Comments about Integrated Information Theory of Tononi and Koch

M. Pitkänen
Email: matpitka6@gmail.com.
http://tgdtheory.com/public_html/.

January 3, 2017

Abstract

Integrated Information Theory (IIT) is a neuro- and computer science based theory of consciousness proposed originally by Tononi. This article is a critical summary of IIT and its comparison with TGD inspired theory of consciousness. Basic criticism relates to the circular definition of consciousness leading to a paradox. The printing of a text by printer is a conscious process if no-one knows the text but not so if some-one knows the text. One could test IIT by looking if a system with large Φ (say classical computer in which program is running) has the properties associated with living conscious systems (self-organization in presence of energy feed, metabolism, responsiveness,...). Also the questions about possible experimental testing of IIT raised by the participants of the panel are discussed.

Contents

1   Introduction

I received a link to a very interesting article by John Horgan in Scientific American with title "Can Integrated Information Theory Explain Consciousness?" [J9] (see `http://tinyurl.com/h7btppb`). Originally IIT is a theoretical construct of neuroscientst Giulio Tononi (just Tononi in the sequel). Christof Koch is one of the coworkers of Tononi. IIT can be regarded as heavily neuroscience based non-quantum approach to consciousness and the goal is to identify the axioms about consciousness, which should hold true also in physics based theories. The article of Horgan was excellent and touched the essentials and it was relatively easy to grasp what is common with my own approach to consciousness and comment also what I see as weaknesses of IIT approach.

To my opinion, the basic weakness is the lack of formulation in terms of fundamental physics. As such quantum physics based formulation is certainly not enough since the recent quantum physics is plagued by paradoxes, which are due the lack of theory of consciousness needed to understand what the notion of observer means. The question is not only about what fundamental physics can give to consciousness but also about what consciousness can give to fundamental physics.

The article "Consciousness: here, there and everywhere" of Tononi and Koch [J13] (see `http://tinyurl.com/zgm985f`) gives a more detailed summary about IIT. The article "From the Phenomenology to the Mechanisms of Consciousness: Integrated Information Theory" [J11](see `http://tinyurl.com/z9s4k7n`) gives a more techanical description of IIT. Also the article of Scott Aaronson [J12](see `http://tinyurl.com/zarjfzz`) was very helpful in providing computer scientific view about IIT and representing also mathematical objections.

In the article [J11] it is emphasized that IIT is a work in progress. This applies also to TGD and TGD inspired theory of consciousness. Personally I take writing of TGD inspired commentary about IIT as a highly interesting interaction, which might help to learn new ideas and spot the weaknesses and imperfections in the basic definitions of TGD inspired theory of consciousness. If TGD survives from this interaction as such, the writing of these commentaries have been waste of time.

1.1   Criticism of the axioms of IIT

Consider first a brief critical review of the axioms of IIT.

1.1.1   Philosophical assumptions

1. Consciousness is regarded as as an intrinsic property of matter like mass or charge. This view restates essentially materialistic world view and its problems are well-known (qualia, free will, intentionality).

2. Panphysicism is accepted. This is quite a big step from neuroscience, which tries to reduce consciousness to a property of brain. The motivation probably comes form the idea that computers might be conscious systems too.

   There is no mention of hierarchies although hierarchical structures have turned out to be important also in neuroscience as the success of deep learning programs relying on hierarchies shows. The standard failure of conscious theorists seems to be the assumption that matter is either conscious or not. In physics the notions of scale hierarchies and hierarchies of systems with subsystems with... are standard and this would suggest that also conscious entities form a hierarchy.

1.1.2   Causal evolution and the notion of information

One considers a network and decompositions of system (say brain) into two parts A and B and considers causal evolutions between states of A and B. They could be specified by collections of bits with individual bit telling whether a given neuron fires in given region. A and B could correspond

to input and output of computation or to sensory input and motor response (or response at the level of brain in case that there is not motor response (locked-in patient)).

Causal evolutions between A and B are considered: they might correspond to nerve pulse patterns leading from state of A to that of B. One can define information for a causal evolution from A to B as difference of entropies: $I(A,B) = S(A|B) - S(B)$ Conditional entropy for the state of A with that for B subtracted. Φ corresponds to $I(A,B)$ for a pair for which it is a maximum.

One can critizize this view.

1. The precise identification of the network and of states of the network remains unclear. In the case of computers this is not a problem and one can calculate Φ and decide whether a computer running given program is conscious or not.

2. In the definition of Shannon entropy one implicitly assumes external conscious observer and information corresponds to her information gain as she learns what the state of B is. This notion of conscious information circular and identifies the conscious information of system about itself with that of external system about it.

3. Intuitively it is clear that this information is maximal if A and B corresponds to input and output of a deterministic computer program assigning to each input an output such that all outputs are different and $H(A|B)$ vanishes so that a measure for the complexity of the input is in question. To my opinion this tends to restrict the property called consciousness to be property of classical computers.

To make the criticism more precise, one can look at the expression for $I(A,B) = S(A|B) - S(B)$ with conditional probabilities defined by $p(A|B) = p(A,B)/p(B)$. If A and B are independent events that is if the output has no correlation with input as in the case of thermodynamical system, one has $p(A,B) = p(A) \times p(B)$ and one has $I(A,B) = S(A) - S(B)$. Second law tells that the information is negative. In thermal equilibrium $I(A,B) = 0$. Quite a reasonable result.

Intuitively optimal situation is achieved when $S(A|B)$ having interpretation as the entropy associated with the causal evolution is zero: evolution would be completely deterministic as in classical computer programs or quantum computer programs during computation. Therefore classical computer programs, which do not map two inputs to same output would be ideal (the error correction program mentioned by Scott Aaronson) as far as consciousness is involved: this is not surprising taking into account the idea about neuron as bit.

The situation would be optimal for the maximally entropic initial state: this looks admittedly strange. Printing of a page of text about whose content I know nothing would be a highly conscious process! If I knew the content of the page, it would not be a conscious process! Obviously this is true but for me, not the system claimed to be conscious! The circulatory definition of conscious information leads to this non-sensical result. All definitions of conscious information based on ordinary Shannon entropy lead to the same result. One should have genuine definition of information.

1.1.3   Causal networks and the assignment of qualia to the links of the causal network

Causal network is assumed with motivations coming from neuroscience and qualia are assigned with the links of this network. They would correspond to axons or neural pathways in neuroscience.

Also this view can be criticized.

1. The idea that various sensory qualia could be understood in terms of topological structure of a network formed by neurons and and axons is old but has not led to the understanding of qualia. The neural network looks exactly the same in various sensory areas. Also the sensory pathways look the same.

2. Causal interactions between parts of brain are assumed to give rise to consciousness. People having no corpus callosum have synchronous left and right hemispheres [J7] (see http://tinyurl.com/3gjhtgb)! One might expect that causal interactions between hemispheres must be responsible for the synchrony. There seems to be something like "boss" forcing both hemispheres to synchrony.

1.1.4 Exclusion axiom

Exclusion states the decomposition (A,B) with maximum of Φ contributes to conscious experience. There would be competion for consciousness.

Exclusion axiom cannot make sense for arbitrary system since it always allows decomposition with maximum Φ. Exclusion axiom also leads to a strange situation if their is also competition between systems of different sixes. The larger one takes the overall system size to be, the smaller the probability of a system with given size to be conscious. A manner to escape the situation is to assume hierarchy of consciousness with levels naturally characterized by length and time scales so that one considers systems smaller than given scale at given level.

1.2 Comparison with TGD view

TGD inspired theory of consciousness is essentially quantum measurement theory in Zero Energy Ontology (ZEO).

1.3 Self as generalized Zeno effect in Zero ENergy Ontology

1. In ZEO physical states are replaced by pairs of states analogous to physical events: the members of state pair are localized to 3-surfaces at opposite light-like boundaries of causal diamond (CD) defined as intersection of future and past directed light-cone and replacing its points with CP_2. Causal diamonds form a hierarchy and this implies self hierarchy with subselves as subselves assignable to sub-CDs. In twistor lift of TGD ZEO and CDs forced by finiteness of the action [L5].

   The assumption that the states having vanishing total conserved quantum numbers and classical charges realizes conservation laws and allows consistency with physics without loss of non-determinism required by free will (subject to constraints of state function reduction). Negentropy Maximization Principle (NMP) is the basic variational principle of TGD inspired theory of consciousness.

2. Self as generalized Zeno effect corresponds to a sequence of state functions leaving the state at "passive" boundary of CD and the passive boundary itself unaffected and changing the state at active boundary and moving it father away from the passive boundary. This shift is quantum process involving localization for the positions of active boundary and reducing to a sequence of discrete unitary time evolutions defining the analog of unitary time evolution in ordinary quantum theory. This shift of active boundary of CD gives rise to the experience about flow of time. The passive boundary gives rise to experience about the existence of permanent self. Subselves as mental images give rise to qualia as their unchanging part.

3. Self dies as the first state function reduction to the opposite boundary of CD is forced by NMP but is predicted to re-incarnate as time reversed self. A possible interpretation for sensory-motor cycle is as sensory mental image and its time reversal identified as mental image assignable to motor action. Motor action would mean sensory input in reversed direction of time at some level of self hierarchy. This conforms with the Libet's finding that conscious decision about motor action is preceded in geometric time by neural activity.

1.3.1 Criterion for consciousness

The notion of conscious self relies on the notion of quantum entanglement to which one can assign information measures.

