Finite Fields and TGD

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Abstract

TGD involves geometric and number theoretic physics as complementary views of physics. Almost all basic number fields: rationals and their algebraic extensions, p-adic number fields and their extensions, reals, complex number fields, quaternions, and octonions play a fundamental role in the number theoretical vision of TGD.

Even a hierarchy of infinite primes and corresponding number fields appears. At the first level of the hierarchy of infinite primes, the integer coefficients of a polynomial Q defining infinite prime have no common prime factors. $P = Q$ hypothesis states that the polynomial P defining space-time surface is identical with a polynomial Q defining infinite prime at the first level of hierarchy.

However, finite fields, which appear naturally as approximations of p-dic number fields, have not yet gained the expected preferred status as atoms of the number theoretic Universe. Also additional constraints on polynomials P are suggested by physical intuition.

Here the notions of prime polynomial and concept of infinite prime come to rescue. Prime polynomial P with prime order $n = p$ and integer coefficients smaller than p can be regarded as a polynomial in a finite field. The proposal is that all physically allowed polynomials are constructible as functional composites of prime polynomials satisfying $P = Q$ condition.

One of the long standing mysteries of TGD is why preferred p-adic primes, characterizing elementary particles and even more general systems, satisfy the p-adic length scale hypothesis. The proposal is that p-adic primes correspond to ramified primes as factors of discriminant D of polynomial $P(x)$. $D = P$ condition reducing discriminant to a single prime is an attractive hypothesis for preferred ramified primes. M^8-H duality suggests that the exponent $exp(K)$ of Kähler function corresponds to a negative power D^{-k}. Spin glass character of WCW suggests that the preferred ramified primes for, say prime polynomials of a given degree, and satisfying $D = P$, have an especially large degeneracy for certain ramified primes P, which are therefore of a special physical importance.

1 Introduction

This article represents some material related to two articles discussing number theoretical vision of TGD. The first article [L10] was about the fusion of geometric and number theoretic views of TGD to single coherent theory.

Second article [L9] was about my attempts to understand Langlands correspondence, which postulates a deep correspondence between number theory and geometry, and its relation to the geometric and number theoretic views of TGD. Both articles led to two unexpected new ideas and because of the potential importance of these ideas, I decided to write a separate article raising these ideas to table, as one might say.

1.1 Brief summary of the basic mathematical notions behind TGD

The theoretical framework behind TGD involves several different strands and the goal is to unify them to a single coherent whole. This challenge was discussed in [L10].

TGD involves number theoretic and geometric visions about physics and $M^8 - H$ duality, analogous to Langlands duality, is proposed to unify them. Also quantum classical correspondence (QCC) is a central aspect of TGD. One should understand both the $M^8 - H$ duality and QCC at the level of detail.

The following mathematical notions are expected to be of relevance for this goal.

1. Von Neumann algebras, call them M, in particular hyperfinite factors of type II_1 (HFFs), are in a central role. Both the geometric and number theoretic side, QCC could mathematically correspond to the relationship between M and its commutant M'.

   For instance, symplectic transformations leave induced Kähler form invariant and various fluxes of Kähler form are symplectic invariants and correspond to classical physics commuting with quantum physics coded by the super symplectic algebra (SSA). On the number theoretic side, the Galois invariants assignable to the polynomials determining space-time surfaces are analogous classical invariants.

2. The generalization of ordinary arithmetics to quantum arithmetics obtained by replacing $+$ and $\times$ with $\oplus$ and $\otimes$ allows us to replace the notions of finite and p-adic number fields with their quantum variants. The same applies to various algebras.

3. Number theoretic vision leads to adelic physics involving a fusion of various p-adic physics and real physics and to hierarchies of extensions of rationals involving hierarchies of Galois groups involving inclusions of normal subgroups. The notion of adele can be generalized by replacing various p-adic number fields with the p-adic representations of various algebras.

4. The physical interpretation of the notion of infinite prime has remained elusive although a formal interpretation in terms of a repeated quantization of a supersymmetric arithmetic QFT is highly suggestive. One can also generalize infinite primes to their quantum variants. The proposal is that the hierarchy of infinite primes generalizes the notion of adele.

   Second proposal, discussed already in [L10] and to be discussed separately in this article, was that the polynomial Q defining infinite prime at the first level of the hierarchy are identical to the polynomial P defining 4-surface in M^8 and by $M^8 - H$ correspondence space-time surface in $H = M^4 \times CP_2$. This would realize quantum classical correspondence at very deep level.

The formulation of physics as Kähler geometry of the "world of classical worlds" (WCW) involves f 3 kinds of algebras A; supersymplectic isometries SSA acting on $\delta M^4_+ \times CP_2$, affine algebras Aff acting on light-like partonic orbits, and isometries I of light-cone boundary δM^4_+, allowing hierarchies A_n.

The braided Galois group algebras at the number theory side and algebras $\{A_n\}$ at the geometric side define excellent candidates for inclusion hierarchies of HFFs. $M^8 - H$ duality suggests that n corresponds to the degree $n$of the polynomial P defining space-time surface and that the n roots of P correspond to n braid strands at H side. Braided Galois group would act in A_n and hierarchies of Galois groups would induce hierarchies of inclusions of HFFs. The ramified primes of P would correspond to physically preferred p-adic primes in the adelic structure formed by p-adic variants of A_n with $+$ and $\times$ replaced with $\oplus$ and $\otimes$.

1.2 Langlands correspondence and TGD

In the article [L9], the TGD counterpart of Langlands program was discussed and this led as a side product to a realization how finite fields could serve as basic building blocks of the number theoretic vision of TGD.

1. Concerning the concretization of the basic ideas of Langlands program in TGD, the basic principle would be quantum classical correspondence (QCC), which is formulated as a correspondence between the quantum states in the "world of classical worlds" (WCW) characterized by analogs of partition functions as modular forms and classical representations realized as space-time surfaces. L-function as a counter part of the partition function would define as its roots space-time surfaces and these in turn would define via Galois group representation partition function. QCC would define a kind of closed loop giving rise to a hierarchy.

2. If Riemann hypothesis (RH) is true and the roots of L-functions are algebraic numbers, L-functions are in many aspects like rational polynomials and motivate the idea that, besides rationals polynomials, also L-functions could define space-time surfaces as kinds of higher level classical representations of physics.

3. One concretization of Langlands program would be the extension of the representations of the Galois group to the polynomials P to the representations of reductive groups appearing naturally in the TGD framework. Elementary particle vacuum functionals are defined as modular invariant forms of Teichmüller parameters. Multiple residue integral is proposed as a manner to obtain L-functions defining space-time surfaces.

4. One challenge is to construct Riemann zeta and the associated ξ function and the Hadamard product leads to a proposal for the Taylor coefficients c_k of $\xi(s)$ as a function of $s(s-1)$. One would have $c_k = \sum_{i,j} c_{k,ij} e^{i/k} e^{\sqrt{-1}2\pi j/n}$, $c_{k,ij} \in \{0, \pm 1\}$. $e^{1/k}$ is the hyperbolic analogy for a

root of unity and defines a finite-D transcendental extension of p-adic numbers and together with n :th roots of unity powers of $e^{1/k}$ define a discrete tessellation of the hyperbolic space H^2.

