically the formulation of NMP since U -matrix acts between zero energy states and can be regarded as a collection of orthonormal M -matrices, which generalize the ordinary S -matrix and define what might be called a complex square root of density matrix

so that kind of a square root of thermodynamics at single particle level justifying also p-adic mass calculations based on p-adic thermodynamics is in question.

2. The hierarchy of Planck constants labelling a hierarchy of quantum criticalities is a further new element having important implications for consciousness and biology.
3. Hyper-finite factors of type II_1 represent an additional technical complication requiring separate treatment of NMP taking into account finite measurement resolution realized in terms of inclusions of these factors.

NMP has wide range of important implications.

1. In particular, one must give up the standard view about second law and replace it with NMP taking into account the hierarchy of CDs assigned with ZEO and dark matter hierarchy labelled by the values of Planck constants, as well as the effects due to NE. The breaking of second law in standard sense is expected to take place and be crucial for the understanding of evolution.
2. Self hierarchy having the hierarchy of CDs as embedding space correlate leads naturally to a description of the contents of consciousness analogous to thermodynamics except that the entropy is replaced with negentropy.
3. In the case of living matter NMP allows to understand the origin of metabolism. NMP demands that self generates somehow negentropy: otherwise a state function reduction to the opposite boundary of CD takes place and means death and re-incarnation of self. Metabolism as gathering of nutrients, which by definition carry NE is the manner to avoid this fate. This leads to a vision about the role of NE in the generation of sensory qualia and a connection with metabolism. Metabolites would carry NE and each metabolite would correspond to a particular qualia (not only energy but also other quantum numbers would correspond to metabolites). That primary qualia would be associated with nutrient flow is not actually surprising!
4. NE leads to a vision about cognition. Negentropically entangled state consisting of a superposition of pairs can be interpreted as a conscious abstraction or rule: negentropically entangled Schrödinger cat knows that it is better to keep the bottle closed.
5. NMP implies continual generation of NE. One might refer to this ever expanding universal library as “Akaschic records”. NE could be experienced directly during the repeated state function reductions to the passive boundary of CD - that is during the life cycle of sub-self defining the mental image. Another, less feasible option is that interaction free measurement is required to assign to NE conscious experience. As mentioned, qualia characterizing the metabolite carrying the NE could characterize this conscious experience.
6. A connection with fuzzy qubits and quantum groups with NE is highly suggestive. The implications are highly non-trivial also for quantum computation allowed by weak form of NMP since NE is by definition stable and lasts the lifetime of self in question.

6.1.3 Self and Binding: Part I

This chapter is the first part of a representation devoted to the notion of self. The original definition of self was as a subsystem able to remain unentangled under state function reductions associated with subsequent quantum jumps. Everything is consciousness but consciousness can be lost if self develops bound state entanglement during U process so that state function reduction to smaller un-entangled pieces is impossible. A second aspect of self was assumed to be the integration of subsequent quantum jumps to coherent whole giving rise to the experienced flow of time. This view had however problems, which are rather obvious and it seems that new physics is needed.

The TGD based notion of self involves several new physics ingredients. These include Zero Energy Ontology (ZEO), hierarchy of Planck constants labelling a fractal hierarchy of quantum critical systems, and adelic view about quantum physics fusing real and various p-adic physics serving as correlates of cognition to single coherent whole.

Negentropic entanglement is a crucial notion. There exists an infinite hierarchy of number theoretical entropies making sense for rational or even algebraic entanglement probabilities. In this case the entanglement negentropy can be negative so that Negentropy Maximization Principle

(NMP) favors generation of negentropic entanglement, which need not be bound state entanglement in standard sense. This leads to the vision that negentropic entanglement defines kind of Akashic records, kind of library storing potentially conscious information becoming conscious in interaction free measurement. Akashic records could define self model as opposed to self. Consistency with standard quantum measurement theory requires that density matrix for negentropic entanglement is projector and thus proportional to unit matrix associated to entanglement matrix characterized by a unitary matrix associated with quantum computation.

