What does one mean with quantum fluctuations in TGD framework?

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Abstract

What does one mean with quantum fluctuation? Often Uncertainty Principle is assigned with quantum fluctuations. Eigenstate of say momentum is necessary de-localized maximally, and one could say that there are quantum fluctuations in position. Same applies to eigenstates of energy.

Path integral formalism provides a nice definition of quantum fluctuation. In path integral formalism one interprets transition amplitude as a sum over all paths - not only classical one - leading from given initial to given final state. In stationary phase approximation making possible perturbative approach one performs path integral around the classical path. The paths which differ from the classical path correspond naturally to quantum fluctuations. For interacting quantum field theories (QFT) the expansion in powers of coupling constant - say $\alpha = e^2/4\pi\hbar$ - would give radiative corrections identifiable as being due quantum fluctuations. The problem of path integral formalism is that path integral does not exist in a strict mathematical sense.

Since TGD is quantum critical one can ask whether a stronger notion for which quantum fluctuation would be analogous to thermodynamical fluctuation at criticality could exists. In this article I proposed this kind of notion relying on Zero Energy Ontology, hierarchy of Planck constants, and other basic elements of TGD. This view also also nice description of quantum phase transitions.

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1 Introduction

The notion of quantum fluctuation is far from being well-defined. Often Uncertainty Principle is assigned with quantum fluctuations. Eigenstate of say momentum is necessary de-localized maximally, and one could say that there are quantum fluctuations in position. Same applies to eigenstates of energy. Personally I would prefer stronger notion for which quantum fluctuation would be analogous to thermodynamical fluctuation at criticality.

Path integral formalism provides a stronger definition. In path integral formalism one interprets transition amplitude as a sum over all paths - not only classical one - leading from given initial to given final state. In stationary phase approximation making possible perturbative approach one performs path integral around the classical path. The paths which differ from the classical path correspond naturally to quantum fluctuations. For interacting quantum field theories (QFT) the expansion in powers of coupling constant - say $\alpha = e^2/4\pi\hbar$ - would give radiative corrections identifiable as being due quantum fluctuations. The problem of path integral formalism is that path integral does not exist in a strict mathematical sense.

Since TGD is quantum critical one can ask whether a stronger notion for which quantum fluctuation would be analogous to thermodynamical fluctuation at criticality could exists. In the sequel I propose this kind of notion relying on the geometrization of quantum physics in terms of the geometry of "World of Classical Worlds" (WCW) [**?**, K1], physics as generalized number theory vision [K5], Zero Energy Ontology (ZEO), strong holography, hierarchy of Planck constants, and p-adic length scale hypothesis. This view also also nice description of quantum phase transitions.

I will start with a summary of basic ideas of TGD and summary of its relationship to the path integral approach to QFTs and then discuss the ZEO based proposal for how quantum critical fluctuations could be defined.

2 Some relevant ideas about TGD

To discuss the situation in TGD framework one must first introduce some key ideas of TGD related to the path and functional integrals. The first thing to notice is of course that path integral and functional integral might be un-necessary historical load in the definition scattering amplitudes in TGD framework. Scattering diagrams are however central in QFT and also in dramatically simpler twistorial approach. In ZEO one indeed expects that diagrams in some form are present. The functional integral over 3-surfaces replaces path integral over all 4-surfaces - the first naive guess for quantization, which completely fails in TGD framework. The recent view indeed is that the scattering amplitudes reduce to discrete sums of generalized scattering diagrams.

1. In TGD framework path integral is replaced with a functional integral over pairs of 3-surfaces at boundaries of causal diamonds (CDs: CDs form a scale hierarchy) [K4]. The functional integral is weighted by a vacuum functional, which is product of two exponent. The real exponent guarantees the convergence as functional integral and hopefully makes it mathematically well-defined. The exponent of imaginary phase is analogous to action exponential appearing in QFTs and gives rise to the crucial interference effects. In Zero Energy Ontology (ZEO) one can say that TGD is a complex square root of thermodynamics with partition function replaced with exponential of complex quantity so that fusion of QFT and thermodynamics is obtained.

2. There is no integration over paths and the interpretation is in terms of holography implying that pair of 3-surfaces is accompanied by a highly unique space-time surface analogous to Bohr orbit.

   Holography follows from general coordinate invariance (GCI): the definition of WCW Kähler geometry must assign to given 3-surface(!) a hopefully unique space-time surface for 4-D(!) general coordinate transformations to act on. This space-time surface corresponds to a preferred extremal of Kähler action [K6].

3. One can strengthen the notion of holography by demanding that it does not matter whether one identifies 3-surfaces as pairs of space-like 3-surface pairs at the boundaries of causal diamond CD or as light-like 3-surfaces between Euclidian and Minkowskian space-time regions defining" orbits of partonic 2-surfaces". 2-D string world sheets carrying induced fermion fields and partonic 2-surfaces would carry all information needed to construct physical state and would have strong form of holography (SH) [K2]. This would mean almost string model like description of TGD. Preferred extremals satisfy at their ends infinite number of conditions analogous to Super Virasoro conditions and defining the analog of Dirac equation at level of WCW. This is what makes the situation almost - or effectively 2-dimensional.

