QUANTUM SELF-ORGANIZATION THEORY WITH APPLICATIONS TO HYDRODYNAMICS AND THE SIMULTANEITY OF LOCAL CHAOS AND GLOBAL PARTICLE-LIKE BEHAVIOUR

M. DUDZIAK[1] and M. PITKÄNEN[2]

1 MODIS Corporation, Washington D.C. & Dept. of Physics, Moscow State University.

2 Dept. of Physics, University of Helsinki, Helsinki, Finland.

Abstract

There is evidence that self-organization processes can be regarded as iteration in the sense that a subsystem perceives the state of its complement and reacts to it, perhaps non-deterministically. This iterative structure leads automatically to the generation of fractal like structures as fixed points of iteration. The physical origin of this iterative structure is not well understood and one cannot exclude the possibility that some new physics is involved.

Quantum topological geometrodymamics (TGD) suggests identification of the basic iterative basic step in self-organization as quantum jump between quantum states identified as quantum histories (by the requirement of General Coordinate Invariance). One of the basic consequences of TGD is the manysheetedness of the spacetime representable as a surface in certain 8-dimensional space. The interaction between different spacetime sheets is mediated by "wormholes" (with size of order 10^4 Planck lengths) feeding gauge and gravitational fluxes between spacetime sheets. The p-adic length scale hypothesis, stating that certain p-adic primes are in physically favored position, leads to rather strong quantitative predictions about the size and relationships among entities in a given spacetime topology.

In this article the formulation of hydrodynamics in many-sheeted spacetime, hydrodynamical self-organization, the description of transition to turbulence and mechanisms of energy transfer between different spacetime sheets are considered from TGD point of view. The essential element of description is the failure of the hydrodynamic approximation below the p-adic length scale L_p giving minimum size for the particle at level p and the necessity to apply particle description below this length scale. The generalized concept of locality (TGD based physics is local in the configuration space containing 3-surfaces as its points) explains how it is possible to have locally chaotic behavior and global particle like behaviour simultaneously. Examples of this phenomenon are hydrodynamic and also aerodynamic vortices such as hurricanes and typhoons.

Classical modelling of asynchronous and synchronous behavior in heterogenous oscillator networks such as may be used to represent large-scale hydrodynamic or aerodynamic events has tended to focus upon deterministic phase synchronization among neighboring elements and the development of cluster formation. The role of a quantum topological principle has been generally overlooked since the macroscopic scale has been understood to be ontologically different from the near-Planck scale. TGD suggests different approach and opens the door to the possibility that many interesting cooperative network phenomena may have an underlying quantum topological mechanism which is approximated by such classical models as the synchronization of nonequilibrium networks through simple period signals.

Keywords

Chaos, self-organization, co-operativity, criticality, iteration, fractals, synchronization, quantum jump, quantum entanglement, negentropy, quantum coherence, hydrodynamics, turbulence, energy transfer mechanisms.

[1]Chairman and Chief Scientist, mdudziak@silicond.com, (804) 329-8704, (804) 329-1454

[2]Dept. of Physics, University of Helsinki, Helsinki, Finland, matpitka@rock.helsinki.fi

1 INTRODUCTION

In topological geometrodynamics [Pitkänen$_1$,1995] approach to the unification of the fundamental interactions, spacetime is replaced by a surface of 8-dimensional space $H = M^4_+ \times CP_2$, where M^4_+ is the interior of the future light cone of 4-dimensional Minkowski space and CP_2 is complex projective space with real dimension four. TGD:eish spacetime can be regarded as a manysheeted surface. The distances between parallel sheets are extremely small, of the order of CP_2 size R about 10^4 Planck lengths. Sheets have a finite size and outer boundary and form a hierarchical structure ordered by the typical size of the sheet. Spacetime sheet is identified as a geometric representations of a material object so that 'matter' (in the sense of 'res extensa') reduces to spacetime topology in TGD. Elementary particles correspond to surfaces with size of order R, which have suffered topological condensation ('gluing' by topological sum contact) to a larger spacetime sheet.

The construction of quantum TGD relies on the hypothesis that quantum theory reduces to the spinor geometry of the infinite-dimensional configuration space consisting of all possible 3-surfaces in H. Physical states correspond to the modes of the (purely classical) configuration space spinor field. Basic features of quantum TGD are quantum criticality, which suggests the existence of macroscopic quantum systems in all length scales, and spin-glass analogy which suggests that the TGD:eish counterpart of energy landscape possesses ultrametric topology, which is p-adic [Pitkänen$_2$,1995] (there is infinite series of p-adic number fields R_p, p prime). Ultrametric norm satisfies $N(x+y) \leq Max\{N(x), N(y)\}$ rather than $N(x+y) \leq N(x) + N(y)$ satisfied by the real norm: this implies that p-adic numbers are not well ordered like reals. A stronger hypothesis is that also effective quantum average spacetime can be endowed with effective p-adic topology. The so called p-adic length scale hypothesis states that p-adic primes $p \simeq 2^k$, k power of prime, are physically especially interesting and leads to a very successful model for the massivation of elementary particles based on p-adic thermodynamics in Super Virasoro algebra: p-adic length scales associated with p is given by $L(p) = \sqrt{p}l$, $l \simeq 1.288 \times 10^4\sqrt{G}$ ($\sqrt{G}$ denotes Planck length) and there are not too many p-adic length scales between CP_2 length scale l and cosmological length scale.

An essential element of quantum TGD is the generalization of the quantum measurement theory provided by the so called strong form of Negentropy Maximization Principle (NMP). General Coordinate Invariance forces the identification of quantum states as entire quantum histories and state function collapse can be identified as a quantum jump between quantum histories. In this manner one avoids the basic paradox related to the nondeterminism of the state function collapse contra determinism of the Schrödinger equation. NMP states that quantum jump for a given subsystem leads to a state which corresponds to a minimum of entanglement entropy: this state corresponds to an eigenstate of subsystem's density matrix, which can be therefore regarded as a universal observable measured in the quantum jump. Strong NMP states that in a given quantum state, the subsystem (or of one of the subsystems) giving rise to maximum negentropy gain, can make quantum jump. Subsystem is defined as time=constant section of the quantum history so that one can associate definite value of time to the quantum jump. What strong NMP (or rather its p-adic version) says is that the most quantum entangled subsystem makes the quantum jump. The principle favours the generation of quantum entanglement and hence of entropy so that the second law of thermodynamics can be understood as a consequence of strong NMP.

