Commentary on "Consciousness as a phenomenon in the operational architectonics of brain organization: Criticality and self-organization considerations" by Adrew A. Fingelkurts, Alexander A. Fingelkurts, and Carlos F. H. Neves

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1 Introduction

I received an interesting article by brothers Fingelkurts (Andrew and Alexander) and Carlos Neves to be published in Chaos, Solitons & Fractals [3]. The title of the article is *Consciousness as a phenomenon in the operational architectonics of brain organization: Criticality and self-organization considerations*.

Already on basis of the title it is clear that article is interesting also from the point of view of Topological Geometrodynamics (TGD) (for overview see Topological Geometrodynamics: an Overview [9], especially the part II), where quantum criticality replaces thermodynamical criticality as a basic characteristic of the Universe dictating uniquely the dynamics fixing the geometry of the "world of classical worlds" (WCW [8]) consisting of 3- surfaces in certain 8-dimensional space-time. Quantum criticality is also central in TGD inspired theory of consciousness and the basic picture is roughly the same as in OA model. The chapter Comparison of TGD Inspired Theory of Consciousness with Some Other Theories of Consciousness [10] might help to get an overview about TGD inspired theory of consciousness.

Quantum self-organization [4] is second key element of TGD inspired theory of consciousness and corresponds to a cascade of quantum jumps proceeding from level of given causal diamond (CD) defined as intersection of future and past directed light-cones of 4-D Minkowski space to shorter scales (sub-CDs, their sub-CDs, etc..). Quantum jump corresponds to a state function reduction at either boundary of CD and have interpretation as sensory perception and motor action (time reversed sensory perception). CD is identified as geometric correlate for "spotlight of consciousness".

In the following I summarize the basic concepts and ideas of the article and compare them with TGD approach to consciousness. There is also a section devoted to quantum criticality in TGD Universe. The approach is certainly TGD centred and I can only apologize this.

2 The model for operational architecture of brain (OA)

In the following I summarize my understanding of OA model by comparing in with TGD approach to consciousness.

2.1 Basic philosophy

Concerning physics, the proposed model is necessarily conservative. Non-physicist - and I am afraid that also physicist - proposing theory of consciousness hardly has any other option. The model is basically thermodynamical: no quantum effects are considered although the general structure of the model can be considered also in quantum framework by allowing macroscopic quantum effects and replacing criticality and self-organization with their quantum counterparts. The vision is roughly the following.

1. *Spatiotemporal separability stating that two regions with space-like separation are un-correlated.* This assumption is natural if one believes that classical physics is all that is needed. In quantum field theory (QFT) this corresponds to micro-causality and assumption of point-like particles. In quantum theory entanglement challenges this assumption. This assumption does not make easy to understand the unity of consciousness and the coherent behaviour of living organisms.

   TGD approach differs here from the proposed one. Point like particle is generalized to 3-surface and the notion of topological field quantization brings in the notions of field body and magnetic body. Magnetic body becomes the intentional agent using biological body to its purposes. Magnetic flux tubes serve as correlates for directed attention and for negentropic entanglement and bind disjoint systems to single quantum system in some degrees of freedom.

2. *The neuro-physiogical state of brain (extracellular electric fields reflecting themselves via EEG)* is in 1-1 correspondence with the contents of phenomenal consciousness. Therefore the approach is materialistic. Phenomenal consciousness is not however doomed to be illusion (whatever this could mean) and is even allowed to have causal powers. Strong emergence (system has qualities not directly traceable to those of component systems) seems to be the philosophical characterization of their approach. Therefore the main criticism that can be made against the theory of Fingelkurts et al is that both phenomenal consciousness and causal powers emerge in miraculous manner as Revonsuo puts it. In TGD Universe the space-time sheet containing the smaller space-time sheet is something which does not reduce to the properties of the smaller space-time sheets.

   Macroscopic quantum effects are not considered, which I take to mean that quantum statistical determinism holds true. In this framework it is difficult to understand the non-determinism accompanying the causal powers of consciousness. The proposal seems to be that thermodynamical phase transitions are the source of causal powers.