This construction led to the question whether also finite fields could play a fundamental role in the number theoretic vision. Prime polynomial with prime order $n = p$ and integer coefficients smaller than $n = p$ can be regarded as a polynomial in a finite field. If it satisfies the condition that the integer coefficients have no common prime factors, it defines an infinite prime. The proposal is that all physically allowed polynomials are constructible as functional composites of these.

One can end up to the idea that prime polynomials and finite fields could be fundamental in TGD also by a different route.

1. A highly interesting feedback to the number theoretic vision emerges. The rational polynomials P defining space-time surfaces are characterized by ramified primes. Without further conditions, they do not correlate at all with the degree n of P as the physical intuition suggests.

2. In [L10] it was proposed that P can be identified as the polynomial Q defining an infinite prime [K5]: this implies that the coefficients of the integer polynomial P (to which any rational polynomial can be scaled) do not have common prime factors.

3. An additional condition could be that the coefficients of P are smaller than the degree n of P. For $n = p$, P could as such be regarded as a polynomial in a finite field. This proposal is too strong to be true generally but could hold true for so-called prime polynomials of prime order having no functional decomposition to polynomials of lower degree [A1, A2]. The proposal is that all physically allowed polynomials are constructible as functional composites of irreducible prime polynomials. Also finite fields would become fundamental in the TGD framework.

One of the long standing mysteries of TGD is why preferred p-adic primes, characterizing elementary particles and even more general systems, satisfy the p-adic length scale hypothesis. The proposal is that p-adic primes correspond to ramified primes as factors of discriminant D of polynomial $P(x)$. $D = P$ condition reducing discriminant to a single prime is an attractive hypothesis for preferred ramified primes.

M^8-H duality suggests that the exponent $exp(K)$ of Kähler function corresponds to a negative power D^{-k}. Spin glass character of WCW suggests that the preferred ramified primes for, say prime polynomials of a given degree, and satisfying $D = P$, have an especially large degeneracy for certain ramified primes P, which are therefore of a special physical importance.

Because of the potential importance of this idea, which emerged while writing article about my attempts to understand Langlands correpondence and its relation to TGD, I decided to write a separate article about the role of finite fields in the TGD based world order.

2 Infinite primes as a basic mathematical building block

Infinite primes [K5, K1, K4] are one of the key ideas of TGD. Their precise physical interpretation and the role in the mathematical structure of TGD has however remained unclear.

3 new ideas are be discussed. Infinite primes could define a generalization of the notion of adele; quantum arithmetics could replace $+$ and $\times$ with $\oplus$ and $\otimes$ and ordinary primes with p-adic representations of say HFFs; the polynomial Q defining an infinite prime could be identified with the polynomial P defining the space-time surface: $P = Q$.

2.1 Construction of infinite primes

Consider first the construction of infinite primes [K5].

1. At the lowest level of hierachy, infinite primes (in real sense, p-adically they have unit norm) can be defined by polynomials of the product X of all primes as an analog of Dirac vacuum.

   The decomposition of the simplest infinite primes at the lowest level are of form $aX + b$, where the terms have no common prime divisors. More concretely $a = m_1/n_F$ $b = m_0 n_F$, where n_F is square free integer analogous and the integer m_1 and n_F have no common prime divisors divisors. The divisors of m_2 are divisors of n_F and m_i has interpretation as n-boson state. Power p^k corresponds to k-boson state with momenta p. $n_F = \prod p_i$ has interpretation as many-fermion state satisfying Fermi-Dirac statistics.

   The decomposition of lowest level infinite primes to infinite and finite part has a physical analogy as kicking of fermions from Dirac sea to form the finite part of infinite prime. These states have interpretation as analogs of free states of supersymmetric arithmetic quantum field theory (QFT). There is a temptation to interpret the sum $X/n_F + n_F$ as an analog of quantum superposition. Fermion number is well-defined if one assigns the number of factors of n_F to both n_F and X/n_F.

   These infinite primes define polynomials of ordinary variable x with rational root $m_0 n_F^2/m_1$. This gives all rational roots proportional to square free integers n_F but also the roots $m_0 n_F/m_1$ correspond to infinite primes and run over all possible rational roots. This would require modification of the definition. Fermions corresponding to prime factors of n_F are kicked out of Fermi sea but some of them can be annihilated by dropping some factors of n_F. This definition looks number-theoretically more natural.

2. More general infinite primes correspond to polynomials $Q(X) = \sum_n q_n X^n$ required to define infinite integers, which are not divisible by finite primes or by powers of monomials defined by the infinite primes linear in X so that one has an irreducible polynomial having no rational roots.

   Each summand $q_n X^n$ must be an infinite integer. Note that the signs of q_n can be also negative. This requires that q_n for $n > 0$, is given by $q_n = m_{B,n}/\prod_{i=1}^{n} n_{F,i|n}$ of square free integers $n_{F,i}$ having no common divisors. Let q_0 be the finite part of infinite prime having prime divisors p_i. For given p_i, at least one of the summands $q_n X^n$ must be indivisible by p_i to guarantee the indivisibility of infinite prime by any finite prime. Therefore, for some value $n = n_0$, $\prod_{i=1}^{n} n_{F,i|n}$ must have p_i as a divisor.

   The coefficient $m_{B,n}$ representing bosonic state have no common primes with $\prod n_{F,i|n}$ and there exists no prime p dividing all coefficients $m_{B,n}$, $n > 0$ and q_0: that is there is no boson with momentum p present in all states in the sum.

   These states could have a formal interpretation as bound states of arithmetic supersymmetric QFT. The degree k of Q determines the number of particles in the bound states.

   The products of infinite primes at a given level are infinite primes with respect to the primes at the lower levels but infinite integers at their own level. Sums of infinite primes are not in general infinite primes.

   Notice that since the roots of a polynomial P are not affected by a scaling of P, irreducibility as a criterion for infinite prime property allows the scaling of the infinite prime so that one obtains an irreducible polynomial of X with integer coefficients.

3. At the next step one can form the product of all finite primes and infinite primes constructed in this manner and repeat the process as an analog to second quantization. This procedure can be repeated indefinitely. This repeated quantization a hierarchy of infinite primes, which could correspond to the hierarchy of space-time sheets.

   At the n:th hierarchy level the polynomials are polynomials of n variables X_i. A possible interpretation would be that one has families of infinite primes at the first level labelled by n_1 parameters. If the polynomials $P(x)$ at the first level define space-time surfaces, the interpretation at the level of WCW could be that one has an $n - 1$-D surface in WCW parametrized by $n - 1$ parameters with rational values and defining a kind of sub-WCW. The WCW spinor fields would be restricted to this surface of WCW.

The Dirac vacuum X brings in mind adele, which is roughly a product of p-adic number fields. The primes of infinite prime could be interpreted as labels for p-adic number fields. Even more generally, they could serve as labels for p-adic representations of various algebras and one could even consider replacing the arithmetic operations with $\oplus$ and $\otimes$ to get the quantum variants of various number fields and of adeles.

