TGD counterpart of Feynman diagrammatics with application to QFT limit and CP violation

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Abstract

Hitherto only the construction of scattering amplitudes for a fixed space-time surface have been considered in the TGD framework. The challenge is to extend this construction to the level of "world of classical worlds" (WCW).

The QFT limit of TGD requires understanding of the TGD counterparts of various notions such as fermion lines, vertices, fermion pair creation, and loops. Holography= holomorphy vision implies that space-time surfaces are minimal surfaces with edges defining defects of the standard smooth structure. In dimension $D = 4$, the defects give rise to exotic smooth structures making possible fermion pair creation. At edges V-shaped fermion lines, allowing an interpretation as creation of a fermion pair, are possible.

Concerning the construction of full scattering amplitudes, the basic ideas are simple.

1. The n-point functions of QFT generalize to n-point functions for the WCW spinor field at points, which correspond to the 3-D edges of the space-time surface.
2. The action exponential with functional integration over 4-Bohr orbits defines the n-point functions and S-matrix elements.
3. The action exponential is the sum of classical action and of the induced Dirac action. The induced Dirac action vanishes expect at the singularities, where the normal derivatives of the imbedding space coordinates are discontinuous so that the trace H^k of the second fundamental form (local 6-D acceleration in H having an interpretation as a generalized Higgs field) has a 3-D delta function singularity. The term $\overline{\Psi}H^k\Gamma_k\Psi$ has 3-D delta function singularity. Also the remaining part of the action gives an analogous term and by classical field equations these terms sum up to zero. Also the induced spinor field is discontinuous at singularity and the normal derivatives give rise to 3-D delta function singularity and gauge couplings. One obtains just the gauge couplings.
4. The counterparts of loops due to the powers of WCW propagators are present but are smoothed out and finite by the 3-dimensionality of the particles.

This picture is applied to CP violation requiring loops in QFT picture. TGD predicts an entire hierarchy of standard model physics and a given standard model physics corresponds to a color multiplet associated with the given mode of the Dirac equation in H. To each multiplet one can assign a p-adic mass scale. The local transition to a scaled variant of hadron physics with a larger p-adic mass scale contributes to CP violation. The CP violation can be assigned to the instanton part of the Kähler action giving rise to Kähler-Chern-Simons term assignable to the light-like partonic orbit carrying the fermion line.

1 Introduction

TGD [L18, L19] emerged as a solution to the energy problem of general relativity: Poincare symmetry of the Minkowski space is lost and by Noether's theorem also the classical conservation laws and even the notions of energy and momentum are lost. The proposal is that space-times are 4-surfaces in $H = M^4 \times CP_2$ guarantees classical symmetries and conservation laws. CP_2 in turn predicts standard model symmetries.

TGD can be also regarded as a generalization of the string model: point-like particles are generalized to 3-surfaces and their orbits define space-time surfaces.

TGD involves two visions of physics: geometric vision and number theoretic vision, which are complementary to each other. This complementarity is the 4-D counterpart for the geometric version of Langlands duality [L15, L21] and involves holography = holomorphy hypothesis as a key element.

The realization of general coordinate invariance in 4-D forces holography and holography = holomorphy vision [L15, L21] allows to solve the field equations for space-time surfaces X^4 exactly by reducing them to algebraic equations. This also leads to a generalization of the Langlands duality stating that the complementarity of geometric and number theoretic views of physics..

Classical number fields, the algebraic extensions of rational numbers and p-adic number fields and their algebraic extensions giving rise to adelic physics [L2, L1, L22, L32] are key elements of the number theoretic vision. Also function fields, in particular the function field counterparts of p-adic number fields, emerge from holography = holomorphy vision [L21, L16].

Very concisely, space time surfaces can be regarded as representations of numbers in several senses of the word. The space of space-time surfaces, "world of classical worlds" (WCW) and the spinor fields in WCW can be regarded as Quantum Platonia. Conscious experiences are associated with the quantum jumps between the modes of the WCW spinor field.Number theoretical vision predicts evolution as the increase of algebraic complexity so that quantum Platonia becomes a living and evolving and learning system.

M^8-H duality [L29, L24] relates the geometric and number theoretic visions and involves classical number fields in an essential manner. Geometric symmetries as isometries and holonomies, giving rise to the standard model symmetries, have number theoretic counterparts as number theoretic symmetries the level of M^8 allowing interpretation as octonions, and having physical interpretation as 8-D momentum space. Number theoretic dynamics relies on the associativity conditions for the tangent space-of the 4-surfaces $Y^4 \subset M^8$ as duals of space-time surfaces $X^4 \subset H$.

A longer representation of the situation as it was in 2024 can be found in [L18, L19]. Representations summarizing aspects of the recent state can be found in [L13, L14, L11, L20, L16].