Quantum TGD leads to a quantum theory of self-organization. There are good reasons to believe that the fundamental element of self-organization is essentially iteration at very general level leading to the formation of fractal patterns as the fixed point of the iteration process. The basic features of this iteration step are the interaction of some subsystem with its complement followed by a possibly nondeterministic reaction. Clearly, quantum jump is an excellent candidate for the fundamental iterative step of self organization. Strong form of NMP selects the subsystem which in a given quantum state can perform the quantum jump and implies that entanglement feed (implying entanglement entropy feed) is a necessary prequisite of self-organization.

Biosystems and hydrodynamical systems provide especially interesting potential applications of the many-sheeted spacetime concept, p-adic length scale hypothesis and quantum theory of self-organization. On the order of hydrodynamic phenomena, the many-sheeted spacetime concept forces to replace hydrodynamics with a hierarchy of hydrodynamics, one for each spacetime sheet. At given spacetime sheet, characterized by a p-adic prime p, particles have size not smaller than p-adic length scale and p-adic length scale gives natural cutoff length scale below which hydrodynamic approximation fails. p-Adic length scale hierarchy leads to testable predictions since p-adic length scales should manifest themselves in the properties of the hydrodynamic flow involving several p-adic length scales: in particular, turbulent flow should exhibit large number of p-adic length scales. In particular, TGD suggests energy and angular momentum transfer mechanisms between different spacetime sheets: these should play important role in biology. Quantum theory of self-organization suggests that self-organization in even, say Benard flow, should occur basically via quantum jumps and provided there is entanglement entropy feed to the system. This is certainly in conflict with the standard belief about the unimportance of quantum effects in macroscopic physics. As a matter fact, quantum entanglement might provide the royal road to the understanding of the biosystems as macroscopic quantum systems (see the last parts of [Pitkänen$_1$,1995] and [Pitkänen$_2$,1995] and the articles about TGD inspired theory of biosystems [Pitkänen$_5$,1998]).

Neural systems in particular, including both biological and artificial neural networks, have generally been modelled through purely classical network dynamics. However the problem of synchronization and self-organization, while shown [Dudziak, 1993; Chinarov and Gergely, 1997; Chinarov and Gergely, 1998] to be addressable by periodic input signals and the introduction of mean-field and nearest-neighbor couplings including variants of simple cosine interactions, does not receive an explanation for the emergence and development of particular pathways and structures for such signaling and couplings, particularly between widely separated and seemingly disparate regions of a larger topology (e.g., the brain).

Note: the units used in the sequel will be $\hbar = 1, c = 1$.

2 BRIEF INTRODUCTION TO TGD

TGD [Pitkänen$_1$,1995, Pitkänen$_2$,1995] was born about twenty years ago as an attempt to solve the so called energy problem of General Relativity by assuming that the physically allowed spacetimes are representable as 4-dimensional surfaces in certain 8-dimensional spacetime. Quite soon it became clear that TGD could also be regarded as a generalization of the old-fashioned hadronic string model obtained by replacing 1-dimensional strings with 3-dimensional surfaces. It took several years to unify these completely disparate looking approaches and this required a radical generalization of the concept of 3-space.

2.1 How to enter TGD from the energy problem of GRT?

The basic hypothesis of General Relativity is that the presence of matter makes spacetime curved. This idea however leads to difficulties with the well tested deep ideas about symmetries since the the translational symmetries of the Minkowski space giving rise to the conservation of four-momentum are lost.

There is a manner to circumvent the energy problem. Assume that spacetime is representable as a 4-dimensional surface of some higher-dimensional spacetime $H = M^4 \times S$ obtained by replacing every point of the empty Minkowski spacetime M^4 with an N-dimensional space S with a very small size (of order Planck length which corresponds to about 10^{-35} meters). This space possesses the symmetries of the empty Minkowski space plus some

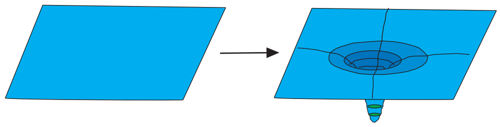

Figure 1: Gravitation makes spacetime curved and leads to a loss of translational symmetries in GRT.

additional symmetries, namely those of S. This suggests the existence of a theory for which spacetime is a 4-dimensional surface of H determined by field equations which allow the symmetries of H as symmetries. This would mean a solution of the energy problem since energy would now correspond to time translations of H rather than of 4-dimensional spacetime as in General Relativity.

As a by product one obtains also additional symmetries: namely those of S and identifying these symmetries as color symmetries characteristic for quarks and gluons, one can identify S uniquely as so called complex projective space $S = CP_2$ having dimension four so that the space H is 8-dimensional and theory becomes unique. For cosmological and mathematical reasons one is forced to replace M^4 by (interior of) the future light cone of M^4, to be denoted by M^4_+: M^4_+ corresponds to empty Robertson-Walker cosmology.

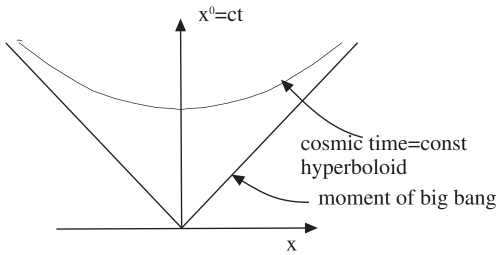

Figure 2: Geometry of the future lightcone M^4_+.

