TGD Inspired Comments about Integrated Information Theory of Consciousness

M. Pitkänen,

February 2, 2024
Email: matpitka6@gmail.com.
`http://tgdtheory.com/public_html/`.
Postal address: Rinnekatu 2-4 A 8, 03620, Karkkila, Finland. ORCID: 0000-0002-8051-4364.

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Abstract

Integrated Information Theory (IIT) is a theory of consciousness originally proposed by Giulio Tononi. The basic goal of IIT is to abstract from neuroscience axioms about consciousness hoped to provide constraints on physical models. IIT relies strongly on information theory. The basic problem is that the very definition of information is not possible without introducing conscious observer so that circularity cannot be avoided. IIT identifies a collection of few basic concepts and axioms such as the notions of mechanism (computer program is one analog for mechanism), information, integration and maximally integrated information (maximal interdependence of parts of the system), and exclusion. Also the composition of mechanisms as kind of engineering principle of consciousness is assumed and leads to the notion of conceptual structure, which should allow to understand not only cognition but entire conscious experience.

A measure for integrated information (called Φ) assignable to any partition of system to two parts is introduced in terms of relative entropies. Consciousness is identified with a maximally integrated decomposition of the system to two parts (Φ is maximum). The existence of this preferred decomposition of the system to two parts besides computer and program running in it distinguishes IIT from the computational approach to consciousness. Personally I am however afraid that bringing in physics could bring in physicalism and reduce consciousness to an epiphenomenon. Qualia are assigned to the links of network. IIT can be criticized for this assignment as also for the fact that it does not say much about free will nor about the notion of time. Also the principle fixing the dynamics of consciousness is missing unless one interprets mechanisms as such.

In this article IIT is compared to the TGD vision relying on physics and on general vision about consciousness strongly guided by the new physics predicted by TGD. At classical level this new physics involves a new view about space-time and fields (in particular the notion of magnetic body central in TGD inspired quantum biology and quantum neuroscience). At quantum level it involves Zero Energy Ontology (ZEO) and the notion of causal diamond (CD) defining 4-D perceptive field of self; p-adic physics as physics of cognition and imagination and the fusion of real and various p-adic physics to adelic physics; strong form of holography (SH) implying that 2-D string world sheets and partonic surfaces serve as "space-time genes"; and the hierarchy of Planck constants making possible macroscopic quantum coherence.

Number theoretic entanglement entropy (EE) makes sense as number theoretic variant of Shannon entropy in the p-adic sectors of the adelic Universe. Number theoretic EE can be negative and corresponds in this case to genuine information: one has negentropic entanglement (NE). TGD inspired theory of consciousness reduces to quantum measurement theory in ZEO. Negentropy Maximization Principle (NMP) serves as the variational principle of consciousness and implies that NE can can only increase - this implies evolution. By SH real and p-adic 4-D systems are algebraic continuations of 2-D systems ("space-time genes") characterized by algebraic extensions of rationals labelling evolutionary levels with increasing algebraic complexity. Real and p-adic sectors have common Hilbert space with coefficients in algebraic extension of rationals so that the state function reduction at this level can be said to induce real and p-adic 4-D reductions as its shadows.

NE in the p-adic sectors stabilizes the entanglement also in real sector (the sum of real (ordinary) and various p-adic negentropies tends to increase) - the randomness of the ordinary state function reduction is tamed by cognition and mind can be said to rule over matter. Quale corresponds in IIT to a link of a network like structure. In TGD quale corresponds to the eigenvalues of observables measured repeatedly as long as corresponding sub-self (mental image, quale) remains conscious.

In ZEO self can be seen as a generalized Zeno effect. What happens in death of a conscious entity (self) can be understood and it accompanies re-incarnation of time reversed self in turn making possible re-incarnation also in the more conventional sense of the word. The death of mental image (sub-self) can be also interpreted as motor action involving signal to geometric past: this in accordance with Libet's findings.

There is much common between IIT and TGD at general structural level but also profound differences. Also TGD predicts restricted pan-psychism. NE is the TGD counterpart for the integrated information. The combinatiorial structure of NE gives rise to quantal complexity. Mechanisms correspond to 4-D self-organization patterns with self-organization interpreted in 4-D sense in ZEO. The decomposition of system to two parts such that this decomposition can give rise to a maximal negentropy gain in state function reduction is also involved but yields two independent selves. Engineering of conscious systems from simpler basic building blocks is predicted. Indeed, TGD predicts infinite self hierarchy with sub-selves identifiable as mental images. Exclusion postulate is not needed in TGD framework. Also network like

structures emerge naturally as p-adic systems for which all decompositions are negentropically entangled inducing in turn corresponding real systems.

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?" [J3] (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 [J6] (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" [J4](see `http://tinyurl.com/z9s4k7n`) gives a more techanical description of IIT. Also the article of Scott Aaronson [J5](see `http://tinyurl.com/zarjfzz`) was very helpful in providing computer scientific view about IIT and representing also mathematical objections.

In the article [J4] 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.

The key questions relate to the notion of information more or less identified as consciousness.

1. In IIT the information is identified essentially as a reduction of entropy as hypothetical conscious entity learns what the state of the system is. This definition of information used in the definition of conscious entity is circular. It involves also probabilistic element bringing thus either the notion of ensemble or frequency interpretation.

2. In TGD the notion of information relies on number theoretical entanglement entropy (EE) measuring the amount of information associated with entanglement [K9]. It makes sense for algebraic entanglement probabilities. In fact all probabilities must be assumed to belong to algebraic extension of rationals if one adopts p-adic view about cognition and extends physics to adelic physics involving real and various p-adic number fields. Circularity is avoided but the basic problem has been whether one can apply the number theoretic definition of entanglement entropy only in p-adic sectors of the adelic Universe or whether it applies under some conditions also in the real sector. Writing this commentary led to a solution of this problem: the state function reduction in the intersection of realities and p-adicities which corresponds to algebraic extension of rationals induces the reductions at real and p-adic sectors. Negentropy Maximization Principle (NMP) maximizes the sum of real and various p-adic negentropy gains. The outcome is highly non-trivial prediction that cognition can stabilize also the real entanglement and has therefore causal power. One can say that cognition tames the randomness of the ordinary state function reduction so that Einstein was to some degree right when he said that God does not play dice.

3. IIT identifies qualia with way, which I find difficult to take seriously. The criticism however led also to criticism of TGD identification of qualia [K6] and much simpler identification involving only the basic assumptions of ZEO based quantum measurement theory emerged. Occam's razor does not leave many options in this kind of situation.

IIT predicts panpsychism in a restricted sense as does also TGD. The identification of maximally integrated partition of elementary system endowed with mechanism, which could correspond to computer program, to two parts as conscious experience is rather near to epiphenomenalism since it means that consciousness is property of physical system. In TGD framework consciousness has independent causal and ontological status. Conscious existence corresponds to quantum jumps between physical states re-creating physical realities being therefore outside the existences defined by classical and quantum physics (in TGD classical physics is exact part of quantum physics).

2 Critical Summary of IIT

Tononi starts from neuroscience and information theory. Information theoretic approach has the virtue that can avoid sticking into the dogmas of existing philosophy. Tononi and Koch emphasize that IIT tries to axiomatisize the essential aspects of consciousness so that physical theories of consciousness could start from this picture. Concerning the definition of information the starting point is classical probability theory.

One can criticize this view. Quantum physics provides extremely non-trivial new view about physical existence that it seems almost impossible to comprehend by organisms at our evolutionary level. Quantum measurement theory - the poorly understood part of quantum theory - forces to ask fundamental questions about the nature of consciousness, which suggests that neglecting it can mean a fatal loss of information. Quantum information theory is rapidly developing and should be highly relevant for any theory of consciousness starting from the notion of information. IIT's integrated information Φ is also a measure for complexity. Quantum theory provides a vision about complexity based on quantum entanglement. Also quantum biology has emerged as a new branch of science.