   The localization of modes of induced spinor fields to 2-surfaces follows from the physically well-motivated requirement that the modes of induced spinor field have well-defined eigenvalue of em charge. This demands that the induced W gauge potentials vanish: the condition requires 2-D CP_2 projection and is in the generic situation satisfied at string world sheets. Also number theoretic arguments favor the condition: in particular, the idea that string world sheets are either complex or co-complex 2-surfaces of quaternionic space-time surface is highly attractive. The boundaries of string world sheets would in term be real/co-real (imaginary) "surfaces" of string world sheets. It is not clear how unique the choice of strings world sheets is.

4. It would be very nice if preferred extemals were unique. In fact, extended number theoretic vision suggests that this might *not* be the case. There could be a kind of gauge symmetry analogous to that encountered in M-theory where two different Calabi-Yau geometries would describe the same physics.

   Number theoretic vision [K7] states that space-time surfaces are correlates for sequences of algebraic operations transforming incoming collection of algebraic objects to an outgoing collection of them. There would be an infinite number of equivalent computations and in absence of some natural cutoff this in turn would suggest that infinite number of space-time surfaces - generalized scattering diagrams - corresponds to the same scattering amplitude.

   This would extend the old fashioned string model duality to an infinite number of dualities allowing to transform all loopy diagrams to braided tree diagrams as in QFT without interactions. The functional integration over WCW would not involve summation over different topologies of generalized scattering diagrams, choice of gauge would select one of them: in the similar manner in hadronic string model one does not sum separately over s-channel and t-channel exchanges.

   It must be however emphasized that these loops are topological, and include besides stringy loops (having different physical interpretation in TGD: particle just travels along different paths as in double slit experiment) also new kind of loops due to the new kind of vertices analogous to those for ordinary Feynman diagrams. The new elements are that the lines of Feynman diagrams become 4-D: orbits of 3-surfaces and at generalized vertices these generalized lines meet at their ends. At this kind of vertex not encountered in string models the 4-surface is locally singular although 3-surface at the vertex is non-singular. In string model string world sheets are non-singular but strings are singular at vertices (eye glass type closed string is basic example).

5. There is also a functional integral over small deformations of a diagram with given topology (which could be chosen to be the tree topology). Quantum criticality suggests that coupling constants do not evolve locally being analogous to critical temperature and change in phase transition manner as the character of quantum criticality changes. Also p-adic considerations suggest that coupling constant evolution reduces to a discrete p-adic coupling constant evolution. Coupling constants would be piecewise constants and depend only on the p-adic length scale and the value of Planck constant $h_{eff} = n \times h$. Theory would be as near as possible to a physically trivial theory in which couplings constants do not evolve at all. The local vanishing of radiative corrections would guarantee absence of divergences and would have interpretation in terms of integrability of TGD.

6. By SH functional integral should reduce to that over string world sheets and partonic 2-surfaces assignable to special prefered extremals. For them vacuum functional would receive contributions from Euclidian and Minkowskian regions and have maximum modulus and stationary phase. Functional integral over deformations of these 2-surfaces would reduce to exactly calculable Gaussian. As a matter fact, the Gaussian determinant and metric determinant from WCW geometry should cancel so that one would have only discrete sum of action exponentials - perhaps only single one for given diagram topology which by generalization of string model duality would be equivalent as representations of equivalent series of algebraic computations. This would be a highly desired result from the point of view of number theoretic universality.

One could of course challenge the entire idea about functional integral. Why not just replace the functional integral with a sum over amplitudes assignable to preferred extremals corresponding maxima/stationary phase 3-surfaces weighted by exponent of Kähler action? Classically the theory would be effectively on mass shell theory. This would automatically give number theoretic universality. If the generalization of duality symmetry inspired by the idea about scattering as computation holds then one could include only braided tree diagrams.

3 Quantum fluctuations in ZEO

What quantum fluctuations could mean in TGD Universe? Here the quantum criticality of TGD suggests that interesting quantum fluctuations are associated with quantum criticality.

1. One can start from a straightforward generalization of the definition of quantum fluctuations suggested by path integral approach. Holography would suggest that quantum fluctuations correspond to a delocalization in the space of highly correlated pairs of 3-surfaces. This is a nice definition consistent also with the weakest definition relying on Uncertainty Principle but this looks somewhat trivial.

2. Quantum criticality [K3] is key feature of TGD and would suggest that quantum fluctuations are analogous to thermodynamical fluctuations at criticality and thus involve long range correlations and non-determinism. Thermodynamical fluctuations induce phase transitions. Same should apply to quantum critical quantum fluctuations.

   In the adelic approach to TGD [K5] p-adic primes and values of h_{eff} correspond to various quantum phases of matter. In ZEO phase transition should correspond for particle space-time surface a situation in which the two ends of CD correspond to different phases, that is to different values of p-adic prime p and/or h_{eff} and other collective parameters: note that algebraic extensions of rationals define an evolutionary hierarchy and should also appear as this kind of parameters.

   Zero energy state would have well-defined values of prime p and/or h_{eff} at the passive boundary of CD left unchanged by a sequence of repeated state function reductions (generalized Zeno effect). At the active end of CD, which changes during the sequence and at which members of state pairs change, one would have quantum superposition of phases with different values of p and/or h_{eff}. This conforms with the idea about what quantum critical fluctuations should mean. Passive end would not fluctuate but active end would do so. Quantum fluctuations would become part of the definition of quantum state in ZEO. The state function reduction to the opposite boundary of CD would change the roles of active and passive boundaries of CD. This would have interpretation as a quantum phase transition leading to well-defined phase at the formerly active boundary. Hence the notion of quantum phase transition would also become precisely defined.

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