Concerning the construction of scattering amplitudes, the M^8 approach provides a very nice picture [L24] about the scattering amplitudes in the momentum space representation in the fermionic sector involving only 2-vertices identifiable in terms of analog of Brownian motion. This representation is however restricted to scattering amplitudes for a fixed space-time surface. The full scattering amplitudes require a functional integral over the WCW and this gives rise to the counterparts of bosonic propagators. In this article this aspect will be discussed.

In the sequel the basic notions and ideas of TGD are summarized first. After that the generalization of the construction of scattering amplitudes from the level of a single space-time surface to the level of WCW is discussed. The QFT limit of TGD must exist and emerge naturally from the full theory. This gives strong hints.

One should understand the TGD counterparts of various notions such as fermion lines, vertices, fermion pair creation, and loops. The basic idea is simple: n-point functions of QFT generalize to n-point functions for the WCW spinor field at points which correspond to the 3-D edges of the space-time defining the vertices. Edges are 3-D delta function singularities for the trace of the second fundamental form for space-time surface as minimal surface, vanishing elsewhere and having an interpretation as a generalized acceleration and generalized classical Higgs field. This is true for any general coordinate invariant action constructible in terms of the induced geometry and has interpretation as universality associated with 4-D quantum criticality.

A key role is played by the notion of exotic smooth structure [A3, A4, A1] discussed from the TGD point of view in [L3, L8, L20, L10]. Exotic smooth structure is realized in terms of edges of the space-time allowing V-shaped fermion lines. In time direction this corresponds to a creation of a fermion pair.

Concerning the construction of full scattering amplitudes, the basic ideas are simple.

1. The n-point functions of QFT generalize to n-point functions for the WCW spinor field at points, which correspond to the 3-D edges of the space-time surface.

2. The action exponential with functional integration over 4-Bohr orbits defines the n-point functions and S-matrix elements.

3. The action exponential is the sum of the classical action and of the induced Dirac action. The induced (and also modified) Dirac action vanishes expect at the singularities, where the normal derivatives of the imbedding space coordinates are discontinuous so that the trace H^k of the second fundamental form (local 6-D acceleration in H having an interpretation as a generalized Higgs field) has a 3-D delta function singularity. The term $\overline{\Psi}H^k\Gamma_k\Psi$ has 3-D delta function singularity. Also the remaining part of the action gives an analogous term and by classical field equations these terms sum up to zero. Also the induced spinor field is discontinuous at singularity and the normal derivatives give rise to 3-D delta function singularity and gauge couplings. One obtains just the gauge couplings.

4. The counterparts of loops due to the powers of WCW propagators are present but are smoothed out and finite by the 3-dimensionality of the particles.

5. Remarkably, classical action makes itself visible only in functional integral and in determining the singularities and one can ask whether the choice of the classical action is a part of a definition of quantum state.

This picture is applied to CP violation, whose understanding relies on loops. TGD predicts an entire hierarchy of standard model physics. A given standard model physics corresponds to color multiplets associated with a given mode of the Dirac equation in H [L23, L25]. To each multiplet one can assign a p-adic mass scale. The local transition to a scaled variant of hadron physics with a larger p-adic mass scale contributes to the CP violation. The CP violation can be assigned to the instanton part of the Kähler action giving rise to Kähler-Chern-Simons term assignable to the light-like partonic orbit carrying the fermion line [L11, L28].

2 Brief summary of the basic ideas and concepts of TGD

The following brief summary discusses the idea relevant to the construction of the TGD counterpart of Feynman rules.

2.1 Dynamical degrees of freedom and dynamics

1. Classical bosonic fields of the standard model are geometrized in terms of the induced geometry involving metric and spinor structure. What is new is that color and electroweak interactions are both seen as aspects of color interaction: the reason is that the holonomy group of CP_2 can be regarded as subgroup of color group and electroweak interactions can be regarded as interactions in CP_2 spin degrees of freedom.

2. Classical physics satisfies holography=holomorphy hypothesis [L15, L21, L16]. Any general coordinate invariance variational principle depending on induced geometry predicts minimal surfaces with 3-D singularities as edges where the trace of the second fundamental form identifiable as 8-D local acceleration has a delta function singularity. Also the interpretation as a generalization of the Higgs field is possible.

3. At the fundamental level, only quarks and leptons are present as second quantized free spinor fields in H. Bosonic quanta are identified as bound states of fundamental fermions and the notion of Galois confiment leads to rather strong predictions [L19]. All particles correspond to bound states of fundamental fermions assignable to 3-surfaces. Only fermionic and geometric degrees of freedom are present.

4. Massless Dirac equation for H spinor fields [L25] predicts infinite hierarchy of color partial wave multiplets for both quarks and leptons. The proposal is that they correspond to p-adic mass scales. This means an entire hierarchy of standard model physics. This has strong implications and there are indications that one such copy is visible at LHC energies [L26] and even in the physics of the solar surface [L17]. In particular, the CP violation should be understandable in terms of local transitions from the standard hadron physics to its scaled copy.

