# The recent view of TGD inspired theory of consciousness

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## Contents



**Abstract**

This article gives a summary of TGD inspired theory of consciousness as it is towards the end of 2025. In the TGD framework, it is not possible to discuss consciousness without the TGD view of space-time and quantum. Also the applications to quantum biology and neuroscience have been essential in the development of ideas. The basic inspiration has come from the deep philosophical problems of recent day physics and philosophy of consciousness. The TGD view of consciousness can be seen as a generalization of quantum measurement theory: the observer as an outsider becomes a part of the system.

The basic new element is zero energy ontology (ZEO) as a new quantum ontology forced by the new view of space-time as 4-surfaces analogous to Bohr orbits of particles as 3-D surfaces. The dynamics of the classical space-time obeys holography = holomorphy principle. The failure of a strict classical determinism provides geometric correlates of intention and cognition. ZEO allows us to solve the basic problem of quantum measurement theory, allows free will, and provides a new view of the relation between geometric time and subjective time.

There are two different kinds of existence. Physical existence is identified as the mathematical existence of quantum states: one can speak of quantum Platonia. Conscious existence is identified as quantum jumps between them. The classical non-determinism gives rise to quantum jumps giving rise to conscious entities, selves, and the ordinary quantum jumps are predicted to change the arrow of time. This means death and reincarnation of self with an opposite arrow of time.

Also the number theoretic vision of TGD is central. A key implication of the number theoretic vision is a hierarchy of Planck constants $h_{eff}$ making possible quantum coherence in arbitrarily long scales crucial for the coherence of living matter. p-Adic length scale hierarchy is the second number theoretic prediction. The applications to quantum biology and neuroscience rely on these hierarchies.

In the sequel, the key notions and ideas of TGD, especially those relevant to consciousness and quantum biology, and the recent view of TGD inspired theory of consciousness are summarized.

# 1 Introduction

Topological GeometroDynamics (TGD) [L61, L62] was born as a proposal for a unified theory of fundamental interactions. The basic idea came in 1977 and my thesis was published in 1982. Around 1995 I started a systematical development of TGD inspired theory of consciousness and quantum biology (for a material about TGD see this).

## 1.1 What TGD inspired theory of consciousness is?

TGD inspired theory of consciousness solves the problem of free will. Free will is in conflict with the determinism of classical physics and with the statistical determinism of quantum physics. Also the basic problem of quantum measurement theory is due to the conflict between non-determinism of state function reduction (SFR) and determinism of unitary time evolution. The logical steps of the proposed solution are as follows.

### 1.1.1 The new view about the space-time

Consider first the new vision about space-time.

1. In TGD space-time of general relativity is replaced with a 4-D space-time surface $X^4$ in 8-D embedding space $H = M^4 \times CP_2$ (see the illustration) [L61, L62]. This solves the conflict of general relativity with classical conservation laws: since the $M^4$ factor of $H$ realizes Poincare invariance.

2. The realization of general coordinate invariance requires holography since path integral approach solving it formally does not allow a renormalizable quantum theory. One must be able to assign to a given 3-surface as analog of a particle a 4-surface as its "orbit" obeying holography.

   Holography = holomorphy (H-H) principle allows this. [L56, L63, L58]. By Holography the space-time surface is a minimal surface $X^4$ irrespective of the classical action principle.

$X^4$ is analogous to a 4-D Bohr orbit of a particle identified as 3-surface. It is nowever not strictly deterministic: this is true already for 2-D minimal surfaces spanned by frames.

This forces us to take the Bohr orbits as basic objects instead of 3-surfaces. This gives rise to zero energy ontology (ZEO) [K10] [L18, L46].

3. Causal diamonds $CD = cd \times CP_2$, where $cd$ is the intersection of future and past directed light-cones, are a key aspect of ZEO [L48] (see this). $cd$ is a counterpart for quantization volume and analogous to cosmology: big bang followed by a big crunch. $cd$s appear with all size scales and define a fractal hierarchy. This predicts Russian doll cosmology with $CD$s within $CD$s. Each $sub - CD$ carries a sub-cosmology.

   CD, or rather the parts of space-time surface, contained inside CD, defines the 4-D analog of a perceptive field.

### 1.1.2 The new view about quantum

Consider next the new quantum ontology.

1. Quantum states correspond to wave functions in the space of Bohr orbits ("world of classical worlds" (WCW), see the illustration) and quantum jump occurring in state function reduction occurs between these states.

   Hence TGD could be seen as a generalization of wave mechanics by replacing point-like particles, not with 3-surfaces, but with their Bohr orbits. Classical field equations and the analog of Schrödinger equation are not violated and the non-determinism of state function reduction (SFR) is not in violation with classical field equations. This leads to zero energy ontology (ZEO), which solves the quantum measurement problem [L18] [K10].

2. The slight failure of classical determinism, predicted by holography = holomorphy vision (H-H) [L58], forces to replace the sequence of repeated quantum measurements, having no effect in standard quantum theory (Zeno effect), with a sequence of "small" SFRs (SSFRs) in which the observables assignable with the discrete degrees of freedom assignable to the classical non-determinism, interpreted in terms of cognition, are measured. This sequence of self measurements defines a conscious entity, self. Subjective time corresponds to a sequence of SSFRs.

3. The ZEO assigns to the opposite boundaries of CD 3-D many-fermion states. Holography requires that the 3-surfaces defining the holographic data at the passive boundary of the CD are not affected in the cognitive measurements.

   This is achieved in quantum sense, if the cognitive measurements induce only a scaling of the CD mapping the passive boundary to itself and the wave function in WCW and 3-D fermionic states are invariant under these scalings: this corresponds to conformal invariance.

   These scalings change the size of the CD and the distance between the tips defines geometric time, which increases in a statistical sense in the sequence of SSFRs defining subjective time. Therefore subjective time and geometric time correlate but are not identical,

   One can choose either boundary of the CD as a passive boundary and these choices correspond to opposite arrows of geometric time.

4. What about the TGD counterparts of the ordinary quantum measurements in which a system measures observables of another system (self and environment). They would correspond to "big" SFRs (BSFRs) reducing entanglement with the environment and possibly inducing sensory perceptions.

   The proposal is that in BSFRs the arrow of time changes (see the illustration). The sequence of SSFRs ends, the self dies, and reincarnates with an opposite arrow of geometric time (to be distinguished from the subjective time). Falling asleep and biological death are familiar examples of BSFR.

5. This view has several implications.

(a) The basic paradox of measurement theory is solved in ZEO. Wave functions in the space of slightly non-deterministic 4-D Bohr orbits for particles as 3-surfaces are crucial elements: there is no need to violate classical field equations in the SFRs. Classical causality and the causality of free will are not in conflict since SFR does not force violation of classical field equations.

(b) There are two times and two causalities: geometric time and subjective time, causality of field equations and causality of free will. They correlate but are not identifiable.

(c) ZEO enables memory. Basic objects are 4-D Bohr orbits and memory locations can be identified as the 3-D loci of classical non-determinism. Memory recall reduces to a communication with the locus of the non-determinism in the geometric past.

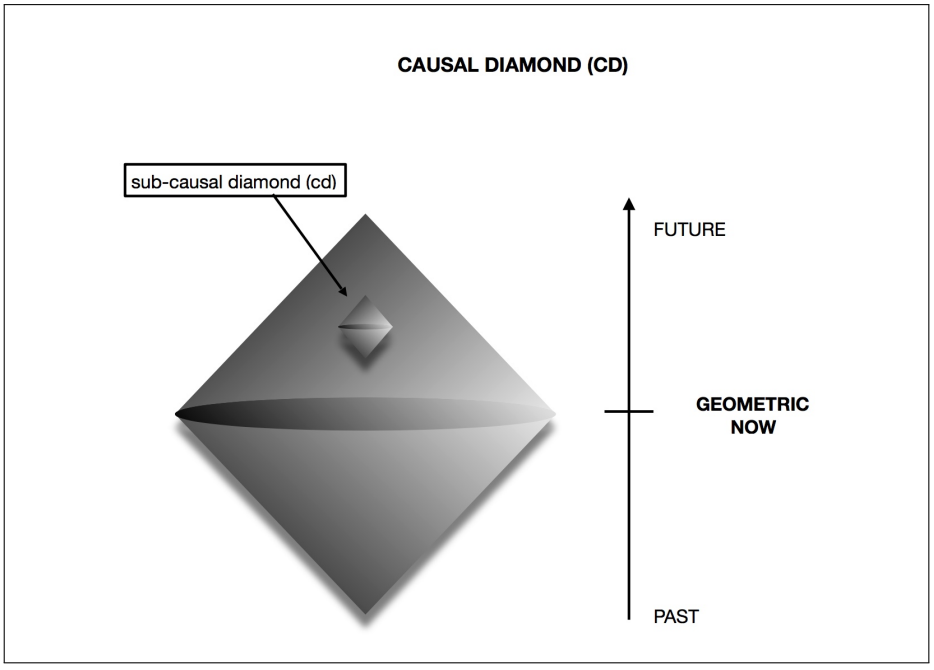


**Figure 1:** Causal diamond.

## 1.2 What phenomena TGD inspired theory of consciousness explains that materialism fails to explain?

1. Free will: Free will ceases to be a mystery and is not anymore in conflict with the laws of physics.

2. Life: TGD also predicts a hierarchy of Planck constants $h_{eff}$ meaning the possibility of quantum coherence in arbitrarily long scales. This quantum coherence at the field body of the system as a TGD analog for its classical em fields, induces the coherence of the ordinary biomatter, which is difficult to understand in the standard biology. The universality of quantum coherence together with the fractality of the TGD Universe suggests that consciousness and life are universal phenomena.