Information, integration and conceptual structure are basic notions introduced by Tononi. All these notions are poorly understood in standard physics framework. Also the notion of elementary mechanism is introduced. Mechanism could correspond to computer program or asequence of neural associations or formation of self-organization pattern. Elementary mechanisms can be combined to more complex mechanisms and these into systems of mechanisms. Mechanism can be identified as time evolution of some kind and has has inherent time arrow associated with it.

As the title "Consciousness, here, there, and everywhere" of [J4] expresses, panpsychism is adopted in IIT in the form that consciousness can be a property of any material system. For this reason the approach of Tononi is regarded by Horgan as an extremely ambitious approach - certainly it is so from the perspective of neuroscience. For a physicist taking consciousness seriously panpsychism in some sense is the only possible option and predicts hierachy of conscious entities.

This panpsychism does not mean that everything is conscious but that everything can be conscious. The criterion for this is that integrated information is large enough. This roughly means that system is coherent structure such that information cannot be localized to its part.

2.1 Information

The key vision is that conscious experience carries information and that this information is integrated in the sense that parts of experience give information of each other: one might say that conscious information defines a rule $A \rightarrow B$. In neuroscience association would be the counterpart for this. This relationship need not be strictly causal but is as near to causal as possible.

In quantum theory entanglement could realize the strong correlation: now one however knows the state of the entire system but has very little information about the states or parts.

A mechanism can contribute to consciousness only if it specifies "differences that make differences" within a system. This sounds rather fuzzy statement. A slightly clearer manner to say this is that a mechanism generates information only if it constrains the states of a system than can be its possible causes and effects. One speaks of cause-effect repertoire. An even clearer identification of mechanism is as a dynamics of some kind.

In biology one could interpret cause-effect repertoire as a counterpart of a biological function assigning to sensory input a a motor output. In neuroscience mechanism could correspond to a sequence of associations defined by nerve pulse patterns or a behavior assigning a motor response to a given sensory input. Mathematician could speak of function. Physicist could speak of time

evolution - say classical or self-organization. In computational science one could interpret Boolean functions or computer programs as mechanisms. The obvious criticism is that one can imagine endless variety of mechanisms and the theory loses its predictive power.

For a mechanism leading from a state of A to that of B information could be defined mathematically as $I(A \rightarrow B) = H(B|A) - H(A)$ by subtracting from conditional entropy for output associated with probabilistic input the entropy of the input. The information serves a measure for the reduction of ignorance and one cannot speak of ignorance without assuming a conscious entity able to interpret the output. This kind of notion in the definition of conscious information implies circularity.

One of the predictions is that feedback in the dynamics of mechanism is necessary for consciousness. Intuitively feedback means self-control characteritizing living systems (homeostasis). It is known that system theoretically a system with feedback can be approximated with a more complex system with only forward feedback. A system with/without feedback could/would be conscious/zombie. The theory would not therefore be behavioristic. Also rather simple non-living systems with feedback could be conscious.

I must admit that I did not quite understand why feedback is necessary for consciousness. If one defines information assignable to mechanism as sum $I(A \rightarrow B) + I(B \rightarrow A)$ then it is is easy to understand the importance of feedback. For instance, if the output depend only weakly of the input as in self-organizing systems without feedback (all irrelevant details are polished away in thermal non-equilibrium state), $I(B|A)$ would be very small and the criterion for cause-effect relationship would not be satisfied. Feedback changes the situation.

2.2 Integration

Intuitively it seems that intelligent systems consist of highly correlated parts but that the correlation cannot be too high (completely random system carries no information and spontaneously magnetized systems carries just one bit of information). Tononi introduces a measure -Φ - that he calls integrated information that would serve as a measure for this property measuring the level of consciousness.

This suggests that a mechanism can contribute to consciousness only if it specifies a cause-effect repertoire that is irreducible to independent components. The irreducibility of experience means that the experience cannot be reduced to parts. A more comprehensible statement is that information contained by system cannot be localized to any art of it. Here one can criticize: mental images could be seen as rather independent parts of experience.

Tononi speaks of integrated information defined in terms of maximum of relative entropy (see `http://tinyurl.com/hazmflc`). Scott Aaronson represents a rather comprehensible definition.

1. One wants a concrete measure for the interdependence of the subsystems A and B defining partition of the system. The integrated informations should correspond to maximally interdependent partition. The measure for integrated information - call it Φ - must have a maximum Φ_{max} if A and B are in causal relation. Φ is obtained by maximizing over all divisions of system to two parts A and B some measure of the sum of mutual informations definable in terms of conditional entropies assuming that the states in either A or B are random. Conditional entropy is entropy $H(A|B) - H(B)$ and if A and B are strongly correlated is negative and has interpretation as information. FIn the case of brain, left and right hemispheres are natural candidates for maximally integrated pair (A,B) and one could understand left-/right- hemisphere dominance as a failure of integration.

   These entropies are associated with mechanism, which translates to a function mapping the states of the entire systems to its states. The maximizing pair (A,B) would define the maximally causal relationship and give rise to a building brick of experience deserving to be called quale. This definition of quale is to my opinion rather ad hoc. The introduction of the mechanism brings in so many subjective assumptions that the definition might not have practical value. There are also difficulties related to the estimation of maximally integrated subsystem and thus of Φ_{max}: this might represent problem in NP class.

2. A measure for complexity is in question and numerous measures for complexity has been introduced by mathematicians. Φ would be a measure for feedback between and interdependence of different parts of the system. When Φ is above critical value, system is conscious.

Intuitively, if the parts of the system are not correlated and communicating, system is not conscious. Even proton could be conscious since quarks are strongly correlated although it is questionable whether it makes to sense to talk about feedback in this context. In any case, this looks rather reasonable. $\Phi_{max} = 0$ means that system is completely reducible into its parts. The problem is that the connection with fundamental physics is lacking. Φ_{max} would measure the level of consciousness. I do not know how Φ_{max} would be measured and probably no one knows.

3. Aaronson gives a concrete example giving a gist about what integrated information could means. He also demonstrates that the definition of Tononi leads to technical problems using his identification of mechanism as a map of states of system to states of system. This could be of course quite too limited definition.

   The idea is to consider all partitions of the system to two parts A and B. One can consider a system consisting of a ordered set of points to which one can assign finite number of states. Also binary digits could be considered. The states in set A are assumed to be random.

   To identify the partition giving rise to maximal integrated information, one calculates the relative entropies for the images of the points and identifies integrated information as their sum. One can do the same by regarding the states assignable to points of B as random. One sums the relative entropies. If there is strong correlation between A and B then the randomness in A implies that this sum is large. If there is no dependence between A and B the sum vanishes. The partition (A,B) for which the sum of entropies is minimal corresponds to the partition defining the decomposition, which can define cause-effect pair. Integrated information is assigned with this pair.

4. Aaronson's first objection relates to the difficulty of identifying of the connection network of brain. One does not even idea about how to identify the nodes of this network. Neurons in state 1 or 0 is hardly suggested by anyone nowadays. Should one try to reduce to microtubular level. Or perhaps to the level of DNA and proteins? The identification of mechanisms as analogs of functions is a further heavy difficulty. Do their correspond to analogs of classical computer programs or to sequences of associations? Aaronson also thinks that panpsychism is unacceptable. To my view this particular criticism cannot be taken too seriously.

Consciousness can be present even when neural activity is low as in meditative states and IIT can explain also these states. What matters is the degree of integration - not so much the input. This leads to ask whether a closed system without sensory input and metabolic feed can be conscious. IIT says makes no obvious statements about the role of metabolism. IIT is also silent about the social aspects of consciousness and reduces consciousness to the properties of a network.

The assumption that the decomposition (A,B) corresponding to maximally integrated information as characterizing the contents of consciousness is to my opinion very problematic. Information is a relative notion: only a conscious system can have information about something. One therefore defines consciousness as an aspect of conscious experience so that the definition is circular. Second problem is that information as also consciousness is always about something unlike matter which such exists. Information as independent "substance" makes no sense.