   It is not quite clear whether it is appropriate to assign the Dirac equation also to the causal diamond $CD = cd \times CP_2$, where cd is the causal diamond of M^4 and defines the analog of quantization volume. In this Dirac equation M^4 Kähler structure as Hamilton-Jacobi structure would appear.

5. The notion of induced spinor field satisfying induced Dirac equation as an analog of massless Dirac equation is also central [L23]. Masslessness in the sense of induced Dirac equation. M^4 Kähler structure or Hamilton-Jacobi structure [L11] is important. The Kähler form is restricted to transversal space-like degrees of freedom involved. Interactions involve incoming and outgoing states constructed in terms of the oscillator algebra associated with the spinor modes of the embedding space and interaction volume as the space-time surface inside which the induced Dirac equation holds true. This generalizes the description of strong interactions in terms of the formation of quark-gluon phase by fragmentation followed by hadronization to all interactions.

2.2 Zero energy ontology

Holography = holomorphy vision allows no path integral since particles as 3-surfaces are accompanied by slightly non-deterministic Bohr orbits as 4-surfaces satisfying holography = holomorphy principle [L15, L21, L16]. This means that space-time surfaces in Minkowskian regions are roots for a pair $f = (f_1, f_2)$ of analytic functions of 4 generalized complex coordinates of $H = M^4 \times CP_2$. One of them is the hypercomplex coordinate. If the action is general coordinate invariant and constructible in terms of the induced geometry, the solutions are minimal surfaces except at 3-D singularities which correspond to edges of the space-time surface. At these singularities the trace of the second fundamental form has a delta function singularity. The "world of classical worlds" (WCW) as the space for these Bohr orbits becomes the fundamental geometric object and the arena of quantum physics.

The classical non-determinism forces to identify the 4-D Bohr orbits are the fundamental objects. The discrete degrees of freedom associated with the classical non-determinism are proposed to serve as correlates of cognition predicted to be possible in all scales. It turns out that these degrees of freedom are crucial also for the construction of scattering amplitudes. The non-determinism is present already for 2-D minimal surfaces in which case it is associated with the frames defining the soap film. In the 4-D case, the frames correspond to 3-D surfaces defining singularities as edges of the space-time surface. The construction of space-time surfaces using holography = holomorphy principle allows symmetries, which allow the construction of new space-time surfaces by a procedure based on the construction of functional composites of analytic maps $C^2 \to C^2$, reducing to the iteration of functions as a special case. In TGD inspired theory of consciousness, the interpretation is in terms of cognitive hierarchies.

This leads to a generalization of the notion of p-adic number to its functional counterpart and p-adic length scale hypothesis can be understood [L22, L32]. The loci of non-determinism are analogous to the frames of 2-D soap films [L5]. The failure of the classical determinism is proposed to have as a counterpart the failure of determinism for p-adic differential equations for which pseudo constants are functions which depend on finite number of binary digits and have vanishing derivative. The edges associated with singularities would relate to the non-constancy of the pinary digits for the gradients of the embedding space coordinates making them discontinuous at edges. This forces a new quantum ontology [K12] [L4] which I call zero energy ontology (ZEO). In ZEO, quantum states are superpositions over 4-D Bohr orbits, or more precisely, modes of WCW spinor fields assigning to every Bohr orbit mode of WCW spinorhaving interpretation as a pair of fermion states assignable to the two opposite boundaries of the causal diamond $CD = cd \times CP_2$ where cd is the causal diamond of M^4 [L13, L12]. They are analogs of incoming and outgoing states of a deterministic time evolution. The analog of WCW can be realized also in the standard wave mechanical picture of atoms.

ZEO solves the basic paradox of quantum measurement theory. The replacement of the superposition of Bohr orbits with a new one in state function reduction (SFR) does not violate classical field equations. Bohr orbits are inside the CD. There are two kinds of SFRs [L30, L31]. "Small" SFRs (SSFRs) leave either boundary of CD having two boundaries, passive and active. The states at the passive boundary and passive boundary itself suffer only a scaling leaving the quantum states invariant: this is the counterpart of Zeno effect. In SSFRs, the active boundary and states at it change and in statistical sense it increases. The sequence of SSFRs defines the subjective time correlating with the geometric identifiable for instance as the distance between the tips of the CD. Two arrows of geometric time are predicted. In "big" SFRs (BSFRs) as counterparts of ordinary SFRs, the roles of the passive and active boundary are changed and the arrow of time changes. Since quantum coherence is possible in arbitrarily long scales in the TGD Universe, this has rather dramatic implications in all scales, even in cosmology.