What is the precise identification of self allowing to understand both of the above mentioned aspects turned out to be difficult problem. I became aware the solution of the problem in terms of ZEO only rather recently (2014). Self indeed corresponds to a sequence of quantum jumps integrating to single unit, but these quantum jumps correspond to state function reductions to a fixed boundary of CD leaving the corresponding parts of zero energy states invariant. In positive energy ontology these repeated state function reductions would have no effect on the state but in TGD framework there occurs a change for the second boundary and gives rise to the experienced flow of time and its arrow and gives rise to self. The first quantum jump to the opposite boundary corresponds to the act of free will and death of self and its re-incarnation at the opposite boundary CD. Also the arrow of geometric time is changed.

Self is assumed to experience sub-selves as mental images identifiable as “averages” of their mental images. This implies the notion of ageing of mental images as being due to the growth of ensemble entropy as the ensemble sub-sub-selves increases.

The sub-selves of two unentangled selves can entangle although selves remain unentangled. This is possible by the modification of the subsystem concept forced by the p-adic length scale cutoff. The entanglement of sub-selves means fusion and sharing of mental images providing a universal telepathy like quantum communication mechanism and presumably making possible both molecular, cellular, and human societies.

6.1.4 Self and Binding: Part II

This chapter is second part of a representation devoted to the notion of self as it is understood in TGD framework.

The possibility of negentropic entanglement has profound implications. It leads to a vision about learning as a basic quantum process possible in the intersection of real and p-adic worlds and made possible because state function reduction ceases to be a random process for negentropically quantum states. Quite concrete ideas about the role of synaptic transmission and neural transmitters for consciousness emerge. Music experience provides an especially interesting application for the vision about consciousness and zero energy ontology together with number theoretical vision inspires several concrete interpretations. Synchronous firing of neurons- in particular at 40 Hz frequency- is an attractive correlate for the negentropic entanglement and synesthesia can be interpreted as a particular manifestations of negentropic entanglement.

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. Indeed, the notion of magnetic body as a space-time correlate of self has become a key concept in TGD inspired biology. Magnetic body carrying dark matter identified as large h_{eff} phases can be seen as intentional agent using biological body as motor instrument and sensory receptor.

6.1.5 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 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. The vision goes as follows.

1. 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. 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.
2. 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). Zero energy ontology (ZEO) provides a firm theoretical justification for the notion of negative energy signal to past obeying reversed arrow of time.
3. 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 correspondin 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.
4. 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 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. In zero energy ontology causal diamonds become the embedding space correlates of mental images and one can ask whether Negentropy Maximization Principle -perhaps suitably generalized- could force their generation.
5. 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.

6. Zero energy ontology together with the notion of causal diamond (CD) identified as embedding space correlate of self and the moduli space of CD s, the description of dark matter in terms of a hierarchy of Planck constants implying a generalization of the notion of the imbedding space, and the vision about living matter as something residing in the intersection of real and p-adic worlds and carrying positive entanglement negentropy allow to make this vision more detailed and lead to surprisingly precise quantitative predictions and connect the basic biological time scales to those assignable to elementary particles in zero energy ontology. The notion of spectroscopy of consciousness can be formulated for the geometric aspects of conscious experience in terms of the moduli space of causal diamonds and the frequencies of the generalized EEG.

6.2 PART II: TIME AND CONSCIOUSNESS

6.2.1 Time and Consciousness

This chapter as also other chapters about the notion of time appearing in books about TGD inspired theory of consciousness should be taken as stories about how ideas developed through many tortuous twists and turns. In this abstract I only summarize the outcome and leave the description of the tortuous path to the chapter.

If one accepts the identification of moment of consciousness as quantum jump between quantum histories, 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 as such 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 understanding of the notion of psychological time and its arrow - or equivalently, the relationship between subjective and geometric time - turned out to be quite difficult challenge and led to a handful of proposals based on the identification of space-time sheet as a correlate of self and the idea that the experienced flow of geometric correspond to some kind of motion in space-time or in embedding space. These identifications did not lead to anything practical and generated paradoxes. Also the notion of self turned to be problematic.

The most recent proposal involves no ad hoc assumptions and relies on the recent formulation of quantum TGD using zero energy ontology (ZEO) and the understanding of both nature of time and self reduces to a more precise view about what happens in state function reduction in ZEO.