Standard physics allows only to speak about entropy characterizing the lack of information about the state of system. When intelligent entity learns what the state of system is it receives information equal to this entropy. Here however the notion of conscious experiencer leaks in! The assignment of information to a bit sequence assumes that there is system for which the bit sequence has meaning by generating a process leading to a conscious experience interpreted as understanding. I dare guess that for my cat (or even for standard man in the street) these lines carry absolutely no information. Thus the dream about measuring information as a physical observable and concluding from this whether system is conscious and what the level of consciousness is, fails. The identification of Tononi leads to the notion of consciousmeter. To me this notion crystallizes what goes wrong with the physicalistic and purely information theoretic approaches.

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 Shannon entropy lead to the same result. One must have genuine definition of information.

These are classical considerations. Could this paradoxical situation make sense quantally or in TGD framework? Conscious entity - self - would live in adelic world and would be negentropically entangled subsystem - superposition of several state pairs. By NMP in Zero Energy Ontology implying self as generalized Zeno effect it would not allow state function reduction during its lifetime so that outsider could not learn what it's state is!

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 the same value). In TGD inspired theory of consciousness the paradoxical statement would thus make sense! Schrodinger 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 are secretive!

2.3 Architecture of consciousnes

2.3.1 Exclusion

Exclusion means that a mechanism can contribute to consciousness at most one cause-effect repertoire. This repertoire has maximum value of integration/irreducibility Φ_{max}. Exclusion is taken to mean that although subsystems of brain can have large Φ the entire brain masks their contribution to conscious experience. The masking postulate looks rather strange but is necessary unless one assumes hierarchy of consciousness so that subconscious would correspond to conscious but not at our level of hierarchy. Not all brain activity would be conscious to us. The activities of brain regions such as cerebellum are regarded as unconscious although there are more neurons there than in cortex. It could be that cerebellum is only unconscious to us?

2.3.2 Composition of mechanisms and conceptual structure

It is also possible to compose mechanisms. This is analogous to the composition of functions or formation of network from modules defining elementary functions. Composition can be also in time domain - say as a sequence of program modules as in computer program - so that the spatial realization is not changed. Composition is also analogous to what engineer is doing when he constructs more complex structures from primitive ones or programmer builds more complex programs from simple basic modules. This principle is very clearly present in biology and neuroscience based notion of conceptual structure.

The above postulates apply also to systems of mechanisms obtained by composition. This defines a conceptual structure identified as a constellation of points in concept space, where each axis consists of past/future state of the set of elements, and each point is a concept specifying differences that make a difference within a set. The higher the number of different concepts and Φ_{max} value, the higher the conceptual information.

Conceptual structure is kind of network build from mechanisms and analogous to a composition of functions or of computer programs. From the definitions it seems clear that conceptual structure does not correspond to independent ontological level in any sense. Conceptual structure should determine qualia and intensity of conscious experience. Here physicist starts to shake his head. I find it very difficult to imagine that qualia could be reduced to a structure of a network diagram.

The unsuccessful attempts to identify qualia in terms of neural networks have demonstrated this (it is not possible to demonstrate any difference between the structure of neural networks in various sensory areas nor in the structure of sensory pathways).

The partial reduction of consciousness to mechanisms is in accordance with the idea about brain as computer. In this framework imagination might perhaps be understood as motor actions stopped before becoming real. Virtual sensory inputs which do not begin from sensory receptors is interpretation in the case of sensory experiences. They might have also this aspect but there might be something deeper distinguishing between imagination and reality.

2.3.3 Identity postulate

One of the axioms states that consciousness exists. Something rather trivial. But does this mean that consciousness exists as something reducing to matter/physics as we know it. This is the crucial question distinguishing between monistic and dualistic and possible other theories.

One of these dogmas manifests in the question "dualistic or monistic" inspired by the belief that no other options are possible (TGD represents such an option). Tononi answered the question whether IIT is materialistic or dualistic theory of mind cryptically by saying "IIT is what IIT is". On the other hand, the proposal of consciousmeter could come only from a physicalist and physicalism reduces consciousness to an epiphenomenon.

IIT resembles physicalistic/materialist approach in that it identifies consciousness with the decomposition of elementary system to a pair (A,B) of subsystems information measure Φ and selects a unique pair as that for which this information is maximal. I_{max} measures the intensity of conscious experience. To this pair one assigns experience. Thus experience corresponds to unique decomposition of system to two parts. The technical problem is that this decomposition need not be unique! In any case, the structure and dynamics of system defined by mechanism would dictate completely the contents of consciousness.

2.3.4 Qualia

Qualia are assigned with the links of a net like structure. If I understand correctly, this structure corresponds to a collection of mechanisms with link identified as a mechanism connecting members of a causal pair. One assigns to link an information as relative entropy defines as the difference of entropies of the network and network without the link.

Why the link should carry say sensory quale remains a mystery to me. I would be ready to accept that the structure of experience corresponds to a network but assigning qualia with the links does not look like a feasible idea. It remained unclear to me whether qualia space corresponds to the links of the network or whether it corresponds to a collection of the networks. For instance, it is not easy to understand how basic colors could be understood in his framework. What properties of the link identified as mechanism or its relationship to the rest of the network could make the color quale "red" instead of "green".

3 TGD inspired theory of consciousness as quantum measurement theory in ZEO

To make the comparison easier for the reader I first summarize very briefly the basic ideas of TGD inspired theory of consciousness identified as quantum measurement theory in zero energy ontology (ZEO).

3.1 Zero Energy Ontology (ZEO)

ZEO [K11] was motivated by TGD inspired cosmology. Physical states have vanishing conserved net quantum numbers and are decomposable to positive and negative energy parts. The particle physics interpretation is as initial and final states of a particle reaction. A profound modification of existing views about realization of symmetries is in question.

The notion of causal diamond (CD) is closely related to ZEO. CD corresponds to an intersection of past and future directed light-cones of Minkowski space (with points replaced by CP_2). Positive

and negative energy parts of physical states are at future and past boundaries of CD which form part of light-one. Poincare transforms of CDs are allowed and CDs for a fractal hierarchy. A number-theoretically attractive hypothesis is that the distance between the tips of CD is quantized essentially as multiple of the size scale CP_2. CD can be interpreted as the 4-D perceptive field of conscious entity: zero energy state corresponds to a superposition of space-time surfaces having their ends about light-like boundaries of CD.

S-matrix and density matrix are unified to the notion of M-matrix defining time-like entanglement and expressible as a product of square root of density matrix and of unitary S-matrix. At least formally, thermodynamics becomes therefore a part of quantum theory, which can be regarded as "complex square root" of thermodynamics. One has kind of thermodynamical holography in the sense that square roots of thermal ensembles are realized at single particle level. One must distinguish M-matrices identifiable as products of orthonormal hermitian square roots of density matrices and universal S-matrix from U-matrix defined between zero energy states and analogous to S-matrix and characterizing the unitary process associated with quantum jump. The detailed description of U- and M-matrices is considered in [K11].

The most dramatic ontological implication is that quantum jump sequence can in principle lead to any zero energy state: this allows to avoid many unpleasant paradoxes forcing theorist to wonder whether theories are needed at all (in deterministic context only single solution of field equations is realized!). ZEO is consistent with the basic laws of quantum physics, allows maximal free will, and allows to solve the basic paradoxes of quantum measurement theory (determinism viz. non-determinism paradox and problems with the notion of time).

3.2 Hierarchy of Planck constants and dark matter hierarchy

One motivation for the hierarchy of Planck constants came from neuroscience from the observations made by Blackman and other pioneers of bio-electromagnetism [J1] [K18]. The observations could be summarized by saying that electromagnetic radiation of vertebrate brain at ELF frequencies (say multiples of 15 Hz) has both physiological and behavioral effects, which also look quantal. Quantal character is in conflict with the fact that ELF frequencies correspond to photon energies $E = hf$, which are extremely low, something like 10 orders of magnitude below thermal at physiological temperature. This inspired the proposal that photons are dark in the sense that for them one has $h_{eff} = n \times h$.