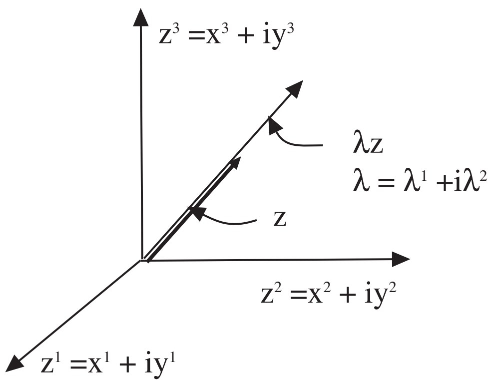

Figure 3: CP_2 as a complex projective space of real dimension 4.

Sub-manifold geometry leads to a natural geometrization of gauge fields and quantum numbers. Induction procedure for the metric means that distances in spacetime surface are measured using the meter sticks of the imbedding space. In case of the gauge fields induction means that parallel translation is performed using the parallel translation defined by the spinor connection of the imbedding space. The requirement that electroweak gauge structure results fixes the space S uniquely to $S = CP_2$. Also the geometrization of known elementary particle quantum numbers results.

2.2 TGD:eish spacetime concept

One can enter up with TGD also as a generalization of the old fashioned hadronic string model by generalizing the description of hadrons as strings having quarks at their ends with the description of particles as small 3-surfaces X^3 containing quantum numbers at their boundaries. This leads to a topological explanation of the family replication phenomenon and makes it possible to explain the known elementary particle quantum numbers in terms of H-geometry. The TGD resulting from the generalization of string is however quite different from the TGD resulting as a solution of the energy problem of GRT.

The only manner to unify these two TGD:s is provided by a generalization of the spacetime concept. The macroscopic spacetime with matter is identified as a many-sheeted surface with hierarchical structure. There are sheets glued on larger sheets glued on larger sheets..... Each sheet has outer boundary and material objects are identified as spacetime sheets. Gluing is performed by topological sum operation connecting different spacetime sheets by very tiny wormholes with size of order CP_2 radius. Wormholes reside near the boundaries of a given spacetime sheet and they feed various gauge fluxes to the larger spacetime sheet (external world from the view point of the smaller spacetime sheet). Elementary particles correspond to so called CP_2 type extremals, which have Euclidian metric and negative finite action and have very much the same role in TGD as blackholes in GRT.

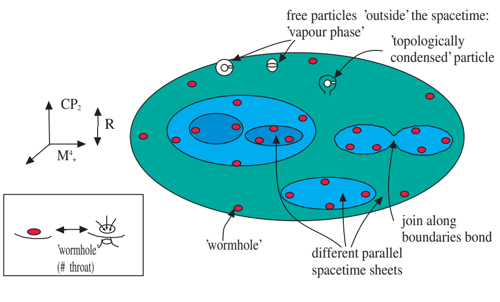

Figure 4: Topological condensate and vapour phase: two-dimensional visualization.

2.3 Quantum TGD very briefly

The construction of quantum TGD reduces to the construction of spinor geometry for the infinite-dimensional configuration space CH of TGD consisting of 3-dimensional surfaces in the 8-dimensional space $M^4_+ \times CP_2$ (for details see the first two parts of [Pitkänen$_1$,1995]) This means the construction of the metric and spinor structure. Quite general physical requirements lead to the conclusion that the geometry of CH must be so called Kähler geometry[1] allowing complex structure in its tangent space. The construction of the CH metric reduces to that of identifying the so called Kähler function $K(X^3)$ as a functional of 3-surface. The construction of the gamma matrices associated with the spinor structure reduces to the second quantization of free induced spinor fields on spacetime surface: anticommuting gamma matrices are superpositions of anticommuting fermionic oscillator operators.

2.3.1 General Coordinate Invariance

The basic physical requirement is 4-dimensional General Coordinate Invariance. This can be realized provided that the Kähler function associates to a given 3-surface X^3 appearing as its argument a unique spacetime surface $X^4(X^3)$ for 4-dimensional diffeomorphisms to act on. This spacetime surface could be called the classical spacetime associated with given 3-surface. A very convincing guess for the Kähler function $K(X^3)$ is as the absolute minimum of so called Kähler action for all spacetime surfaces going 'through' X^3. A good analogy are the membranes going through a wire: one of them provides the surface with minimum area passing through the wire.

2.3.2 Quantum criticality

Kähler action involves only one a priori free parameter, the so called Kähler coupling strength α_K, and the fact that vacuum functional is precisely analogous to the partition function of a critical system with Kähler coupling strength in the role of temperature suggests that the physical theory corresponds to a critical value of the Kähler coupling strength. An important prediction is the existence of long range quantum correlations in all length scales: this suggests that TGD could provide the mechanisms needed for understanding biosystems as macroscopic

[1] Annihilation and creation operators are the quintessence of quantum field theory. Kähler structure in the configuration space of 3-surfaces geometrizes this concept. In Kähler geometry imaginary unit i is geometrically realized as an antisymmetric tensor, so called Kähler form J, whose square is -1, 1 being realized as the metric tensor. Physically Kähler form behaves like sourceless Maxwell field. The simplest example of Kähler geometry is two-dimensional (q,p)- phase space for one-dimensional harmonic oscillator regarded as a complex plane with complex coordinate (z=q+ip).

quantum systems.

2.3.3 Super Virasoro symmetry and spin glass analogy

Configuration space geometry is fixed by symmetry considerations and the by the requirement of divergence cancellation (recall that the situation is infinite-dimensional!) to a very high degree. Super Virasoro and Super Kac Moody symmetries of the string models generalize and play absolutely essential role in the construction. The construction works only for $M^4_+ \times S$, where S is four-dimensional Kähler manifold. This is due to the very special conformal properties of the 4-dimensional light cone boundary (the moment of the big bang). 8-dimensionality is in turn necessary in order to construct spinor structure: all boils down to the observation that only in 8-dimensional case the number of spinor components of a fixed chirality is the same as the dimension of the space itself. Super Virasoro invariance dictates the mass spectrum of the theory as well and S-matrix can be regarded as an exponential of a Hamiltonian, which is just Super Virasoro generator L_0.