1. The embedding space correlate of self is so called causal diamond (pair of future and past directed light-cones) which is 8-D sub-manifold of the embedding space rather than space-time sheet.
2. In ZEO state function reduction can occur at both boundaries of CD but can occur repeatedly at given CD boundary. In the repeated reduction the already reduced positive/negative energy state remains the same just as the state function remains invariant in ordinary repeated state function reduction. Second boundary of CD corresponds to a wave function in the moduli space of CD s and changes: since the distance between the tips of CD is one particular modular degree of freedom, the average value of this distance tends to increase just as the distance of particle diffusing inside cone increases during diffusion. This gives rise to the experience flow of geometric time identified this temporal distance.
3. Self can be understood as a sequence of repeated state functions at the same boundary - the original identification was as sequence of all quantum jumps. The arrow of geometric time changes at some level of self hierarchy when quantum jump takes at the second boundary of CD and could correspond to volition, act of free will.

4. The notion of negentropic entanglement also leads to a model for self model to be carefully distinguished from self.

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.

6.2.2 About the Nature of Time

This chapter as also other chapters about the notion of time appearing in books about TGD inspired theory of consciousness should be taken as stories about how ideas developed through many tortuous twists and turns. In this abstract I only summarize the outcome and leave the description of the tortuous path to the chapter.

The identification of the experienced time t_e and geometric time t_g involves well-known problems. Physicist is troubled by the reversibility of t_g contra irreversibility of t_e , by the conflict between determinism of Schrödinger equation and the non-determinism of state function reduction, and by the poorly understood the origin of the arrow of t_g . In biology the second law of thermodynamics might be violated in its standard form for short time intervals. Neuroscientist knows that the moment of sensory experience has a finite duration, does not understand what memories really are, and is bothered by the Libet’s puzzling finding that neural activity seems to precede conscious decision.

These problems are discussed in the framework of Topological Geometroynamics (TGD) and TGD inspired theory of consciousness constructed as a generalization of quantum measurement theory. In TGD space-times are regarded as 4-dimensional surfaces of 8-dimensional space-time $H = M^4 \times CP_2$ and obey classical field equations.

The basic notions of consciousness theory are quantum jump and self. Subjective timew as originally identified as a sequence of quantum jumps, which somehow integrate to form single coherent entity, self. Self has as a geometric correlate a fixed volume of H - “causal diamond”-defining the perceptive field of self. This picture leaves however open two key questions. How the arrow of time and localization of contents of sensory experience emerge and what self do really mean? This chapter discusses several approaches to the problem.

The most recent and one might hope also the final proposal involves no ad hoc assumptions and relies on the recent formulation of quantum TGD using zero energy ontology (ZEO) and the understanding of both nature of time and self reduces to a more precise view about what happens in state function reduction in ZEO.

1. The embedding space correlate of self is so called causal diamond (pair of future and past directed light-cones) which is 8-D sub-manifold of the embedding space rather than space-time sheet.
2. In ZEO state function reduction can occur at both boundaries of CD but can occur repeatedly at given CD boundary. In the repeated reduction the already reduced positive/negative energy state remains the same just as the state function remains invariant in ordinary repeated state function reduction. Second boundary of CD corresponds to a wave function in the moduli space of CDs and changes: since the distance between the tips of CD is one particular modular degree of freedom, the average value of this distance tends to increase just as the distance of particle diffusing inside cone increases during diffusion. This gives rise to the experience flow of geometric time identified this temporal distance.
3. Self can be understood as a sequence of repeated state functions at the same boundary - the original identification was as sequence of all quantum jumps. The arrow of geometric time changes at some level of self hierarchy when quantum jump takes at the second boundary of CD and could correspond to volition, act of free will.

4. The notion of negentropic entanglement also leads to a model for self model to be carefully distinguished from self.

6.2.3 Quantum Model of 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.

1. 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.
2. 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.

3. Zero energy ontology (ZEO) brings in the possibility of temporary change of the arrow of geometric time at some level of the hierarchy of space-time sheets. This provides a justification for the notion of negative energy signals. 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 a 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 hierarchy of Planck constants emerging from the non-determinism of Kähler action implying also spin glass degeneracy provides a more precise view about the emergence of quantum

coherence. Also a connection with quantum criticality and hierarchy of breakings of conformal invariance emerges.