1. Conscious self would correspond in zero energy ontology (ZEO) to negentropically entangled system at the passive boundary of CD and would not decompose to tensor products of unentangled systems. Selves can be assigned with causal diamonds (CDs), and the simplest option is that CD corresponds to single self. Sub-CDs correspond to sub-selves experienced by self as mental images. This condition decomposes the system uniquely to conscious entities and it is not sensible to ask whether arbitrarily chosen subsystem is conscious or not. Only the state at the "passive" boundary of causal diamond (CD) correspond to self in this sense.

The state at the active boundary of CD which moves reduction by reduction farther away from the passive boundary is entangled and one cannot decompose it in this manner. Note that self has sub-selves, which represent sub-CDs and these contribute to mental images of self.

2. The notion of many-sheeted space-time is essential. Subselves correspond to smaller space-time sheets "glued" to space-time sheet assignable to self. They represent subsystems but not as a tensor factor as in standard quantum theory based on single-sheeted space-time. The theory of hyperfinite factors allows more general notion of tensor product, and it seems that this kind of tensor product is in question.

   This relates closely to the notion of measurement resolution. Self experiences subself as mental image but the mental images of subself are experienced as an average. This prevents self from drowning to conscious information. Second implication of this notion of subsystem forced by many-sheeted space-time is following: two selves at the same hierarchy level are by definition un-entangled. Their subselves can however entangle to single subself shared as mental image by both. This could be behind stereo vision and "stereo consciousness" and could be essential for communications. Also remote mental interactions would involve stereo consciousness.

The fundamental criterion for consciousness would be therefore formulated in terms of entanglement. At the level of living systems betabolic energy feed would be a more practical criterion to decide whether some living system is conscious at some hierarchy level. Self-organizing systems are systems in which the feed of energy to the system leads to a complex self-organization patterns. Are these systems conscious? Does the feed of energy lead to a generation of negentropic entanglement (NE) and metabolism leading to a dynamics analogous to that in biochemistry (NE is always present in p-adic sectors). Any system has magnetic body (MB, also a new element) and one must consider seriously this possibility. The time scale of this dynamics could be quite slow. Second important factor is the coupling of dark matter at MBs to ordinary matter. If this coupling is small, consciousness does not have much causal power.

1.3.2   Negentropic entanglement as the counterpart of Φ in TGD

In TGD framework information (Φ) is associated with NE for which the sum of number theoretic entanglement negentropies assignable to p-adic primes is maximal [L8] [K3]. The notion of NE and precise formulation of NMP has taken a long time. The recent formulation is in terms of adelic physics combining real number based physics of sensory experience with various p-adic physics of cognition. The key realization was that there is just single number theoretically universal entanglement. In real context it has always non-negative entropy and measures the lack of information of outsider about the system . In p-adic contexts the p-adic variant of entropy can be negative and has interpretation as information and measures the conscious information of system about itself.

1. Both real entropy and its p-adic variants in algebraic extension of rationals defining the coefficients of Hilbert space is used (this is essential and forced by number theoretical existence). In p-adic context the definition of entanglement entropy relies on a modification of Shannon entropy satisfying same axioms as in real case. For given p-adic prime this entropy can be negative and is identified as negentropy associated with entanglement. The superposition of state pairs (a_i, b_i) can be identified as an rules with pairs as instances of the rule. Information can be said to be in the quantum relationship between A and B - not about A or B. One finds also now the pair for which NE is minimal. State function reduction can occur for this pair and reduce the entropic entanglement or produce more NE.

2. Number theoretical universality is an important additional restriction demanding that the entanglement probabilities in various p-adic sectors are of form $P_i = X_i/N$, where N is the number of state pairs in the superposition and X_i depend only on the algebraic numbers defining the extension having unit p-adic norm but do not involve ordinary p-adic integers and therefore have unit p-adic norm. This implies that the sum of p-adic negentropies is maximal and depends on N only and equals to the real entropy associated with maximal entanglement with $p_i = 1/N$. The the sum of p-adic negentropies is not smaller than real entropy and equals to it for rational entanglement $p_i = 1/N$.

Could the paradoxical situation encountered in IIT (printer is conscious when it prints file about contents of which no one knows and unconscious otherwise) make sense in TGD framework somehow?

1. Conscious entity - self - would live in adelic world and would be negentropically entangled subsystem - superposition of several state pairs. Self can be regarded as generalized Zeno effect in ZEO. NMP does allow state function reduction during its lifetime to the passive boundary of CD so that outsider could not learn what it's state is!

2. Real entanglement entropy would describe this missing information and the sum of p-adic negentropies the conscious information posssessed by the self (for rational entanglement probabilities these two measures would have same value). In TGD inspired theory of consciousness the paradoxical statement would thus make sense! Schrödinger cat remains conscious as long as no-one is able to measure the state of cat (note that here dead-alive dichotomy as a metaphor is not good). Conscious systems would be secretive!

The correlation produced by causal evolution in IIT is replaced with NE in TGD. Hence the two views look rather different as far as conscious information is considered. On the other hand, classical physics is exact part of TGD and quantum classical correspondence is realized by strong form of holography (SH). Quantum computation accompanies self and quantum computation is accompanied by a quantum superposition of classical computations. Therefore one can ask whether the generalization of the formula for $I(A, B)$ could be meaningful in TGD and even relate to consciousness.

1. In TGD framework the superpositions of classical space-time surfaces identified as preferred extremals connecting the positive and negative parts of zero energy states at opposite boundaries of CD define the counterparts of causal evolutions. Quite generally, classical deterministic evolution is highly analogous to a classical computer program.

2. The analog of $I(A, B)$ in TGD could be assigned with the evolution zero energy state based on time evolution of the space-time surfaces: A and B would correspond to the positive and negative energy parts of states at opposite boundaries of CD (initial and final states of classical time evolution) defining self. B would correspond the passive boundary of CD and A to the active boundary, which moves farther from B during the reduction sequence and states at it experience a discretized variant of unitary time evolution. The evolution for the active boundary of CD is the analog of unitary Schrödinger evolution and analogous to quantum computer program.

   Note: In TGD framework quantum theory is purely classical theory formally! WCW spinor fields representing zero energy states are indeed purely classical spinor fields formally. Only state function reduction is something genuinely quantal.

3. $S(A|B)$ could be interpreted as entropy generated by evolution analogous to classical computation. The time evolution however fails to be strictly deterministic and particle reactions represented topologically in terms of generalized Feynman diagrams would naturally relate to this non-determinism. Hence $S(A|B) > 0$ is expected to hold true and could be very much like entropy generated by particle decays and creation and the interpretation in terms of thermodynamics would be natural.

4. The very existence of self thus breaks second law (note however that state function reductions occur for sub-CDs assignable to mental images which die and are reborn). As self dies, thermodynamical entropy increases since this reduction is non-deterministic. On the other hand, new time-reversed self is born and carries NE and there is negentropy gain by NMP [K3]. Second law holds true in time scales longer than the life time of the long-livest self. $I(A, B) > 0$ could be thus assigned with selves during their life-time. Since the state function reduction to the opposite boundary of CD is non-deterministic, the conjecture that $I(A, B)$ equals to negentropy gain in this reduction, does not make sense.

5. The definition of $I(A, B)$ is non-trivial problem and discretization implied by finite measurement resolution at fundamental level is necessary in order to avoid mathematical difficulties in the case of deterministic evolution.

1.3.3   The counterparts of networks in TGD

In TGD framework the networks emerge naturally as networks of magnetic flux tubes [L8].

1. The "boss" forcing the synchrony of disconnected left and right hemispheres would be magnetic body (MB) of brain [L10]. Magnetic bodies appear in all scales. NE between nodes of this network is what is more significant.

2. The so called tensor networks [B1] [L6] (see `http://tgdtheory.fi/public_html/articles/tensornet.pdf`), which have emerged as realizations of error correction codes in quantum computation and realize holography can be seen as a realization of NE. One can say that each node is unitary in generalized sense and that the nodes at the ends of lines are unitarily entangled. The realization in terms of magnetic flux tubes could define kind of template for the dynamics of bio-systems. Magnetic body (MB) would define both geometric and dynamical template for bio-chemistry and even genetic code could be reduced to this level. MB would extend the organism-environment duality to trinity. It has been proposed that entanglement between the nodes leads to the emergence of 3-space. What would emerge in TGD framework would not be 3-space but proprioception - conscious experience about 3-space. These networks would define "magnetic spine" of an organism.

3. The dynamics of MB (motor actions of MB as reconnections, contractions of flux tube, changes of the topology of the network inducing NE transfer) and also the dynamics at MB (supra currents, dark photons propagating along flux tubes in targeted manner) would define the analog for the causal dynamics appearing in IIT. ADP-ATP transition attaching phosphate to ADP has interpretation as transfer of NE. Phosphate-X (X some large system) flux tube is attached to ADP to give ATP-X NE and when ATP gives phosphate to bio-molecule Y one obtains Y-X NE (for what Y could be, see below). Metabolic energy could go basically to transfer NE between systems. This would mean that the local dynamics of the network would be central for what it is to be living.

4. This picture would suggest that the changes of topology making possible transfer of negentropy are crucial for consciousness in living systems. Dynamics of bits in static networks represents only the classical communications associated with genuinly quantal system.

Bio-photons identified as decay products of dark photons with large value of Planck constant h_{eff} is an essential element of resonant like precisely targeted communications along flux tubes of MB. It must be made clear that TGD has had an interpretational problem related to the identification of bio-photons as decay products of dark protons [K8, K9]. The resolution of this problem leads to conclusion that MBs with field strengths assignable to Earth's *resp.* galactic magnetic fields control living matter and have EEGs related by scaling: for details see [L8].