2.3 The "world of classical worlds"

The "world of classical worlds" (WCW) [K3, K2, K11, K8] [L3] corresponds to the infinite-dimensional space of 4-D Bohr orbits. There are strong reasons to believe that WCW has a unique Kähler geometry made possible by a maximal group of isometries and that this geometry exists only for $H = M^4 \times CP_2$. The existence of twistor lift [L6, L7] requires Kähler geometry for the twistor twistors space of M^4 and CP_2: these spaces are the only 4-manifolds with this property [A2]. Also the number theoretic vision involving $M^8 - H$ duality and the interpretation of M^8 as octonions forces $H = M^4 \times CP_2$.

Quantum states in WCW are identified as modes of WCW spinor field [K11] and have the geometric degrees of 4-D Bohr orbit as the orbital degrees of freedom. Many-fermion states define the spin degrees of freedom for WCW spinor fields and anticommuting gamma matrices are identifiable as linear combinations of fermionic oscillator operators for the second quantized spinor fields of H. The isometry algebra extends to super-symplectic algebra with WCW gamma matrices in the role of super generators. Also the 4-D analog of super-conformal algebra is involved.

2.4 Hierarchy of standard model physics as a basic prediction

The hierarchy of scaled versions of standard model physics is the strongest and most radical prediction of quantum TGD.

Color partial wave multiplets for both quarks and leptons define a hierarchy of scaled variants of the standard model physics [L26]. Color multiplets correspond to p-adic mass scales. Functional field analogs of p-adic number fields emerging from holography= holomorphy vision explain the origin of p-adic length scale hypothesis.

The situation is satisfactorily understood at the level of embedding space spinor modes but not so well at the level of space-time surfaces. The algebraic complexity of the space-time surface assignable to the quark however correlates with the p-adic prime p thanks to the existence of dynamical symmetries defined by maps $g : C^2 \rightarrow C^2$ defining cognitive hierarchies.

2.5 Massivation by p-adic thermodynamics

p-Adic thermodynamics [K4, K1] [L9, L22, L32] replaces the Higgs mechanism as a description of massivation although the Higgs field as a quantum field has a classical counterpart as the trace of the second fundamental form. TGD and also the analog for classical Higgs field and its vacuum expectation make sense.

1. p-Adic thermodynamics should have a "square root" giving rise to the analogs of thermal states as quantum states. Generalized 4-D conformal symmetry implied by holography = holomorphy vision and the identification of mass squared as conformal weight are essential elements. Functional field analogs of p-adic number fields emerge from H-H vision and explain the p-adic length scale hypothesis. At the level of H, massivation corresponds to a generation of analog of thermal conformal weight and must have a counterpart also at space-time level.

2. What is the counterpart for the generation of conformal weight at space-time level? How the induced geometry could generate conformal weight? The notion of induced spinor field is essential here [**?**]. The induced Dirac equation can be said to be massless in the 4-D sense. The induced Dirac equation is exactly solvable and conformal weights label the modes of the induced spinor field. M^4 Hamilton-Jacobi structure [L11] is essential. Superposition involving non-vanishing conformal weights is allowed by conformal invariance. This would naturally correspond to the square root of p-adic thermodynamics.

3. Massivation is satisfactorily understood at the level of embedding space spinor modes. At the level of space-time surface holography = holomorphy hypothesis predicts that algebraic complexity of the space-time surface correlates with the p-adic prime p assigned with the color multiplet in a very concrete way.

3 How could the QFT limit of quantum TGD emerge?

The understanding of the QFT limit of TGD has been a long-standing problem. In particular, the question of how the TGD counterparts of the loops central for QFT approach emerge in TGD, is central.

The intuitive picture is that TGD has a QFT limit in which standard model fields are superpositions for the induced standard model fields associated with the geometrically parallel sheets of the many-sheeted space-time. This intuitive picture is not enough for computations. A precise identification of the TGD counterparts of Feynman diagrams, in particular loops, is required.

In order to understand whether and how the standard model as a QFT limit of TGD emerges, one must understand how the scattering amplitudes are defined. The geometric interaction mechanism is proposed to be a contact interaction of space-time surfaces that gives rise to 2-D string world sheets if the holography= holomorphy hypothesis holds true. Hitherto only the fermionic scattering amplitudes for a single space-time surface has been understood satisfactorily [L24]. The challenge is to extend the construction to the level of WCW.

3.1 How do the analogs of Feynman diagrams emerge?

The question of what are the TGD analogs of Feynman diagrams decomposes to several subquestions.

1. How is fermion pair creation possible at all in the TGD Universe? Intuitively, fermion pair creation corresponds to a fermion line turning backwards in time. The vertices would correspond to edges of space-time in which smoothness fails. The encouraging news is that just in the 4-D case, exotic smooth structures exist [A3, A4, A1] and correspond to 4-manifolds with singular 3-surfaces identified as defects of the standard smooth structure. This is discussed from the TGD point of view in [L3, L8, L20, L10]. TGD-like physics thus exists only in 4-D space-times identified as surfaces in $H = M^4 \times CP_2$.