   Even classical thermodynamics assigns to thermodynamical fluctuations at thermodynamical criticality certain kind of non-determinism: the motivation is the simple fact that experimentally this seems to be the case. Theoreticians must be in this kind of situation slightly illogical! Quantum non-determinism in microscopic scales might explain the non-deterministic features of critical systems extremely sensitive to fluctuations, even quantum fluctuations. If hidden macroscopic quantum coherence assignable to dark matter is present, the reduction to quantum level looks even more plausible. In TGD Universe dark matter identified as a hierarchy of phases with arbitrarily large effective value of Planck constant might be therefore also behind the long range fluctuations at thermodynamical criticality. Certainly these phase are crucial for biology in TGD Universe.

3. *Consciousness is localized to brain.* This includes also sensory qualia. This identification has well-known problems. Even the term "consciousness" is problematic since strictly speaking "-ness" implies that "consciousness" refers to a property of system: this leads to problems unless one is ready to accept materialism (in TGD approach consciousness is in quantum jump, between two worlds rather than in the world or a property of the world). Secondly, the localization of conscious experience in space-time is a problematic assumption: a weaker assumption is that the contents of conscious experience *is about* some region of space-time (causal diamond in TGD

approach). Thirdly, even the localization of contents of conscious experience to brain only is problematic (sensory qualia). A weaker assumption is that only reflective consciousness consisting of recognition of objects of perceptive field and naming them and producing a representation of the external world and self in this manner is *performed* by brain (and by magnetic body in TGD context). Brain could be seen as a manufacturer of standardized mental images - representations - and phenomenal consciousness would correspond to sensory qualia. In TGD framework it is also possible to assume that sensory receptors are the seats of sensory qualia: neurons could serve as seats of qualia not conscious-to-us since selves form a hierarchy.

One can consider even the possibility that sensory organs generate quantum entanglement with the target of attention by reconnection of flux tubes of the magnetic bodies so that perceiver and perceived form a single quantum coherent system. This would explain among other things the 3-D character of sensory perception requiring complicated neural computation if strictly 2-D data at retina is used to build the perception as a virtual world representation of the external world.

4. *Consciousness consists of a discrete series of mental images assignable to sharp phase transitions between thermodynamical far from equilibrium states.* There is a neuro-scientific support for this belief and the pleasant news is that it is just what TGD predicts via the identification of quantum jump as a moment of consciousness.

2.2 Basic ingredients of the model

Consider now the basic ingredients of the model.

1. *Living matter as open self-organizing thermodynamical system.* Energy flows through the system and gives rise to self-organization patterns with dissipation serving as a Darwinian selector taking care that very many initial states lead to the same final self-organization patterns. Second law translating to minimization of free energy is the essential element of the model.

   In TGD framework self-organization is replaced by 4-D self-organization for quantum superpositions of space-time sheets leading to asymptotic spatio-temporal rather than only spatial patterns accompanied by standardized mental images. EEG pattern would be one example of this. The 4-D self-organization has also 3-D counterpart since space-time evolution represents space-time correlate for dissipation. The new prediction is that the arrow of imbedding space geometric time of the resulting zero energy state is opposite in subsequent state function reductions at opposite boundaries of given CD.

   Negentropy Maximization Principle (NMP) [12] states that the information contents of conscious experience is maximal. This requires a more detailed explanation.

   (a) In TGD framework state function reduction taking place in quantum jump means a measurement of subsystem density matrix leading to an eigen-space of density matrix. Hence the final state density matrix is $N \times N$ unit matrix with a degenerate eigenvalue $P = 1/N$ giving entanglement probabilities. These probabilities are rational numbers belonging to the intersection of reals and p-adic number fields Q_p. One can therefore assign to the resulting entangled state information measure that I call number theoretic entanglement entropy obtained from Shannon entropy by replacing logarithms of probabilities with p-based logarithms of the p-adic norms of probabilities. If the p-adic prime p divides N, the entropy is negative and maximum for the largest prime power factor of N: this assigns a unique p-adic prime to the final state.

   (b) The proposal is that quantum jumps between real and p-adic states creating cognitive representations correspond to transitions transforming real state to p-adic one with this particular p-adic prime to satisfy NMP [12]. The interpretation is that the state pairs in the superposition of state pairs represent instances of a rule. This negative entropy should not be confused with thermodynamical entropy which characterizes the lack of information about a member of ensemble.