What the mysterious looking entity X could then be?

1. The MB of Earth assignable with Earth's mass via $h_{eff} = h_{gr} = GMm/v_0$, where v_0 is a parameter with dimensions of velocity, is the first candidate for X but for it EEG would be scaled down since the the flux tubes would correspond to those of galactic magnetic body with $B_{gal} \sim 10^{-9}$ Tesla: 10 Hz alpha band would correspond to 72 minute time scale and natural periodicity would be given by sidereal day.

2. What puts bells ringing is that Spottiswoode observed that sidereal day defines periodicity for precognition [J10]. A mass $M_D \simeq 5. \times 10^{-5} M_E$ forming a spherical layer at the distance of Moon from Earth associated with the magnetic Mother Gaia controlling bio-dynamics would correspond to the ordinary EEG. This would also predict that 1 s cyclotron time for DNA sequences in $B_{end} = .2$ Gauss corresponds to 12 h cyclotron time for $B_{gal} = .63$ nT.

The presence of these two MBs be a dramatic manifestation of non-locality and profoundly change neuroscience views about consciousnes. These MBs would make life possible at Earth. Both MBs would be in continual contact with biomolecules like ATP and the molecules for which ATP attaches or provides the phospate. Metabolic energy would be used to this process. These MBs would be "goddesses" directing their attention to tiny bio-molecules. If this picture is correct, the ideas about consciousness independent on material substrate and assignable to a running computer program can be safely forgotten.

1.3.4   Qualia in TGD framework

In TGD the qualia correspond to the eigenvalues assignable to the observable measured during repeated state function reductions leaving the states at the passive boundary of sub-CDs representing mental images of self invariant. Non-locality and new view about time allows to consider also the possibility that qualia can be assigned with the sensory organs [K2]. One cannot of course exclude the possibility that also neurons can have primary sensory experiences rather than just sharing the primary sensory mental images assignable to the sensory organs.

Sensory qualia reduce in principle to quantum numbers assignable to the maximally commuting set of observables, which in turn would reduce to Cartan algebra for the Lie algebra of symmetries. This algebra is infinite-dimensional in TGD framework since the mathematical existence of the theory demands maximal possible symmetries at the level of "World of Classical Worlds" (WCW). If this view is correct, sensory qualia would be universal.

1.3.5   Panphysicism in TGD

Pan-physicism is basic prediction of TGD approach. Entire hierarchy of selves is predicted. The mental images of self are identified as subselves and there is p-adic length scale hierarchy defining a cognitive hierarchy and hierarchy of Planck constants $h_{eff} = n \times h$ defining a hierarchy of dark matters. Our mental images correspond to conscious entities and we ourselves are mental images of higher level self. The hierarchy of space-time sheets of many-sheeted space-time is essential element and lost in the GRT-gauge theory limit of TGD. One can say that length scale reductionism is replaced with fractality.

This kind of scale hierarchy would immediate allow to answer quastions like "Is cerebellum conscious?" and "Are we conscious during sleep?". The answer would be "yes, but in different scales than brain in wake-up state". The duration of mental images of cerebellum would be measured in perhaps milliseconds. The conscious motor actions of cerebellum would correspond to fine details of motor actions. During sleep absence of sensory input and motor output would mean that corresponding mental images are absent. In TGD framework this alone explains why we do not have memories about sleep periods!

1.4   Are the following questions addressed in IIT?

There are many questions, which the articles about IIT that I have seen does not address.

1. What directed attention means in IIT? Could one assign this to a link of network?

2. What, if anything, free will means in IIT?

3. What intentionality means in IIT? Can computer behave intentionally?

4. What could serve as correlate of cognition?

5. Why metabolism?

6. Why EEG?

TGD answer to some of these questions can be found from [L8]. For a more detailed TGD based criticism of IIT see [K13].

1.5   Some abbreviations

In the sequel I will answer the questions raised by Lian Sidoroff about IIT, by Patrizio Tressoldi about intention and energy, and by Ben Goertzel about IIT and possibility of post-quantum physics.

To help the reader I list some abbreviations to be used in the sequel. Zero Energy Ontology (ZEO), Causal Diamond (CD), World of Classical Worlds (WCW), Strong (Form of) Holography (SH), Negentropy Maximization Principle (NMP), Negentropic entanglement (NE), Magnetic Body (MB), Biological Body (BB).

2 Questions about IIT, remote mental interactions, intentionality, and need for post-quantum theory to describe consciousness

In the following are my TGD inspired responses to the questions posed by Lian Sidoroff - mostly about IIT and remote mental interactions, to the questions of Patrizio Tressoldi related to the notions of intentionality and energy, and to the questions of Ben Goertzel about IIT and remote mental interactions and possible need for post-quantum physics to understand consciousness. I do not copy below the full questions of Lian since they would take too much space. The chapter about non-locality in TGD framework [L8] summarizes TGD bakground. I have also written about two chapters related to IIT [K13, K12].

2.1 Basic TGD based criticism of IIT

IIT in its basic form seems to regard consciousness and life as rather independent properties of system. For computers the value is maximal when the output of program distinguishes between all inputs and - rather counter-intuitively - if the entropy of the initial state identifiable as lack of information of the external observer about the state of system is maximal.

It is of course an open question how many common properties conscious and living systems share but my intuitive view is that life is prerequisite of intelligent consciousness able to receive information about environment and react to changes in it. Also the TGD view about self implies that conscious system eventually dies and is living in this minimal sense not yet implying genetic code. One could therefore test the street plausibility of IIT by evaluating Φ reliably for some system and finding whether other plausible signatures of consciousness familiar from living systems are present when the value of Φ is high.

There is a long list of such signatures: abilities to self-organize under energy feed, to attend, to intend, and to respond via sensory-motor loop, behavior suggesting free will and cognition,... At the physical level there is metabolism, EEG, biochemistry involving bio-catalysis, perhaps even some kind of genetic code at level deeper than chemistry, replication, etc...

To my opinion, IIT would be very natural description of consciousness if AI systems were conscious. These systems perform algorithms written by programmers. So called deep algorithms with many hierarchical levels have been unexpectedly successful: this has been seen as a message that the physical Universe is in some sense very simple and has natural hierarchical structure (see `http://tinyurl.com/hz2jp8z`). These programs can even rewrite themselves but also this is based on program written by a programmer. In a well-defined sense these systems are intelligent, and one can even make them to mimic free will by using random generators. They are however not intentional and I think that this is the fatal failure. They are like some brain patients with damaged frontal lobes. These persons are intelligent but cannot intend and realize their intentions in the time time scales needed in say everyday life.

2.2 Questions by Lian Sidoroff

2.2.1 Responsiveness

Q1: How do we define consciousness phenomenologically? Could responsiveness serve as a signature of consciousness?

The motivation for the question comes from Aaronson's observation that a system doing mere parity check can be much more conscious that human brain if Φ is used as criterion. To my opinion Scott is quite right. Something is missing from IIT: Φ cannot serve as sole criterion for what it is to be conscious. The following considerations are strongly TGD centered reaction to the idea.

1. Responsiveness means essentially motor action induced by sensory input. The problem is that any system responds to perturbations. For instance, computer programs can respond by learning and can even by rewriting themselves. I would not conclude from this that the computer running this kind of program is conscious. To my opinion one should characterize what the responsiveness of conscious system does mean.

Perhaps it could mean response, which is somehow unexpected. Say, my PC doing something that it is not programmed to do. Or a response of a computer network in a scale much larger than one would expect to a perturbation that the system is not programmed to notice at all. In TGD framework it would reflecting non-locality involving essentially entanglement in long scales.

2. Conscious response requires directed attention selecting some preferred target. Also computers can be taught to direct respond to specific features and this could be called directed attention. What makes the directed attention conscious? That it is directed in an unexpected manner? A computer responding to signals which it is not programmed to respond?

3. Can the system with large Φ direct its attention? To my TGD inspired opinion the change of the topology of the network occurring by state function reductions in appropriate scales is absolutely essential for directed attention. At given level of hierarchy it has interpretation as changing focus of attention. Φ is defined for a fixed network. I see this as a problem (, which might be easily removable).

   At the fundamental ATP level directed attention corresponds to the transfer of NE involving the change of topology of network in molecular scale: this would be responsiveness in molecular scale. Metabolic energy is needed to make possible NE transfer and therefore the rate for the use of metabolic energy looks like a reliable criterion for being consciousness. The axiomatics of IIT seems to miss this aspect totally.

   Also general self-organizing systems involve feed of energy. Are they conscious and in what time scale? Is this time scale too long/short for human observer? Could general self-organizing systems have motor actions as reactions to stimuli?

4. In TGD Universe response involves sensory message to MB and the message inducing motor action sent as signal in reverse time direction. In ZEO this corresponds to a state function reduction to the opposite boundary of sub-CD in which subself "dies" and reincarnates as time reversed self. This time reversed subself corresponds to a signal to geometric past, which initiates neural activities (Libet's findings find explanation). Besides responsiveness and intentionality can be seen as a characteristic of consciousness and I find difficult to see how a computer with large Φ could have it.

   I would thus argue that conscious response involves the time reversed reaction (creation time reversed subself) giving rise to motor action allowing to distinguish it from the response of a non-conscious systems.