A central role in the construction is played by the precise mathematical analogy with the spin glass phase, which implies the existence of an infinite number of zero modes, whose coordinates do not appear at all in the line element defining the Riemannian metric of CH. Zero modes characterize the shape and size of 3-surface and the induced Kähler field on 3-surface. The zero modes, which are genuinely TGD:eish phenomenon, can be identified as TGD counterpart for the order parameter appearing in the theory of self-organization based on non-equilibrium thermodynamics [Haken, 1988]. The basic consequence of spin glass analogy is ultrametricity of the generalized energy landscape [Parisi, 1992], which in turn leads to the hypothesis that effective spacetime topology is p-adic.

2.3.4 The concept of quantum average effective spacetime

The concept of the 'quantum average effective spacetime' is crucial for relating the theory to QFT description. The exponent $exp(K/2)$ of the Kähler function, analogous to oscillator Gaussian, defines a unique vacuum functional for the theory. The maxima of the Kähler function with respect to non-zero modes as function of zero modes can be identified as 'effective spacetimes', whose dynamics is dictated by the absolute minimization of Kähler action so that the 'effective action' defining the low energy limit of the theory only selects some of the maxima of the Kähler function. The hypothesis that the maximum of the Kähler function as a function of zero modes is p-adic fractal [Pitkänen$_2$,1995] is motivated by criticality and spin glass analogy and leads to the long sought for connnection between quantum TGD and p-adic TGD (, which leads to very succesfull predictions of elementary particle masses [Pitkänen$_2$, 1995]).

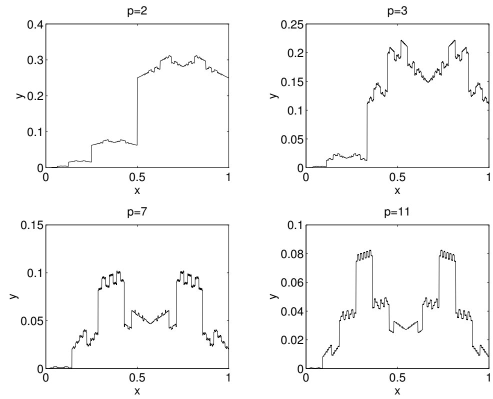

Figure 5: The p-adic fractal defined by p-adically analytic function $f(x) = x^2$ by the formula $f](x) = I \circ \hat{f} \circ I^(-1)(x)$ where I is so called canonical identification $I : \sum x_n p^n \rightarrow \sum_n x_n p^{-n}$ mapping p-adics to reals.

If the effects related to the induced metric (classical gravitation) are neglected the canonical transformations of CP_2 act as $U(1)$ gauge symmetries and all canonically related surfaces are physically equivalent. Gravitation however breaks this gauge invariance but due to the extreme weakness of the gravitational interaction one has good reasons to expect that the maxima of Kähler function for given values of the zero modes are highly degenerate. This means that the classical effective spacetime surface is not unique but one must consider quantum superposition of several effective spacetimes just like in wave mechanics electron can exist in several places simultaneously. This leads to a generalization of the catastrophe theory [Zeeman,1977] to the infinite-dimensional configuration space context with zero modes playing the role of the control parameters and nonzero modes playing the role of the state variables. Also a connection with the nonequilibrium thermodynamics of Haken [Haken,1988] and with Penrose-Hameroff picture [Penrose and Hameroff,1996] emerges.

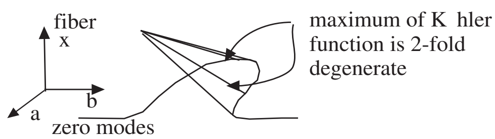

Figure 6: Cusp-catastrophe. Control parameters a and b correspond to zero modes and statevariable x corresponds to non-zero modes in TGD context.

2.4 p-Adic length scale hypothesis

p-Adic length scale hypothesis [Pitkänen$_2$,1995] states that to a given p-adic prime p there corresponds a p-adic length scale $L_p = \sqrt{p}l$, $l \simeq 1.288 \times 10^4\sqrt{G}$ ($\sqrt{G}$ denotes Planck length) and that physically favoured primes correspond to $p \simeq 2^k$, k power of prime. The justification for the first part of the hypothesis comes from Uncertainty Principle and from the p-adic mass calculations predicting that the mass of elementary particle, resulting from the mixing of massless states with $10^{-4}m_{Planck}$ mass states described by p-adic thermodynamics, is of order $1/L_p$ for the light states. The justification for the preferred values of p comes from elementary particle blackhole analogy (see the chapter 'Physical building blocks' of [Pitkänen$_2$,1995]) generalizing the Bekenstein-Hawking area-entropy law to apply to the elementary particle horizon defined as the surface at which the Euclidian signature for the so called CP_2 type extremal describing elementary particle changes to the Minkowskian signature of the background spacetime at which elementary particle has suffered topological condensation.

It is natural to postulate that spacetime sheets form a hierarchy with respect to p in the sense that the lower bound for the size of the spacetime sheets at level p is of order L_p and that $p_1 < p_2$ sheets condensed on p_2 sheets behave like particles on sheet p_2. Furthermore, there are good arguments in favour of the hypothesis stating that spacetime sheets have effective p-adic topology below the length scale L_p and that real topology applies above resolution L_p.

The following table lists the p-adic length scales L_p, $p \simeq 2^k$, k power or prime, which might be interesting as far as condensed matter is considered (the notation $L(k)$ will be used instead of L_p). It must be emphasized that the definition of length the scale is bound to contain some unkown numerical factor K: the requirement that the thickness of cell membrane corresponds to $L(151)$ fixes the proportionality coefficient K to $K \simeq 1.1$.

k	127	131	137	139	149
$L_p/10^{-10}m$	.020	.082	.65	1.3	42.0
k	151	157	163	167	169
$L_p/10^{-7}m$	.083	.67	5.3	21	42
k	173	179	181	191	193
$L_p/10^{-3}m$	.0017	.14	.28	8.9	17.8

Table 1. p-Adic length scales $L_p = 2^{k-127}L(127)$, $p \simeq 2^k$, $L(127) \equiv \frac{\pi\sqrt{5+Y}}{m_e}$, $Y = .0317$, k power of prime, possibly relevant to condensed matter physics.