3. Death: BSFR gives rise to a death of self as a sequence of SSFRs. Death in this sense would be universal and take place on all scales. Death means reincarnation with an opposite arrow of geometric time. A sequence of reincarnations with a given arrow of geometric time is predicted. [L34].

4. Evolution: The value of effective Planck constant $h_{eff}$ is a measure for the algebraic complexity of the space-time surface and serves as a kind of IQ predicted to increase during evolution as an increase of complexity (see the illustration). [L17, L41, L44]. It is natural to assign a value of effective Planck constant to classical gravitational and electric fields. The values of $\hbar_{gr}$ and $\hbar_{em}$ can be very large and characterize interacting particle pairs connected by monopole flux tubes (see the illustration) . [L17, L41, L44].

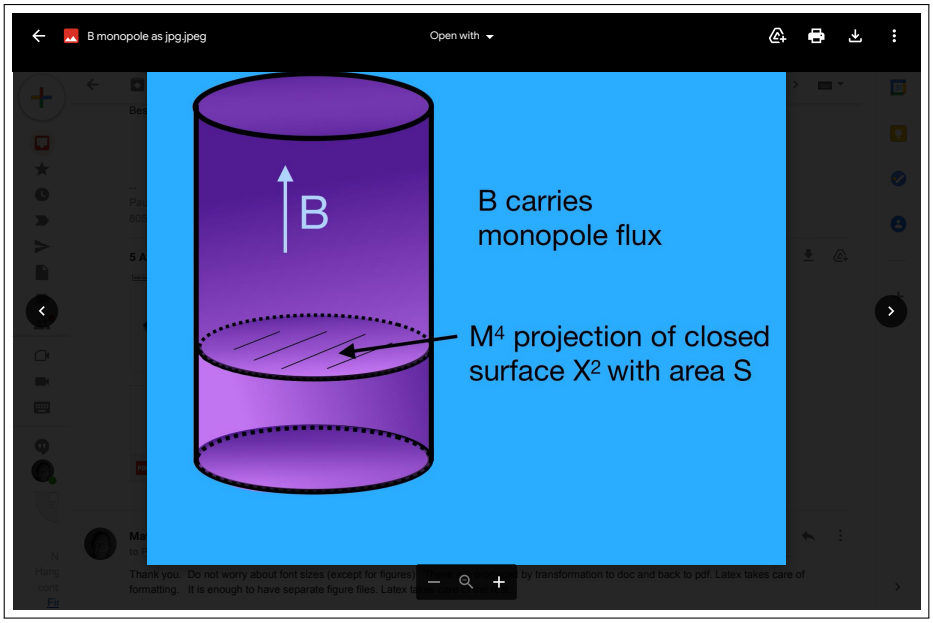


**Figure 2:** Monopole flux tubes

5. Basic aspects of conscious experience:

   (a) The slight non-determinism of the classical dynamics, inducing similar non-determinism in fermionic degrees of freedom, predicts the presence of discrete degrees of freedom assignable to the space-time surface: cognitive/internal degrees of freedom (IDF) might be the proper term. Intention can be also assigned to these degrees of freedom.

   IDF could be responsible for cognitive consciousness. IDF can entangle with the ordinary physical degrees of freedom (ODF) associated with the system itself or with another system. Also the entanglement between the IDF of two separate systems is possible.

   (b) Quantum measurements reducing these entanglements provide a model for sensory perception and motor action [L4] and IDF-ODF entanglement provides a model for various exotic phenomena of consciousness such as telepathy, psychokinesis, and hypnosis. Also intentions and intentional actions can be understood in terms of IDF-ODF coupling.

   (c) I have also discussed TGD based models of sensory qualia [K4] as related to the measurements of ordinary observables and proposed that emotions might be sensory qualia at the level of magnetic/field bodies. IDF-ODF entanglement could assign cognitive representations to the sensory perceptions.

   (d) Zero energy ontology and the 4-D character of the "Bohr orbits" allows us to understand memories as conscious experiences: [L59]: this is something different from memories as conditioned behaviors. Entire 4-D space-time surface would serve as a memory storage quantum entanglement between the 3-D loci of non-determinism would make possible conscious memories as an outcome of the reduction of this entanglement.

## 1.3 What predictions can it make, and what experiments can test them?

Most predictions relate to neuroscience and quantum biology. ZEO [K10]; the number theoretic vision predicting evolution [L9] and generalizing the second law to Negentropy Maximization Principle [L46]; the notion of field/magnetic body carrying large $h_{eff}$ phases of the ordinary matter with long range quantum coherence and implying ordinary coherence [K5]; the evolutionary survivors as systems able to communicate with each other; and universal genetic code [L43] play key roles in the model.

1. The new view of time provided by ZEO allows us to understand the strange findings of Libet [J2, J3].

2. TGD implies a new view of classical fields in which the notion of a field body, which can be gravitational, electric or magnetic, plays a key role. The field/magnetic bodies of the brain and organism play a key role. A universal communication mechanism from the cell membrane to the field body, based on frequency modulation of dark Josephson radiation, emerges. EEG would relate to the communications to the magnetic body and to control by it. This leads to detailed models for EEG and nerve pulse [K3, K9] [L52] and model for the sensory perception [L4].

   Also the surprising findings of Levin [I3] about the role of electric fields of the cell membrane can be modelled in the TGD framework [L54, L57].

3. The dark matter at field/magnetic bodies with a large value of $h_{eff}$ has higher "IQ" and controls the ordinary biomatter and receives information from it (say by EEG). The increase of $h_{eff}$ requires energy and the role of metabolic energy is to preserve its value distribution. Pollack effect [I2, L1, I6, I5] plays a key role in providing the energy making possible the transfer of ordinary particles to dark phases at the field bodies [L1, L3, L49, L26, L50, L44]. p-Adic length scale hypothesis [L42, L64], for which the number theoretic vision provides a justification, makes possible quantitative predictions.

4. Biology has a long list of unanswered questions. What does evolution mean at the fundamental level?; What makes possible the coherence of biosystems?; What is behind morphogenesis?; What makes biocatalysis so effective?; What is the precise role of metabolism?; What is the essence of homeostasis?; What does ageing mean?; How to solve various hen-and egg problems of biology.

   Second list of questions relates to the molecular level. How were the key biomolecules chosen?; What happens in DNA replication, transcription and translation; What is the origin of the genetic code?

   The TGD view of consciousness and quantum theory allows a possible answer to these questions. [L12].

5. TGD predicts a universal genetic code realized in terms of a completely unique tessellation of hyperbolic 3-space [L35, L43], which is in a central role in TGD. Genetic code should have realizations in all scales and also very many different realizations. One example, in terms of dark photons.

6. Also new lifeforms are predicted. In particular, plasmoids [L44] are such a lifeform and NASA has reported evidence for this kind of lifeforms in the ionosphere. TGD also allows us to consider the possibility of conscious computers as hybrids of ordinary and quantum computers using topological qubits realized in the TGD framework [L60, L68].

## 1.4 How the model expands human knowledge and supports a postmaterialist paradigm?

One must be cautious with what one means with the notion of "post materialistic paradigm". TGD does not propose that this paradigm should be based on idealism. The ontology behind TGD differs from both the materialistic ontology denying subjective existence and idealistic ontology denying the material existence. The "objective reality" is replaced with "objective realities" identified as quantum states identified as mathematical objects. Quantum Platonia having spinor fields of WCW as basic objects is a proper name for this view.