The quantum counterparts of infinite primes at the lowest and also at the higher levels of hierarchy could be seen as a generalization of adeles to quantum adeles.

2.2 Questions about infinite primes

One can ask several questions about infinite primes.

1. Could $\oplus$ and $\otimes$ replace $+$ and $-$ also for infinite primes. This would allow us to interpret the primes p as labels for algebras realized p-adically. This would give rise to quantal counterparts of infinite primes.

2. What could $+ \to \oplus$ for infinite primes mean physically? Could it make sense in adelic context? Infinite part has finite p-adic norms. The interpretation as direct sum conforms with the fermionic interpretation if the product of all finite primes is interpreted as Dirac sea. In this case, the finite and infinite parts of infinite prime would have the same fermion number.

3. Could adelization relate to the notion of infinite primes? Could one generalize quantum adeles based on $\oplus$ and $\otimes$ so that they would have parts with various degrees of infinity?

2.3 $P = Q$ hypothesis

One cannot avoid the idea that that polynomial, call it $Q(X)$, defining an infinite prime at the first level of the hierarchy, is nothing but the polynomial P defining a 4-surface in M^4 and therefore also a space-time surface. $P = Q$ would be a condition analogous to the variational principle defining preferred extremals (PEs) at the level of H.

There is however an objection.

1. $P = Q$ gives very powerful constraints on Q since it must define an infinite integer. The prime polynomials P are expected to be highly non-unique and an entire class of polynomials of fixed degree characterized by the Galois group as an invariant is in question. The same applies to polynomials Q as is easy to see: the only condition is that powers of a_kX^k defining infinite integers have no common prime factors.

2. It seems that a composite polynomial $P_n \circ ... \circ P_1$ satisfying $P_i = Q_i$ cannot define an infinite prime or even infinite integer. Even infinite integer property requires very special conditions.

3. There is however no need to assume $P_i = Q_i$ conditions. It is enough to require that there exists a composite $P_n \circ ... \circ P_1$ of prime polynomials satisfying $P_n \circ ... \circ P_1 = Q$ defining an infinite prime.

   The physical interpretation would be that the interaction spoils the infinite prime property of the composites and they become analogs of off-mass-shell particles. Exactly this occurs for bound many-particle states of particles represented by P_i represented composite polynomials $P_1 \circ ... P_n$. The roots of the composite polynomials are indeed affected for the composite. Note that also products of Q_i are infinite primes and the interpretation is as a free many-particle state formed by bound states Q_i.

There is also a second objection against $P = Q$ property.

1. The proposed physical interpretation is that the ramified primes associated with $P = Q$ correspond to the p-adic primes characterizing particles. This would mean that the ramimied primes appearing in the infinite primes at the first level of the hierarchy should be physically special.

2. The first naive guess is that for the simplest infinite primes $Q(X) = (m_1/n_F)X + m_2n_F$ at the first level, the finite part m_2n_F has an identification as the discriminant D of the polynomial $P(X)$ defining the space-time surface. This guess has no obvious generalization to higher degree polynomials $Q(X)$ and the following argument shows that it does not make sense.

   Since Q is a rational polynomial of degree 1 there is only a single rational root and discriminant defined by the differences of distinct roots is ill-defined that $Q = P$ condition would not allow the simplest infinite primes.

   Therefore one must give either of these conjectures and since $P = Q$ conjecture dictates the algebraic structure of the quantum theory for a given space-time surface, it is much more attractive.

The following argument gives $P = Q$. One can assign to polynomial P invariants as symmetric functions of the roots. They are invariants under permutation group S_n of roots containing Galois group and therefore also Galois invariants (for polynomials of second order correspond to sum and product of roots appearing as coefficients of the polynomial in the representation $x^2+bx+cx$). The polynomial Q having as coefficients these invariants is the original polynomial. This interpretation gives $P = Q$.

3 How also finite fields could define fundamental number fields in Quantum TGD?

One can represent two objections against the number theoretic vision.

1. The first problem is related to the physical interpretation of the number theoretic vision. The ramified primes p_{ram} dividing the discriminant of the rational polynomial P have a physical interpretation as p-adic primes defining p-adic length- and mass scales.

   The problem is that without further assumptions they do not correlate at all with the degree n of P. However, physical intuition suggests that they should depend on the degree of P so that a small degree n implying a low algebraic complexity should correspond to small ramified primes. This is achieved if the coefficients of P are smaller than n and thus involve only prime factors $p < n$.

2. All number fields except finite fields, that is rationals and their extension, p-adic numbers and their extensions, reals, complex numbers, quaternions, and octonsions appear at the fundamental level in TGD. Could there be a manner to make also finite fields a natural part of TGD?

These problems raise the question of whether one could pose additional conditions to the polynomials P of degree n defining 4-surfaces in M^8 with roots defining mass shells in $M^4 \subset M^8$ (complexification assumed) mapped by $M^8 - H$ duality to space-time surfaces in H.

3.1 $P = Q$ condition

One such condition was proposed in [L10]. The proposal is that infinite primes forming a hierarchy are central for quantum TGD. It is proposed that the notion of infinite prime generalizes to that of the notion of adele.

1. Infinite primes at the lowest level of the hierarchy correspond to polynomials of single variable x replaced with the product $X = \prod_p p$ of all finite primes. The coefficients of the polynomial do not have common prime divisors. At higher levels, one has polynomials of several variables satisfying analogous conditions.

2. The notion of infinite prime generalizes and one can replace the argument x with Hilbert space,group representation, or algebra and sum and product of ordinary arithmetics with direct sum $\oplus$ and tensor product $\otimes$.

3. The proposal is $P = Q$: at the lowest level of the hierarchy, the polynomial $P(x)$ defining a space-time surface corresponds to an infinite prime determined by a polynomial $Q(X)$. This would be one realization of quantum classical correspondence. This gives strong constraints to the space-time surface and one might speak of the analog of preferred extremal (PE) at the level of M^8 but does not yet give any special role for the finite fields.

4. The infinite primes at the higher level of the hierarchies correspond to polynomials $Q(x_1, x_2, ..., x_k)$ of several variables. How to assign a polynomial of a single argument and thus a 4-surface to Q? One possibility is that one does as in the case of multiple poly-zeta and performs a multiple residue integral around the pole at infinity and obtains a finite result. The remaining polynomial would define the space-time surface.

3.2 Proposal

The speculations related to the p-adicization of the ξ function associated with the Riemann zeta discussed in [L9] inspired the following proposal.

1. The integer coefficients of $P = Q$ are smaller than n. For the most general option for infinite primes, one would have irreducible polynomials equivalent by scaling with polynomials with integer coefficients smaller than n. One could say that the corresponding space-time sheet effectively lives in the ring Z_n instead of integers. For prime value $n = p$ space-time sheet would effectively "live" the finite field F_p and finite fields would gain a fundamental status in the structure of TGD.

   One could allow both signs for the coefficients as the interpretation as rationals would suggest? In this case, finite field interpretation would mean the replacement of -1 with $p - 1$.