The existence of classical Z^0 fields analogous to electromagnetic fields are almost unavoidable prediction of TGD and implies a lot of new physics even in condensed matter length scales and the related mathematical and physical constraints fix the structure of the many-sheeted spacetime to very high degree. These constraints are discussed in detail in part V of [Pitkänen$_2$,1995] and shown to lead to rather nontrivial predictions both in nuclear and condensed matter physics. Classical Z^0 force is predicted to be important in biology and hydrodynamics: for instance, chirality selection in biosystems has an explanation based on classical Z^0 force.

2.5 The role of 'wormholes'

The interaction between spacetime sheets is mediated by the the extremely tiny 'wormholes' having size of order CP_2 radius R and located near the boundaries of the smaller spacetime sheet. Wormholes feed the electromagnetic, Z^0 and gravitational gauge fluxes from the smaller spacetimesheet to the larger one (say from the atomic sheet to some molecular sheet). p-Adic considerations suggest that wormholes are light having mass of order $1/L_p$: this implies that they suffer Bose-Einstein condensation on the ground state. One could even say that spacetime sheets 'perceive' the external world with the help of the charged wormhole BE condensates near their boundaries. TGD suggests a model of nerve pulse and EEG based on Josephson junction formed by the wormhole BE condensates associated with the lipid layers of the cell membrane (see the chapter 'TGD inspired model of EEG and nervepulse' of [Pitkänen$_1$,1995]). Josephson junctions are known to be self-organizing systems. The gradual generation of phase coherence makes in this case possible the coherent oscillations of entanglement making possible the self-organizing quantum jumps. Coherent light is also a school example of self-organization [Haken,1988] and is predicted to be emitted by linear bio-structures, such as microtubules and possibly also DNA (see the chapter 'Microtubules as quantum antennas' of [Pitkänen$_1$,1995]).

Wormholes provide a very general mechanism making possible the transfer of classical electromagnetic fields and various quantum numbers such as energy, momentum and angular momentum, between different spacetime sheets. Besides biosystems also hydrodynamical systems provide promising applications for TGD based concepts.

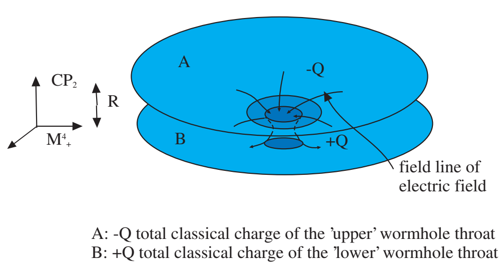

Figure 7: Wormholes feed the gauge fluxes from smaller to larger spacetime sheets and viceversa.

3 QUANTUM THEORY OF SELF-ORGANIZATION

Self-organization [Haken,1988] is closely related to the generation of fractal patterns and the book of Barnsley [Barnsley,1988] about fractals gives rather convincing arguments supporting the belief that fractals are fixed points of iteration. The space in which fixed point exists is rather abstract: typically it belongs to the set of subsets of some space, say, 3-dimensional Euclidian space. This fixed point can be a landscape, biosystem, ecological population, hydrodynamical flow,... For instance, the success of this receipe in reproducing even a virtual photo of a forest is amazing [Barnsley,1988]. Even evolution could be regarded as resulting from this kind of iterative process leading gradually to a fixed point.

There is no obvious manner how this iteration could result from the equations of the classical physics. TGD suggests that the quantum jump between different quantum histories could be the fundamental iteration step [Pitkänen$_3$,1997, Pitkänen$_4$,1998]! Furthermore, the strong form of Negentropy Maximization Principle (NMP) tells that in a given quantum state only, only (one of) the subsystem(s) possessing largest entanglement entropy can perform the quantum jump. Therefore strong NMP predicts that self organization and fractalization can occur only for open systems fed by (entanglement) entropy.

3.1 Iteration as a basic step in self-organization

Iteration, understood in a very general sense, seems to be the basic element of self-organization. A good example is provided by cellular automata (game of life is the best known example). Cellular automaton consists of cells, which perceive their surroundings and perform a decision to change their state according to some rule. Rule need not be deterministic but the dynamics dictated by it is irreversible. This is what makes it so difficult to understand how iteration might result from the reversible equations of physics and suggests that thermodynamics or some deeper principle underlying thermodynamics is important.

Second example is camera, which monitors tv screen to which the picture taken by the camera is fed back. This system exhibits typical self-organization patterns obtained by varying the direction angle of the camera with respect to the TV screen. Iteration is rather abstract process now: camera perceives the state of tv and reacts by sending a new picture to the TV screen.

Benard convection is a third standard example of self-organization. When liquid is heated evenly from below, a temperature gradient develops and at some critical value of the temperature gradient, convection sets on. A flow pattern consisting of liquid cells is formed. The size and shape of cell as well as the pattern of the liquid motion in the cell depends on the parameters charactering the situation (size and shape of the liquid vessel, the temperature difference,...). As temperature difference increases, more complicated flow patterns emerge: what happens is essentially that patterns of larger scale coherent motion emerge by the organization of the Benard cells to larger units.

Biosystems provide more complicated examples of self-organization. In this case self-organization has many hierarchical levels. First DNA and proteins together with genetic code are formed by self-organization at the molecular level, at some stage come monocellulars, multicellulars,..., individuals, families, social organizations,... Clearly, the subsystems of the previous level combine to form larger coherent subsystems at the higher levels of self-organization.

3.2 Quantum jump as the basic iterative step in self-organization

The common feature of the self-organizing systems is the decomposition into subsystems as a result of self-organization. Subsystem perceives the state of the external world and reacts to it. The active subsystem need not be the same in subsequent iteration steps unless one formally regards the entire system as the reacting system. Human society is a typical example in which individuals or groups of them perceive and react.