No physical reality as matter behind these mathematical entities is needed since state functions (SFRs) as quantum jumps between them explain the conscious experience. Therefore the ontology is minimal. Number theoretic vision predicts evolution as an increase of the conscious information content. ZEO provides a mechanism of conscious memory so that quantum Platonia learns of itself. ess. The article "Philosophy of adelic physics" (2017) [L9, L11] describes a number theory based vision of TGD and extends real number based physics to p-adic number fields to describe physical

correlates of cognition. The most recent mathematical progress concerning the construction of scattering amplitudes in TGD is discussed in the articles [L28, L29, L30].

The article "Summary of Topological Geometrodynamics" (2020) [L32] provides the most recent summary of TGD with illustrations. My CV (`https://cutt.ly/3bJ2aSm`) contains a list of published articles, books, and online books about TGD. A list of online articles can be found at `https://cutt.ly/ZbJ2s75`.

## 1.5 The basic problem and idea behind TGD

TGD relies on a new view of space-time inspired by the problem of GRT due to the loss classical conservation laws (the "energy problem"). Matter makes the flat Minkowski space $M^4$ of Special Relativity (SRT) curved so that it loses Poincare transformations as its symmetries. Poincare invariance implies the conservation laws of energy, momentum, and angular momentum via Noether's theorem so that they are lost in GRT.

The following is a short summary of the solution of this problem provided by TGD (see the illustration).

1. If space-times are 4-surfaces in a space of form $H = M^4 \times S$, $S$ some compact space with a very small size, space-time isometries (Poincare transformations) are lifted to those of $H$. If these isometries act as symmetries of a general coordinate invariant action determining the space-time surface as an orbit of a 3-surface, Poincare symmetries are not lost and Noether's theorem guarantees the existence of conserved charges and gives explicit expressions for them [L51].

   The geometry of $S = S = CP_2$ codes for the symmetries of SM: color symmetries correspond to the isometry group $SU(3)$ and electroweak symmetries to the holonomies of $CP_2$ being broken by $CP_2$ geometry. $CP_2$ does not allow spinor structure in the standard sense [L51] but - as already observed by Hawking and others [A3, A1] - it allows a modified spinor structure obtained by coupling spinors to an odd multiple of the Kähler gauge potential: this coupling is essential to obtain correct electromagnetic charges for fermions. For quarks and leptons the couplings would correspond to $n = 1$ and $n = 3$.

2. Dirac equations appear at several levels: at the level of $H$; at the level of causal diamond (CD); at the level of space-time surfaces; and at the level of WCW. The most recent steps of progress relate to the detailed mathematical understanding of the solutions at the level of $H$, CD and space-time surface. One can understand color confinement already at the level of $H$ and a rather dramatic prediction of an entire fractal hierarchy of standard model physics emerges [L66, L65, L67].

3. Besides sub-manifold geometry, topology also becomes important (hence the term "**TGD**") since the many-sheeted space-time of TGD is topologically non-trivial at all scales and the physical objects that we see around us correspond directly to space-time sheets, topologically condensed at ever larger space-time sheets. Fracal length scale hierarchies are formed.

It must be emphasized that TGD not yet a theory able to provide precise rules for calculating scattering amplitudes although also in this respect dramatic progress has taken place during the last years. A collective theoretical and experimental effort would be needed to achieve the analogs of Feynman rules.

Applications have played a key role in the development of TGD. TGD replaces the length scale reductionism of the standard model and string theories with fractality so that the applications range over all scales from QCD type physics, via nuclear and hadron physics, to atomic and molecular physics and biology and eventually to astrophysics and cosmology. In all scales the basic concepts which are new from the perspective of the standard model physics play a key role and lead to non-trivial predictions.

Furthermore, the new view of quantum measurement theory together with number theoretic vision leads to a TGD inspired theory of consciousness as a generalization of quantum measurement theory solving the basic problem of the standard quantum measurement theory and also predicts the possibility of quantum coherence in arbitrarily long scales. Applications are not discussed in

this article but there are numerous articles and quite a number of books at my homepage as also articles published in the journals founded by Huping Hu, which are devoted to various applications.

It is perhaps good to explain what TGD is not and what it is or hoped to be. The article [L27] gives a slighly out-of-date overview of various aspects of TGD and is warmly recommended.

## 1.6 Geometric vision

"Geometro-" refers to the idea about the geometrization of physics. The geometrization program of Einstein is extended to gauge fields allowing realization in terms of the geometry of surfaces so that Einsteinian space-time as abstract Riemann geometry is replaced with sub-manifold geometry. The basic motivation is the loss of classical conservation laws in General Relativity Theory (GRT)(see the illustration). Also the interpretation as a generalization of string models by replacing string with a 3-D surface is natural.

Standard model symmetries uniquely fix the choice of 8-D space in which space-time surfaces live to $H = M^4 \times CP_2$ [L51]. Also the notion of twistor is geometrized in terms of surface geometry and the existence of twistor lift fixes the choice of $H$ completely [A4] so that TGD is unique [L10, L13, L38, L39] (see the illustration).

Practically any GCI action has the same universal basic extremals: $CP_2$ type extremals serving basic building bricks of elementary particles, cosmic strings and their thickenings to flux tubes defining a fractal hierarchy of structure extending from $CP_2$ scale to cosmic scales, and massless extremals (MEs) define space-time correlates for massless particles. World as a set or particles is replaced with a network having 3-D particles as nodes and flux tubes as bonds between them serving as correlates of quantum entanglement.

### 1.6.1 Holography = holomorphy principle

During last years it has become clear that holography reduces to the notion of generalized complex structure for both imbedding space and the space-time surface [L45] and space-time surfaces correspond to roots of two functions $f_1$ and $f_2$ analytic with respect to the 4 generalized complex coordinates, one of which is real number valued hypercomplex coordinate varying along light-like curves.

This means a general solution of field equations which is universal in the sense that it the same for any general coordinate invariant action constructible in terms of the induced geometry. The dependence on action comes only from, presumably 2-D, singularities at which the generalized holomorphy and the associated minimal surface property fail. There are good reasons to believe that the singularities contain the information needed to construct the scattering amplitudes.

1. The space-time surfaces in the imbedding space $H = M^4 \times CP_2$ are identified common roots for the pair $(f_1, f_2)$ of generalized holomorphic functions defined in $H$. If the Taylor coefficients of $f_i$ are in an extension of rationals, the conditions defining the space-time surfaces make sense also in an extension of p-adic number fields induced by this extension. As a special case this applies to the case when the functions $f_i$ are polynomials. For the completely Taylor coefficients of generalized holomorphic functions $f_i$, the p-adicization is not possible. The Taylor series for $f_i$ must also converge in the p-adic sense. For instance, this is the case for $exp(x)$ only if the p-adic norm of $x$ is not smaller than 1.

2. The 6-D surfaces satisfying only the condition $f_i = 0$,$i = 1$ or $i = 2$, have interpretation as analogs of twistor spaces of $M^4$ and $CP_2$ and the proposal is that this description is equivalent with the twistor lift of TGD introducing the twistor space of $H$ as a product of twistor spaces of $M^4$ and $CP_2$ and defining twistor space of the space-time surface as a 6-D surface.

3. Also the maps defined by analytic functions $g$ in the space of function pairs $(f_1, f_2)$ generate new space-time surfaces. One can assign Galois group and ramified primes to $h$ if it is a polynomial $P$ in an extension of rationals. The composition of polynomials $P_i$ defines inclusion hierarchies with increasing algebraic complexity and as a special case one obtains iterations, an approach to chaos, and 4-D analogs of Mandelbrot fractals.

Holography=holomorphy hypothesis allows to reduce the classical field equations to purely algebraic conditions $(f_1, f_2) = (0, 0)$, where $f_i$ are analytic functions of one hypercomplex and 3 complex coordinates of $H = M^4 \times CP_2$. The solutions are minimal surfaces irrespective of the classical action as long as it is general coordinate invariant and expressible in terms of induced geometry. This means universality of the dynamics and is quantum criticality expressed by the holomorphy. This implies saddle surface property for the spacetime surface meaning that the real parts of $f_i$ do not have minima or maxima in general.

The iterates of a polynomial $(g, 1)$ (say) with prime degree p, define analogs of primes. This leads also to a generalization of the p-adic number fields to function fields with elements expressed as functional power series as powers of $g$ in which the powers $g^k$ are multiplied by polynomials with degree lower than $p$. This leads to a definition of functional primes providing an explanation for the origin of p-adic length scale hypothesis. One can say that p-adic function fields and the adele form by them emerges from the real dynamics. The p-adic variants of the embedding space and space-time are convenient auxiliary structures but need not be fundamental.