The spin glass degeneracy associated with the join along boundaries bonds (the original space-time correlates for the bound state formation replaced later by magnetic flux tubes) lengthens the lifetimes of the bound states dramatically and solves thus the basic objections against quantum consciousness. The spin glass degeneracy is broken only by 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 neuro level model of long term memory is discussed. The model conforms with the basic facts known about the relationship of hippocampus and long term memory.

6.3 PART III: INTELLIGENCE, INFORMATION, AND COGNITION

6.3.1 Conscious Information and Intelligence

The notions of information and intelligence are discussed in TGD framework. Possible 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.

1. The key element of the approach is the number theoretic generalization of entanglement entropy. Quantum entanglement between real and p-adic degrees of freedom makes sense if entanglement coefficients are rational or even 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 information measure for cognitive entanglement, and positive entanglement negentropy can be interpreted as a correlate for the experience of understanding. Number theoretic entanglement measures are natural in what might be called the intersection of real and p-adic worlds (partonic 2-surfaces have mathematical representations making sense both p-adically and in real sense) and this leads to a vision about life as something residing in this intersection. The consistency with standard quantum measurement theory leads to the conclusion that negentropic entanglement must correspond to a density matrix proportional to unit matrix. Entanglement matrix proportional to a unitary matrix characterizing quantum computation gives therefore rise to negentropic entanglement.
2. Various measures for the information contents of consciousness are discussed.
 - (a) The reduction of entanglement entropy defines a natural measure for conscious information gain in single step of the state of state function reduction process decomposing subsystem to a pair of un-entangled sub-systems. If entanglement is negentropic the entanglement negentropy either increases or the system is stable against state function reduction.
 - (b) It seems natural to assume that the information measures are associated with the entire cascade and that they are additive in the sense that information gain is sum over the information gains of the steps of the cascade and that a given step contributes by the sum of the information gains associated with unentangled subsystems which are subject to self measurement in a given step of the cascade.
 - (c) One can also assign information measures to the resulting indecomposable systems. For subsystem which is bound state in the normal sense and thus has entropic entanglement, one can consider all possible decomposition of the system to a sub-system and its complement and define the entanglement negentropy as the negative for the minimum value of entropy obtained in this manner. If the system is negentropically entangled one can

define entanglement negentropy as the maximum of entanglement negentropy obtained in this manner. This means that one can assign to the final state of state function reduction unique negentropy as the sum of the negative contributions associated with selves which are internally bound state entangled and positive contributions of negentropic selves.

- (d) 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. One can also assign to non-decomposable subselves the information measures and they give either positive or negative contribution to the information content of self.
 - (e) In principle this allows to define also the net information gain of quantum jump as the difference of the total negentropies of the final and initial states of quantum jump identified as those produced by the state function reduction process. Initial and final state negentropies would characterize spinor fields of WCW (“world of classical worlds”).
3. Information theoretic interpretation of the Kähler function is discussed in detail. Quantum classical correspondence suggests that the magnetic part of Kähler action would correspond to information content of negentropic entanglement and electric part to the negative information content of entropic bound state entanglement. Kähler function defined as the negative of the Kähler action can be interpreted as an entropy type measure for the information content of the space-time surface. Without quantum criticality entropic configurations carrying strong Kähler electric fields would be favored. The proposal is that the quantum criticality of Kähler action possible for the critical value of Kähler coupling strength makes possible large degeneracy of the negentropic extremals carrying large Kähler magnetic action and makes TGD universe maximally interesting and maximizes its intelligence so that even infinite negentropy is possible. Number theoretical criticality would relate to this criticality very closely. The proposal that living matter is near vacuum extremal so that the degeneracy of negentropic configurations is high is discussed.
 4. The physical interpretation for the hierarchy of Planck constants would be in terms of a hierarchy of quantum criticalities concretizing the vision about quantum criticality of TGD Universe. TGD Universe would be like a hill at the top of a hill at The larger the Planck constant the larger the size scale of the hill. Criticality involves crucially the notion of conformal gauge symmetry. The conformal symmetries correspond to sub-algebra of the full algebra isomorphic to it acting as gauge symmetries and with conformal weights coming as n -multiples of those for the full symmetry algebra. $h_{eff} = n \times h$ would label the levels of the hierarchy. This hierarchy would correspond directly to the hierarchy of measurement resolutions and to hierarchy of hyperfinite factors of type II_1 (HFFs). Also now one obtains infinite hierarchies of symmetry breakings and the identification with the hierarchies of inclusions of HFFs is compelling. Hence various hierarchies reflect the same underlying phenomenon.