5. Locked-in patients are conscious but have no motor activities so that the naive behavioristic dogma fails. To be responsive in TGD Universe it is however enough for MB to respond by generating a control signal, which would normally induce neural activities leading to a motor response but remain now only an imagined motor action (maybe). This cannot happen for locked-in patients but does not mean that the patient is unconscious since there would be reaction also at neuronal scale. Could general self-organizing system or even computer have MB carrying dark matter as $h_{eff} = n \times h$ phases, which reacts and responds but the response is not visible to us because we are not yet able to observe dark matter?

To my opinion responsivity is only one signature of consciousness. The ability to intend and realize intentions, and free will reflecting itself as a non-deterministic behavior, are additional criteria. In TGD Universe one cannot talk about systems which are conscious but dead and I tend to believe that this is true universally. Living systems self-organize and presumably so also conscious systems.

MB is essential piece of the story about living conscious systems in TGD framework. EEG and its variants in various scaled up frequency ranges make possible communications between various onion like layers of MB and biological body (BB) using dark photons. It looks natural to assign to a conscious and living system MB carrying dark matter matter as $h_{eff} = n \times h$ phases making the system macroscopically quantum coherent: this would make possible for the system to generate macroscopic quantum entanglement and behave like a single coherent unit.

1. Can one assign scaled variant EEG to systems like ant nest or bee flock, or even Internet. Could one measure the analog of EEG experimentally?

2. In human EEG there is clear decomposition to quasi-stationary periods of duration of order .3 seconds (roughly) separated by sharp transition periods (see [J2] and [L1]). These could be identified as correlates for mental images as sub-selves. Could one distinguish between the EEG counterparts of subself and its time-reversal? If one can identify the analog of EEG for say ant nest, could one identify also these correlates of mental images of ant nest?

Could one use these criteria tell whether classical computer is conscious?

1. There is energy feed but can one say that computer is self-organizing system? The defining feature of classical computer is that it has fixed circuitry and it does just what the program tells it to do: this does not look like self-organization. There are programs able to rewrite themselves but also these are based on programs.

2. Could classical computer have MB, which self-organizes and can act as intentional agent and therefore force the computer to do something original?

3. Could classical computer have something analogous to EEG? Is classical computer like locked-in patient? If one requires also NE, it seems that the idea about classical computer as a conscious entity can be forgotten unless one regards life and consciousness as completely independent phenomena.

4. Could the two big MBs (assignable to Earth and galaxy) come in rescue and blow spirit to the classical computers? Maybe but this spirit might not have anything to do with the computation running in it.

In the case of quantum computers situation changes in TGD. Self can be in very abstract sense be seen as a quantum computer program, which runs as long as generalized Zeno effect lasts and dies when the program halts. What is new is the reincarnation as time-reversed self making possible computation able to overcome the standard limits for ordinary computation and computation not possible in standard positive energy ontology could be carried in ZEO in finite time.

2.2.2   Network perturbation as variant of responsitivity

Massimini [J3] has suggested a kind of microscopic variant of responsivity. Perturb brain directly by say transcranial magnetic perturbation and find whether there is a response in the scale of brain. Massimi found that TMS perturbation allowed to distinguish between sleep and awake states. This option would apply also to locked-in patients and looks rather reasonable. Again one must however remember that also the scale matters. Part of brain could allow consciousness in some scale and this scale could be rather small, even that for single neuron or pair or neurons connected by axon.

Q2: Could sensitivity to network perturbations be scaled to GCP network. Could it be possible to wake it up in major global events such as catastrophes and could this wake-up state be detected?

A: Perturbation would be now a major global event. GCP includes also the users might be essential so that one could not regard GCP as independent conscious entity. The connections in the network are dynamical in the sense that two participants can be connected or not and in this sense this brings in mind biomatter. TGD framework also MB of this network would be responsible for reacting to global stimulus and possibly inducing some synchronous reaction visible in the entire network but I would suspect that one cannot treat the network as separate.

2.2.3   Integration

Q3: Where does Remote Viewing perception fall on the spectrum of consciousness? Where does intent/target focus fit in this AIM (Hobson)/IIT (Tononi) phase space and what kind of influence does it exert on the state of consciousness?

A: Lian argues that the perception of RV viewed target is something very different from that postulated in IIT. This difference could reflect also the fact that RV percept is gradually evolving. Ordinary percepts are stimulated by waking up already existing standardized mental images.

Stereograms could provide a good analogy for how RV evolves. The stereograms contains a lot of wrong cues and if you direct attention to these details you are lost. There is however a method: look at the picture very near so that you are not able to direct your left-brainy attention to the details and suddenly with the help of your holistic right brain you see the beautiful 3-D picture! After than you can fill in the details.

This process means an emergence of totally new mental image, discovery, and I think that what people are achieving in science now and then is just this. Interestingly, a 40 Hz peak in EEG accompanies the ermgence of the 3-D picture [J1]. It accompanies also the transition to a meditative state. The elimination of small scale details is essential part of the process and meditative practices do this.

Here the weakness of IIT in its static form becomes obvious. What would be needed is emergence of a totally new kind of network pattern. This experience cannot be described assuming a fixed network: computers do not have enlightment experiences. In TGD this would mean emergence of new negentropically entangled subsystem in state function reduction to opposite boundary for some sub-CD.

Note that the integration of conscious experience corresponds naturally to NE in TGD framework.

2.2.4 La Bete

Why are spontaneous non-local conscious phenomena (telepathy, precognition) associated with meditation and dreaming? The absence of sensory and motor component in conscious experience would not mask the mental images involved with remote mental interactions. The explanation for the emergence of stereogram could also help to understand. One develops holistic view getting rid of details and is able to see the big picture. Ability to see in given resolution is also an implication of the scale hierarchy for conscious entities.

a) Could one test non-locality in long scales?

LS mentions examples about non-locality in remote mental interactions. Persinger et al have published a lot of articles related to biophotons, EEG, and long length scale entanglement between brains. See for instance [J4, J5, J6]: for TGD interpretation see [K7].

Spottiswoode found evidence that the probability for the occurrence of precognition is maximum at a fixed hour of sidereal day [J10]. On the other hand, the condition that the cyclotron frequencies for h_{gr} assignable to Earth mass correspond to the energy scale of bio-photons requires that the flux tubes of galactic MB with $B_{gal} \simeq .36$ nT mediate the gravitational interaction of Earth.

This implies that the cyclotron frequency 10 Hz for "endogenous" dark magnetic field .2 Gauss is scaled down by factor 5×10^{-5} and corresponding time scale is 36 minutes. EEG time scales in the range 1 s -.01 s correspond to a scaled up time scale range 7.2 min - 12 hours - typical time scales assignable with daily conscious activities. Ordinary EEG would correspond to h_{gr} assignable with a mass shell at distance of Moon for which there is also other evidence [K9]. Also this is a rather dramatic prediction.

The existence of a scaled down variant of EEG in this frequency range in the em spectrum of brain could be tested. The crucial test would be whether the day associated with this EEG is sidereal day (mean duration is 23 hours, 56 minutes, 4.0916 s) rather than solar day. The rotation period of Earth around galactic center is 26,000 years: could this period reflect itself as a periodic modulation in the evolution of human consciousness? Milankovic theory for ice ages involving also the rotation around galactic nucleus predicts 21,000 year astronomical periodicity giving the period for the occurrence of ice ages (see `http://tinyurl.com/qhnzt5r`). This could provide very concrete reasons for the modulation.

Q4a:: Can we test the IIT hypothesis on a nonlocal scale - and thus break free of the neuro-centric definition of consciousness?

A: I would ask can one test non-locality, which as such does not provide support for IIT, which relies still physicalistic picture about consciousness as a property of physical system.

b) Complexity,telepathy, power amplification, a replicate of RV

Lian suggests a detailed protocol for an analog of RV experiment testing various aspects of non-locality but to my view it tests non-locality but not IIT.

A very brief summary of the experimental protocol proposed of Lian goes as follows. The experiment involves 8 different stimulations of 4 mouses A,B,C,D and mouse F not familiar with other mouses and without any stimulation. For A,B,C,E but not D the stimulation involves stimulation of fear circuit. For A,B,C,D but not E also the image of cat is shown. Also the image of some other mouse is shown; A sees B or C; B sees A, C sees A; D sees E; E siis B. This stimulation creates a associations fear-presence of cat- presence of some other mouse for some sub-association of this. Mouse C is activated in additional manner strengthening the fear-cat-mouse A association. The reactions of other mice are monitored as one of them, mouse A, is isolated from others receives a stimulus activing the fear circuit.

Q4b: Telepathy. Is the fear transferred telepathically to the mouses and does it induce also the associations? There are also subquestions.

Q4c: Power amplification. Will repeated application of the experimental stimulus (power amplification) increase/ broaden the activation at the receiver's end?

Q4d: Replica of RV. One encloses mouse B generating fear association in mouse A to a black box. If mouse A is able to remote view the presence of B in the box, the fear circuit should activate. Does this occur? What if mouse C with larger association basin is in the box. Is the telepathic effect stronger?

A: My own answer to the questions is in general affirmative if the telepathic communication really occurs. I dare not predict whether it does!

This experiment would test non-locality of consciousness but it is not clear to me whether this test can provide evidence pro or con IIT.

c) Is sleep conductive to nonlocal network activation?

A similar experiment could be run with any dreaming mammals to test the effect of particular brain states on facilitation/ inhibition of these nonlocal resonant loops and the ability of the ensuing "dynamic coalition of adaptively resonant populations of neuron" to reach conscious dominance,

Q4e: Would activation of fear at the "sender mouse" while the receiver is in various sleep stages (nREM S2, S3-4, REM) result in more rapid/ more powerful activation at the receiver's end?