### 1.6.2 The world of classical worlds

Quantum TGD leads to a generalization of the geometrization of the physics program of Einstein. The geometrization applies even to the quantum theory itself and the space of space-time surfaces - "the world of classical worlds" (WCW) - becomes the basic object endowed with a Kähler geometry (see the illustration). General Coordinate Invariance (GCI) for space-time surfaces has dramatic implications. A Given 3-surface fixes the space-time surface almost completely as an analog of Bohr orbit (preferred extremal [K1]). This implies holography and leads to zero energy ontology (ZEO) in which quantum states are superpositions of space-time surfaces. Quantum TGD reduces to wave mechanics in the space of these Bohr orbits, the WCW.

Quantum theory is geometrized in terms of the notion of a "world of classical worlds" (WCW) consisting of space-time surfaces identifiable as preferred extremals (PEs) analogous to Bohr orbits. General Coordinate Invariance (GCI) implies 3-D holography and probably also effectively 2-D holography (strong holography (SH)).

The mere existence of WCW Kähler geometry requires a maximal isometry group. This was shown by Freed [A2] to be the case for loop spaces. This leads to the vision that physics is unique from its existence. Indeed, the twistor lift of TGD [L22, L23] works only for $H = M^4 \times CP_2$ [A4] since only $M^4$, $E^4$, and $CP_2$ have twistor spaces with the Kähler structure required by the existence of the twistor lift based on 6-D Kähler action. On the number theory side, the octonionic $M^8$ is the unique choice.

Later it turned out that it might be possible to realize the counterparts of the twistor spaces of $M^4$ and $CP_2$ without the introduction of the twistor spaces of $H$ or $M^8$ as 6-D surfaces in $H$ such that their 4-D intersection defines the space-time surface [L56, L63, L69].

### 1.6.3 Zero Energy Ontology

In Zero Energy Ontology (ZEO), the superpositions of space-time surfaces inside causal diamond (CD) having their ends at the opposite light-like boundaries of CD, define quantum states. CDs form a scale hierarchy (see this and this).

Quantum jumps occur between superpositions of 4-D time evolutions and the basic problem of the standard quantum measurement theory disappears. Ordinary state function reductions (SFRs) correspond to "big" SFRs (BSFRs) in which the arrow of time changes (see the illustration). This has profound thermodynamic implications and the question about the scale in which the transition from classical to quantum takes place becomes obsolete. BSFRs can occur in all scales but from the point of view of an observer with an opposite arrow of time they look like smooth time evolutions [L15].

In "small" SFRs (SSFRs) as counterparts of "weak measurements" the arrow of time does not change and the passive boundary and the states at it remain unchanged (Zeno effect). The sequence of "small" state function reductions (SSFRs) defined the TGD counterpart of the generalized Zeno effect, would correspond to an analysis having as a correlate the decay of 3-surface to smaller 3-surfaces and would also give rise to a conscious entity, self.

This means considerable progress in the understanding of the quantum measurement theory based on ZEO [L18, L40, L48] [K10].

1. Negentropy Maximization Principle [L46] implying evolution follows as an analog of the second law. In the sequence of quantum jumps the algebraic complexity, which is measured as the dimension of extension of rationals associated with the polynomials associated with the singularities, is bound to increase in a statistical sense.

2. The second new result [L48] is a quantum formulation of the ZEO. Zero energy states within a single CD as an analog of a perceptive field and containing space-time surfaces is generalized so that quantum states also involve a wave function in the space of CDs. The moduli space of CDs is finite-dimensional and maximally symmetric and forms the backbone of WCW in the sense that each space-time surface satisfying holography is within a particular CD. This leads also to a new view of Poincare symmetry allowing to overcome the problems due to the fact that CD itself is not Poincare invariant.

3. Zero energy ontology [K10] is realized in terms of the holography = holomorphy principle (H-H) [L56, L63, L58, L70]. The reduction of extremely non-linear partial differential equations to local algebraic equations is a huge simplification as such and one can say that TGD is exactly solvable.

   The slight failure of the classical non-determinism associated with H-H has a natural identification as a counterpart of the p-adic non-determinism and has deep implications for TGD inspired view of consciousness and TGD itself since it plays a key role in the construction of scattering amplitudes.

   This leads also to a generalization of the p-adic number fields to function fields and explains the origin of p-adic length scale hypothesis. One can say that p-adic function fields and the adele form by them emerges from the real dynamics. The p-adic variants of the embedding space and space-time are convenient auxiliary structures but need not be fundamental.

TGD develops by explaining what TGD is and also this work led to considerable progress in several aspects of TGD.

1. The understanding of the details of the $M^8 - H$ duality have developed through many twists and turns [L24, L25, L47, L55, L58] to its most recent form [L71]. $M^8$ as the analog of momentum space is identified as octonions and the dynamics of 4-surfaces in $M^8$ is coded by associativity. The number theoretic local $G_2$ symmetry provides the long sought concrete realization of the $M^8 - H$ duality mapping the associativity based dynamics in $M^8$ to the dynamics on $H$ relying on generalized holomorphy.

2. The notion of causal diamond (CD) [L48] is central to zero energy ontology (ZEO) [K10] and emerges as a prediction at the level of $H$. The pre-image of CD under $M^8 - H$ duality in $M^8$ is a region bounded by two mass shells in the normal space of $y \in Y^4 \subset M^8$, which itself is an Euclidean region.

   $M^8 - H$ duality maps the points of cognitive representations defined by the points of $Y^4$ with coordinates as algebraic integers in the algebraic extension of rationals and identified as momenta of fermions with a fixed mass squared in $M^8$ to either boundary of CD in $H$.

3. The emergence of holography = holomorphy principle (H-H) [L56, L63, L58, L70] forces a profound modification of the ideas about $M^8 - H$ duality and number theoretical vision.

4. Galois confinement for physical states at the level of $M^8$ is understood at the level of momentum space and is found to be necessary. Galois confinement implies that fermion momenta using a suitable unit determined by CD are algebraic integers but integers for Galois singlets just as in ordinary quantization for a particle in a box replaced by CD. Galois confinement could provide a universal mechanism for the formation of all bound states.

## 1.7 Number theoretic vision

Number theoretical vision adds to "geometric" and "topological" a third aspect to what it is to be TGD. There is however no natural way to add this aspect to "TGD".

### 1.7.1 p-Adic and adelic physics

The notion of p-adic physics generalized to adelic physics in which physics in various p-adic number fields and real physics fuse to a larger whole. Adelic physics fusing real and various p-adic physics are part of the number theoretic vision, which provides a kind of dual description for the description based on space-time geometry and the geometry of "world of classical worlds".

The hierarchy of algebraic extensions of rationals gives rise to a hierarchy of Planck constants $h_{eff} = nh_0$ and defines extensions of p-adic number fields and adeles allowing an interpretation as an evolutionary hierarchy (see the illustration). Physically this defines a hierarchy of phases of ordinary matter behaving like dark matter. The interpretation is not in terms of galactic dark matter but in terms of missing baryonic matter identified.

The polynomials with rational coefficients are characterized by ramified primes. A possible interpretation for ramified primes is as p-adic primes characterizing elementary particles [L42, L64] [K6, K2]. An alternative, and in fact more plausible, interpretation for the p-adic primes characterizing space-time sheets is provided by p-adic function fields: this option explains the p-adic length scale hypothesis [L56, L63]. The notion of multi-p-adicity is also possible for numbers expressing as power series of $n$. In this case p-adic topology is possible for any prime factor of $n$.

Adelic physics predicts two fractal length scale hierarchies: p-adic length scale hierarchy and the hierarchy of dark length scales labelled by $h_{eff} = nh_0$, where $n$ is assumed to correspond to the dimension of extension of rationals. The interpretation of the latter hierarchy is as phases of ordinary matter behaving like dark matter. Quantum coherence is possible in all scales.

### 1.7.2 $M^8 - H$ duality

The idea of $M^8 - H$ duality has progressed through frustratingly many several twists and turns. I have discussed several variants of $M^8 - H$.

1. The basic technical problem relates to the lack of the concrete realization of the $M^8 - H$ duality since explicit realization of the parametrization of the quaternionic normal space has been missing.

2. The second open question is whether $M^8 - H$ duality is between 4-D surfaces in $M^8$ and space-time surfaces in $H$ or is it enough that only the 3-D holographic data in $H$ are fixed by $M^8 - H$ duality. There are indeed some intuitive arguments supporting the latter view. Could it be that $M^-H$ duality is not an alternative view to see the dynamics but a way to determine holographic data in $H$ so that a consistency with holography = holomorphy hypothesis is obtained?

Quite recently it turned out [L71, L58] that a modification of the original form of the $M^8 - H$ duality formulated in terms of a real analytic function $f(o)$ of octonions leads to a possible solution of these problems. The crucial element is local $G_2$ invariance of the conditions involved.