The phase transitions reducing criticality would take place spontaneously unlike opposite phase transitions. This vision is especially powerful in biology, where homeostasis could be seen as mechanisms preventing the reduction of criticality but at expense of metabolic energy. The basic goal of living system would be staying at criticality. Eastern philosophies would formulate this fight for staying at criticality using the notions of ego and Karmic cycle. In the phase transition increasing $h_{eff} = n \times h$ part of gauge degrees of freedom assignable to a sub-algebra of the full super-symplectic algebra are transformed to physical ones and this implies better measurement resolution. The new HFF contains the previous one as sub-factor. Evolution understood as increase of h_{eff} forced by Negentropy Maximization Principle as also interpretation improvement of measurement/cognitive resolution.

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

1. Zero energy states -which replace the earlier notion of association sequence inspired by the failure of strict determinism for Kähler action in standard sense - can be seen as memes with M -matrices characterizing the time-like entanglement representing “laws of physics”. Negentropic time like entanglement makes possible for fully state function reduced states to represent rules as quantum superposition of state pairs representing instances $a \rightarrow b$ for a

general rule $A \rightarrow B$. Also space-like negentropic quantum entanglement is important piece of the story. For fermion Fock states this gives Boolean rules as a special case. Zero energy states 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.

2. TGD Universe is quantum computer in a very general sense. Negentropic quantum entanglement stabilizes qubits but makes them fuzzy. This leads to a modification of the standard paradigm of quantum computation. 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 Feynman diagram with lines thickened 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 Feynman diagram: negative energy MEs are the crucial element of sensory perception, motor action, and memory.

3. 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. ZEO and the notion of CD (causal diamond) provides justification for the memetic code and relates it to fundamental elementary particles time scales. The codewords of the memetic code consist of sequences of 126 bits and are represented in terms of nerve pulse sequences or membrane oscillations and time varying quark 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.

6.3.2 p-Adic Physics as Physics of Cognition and Imagination

TGD as a generalized number theory vision supports the interpretation of the p-adic physics in terms of physical correlates of cognition and intentionality so that matter-mind dichotomy would correspond 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.

The vision about life and conscious information and intelligence as something in the intersection of real and p-adic worlds is the key guiding principle also in TGD inspired quantum biology. The very fact that the notion of conscious information makes sense only in this intersection supports the proposed interpretation of p-adic physics. Zero energy ontology (ZEO) and the notion of causal diamond (CD) with zero energy states having interpretation as memes in very general sense is

also of central importance, and allows a quantitative formulation reducing the fundamental bio-rhythms to fundamental elementary particle time scales. The hierarchy of Planck constants as an explanation of dark matter and energy as macroscopic quantum phases even in astrophysical scales and implying that dark matter is a key actor in the drama of life is the third key element.

In this chapter the implications of this vision are studied from the point of view of cognitive consciousness. The basic ideas behind the proposed vision about intentionality and cognition are following.