   (c) The systems with degenerate density matrix are clearly very special systems - quantum critical in well-defined sense- and the proposal is that the hierarchy of effective values

$\hbar_{eff}/\hbar = N$ of Planck constants corresponds to this kind of systems. This hierarchy would be identifiable in terms of N-furcations of space-time surface made possible by the failure of the strict determinism of Kähler action serving as the variational principle dictating the dynamics of space-time surfaces.

(d) Clearly, several ideas are unified: quantum criticality as a presence of N degenerate states realized by space-time sheets of N-furcation, negentropic entanglement with N-fold degeneracy, hierarchy of Planck constants $\hbar_{eff}/\hbar = N$, and the idea about life as something in the intersection of real and p-adic worlds ($p = 1/N$ is rational number). Furthermore, the measurement of density matrix automatically leads to exact criticality. In dynamics without state function reduction criticality is approached only asymptotically. Note that in self-organized criticality [2] the criticality corresponds to a minimum of potential with some flat directions in which the situation is non-deterministic at criticality.

(e) Second law holds true also in TGD framework for (ordinary) matter, which is not negentropically entangled and is implied by the non-determinism of state function reduction at the level of thermodynamical ensemble. NMP however governs the quantal behaviour of dark matter crucial for the generation of negentropically entangled systems responsible for various representations as approximate invariants under quantum jumps (by NMP) and here negentropic entanglement enters the game. For some years ago I considered the pessimistic scenario [13] in which the negentropy assignable to negentropic entanglement is compensated by thermodynamical ensemble entropy. Experimentally the situation remains open since we do not have yet experimental methods to detect dark matter - and certainly not dark matter in the sense of TGD. At this moment only the evolution of intelligence and science itself could be seen as a support for optimistic scenario saving the Universe from eventual heat death.

2. *Renormalization group principle.* Thinning of degrees of freedom means reducing the measurement resolution and forgetting the un-necessary details. This gives rise to abstraction at the level of cognitive and sensory representations characterized by cognitive resolution. The higher the abstraction level, the more un-necessary details are dropped from the representation. This means that reflective consciousness has a hierarchical structure.

In TGD framework causal diamonds (CDs) within CDs define this kind of hierarchy characterized by spatial and temporal scales defining imbedding space correlate for the self hierarchy. Many-sheeted space-time serves as a geometric correlate for the hierarchical structure of consciousness.

p-Adic length scale hypothesis makes the hypothesis quantitative and means that continuous renormalization group evolution is replaced with a discrete p-adic coupling constant evolution. Finite measurement resolution implies effective discretization at space-time and imbedding space level.

Discretization is also forced by the notion of p-adic manifold [11], whose definition forces the introduction of finite length scale and angle resolutions having number theoretic interpretations. The common rational (or even some algebraic) points of real and p-adic space-time surfaces define the discrete cognitive representations at space-time level. One can say that life resides in the intersection of reality and various p-adicities.

3. *Self-organized criticality (SOC).* The sensitivity of sandpile to avalanches serves as an illustration for self-organized criticality (SOC [2])). A very elegant characterization of SOC is as a critical point which is an attractor but such that the matrix defined by the second order partial derivatives of potential function has non-maximal rank being thus non-invertible.

SOC inspires the notion of neuronal avalanche. Neuron groups form synchronically firing structures which end up to criticality. At criticality a fast increase of entropy takes place (the reduction of free energy per time is maximal: eat the food as fast as possible so that others do not steal it!). After this the system uploads the entropy to environment and generates negentropy for a while later compensated by entropy. There is evidence that a sequence of neural avalanches self-organize to avalanches in longer time scale. Temporal sequences of associations representing memories and predictions would be possible interpretation.

In TGD framework this picture has interpretation in terms of the basic fractal structure of quantum jump. In quantum jump negentropic entanglement is generated: NMP dictates this.

After this follows a cascade of quantum jumps (state function reductions for sub-CDs unless they are mutually negentropically entangled) and this generates ensemble entropy because the outcome of state function reduction for ordinary entanglement is random and takes entanglement entropy to zero. The process continues and certainly ceases when all sub-CDs have internal negentropic entanglement so that nothing can happen. At least after this the state function reduction to the opposite boundary of CD occurs. Whether second law is satisfied remains an open question as already noticed.