1. The conditions $f(o) = 0$ and $f(o) = 1$ are invariant under local $G_2$ and give as a solution a discrete set of 6-spheres. Also the conditions $Re(f) = 0$ and $Im(f) = 0$ are invariant under local $G_2$. These conditions give rise to dual time evolutions of a six-sphere $S^6$. The intersection with the complement of quaternionic $M^4$ gives rise to 4-D surfaces $Y^4$ as dual time evolutions of a 3-sphere with respect to the time defined by the real part of the octonion.

   The condition $RE(f) = 0$, where RE (IM) refers to quaternionic real (imaginary) part, is equivalent with the condition $f(o) = 0$ whereas the condition $IM(f) = 0$ is equivalent with the condition $Im(f) = 0$ . The local $G_2$ acts as a dynamical spectrum generating symmetry group since $f \circ g_2 = g_2 \circ f$ holds true. The roots of $f(o) = 0/1$ for the simplest situation in which the quaternionic normal space is fixed $M^4$, are 6-spheres $S^6$.

2. The 4-surfaces $Y^4 \subset M^8$ for the simplest solutions $Im(f) = 0$ and $Re(f) = 0$ is identifiable as the intersection $Y^4 = E^4 \cap S^6$, where $E^4$ is the normal space of a fixed quaternionic $M^4 \subset M^8$. This guarantees that the normal space of $Y^4$ at each point is quaternionic $M^4$. The assumption that $M^4$ contains a commutative subspace $M^2$ guarantees that the normal space correspond to a point of $CP_2$ so that the $Y^4$ can be mapped to $X^4 \subset H = M^4 \times CP_2$.

3. Local $G_2$ transformations give more general surfaces $Y^4$. One can choose the function $f(o)$ to be a real part of an analytic function of a hypercomplex coordinate of $M^4$ and 3 complex coordinates of $M^8$. This gives good hope that the image $X^4$ of $Y^4$ satisfies the holography = holomorphy hypothesis. Local $G_2$ also defines the moduli space of Hamilton-Jacobi structures [L45] of $M^8$ and $M^4$ and $X^4$.

4. The real analytic functions $f(o)$ and $g(o)$ can be multiplied, divided and summed so that the analog of a function field is in question. Also iterations of $f(o)$ are possible. The roots $Im(g) = 0$ of $g = f \circ f ... \circ f$ contain the roots of $f$ plus roots of higher iterates. A complexity hierarchy analogous to that appearing for function pairs $(f_1, f_2)$ at $H$ sides emerges and the interpretation in terms of cognitive hierarchies is suggestive. An interesting question is whether there is a simple relationship between functions $f(o)$ and function pairs $(f_1, f_2)$.

5. An interesting question is whether the 3-spheres associated with the roots $f(o) = 0$ correspond to "very special moments of time", which emerged in the original form of $M^8 - H$ duality. Could these spheres correspond at the level of $H$ singularities at which the local $G_2$ element becomes multiple-valued so that the quaternionic normal space is not unique. The situation is analogous to a singularity of a vector field. This would give rise to cosmic strings and $CP_2$ type extremals. These singularities could be also associated with the classical non-determinism of H-H principle. Also the vertices of particle reactions could be assigned with them.

6. The ramified primes of a polynomial of a single variable are expected to play an important role in the number theoretic view of TGD. If $f$ assigned to $M^8 - H$ duality [L71] is a polynomial $P$ with rational coefficient, the ramified primes would be assigned with the discriminant of $P$. The conjecture is that the classical action defining the space-time surface is expressible as a power of discriminant of $P$ defined by the differences of these ramified primes [L51]. This would be one aspect of the 4-D version of Langlands duality [L56, L63]. This would imply a huge degeneracy since alll space-time surfaces related by local $G_2$ transformations as analogs of conformal transformations would have the same classical action defining the Kähler metric of WCW. Local $G_2$ would define zero modes for the WCW metric and symplectic degrees of freedom would correspond to non-zero modes as also conjectured [L53].

# 2 TGD inspired theory of consciousness

TGD inspired theory of consciousness can be regarded as an extension of quantum measurement theory to a theory of consciousness that relies on Zero Energy Ontology (ZEO) [L33]. When I wrote the first version of this chapter, the view about ZEO, in particular about what happens to the causal diamonds (CDs) in state function reductions, involved many uncertainties. In [L48] the recent, much more precise view is represented.

## 2.1 Conditions satisfied by the theory of consciousness

Any quantum theory of consciousness must be consistent with existing physics. Since existing physics cannot explain biological phenomena and consciousness, a theory explaining them is bound to predict some new physics.

The new theory must solve the basic problems intractable to current theoretical physics. Many of these problems are philosophical. This theory should also be applicable to quantum biology and neuroscience and answer at least the following questions.

1. In everyday life everyone, even a strict physicalist, will in their subjective experience, regard free will as real, but in the role of natural scientist, deny it since it is inconsistent with the determinism of classical physics. Could the underlying view of time be wrong? Could free will be consistent with deterministic field equations after all?

   It seems that behavior is built from deterministic time evolutions connecting initial and final states. Biological functions, behaviors, and computer programs represent good examples of this. Could free will be in the selection between deterministic time evolutions. These

questions suggest a new ontology in which a deterministic classical time evolution becomes the basic entity instead of the time=constant snapshot of time evolution central to the standard ontology.

2. A similar problem plagues quantum measurement theory. The state function reduction (SFR) is non-deterministic whereas the Schrödinger equation is deterministic. This has led to myriads of "interpretations". This problem is analogous to the conflict between free will and classical deterministic physics.

   It is easy to trace the origin of the problem. In standard quantum theory the observer can affect the measured system but still remains an outsider. A quantum theory of consciousness would generalize quantum measurement theory. The notion of "self" as part of a system would replace that of "observer".

   Quantum coherence is assumed to be possible only at very short scales. Coherence of biological systems, however, suggests this assumption is wrong. There is also the question whether there is some scale at which quantum behavior transforms to classical behavior. This question has not been answered. Could the quantum world actually prevail at all scales and only appear as classical? Could discontinuous quantum jumps somehow look like deterministic and smooth classical time evolutions?

3. Experienced time and the geometric time of the physicist are very different. Subjective time however correlates with geometric time: contents of sensory experience correspond to a moment of geometric time within an accuracy of .1 second: one can speak of a sensory chronon. How should one distinguish between these two times?

4. Are there physical correlates for cognition and imagination? Could they be realized at the level of space-time?

5. What do life, death, and aging mean? Could they be universal notions applicable at all scales? Does consciousness survive after the cessation of bodily function in some sense? If this were the case, universality might make it possible to provide indirect, and yet convincing, evidence for life after death.

## 2.2 ZEO based quantum measurement theory extends to a theory of consciousness

ZEO based quantum measurement theory [L33] leads to a quantum theory of consciousness (see the illustration). In particular, the theory predicts that the arrow of time (AT) changes in "Big" (ordinary) SFRs (BSFRs) (see the illustration) as opposed to "Small" SFRs (SSFRs) as the counterparts of "weak" measurements (`http://tinyurl.com/zt36hpb`).

BSFR suggests that self-organization (SO) at all scales partially reduces to dissipation with a reversed AT implied by the generalization of the second law of thermo-dynamics (SL).

1. SO always involves an energy feed. The energies of quantum states increase with $h_{eff} = nh_0$ and $h_{eff}$ tends to be reduced spontaneously. The energy feed prevents this and hence the reduction of the universal "Intelligence Quotient (IQ) as the dimension $n$ of EQ characterizing the algebraic complexity of EQ and of a space-time surface [L29, L30]. This prevents also the reduction of the scale of quantum coherence. In biology this corresponds to the metabolic energy feed.

2. In ZEO, the energy feed necessary for SO could be partially replaced with an extraction of energy from the environment by dissipation in a reversed direction of time. The self-organizing system could effectively send negative energy to the environment.

   The basic signature is a generation of gradients in conflict with SL in its standard form. This conforms with what happens in SO but does not of course prove that SO is based solely on time reversed dissipation. Both the energy feed and the extraction of energy from the environment are involved.

   For time reversed dissipation no specific mechanisms are required and only metabolic energy storages - systems able to receive the negative energy dissipated in a reversed time direction

- are enough. Even thermal energy could be used and there is evidence for this [L72]. This inspires a totally new vision, not only of living matter, but also in regards to possible energy technologies.

3. Time reversals occur at very short time scales at the elementary particle level and for ordinary matter with $h_{eff} = h$). For MBs controlling ordinary matter, time reversals would have long lasting effects on ordinary matter as well.