1. p-Adic space-time sheets are identified as the correlates of cognition and intention. The possibility to identify the inherent non-determinism of the p-adic field equations as the non-determinism of imagination makes this identification attractive. Only the p-adic space-time sheets in the intersection of real and p-adic worlds allow the transformation of intentions to actions and sensory input to cognitions. Cognitions and intentions are related by time reversal in zero energy ontology. The common algebraic points of real and p-adic partonic 2-surfaces in the algebraic extension or rationals guaranteeing that the representation of 2-surface makes sense both in real and p-adic senses define fundamental cognitive representations as finite point sets.
2. 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. This transition can be thought to occur in the intersection of real and p-adic worlds where the mathematical representations of partonic 2-surface make sense both in real and p-adic sense. Motor action would correspond to the transformation of p-adic space-time sheets to their real counterparts and during sensory experience the reversal of this transformation would take place. In zero energy ontology these transformations could reduce to quark and lepton level as is suggested by the fact that the time scales assignable to quarks and leptons correspond to 1 ms and .1 s defining fundamental time scales of nerve pulse activity and EEG.
3. The obvious question is how to test p-adic physics empirically. First of all, thinking could be interpreted as 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.

The following topics are discussed in the chapter.

1. The relationship between p-adic physics, intentionality, and cognition are discussed on general level. Basic cognitive functions such as imagination, hallucinations, formation of cognitive representations, Boolean mind, and learning are discussed in this conceptual framework.
2. Possible - necessarily indirect - evidence for p-adic cognition is considered.
3. In the mathematical sections the relationship between intentionality, cognition and number theory is discussed. Also the relation between p-adic and real physics is discussed at general level with basic vision being that the intersection of real and p-adic space-time sheets in the intersection of real and p-adic worlds consists of points belonging to the algebraic extension of rational needed to guarantee that the mathematical representation of the partonic 2-surface makes sense both in real and p-adic sense.
4. Frontal lobes are known to be the seat of the higher level intentional action and are discussed from p-adic point of view.
5. A generalization of the memetic code to cognitive codes is discussed and some proposals about codes are made. This generalization is based on p-adic length scale hypothesis. If the time scales involved correspond to time scales assignable to the CDs of the known elementary

particles, the generalization is not favored. On the other hand, dark matter sector could allow entire fractal hierarchy of elementary particle physics whose existence is reflected as fundamental bio-rhythms and cognitive codes.

6. The intersection of real and p-adic partonic 2-surfaces defining space-like cognitive representations consist of algebraic points. The hypothesis that these intersections obey various kind of symmetries identifiable as molecular symmetries is discussed.

6.4 PART IV: PARANORMAL PHENOMENA

6.4.1 Quantum Model of Paranormal Phenomena

The general quantum model for bio-systems leads to a model for 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. The basic difference is that magnetic body receives information and controls “foreign” biological (or even magnetic) body or “dead” matter system.

The basic notions of the model are magnetic body as an intentional agent controlling biological body and receiving data from living body or even “dead” matter system with massless extremals (MEs) mediating these communications, zero energy ontology and the related notion of causal diamond (CD) serving as an embedding space correlate of self and assigning to elementary particles fundamental macroscopic time and length scales as those of CD, the hierarchy of Planck constants making possible macroscopic quantum phases and zoom-ups of quantum systems, and the vision about living matter as something residing in the intersection of real and p-adic worlds and the closely related notion of negentropic entanglement crucial for the functioning of living matter and conscious intelligence in TGD Universe.

Negentropic entanglement, which can be both space-like and time-like in zero energy ontology, makes possible quantum superposition of macroscopically different configurations of the target system correlated with the states of operator system. The operator should be able to achieve the negentropic entanglement and intentionally increase the amplitude of the desired outcome in this superposition. Negentropic entanglement need not involve binding energy and I have proposed this as a deeper level explanation for the nebulous notion of high energy phosphate bond crucial for metabolism in living matter. Quite generally, negentropic entanglement would make possible for the operator to transfer metabolic energy and momentum to the target. The hierarchy of values of Planck constant would make possible this process in long time and length scales.

1. Magnetic mirrors (ME-magnetic flux tube pairs) connecting the sender and receiver make possible a universal mechanism for the transfer of intent and action. The pair of flux tubes forms a kind of sensory-motor loop. In biology the fundamental realization could be by a pair of flux sheets going through the strands of DNA with passive strand sending sensory data to the magnetic body and active strand receiving control commands leading to various forms of gene expression. MEs are ideal for the transfer of both classical information and momentum.
2. 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. This makes sense only in the intersection of real and p-adic worlds.
3. 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!).
4. The ME-magnetic flux tube pair connecting sender and receiver can act 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, in living matter sender can initiate complex biological programs without knowing anything about their functioning.