2. How do the vertices emerge? In quantum field theories in classical backgrounds quantum fields are replaced by classical fields and pair creation is possible in classical fields. The proposal is that the same description works in TGD as an exact description. The proposal is that 3-D singular surfaces at which the trace of the second fundamental form as a generalization of acceleration has a delta function singularity, correspond to vertices in geometric sense. This indeed implies that the derivatives of embedding space coordinates are discontinuous so that a defect of the standard smooth structure is in question.

3. Fermionic propagators exist and can be calculated since the Dirac equation in H is exactly solvable. There are no primary boson fields but bosonic quanta could correspond to fermionic bound states. One can identify fermion lines as boundaries of string world sheets assignable to the intersection of two interacting space-time surfaces so that fermions are effectively point-like.

What could be the counterparts of the bosonic propagators?

1. The vertices as edges involve only classical boson fields as an induced metric, the induced spinor connection and also the trace of the second fundamental form having 3-D delta function singularity. The counterparts of bosonic propagators should emerge in geometric degrees of freedom as correlation functions between the geometric degrees of freedom associated with the 3-D singularities as vertices.

2. How to define the generalization of bosonic propagator and propagator in general? The replacement of point-like particles with 3-surfaces or rather, with their 4-D Bohr orbits, suggests that one replaces M^4 with WCW and correlation functions for quantum fields with correlation functions for the modes of WCW spinor fields. It is hard to imagine anything simpler.

   One can define correlation functions between the modes of WCW spinor fields at the 3-D singularities by using functional integral over Bohr orbits in WCW. Unlike the path integral, this integral exists mathematically: the condition for its well-definedness in fact forces the unique Kähler geometry of WCW with maximal isometry group. Nothing prevents us from defining the quantum states in such a way that this functional integral exists! Situation is very much like in wave mechanics. The finiteness condition constrains the solutions of Schrödinger equation.

   The propagator for WCW spinor fields as analog of fermion propagator decomposes to the correlation functions between the modes of spinor fields in geometric degrees of freedom at the QFT limit when the singularities are idealized as points. For fermionic parts the propagators can be calculated for a given Bohr orbit. The vertices can involve modes of

WCW spinor fields and can carry arbitrary fermion number and partial waves in WCW degrees of freedom generated by superconformal and supersymplectic algebras.

3. This would give rise to the analog of Feynman diagrammatics with propagators as correlation functions defined by the modes of WCW spinor field having varying fermion number. The contributions to scattering amplitudes could be represented diagrammatically by replacing the singular 3-surfaces with point-like vertices in M^4 at QFT limit at least.

4. Besides the finite functional integral over the 3-D holographic data, there would be a discrete sum over non-deterministic degrees of freedom but there would be no path integral. There are vertices and propagator lines as M^4 projections of the Bohr orbits. Fermion lines at space-time surfaces have edges so that one has an analog of Brownian motion. Bosonic propagators are geometric and connect the vertices as edges.

3.2 Are the counterparts of fermionic and more general loops possible?

Loop corrections have an essential role in the standard model and one of its greatest victories. Loops are also crucial in the standard model description of the CP violation. In particular, fermionic loops are important. Although the elimination of divergences associated with loops is a rather ugly process, they predict effects which are verified to a high precision.

The description of the TGD counterparts of loops is a challenge for TGD. The counterparts of loops should be present and be manifestly finite, implying that the QFT limit of TGD is renormalizable and allows a regularization making them finite. In QFTs, loops emerge when $n > 2$-vertices are present. Now only 2-vertices are possible for fermions. Is it possible to have an analog of a fermionic loop in TGD? In the TGD context the loops, if they exist, must be assigned with correlation functions of WCW spinor fields.

The fermionic spine of the generalized Feynman diagram consists of a graph of a Brownian motion. Is this true also for WCW "fermions" as WCW spinor fields so that only two-vertices defined by the singularities are possible? This would conform with the idea that the theory in fermionic degrees of freedom is free also at the level of WCW. Bosonic propagators would be replaced by WCW correlation functions with arguments defined by the vertices as singularities.

1. In QFT fermionic loop gives square of the fermionic propagator connecting points x and y. This gives a divergent integral over the virtual 4-momenta. In the TGD framework, a fermionic loop would mean that a fermion pair is created at a defect representing edge and later annihilates at the second defect. Classical intuition suggests that fermion lines at Bohr orbits are straight so that this is not possible by classical momentum conservation except when the fermion returns backwards in time as antifermion along the same line.

2. Is this contribution finite in TGD? Holography and supersymmetry at the level of WCW [L14] require that also the dynamics of fermions is determined by holography and almost deterministic with the defects as loci of finite non-determinism. At the level of H, the induced Dirac equation as an analog of massless Dirac equation for the induced spinor structure is satisfied and holography = holomorphy hypothesis [L15, L16] allows to solve the modes, much in the same way as in string models. Just as in the case of minimal surfaces, fixing of the spinor modes as holography data should leave only a discrete set of degrees of freedom.