The identification of dark matter as phases having large value of Planck constant [K17, K5, K4] led to a vigorous evolution of ideas. Entire dark matter hierarchy with levels labelled by increasing values of Planck constant coming as integer multiples $h_{eff} = n \times h$ of ordinary Planck constant is predicted. A further assumption was that the dark matter in question is at magnetic flux tubes of the magnetic body of living system or of its part. This leads to the identification of EEG as a communication tool from biological body to magnetic body (MB). MB would receive sensory data from cellular and nuclear membranes and send control commands - most naturally via genome - to the biological body. MB would act as intentional agent using biological body as sensory receptor and motor instrument. This assumption allows to identify a long list of mechanisms used by magnetic body. Bio-photons can be understood as ordinary photons resulting when dark photons transform to ordinary ones [K2, K1].

The mathematical understanding of the hierarchy of Planck constants took a longer time [K5, ?]. The original vision was that the hierarchy of Planck constants demands a generalization of quantum TGD. This would have required a generalization of the causal diamond $CD \times CP_2$, where CD is defined as an intersection of the future and past directed light-cones of 4-D Minkowski space M^4. It however became clear that the hierarchy of Planck constants labels a hierarchy of quantum criticalities characterized by sub-algebras of super-symplectic algebras possessing a natural conformal structure. The sub-algebra for which the conformal weights come as n-ples of those for the entire algebra is isomorphic to the full algebra and acts as a conformal gauge algebra at given level of criticality.

In particular, the classical symplectic Noether charges for preferred extremals connecting 3-surfaces at the ends of CD vanish - this defines preferred extremal property. There would be n conformal gauge equivalence classes of preferred extremals which would correspond to n sheets of a covering of the space-time surface serving as base space. There is very close similarity with the Riemann surfaces. Therefore coverings would be generated dynamically and there is no need for

actual coverings of the embedding space.

The gauge degeneracy corresponds to the non-determinism associated with the criticality having interpretation in terms of non-determinism of Kähler action and with strong form of holography. The extremely strong super-symplectic gauge conditions would guarantee that the continuation of string world sheets and partonic 2-surface to preferred extremals is possible at least for somes value of p-adic prime. A good guess is that this is the case for the so called ramified primes associated with the algebraic extension in question at least. These ramified primes would characterize physical system and the weak form of NMP would allow to understand how p-adic length scale hypothesis follows [K19]. The continuation could be possible for all p-adic primes due to the possibility of p-adic pseudo-constants having vanishing derivative. It could quite well happen that the continuation fails for most configurations of partonic 2-surfaces and string world sheets in the real sector: the interpretation would be that some space-time surfaces can be imagined but not realized [K13]. For certain extensions the number of realizable imaginations could be exceptionally large. These extensions would be winners in the number theoretic fight for survivalandcorresponding ramified primes would be preferred p-adic primes.

A further strong prediction is that the phase transitions increasing h_{eff} and thus reducing criticality (TGD Universe is like hill at the top of the hill at....) occur spontaneously [?]. This conforms with NMP and suggests that evolution occurs spontaneously. The state function reduction increasing h_{eff} means however the death of a sub-self so that selves are fighting to stay at the criticality. The metabolic energy bringing in negentropic entanglement (NE) allows to satisfy the needs of NMP so that the system survives and provides a garden in which sub-selves can are born and die and gradually generate NE. Living systems are thus negentropy gatherers and each death and re-incarnation generates new negentropy.

All particles in the vertices of scattering diagrams have the same value of Planck constant so that the particles at different pages cannot have local interactions. Thus one can speak about relative darkness in the sense that only the interactions mediated by the exchange of particles and by classical fields are possible between different pages. Dark matter in this sense can be observed, say through the classical gravitational and electromagnetic interactions. It is in principle possible to photograph dark matter by the exchange of photons which leak to another page of book, reflect, and leak back. This leakage corresponds to h_{eff} changing phase transition occurring at quantum criticality and living matter is expected carry out these phase transitions routinely in bio-control. This picture leads to no obvious contradictions with what is really known about dark matter and to my opinion the basic difficulty in understanding of dark matter (and living matter) is the blind belief in standard quantum theory. These observations motivate the tentative identification of the macroscopic quantum phases in terms of dark matter and also of dark energy with gigantic "gravitational" Planck constant [?, K14].

The construction gives also the 4-D space-time sheets associated with the light-like orbits of the partonic 2-surfaces: it remains to be shown whether they correspond to preferred extremals of Kähler action. The hierarchy of Planck constants has become an essential part of the construction of quantum TGD and of mathematical realization of the notion of quantum criticality rather than a possible generalization of TGD.

3.3   p-Adic physics as physics of cognition and imagination

During years it have become more and more clear that consciousness involves cognition in an essential manner.

3.3.1   Extension of real physics to adelic physics

In TGD framework cognition is described in terms of p-adic number fields and has led to a fusion of real and various p-adic physics to what I call adelic physics [K19]. Real physics corresponds to sensory experience and p-adic physics to cognition and imagination. Originally I talked about p-adic physics as physics of cognition and intentionality but I have dropped intentionality away since I am not quite certain.

The difficult question has been how real and p-adic physics relate to each other. The naïve idea is that rationals belong to the intersection of reals and p-adics. More generally, points in algebraic extension of rationals would be common to realities and p-adicities which correspond to "thought

bubbles" or imaginations. This hierarchy defines a hierarchy of adeles having interpretation in terms of evolution leading to increasingly complex algebraic extensions of rationals.

The first guess was that this means at space-time level that embedding space points with rational valued coordinates (or values in the extension of rationals) correspond to common points of real and p-adic space-time surfaces. This picture however leads to problems with both general coordinate invariance and key symmetries of TGD. What are the preferred coordinates of space-time surface which would be in algebraic extension of rationals in the intersection? Should one restrict symmetry groups to their discrete subgroups?

The resolution of the problem came from the realization that the intersection of realities and p-adicities corresponds to space-time surfaces, whose representation is such that they make sense both in real and p-adic sense. This requires that the WCW coordinates of these surfaces are invariant under various symmetries and general coordinate transformations of space-time belong to the extension of rationals in question. At the level of WCW the coordinates are highly unique on basis of symmetries and by general coordinate invariance at space-time level. This also means discretization of the infinite-dimensional WCW and together with huge isometry group of WCW gives hopes about computatibility of TGD.

3.3.2 Negentropic entanglement

In given p-adic sector the EE is defined by replacing the logarithms of probabilities in Shannon formula by the logarithms of their p-adic norms. The resulting entropy satisfies the same axioms as ordinary entropy but makes sense only for probabilities, which are rational valued or in an algebraic extension of rationals. The algebraic extensions corresponds to the evolutionary level of system and the algebraic complexity of the extension serves as a measure for the evolutionary level. p-Adically also extensions determined by roots of e can be considered. What is so remarkable is that the number theoretic entropy can be negative.

A simple example allows to get an idea about what is involved. If the entanglement probabilities are rational numbers $P_i = M_i/N$, $\sum_i M_i = N$, then the primes appearing as factors of N correspond to a negative contribution to the number theoretic entanglement entropy and thus to information. The factors of M_i correspond to negative contributions. For maximal entanglement with $P_i = 1/N$ in this case the EE is negative. The interpretation is that the entangled state represents quantally concept or a rule as superposition of its instances defined by the state pairs in the superposition. Identity matrix means that one can choose the state basis in arbitrary manner and the interpretation could be in terms of "enlightened" state of consciousness characterized by "absence of distinctions". In general case the basis is unique.

Metabolism is a central concept in biology and neuroscience. Usually metabolism is understood as transfer of ordered energy and various chemical metabolites to the system. In TGD metabolism could be basically just a transfer of NE from nutrients to the organism. Living systems would be fighting for NE to stay alive (NMP is merciless!) and stealing of NE would be the fundamental crime.

TGD has been plagued by a longstanding interpretational problem: can one apply the notion of number theoretic entropy in the real context or not. If this is possible at all, under what conditions this is the case? How does one know that the entanglement probabilities are not transcendental as they would be in generic case? There is also a second problem: p-adic Hilbert space is not a well-defined notion since the sum of p-adic probabilities defined as moduli squared for the coefficients of the superposition of orthonormal states can vanish and one obtains zero norm states.