If metabolic energy interpreted as energy going to re-orgnized network connections, metabolic energy does not go during sleep (rather than dreaming) to the build of mental images related to sensory and motor activities, and must go to something else and building up and activating of network connections in longer length scales would be natural target. EEG is indeed concentrated to theta and below which would mean that the scale of the layers of MB involve would be roughly 4-10 times longer (1-4 Hz dring sleep) than usually (10 Hz). The four states of sleep would correspond to different length scales for MB. Activation would mean that cyclotron radiation and generalize Josephson radiation generated in neuronal neuronal membrane proteins acting as generalized Josephson junctions propagate along flux tubes. A possible interpretation for MB would be as counterpart for the third person aspect of consciousness.

What the telepathic activation of sensory and fear circuits during sleep could the mean? The natural guess is that it wakes up some sensory areas and by association fear circuit so that one would have analog of REM sleep manifesting as the activation of higher EEG bands serving also as signature for the telepathic response.

2.2.5   Is Φ dependent on brain's phase space - can the brain alternate between classical and quantum computational modes?

Q5a: What role do you think microtubules play in gating and reshaping brain computational patterns?

A: I see microtubules as one layer in the self hierarchy and proposed for about two decades ago a vision in which microtubules act as quantum antennas [K4] sending and receiving signals and performing frequency modulation by modulating their lengths.

I have also considered a model of microtubules inspired by the findings of Bandyonophyay et al [J8]. This model [L4] leads to rather concrete ideas about aromatic rings as basic units of molecular consciousness and would explain why aromatic rings are so important (contained by all DNA nucleotides and by some amino-acids and typical for neuro-active molecules such as psychdelics [**?**]).

External AC perturbations of microtubules at critical frequency would induce what I have interpreted as a quantum phase transition between two configurations A and B of microtubules: only the configuration B for which helical symmetry is broken is observed in laboratory (objection against Penrose-Hameroff hypothesis) but the configuration A with helical symmetry would be created in this phase transition increasing h_{eff} and quantum coherence length as helical symmetry suggests [L4].

Quantum criticality is in accordance with the general vision about living systems as quantum critical systems and would make possible large h_{eff} phases and dark photons with energy scaled up by h_{eff}/h so that it is above thermal threshold - perhaps in the range of bio-photon energies - and can induce molecular transitions. Topological quantum computations [K1] involving braiding of the flux tube connections between microtubuli and axonal membranes such that nerve pulses induce re-braiding as a kind of memory representation can be also considered.

The second question concerns the roles of classical and quantum computations for brain. Brian Millar has suggested that the brain contains both classic and quantum computational functions. The fact that nonlocal conscious interactions may and do occur superimposed on routine diurnal consciousness (the operator in a typical RV session is a perfect example of such a superimposition of rapidly alternating states or computations activities; spontaneous telepathy has been reported in both nocturnal and diurnal contexts; and studies of distant mental interactions with living systems, including human receivers, do not require the target to achieve any particular mental states, although many operators find it more effective to go through a cool-down or meditative phase at the beginning of the session) suggests that both of these computational processes occur simultaneously however, in the highly competitive environment of brain activity, it may be that the power of such alternative (possibly MT-mediated) resonant circuits may remain below the threshold of awareness under most circumstances, being brought into the spotlight only by deliberate suppression of classic neuronal activity, coupled with the power amplification derived from persistent target focus. The question is following.

Q5b: Could there be a connection between the effects of slow wave sleep and meditation on the global gating configuration of the brain - perhaps leading to a reshuffling and eventually more favorable, more "sensitive" quantum computational state - whether based on MTs or another interface (Millars quantum brain)? Could circadian rhythms play a role in such a daily balance between classical and quantum brain computational modes?

A: Before answering the question some background.

1. I would not see classical and quantum computations as alternatives. Self represents quantum computation like process having analogs of quantum and classical computation as its aspects, which could be also seen as dual representations in the sense of holography. Here I however understand with classical computation something much more general than that occurring in my PC.

2. MB and braiding of flux tubes makes possible quantum computation type activities: quantum computation in standard sense is probably quite too restricted metaphor. Classical computation in the sense as I understand it, is even more dangerous metaphor. Classical computationalism involves many assumptions, which seem to guarantee that ideal computer is un-conscious: the notion of memory storage and deterministic program represents too such notions. In TGD framework there are no files in which data would be stored [K5]. There is no deterministic classical program running in brain.

3. I would compare self as a generalized Zeno effect to a quantum computation, which halts as self dies and reincarnates at the opposite boundary of CD and a new quantum computation proceeding in opposite direction of clock time using the wisdom gained as NE is performed (the temporal distance between tips of CD increases all the subjective time). Each mental image would be kind of quantum computation and repeated re-incarnations might make it possible to overcome the usual restrictions on what one can do in finite time [L9] (see http://tinyurl.com/jpzd6xq).

4. The space-time surface connecting initial and final 3-surfaces at the boundaries of CD would define classical time evolution analogous to classical computation serving. More concretely, the dynamical time like braiding of flux tubes (dance metaphor) would generate a space-like

braiding (think of dancers with threads from the feet to wall: dance is coded to a memory about the dance) [K1].

5. One would have quantum superposition of these space-time surfaces and it would represent self-organization pattern in 4-D sense. The state function reduction sequence during the life period of self would lead to asymptotic pattern. A space-time representation for function, skill, or memory understood as learned skill would be in question. The experiments with flatworms [I1] demonstrate that the both ends of flatworm can inherit the memories in this sense: the replication of MB could explain this [K6]. The classical space-time surfaces have therefore several interpretations: as space-time correlate for intentional action, behavior, function, classical computation, etc...

The dominance of slow wave EEG during sleep would mean that magnetic bodies with weak magnetic fields and larger size roughly defined by the wavelength associated with EEG frequency would dominate. These would correspond to more non-local and more abstract conscious information and information processing. The difference to daytime situation would be quantitative: the spatial and time scales would be longer.

The absence of sensory input during both meditation and slow wave sleep would give for MB a more pronounced role. It can use brain for its purposes and probably does so since brain uses metabolic energy also during sleep and is conscious in some, probably different scales that at day-time. What could be those purposes? Do we entangle with other brains perhaps and give rise to entangled self formed by the sleeping brains - representing perhaps "human condition"?

2.2.6   Φ and Ueber-Φ

Q6: How do you see the interplay between the consciousness of Self and the ability to participate in such nonlocal conscious phenomena in terms of Phi?

My answer reflects by belief system. This may sound dogmatic but I just cannot take Φ as the solution to the riddle of consciousness for the reasons that I have explained. Therefore I am unable to answer the question.

2.3   Questions by Patrizio Tressoldi

There are actually two questions by Patrizio Tressoldi related to intentionality and energy.

Q7a: Is it possible to measure the "mental energy" underlying both local and non-local mind-matter interactions? Is it also possible to investigate the characteristics of these interactions, e.g. do these interactions look like a single shot or like a long-lasting wave of energy? Could this line of investigation shed light on the basic "stuff" of our mind?

What has been observed by Tressoldi et al. (in press) after one pilot, one failed and one positive replication can be summarized as follows: mental entanglement (ME) at distance with a photomultiplier reveals its effects by increasing the bursts of photons exceeding by more than 6σ the average count, corresponding to bursts with more than ten photons. In other words, it seems that ME effects correspond to very fast bursts of light of approximately 20 photons/sec equivalent to an energy estimated in 65 eV, at approximately 788 THz, a really non trivial energy. Furthermore, these effects seem to appear even after a delay of approximately 35 minutes.

A: My view is that remote mental interactions involve both quantal and classical aspects. Classical aspect requires a contact of magnetic bodies of the two systems by reconnection - correlate for directed attention. Classical signals would propagate along the flux tubes connecting the two systems. Reconnection would occur for instance in experiments of Persinger's group involving rotation magnetic fields and bio-photons discussed in [K7]. Reconnection is made more probable if the magnetic field of either system or both is dynamical, say rotating. After the reconnection classical dark photon signals would flow between the two systems, and also supra currents of say dark electrons are possible. Classical signals require metabolic energy. For instance, EEG would correspond to this kind of communications between biological and MB and the dark photons with $h_{eff} = n \times h$ of EEG would have energies in the range of bio-photon energies.

Teleportation can be seen as communication - in particular communication of mental images - and requires also classical communication. Could maximally entangled subsystem representing mental image be teleported without destroying the original mental image? No-cloning theorem tells

that complete cloning is not possible for a general quantum state. There are however exceptions: a quantum state with maximal entanglement can be cloned (see `http://tinyurl.com/h48qjp8`). Maximal entanglement - entanglement probabilities are identical - corresponds p-adically to maximally negentropic entanglement. Maximally negentropic entanglement is p-adic notion (cognition) and much more general than maximal entanglement. Is it possible to clone also it?

Q7b: Human (external qi) intention is a form of information.There are many reports on this. The first few white papers by William Tiller are interesting (see `http://tinyurl.com/j5xyjn8`).

What if intention is simply thought-like energy? See our study "*Can Our Minds Emit Light at Distance? A Pre-Registered Confirmatory Experiment of Mental Entanglement with a Photomultiplier*" in press in Neuroquantology (see `http://tinyurl.com/h4eoxgw`).