2. The construction of the proposed polynomials is very simple. Only integers $a_n < n$, having as their factors primes $p < n$, are possible as coefficients p_n of P and p_n and the condition is that the polynomials are irreducible and therefore do not have rational roots.

   The number of polynomial coefficients is $n+1$ for an n:th order polynomial, and the number of possible values of a_k is n. This would give $(n+1)^n$ different polynomials and irreducibility poses additional restrictions. Note that the number of primes smaller than n behaves as $n/log(n)$.

The proposal would solve the two problems mentioned in the beginning.

1. For $n = p$, P would make sense in a finite field F_p if the second condition is true. Finite fields, which have been missing from the hierarchy of numbers fields, would find a natural place in TGD if this condition holds true!

2. Also an upper for ramified primes in terms of order of P emerges and for prime polynomials of order p is given by p^p. This will be discussed in more detail in the sequel.

3.2.1 How does the proposal relate to prime polynomials and polynomials having finite field interpretation?

One can invent an objection against the proposal that the reducible polynomials have coefficients smaller than the order of the polynomial. One of the basic conjectures of the number theoretic vision has been that functional composition of polynomials $P = P_2 \circ P_1$ of degrees m and n giving more complex polynomials is possible. This would give rise to evolutionary hierarchies and could also correspond to the inclusion hierarchies for hyperfinite factors of type II_1 (the additional assumption has been that the polynomials vanish at $x = 0$ that $P_0 = 0$ but this condition could be reconsidered).

Could the proposed conditions hold true for so-called prime polynomials, which are analogous to infinite primes? Prime polynomials are discussed in [L10].

1. Polynomials can be factorized into composites of prime polynomials [A1, A2] (`https://cutt.ly/HXAKDzT` and `https://cutt.ly/5XAKCe2`). A polynomial, which does not have a

functional composition to lower degree polynomials, is called a prime polynomial. It is not possible to assign to prime polynomials prime degrees except in special cases. Simple Galois groups with no normal subgroups must correspond to prime polynomials.

2. For a non-prime polynomial, the number N of the factors P_i, their degrees n_i are fixed and only their order can vary so that n_i and $n = \prod n_i$ is an invariant of a prime polynomial and of simple Galois group [A1, A2]. Note that this composition need not exist for monic polynomials even if the Galois group is not simple so that polynomial primes in the monic sense need not correspond to simple Galois groups.

Prime polynomials indeed satisfy the conditions of the proposal.

1. The degree of a composite of polynomials with orders m and n is mn. Therefore a polynomial with a prime degree p does not allow an expression as a composite of polynomials of lower orders so that any polynomial with prime order is a prime polynomial. Any irreducible polynomial with prime order is also a prime polynomial and corresponds to an infinite prime.

2. Polynomials of order m can in principle be functional composites of prime polynomials with orders, which are prime factors of m. All irreducible prime polynomials would satisfy the proposal.

3. The natural conjecture is that the functional composites of irreducible prime polynomials are irreducible. If this is the case, irreducible prime polynomials as counterparts of special infinite primes could be used to construct more general polynomials in correspondence with infinite primes.

These observations suggest the tightening of the proposal. There are two alternative additional conditions.

All physically allowed polynomials P are functional composites of the irreducible prime polynomials P of order $n = p$ or $n = p - 1$ with coefficients smaller than n. For $n = p$ one would have prime polynomials. For $n = p - 1$ the polynomials would have interpretation as polynomials in finite field.

1. The degree $n = p - 1$ required by finite field interpretation is not the same as the degree $n = p$ implied by prime polynomial interpretation. Could both interpretations make sense! Indeed, if one has $P_p = xP_{p-1}$ so that P is reducible, one has both interpretations. $D(P)$ has a general expression as a product of root differences. For $P_p = xP_{p-1}$, $D(P)$ reduces to a product of two terms: the product of roots of P_{p-1} and $D(P_{p-1})$.

   Note that it is not clear whether $P_p = xP_{p-1}$ can be a prime polynomial.

2. The functional composite $P \circ R$ of a polynomial $P = xQ$ with a polynomial R has the property that the roots of R are also the roots of P: $P \circ R$ inherits the roots of R. I have proposed that this inheritance of information could be more than analogous to genetic inheritance [L8]. One would have composition hierarchies of this kind of polynomials? Could they correspond to prime polynomials?

Therefore one can consider also a third alternative:

All physically allowed polynomials P are functional composites of the reducible prime polynomials $P = xQ$ of order $n = p$ such that Q is irreducible polynmial of order $p - 1$. In a rather precise sense, finite fields would serve as basic building blocks of the Universe.

4 Do elementary particles correspond to polynomials possessing single ramified prime?

The physical motivation for the calculation comes from p-adic mass calculations [K2] and number theoretic vision justifying them.

1. The notion of p-adic prime is central in the p-adic mass calculations. p-Adic primes define the p-adic length scales assignable to elementary particles, actually to any system. p-Adic length/mass scale defines the mass scale of the particle [K2]. p-Adic length scale hypothesis states that these primes are near powers of 2 or possibly also other small primes such as 3 (there is some evidence for this [K3]). One should find a convincing mathematical justification for the p-adic length scale hypothesis.

2. Number theoretical vision suggests the interpretation of p-adic prime as a ramified prime of an extension defined by a rational (or equivalently integer) polynomial $P = Q$ defining the space-time surface by $M^8 - H$ duality. I have proposed the interpretation of ramified primes as

3. There is a long standing interpretational problem related to ramified primes. How are elementary particles distinguished from composite particles and many-particle states?

   Could elementary particles be characterized by only a single ramified prime? Or more generally: could the ramified primes associated with the many-particle state correspond to p-adic mass scales of the particles possibly present in the many-particle state?

   If this were the case, theory would be very predictive: one could identify the polynomials that could give rise to the space-time surfaces associated with the elementary particles!

   This condition becomes even stronger if one assumes prime polynomials of degree $n = p$ or polynomials with finite field interpretation and with degree $n = p - 1$.

4.1 Calculation of ramified primes

Consider now the calculational problem.

1. One considers polynomials $P(x) = a_0+a_1x+a_2x^2+....x_nx^n$ (they define space-time surfaces in TGD by $M^8 - H$ duality). P is characterized by the vector $[a_0, a_1, ..., a_n]$. The coefficients a_i are positive or negative integers and satisfy the condition $a_i < n$. This condition is physically very relevant since it implies a correlation between the degree of P and the maximal size for its ramified primes.

2. Especially interesting values of n are primes $p = 2, 3, 5, 7....$ These correspond to prime polynomials having no functional decomposition to polynomials of lower degree.

   Also the values $n = p - 1$ are highly interesting since in this case the polynomial defines a polynomial in finite field F_p.

3. Polynomials are irreducible. This guarantees that P defines what I call infinite prime at the first level of the hierarchy.

4. Example 1: $n = p = 2$. Polynomials of degree 2. $[a_0, a_1, a_2]$. Coefficients are equal to ± 1 or 0.

   Example 2: $n = p = 3$: $[a_0, a_1, a_2, a_3]$. Coefficients are equal ± 2 , ± 1 or 0.