   MB has an onion-like layered structure implied by the p-adic length scale hypothesis [K8] and $h_{eff}$ hierarchy [L17]. Layers have sizes even larger than the size of the Earth. The slaving hierarchy formed by the layers of MB carrying dark matter could control the dynamics by inducing time reversals at the lower levels as BSFRs interpreted as generalized motor actions (master and slave are standard notions in the theory of SO). A given layer of MB is characterized by its size determined by a p-adic length scale characterizing flux tube thickness and by the value of $h_{eff}$.

### 2.2.1 ZEO

The TGD based view of consciousness relies on ZEO solving the basic paradox of quantum measurement theory. First, a brief summary of ZEO [L33] is required.

1. The notion of a causal diamond (CD) (see the illustration) is a central concept. Its little cousin "cd" can be identified as a union of two half-cones of $M^4$ glued together along their bottoms (3-D balls). The half-cones are mirror images of each other. CD=$cd \times CP_2$ is the Cartesian product of cd with $CP_2$ and obtained by replacing the points of cd with $CP_2$. The notion of CD emerges naturally in the number theoretic vision of TGD (adelic physics [L8])via the $M^8 - H$ duality [L21, L29, L30].

2. The quantum formulation based on the notion of fini-dimensional moduli space of CDs forming that backbone of WCW [L48]. This formulation makes it possible to get rid of various uncertainties of the earlier formulations. The sequences of "small" state function reductions (SSFRs), or rather a sequence unitary transformations, which in the moduli space of CDs correspond to dispersion analogous to that associated with Schrödinger equation followed by localizations in the moduli space (SSFR) as position measurements. These are the TGD counterparts of sequences of measurements of the same observables. Present are also "big" SFRs (BSFRs) changing the arrow of time and serving as the TGD counterparts of the ordinary SFRs.

3. In the ZEO, quantum states are not 3-dimensional, but superpositions of 4-dimensional deterministic time evolutions connecting ordinary 3-dimensional states. By holography time evolutions are equivalent to pairs of ordinary 3-D states identified as initial and final states of time evolution.

   Quantum jumps replace this state with a new one: a superposition of deterministic time evolutions is replaced by a new superposition. The classical determinism of individual time evolution is not violated. This solves the basic paradox of quantum measurement theory. There are two kinds of SFRs: BSFRs (counterparts of ordinary SFRs) changing the arrow of time (AT) and SSFRs (analogs of "weak" measurements) preserving AT that give rise to an analog of the Zeno effect [K10] [L33].

To avoid confusion, one may emphasize some aspects of ZEO.

1. ZEO does not mean that the physical states identified in standard quantum theory as 3-D time= constant snapshots - and assigned in ZEO to the opposite boundaries of a causal diamond (CD) - would have zero energy. Rather, these 3-D states have the same conserved quantities, such as energy. Conservation laws allow us to adopt the convention that the values of conserved quantities are opposite for these states so that their sum vanishes.

   This is not new: in quantum field theories (QFTs), one speaks, instead of incoming and outgoing particles, external particles arriving from the geometric past and future and having opposite signs of energy. That conserved quantities vanish in the *4-D* sense, expresses only

the content of conservation laws. A weaker form of this condition [L36] states that the total conserved Poincare charges are opposite only at the limit of infinitely large CD. CD would be an analog of quantization volume in QFTs, whose finiteness implies a small conservation of momentum.

2. ZEO implies *two* times:subjective time as a sequence of quantum jumps and geometric time as a space-time coordinate: for instance, the proper time of the observer. Since subjective time does not correspond to a real continuum, these times are not identifiable but are strongly correlated. This correlation has led to their identification although they are different.

### 2.2.2 BSFR as death and reincarnation in universal sense

In BSFRs, AT is changed and the time evolution in the final state occurs backwards with respect to the time of the external observer. The BSFRs can occur at all scales since TGD predicts a hierarchy of effective Planck constants $h_{eff}$ with arbitrarily large values. There is empirical support for BSFRs.

1. The findings of Minev *et al* [L15] for atomic systems can be explained by the same mechanism [L15]. BSFR replaces the zero energy state with a new one and changes the roles of the 3-D states (active and passive state) at the boundaries of CD.

   For an observer with a standard AT, the final zero energy state is a superposition of deterministic, smooth time evolutions leading to a fixed 3-D state at the formerly active boundary of CD. Interestingly, once this evolution has started, it cannot be stopped unless one changes the stimulus signal inducing the evolution. The ZEO based interpretation is that a second BSFR as a return back to the initial state occurs.

2. Libet's experiments on the active aspects of consciousness [J2] can be understood from this perspective. For instance, a test subject raises his index finger and neural activity starts *before* the conscious decision to do so. In a physicalistic framework, neural activity leads to the experience of making the decision so that free will would not be real.

   Libet himself proposed what he called a veto option: free will is in the decision to stop the action already initiated. The problem with the veto option [J1] is that the activity beginning .5 seconds earlier looks like dissipation with a reversed AT. In the standard direction of time this looks like self-organization which leads from a chaotic state to an ordered state at around .15 seconds before the raising of the finger. The ZEO explanation is that a macroscopic BSFR occurred and generated a signal proceeding backwards in time which generated neural activity and dissipated to randomness.

3. An example from a different scale comes from earthquakes and supports universality. Earthquakes involve a strange anomaly: they are *preceded* by ELF radiation. One would expect that ELF radiation would follow the earthquake. In the TGD framework, the identification as BSFR can explain the anomaly [L19, L14].

   In biology, the reversals of AT may occur routinely [J4] and indeed are a central element of biological SO in the TGD framework. Time reversal also explains self-organized quantum criticality (SOQC) identifiable as the basic mechanism of homeostasis [L20, L72]. Homeostasis would occur spontaneously rather than being a result of programming.

### 2.2.3 Sequence of SSFRs as life cycle

The original proposal was that SSFRs are TGD counterparts of "weak" measurements, which are much like classical measurements and do not involve any dramatic changes. One can ask what weak measurements actually are and holography = holomorphy vision suggests that they correspond to the classical non-determinism of field equations present already for 2-D minimal surfaces.

The sequence of SSFRs gives rise to a conscious entity - self - as a sequence of moments of consciousness. Subjective time as a sequence of SSFRs correlates with the geometric time for which one identification is as the distance $T$ between the tips of CD, whose size increases statistically.

1. In SSFRs [L31] members of states at the "passive" boundary (PB) of the CD are not changed and PB itself is not shifted although it increases in size. The active boundary (AB) recedes from PB and increases in size in a statistical sense. Also, the states at AB change by unitary time evolutions followed by SSFRs that do not affect the states at PB.

   SSFRs correspond to a measurement of observables whose action does not affect the states at PB. Cognitive measurements are excellent candidates for these kind of measurements [L31]. Cognitive measurement would be a measurement involving entanglement with the degrees of freedom related to the classical non-determinism of space-time surfaces predicted by holomorphy = holography principle [L58]. The time $T$ identified as the temporal distance between the tips increases in a statistical sense and correlates with the subjective time identified as a sequence of SSFRs.

2. The identification of a "geometric now" as a correlate of "subjective now" is not unique. The most natural identification of the geometric time is as the linear $M^4$ time coordinate assignable with the line connecting the tips of CD (see the illustration). The "geometric now" would correspond to the $T_{now} = T/2$ which corresponds to a 3-D ball (not a 2-D sphere, which is its boundary) at which the expansion of 3-ball with light-velocity changes to contraction - the analogy with the Big Bang followed by the Big Crunch is obvious. $T_{now}$ increases in a statistical sense.

3. $M^8 - H$ duality suggests that the 3-D roots $r_n$ of the real analytic function $f(o)$, in a special case polynomial $P(o)$ (or even analytic function) define special moments $t = r_n$ of $M^4$ linear time: I have called them "very special moments in the life of self" [L5, L6, L7, L16, L29, L30]. The surfaces $Y^4 \subset M^8$ would in turn correspond to the roots of $Im(f) = 0$ or of $Re(f) = 0$ as duals of each other. If these moments correspond to the values of $T_{now}$ for SSFRs, the size of CD increases in a step-wise manner.

   The two views are consistent if the roots $r_n$ correspond to the loci of classical non-determinism. This could be the case that the $g_2$ element as holomorphic function of generalized complex coordinates of $M^8$ has singularity at $r_n$. This would mean that the quaternionic plane $M^4$ is not unique at it. The singularity would be analogous to a singularity of a vector field and would naturally be associated with $f(o) = 0$ just like the singularity of a vector field is naturally associated with its zero.

4. The Lorentz invariant light-cone proper time "$a$" labeling the hyperboloids inside the lower and upper half-cones of the $CD \subset H = M^4 \times CP_2$ is the second natural candidate for the geometric time coordinate and is completely analogous to cosmic time. It reduces in a good approximation to "$t$" near the time axis connecting the tips of CD.