These problems disappear if the reduction occurs in the intersection of reality and p-adicities since here Hilbert spaces have some algebraic number field as coefficient field. By SH the 2-D states states provide all information needed to construct quantum physics. In particular, quantum measurement theory.

1. The Hilbert spaces defining state spaces has as their coefficient field always some algebraic extension of rationals so that number theoretic entropies make sense for all primes. p-Adic numbers as coefficients cannot be used and reals are not allowed. Since the same Hilbert space is shared by real and p-adic sectors, a given state function reduction in the intersection has real and p-adic space-time shadows.

2. State function reductions at these 2- surfaces at the ends of CD take place in the intersection of realities and p-adicities if the parameters characterizing these surfaces are in the algebraic extension considered. It is however not absolutely necessary to assume that the coordinates of WCW belong to the algebraic extension although this looks very natural.

3. NMP applies to the total EE. It can quite well happen that NMP for the sum of real and p-adic entanglement entropies does not allow ordinary state function reduction to take place since p-adic negative entropies for some primes would become zero and net negentropy would be lost. There is competition between real and p-adic sectors and p-adic sectors can win! Mind has causal power: it can stabilize quantum states against state function reduction and tame the randomness of quantum physics in absence of cognition! Can one interpret this causal power of cognition in terms of intentionality? If so, p-adic physics would be also physics of intentionality as originally assumed.

A fascinating question is whether the p-adic view about cognition could allow to understand the mysterious looking ability of idiot savants (not only of them but also of some greatest mathematicians) to decompose large integers to prime factors. One possible mechanism is that the integer N represented concretely is mapped to a maximally entangled state with entanglement probabilities $P_i = 1/N$, which means NE for the prime factors of P_i or N. The factorization would be experienced directly.

One can also ask, whether the other mathematical feats performed by idiot savants could be understood in terms of their ability to directly experience - "see" - the prime composition (adelic decomposition) of integer or even rational. This could for instance allow to "see" if integer is - say 3rd - power of some smaller integer: all prime exponents in it would be multiples of 3. If the person is able to generate an NE for which probabilities $P_i = M_i/N$ are apart from normalization equal to given integers M_i, $\sum M_i = N$, then they could be able to "see" the prime compositions for M_i and N. For instance, they could "see" whether both M_i and N are 3rd powers of some integer and just by going through trials find the integers satisfying this condition.

3.3.3 Strong form of holography and p-adic view about imagination

A further step in the progress came from the discovery of strong form of holography (SH) [K3]. 2-dimensional surfaces (string world sheets and partonic 2-surfaces) are fundamental objects and 4-D physics is a kind of algebraic continuation from this intersection of reality and various p-adicities in both real and p-adic sectors of the adelic Universe. 4-D space-time surfaces are preferred extremals of Kähler action making them effectively 2-D in the sense that the 2-D surfaces serve as space-time genes. Also the quantum states assignable to the 2-D surfaces can be algebraically continued to the entire 4-D space-time.

It is however quite possible that the continuation in the real sector to a preferred extremal of Kähler action fails. In p-adic sectors the possibility of p-adic pseudo constants which are piecewise constant functions with vanishing derivative makes the continuation much easier. This inspires the idea that imagination corresponds to these p-adic continuations. p-Adic continuation might be possible whereas real continuation could fail: one would have imagined world, which cannot be realized as often happens!

3.4 Quantum measurement theory in ZEO

NE is key notion and entanglement negentropy identified as number theoretic entanglement entropy (EE), which can be negative, takes in some sense takes the role of Φ serving as a measure for integrated information of TGD to be discussed below. NE can only increase in state function reductions and this brings in evolution forced by NMP. This leads to a precise identification for the notion of self, allows to understand the relationship beween subjective time and geometric time, and even what life and death of a conscious entity mean. Here only the key aspects are listed.

1. Causal diamond (CD) is a central notion in ZEO and serves as embedding space correlate for self. State function reduction can occur to either boundary of CD ("upper" or "lower"). Self can be seen as a generalized Zeno effect - a sequence of state function reductions to either boundary of CD. These two kinds of selves can be said to be time reversals of each other.

The period of non-boiling pot corresponds to the passive boundary of CD not changing in the reductions: also the parts of zero energy states at this boundary remain unaffected. The opposite - active - boundary is shifted towards future reduction by reduction and states at it are changed. The shifting the geometric future gives rise to the experienced time flow. This is the analog of unitary time evolution.

2. One possibility is that sensory input and mental images ("Maya") generated by it can be assigned with the active boundary of CD. A more elegant assumption suggested by quantum measurement theory is that the passive boundaries for sub-CDs give rise to mental images as outcomes of repeated quantum measurements. The unchanging part of self ("Self") is associated with the passive boundary. It corresponds to negentropically entangled subsystem having no entanglement with environment. In ordinary ontology it would not be possible keep self un-entangled from the environment.

3. NMP forces eventually the first state function reduction to the opposite boundary of CD: the pot starts to boil. Self dies and re-incarnates as time reversed self at the opposite boundary. The life-time of self is measured as the increase of the temporal distance between the tips of CD. Time reversed self evolves as reductions shifting the opposite boundary of CD to opposite time direction so that the size of CD continues to increase and defines a measure for the duration of the entire sequence of re-incarnations. This implies quantum physical realization for the idea about transmigration of souls! Excellent manner to get rid of street-credibility is to tell to academic audience about this implication.

4. One big news is that selves form a hierarchy (CDs within CDs) and sub-selves are identified as mental images. In TGD framework it is also possible for sub-selves of two unentangled selves to entangle negentropically. This corresponds to sharing of mental images and means that our conscious experience is not completely private. The pool of shared mental images might in fact make possible communication and social structures. Sharing of mental images is possible only in many-sheeted space-time forcing to generalize the standard view about subsystem.

The divisions of system to two parts are involved with the definition of integrated information. Also in the formulation of NMP in terms of maximal negentropy gain one considers divisions of the system into subsystem and complement and finds the pair for which the reduction of entanglement would give maximum reduction of entropy. If the system is irreducible this kind of pair characterized by entropic entanglement cannot be found. The eigenstates of density matrix for negentropically entangled subsystems are in 1-1 correspondence. An interesting question is whether associations in the sense of neuro science corresponds to NE between the states of associated systems.

State function reduction scade is also key notion. State function reduction sequences is a top down cascade propagating downwards to smaller system sized. First the reduction in CD scale occurs. The resulting two subsystems decompose to two parts and so on untile decomposition is not possible anymore because it would not generate negentropy.

3.5   TGD view about qualia

The TGD inspired theory of qualia [K6] has evolved gradually.

1. The original vision was that qualiaandother aspects of consciousness experience are determined by the change of quantum state in the reduction: the increments of quantum numbers would determine qualia. I had not yet realized that repeated state function reduction (Zeno effect) realized in ZEO is central for consciousness. The objection was that qualia change randomly from reduction to reduction.

2. Later I ended up with the vision that the rates for the changes of quantum numbers would determine qualia: this idea was realized in terms of sensory capacitor model in which qualia would correspond to kind of generalized di-electric breakdown feeding to subsystem responsible for quale quantum numbers characterizing the quale. The Occamistic objection is that the model brings in an additional element not present in quantum measurement theory.

3. The view that emerged while writing the critics of IIT of Tononi is that qualia correspond to the quantum numbers measured in the state function reduction. That in ZEO the qualia remain the same for the entire sequence of repeated state function reductions is not a problem since qualia are associated with sub-self (sub-CD), which can have lifetime of say about .1 seconds! Only the generalization of standard quantum measurement theory is needed to reduce the qualia to fundamental physics. This for instance supports the conjecture that visual colors correspond to QCD color quantum numbers. This makes sense in TGD framework predicting a scaled variants of QCD type physics even in cellular length scales.