One must calculate the ramified primes of P. They are the primes dividing the discriminant D of P. The definition of D in terms of $[a_n, ..., a_0]$ can be found from Wikipedia (`https://en.wikipedia.org/wiki/Discriminant`). The definition in terms of root differences requires the calculation of roots and remains always approximate.

1. One considers both the polynomial

$$P(x) = a_nx^n + a_{n-1}x^{n-1} + \cdots + a_1x + a_0$$

   and its derivative

$$P'(x) = na_nx^{n-1} + (n-1)a_{n-1}x^{n-2} + \cdots + a_1$$

2. The resultant of P and P' is the determinant of the Sylvester matrix S (`https://en.wikipedia.org/wiki/Sylvester_matrix`).

   Sylvester matrix is defined as the following $(2n-1)\times(2n-1)$ matrix.

$$S = \begin{pmatrix} a_n & a_{n-1} & ... & a_0 & 0 & 0 & ... & 0 \\ 0 & a_n & a_{n-1} & ... & a_0 & 0 & ... & 0 \\ . & & & & & & & \\ . & & & & & & & \\ .0 & 0 & 0 & .... & a_n & a_{n-1} & ... & a_0 \\ na_n & (n-1)a_{n-1} & ... & a_1 & 0 & 0 & ... & 0 \\ & na_n & (n-1)a_{n-1} & ... & a_1 & 0 & ... & 0 \\ . & & & & & & & \\ . & & & & & & & \\ .0 & 0 & 0 & ..... & na_n & (n-1)a_{n-1} & ... & a_1 \end{pmatrix}$$

3. The resultant of P and P' is defined as the determinant of the Sylvester matrix:

$$Res_x(P,P') = det(S)$$

   Discriminant $Disc \equiv D$ is defined as

$$Disc \equiv D == (-1)^{n(n-1)/2}\frac{Res_x(P,P')}{a_n} = (-1)^{n(n-1)/2}\frac{det(S)}{a_n}$$

One should calculate D and find whether it has prime values. What one should do is the following.

1. One should calculate the determinant and ramified primes for polynomials or order n. $n=p$ defines prime polynomials. Order $n=p-1$ allows finite field interpretation.

2. One could study the density of polynomials in the space of arrays $[a_0,...,a_p]$ having only a single ramified prime. It might be possible to find rather large primes for reasonably small cutoff for p, say around $p=13$, since the sizes of the individual terms in D have upper bound of order p^{2p+1} and their number is $(2p+1)!$.

The calculation is very straightforward and anyone having access to programs like Mathematica can do it. Unfortunately, as a science dissident living at the income border, I cannot afford this kind of luxury.

1. Build the matrix S for arbitrary integer n. One could also restrict to the cases $n=p$ and $n=p-1$. Assume $a_k<n$.

2. Calculate the quantity $D=(-1)^{n(n-1)/2}det(S)/a_n$.

3. Calculate ramified primes as the prime factors of D.

4. For each n, one could perform a multiloop over the values of $a_k<n$. One should print the set of ramified primes or prime decomposition of D for each combination and store it in a list. One can use this program to study how ramified primes depend on $n=p$.

Also $n=p-1$ case, which would correspond to finite fields should be considered.

If one has $P_p(x)=xP_{p-1}(x)$ one can say that one has both the cases P_{p-1} and P_p. In this case, the roots of $P_{p-1}(x)$ are inherited by P_p. The formula of discriminant as a product of root differences gives the discriminant as product $D(xP(x))=\prod_k r_kD(P)=a_0D(P)$. Also the prime factors of the coefficient a_0 appear as ramified primes of $x(Px)$ besides those of $P(x)$. For $a_0=1$ the ramified primes are the same. It is enough to consider only polynomials $P_{p-1}(x)$ in this case.

4.2 Could $D = P$ correspond to a maximum of D or of maximal ramified prime P_{max} for D?

On basis of $M^8 - H$ duality [L2, L3], one can argue that the vacuum functional in WCW defined as exponent $exp(K)$ of Kähler function has a number theoretic counterpart. The most natural number theoretical invariant is the discriminant D for the polynomial $P(x)$ defining the space-time surface by $M^8 - H$ duality. This quantity makes sense also at the continuum limit based on polynomials with continuous coefficients.

One could have $exp(K) = 1/D$. An alternative identification would be as $exp(K) = 1/P_{max}$, where P_{max} is the maximal ramified prime dividing the discriminant D for $P(x)$. This makes sense only for integer coefficients of $P(x)$..

The most probable 3-surfaces correspond to maxima of $exp(K)$. A natural guess is that $D = P$ corresponds to a local maximum of D for the polynomials considered. A weaker hypothesis is that $D = P_{max}$ corresponds to a local maximum of the maximal ramified primed P_{max}.

1. The exponent of the Kähler function for the most probable space-time surfaces in $H = M^4 \times CP_2$ as analogs of Bohr orbits is a local maximum in the "world of classical worlds" (WCW). The space-time surface is that with the highest probability.

2. This conforms with the notion of cognitive representation as a discretization obtained by replacing space-time surface with sets of points, which have coordinates in the extension of rationals defined by $P(x)$. The discretization of WCW would consist of discretizations of the most probable space-time surfaces.

3. $M^8 - H$ duality and number theoretic vision [K6] suggest that the value of vacuum functional as exponent $exp(K)$ of the Kähler function is equal to the p-adic counterpart of the discriminant D for the ramified prime $D = P$: $exp(K) = 1/D$.

   $D = P$ could correspond to either a maximum of $exp(K) = 1/D$ for $D = P$ or maximum of $exp(K) = 1/P_{max}$ for the maximum of P_{max}. The latter form of the hypothesis is weaker. $D = P$ could indeed correspond to a maximum of P_{max} since all other values are at least by a factor 1/2 smaller in the vicinity of the maximum of P_{max}.

4. If the proposed connection between the Kähler function and D or P_{max} is true, one can ask whether D or P_{max} has the largest possible value for polynomials of a given degree. This is so if there is only a single local maximum. However, spin glass property, suggested to be the basic characteristic of the dynamics, suggests a counterpart energy landscape with valleys within valleys [L5] so that a large number of single ramified primes is expected for a polynomial of a given degree.

   This is not surprising. D is proportional to $det(S)$, which is the sum of $(2p+1)!$ terms which are products of $2p+1$ matrix elements. The terms in the sum tend to sum up to zero and the terms in which all matrix elements are near the largest possible value give the dominating contribution. The order of magnitude for this kind of term is p^{2p+1}. For $p = 13$ this gives 1.2×10^{30}. Since there are a large number of terms, it is possible to have considerably larger values of $D = P$ than this. Therefore one expects that physically realistic values of ramified primes,the Mersenne prime $M_{127} = 2^{127} - 1$ characterizing electrons in p-adic mass calculations, are possible to relatively small primes p.

4.3 Spin glass analogy for WCW geometry as a guide line

The spin glass analogy suggests a physics inspired interpretation of the set of the most probable 4-surfaces defined by a polynomial or even set of polynomials as a discretization of a part of WCW.