One can distinguish between psychokinesis applied to living matter and “dead” matter.

1. When the target consists of living matter the mechanisms would be same as in communications between magnetic and biological bodies making possible bio-control of biological body by magnetic body and the receipt of sensory input from biological body by magnetic body. Hypnosis would be one example of this kind of interaction.
2. Remote mental interactions in the case “dead” could use simpler variants of the fundamental mechanisms utilized in living matter. For instance, zero energy ontology assigns with the CD of electron and quarks time scales .1 s and 1 ms defining fundamental biorhythms. The CD assignable to elementary particles could be involved also with psychokinesis. Negentropic entanglement could be essential for the transfer of metabolic energy (say in simple psychokinesis moving an object) and for control actions -say in intentional change of sequences of binary digits produced by random number generator. Target system would not be completely “dead”. Thermodynamical restrictions favor large values of Planck constant.

The basic problem in many remote mental interactions such as the intentional effect on random number generator is “Who knows how?”. How the mere intent can be transformed to action without any knowledge about the details of the action? The attempt to understand how neuro-feedback affect the behavior of single neuron leads to the same question.

1. 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.
2. It is quite possible that also multibrained and -bodied higher level collective selves actively participate in the process as a third party such that the remote mental interactions would act as a relay states. I have suggested similar explanation for Sheldrake’s findings about learning at the level of species and Tiller’s findings about the “transfer of intent”. This could make possible coherent amplification effects (TEM, prayer groups) and could make 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.
3. A 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 a fast amplitude modulation of 10 Hz basic vibration frequency of speech organs (assignable to electron CD as a fundamental frequency) and kHz (quarks) frequency is a special frequency from the point of view of hearing.

6.4.2 TGD Based Model for OBEs

Out-of-body experiences (OBEs) are often understood as experience of seeing oneself from a position outside of the body. OBEs are poorly understood in the framework of neuro science and pose a challenge for the reductionistic world view.

In TGD framework the notion of magnetic body provides an attractive starting point in attempts to understand what OBEs and related experiences are. The basic idea is that magnetic body serves effectively as a mirror defining a third person view as a cognitive representation also in ordinary wake-up state and that during OBEs this representation becomes sensory representation. Magnetic body need not always be a personal magnetic body but could correspond to a magnetic body receiving information from several brains (collective consciousness), magnetic body of another person, or be even associated with “dead” matter.

The progress in identifying dark matter as a phase of matter with large value of Planck constant making possible macroscopic quantum coherence has led to the vision about dark matter at magnetic flux quanta as quantum controller of ordinary matter in living systems. The Bose-Einstein condensates of dark photons decaying via decoherence to ordinary photons mediate interactions between ordinary and dark matter and the hypothesis is that dark photon “laser” beams from body and brain reflected at magnetic flux quanta give rise to third person aspect of consciousness

which in OBEs and related experiences are realized as sensory representations. The identification of bio-photons as end products of the de-coherence of dark photon beams is natural.

Zero energy ontology and the notion of causal diamond (or CD defined roughly as the intersection of future and past directed light-cones) brings additional quantitative ingredients to the model. Sub-CDs define embedding space ($M^4 \times CP_2$) correlates for selves and by holography the 2-D partonic 2-surfaces at the light-like future and past boundaries of CDs are the ultimate space-time correlates for mental images. The moduli space for CDs makes possible a more detailed view about sensory representations.

A further new element is the vision about life as something in the intersection of real and p-adic worlds. The most important outcome is that the notion of number theoretic entanglement negentropy making sense in this situation is positive so that entanglement carries conscious information. The fusion of selves (in particular mental image) by negentropic entanglement is experienced as expansion of consciousness. It is negentropic entanglement between parts of biological body and corresponding parts of the magnetic body and biological body which makes living system living. This negentropic entanglement between magnetic body and biological body is important also for OBEs.

The model leads also to a model for dreams, hallucinations, sensory feedback from brain to sensory organs, and directed attention. Concrete models for how dark photons can give rise to experiences in various sensory modalities such as vision, hearing, olfaction, and tactile senses, are proposed.

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