Category theory has been applied in particular to biological systems by Rosen [Rosen, 1991] and others in an attempt to model a non-mechanistic, non-reductionist conception of biological systems and their interactions at different scales of magnitude but also different scales of action. A network thermodynamic approach to cellular and cell membrane processes in fact, though purely classical in its dynamics, has been developed within theoretical biology [Mikulecky, 1993] and this increasingly points to a view that distinguishes complexity and cross-scalar interactions of a non-algorithmic nature that can at best and for precisely bounded examples be modeled with sufficient approximation by classical deterministic formalisms [Kampis, 1991].

Is it the iterative step that is in some fashion "self-modifying" in that the next state in the evolution of a process of a reacting system is influenced not by the same set of factors or parameters in a strict linear historical evolution but by consequences that are fundamentally entangled or superposed. In other words, the micro-history may be said to change, and the very model of cause and effect, in the sense of specific and linear connectivity, may need to be modified to incorporate what Rosen and others term a component model of systems evolution and self-organization, the components being inseparable but partially distinguishable "views" of the larger system from a particular perspective and quite importantly from a particular scale of observation and measurement.

What is being suggested is that the measurement process is not only fundamental but decisive in the sense that the system future and all discussion of self-organization actually revolve around non-deterministic changes or shifts in measureable state-values by a subsystem of the environment (related subsystem components) around it. The parameters that are or can be measured are determined by the collective interactions of the neighboring components in the larger system of which one measuring subsystem (component) is a member. This begins to take on the appearance of a collective, population-driven type of problem, one for which the societal metaphor is more than just a metaphor.

This suggests that the fundamental iteration step is actually quantum jump: in a given quantum state the subsystem possessing largest quantum entanglement, performs quantum measurement and as a consequence, jumps to a new state, which is an eigenstate of the density matrix. In TGD context this new state corresponds to a new quantum history, say a new solution to the equations of hydrodynamics in Benard convection. Quantum jump is clearly a 'social' process: subsystem perceives (quantum measures) the external world and reacts to it. Subsystem can in principle be any subystem of the entire system so that the scenario is considerably more general than cellular automaton. The process can also create a subsystem such as Benard cell in Benard convection or a cell in biological evolution. Evolution of larger subsystems is possible: for instance, the quantum entanglements for a large ensemble of subsystems could oscillate coherently making possible quantum jumps of the entire ensemble at the maxima of the entanglement and give rise to quantum clock. Although quantum jump itself is nondeterministic, quantum statistical determinism implies that self-organization patterns are predictable at the limit of a large number of subsystems: at the level of the large subsystems there is always non-predictability involved.

3.3 Co-operativity, long range correlations and quantum entanglement

The generation of the long range order is one of the basic characters of the self-organized systems (the formation of Benard cells in Benard convection, the formation of Taylor's vortex belts in the rotation of a cylinder containing fluid, concentration patterns in Belounow-Zabotinsky reaction). In Benard convection the long range order corresponds to the formation of the Benard cells, whose size and shape depend on the temperature difference and the size and the shape of the vessel. The TGD based explanation of co-operativity could involve both quantum entanglement and manysheeted spacetime concept forcing the generalization of the particle concept. For instance, in Benard convection heating could create quantum entanglement between distant fluid particles.

Co-operativity is especially important feature of biosystems. One could even consider the possibility that the fundamental reason for why replication (and pairing process!) occurs in biosystems is that replication creates quantum entangled systems just like the annihilation of photon creates a quantum entangled pair of charged particles.

3.4 Necessity of entropy feed and strong NMP

Essential for the self-organization is external *entropy* feed as paradoxal as the latter statement might sound (Benard convection and even the general intuition about biosystems as systems living at the boundary between chaos and order). This can be understood on basis of strong NMP, which implies the second law of thermodynamics among other things. Strong NMP tells that in a given quantum state the subsystem with maximum entanglement entropy performs the quantum jump (perception+ reaction). In absence of entropy (entanglement) feed, the generation of quantum entanglement occurs slowly if at all and subsystems do not get the opportunity to perceive and react and iterative process is not possible. In presence of entropy (entanglement) feed, the situation changes and the system gets an opportunity to self-organize.

The same principle applies in case of brain. Metabolism represents the entropy feed generating quantum entanglement making possible quantum jumps and leading to the iterative process leading to self-organized fractal patterns.

4 HYDRODYNAMICS IN MANY-SHEETED SPACETIME

The application of the quantum theory of self-organization, manysheeted spacetime concept and p-adic length scale hypothesis to hydrodynamics are considered in the sequel.

4.1 Hierarchy of hydrodynamics

In TGD framework, hydrodynamics (and also thermodynamics) generalizes to a hierarchy of hydrodynamics, one for each spacetime sheet labeled by the powers of primes $k = 131, 137, 139, \ldots$. The sheets of 3-space, which can be regarded the basic units of flow (say vortices) at a given p-adic length scale appear as particles at larger spacetime sheets. The motion of the smaller spacetime sheets condensed on a sheet of a given size can in turn be described hydrodynamically under some circumstances. Of course, the system can behave as a liquid at sheet k_1, as a gas at sheet k_2 and and as a solid at sheet

k_3,... Liquid-crystals might be regarded as an example of this kind of multiphase behaviour.

The p-adic length scale $L(k)$ is a good guess for a minimum size of a particle at level k. Basic units of this size can combine to form larger units by the formation of join along boundaries bonds: this corresponds to the formation of chemical bonds in atomic length scales. The formation of the join along boundaries bonds provides a concrete realization for the quantum criticality of TGD predicting quantum coherent subsystems of all possible sizes. This criticality might be the most important feature of water making it ideal element as far as the formation of macroscopic quantum systems is considered. The failure of the hydrodynamic approximation below the p-adic length scale is obvious. Hydrodynamics applies when the number of spacetime sheets condensed on a given spacetime sheet is large enough. p-Adic length scale hierarchy suggests scaling laws for the parameters characterizing hydrodynamics. In particular, viscosity should satisfy appropriate scaling law (see the chapter 'TGD and condensed matter physics' of [Pitkänen$_2$,1995]).