1. Spin glass corresponds to a discretized energy landscape that is a fractal and obeys ultrametric topology just like p-adic number fields. For spin glass the notion of ergodicity fails. Global thermodynamic equilibria are impossible because the system tends to stick into a potential well.

   This has spontaneous magnetization and the Higgs mechanism as a very simple analogues. Thermodynamics would suggest no magnetization since there is no preferred direction for it.

The magnetization however occurs since the thermodynamic ensemble with even distribution over all magnetization directions is not physically sensible: localization occurs.

In the case of spin glass, the situation is much more complex: instead of magnetization direction, there are an infinite number of different configurations which correspond to local minima of free energy. The system is typically caught into some local potential well containing smaller potential wells and is unable to get out of the well so that the thermal equilibrium reduces to a smaller scale. In a process known as quenching the system can be brought by reheating and cooling to an increasingly deep potential well.

2. In TGD the exponent of free energy would correspond to $exp(K)$. Number theoretic constraints suggest that it is equal to a negative power of D or P_{max}. The probabilities of individual surfaces characterized by polynomials $P(x) \leftrightarrow [a_0, ...a_k]$ would be proportional to $1/D^k$ or $1/P_{max}^k$.

   One could assign to them probabilities by normalizing these numbers by analog of partition function $Z = \sum d_D D^{-k}$ or $Z = \sum d_{P_{max}} P_{max} - k$. Here d_D *resp.* $d_{P_{max}}$ gives the degeneracy of D *resp.* P_{max} as number of polynomials with this value of D. Z is analogous to Riemann zeta at the point $s = k$ of the real axis. k is analogous to inverse temperature. This thermodynamics is however different from standard thermodynamics in which Boltzman weights are given by $exp(-E/T)$. Now Boltzmann weights would be analogous to powers E^{-k}. One has scaling invariance. Spin glasses indeed correspond to this kind of thermodynamics [L5] and in TGD framework the p-adic thermodynamics is indeed defined by a scaling generator rather than energy.

One can assign to polynomials of a given degree k or degree k smaller than maximum value k_{max} an analog of Riemann zeta, which might be perhaps called TGD zeta.

1. All these zeta functions have a finite number of terms. Also the "full" TGD zeta obtained at the limit $k_{max} \to \infty$ could make sense. The degree k or its maximal value k_{max} could define the analog for the inverse temperature. This gives a nice connection with the speculations [L9] inspired by the geometry-number theory duality coded by $M^8 - H$ duality in the TGD framework and by Langlands correspondence in pure mathematics.

2. One has also other interpretations for k. The degree k of polynomial $P(x)$ is much smaller than the largest ramified prime P_{max} associated with it. On the other hand, the p-adic length scale hypothesis states that the p-adic primes are near to powers of small primes p, in particular $p = 2$. This suggests that for these physically preferred p-adic primes P, having a very large degeneracy factor $d(P)$, the relationship $P \simeq 2^k$ holds true.

   The interpretation of k as the counterpart of the running Kähler coupling strength α_K is also natural and the quantization of $1/alpha_K$ to integer values is natural by the number theoretic universality. This conformas with the generic logarithmic depends of the Kähler coupling strength on the p-adic length scale. Therefore the logarithmic p-adic coupling constant evolution for α_K could be equivalent with the p-adic length scale hypothesis!

3. Spin glass is never in a complete thermal equilibrium since ergodic theorem fails for it. One can consider various analogs of spin glass ensembles assuming the existence of temperature as a parameter.

   In the case of TGD, the running Kähler coupling strength $1/\alpha_K$ would serve as a temperature like parameter. At the high temperature limit (short scales), analogies of spin glass ensembles involving several degrees $d(P)$ for polynomials $P(x)$ can be considered. At low temperatures (long scales), single degree becomes possible and one can also consider a localization around a single configuration such as a polynomial with $D = P$. Elementary particles could correspond to maximal localization around $D = P$.

   At the number theoretic side, the integer k is analogous to the argument s of the zeta function, and analogous to inverse temperature. $s = 1$ for ζ corresponds to a high temperature limit at which ζ diverges. $k = 1$ would be analogous to the inverse of maximal temperature known as Hagedorn temperature in string models. Large values of k correspond to low temperatures.

4. How does this picture relate to p-adic thermodynamics? In p-adic thermodynamics, one considers single P so that localization is maximal apart from the degeneracy factor d. The p-adic temperature for fermions corresponds to maximal p-adic temperature $T_p = 1$. On the other hand, the localization around single P would suggest a minimal temperature. One should be however cautious in comparisons since the thermodynamics in question are totally different: one with p-adic variants of Boltzmann weights and the second with their scaling covariant analogs.

5. A longstanding open problem of TGD is what determines the preferred ramified primes suggested by p-adic mass calculations to be near powers of small primes, in particular $p = 2$. What these ramified primes correspond to preferred valleys of the spin glass energy landscape? What comes to mind is that some values of $D = P$ (or P_{max}) do occur with a large degeneracy d_D (or $d_{P_{max}}$). Preferred ramified primes could correspond to especially large values of d. The quenching-like processes (cooling and reheating) defined by the cosmic evolution leading to lower temperatures would tend to localize the elementary particles to the wells corresponding to ramified primes satisfying p-adic length scale hypothesis.

4.4 The ultrametric topology of discretized WCW

Can one give a concrete interpretation for the ultrametricity of the spin glass energy landscape in the case of WCW?

Ultrametricity can be formulated as a condition for a distance function $d(A, B)$ defined between two valleys of spin glass energy landscape. The distance along a given path from point A to B is the height of the highest mountain at the path and is minimized for the shortest path (MiniMax principle.

It is easy to see that the ultrametricity condition $d_{AB} \leq Max\{d(A, C), d(C, B)\}$ is satisfied. In the recent case, the value of D for a given $P(x)$ in the discretization of WCW by polynomials should naturally define an integer valued height h of the mountain.

There are several questions to be answered.

1. Ultrametricity means the presence of very many p-adic topologies in WCW discretized in terms of polynomials. Somehow this number theoretic WCW decomposes into subsets with different p-adic topologies.

   It would be very natural to assign p-adic topology to some, or more naturally, to all ramified primes dividing the discriminant of a given polynomial $P(x)$. Here the physical picture generalizing the notion of Feynman diagram comes to rescue. The lines of the Feynman diagram become 4-surfaces representing particles and vertices become 4-surfaces defining interaction regions in which external particles arrive.

   Free particles would correspond to $D = P$ and vertices as space-time regions where interactions between particles take place would correspond to discriminants D having a decomposition to several primes labelling the external particles of the Feynman diagram. This would solve the longstanding problem of how particles characterized by different values of p-adic primes P can interact in the same vertex.

2. The notion of p-adic nearness is very different from its real counterpart. Two points of WCW as polynomials can be very far from each other in the real sense but be close to each other p-adically. It is natural to arrange the points of the sub-WCW WCW_P defined by a subset of polynomials to subsets such that points belonging to the same subset have a common ramified prime P.