A: I identify energy as a physicists and what comes in mind is metabolic energy. I see metabolic energy as a prerequisite for intention but cannot identify it as intention. Intention has inherent directedness but energy as a notion does not have it. My own proposal is based on ZEO in which zero energy states have as correlates (quantum superpositions of) space-time surfaces connecting 3-surfaces at past and future boundaries of CD. Zero energy states are asymmetric with respect to the exchange of boundaries. The state at other boundary is reduced and unaffected during the sequence of state function reductions as also this boundary. The state at other boundary changes and also the boundary shifts farther away. Zero energy states would be by their directedness natural correlates for intentions and space-time surfaces could represent the classical space-time correlates of intentions. They can be seen also as correlates for functions (in biological sense) and behaviors.

2.4   Questions by Ben Goertzel

The first question of Ben Goertzel relates to IIT. The remaining questions are subquestions inspired by a general question "*Is recent quantum theory enough?*".

2.4.1   Could integrated information help to undersand Psi phenomena?

Q8: Could looking at integrated information on the quantum level (or in the context of some extension of current quantum theory) yield insight regarding Psi phenomena? Might there actually be subtle integrated information spanning systems that are currently thought of as disentangled from each other? Could this provide the foundation for some sort of "universal consciousness"?

Answer: As I have already explained, I do not see the measure for integrated information as internally consistent. In TGD framework integrated information is replaced with entanglement negentropy. Negentropic entanglement (NE) in large scales is an important aspect of remote mental interactions since it binds conscious entities to larger conscious entities temporarily and is central element of directed attention and also of remote mental interactions which do not differ in any radical manner from those occurring between MB and BB. In this framework consciousness and even cognition are universal.

2.4.2   Post-quantum physics?

Q9. Supposing that some sort of non locality going beyond what is allowed in classical physics is required to explain Psi phenomena - is quantum theory actually enough? Or do we need some broader form of non locality? If so, what additional aspects must the non locality needed to explain Psi possess?

A: To my opinion the prevailing quantum theory is not enough.

1. To develop a new theory it is best to start from a problem of old theory. The basic problem to start from is now quantum measurement theory. The identification of experienced time with the geometric time and therefore of the corresponding causalities leads to the basic paradox and to the plethora of "interpretations" trying to overcome the problem. In TGD framework zero energy ontology (ZEO) allows to overcome the paradox. ZEO predicts also temporal non-locality and by holography 4-D dynamical patterns become basic physical objects as they indeed are in biology and neuroscience.

2. The non-locality in ordinary quantum mechanics has no classical (geometric or topological) space-time correlate. The non-locality at space-time level emerges in TGD framework from the replacement of point like particles with 3-D surfaces (or pairs of them at opposite boundaries of CD. Particle is classically space-time quantum, one might say. This allows to understand classically non-locality as it appears in EPR and also in remote mental interactions: magnetic flux tubes serve as a geometric correlate for entanglement so that situation ceases to be so "spooky".

   At the level of WCW one has locality. Apart from state function reduction the theory is even classical formally: WCW spinor fields are formally classical free spinor fields satisfying the analog of massless Dirac equation realized as a generalization Super Virasoro conditions familiar from super string models and expressing generalization of conformal invariance.

3. Quantum consciousness theories demand macroscopic quantum coherence but standard quantum theory does not give much hopes about this: Planck constant is too small. The anomalous quantal effects of ELF em fields on vertebrate brain led originally to the idea about hierarchy of Planck constant $h_{eff} = n \times h$ labelling dark matter as phases of ordinary matter. This hierarchy is strongly suggested also by the generalization of super-conformal symmetries in TGD framework gives rise to a hierarchy of quantum criticalities labelled by the values of h_{eff}. The hierarchy would also have a concrete geometric interpretation in terms of the topology of many-sheeted space-time. The latter is possible only if one assumes that space-times are representable as 4-surfaces.

Q10: Will the standard "scientific method" as now practiced and understood (involving gathering empirical data that is considered as provisionally true in an objective sense, and validated as such by members of the scientific community) be adequate for understanding Psi phenomena? Or might an understanding of Psi phenomena require a shift to a new understanding of science, involving a more radical subjectivity, a more relational interpretation of observations or something else?

A: I believe that this not the case. I believe that remote mental interactions as also those crucial for living matter are quantum critical phenomena. This makes it difficult to replicate the experiments. First of all, the experimenter must know that a critical system is in question. If dark matter indeed corresponds to large h_{eff} phases generated at criticality, the attempts to detect dark matter identified as some exotic particle are bound to fail and have indeed failed. Dark matter could be be detected only transforming it to ordinary matter or vice versa and this would occur at quantum criticality. Quantum criticality would also make possible long range correlations and the interaction between experimenter and the experimental arrangement including subject persons in experiments carried out in medicine (interactions between magnetic bodies). Therefore the idea about possibility to completely isolate observer and observed system in principle fails in quantum critical case (TGD Universe is quantum critical meaning that any system is quantum critical in some time scale!).

Q11: Are our current notions of "causation" and "correlation" adequate to understand Psi phenomena? Or need they be extended somehow? If so, how?

A: My belief is that the problems of quantum measurement theory can be solved by distinguishing geometric and subjective time and corresponding causations. The first causation is that of field equations and the latter causation that of free will and can be assigned with quantum jump/state function reduction. This causation replaces superpositions entire geometric time evolutions with new one and this is something new (note however Wheeler's delayed choice experiment). ZEO based quantum measurement theory would be the manner to describe it.

Correlation assignable to geometric time (or between space-time-time points or their generalization to 3-surfaces) is a generalization of that applied in quantum field theories. Correlation have any meaning with respect to subjective time since it does not correspond to continuous coordinate at fundamental level although one can assign to it clock time in ZEO as increasing distance between the tips of CD.

Q12: Can we make scientific (or some sort of meaningful post-scientific) sense of the notion of a broader universe beyond our physical universe? How does the mystical notion of a world beyond our world, relate to the higher-dimensional aspects of physical reality postulated in modern physics theories? What properties would a broader "world beyond our world" need to have, in order to

have useful explanatory value for phenomena we observe in this world, or for experiences we have and report that hint at the existence of realities beyond this physical world?

A:. I see several levels in the geometric hierarchy of geometric objects. Besides space-time surfaces, which are dynamical objects, there is imbedding space and WCW, which are non-dynamical geometric objects and dictated by general arguments highly uniquely.

1. The minimal generalization is to keep space-time 4-D but assume that it is 4-surface in a higher-dimensional space-time - call it H - having standard model symmetries and explaining corresponding quantum numbers elegantly. The minimal choice is 8-D $H = M^4 \times CP_2$. The emerging space-time concept - many-sheeted space-time - is topologically extremely rich and leads to new notions like MB and space-time surfaces having interpretation in terms of dark matter as $h_{eff} = n \times h$ phases. MB extends the system-environment double of biology to the triple MB-system-environment and is responsible for most non-trivial elements of TGD inspired biology.

   Also the imbedding space H plays a central role. In ZEO also the hierarchy of causal diamonds (CDs) in H serving as correlate for self hierarchy is important and is needed to to realize holography and its strong form. The pairs of 3-surfaces with members at opposite boundaries of CD is correlate for (classical) event and WCW spinor field representing zero energy state is the analog of Schröödinger amplitude in this space of classical events. The twistor lift of TGD [L5] requires ZEO and CDs: the action for infinitely-sized space-time surfaces in H would be infinite because of the volume term implied by the twistorial life and identifiable in terms of cosmological constant: for CDs it is finite.

   Strong form of holography (SH) implied by strong for of general coordinate invariance implies that string world sheets and partonic 2-surfaces carry the data needed to construct zero energy states and also space-time surfaces as preferred extremals of Kähler action. They would act as "space-time genes".

   WCW would represent the highest level of hierarchy and has decomposition to sub-WCWs assignable to CDs in their size scale hierarchy with levels labelled by integer characterizing the size scale of CD (by number theoretical universality argument).

   Therefore space-time surface would be replaced with a hierarchy of strings, string world sheets and partonic 2-surfaces, pairs of 3-surfaces at opposite boundaries of CD and connecting 4-surfaces, hierarchy of CDs, imbedding space, WCW!

2. A further generalization is required by the need to have space-time correlates for cognition and imagination. Here p-adic number fields provide a natural candidate and one ends up with an extension of real physics to p-adic physics involving p-adic variants for the above geometric structures. The physics in various number fields are in turn combined to give rise to adelic physics in which one replaces space-time surface with the Cartesian product of its variants in various number fields obeying same field equations and having even same formal representation at the level of "space-time genes".

   The space of quantum states is however common to all sectors of the adelic world and the coefficient field of this Hilbert space must be in intersection of all number fields and thus consist of numbers identifiable as algebraic numbers in some extension of rationals inducing finite-D extensions of p-adic number fields. There exists an infinite number of extensions of rationals and they define naturally an evolutionary hierarchy so that evolution corresponds to increase in algebraic complexity.

Q13: How useful is Sheldrakes notion of "morphic resonance"? Is it too vague to be used to draw concrete conclusions about practical situations? How might it be refined into more precise ideas? How does it relate to quantum mechanics?

A: My answer to this question has developed during last half year and dicussions with Sheldrake in SSE-2016 conference inspired to find a concrete interpretation for the action of morphogenetic field. I have considered morphogenesis in earlier articles [L2, L12, L11, L7]. Below I describe the most important aspects of TGD model as I see it now.

1. Magnetic body as template for the dynamics of the ordinary matter

I would understand "morphic resonance" as one implication of ZEO and of the notion of MB (MB). The ZEO replaces 3-space as basic geometric object with a pair of 3-surfaces with members at opposite boundaries of CD. By holography this pair is equivalent with 4-D space-time surface. MB can be seen also as 4-D field pattern satisfying the conditions defining preferred extremal of basic action principle and actually implying strong form of holography (SH). MBs as 4-D objects would serve as space-time correlates for functions/behaviors/habits and even intentions. 4-D self-organization by quantum jumps would lead to asymptotic 4-D MB. Note that also geometric past also changes in each quantum jump. This time-non-locality was realized already in the context of ordinary quantum theory by Wheeler (delayed choise experiment). The effect has been verified.