An important element is certain degree of nonlocality crucial for understanding self-organization phenomena. In TGD, the spacetime locality of the standard quantum physics is replaced by a locality in the infinite-dimensional space of 3-surfaces, in which single 3-surface becomes a point. Hence, even at the level of hydrodynamics, the structures of the flow behave as genuine quantum particles in the zero mode degrees of freedom characterizing among other things the size and shape of the 3-surface. Good examples of hydro- and aero-dynamic particles are vortices, hurricanes and tornados. The hydrodynamic flow for the aerodynamical particles condensed on 'hurricane spacetime sheet' is chaotic but the hurricane itself behaves like a coherent dynamical unit.

The detailed study of simple imbeddings of electromagnetic and Z^0 gauge fields (see chapter 'Macroscopic quantum phenomena and CP_2 geometry' of [Pitkänen$_1$,1995]) as induced gauge fields leads to a conclusion that spacetime sheets, 'topological field quanta', are typically characterized by a handfull of vacuum quantum numbers characterizing the dependence of the phase of the two CP_2 complex coordinates on spacetime coordinates. Two frequency- and momentum type quantum numbers and two angular momentum type quantum numbers appear. Ordinary hydrodynamics corresponds to the large vacuum quantum number limit and super fluidity to small quantum number limit of the theory (see the chapter 'Hydrodynamics and CP_2 geometry' of [Pitkänen$_1$,1995]. Also the Z^0 magnetic and magnetic fluxes are define analogous and closely related quantum numbers since spacetime topology is in general multiply connected in TGD.

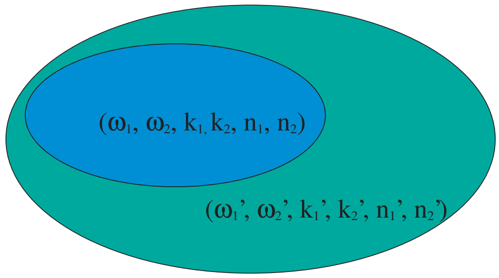

Figure 8: Topological field quantization: spacetime sheets are characterized by frequency, momentum and angular momentum like quantum numbers.

4.2 Hydrodynamical self-organization

The basic claim is that without quantum jumps, the equations of hydrodynamics could *never* give rise to the self-organized pattern of, say Benard flow. Spacetime sheets form in a natural manner master-slave hierarchy with respect to the p-adic length and time scales: short length scale motion adopts its behaviour to the slow dynamics of external world represented by spacetime sheets with larger values of the p-adic prime p. p-Adic length scale hypothesis together with the expected scaling laws means that master-slave hierarchy in principle allows to deduce rather precise quantititative predictions. An example of hydrodynamic self-organization is provided by Benard flow. In this case the heat source below the liquid vessel induces heat flow and corresponding feed of quantum entanglement to the system and self-organization occurs as a consequence.

In TGD picture chaotic behaviour should result at the limit when entanglement (entropy) feed becomes very large. The large entropy feed involved should cause chaoticity although quantum jumps would still occur. For instance, in the transition to hydrodynamic turbulence entanglement feed/energy feed increases and leads to the larger entropy and generates gradually chaotic flow. In accordance with strong NMP, the increase of entanglement feed makes possible the formation of quantum entangled systems of increasingly larger size and characteristic time scale of dynamics and it is tempting to interpret each period doubling bifurcation as an emergence of a larger unit of flow with a larger characteristic time scale. It might be possible to relate the appearence of the time scales related by powers of two to p-adic length scale hypothesis which also predicts that physically interesting length scales correspond to certain powers of two. One must however notice that the mere presence of iteration process could explain period doubling. In the chapter 'Hydrodynamics and CP_2 geometry' of [Pitkänen$_1$,1995], a model for the generation of hydrodynamic turbulence based on the decay of hydrodynamics vortices is considered quantitatively: the model does not involve either p-adic length scale hypothesis nor self-organization ideas and is certainly only a partial description but gives an idea about what it is involved.

4.3 Energy transfer mechanisms

Hydrodynamic dissipation must correspond to the transfer of energy from the hydrodynamical flow at larger p-adic length scales to thermal energy at atomic length scales. The basic dissipation mechanism at level p is the collision of two sheets of 3-space (particles) at level p leading to the transfer of kinetic energy of these particles to the kinetic energy of the smaller spacetime sheets p_1 condensed on sheets p. In this manner the energy is gradually fed from longer to shorter p-adic length scales where it is eventually transformed to radiation energy and to the thermal energy of atoms and molecules.

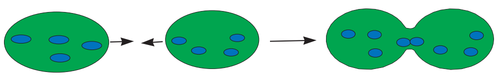

Figure 9: Energy dissipation by collisions of spacetime sheets leading to the transfer of kinetic energy from given p-adic length scale to shorter p-adic length scales.

The transfer of angular momentum and energy via the penetration of Z^0 and ordinary magnetic fields from sheet p to $p_1 \leq p$ via wormholes is also possible. The penetration can take place either by the induction of charged wormhole currents near the boundaries of the condensed sheet of 3-space (this could occur in super conductors of type I) or by the formation of wormholes feeding quantized magnetic flux (this could occur in superconductors of type II).

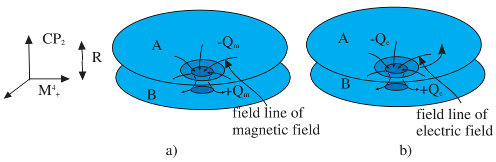

Figure 10: Magnetic field can penetrate from spacetime sheet to another one either a) through magnetically charged wormhole contacts or b) with the help of the wormhole currents.

In biosystems also the mechanisms of energy transfer from molecular length scales to larger p-adic length scales are important and should be crucial for understanding how the metabolic energy is consumed. A possible mechanism is the interaction of charged particles (electrons) of the atomic spacetime sheet with the charged wormholes, whose motion in turn generates emf:s on larger spacetime sheets. The coupling of the charged wormholes on the geometry of the boundary of the spacetime sheet makes possible the control of the shape and size of the biosystem by electrons (see the chapter 'TGD and biosystems' of [Pitkänen$_1$,1995]).