2.3   Operational architectonics of brain

This picture combined with the decomposition of local EEG to quasi-stationary segments leads to the notion of Operational architectonics of brain.

1. *Operational architectonics of brain (OA).* The hypothesis is that neuronal avalanches represent the primary building bricks of more complex brain activities. These more complex activities are constructed as operational modules (OM) from the elementary neuronal self organization patterns. This however requires synchronous firing of neurons and the challenge is to understand how this is physically possible if one assumes that disjoint regions of 3-space do not have any correlations.

   The spatiotemporal patterns of extracellular electric fields are assumed to be in 1-1 correspondence with phenomenal experiences. Authors introduce also the notion of operational space-time (OST) assumed to exist within internal physical space-time (IPST). These notions remain somewhat fuzzy in the framework of classical physics.

   The proposed architectonics is 4- rather than 3-dimensional. The notions of 4-D brain and causal diamond (CD) as 4-D spotlight of consciousness define the counterpart for OA in TGD framework. In TGD framework OST and IPST bring in mind p-adic and real variants magnetic body and the topological light rays parallel to them.

   Braiding of the short portions of flux tubes connecting bio-molecules (say tubulins and axonal membrane) serve as a geometric correlate for negentropic entanglement and negentropically entanglement subsystems give rise to various representations as "Akashic records", which can be read by interaction free measurement modified so that one obtains holographic representation of the data readable by using reference beam (see this [10]). The detectors in interaction free measurement correspond to the hologram substrate analogous to excitable lasers. The cyclotron Bose-Einstein condensates of dark matter with large value of $\hbar_{eff}/\hbar$ at the "long" portions of flux tubes and large flux sheets (with size scales exceeding even the Earth's radius) carry sensory and other representation as analogous of lasers excited in the reading of the representations.

2. *The decomposition of local EEG to quasi-stationary segments.* The proposal is that the sequences correspond to self-organization patterns for neuronal assemblies and serve as correlates simple qualia. The transitions between the quasi-stationary segments are sharp and the interpretation is as correlates for the above described phase transitions: they care referred to as rapid transitional processes (RTPs).

   In TGD framework EEG [6] serves as a control and communication tool for magnetic body using biological body as sensory receptor and motor instrument. There is a strong temptation to assign the quasi stationary segments of EEG to self-organization patterns assignable CDs with frequency scale in 1-1 correspondence with the scale of CD (discrete). The amplitude- and frequency modulation of the Josephson radiation emitted by cell membrane acting as Josephson junction would map neural activity to temporal patterns of EEG.

3. *Neuronal synchrony binding neuron groups to operational modules.* Authors have introduced the notion of operational synchrony (OS) to describe the needed synchrony. This synchrony should be visible in EEG channels as correlations of the quasi-stationary segments.

   In TGD context OMs would be formed and destroyed by the reconnection of magnetic flux tubes building different quantum coherent structures formed from neurons. For instance, patterns defining objects of the visual field could correspond to this kind of quantum coherent units. This process would take place in all living matter and ATP-ADP transformation could generate

standardized reconnection and negentropic entanglement between distant biomolecules. The basic function of metabolism would be production and modification of negentropic entanglement

3 About the notion of criticality in TGD framework

Criticality is one of the basic notions in Fingelkurts et al's model and has quantum criticality as TGD counterpart. As a matter of fact, quantum criticality is a fundamental physical principle of TGD dictating the classical and also quantum dynamics so that it deserves a separate discussion. The value of Kähler coupling strength - the only parameter of theory - is fixed as the analog of critical temperature. In order to characterize the critical degrees of freedom one must say something about the Kähler metric of "world of classical worlds" (WCW) [8].