   The points of WCW_P would allow p-adic topology characterized by P and consist of both particles characterized by $D = P$ and vertices with D divided by P. The subsets WCW_P would intersect along the 4-surfaces with D divided by several primes P.

3. Between the points of this set one can define the p-adic distance function $d_P(A, B)$ using the above general definition using D as a positive integer defining the mountain height. There are two options for the paths involved.

The paths could be paths in WCW and go also through points of discretized WCW, which do not belong to WCW_P or could be contained in WCW_P. These metrics would be analogous to the distance between two points of the space-time surface defined by the shortest path in $X^4 \subset M^4 \times CP_2$ (metric of H) and by the shortest path along X^4 (induced metric).

4. The height function h for a mountain defined by polynomial $P(x)$ with discriminant D could be obtained from D identified as a P-adic number. If t h is identified as the P-adic norm of D, the height function is very rough. A more refined distance function is obtained by the canonical identification $I : \sum x_n p^n \rightarrow \sum x_n p^{-n}$ used in the p-adic mass calculations [**?**]apping $h_P = D = \sum h_n P^n$ to $h_R = h_n P^{-n}$. I maps p-adic numbers to reals in a continuous manner and takes p-adic numbers P^n to P^{-n}.

In the standard ontology, one can predict scattering rates but particle densities cannot be predicted without further assumptions. In ZEO both can be predicted since there is a complete democracy between particles and particle reactions. Physical event as a superposition of deterministic time evolutions becomes the basic notion and both particles and particle reactions correspond to physical events.

The statistical model represents the probabilities of physical events within the quantization volume defined by CD. Particle characterized by $D = P$ and corresponds to a scattering event with a single incoming and outgoing particle, and the statistical model predicts the densities of various particles as probabilities of $D = P$ events. Genuine particle reaction corresponds to $D = \prod P_i$ and the model gives the probabilities of observing these events within CD.

4.5 How to study the hypothesis?

There are several ways to study the hypothesis.

1. One could think of finding the polynomial corresponding to the maximum of $D = P$ by considering the coefficients of $P(x)$ as real variables in some region of the coefficient space and finding the nearest polynomial with integer coefficients.

2. One could consider the maximization of D by keeping the polynomial coefficients as real numbers with magnitude below p, say $p = 13$. At maximum the partial derivative of D vanishes unless the point is at the boundary of the region of allowed values. This boundary for allowed values is a $p + 1$-cube and consists of parts for which some coefficients a_k have the maximal value $\pm p$.

3. One could check what one obtains by putting some values of a_k to $a_k = p$. For $k = p$ this would give for the derivative $P' = [pa_p, ...]$ so $a_k = p$ for k near p is favoured.

4. A very simple test for the hypothesis that $D = P$ holds true for a) the maxima of D or b) for the maximal primes P_{max} of D) would be based on small variations of a polynomial $P(x) \leftrightarrow [a_0, a_1, ..., a_n]$, which corresponds to $D = P$: these should be relatively easy to find.

   One could vary the coefficients a_i in the range $a_i + \{-1, 0, +1\}$. This would give 3^{p+1} trials for a prime polynomial $P_p(x)$: this is a rather reasonable number. Finding only a single P for which this is not the case, would kill the hypothesis. If $D < P_0$ is true for all variations, the hypothesis could be tested for further cases $D = P$.

5 Gödel's Undecidability Theorem and TGD

$M^8 - H$ duality [L2, L3] relates number theoretic and geometric views of physics [L9, **?**]. Gödel's incompleteness theorem relates to number theory. Could one consider a geometric and physical interpretation of Gödel's incompleteness theorem in the TGD framework?

The following response to Lawrence Crowell in the discussion group "The Road to Unifying Relativistic and Quantum Theories" indeed suggests such an interpretation. The topic of discussion related to Gödel's theorem and its possible connection with consciousness proposed by Penrose [J1].

My own view is that quantum jump as state function reduction (SFR) cannot reduce to a deterministic computation and can be seen as a moment of re-creation or discovery of a new truth not following from an existing axiomatic system summarizing the truths already discovered. Zero energy ontology allows to solve the basic paradox of quantum measurement theory [L1, L4].

My emphasis in the sequel is on how the number theoretic vision of the TGD [L2, L3, L9, L7] proposed to provide a mathematical description of (also mathematical) cognition could allow us to interpret the unprovable Gödel sentence and its negation. There is no need to emphasize that these considerations are highly speculative.

5.1 What Gödel's theorem could mean in the TGD Universe?

The basic question concerns the physical and consciousness theoretic interpretation of the Göedel's undecidability theorem in the TGD Universe.

5.1.1 Some TGD background

In the following some necessary conceptual background will be introduced.

1. The polynomials P define space-time surfaces and one possible interpretation is that the ramified primes of P define external particles for a space-time region representing particle scattering. The polynomials P which reduce to single ramified prime would represent forward scattering of a single "elementary" particle.

2. In zero energy ontology (ZEO) [L6], ordinary quantum states are replaced by superpositions of almost deterministic time evolutions so that also "elementary" particle would correspond to a scattering event.

   What exists would be events, and what we call states would reduce to particular events. One could call ZEO as an "eastern" ontology. ZEO would predict not only scattering events but densities of particles as single particle scattering events inside a given causal diamond causal diamond (CD) representing quantization volume [L7].

3. Single space-time surface in $H = M^4 \times CP_2$ is obtained by $M^8 - H$ duality from a 4-surface in M^8 and satisfies in H almost exact holography forced by the general coordinate invariance. At the level of M^8 its preimage obeys number theoretic dynamics forcing the associativity of its normal space [L2, L3]. This 4-surface connects mass shells $H^3_a \subset M^4 \subset M^8$, which correspond to the roots of a polynomial P with integer coefficients.

   Almost holographic space-time surfaces represent a profound deviation from the standard physics view. They can be regarded as analogs of computations or proofs of theorems, counterparts of behaviors in neuroscience, and counterparts of biological functions. Quantum states are their superpositions. Number theoretically realized finite measurement resolution means that the superposition of space-time surfaces having the same theoretic discretization effectively represents a single space-time surface.

   Therefore the idea that the SFRs localizing the state to this kind of surfaces, could represent a physical realization of a mathematical theorem, looks natural. Gödel's theorem could correspond to a space-time surface to which localization by SFR is not possible.

4. The additional hypothesis [L7] motivated by $M^8 - H$ duality is that the values of WCW Kähler function H for its maxima defined by preferred extremals in H and analogous to Bohr orbits have values of vacuun functional $exp(K)$, which is equal to $1/D^k$, where the integer k defines analog of temperature and is inversely proportional the discrete running Kähler coupling strength $1/\alpha_k$. Zero energy states correspond to scattering amplitudes so that this would predict the scattering probabilities in WCW geometric degrees of freedom.

   For elementary particles sfor which D reduces to a single prime $D = P$, $1/\alpha_k$ would roughly behave like logarith of P. This would unify the logarithmic dependence of p-adic coupling constant evolution with the p-adic length scale hypothesis [L7].