   This picture applies at the level of $H$. $M^8 - H$ duality [L29, L30] forces also consider the $M^8$ level. $M^8$ is analogous to momentum space: there is no time and space in the usual sense. Could the claims of timeless and spaceless states of consciousness correspond to the $M^8$ mode? In momentum space, time and spatial coordinates are replaced with energy and momenta.

$M^8 - H$ duality leads to a more detailed picture of the evolution of self. One may consider first what the evolution of self looks like geometrically.

1. A given space-time surface in $M^8$ is determined in terms of $g(g_2(o)) = g_2(f(o))$. As a special case, $f(o)$ is a polynomial $P(o)$ with algebraic or even rational coefficients obtained by algebraically continuing a real polynomial $P(x)$ with rational coefficients (so that p-adic variants of the space-time surface exist). $P(o)$ is decomposed to real and imaginary (in octonionic sense) parts and $Y^4 \subset M^8$ corresponds to a root for the $Im(P)$ or $Re(P)$ [L71].

   The associativity of the normal space of the space-time surface is the number theoretical dynamic principle. It implies that space-time surfaces are minimal surfaces. Also their counterparts in $H = M^4 \times CP_2$ - obtained by $M^8 - H$ duality - are minimal surfaces geometrizing the massless wave equation.

2. One can assign to the half-cones of the CD distinct polynomials which must be identical at $t = T/2$. The condition is satisfied if the polynomials are $P(o)$ for the "lower" half-cone and

$P(T-o)$ for the "upper" half-cone. The space-time surfaces associated with the half-cones are in well-defined sense mirror images glued together at $T_{geom} = T/2$. This is not however the case for the space-time surfaces assignable to sub-CDs of CD interpreted as correlates of the mental images of the self assignable to CD.

This proposal has strong implications.

1. The evolution by steps consisting of unitary time evolution+SSFR increases the size of CD in a statistical sense (the number of CDs larger than the given CD is infinitely larger than those smaller than it). PB remains unaffected apart from scaling. Hence the size of the region of space-time surface identified as a "root" of the real part of $P$, increases: more of the surface determined by $P$ becomes visible in each SSFR. This is like opening a packet containing a gift. Each "very special moment" $t = r_n$ brings something new in light.

2. At $T_{now} = T/2$ the sensory input from the geometric past induces sensory mental images drifting to the geometric future and gives rise to memory mental images assignable to sub-CDs. Contrary to a naive expectation, memory mental images indeed drift to the geometric future of $T_{now}$ as the size of CD increases rather than remaining in the geometric past. The emergence of these sub-CDs in shorter scales breaks the mirror symmetry between half-cones.

   This makes it possible to learn from experiences during a given life cycle and utilize that learning during the next life cycle with an opposite AT. In the BSFR, AB becomes passive and these memory mental images become the "silent wisdom" for the time reversed self representing what was learned during the previous life cycle.

### 2.2.4 Internal degrees of freedom related to the non-determinism of the space-time surfaces and consciousness

In TGD, consciousness and cognition are assigned with the SSFRs assigned with the, presumably discrete, internal degrees of freedom (IDF) assignable with the classical non-determinism. Ordinary SFRs (BSFRs) are assigned with the ordinary degrees of freedom (ODF) assignable to the entire Bohr orbits and measured in the ordinary quantum measurements. Several questions related to the relationship of IDF and ODF, highly relevant to the view of consciousness, come to mind.

Consider two systems A and B. For instance, A could represent a conscious observer and B a part of the environment or second conscious observer. Many kinds of entanglements and entanglement reductions are possible. Besides the ordinary entanglement ODF(A)-ODF(B) also entanglements of type IDF(A)-ODF(B), IDF(A)-IDF(B), and IDF(A)-ODF(A) are possible.

1. There can be ordinary entanglement of type ODF(A)-ODF(B) but no entanglement of other types . Could the reduction of this entanglement relate to sensory perception?

   One can also consider the entanglement of type IDF(A)-ODF(A)-ODF(B). Could this entanglement be relevant for the formation of the cognitive representation as thought about the sensory mental image?

2. The reduction of IDF(A)-ODF(B) entanglement would induce an effect on B. IF B is a conscious entity it could be hypnosis. If B is an ordinary physical system it could be psychokinesis.

3. Could IDF(A)-IDF(B) entanglement for conscious entities make possible telepathy?

4. Could the reduction of IDF(A)-ODF(A) type entanglement relate to the realization of motor action, and more generally, to the realization of intentional actions?

The precise role of quantum criticality in the realization of intentional actions should be understood. In TGD quantum criticality is completely universal as also consciousness so that even elementary particles can cognize and the p-adic length scale hypothesis gives a measure for the degree of cognition. Conservation laws pose strong restrictions in this case: a stable particle like proton or electron serves as an example. The intuitive idea is that a perturbation is needed to trigger a BSFR, which transforms intention realized as entanglement to a motor action or to an action affecting the external world. Is the quantum entanglement of IDF with its ODF enough to trigger a BSFR of the system: a spontaneous decay of an unstable particle would be an example now. Something similar should be true also in the macroscopic situation.

## 2.3 Negentropy Maximization Principle (NMP) as variational principle of consciousness

Negentropy Maximization Principle (NMP) defines the variational principle of consciousness in TGD [K7] [L37] but as an analog of second law rather than as a usual variational principle.

1. NMP replaces the second law (SL) and implies it for ordinary matter. SFR means a reduction of the entanglement for a pair $S_a - S_b$ of sub-system $S_a$ and $S_b$, its complement in $S$. Instead of a single measurement, there is a measurement cascade, proceeding from long to short scales. At each step a system decomposes to a pair of unentangled subsystems. NMP states that the negentropy gain in each step is maximized and selects the pair $S_a - S_b$ at each step. This process can be visualized by a tree diagram.

2. In adelic physics [L9, L11] the entropy $N = -S_1 - S_2$ is the sum of real and various p-adic negentropies. They are real numbers but defined for entangelment probabilities belonging to some extension of p-adic numbers using the generalization of Shannon formula: ordinary e-based logarithms are replaced by p-based logaritms.

   p-Adic negentropies can be positive so that for non-trivial EQs one can have $N > 0$. Negentropic entanglement (NE) is stable against NMP so that the process stops. It is natural to assign positively colored emotions to NE or generation of NE. One can also say that NE distinguishes between living and inanimate matter and between dark and ordinary matter.

### 2.3.1 NMP as a generalization of the second law of thermo-dynamics

On the basis of empirical facts, Jeremy England [I4] has proposed that SL implies evolution. This statement seems to be in conflict with the standard thermodynamic view of biology [L2].

England's view that SL implies evolution, is clearly in error. NMP [L37] explains why England's paradoxical view is apparently true. A generalization of quantum measurement theory to a ZEO based theory of consciousness, and a number theory based view of cognition leading to adelic physics, is required to understand this misinterpretation.

1. SFR decomposes a given system (unentangled from the environment) to 2 subsystems in such a way that the negentropy gain is maximal for the "winning" decomposition. This corresponds to the quantum measurement of a universal observable, identified as the density matrix for the subsystem-complement pair.

2. TGD allows a genuine notion of negentropy assignable to entanglement and thus to the density matrix. The negative of the ordinary entanglement entropy $N = -S$ defines negentropy which at best is $N = 0$ since $N$ is always non-positive.

   A genuine measure of information is needed. Since information is associated with cognition, one must expand the realm of physics to include cognition. One can also assign to the extensions of p-adic number fields an entanglement negentropy by the analog of a Shannon formula replacing logarithms of probabilities with the logarithms of their p-adic norms [K7] [L37].

   Remarkably, p-adic entropy can be negative and NMP mandates this. Furthermore, its magnitude is not smaller than that of real entropy. Therefore negentropy identified as the sum $N = -S_1 - S_2$ of real and p-adic entanglement negentropies can be positive for non-trivial EQs. $N$ defines a genuine measure of information and, by NMP, increases during the life span of the conscious entity. This however implies the increase of real entanglement entropy [L2].

   p-Adic number fields, combining with real numbers to form an adele, are needed [L9, L11]. The algebraic extensions of p-adic number fields induced by EQs form an infinite hierarchy with increasing complexity which is identifiable as an evolutionary hierarchy. EQs emerge from $M^8 - H$ duality [L29, L30]. Space-time regions are determined by polynomials defining the EQs via their roots. Evolution as an increase of the dimension of EQ is unavoidable.

3. Consider now the connection with thermo-dynamics. When SFR occurs, entanglement entropy becomes zero, but ensemble entropy increases. That is, the outcome of measurement

is not deterministic and reduction probabilities correspond to the eigenvalues of the density matrix. This means an increased thermo-dynamic entropy and generation of disorder.