   This view implies that the model of sensory receptor based on the generalization of di-electric breakdown [K9] is wrong as such since the rate for the transfer of the quantum numbers would not define the quale. A possible modification of the model simple: the analog of di-electric breakdown generates Bose-Einstein condensate and the quantum numbers for the BE condensate give rise to qualia assignable to sub-self.

4 Comparison of IIT with TGD

4.1 Basic concepts of IIT from TGD point of view

4.1.1 Pan-psychism, identity postulate, and physicalism from TGD viewpoint

In TGD framework panpsychism is assumed but in different form. Consciousness is not a property of matter unlike in IIT but an independent form of existence not reducible to say geometric existence so that notions like qualia space introduced in IIT do not make sense. Consciousness is the state function reduction occurring between different material worlds. This resolves the fundamental problems related to quantum measurement theory and the notion of time. In ZEO one can talk about conscious entities (this is almost unavoidable since our language reflects the belief that consciousness is a property of physical system) as internally negentropically entangled systems de-entangled from the rest of the world at the possive boundary of CD. In standard quantum theory this would make no sense. All qualia would correspond to outcomes of repeated quantum measurements at passive boundaries of sub-CDs of CD and defining mental images. The flow of time would correspond to contribution from the active boundaries of CDs involved.

4.1.2 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.

Criticism:

1. The idea that various sensory qualia could be understood in terms of topological structure of a network formed by neuronsandaxons 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 looks 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 [J2] (see `http://tinyurl.com/3gjhtgb`)! One might expect that causal interactions between hemispheres must be responsible for the synchrony but it is difficult to imagine anything like this now. There seems to be something like "boss" forcing both hemispheres to synchrony.

In TGD the qualia correspond to the eigenvalues assignable to the observable measured during repeated state function reductions leaving the states at 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. 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.

In TGD framework the networks emerge naturally as networks of magnetic flux tubes [L2].

1. The "boss" forcing the synchrony of disconnected left and right hemispheres would be magnetic body (MB) of brain [L4]. Magnetic bodies appear in all scales. NE between nodes of this network is what is more significant.

2. The so called tensor networks [B1] [L1] (see `http://tinyurl.com/y9kwnqfa`), which have emerged as realizations of error correction codes in quantum computation and realize holography can be seen as a realization of NE. 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 complete the organism-environment duality to trinity.

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 [**?**, K14]. 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 [L2].

What the mysterious looking entity X could then be? The MB of Earth assignable with Earth's mass via $h_{eff} = \hbar_{gr} = GMm/v_0$ is the first candidate for X but for it EEG would be scaled down since 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. Spottiswoode observed that sidereal day defines periodicity for precognition [**?**]. A mass $M_D \simeq 5. \times^{-5} M_E$ 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. 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.

4.1.3   The notion of integrated information (Φ) from TGD viewpoint

In TGD the analog of Φ as measure of complexity would be number theoretic entanglement negentropy involving p-adic norm in its definition. If defined as average for the entanglement negentropies for various partitions of the system to two parts it would define a measure for the complexity and correlations.

Formally a modification of Shannon entropy is in question but the surprise is that it can be negative in which case one has NE It makes sense for entanglement coefficients in algebraic extension of rationals: this predicts number theoretic evolutionary hierarchy of conscious entities. The definition relates closely to p-adic physics as physics of cognition. Number theoretic EE measures the information associated with NE (ordinary EE measures the lack of information about

state of entangled system due to entanglement). The basic variational principles is NMP stating that the negentropy gain is maximal in each state function reduction. NMP forces the amount of NE measured by number theoretic entanglement negentropy to increase. One interpretation for the NE resources of the Universe is as "Akashic records". Universe would be a huge growing library of books formed by negentropic mental images.

In TGD framework the reduction of the system to its parts leading to a loss of consciousness would occur by state function reduction. NMP can prevent this in presence of cognition. That state function reductions occur rather often at elementary particle level tells that their cognitive level is rather low. Breaking of time reversal symmetry analogous to that in thermodynamics is also a signature of cognition.

The proposal about critical value of Φ makes the situation analogous to that in critical thermodynamical systems. This also brings in mind quantum criticality of TGD fundamental for the understanding of the evolution of conscious entities in TGD framework. It brings in the hierarchy of dark matter represented as phases of ordinary matter with non-standard value $h_{eff} = n \times h$, $n = 1, 2, ...$ of Planck constant emerging at quantum criticality and making macroscopic quantum coherence possible.

In TGD NE is a correlate for conscious information. NE also provides a correlate for integration. Conceptual structure could be assigned with the topological structure of NE, which would also be a correlate for complexity in quantum sense. Quantum computer people have indeed realized that the physics of complexity is essentially physics of entanglement. Conscious entity corresponds to the sequence of quantum jumps/reductions at fixed boundary of CD. Conscious entities have inherent NE and they are not entangled with environment. There is however no attempt to identify NE as consciousness.

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 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 that 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 [K9]. 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.

4.1.4   Counterparts of mechanisms and irreduciblity in TGD

Mechanism is central notion in IIT. In ZEO self organization patterns in 4-D sense serve as counterparts of behavioral patterns realizing causal relationship. Space-time surfaces identified as preferred extremals of Kähler action satisfying extremely powerful constraints coming from strong form of holography are space-time correlates for these self-organization patterns. System approaches reduction by reduction to these 4-D patterns: in positive energy ontology these patterns would be 3-D. This difference has profound implications.

The analog for the notion of irreducibility in TGD framework is that any subsystem at the passive boundary of CD is inherently negentropically entangled and remains so as long as the conscious entity lives and is in this sense irreducible at the passive boundary of CD. The information carried by NE cannot be localized.

Maximal NE defines isometric map between subsystem and its complement. In fact, the isometric map is possible for all subsystem complement pairs for so called perfect entanglement discussed by Preskill [B1] in his proposal for error correcting codes based on holography. This model has application in TGD inspired model of living systems based on the notion of magnetic body [L1].

NE is stable against NMP allowing state function reductions in which system splits into subsystem and complement is similar notion. Hilbert spaces with prime dimension are also irreducible in the sense the decomposition into tensor product of two subsystems is not even possible and this might deeply relate to the fact that Mersenne primes seem to be very important in TGD [L5]. (see http://tinyurl.com/gp9mspa).

In TGD framework metabolism is not just feed of ordered energy but feed of NE carried by nutrients [K14, K7]. This NE means feeding in of connections to other system realized in terms of magnetic flux tubes and couple the system to environment and other conscious entities.

4.1.5   Self hierarchy makes exclusion postulate un-necessary

Exclusion postulate looks to me like the most problematic axiom of IIT. Hierarchy of selves with sub-system of system corresponding to sub-self makes exclusion postulate un-necessary in TGD framework. System can have sub-systems conscious sub-systems and these in turn can have conscious sub-systems so that one has a hierarchy. The hierarchy of space-time sheets corresponds to this hierarchy at space-time level and the hierarchy of CDs at embedding space level. Subsystems correspond to mental images, which are kind statistical averages over mental images of sub-selves so that the information about lower levels is only statistical. This saves the system from drowning to irrelevant conscious informations.

Tononi does not consider the possibility of self hierarchy. Maybe the reason is that the idea about hierarchy of selves is central in spiritual practices involving angels and gods but is very difficult to accept in the western science accepting only what is directly perceived. In TGD framework the new space-time concept - in particular the notions of field body and magnetic body - support the notion of self-hierarchy. For instance, EEG could be seen as communications to the magnetic body of organism having onion-like structure with layers with sizes even larger than the size of Earth [K16, K15].

For instance, the damaging of cerebellum does not affect much consciousness. This is true but it is "our" consciousness, which is not affected - only one level in the self hierarchy. Cerebellum could quite well represent a level few levels below cortex in the hierarchy of selves. It can of course decompose to sub-structure, which are negentropically entangled but unentangled with each other.

This failure is reflected in the rather weird looking exclusion postulate. Parts of brain can have Φ allowing them to be conscious. Tononi cannot however make sense of this. The explanation

would be that brain as a whole has so large a Φ that it overrides that for parts so that they are not conscious. By the same argument the Φ of Universe would be so large that there would be not a single conscious entity besides the entire Universe! One ends up with solipsism.