MBs have a rich topological dynamics. Flux tubes contract or expand in h_{eff} changing phase transitions bringing molecules near each other; U-shaped flux tubes reconnect to form flux tube pair connections between distant molecules are larger systems in bio-catalysis - this is also basic mechanism of directed attention; the braiding of flux tubes defines space-time realizations for topological quantum computer programs; the replication of MB would be behind replication of DNA and of transcription and also behind the replication in longer scales. The dark matter at magnetic flux tubes would be in macroscopically quantum coherent phases and the idea is that it would control ordinary matter having dynamics of MBs as a template. Biochemistry would be to some extend shadow for the dynamics of MB. For instance, the already mentioned strange findings about split flatworms could be understood in terms of the replication of MB in 4-D sense: not only BB but also functions and behaviors would be replicated.

Morphic resonance could represent a special instance about the replication of MB in 4-D sense. An important aspect would be that MBs in question are really large: the part of MB corresponding to alpha frequency could correspond to Earth size. This makes possible large scale non-local effects and racial learning. One can even consider the idea about MB associated with entire species. Spottiswoode reports that enhanced precognition occurs with period of sidereal (galactic) day. One ends up also to the proposal that the magnetic field of about 10 Hz and galactic MB corresponds to scaled variant of EEG with periods varying from few minutes to 12 hours. These periods would correspond to ordinary day-time consciousness.

Dark matter as large $h_{eff} = h_{gr}$ phases at flux tubes would be the connection to new quantum mechanics.

2. Morphogenesis and generalized Chladni mechanism

What would be the concrete realization of morphogenesis in this picture?

1. Chladni mechanism is a clever trick to make the nodal curves associated with standing waves visible. This mechanism could transcend to a basic mechanism of morphogenesis [L11]. The idea is very simple. Biomolecules could end up to the nodal surfaces for a standing waves of say electric field since the force on them would vanish at the nodal surfaces. This would give stationary structures. MB could control morphogenesis by using this kind of standing waves forcing the formation of various structures at their nodal surfaces. The structures condensing around nodal surfaces could be also magnetic flux bodies themselves and one could have hierarchical structure. Magnetic bodies carrying Bose-Einstein condensates of charged ions would not experience any electric force at nodal surfaces and magnetc force would be parallel to the nodal surface.

2. The induced fields associated with the simplest "topological light rays" ("massless extremals", MEs) are of form $sin(\omega(t-z))\epsilon(\rho)$, $(c = 1)$. $\epsilon(\rho)$ is polarization function and ρ is a coordinate varying in the direction of local polarization and can be chosen rather freely. Now it is taken to be the radial cylindrical coordinate. $\epsilon(\rho)$ can have zeros, which makes possible stationary nodal surfaces also in the case of propagating MEs.

3. The objection is that TGD does not allow single-sheeted realizations of standing waves needed for instance to realize the standing waves assignable to induction coil and wires of electric circuits. This objection is not lethal. In many-sheeted space-time one can realize effective sinusoidal standing waves as 2-sheeted structures from two MEs propagating to opposite spatial directions and carrying plane waves with a fixed frequency. These two-sheeted structures would serve as basic building bricks. The test particle having necessarily wormhole contacts to both MEs would experience the force caused by the sum of the induced gauge

fields assigned to the two MEs. The force would be same as that caused by a standing wave with separable temporal and spatial dependence not realizable as preferred extremal: that is a product of trigonometric functions - say product of form $sin(\omega t)sin(\omega z)\epsilon(\rho)$.

MEs have also always constant direction of polarization. Circularly polarized effective fields could be generated by pairs of MEs for which one has two linear polarizations in orthogonal directions with a phase lag of $\pi/2$.

4. The electric force would vanish at nodal surfaces, which would thus define naturally the shape of a stationary structure defined by molecules or parts magnetic bodies which serve as templates for them. These surfaces would correspond to the vanishing of $sin(kz)$ factor and to the vanishing of $\epsilon(\rho)$ factor.

   One can take several primitive MEs and allow them to have different directions but common frequency. One would obtain effective standing wave with common factorized time dependence and spatial dependence given by the sum of spatial parts of the sinusoidal waves. The nodal surface for this wave would correspond to the nodal surface for the sum of the spatial waves and one would obtain arbitrarily complex nodal surfaces.

   The nodal surfaces for these waves would naturally associated with the nodes of the tensor network, where the flux tubes of MB indeed meet. Fractal structure with tensor networks with nodes of tensor networks can be assumed in TGD framework.

5. There is a connection with holography in which reference wave and the wave of same frequency reflected from the target interfere. Now all waves can be regarded as standing reference waves coming from different directions and generated by magnetic body and propagating along flux tubes of magnetic body. Bio-structures would be formed to the nodal surfaces of this hologram.

3. The classical dynamics of TGD as dynamics of avoidance

Chladni mechanism is essentially dynamics of avoidance. Charged particles go to the nodal surfaces, where electric forces vanish. The twistor lift of TGD of the generalization of Kähler action adding to it volume term. Amazingly, the dynamics for this action can be seen as a generalization of the dynamics of avoidance.

The addition of the volume term to Kähler action implied by the twistor lift of TGD [L5] has very nice interpretation as a generalization of equations of motion for a world-line extended to a 4-D space-time surface [L7]. The field equations generalize in the same manner for 3-D light-like surfaces at which the signature of the induced metric changes from Minkowskian to Euclidian, for 2-D string world sheets, and for their 1-D boundaries defining world lines at the light-like 3-surfaces. For 3-D light-like surfaces the volume term is absent. Either light-like 3-surface is freely choosable in which case one would have Kac-Moody symmetry as gauge symmetry or that the extremal property for Chern-Simons term fixes the gauge.

The known non-vacuum extremals are minimal surface extremals of Kähler action and it might well be that the preferred extremal property realizing strong form of holography quite generally demands this. The addition of the volume term could however make Kähler coupling strength a manifest coupling parameter also classically when the phases of Λ and α_K are same. Therefore quantum criticality for Λ and α_K would have a precise local meaning also classically in the interior of space-time surface. The equations of motion for a world line of U(1) charged particle would generalize to field equations for a "world line" of 3-D extended particle.

This is an attractive idea consistent with standard wisdom but one can invent strong objections against it in TGD framework.

1. All known non-vacuum extremals of Kähler action are minimal surfaces and the minimal surface vacuum extremals of Kähler action become non-vacuum extremals. This suggest that preferred extremals are minimal surface extremals of Kähler action so that the two dynamics apparently decouple. Minimal surface extremals are analogs for geodesics in the case of point-like particles: one might say that one has only gravitational interaction. This conforms with strong form of holography (SH) stating that gauge interactions at boundaries

(orbits of partonic 2-surfaces and 2-surfaces at the ends of CD) correspond classically to the gravitational dynamics in the space-time interior.

Note that at the boundaries of the string world sheets at light-like 3-surfaces the situation is different: one has equations of motion for geodesic line coupled to induce Kähler gauge potential and gauge coupling indeed appears classically as one might expect! For string world sheets one has only the topological magnetic flux term and minimal surface equation in string world sheet. Magnetic flux term gives the Kähler coupling at the boundary.

2. Decoupling would allow to realize number theoretical universality since the field equations would not depend on coupling parameters at all. It is very difficult to imagine how the solutions could be expressible in terms of rational functions with coefficients in algebraic extension of rationals unless α_K and Λ have very special relationship. If they have different phases, minimal surface extremals of Kähler action are automatically implied. If the values of α_K correspond to complex zeros of Riemann ζ [L3], also Λ should have same complex phase, in order to have genuine classical coupling. This looks somewhat un-natural but cannot be excluded.

   The most natural option is that Λ is real and α_K corresponds to zeros of zeta. For trivial zeros the phases are different and decoupling occurs. For trivial zeros Λ and α_K differ by imaginary unit so that again decoupling occurs.

3. One can argue that the decoupling makes it impossible to understand coupling constant evolution. This is not the case. The point is that the classical charges assignable to super-symplectic algebra are sums over contributions from Kähler action and volume term and therefore depend on the coupling parameters. Their vanishing conditions for sub-algebra and its commutator with the entire algebra give boundary conditions on preferred extremals so that discrete coupling constant evolution creeps in classically from the spectrum of quantum critical coupling constants!

   The condition that the eigenvalues of fermionic charge operators are equal to the classical charges brings in the dependence of quantum charges on coupling parameters. Since the elements of scattering matrix are expected to involve as building bricks the matrix elements of super-symplectic algebra and Kac-Moody algebra of isometry charges, one expects that discrete coupling constant evolution creeps in also quantally via the boundary conditions for preferred extremals. Coupling would be forced by boundary conditions!

The above arguments seem to kill the idea that the dynamics of Kähler action and volume term could couple in space-time interior. The coupling between the two dynamics would be induced just by the condition that the space-time surface becomes an analog of geodesic line by arranging its interior so that the U(1) force vanishes! This would generalize Chladni mechanism! The interaction would be present but be based on going to the nodal surfaces! One would have dynamics of avoidance! Also the dynamics of string world sheets is similar: if the string sheets carry vanishing W boson classical fields, em charge is well-defined and conserved. One would also avoid the problems produced by large coupling constant between the two-dynamics present already at the classical level. At quantum level the fixed point property of quantum critical couplings would be the counterparts for decoupling.