However, if the SFR cannot occur, entanglement is stable. For the negentropic states for which negentropy cannot decrease, NMP prevents SFR! The negentropic states approach cognitive fixed points and replace thermodynamic equilibria for which entanglement negentropy is maximum. The conscious entity maximizes its knowledge during its life-span quite universally: this applies to all systems at all scales, not only humans.

For $h_{eff} = h_0$, NMP implies standard quantum measurement theory. Entanglement can be also non-negentropic for non-trivial EQs. In this case, NMP does not prevent complete de-entanglement from occurring and SL holds true. For dark matter with $h_{eff} > h$ NMP can, however, stabilize entanglement. This gives rise to a generation of conscious information. In summary, a pessimistic SL transforms to an optimistic NMP and implies SL for ordinary matter.

### 2.3.2 Is it possible to measure cognitive entanglement negentropy?

Entanglement negentropy as a measure of conscious information is not the negative of the ordinary entanglement entropy but sum over p-adic contributions obeying however the same kind of formula as the Shannon entropy. For a given p-adic prime $p$, the logarithms of probabilities are replaced by integer value p-based logarithms of their p-adic norms. This requires that the entanglement probabilities are rationals or belong to the extension of rationals. Suppose that they can be measured somehow.

The problem is that the entanglement probabilities cannot be known with an infinite precision and the approximation as a rational number can lead to very different outcomes for the negentropy. For instance, multiplying the probabilities with a rational $r = m/n$ very near to unity such that $m$ and $n$ are very large integers, can change the sum of the p-based logarithms dramatically. The reason is that real and p-adic topologies are very different. The power $p^n$ for large $n$ approaches zero in p-adic sense but to infinity in real sense.

Measurement of the amount of conscious information is in question and it is not surprising if problems emerge if one starts from real numbers which are essentially measures for magnitude: consciousness cannot be weighed.

The first question is of course whether cognitive entanglement negentropy is useful in any way? This seems to be the case. If one takes the number theoretical physics predicted by TGD as a correlate for cognitive consciousness seriously, one can see the effects due to the reduction of negentropy at a qualitative level. In absence of metabolic energy feed needed to increase the values of $h$ to $h_{eff}$, $h_{eff}$ spontaneously decreases and the negentropic resources are reduced. The level of consciousness is reduced and the system gets tired or even loses consciousness. This can be seen as a direct qualitative support for the notion if subjective existence is accepted as something real.

What is clear is that if the cognitive measurement problem can be solved it must be carried out in the number theoretic framework. At least to me this means that notions like field body, zero energy ontology, and number theoretic physics are taken seriously. For the sake of simplicity, consider in the sequel rational probabilities. One can also consider the possibility that the probabilities are always rational: this would conform with the way how they are estimated experimentally, at least in real number based physics by repeated measurements.

1. As far as the approximation as rationals is considered, only the p-based logarithms appearing in the expression of negentropy are problematic. The integer of the lowest power of $p$ is sensitive to the approximation as a rational. Could some additional physically motivated assumptions allow to eliminate this sensitivity? And could one restrict the number of primes involved?

2. Suppose approximate values for the probabilities have been somehow deduced as rational numbers by performing measurements for a cognitive ensemble. The estimates for the probabilities $P_k = m_k/n_k$ are rational. The integers in $m_k$ and $n_k$ can be developed to powers series in powers for a given prime $p_i$ and the integer exponent of the lowest power of $p_i$ determines the norm of $m_k$ and $n_k$. If the actual probabilities $P_k$ are rational

numbers $P_k = m_k/N$, only a finite number of p-adic primes matter since the p-adic norms of numerator and denominator of $P_k = m_k/N$ are equal to 1 for large primes and p-based logarithm vanishes. One should be able to identify for a given probability and given prime $p$, reliably the lowest power in the expansion in powers of $p$. Unfortunately, a small change of the rational approximation can change the situation dramatically.

3. Canonical identification, crucial for the interpretation of p-adic mass calculations [L42, L64], provides an attractive way to fix the p-adic norm assigned to the real probability. Canonical identification $I : \sum x_k p^k \to \sum x_k p^{-k}$ maps p-adic numbers in a continuous way to real numbers. The inverse of $I$ is for a finite number of the pinary digits two-valued. The reason is that the p-adic numbers $-1_p = (p-1)/(1-p)$ and $1/p$ are mapped to the same real number $p$. Assuming that the number of the pinary digits is finite, the image of a real number is unique.

   This could allow us to determine the p-adic norm of the p-adic probability assigned to a real probability reliably. Rationals $r = m/n$ can be mapped by writing them first as a series in powers of $p$. The integers $m$ and $n$ can be also mapped separately to p-adics. The same result is obtained in both ways. This description conforms with the frequency interpretation of probabilities.

4. Canonical identification makes sense also for genuine real numbers $x$: one can write real numbers to a series in base $p$: if the number of the pinary digits is infinite, the p-adic canonical image is unique. However, since the probabilities satisfy $P_k \leq 1$, the p-adic norms of norms satisfy $|P_k|_p = p^{-k}$, $k \geq 1$ and a given prime $p$ gives a contribution $P_k klog(p)/log(2)$ so that the negentropy satisfies $N \geq \sum_p log(p)/log(2)$. For a genuine real number the amount of conscious information would be infinite, which indeed makes sense. In reality a cut in $p$ is required so that negentropy is finite. The rational approximation seems to be the correct way to define the negentropy.

   In any case, this forces us to ask whether one could, at least formally, assign cognitive negentropy also with ordinary probabilities, even with association probabilities associated with language models. If one can assign a useful information measure to these probabilities, one is forced to ask whether the system involved could have rudimentary consciousness?

Consider an actual cognitive measurement (whatever it could mean!).

1. The assumption that the experimenter can control the total number $N$ of measurements looks unrealistic since cognitive entanglement is in question so that standard kind of measurement is simply impossible. It is not possible to put the mind on a scale.

2. The assumption that a measurement in the standard sense is possible indeed leads to problems. The actual measurement $n_i$ would correspond to the total number $N$ of measurements so that one has $P_k = m_k/N$. The problem is that the prime decomposition of $N$ is highly sensitive to its value and changes dramatically in $N \to N + 1$. A technical way to avoid these problems is to assign p-adic norms to the probabilities by canonical identification. This option looks rather convincing.

3. An alternative way to get rid of this sensitivity is to assume that $N$ is not under the control of experiment and the probabilities are deduced in some other way than by performing a measurement for a cognitive ensemble.

4. Could time series of measurement, whose duration cannot be controlled by the observer be considered. Could the number of loci of non-determinism for the Bohr orbit somehow determine the number $N$ of cognitive measurements? If so, the geometric duration of the Bohr orbit would determine the value of $N$ and the probabilities $P_k$.

   p-Adic length scale hypothesis for which the holography = holomorphy vision leading to a generalization of p-adic number fields to their functional counters suggests that favored values for $N$ are primes or powers of prime.

Assuming that one is not satisfied with the proposed mathematics based solution of the problem, could the assumptions about the measured cognitive system help?

1. The number of p-adic primes associated with $m_k$ and $n_k$ in $P_k = m_k/n_k$ are finite and they have a decomposition to a finite number of primes $p_i$. A reasonable assumption is that the integers $m_k$ and $n_k$ can be taken to be as small as possible. This conforms with the frequency interpretation of $P_k$. This would help to make the approximation as rationals more unique and for instance multiplication by a rational, which is a ratio of very large integers and near to unity is not allowed.

2. I have proposed the notion of multi-p p-adicity [L42, L64] motivated by the need to define interaction vertices for particles characterized by different p-adic primes. Multi-p p-adicity would be related to the world of the "classical worlds" (WCW) expected to have a spin glass type structure having a decomposition to regions with ultrametric topology characterized by a p-adic primes.

   In the interfaces of the regions of WCW with different values of p-adic prime $p$, multi-p p-adicity would prevail and mean that the integers involved have expansion in powers of integer $n$: the primes $p_i$ dividing $n$ would define p-adic primes $p_i$ associated with the multi-p p-adicity. This assumption would give very strong constraints on the p-adic expansion of probabilities and the lowest power for each $p_i$ could be highly unique for the integers $m_k$ and $n_p$ in $P_k = m_k/n_k$. The assumption that the integers $m_k$ and $n_k$ have expansion in powers of the same integer $n$ would make the rational approximation highly unique.

3. Negentropy Maximization Principle [L46], which states that the number theoretic evolution tends to maximize algebraic complexity and therefore the maximal value of the negentropy, suggests a possible (admittedly ad hoc guess): determine the rational approximation from the condition that the negentropy is maximized!

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