4.1.6 No variational principle of consciousness is introduced in IIT

In IIT no variational principle defining the dynamics of consciousness is introduced - say a postulate that the property measured by Φ would increase being therefore mathematically analogous to NMP in TGD framework. This kind of variational principle should imply evolution.

The definition of NMP involves quite refined number theoretic details but is consistent with standard quantum measurement theory and with standard measurement theory for ordinary entropic entanglement - that it is for ordinary matter. For dark matter one has NE and the situation changes. One can however say that second law for a given self holds true in time scales longer than the life-time of self.

NMP implies a kind of competition between subsystems, which can reduce their entanglement with environment in state function reduction. One can say that for a given system the state function reduction occurs for the subsystem-complement pair for which the reduction of EE is maximal. This if the entanglement is ordinary entropic entanglement, which is always reduces in accordance with the standard quantum measurement theory. For maximally negentropically entangled systems NMP need not lead to any effect. NE can be stable since as a whole it tends to increase. This does not prevent transfer of NE between systems.

The builder of consciousness theory is eventually led to ask about the origins of ethics and moral. NMP does not completely deterministically select the final state in the case of NE. For instance, if NE corresponds to $N \times N$ identity matrix it can happen that reduction occurs to a lower-dimensional space and one can speak of free will. The outcome can make the negentropy gain smaller but also larger. One can say that system has free will and even speak about ethics based on maximization of negentropy and moral choices. Complete reduction of entanglement would mean the worst possible deed and implies the system is de-entangled and thus isolated from the rest of the Universe.

4.2 Engineering aspect of consciousness

The idea that consciousness is engineered from simple building bricks is rather attractive and realized also in TGD framework.

4.2.1 The problematic notion of conceptual structure

The notion of conceptual structure is problematic in the sense that the assignment of qualia to the links of this structure does not look feasible. In TGD the combinatorial structure of NE the most natural TGD analog of conceptual structure. It would correspond in the most general case to a quantum superposition of networks - the so called spin liquid could actually realize this notion in condensed matter physics. Conscious entity would correspond to a sub-system having no entanglement with environment but its internal entanglement would be negentropic and maximal in well-defined sense. The notion of tensor network, which appears in quantum computations could be equivalent with the notion of negentropically entangled system. A quite recent proposal of Preskill [B1] is that error correcting quantum codes could be realized using tensor networks. This fits very nicely with TGD view [L1].

The structure of NE provides abstract backbone for the structure of conscious experience. The structure of NE does not however give any clue about qualia. In ZEO they can be assigned with either the passive of active boundary of CD. At active boundary they could be assigned with the quantum number transfer rates between the active part of self and environment. At passive boundary they would naturally correspond to the quantum numbers of the passive part of some sub-self at passive boundary of its CD: repeated measurement would give experience about what the quantum numbers are. This option would fit nicely with quantum measurement theory. If one interprets mental images as sub-selves, one can indeed understand why the sensory experiences vary from moment to moment although the passive part of self - "Self" - does not change.

The notion of conceptual structure unavoidably brings in mind p-adic physics as physics of cognition and imagination but these two notions should be distinguished. Adelic physics fuses real and various p-adic physics to single coherent role. To me this option looks much more plausible.

4.2.2 The problems of free will, intentionality, and time

IIT says nothing about volition, intentionality, and (not completely) free will. Mechanisms could be non-deterministic but this does not help much. To my opinion, trying to say something about free will leaves no other options than quantum theory or its generalization.

IIT says nothing about experienced time. Standard quantum measurement theory involves the notion of observer and is plagued by a deep paradox related to the determinism of Hamiltonian time evolution and non-determinism of quantum measurement theory. This has led to the Copenhagen interpretation depriving ontological status from the basic mathematical notions of quantum theory. The problem relates directly to the notion of observer, the question about reality of free will, and to the question about the relationship between the geometric time of physicist and the experienced time.

Obviously, non-conservative theorist cannot imagine more promising starting point for a theory of consciousness. One should generalize quantum theory so that one gets rid of paradoxes and provides a description of observer as conscious entity. In TGD framework the qualia can be reduced to fundamental physics, which to my opinion is much more convincing identification than the identification in terms of a particular partition associated with some mechanism assumed to be associated with the system considered.

The randomness of state function reduction does not resonate with the idea of intentional free will but it could be tamed by cognition making possible intentional free will made possible by the extension of real physics to adelic physics.

In principle ZEO allows also creation of any zero energy from vacuum state without any problems with the laws of physics. That this is impossible in positive energy ontology and is one of the main reasons for adopting the materialistic/physicalistic view about consciousness reducing it to epiphenomenon. It seems that the same reduction occurs in IIT.

TGD provides an elegant interpretation for the act of free will. Since nothing drastic happens during repeated state function reductions to the same boundary of CD, the act of free will can only corresponds to the first reduction to the opposite boundary of causal diamond (CD). The act of volition means the death of sub-self and reincarnation as time reversed sub-self. This explains the finding due to Libet that conscious decision to perform motor action (to raise finger) initiate neural activity before the decision. Negative energy signal to the geometric past of brain would initiate the neural activity.

A further outcome is that p-adic entanglement can be negentropic and by NMP and SH it stabilizes the entanglement also in real sector. Cognition would not be a passive formation of cognitive representations but would have causal power taming the randomness of quantum jumps making possible directed intentional will. Religions express this intuition in various ways: for instance, the Finnish version of Genesis contains the sentence "First was the word". Also Finnish national epic gives magic power to the words: first comes the world and only after it what the word refers to.

4.3 Why deep learning neutral networks are so effective?

Deep learning means AI systems with large number of hierarchy levels: programs calling programs calling... is the first intuitive idea of AI outsider like me. These algorithms are learn from examples mimicking the formation of associations in brain. These programs can also rewrite themselves but all is based on given algorithm.

The surprising finding is that deep learning neural model work much better than one might expect on basis of mathematical arguments alone (see http://tinyurl.com/zvrmao7. This looks like a real mystery. The solution of the puzzle proposed by physicists is elegant. The physical world is much much simpler than mathematicians - wanting to be as general as possible - assume! Simplicity means among other things holography and hierarchical structures and deep learning relies on hierarchical structures. It would be amazing if AI and physics finally could meet each

other (see the article of Lin and Tegmark at `http://tinyurl.com/hz2jp8z` and the remarks of Ben Goertzel at `http://tinyurl.com/z8tcqht`).

4.3.1   Holography and its strong form

The Universe is indeed very simple according to hololographic theories. For instance, in TGD not only holography but strong form of holography holds true. The quantum and classical data assignable to string world sheets and partonic 2-surfaces dictates the dynamics of 4-D space-time surface. This effective 2-dimensionality of dynamics means enormous simplification of the quantum physical world from what it could be. For instance, preferred extremals defining space-time surfaces satisfy infinite number of conditions stating vanishing of certain Noether charges.

This extreme simplicity is lost when the sheets of the many-sheeted are lumped together to obtain the space-time of general relativity and standard model and effective classical fields are sums over geometrizes classical fields associated with the sheets. In biological systems however the dynamics of many-sheetedness comes manifest and the actions of single sheet need not be masked: things get simple in this kind of situation.

4.3.2   Various fractal hierarchies

Holography need not the only reason for the simplicity. The possibly physical world of TGD has hierarchical fractal structure: length scale reductionism is replaced with fractality. Dynamics looks more or less similar in all zooms and this simplifies the situation of mimicker enormously. There are hierarchies of space-time sheets topologically condensed on larger space-time sheets, hierarchy of p-adic length scales defined by primes near powers of two (or more general small prime), hierarchy of Planck constants, self hierarchy. p-Adic length scale hierarchy allows extremely simple model for elementary particle masses: one might perhaps say that one does not model the mass of "real" particle but its cognitive representation about itself in terms of p-adic thermodynamics relying on conformal invariance. The hierarchy of Planck constants means fractal hierarchy of zoom-ups of system: dark matter phases assignable to quantum criticality would be crucial for the understanding of living systems.