4.4 Tests

There are several tests for the proposed rather speculative picture.

a) *The concept of manysheeted spacetime and p-adic length scale hypothesis.* The successful calculations of elementary particle masses give strong support for the concept below nuclear length scales: the reason is that the dependence of the masses is exponentially sensitive to the value of k. In nuclear physics length scales radically new picture for the structure of nuclei and identification of nuclear strong interaction is emerging (see the chapter 'TGD and nuclear physics' [Pitkänen$_2$, 1995]. Wormhole BE condensate picture leads to a mo-del for EEG and nerve pulse and predicts new effects. Also the existence of scaled-up versions of nervous system, nerve pulse and EEG is suggestive. For instance, acupuncture points and so called meridians connecting them could form a larger-scale nervous system.

b) *Classical Z^0 fields.* The smallness of the effects caused by the classical Z^0 force is crucial for deriving a detailed picture of the topological condensate in condensed matter length scales. Indirect support for Z^0 force comes from the solution of the solar neutrino puzzle at qualitative level: it is not yet possible to predict the precise value of the solar neutrino deficit. The explanation of the chirality selection in biosystems is second piece of evidence. Z^0 force would prevent the collapse of Super Novae to blackholes which General Relativity based models tend to predict. The formation of Z^0 magnetic vortices might be the real cause for the lowering of the super fluid critical velocity (see chapter 'Macroscopic quantum phenomena and CP_2 geometry' of [Pitkänen$_1$,1995]). A further evidence for the classical Z^0 force is the anomaly observed in tritium beta decay near the endpoint of the electron spectrum.

c) *Hydrodynamical hierarchy.* As far as hydrodynamics is considered, the length scale of cell should be very special since Z^0 screening by neutrinos occurs in this length scale (see the chapter 'TGD and condensed matter physics' of [Pitkänen$_2$,1995]). Sonoluminescence is an effect having no generally accepted explanation in standard physics. The size of the bubble in question is of order cell size and in the chapter 'TGD and condensed matter physics' of [Pitkänen$_2$,1995] a TGD based version of the shock wave model is proposed. The p-adic length scale hierarchy should reflect itself in the structure of a turbulent flow (hierarchy of viscosities, velocity fields, densities, pressures...).

5 The relationship to the deterministic description of self organization

The leap from a fairly conventional classical nonlinear network to TGD-based interpretations of turbulence and self-organization and the concept of an underlying holo-flux or implicate order such as

Bohm advanced for many years is not as drastic as may seem at first glance but merits more examination of the synchronization behavior that does occur in such deterministic networks. The basic approach taken by [Chinarov and Gergely,1997] and others (cf.. references therein) has been to study networks composed of pairs of coupled elements where each element has functionally different properties. A network is composed of such couples, and the measure of behavior of interest is both in the pair's output and its internal dynamics. An example of such a network would be one that is composed of underdamped and overdamped phase oscillators serving to create an ensemble of Josephson-like elements. The dynamics of such a system is given [Chinarov and Gergely, 1997] by

$$\begin{aligned} \frac{d^2q_i}{dt^2}(t) &= -f_i - h\frac{dq_i}{dt}(t) + sin(j_i(t) - q_i(t)) \\ &+ \frac{a_i^q}{N} sin(q_i(t) - q_j(t)) exp(-a|i-j|) \\ &+ Acos(2\pi ft) \ , \\ \frac{dj_i}{dt}(t) &= j_i^0 - a_i^j sin(j_i(t) - q_i(t)) \ . \end{aligned} \tag{1}$$

In this model q_i and j_i are the phases of the coupled oscillators, h is a friction coefficient, A is the amplitude of a periodic input signal of frequency f, a_i^j is a coupling strength factor, and a is a site-correlation strength. In such a network there are interactions between central and peripheral oscillators and the peripheral units are controlled by the central units.

Synchronization among different clusters of oscillators that are remote from one another in the network is possible. A more interesting phenomenon can be found when there is a separate mean field for peripheral and central oscillators and all elements are synchronized within two asynchronous clusters. There arise strange attractors that, by modulation of the periodic force input, can be controlled and switched in behavior (rotation within the phase plane). Synchronization of randomly switching bistable elements can also be observed through modulation of the mean-field interactions.

In terms of the many-sheeted spacetime framework and the model of hierarchical hydrodynamics based upon energy transfer between multiple-scaled 3-space sheets, one can posit that there is a possible connection between the development of central-peripheral (CO-PO) oscillator couplings and hierarchies of clusters of such CO-PO clusters with the feed-flow networks of quantum entanglements that dictate how a collection of spacetime sheets form coherent master-slave hierarchies following the principles of p-adic length and time scales. Starting from this speculative platform can lead to a perspective such that the structure of such couplings and cluster relations in a network (be it of particles or cells or organisms), including the status of membership of a given oscillator unit into the CO or PO class itself, is a dynamic process. This brings one back to the original QCAM and CLAN model whereby the entire network topological dynamics is reconfigurable on the basis of something like the synchronization patterns that emerge within different parts of the network. A geometry of synchronization could be responsible for the emergence and also the waning and disappearance of organizational connectivity between remote and seemingly random elements and clusters. This geometry would be quite unlike any physical geometry but measureable nonetheless as computer simulations by Kryukov, Chinarov, and others have shown.

Such a synchronization-space topology would exhibit some of the characteristics of non-local and global, holo-flux influence, without any place or need for so-called hidden variables, that was pointed toward by Bohm's quantum potential and implicate order concepts. It may also point the way toward an improved understanding not only of hydrodynamical self-organization but also of phenomena of coherence and synchronicity in biology, medicine, and psychology that have heretofore been relegated to experimental error or pure coincidence. One of the more interesting avenues for further investigation may be in fact to apply these concepts of both quantum self-organization and dynamic network synchronization to the behavior of bioelectromagnetic phenomena such as the meridian system and its field-like interaction with the cell membrane and cytoskeletal dynamics of the central nervous system and in particular with those regions and plexuses throughout the CNS other than the brain that have been traditionally associated with centers of psychophysical energy.

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