3. At the edge singularity the trace of the second fundamental form, having interpretation as 8-D acceleration and generalization of the Higgs field, has a delta function singularity but vanishes elsewhere [L20, L10]. At the level of M^8 [L24] this singularity would naturally correspond to the change of the momentum at the edge of the fermion line and would be fixed by the properties of the singularity rather than being free so that there would be no loop integral over 4-momenta. Also quantum classical correspondence stating that fermionic charges for Cartan subalgebra are identical for classical charges might serve as a justification for this.

4. Could the fermion loop correspond to a space-time surface, which exists for a finite time and has two sheets at which the fermion line and antifermion line are located. Could this be

generalized: is this kind of loop for any mode of WCW spinor field possible? Do these loops correspond to sub-CDs containing the loopy space-time surfaces? This argument should be taken with a caution: the mere smoothing out of singularities due to the 3-dimensionality of the particles might be enough to get rid of infinities and to get counterparts of loops.

3.3 Construction of scattering amplitudes

Concerning the construction of full scattering amplitudes, the basic ideas are simple.

1. The generalization of the QCD picture is assumed. External particles correspond to H level description using spinor modes of H to construct physical states as representations of supersymplectic algebras (also superconformal algebras associated with the boundaries of CD can be considered) [L14]. In the 4-D interaction regions defined by the space-time surfaces, classical action for Bohr orbits and induced/modified Dirac action determine the quantum dynamics as an analog of QFT. The interaction corresponds to a contact interaction as the intersection of two Bohr orbits. Holography = holomorphy principle implies that it consists of a 2-D string world sheets. Otherwise it would consist of discrete points. String world sheets intersect the partonic orbits along fermion lines and singularities at discrete points.

2. The n-point functions of QFT generalize to n-point functions for the WCW spinor field at points, which correspond to the 3-D edges of the space-time surface.

3. The action exponential with functional integration over 4-Bohr orbits defines the n-point functions and S-matrix elements.

   The action exponential is the sum of the classical action and of the induced Dirac action. The induced Dirac action vanishes expect at the singularities, where the normal derivatives of the imbedding space coordinates are discontinuous so that the trace H^k of the second fundamental form (local 8-D acceleration in H having an interpretation as a generalized Higgs field) has a 3-D delta function singularity. The term $\overline{\Psi} H^k \Gamma_k \Psi$ has 3-D delta function singularity. Also the remaining part of the action gives an analogous term. By classical field equations these terms sum up to zero. Also the induced spinor field is discontinuous at singularity and the normal derivatives give rise to 3-D delta function singularity and gauge couplings. One obtains just the gauge couplings. Wheeler would say that, thanks to the possibility of exotic smooth structures, one has interactions without interactions.

4. Remarkably, classical action makes itself visible only in functional integral and in determining the singularities and one can ask whether the choice of the classical action is a part of a definition of quantum state. The classical action would be analogous to an effective action providing the dual of the number theoretic description. In particular, the values of various coupling strengths would be determined theoretically. This view conforms with generalized Langlands duality [L15, L21, L27]. This would conform with the idea that the exponent of the classical action is a number theoretic invariant.

In this framework, loops can be understood in the same way as in QFTs.

1. The perturbative expansion of the action exponential is combinatorially similar to the corresponding expansion in QFTs. Fermionic propagators are H-propagators connecting 3-D singularities as defects of the standard smooth structure and vertices correspond to the gauge coupling terms of the induced (or modified) Dirac action.

2. Fermions are localized to fermion lines as intersections of 2-D string world sheets (intersections of interacting Bohr orbits) with 3-D singularities. The functional integral over Bohr orbits defines the correlation functions geometric degrees of freedom as counterparts of bosonic propagators.

   In QFTs the divergences come from squares and higher powers of the propagators forced by the action exponential. Now they are finite since 3-surfaces replace point-like particles and one has wave functions for the position of fermion lines. This smoothing out the powers of delta functions.

In accordance with the generalization of QCD view about scattering amplitudes, this picture applies in the interaction region defined by a CD.

1. External particles correspond to incoming particles arriving at the CD and outgoing particles leaving it. External particles, meeting the light-like boundaries of CD at 3-D surfaces, define part of the holographic data. At these 3-surfaces WCW spinor fields are contracted with the propagators terms.
2. The modes of the WCW spinor fields belong to the representations of supersymplectic symmetries (the latter in 4-D sense) whereas in the interaction region 4-D superconformal symmetry applies. Just like in QFTs, the fermions associated with these modes are with the fermionic propagators associated with the internal lines.

3.4 What could the transition to a scaled version of the standard model physics mean?

The description of CP breaking would be in terms of local transitions between M_{107} and M_{89} hadron physics means that the color multiplet D_{107} associated with quark spinors is replaced with representation D_{89}. The conjecture is that these color multiplets correspond to the p-adic mass scales associated with Mersenne primes or their Gaussian counterparts.