To sum up, it seems that the complete decoupling of the dynamics of Kähler action and volume term in the interior is favored by both SH, realization of preferred extremal property (perhaps as minimal surface extremals of Kähler action, number theoretical universality, discrete coupling constant evolution, and generalization of Chladni mechanism to a dynamics of avoidance.

REFERENCES

Theoretical Physics

[B1] Preskill J et al. Holographic quantum error-correcting codes: Toy models for the bulk/boundary correspondence. Available at: `http://arxiv.org/pdf/1503.06237.pdf`, 2015.

Biology

[I1] Levin M Somrat T. An automated training paradigm reveals long-term memory in planarians and its persistence through head regeneration. *The J Experimental Biology.* Available at: `http://tinyurl.com/ntlxpep`, 216:3799–3810, 2013.

Neuroscience and Consciousness

[J1] Revonsuo A. Is synchronization the direct neural correlate of visual consciousness? Available at: `http://www.phil.vt.edu/ASSC/engel/revonsuo1.html`, 1998.

[J2] Fingelkurts A et al. Consciousness as a phenomenon in the operational architectonics of brain organization: Critality and self-organization considerations. *Chaos , Solitons & Fractals.* Available at: `http://dx.doi.org/10.1016/locate/j.chaos.2013.02.007`, 2013.

[J3] Massimini M et al. A perturbational approach for evaluating the brain's capacity for consciousness. *Progress in brain research*, 177:201–214, 2009.

[J4] Persinger M et al. Congruence of Energies for Cerebral Photon Emissions, Quantitative EEG Activities and 5 nT Changes in the Proximal Geomagnetic Field Support Spin-based Hypothesis of Consciousness. *J Consc Expl & Res.* Available at: `http://jcer.com/index.php/jcj/article/view/277`, 2013.

[J5] Persinger M et al. Demonstration of Entanglement of Pure Photon Emissions at Two Locations That Share Specific Configurations of Magnetic Fields: Implications for Translocation of Consciousness. *J Consc Expl & Res.* Available at: `http://jcer.com/index.php/jcj/article/view/278`, 2013.

[J6] Persinger M et al. Experimental Demonstration of Potential Entanglement of Brain Activity Over 300 Km for Pairs of Subjects Sharing the Same Circular Rotating, Angular Accelerating Magnetic Fields: Verification by s_LORETA, QEEG Measurements. *J Consc Expl & Res.* Available at: `http://jcer.com/index.php/jcj/article/view/279`, 2013.

[J7] Tyszka JM et al. Intact bilateral resting-state networks in the absence of the corpus callosum. *The Journal of Neuroscience.* Available at:`http://tinyurl.com/3gjhtgb`, 2011.

[J8] Bandyopadhyay A Ghosh G, Sahu S. Evidence of massive global synchronization and the consciousness: Comment on "Consciousness in the universe: A review of the 'Orch OR' theory" by Hameroff and Penrose. *Phys Life Rev*, 11:83–84, 2014.

[J9] Horgan J. Can Integrated Information Theory Explain Consciousness? *Scientific American* Available at: `http://tinyurl.com/h7btppb`, 2015.

[J10] Spottiswoode J. Geomagnetic fluctuations and free response anomalous cognition: a new understanding. *J Parapsychol.* Available at: `http://www.jsasoc.com/docs/JP-GMF.pdf`, 2002.

[J11] Tononi G Oizumi M, Albantakis L. *PLOS. Computational Biology.* Available at:`http://tinyurl.com/z9s4k7n`, 2014.

[J12] Aaronson S. Why I Am Not An Integrated Information Theorist (or, The Unconscious Expander). Available at: `http://www.scottaaronson.com/blog/?p=1799`, 2014.

[J13] Koch C Tononi G. *Phil Transact Royal Soc B.*Available at: `http://tinyurl.com/zgm985f`, 2015.

Books related to TGD

[K1] Pitkänen M. DNA as Topological Quantum Computer. In *Genes and Memes*. Onlinebook. Available at: `http://tgdtheory.fi/public_html/genememe/genememe.html#dnatqc`, 2006.

[K2] Pitkänen M. General Theory of Qualia. In *Bio-Systems as Conscious Holograms*. Onlinebook. Available at: `http://tgdtheory.fi/public_html/hologram/hologram.html#qualia`, 2006.

[K3] Pitkänen M. Negentropy Maximization Principle. In *TGD Inspired Theory of Consciousness*. Onlinebook. Available at: `http://tgdtheory.fi/public_html/tgdconsc/tgdconsc.html#nmpc`, 2006.

[K4] Pitkänen M. Quantum Antenna Hypothesis. In *Quantum Hardware of Living Matter*. Onlinebook. Available at: `http://tgdtheory.fi/public_html/bioware/bioware.html#tubuc`, 2006.

[K5] Pitkänen M. Quantum Model of Memory. In *TGD Inspired Theory of Consciousness*. Onlinebook. Available at: `http://tgdtheory.fi/public_html/tgdconsc/tgdconsc.html#memoryc`, 2006.

[K6] Pitkänen M. Quantum Mind, Magnetic Body, and Biological Body. In *TGD based view about living matter and remote mental interactions*. Onlinebook. Available at: `http://tgdtheory.fi/public_html/tgdlian/tgdlian.html#lianPB`, 2012.

[K7] Pitkänen M. Comments on the recent experiments by the group of Michael Persinger. In *TGD based view about living matter and remote mental interactions*. Onlinebook. Available at: `http://tgdtheory.fi/public_html/tgdlian/tgdlian.html#persconsc`, 2013.

[K8] Pitkänen M. Criticality and dark matter. In *Hyper-finite Factors and Dark Matter Hierarchy*. Onlinebook. Available at: `http://tgdtheory.fi/public_html/neuplanck/neuplanck.html#qcritdark`, 2014.

[K9] Pitkänen M. Quantum gravity, dark matter, and prebiotic evolution. In *Genes and Memes*. Onlinebook. Available at: `http://tgdtheory.fi/public_html/genememe/genememe.html#hgrprebio`, 2014.

[K10] Pitkänen M. From Principles to Diagrams. Onlinebook.Available at: `http://tgdtheory.fi/public_html/tgdquantum/tgdquantum.html#diagrams`, 2016.

[K11] Pitkänen M. Non-locality in quantum theory, in biology and neuroscience, and in remote mental interactions: TGD perspective. In *TGD based view about living matter and remote mental interactions*. Onlinebook. Available at: `http://tgdtheory.fi/public_html/tgdlian/tgdlian.html#nonlocal`, 2016.

[K12] Pitkänen M. Some questions about IIT. In *TGD based view about living matter and remote mental interactions*. Onlinebook. Available at: `http://tgdtheory.fi/public_html/tgdlian/tgdlian.html#panel2016`, 2016.

[K13] Pitkänen M. TGD Inspired Comments about Integrated Information Theory of Consciousness. In *TGD based view about living matter and remote mental interactions*. Onlinebook. Available at: `http://tgdtheory.fi/public_html/tgdlian/tgdlian.html#tononikoch`, 2016.

Articles about TGD

[L1] Pitkänen M. Commentary on "Consciousness as a phenomenon in the operational architectonics of brain organization: Criticality and self-organization considerations" by Adrew A. Fingelkurts, Alexander A. Fingelkurts, and Carlos F. H. Neves. Available at: `http://tgdtheory.fi/public_html/articles/Fingelkurts.pdf`, 2013.

[L2] Pitkänen M. Morphogenesis, morphostasis, and learning in TGD framework. Available at: http://tgdtheory.fi/public_html/articles/morpho.pdf, 2014.

[L3] Pitkänen M. Does Riemann Zeta Code for Generic Coupling Constant Evolution? . Available at: http://tgdtheory.fi/public_html/articles/fermizeta.pdf, 2015.

[L4] Pitkänen M. TGD based model for anesthetic action. Available at: http://tgdtheory.fi/public_html/articles/anesthetes.pdf, 2015.

[L5] Pitkänen M. From Principles to Diagrams. Available at: http://tgdtheory.fi/public_html/articles/diagrams.pdf, 2016.

[L6] Pitkänen M. Holography and Quantum Error Correcting Codes: TGD View. Available at: http://tgdtheory.fi/public_html/articles/tensornet.pdf, 2016.

[L7] Pitkänen M. How the hierarchy of Planck constants might relate to the almost vacuum degeneracy for twistor lift of TGD? Available at: http://tgdtheory.fi/public_html/articles/hgrtwistor.pdf, 2016.

[L8] Pitkänen M. Non-locality in quantum theory, in biology and neuroscience, and in remote mental interactions: TGD perspective. Available at: http://tgdtheory.fi/public_html/articles/nonlocal.pdf, 2016.

[L9] Pitkänen M. Number theoretical feats TGD inspired theory of consciousness. Available at: http://tgdtheory.fi/public_html/articles/numberfeats.pdf, 2016.

[L10] Pitkänen M. Pollack's mechanism and photosynthesis. Available at: http://tgdtheory.fi/public_html/articles/pollackphoto.pdf, 2016.

[L11] Pitkänen M. The anomalies in rotating magnetic systems as a key to the understanding of morphogenesis? Available at: http://tgdtheory.fi/public_html/articles/godin.pdf, 2016.

[L12] Pitkänen M. What could be the physical origin of Pythagorean scale? Available at: http://tgdtheory.fi/public_html/articles/geesinkscale.pdf, 2016.