5.1.2 Gödel numbering in TGD framework and the first for guess for the undecidable statement

Polynomials with integer coefficients (no common factor coefficients) to which all rational polynomials can be scaled without changing the roots define the space-time surfaces. One can pose additional physically well-motivated conditions to these polynomials. These conditions will be discussed later.

What the assignment of a Gödel number to this kind of polynomial could mean? Most of the classical physical content, if not all of it, can be coded by the coefficients $[a_0, , ...a_N]$ of the polynomial.

The Gödel number G associated with polynomial P would be rather naturally

$$G(P) = p_0^{a_0} p_2^{a_1} ... p_N^{a_N} \quad ,$$

where p_i is i:th prime and is an injection. Note that one has $p_0 = 2, p_1 = 3, p_2 = 5, ...$

The discriminant D (`https://en.wikipedia.org/wiki/Discriminant`) is the determinant of an $(2N-1) \times (2N-1)$-matrix defined by P and its derivative dP/dx $([a_1, 2a_2, ..., Na_N])$ and is an integer decomposing to a product of ramified primes of P.

The first guess for Gödels' undecidable statement would that there exist a polynomial P for which one has $G = D$. The number D coding a sentence, whatever it is, would be its own Gödel number. Why this guess? At least this statement is short. Can this statement be undecidable? What undecidability could mean physically?

1. The equation involves both D as a polynomial of a_i and G involving transcendental functions $p_i^{a_i}$ (essentially exponential functions) so that one goes outside the realm of rationals and algebraic numbers.

2. $D = G$ is an analogue of Diophantine equation for $a_1, ..., a_N$ and both powers and exponential $p_i^{a_i}$ appear. If the coefficients a_i are allowed to be a complex numbers, one can ask whether the complex solutions of $G = D$ could form an N-1-D manifold. One can however assume this since $p_i^{a_i}$ leads outside the realm of algebraic numbers and one does not have a polynomial equation.

3. The existence of an integer solution to $D = G$ would mean that the primes p_i for which a_i are non-vanishing, correspond to ramified primes of P with multiplicity a_i so that the polynomials would be very special if solutions exist.

4. It might be possible to solve the equation for any finite field G_p, that is in modulo P approximation. Here one can use Fermat's little theorem $p_i^p = p_i \ mod \ p$. If integer solutions exist, they exist for every G_p.

5.1.3 About the number theoretical content of $G = D$ sentence

It is interesting to look at the number theoretical content of $G = D$ sentence.

1. Integer D would express the sentence/statement. D codes for the ramified primes. Their number is finite and we know them once we know P. Does the unprovable Gödel sentence say that there exists a polynomial P of some degree N, whose ramified primes are the primes p_i associated with a_i? Or does it say that there exists a polynomial satisfying $G = D$ in the set of polynomials of fixed degree N. Note that a priori one does not pose constraints on the values of coefficients a_i.

2. Is it that we cannot prove the existence of integer solution a_i to $P = G$ using a finite computation. Is this due to the appearance of the functions $p_i^{a_i}$ or allowance of arbitrarily large coefficients a_i? The p-adic solutions associated with finite field solutions have an infinite number of coefficients and can be p-adic transcendentals rather than rationals having periodic pinary extensions.

3. Polynomials of degree N satisfying $D = G$ are very special. The ramified primes are contained in a set of $N + 1$ first primes p_i so that D is rather small unless the coefficients a_i are

large. D is a determinant of $2N-1 \times 2N-1$ matrix so that its maximum value increases rapidly with N even when one poses the constraint $a_i < N$. Rough estimates and explicit numerical calculations demonstrate that determinants involving very large primes are possible, in particular those involving single ramified prime identified as analogues of elementary particles, D can reduce to single large prime: $D = P$.

What about the polynomials P in the vicinity of points of the space of polynomials of degree N satisfying $D = 0$: they correspond to $N+1$ ramified primes, which are minimal (note that the number of roots is N). D is a product of the root differences and 2 or more roots coincide for $D = 0$. D is a smooth function of real arguments restricted to the integer coefficients. The value of D in the neighborhood of $D = 0$ can be however rather large. Note that the proposed Gödel numbering fails for $D = 0$, and therefore makes sense only for polynomials without multiple roots.

4. For $D(P) = 0$ one has a problem with the equation $G = D$. $G(P)$ is well-defined also now. The condition $D(P) = 0 = G(P)$ does not however make sense. The first guess is that for 2 identical roots, P is replaced with dP/dx in the definition of D: $D(P) --> D(dP/dx)$. D is nonvanishing and the ramified primes p_i do exist for dP/dx. Therefore the condition $D(dP/dx) = G(P)$ makes sense. For N identical roots one must use have $D(d^{n-1}P/dx^{n-1}) = G(P)$.

5.1.4 About the physical interpretation of the undecidability

What about the physical interpretation of the undecidabililty in the TGD Universe? What kind of scattering events would these analogues of Gödel sentences correspond? Representations of new mathematical axioms as scattering events, not provable from existing axioms, perhaps?

Exactly what we cannot prove to be true or not true for the possibly existing very special polynomials satisfying $G = D$? What could the $G = D$ sentece state? What "proving" could mean from the point of physics and TGD view of consciousness? Could it mean a conscious experience of proof as a localization to the corresponding space-time surface in WCW? The almost deterministic space-time surface would represent the almost deterministic sequence of logical steps for the proof?

Could $G = D$ sentence be a space-time surface to which a localization in WCW is not possible for the simple reason that the additional natural physical conditions on the physical states do not allow its existence in superpositions definition zero energy states?

1. In TGD, the hypothesis [L7] that the coefficients of polynomials of degree N are smaller than N, is physically very natural and would make the number of polynomials to be considered finite so that in this case one can check the existence of a $G = D$ sentence in a finite time. It looks rather plausible that for given N, no $G = D$ sentence, which satisfies the conditions $a_i \leq N$, does exist.

2. One can of course criticize the hypothesis $a_i \leq N$ implying a strong correlation between the degree N of P and the maximal size of ramified primes of P identified as p-adic primes characterizing elementary particles. One can argue that in absence of this correlation predictivity is lost. This hypothesis also makes also finite fields basic building bricks of number theoretic vision of TGD [L7].

3. Could this give rise to a realization of undecidability at the level of conscious experience and cognition relying on number theoretic notions? How?

   Quantum states are superpositions of space-time surfaces determined by polynomials P and if the holography of consciousness is true, conscious experience reflects the number theoretic properties of these polynomials if associated to a localization to a given polynomial P in a "small" SFR (SSFR). This would be position measurement in the "world of classical worlds" (WCW)? The proof of the statement $G = D$ would mean that a cognizing system becomes conscious of the $G = D$ space-time surface by a localization to it.

   Suppose that for a given finite N and condition $a_i \leq N$, $G = D$ sentences do not exist. Hence one can say that $G = D$ sentences go outside the axiomatic system realized in terms of the polynomials considered. Even the space of all allowed polynomials identified as a union of spaces with varying value for degree N would not allow this. $G = D$ sentences would be undecidable by the condition $a_i \leq N$.

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