These hierarchies also define hierarchies of measurement resolutions making possible abstraction, getting rid of details at the level of conscious experience and behavior. The hierarchical structure would be especially important for conscious mind. Self has subselves which it experiences as mental images and is mental image of higher level self. Goal hierarchies mean a lot of structural restrictions making it easier for artificial intelligence to mimick conscious systems.

4.3.3   p-Adic variant for the theory of computation?

In TGD Universe p-adic physics is physics of cognition and imagination and real physics also carries signatures about the presence of p-adic physics as p-adic fractality: this would explain the unexpected success of p-adic mass calculations [K8]. The outcome would be a fusion of real and various p-adic number fields to form adeles. Each extension of rationals giving rise to a finite-dimensional extension of p-adic numbers defines an adele, and there is hierarchy of adeles defining an evolutionary hierarchy. The better the simulation p-adic space-time sheet is for real space-time sheet, the larger the number of common algebraic points is. This intuitive idea leads to the notion of monadic geometry in which the discretization of the embedding space causal diamond is central for the definition of monadic space-time surfaces [L3]. They are smooth both in real and p-adic sense but involve discretization by algebraic points common to real and p-adic space-time surfaces for some algebraic extension of rationals inducing corresponding extension of p-adics.

How this could relate to computation? In the classical theory of computation recursive functions play a key role. Recursive functions are defined for integers. Can one define them for p-adic integers? At the first glance the only generalization of reals seems to be the allowance of p-adic integers containing infinite number of powers of p so that they are infinite as real integers. All functions defined for real integers having finite number of pinary digits make sense p-adically.

What is something compeletely new that p-adic integers form a continuum in a well-defined sense and one can speak of differential calculus. Exact numerics is lost but p-adic continuity (the values $f(x)$ and $f(x + kp^n)$) would be near to each other p-adically) and smoothness could make

possible approximations and would allow to pose additional conditions on recursive functions for given prime p.

How could one map p-adic recursive function to its real counterpart? Does one just identify p-adic arguments and values as real integers or should one perform something more complex? The problem is that this correspondence is not continuous. Canonical identification for which the simplest form is $I : x_p = \sum_n x_n p^n \to \sum_n x_n p^{-n} = x_R$ would however relate p-adic to real arguments continuously [K12]. Note that the real counterpart is rational for finite p-adic integers and real number in the general case. Canonical identification has several variants typically mapping small enough real integers to p-adic integers as such and large enough integers in the same manner as I. In the following let us restrict the consideration to I.

Basically, one would have p-adic valued recursive function $f_p(x_p)$ with a p-adic valued argument x_p. One can assign to f_p a real valued function of real argument - call it f_R - by mapping the p-adic argument x_p to its real counterpart x_R and its value $y_p = f_p(x)$ to its real counterpart y_R: $f_R(x_R) = I(f(x_p) = y_R$. I have called the functions in this manner p-adic fractals: fractality reflects directly to p-adic continuity. It should be made clear that canonical identification maps finite p-adic integers to real rationas and p-adic integers infinite as real integers to reals.

f_R could be 2-valued. The reason is that p-adic numbers $x_p = 1$ and $x_p = (p-1)(p+p^2+..)$ are both mapped to real unit and one can have $f_p(1) \neq f_p((p-1)(p+p^2+..))$. This is a direct analog for $1 = .999...$ for decimal expansion. This generalizes to all p-adic integers finite as real integers: p-adic arguments $(x_0, x_1, ...x_n, 0, 0, ...)$ and $(x_0, x_1, ...x_n - 1, (p-1), (p-1), ...)$ are mapped to the same real argument x_R. Using finite pinary cutoff for x_p this ceases to be a problem.

Recursion plays a key role in the theory of computation and it would be nice if it would generalize in a non -trivial manner to the realm of p-adic integers (or general p-adic numbers).

1. From Wikipedia (see `http://tinyurl.com/m9by2zn`) one finds a nice article about primitive recursive functions. Primitive recursive functions are very simple. Constant function, successor function, projection function. From these more complex recursive functions are obtained by composition and primitive recursion. These functions are trivially recursive also in p-adic context and satisfy the conditions of p-adic continuity and smoothness. Composition respects these properties tool. I would guess that same holds also for primitive recursion.

   It would seem that there is nothing new to be expected in the realm of natural numbers if one identifies p-adic integers as real integers as such. Situation changes if one uses canonical identification mapping p-adic integers to real numbers (for instance, $1 + 2 + 2^2 = 7 - - - > 1 + 1/2 + 1/4 = 7/4$ for 2-adic numbers). One could think of doing computations using p-adic integers and mapping the results to real numbers so that one could do computations with real numbers using p-adic integers and perhaps p-adic differential calculus so that computation using analytic computations would become possible instead of pure numerics. This could be very powerful tool.

2. One can consider also real valued recursive functions and functions having values in (not only) algebraic extensions of rationals. Exponent function is an interesting primitive recursive function in real context: in p-adic context $exp(x)$ exists p-adically if x has p-adic norm smaller than 1). $exp(x+1)$ does not exist as p-adic number unless one introduces extension of p-adic numbers containing e: this is necessary in physically interesting p-adic group theory. $exp(x + kp)$ however exists as p-adic number. The composition of exp restricted to p-adic numbers with norm smaller than 1 with successor function does not exist. Extension of rationals containing e is needed if one wants successor axiom and exponential function.

3. The fact that most p-adic integers are infinite as real numbers might pose problems since one cannot perform infinite sums numerically. p-Adic continuity would of course allow approximations using finite number of pinary digits. The real counterparts of functions involved using canonical identification would be p-adic fractals: this is something highly non-trivial physically.

   One could also code the calculations at higher level of abstraction by performing operations for functions rather than numbers. The finite arithmetics would be for the labels of functions using tables expression the rules for various operations for functions (such as multiplication). Build a function bases and form tables for various operations between them like multiplication

table of algebra, computerize the operations using these tables and perform pinary cutoff at end. The rounding error would emerge only at this last step.

The unexpected success of deep learning is conjectured to reflect the simplicity of the physical world: only a small subset of recursive functions is needed in computer simulation. The real reason could be p-adic physics posing for each value of p very strong additional constraints on recursive functions coming from p-adic continuity and differentiability. p-Adic differential calculus would be possible for the p-adic completions of integers and could profoundly simplify the classical theory of computation.

4.3.4   Quantum states realize finite measurement resolution themselves

Conceptualization means hierarchies and one can say that TGD Universe performs this conceptualization for us! In fact, one can say that quantum state provides its own description. This implies that finite measurement resolution is not a property of description of quantum state but of quantum state itself! For instance, the larger the number of partonic 2-surfaces and string world sheets is, the better the "half-discretization" of 4-D space-time surface by these 2-surfaces is, and the more precise is the conscious experience of system about itself. For instance, magnetic flux tube networks with flux tubes accompanied by strings and with maximally entangled at the ends of nodes would give rise to a universal proprioception. The experience about 3-space would emerge from entanglement rather, not the 3-space as some colleagues fashionably argue.

4.3.5   Simplicity in cosmology

This extreme simplicity is most dramatic in cosmology. The microwave temperature is essentially constant. This cannot be due to the causal interactions but reflects something deeper. Inflationary scenarios are one attempt to explain this but have not led to a breakthrough. A more radical explanation is that macroscopic quantum coherence even in cosmological scales is possible at the space-time sheets of cosmic size scale with large value of Planck constant characterizing phases of ordinary matter behaving like dark matter. The key idea is generalization of point-like particle to 3-surface: particle and 3-space are one and same thing. Particles as 3-surfaces can have even cosmological size.

Deep learning neural nets could be seen as supporting the idea of computer consciousness is involved and therefore would be encouraging also from the point of view of IIT. 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 a damaged frontal lobes. These persons are intelligent but cannot intend and realize their intentions in the time time scales needed in say everyday life.

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