Very roughly, WCW can be seen as a generalization of the loop space of string models or of the super-space of Wheeler consisting of 3-geometries. WCW consists of all 3-surfaces in the 8-D imbedding space $M^4 \times CP_2$. Holography due to 4-D general coordinate invariance implies that one can speak about WCW also as a space of 4-D space-time surfaces with space-time surface being analogous to Bohr orbit. The challenge is to generalize Einstein's geometrization of physics program and geometrize quantum physics by providing WCW with Kähler geometry for which the metric is characterized by single function, so called Kähler function, which by quantum classical correspondence corresponds to Kähler action for its Bohr orbit like preferred extremal. By infinite-dimensionality there are excellent hopes that this geometry is unique since this is the case already for loop spaces. The mere mathematical existence of this geometry requires infinite-D symmetries and for 4-D space-time one (but not for higher dimensions) can indeed generalize the conformal symmetries of super string model and achieve these symmetries. WCW becomes a union of infinite-dimensional symmetric spaces for which all points are geometrically equivalent. The zero modes labelling the symmetric spaces have interpretation as non-quantum fluctuating classical variables needed in quantum measurement theory.

Consider now what criticality means in this framework.

1. The matrix defined by the second order derivatives of Kähler function with respect to WCW coordinates is degenerate as is also the WCW Kähler metric defined by a subset of these derivatives ($G_{K\overline{L}} = \partial_K \partial_{\overline{L}} K$ is the defining formula of Kähler metric in complex coordinates in terms of Kähler function K).

   The reason for the degeneracy is that WCW metric depends on real zero mode coordinates, which do not appear as differentials in the line-element. These coordinate directions of WCW correspond to non-quantum fluctuating classical degrees of freedom not contributing to WCW Kähler metric. The proposed generalization of quantum measurement theory assumes that zero modes are analogous to classical variables defining say the position of a pointer of a measurement instrument and that they are in 1-1 correspondence with the outcomes of quantum measurements in quantum fluctuating degrees of freedom and give rise to quantum classical correspondence.

2. Quantum criticality would corresponds to a situation in which maximum of Kähler function (defining most probable space-time surface in their quantum superposistion) corresponds to a Kähler metric for which some elements of Kähler metric approach zero so that the rank for the matrix defined by the non-vanishing components of the Kähler metric is reduced. The resulting degrees of freedom would be effectively zero modes inside the critical manifold but not elsewhere. The criticalities would define an infinite hierarchy analogous to the finite hierarchy of criticalities for finite dimensional catastrophes Thom's catastrophe theory [1]: cusp catastrophe is the simplest non-trivial example.

3. At the level of conformal symmetry algebras [5] defining the infinite-dimensional symmetries of TGD Universe - call them with generic name A - this hierarchy could have very elegant representation. The elements of conformal algebra are labeled by integer plus other quantum numbers so that one can write the element of algebra $a_{n,\alpha}$. Critical sub-manifolds woud correspond to sub-spaces of WCW for which the elements $a_{nk,\alpha}$ of sub-algebra A_n (k is integer) annihilate the states or creates zero norm f states from them. Here n is a non-negative integer characterizing the critical manifold. Critical manifolds would be in 1-1 correspondence with non-negative integers n. If n_1 divides n_2, the critical manifold Cr_{n_2} belongs to Cr_{n_1}.

4. In the phase transitions between different critical manifolds some quantum fluctuating degrees of freedom become local zero modes in the sense that their contribution to WCW metric at a given point of WCW vanishes at criticality. Also the reverse transformation can take place.

There are some interesting questions to be answered.

1. Criticalities form a number theoretic hierarchy and primes define "prime criticalities". Does this mean that the primes dividing integer n define the possible p-adic topologies assignable to criticality defined by n?

2. The hierarchy of effective Planck constants is labelled by integers and giving integer n corresponds to n-furcation made possible by the failure of strict determinism for Kähler action. Could this integer correspond to the integer defining the criticality? Criticality is indeed accompanied by non-determinism realized as long range fluctuations.

3. Causal diamonds have size scales coming as integer multiples of CP_2 scale. Does this integer relate to the integer defining criticality?

4. The condition that the n characterizes finite measurement resolution in the sense A_n annihilates the physical states everywhere would delocalize the critical states outside the critical manifold. Does this mean that also finite measurement resolution is characterized by integer.

5. How the 4-D spin glass degeneracy due to the huge vacuum degeneracy of Kähler action implying breaking of strict determinism relates to quantum criticality?

These connections together with those suggested by NMP suggest that integer arithmetics is coded directly to the hierarchy of criticalities and is also basic characteristic of consciousness. This would give additional piece of support for the vision about physics as a generalized number theory [7].

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