Suppose that one can assign to each color multiplet a p-adic prime. An attractive assumption is that this prime either increases or decreases with the dimension of the color multiplet.

1. If the dimension of color multiplet increases with p-adic length scale, M_{89} quarks can be regarded as number-theoretically simpler entities than M_{107} quarks. However, as far as color multiplets are considered, they are more complex.

2. The second option is that the dimension of the color multiplet as a measure for complexity decreases as p-adic prime decreases. The finite number of p-adic length scales shorter than hadronic scale and labelled by Mersenne primes and their Gaussian counterparts suggests that this option is correct.

What could these local transitions correspond to? A natural identification would be in terms of ZEO. The region with a scaled version of standard model physics would correspond to a sub-CD of CD such that the particles arriving into sub-CD would interact according to the scaled version of standard model physics and leave the sub-CD as particles of standard model physics.

The change color multiplet for the spinor modes means the restriction of the fermionic propagators to this representation so that the propagator is modified. The space-time surface associated with the fermion would also correspond to the p-adic prime assignable to the color multiplet. The fermions of the scaled version of hadron physics would necessarily appear in loops. They would be created and annihilated as pairs.

4 Comments about CP violation

The CP violation was first observed for kaon system in the decays of neutral kaons and later also in the decays of B_0 (see this). CP violation for baryons was detected recently (2025) (see this). CP symmetry is violated for the CKM matrix describing the mixing of D type quarks CP violation can occur if the number of fermion generations is at least 3.

In the QFT based description the description of CP violation involves loops containing electroweak bosons and heavy quarks, most importantly top quark. The reason is that the CP violation is proportional to the mass squared of the heavy fermions involved. The anomalies of CP violation have been observed for the B_0 system and suggest the existence of new heavy fermions.

In the TGD framework, CKM mixing is due to the different topological mixings of the topologies of partonic 2-surfaces with genus (handle number) $g = 0, 1, 2$. TGD predicts that only the 3 lowest partonic topologies are effectively present [K4, K1]: the lowest 3 genera allow a global Z_2 conformal symmetry, which makes a bound state of $g = 2$ handles possible. The genera $g > 2$

behave like many-handle states at a sphere and have a continuous mass spectrum. The role of CKM matrix is discussed in p-adic mass calculations is discussed in [K7, K6, K9] [L9, L22, L32].

From the above formulated general picture there is a very long path to attempts to understand CP violation and the observed anomalies of its standard model description in terms of scaled variants of hadron physics predicted by TGD. However, since the above considerations were inspired by ponderings related to CP violation, it is reasonable to include general comments about CP violation as an application of the proposed general ideas.

In the TGD framework, one can imagine two basic mechanisms of CP violation. CP violation could be inherent and be induced by instanton-Kähler action reducing to Chern-Simons-Kähler action, which changes sign under CP unlike Kähler action and is associated with the light-like partonic orbits containing fermion lines. One can also ask whether external electroweak gauge fields affecting quarks could induce the CP violation.

4.1 Hamilton-Jacobi structure and CP violation

Generalized complex structure, or Hamilton-Jacobi (H-J) structure [L11], and its CP conjugate correspond to fermions and antifermions. Therefore CP violation and H-J structure should be closely related.

1. M^4, or rather CD, allows many alternative Hamilton-Jacobi (H-J) structures and the H-J structure is dynamical, characterizing the solutions of field equations in holography = holomorphy vision. One can identify several independent conjugations of the generalized complex coordinates of H involving one hypercomplex coordinate. Single H-J structure must be selected for a given connected space-time sheet. Matter and antimatter are related by CP conjugation and CP must correspond to a conjugation for the generalized complex coordinate of H. Fermions and antifermions cannot reside at the same space-time sheet. This selection occurs in all scales and in long scales this leads to a matter-antimatter asymmetry [L21].

   In hadronic scales, the selection of the H-J structure could somehow lead to CP violation. Quark and antiquark associated with mesons cannot exist in the same space-time region but correspond to separate space-time sheets/closed monopole flux tubes/CDs associated with hadrons. Hadronic monopole flux tubes should contain quark-like 3-surfaces as topologically condensed objects.

2. The magnetic fields associated with monopole flux tubes could relate to CP violation. Elementary particles are identified as two-sheeted closed monopole flux tubes, whose Minkowskian space-time sheets differ by complex conjugation. Fermions and antifermions associated with mesons should live at different sheets of the hadronic flux tube. Wormhole contacts fuse together the holomorphic and antiholomorphic regions of the closed monopole flux tube. For fermions/antifermions opposite sheets carry the fermion number.

3. Could the CP asymmetry of the CKM matrix be induced by the environment? Or is it an inherent property of partonic orbits to which one can assign Kähler-Chern-Simons action which changes sign under CP?

4. A local transition to a new hadron physics should lead to (possibly additional) CP violation assignable to short scale physics. In TGD, the generation of dark M_{89} hadron phase is assigned to the transition, which is identified in QCD as a creation of quark-gluon plasma. In this transition h_{eff} increases by a factor 512 to guarantee that the Compton length scales of M_{89} hadrons are same as of ordinary hadrons [K5, K6].

   In the TGD framework, Aleph anomaly [C1] raises the question whether the real top quark could have considerably smaller mass (about 39 GeV) than the official top quark with mass 193 GeV. Could the real top have mass about 39 Gev and could the official top correspond to the u quark of M_{89} hadron physics [L22]? If this is the case, also the standard model description of CP violation would reflect a temporary transition $M_{107} \rightarrow M_{89}$.

5. Quark fragmentation and hadronization as its reversal, would occur at quantum criticality and could also explain the strange findings about what is believed to be transition to quark-gluon plasma phase. The description of the region obeying scaled variant of hadron physics

could be in terms of sub-CD containing the heavy fermions of the scaled variant of standard hadron physics.

Could the attachment of this sub-CD to CD obeying standard hadron physics give rise to CP violation or modify the CP violation at the level of CKM matrix. Why should the topological mixing for the heavy quark at the space-time sheet of sub-CD violate CP?

4.2 Could the instanton term in Kähler action induce CP violation?

Kähler-instanton term, call it I, gives rise to Chern-Simons-Kähler term assignable to the partonic orbit [K8] [L26]. The instanton term changes its sign under CP, which in QCD leads to the strong CP problem (see this) to which axion was proposed as a solution. In fact, also TGD predicts axion-like pseudoscalars, in particular leptopions as bound states of color excited lepton and antilepton [K10]. Could the strong CP problem turn into a victory in the TGD framework? CP violation by Chern-Simons-Kähler action would be inherent to the quark (or lepton) and would not involve interaction with the environment.

The CP violation associated with the sub-CD the CP violation should be larger for the sub-CD , as the proportionality of the amplitudes to the square of large p-adic length scale for fermion mass, requires. The CP violation for CD would be too small to be observed.

1. Could the instanton-Kähler action I give rise to a CP violating CKM matrix? This mechanism would not require external electroweak fields in a larger scale. Instanton action density $I \propto E \cdot B$ reduces to Chern-Simons-Kähler action density proportional to $B \cdot A$ at the partonic orbit. If this leads to CP violating vacuum, the theta parameter could depend on quark.

   Kähler action and I are not affected in charge conjugation C. Kähler action is not affected in CP but I changes sign as a pseudoscalar. This changes the values of the total actions assignable to quark and antiquark and could induce CP violation. In particular, this could lead to different CKM mixings for quarks and antiquarks. Note that this CP violation is not visible as electromagnetic electric dipole moments for quarks.

2. The scaled variant of the standard model with higher color partial wave representation should be characterized by smaller p-adic prime p and larger fermion mass scale. How does the θ parameter depend on the color multiplet characterizing the fermions?

3. The instanton terms associated with the sub-CD containing the M_{89} loops induce CP violation, which is larger than that for M_{107} loops. To understand this, it seems necessary that the notion of fermion loops have a TGD counterpart.

4.3 Could external electroweak fields induce CP violation in CKM matrix?

A more complex option is that electroweak fields external to quark could induce the CP violation at the level of the CKM matrix? External electroweak fields should not induce hadronic electric dipole moments. At the quark level Kähler electric fields cannot generate an electric dipole moment since there are no pair of charged quark and antiquark.

1. The recent TGD view is that $\nu_R\overline{\nu}_L$ screening of weak isospin at both quark and lepton level serves as a correlate for the massivation of weak bosons implying that weak force is screened [L22]. Could the neutrino screening induce CP violation? The neutrino screening for left-handed quarks implies that they have a Z^0 electric field in the direction of monopole flux tube flux tube between quark and screening neutrino. Therefore they have a Z^0 electric dipole moment although the electric dipole moment vanishes.

   Could this dipole moment make possible interaction of the sub-CD with the Z^0 fields assignable with the CD associated with hadron? The direction of the Z^0 electric dipole moment would be different for quark and antiquark. Could this induce CP violation at the level of the CKM matrix?

2. Can this have anything to do with the perturbative calculation of CP breaking in which the CKM matrix gives rise to large CP violating terms coming from large quark masses. Could the CP violating term be proportional to the dimension of the color representation?

   Could a local transition to M_{89} or higher hadron physics involving sub-CD inside CD induce CP violation oran additional CP violation. Could the interpretation of the top quark as a u quark of M_{89} hadron physics make sense? Could Kähler electric fields at M_{107} level act as external Kähler electric fields at M_{89} level inducing CP violation.

A cautious conclusion is that the instanton mechanism is much more simpler and elegant than the mechanism based on the electroweak interaction with the environment.

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