About information thermodynamics and Maxwell's demon in TGD

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Abstract

Information thermodynamics is a generalization of thermodynamics to quantum systems and includes information as an analogy of negative entropy. This leads to a generalization of the second law in which the presence of quantum information is taken into account. Whether this information corresponds to conscious information, is left open. In an article published by Minagawa et al in Nature, a more rigorous proof than before is represented for the statement that the second law of thermodynamics is also valid in quantum theory with information included. The presence of information makes possible an apparent local violation of the second law in the sense that the system can do more work than the Carnot law allows. However, Maxwell's demon requires metabolic energy to function and it loses it when demonizing. This energy must be compensated and the conclusion is that the second law of thermodynamics is valid.

Contents

1 Introduction

Information thermodynamics includes information as an analogy of negative entropy. The associated temperature can be assumed to be the same as the usual temperature but this need not be the case. Information thermodynamics leads to a generalization of the second law taking into accout the presence of quantum information. Whether this information corresponds to conscious information, is left open.

Sciencedaily article (see this) tells about the article of Minagawa et al [B3] (see this) published in Nature, in which a more rigorous proof than before is represented for the statement that that the second law of thermodynamics is also valid in quantum theory with information included. The

presence of information makes possible an apparent local violation of the second law in the sense that the system can do more work than the Carnot law allows. However, Maxwell's demon requires metabolic energy to function and it loses it when demonizing. This energy must be compensated and the conclusion is that the second law of thermodynamics is valid.

I have discussed Maxwell's demon earlier in [K1]. In the following information dynamics and Maxwell's demon are discussed in light of the recent results related to TGD [L9, L11, L17, L13, L15]. The discussion relies on the geometric vision of physics involving holography= holomorphy principle and the number theoretic vision of physics involving p-adic number fields and adeles as mathematical correlates for cognition and the evolutionary hierarchy of extensions of rationals. Negentropy Maximization Principle (NMP) for cognitive information replacing second law and implying it. Zero energy ontology (ZEO) provides the new quantum ontology.

2 What could be the TGD version of Maxwell's demon?

I have discussed Maxwell's demon earlier in [K1]. The following discussion takes into account the recent progress in some key aspects of TGD [L9, L11, L17, L13, L15].

2.1 Some basic ideas of TGD relevant to Maxwell's demon

2.1.1 Geometric vision

Consider first briefly the geometric vision.

1. In the classical TGD, holography= holomorphy vision is a new element not present in the earlier discussion of Maxwell's demon discussed in [K1]. Space time surfaces as roots of analytic function pairs $f = (f_1, f_2) : H = M^4 \times CP_2 \to C^2$ with Taylor coefficients in some extension E of rationals provide exact solution of field equations by reducing them from partial differential equations to algebraic equations. [L9] Polynomial solutions are obtained as an important special case.

   Also the roots $g \circ f = (0,0)$, $g : C^2 \to C^2$ define space-time surfaces. The hierarchy obtained as composites of maps g gives rise to a hierarchy of field bodies. This hierarchy of maps of maps of ... is analogous to an abstraction hierarchy. For $g(0,0) = (0,0)$ the lowest level $(f_1, f_2) = (0,0)$ belongs to the hierarchy [L17].

   The algebraic complexity of the surfaces increases with the number of composites g_i and their inherent complexity measured by degrees with respect to the 3 complex coordinates of H. When g reduces to map $C \to C$ one has ordinary polynomials and one can assign Galois group and ramified primes to it. The "world of classical worlds" (WCW) decomposes to a union of sub-WCWs with f_2 fixed.

2. Field/field body [L4, L6] serves as a carrier phases of the ordinary matter with non-standard value of effective Planck constant $h_{eff} \geq h$ making it a quantum coherent system in arbitrarily long scales. The proposal is that h_{eff} corresponds to the dimension of an algebraic extension of rationals as the order of the Galois group. In the TGD inspired quantum biology, the temperature of the field body is not necessarily the same as the temperature of the biological body, but could be lower and would gradually increase with aging [L18] so that the field body would gradually lose control.

3. Zero energy ontology (ZEO) [L3, L2], forced by the holography, in turn forced by the general coordinate invariance, makes classical physics an exact part of quantum TGD.

   Holography involves space-time surfaces identified as classical Bohr orbits for particles of 3-surfaces as generalization of point-like particles and localized inside CD. These Bohr orbits are slightly non-deterministic already for 2-dimensional minimal surfaces. This forces the replacement of quantum states with superpositions of Bohr orbits and brings in new degrees of freedom related to classical non-determinism. These degrees of freedom are essential for understanding cognition. The identification of quantum states as superpositions of Bohr

orbits allows us to solve the basic problem of quantum measurement theory. In ZEO both arrows of time are possible in all scales.

The hierarchy of causal diamonds $CD = cd \times CP_2$, where cd is causal diamond of M^4 is the geometric correlate of ZEO. CD has interpretation as a 4-D perceptive field of a conscious entity associated with the quantum superpositions of 4-surfaces inside CD. CDs form a scale hierarchy [L8].

In the TGD framework, information means potentially conscious information and involves TGD view of memory based on the classical non-determinism [L10].

2.1.2 Number theoretic vision and the two Galois groups

Number theoretic vision is complementary to the geometric view about TGD. p-Adicization and adelization of the mahematical correlates of cognition is the key idea. Negentropy could correspond to information in information thermodynamics. The production of negentropy requires metabolic energy. This view leads to the proposal of negentropy maximization principle [K2] [L7]. Cognitive negentropy as the sum of p-adic negentropies increases, but so does real entropy. This fits [L1] [K1] with Jeremy England's observations [I3]. Classical non-determinism could correspond to p-adic non-determinism.

In the TGD framework, one can speak of the Galois group in two different senses [L9, L15, L17]. It is convenient to speak about internal Galois group and external Galois group.

1. Internal Galois group

The 4-D Galois group, the internal Galois group, is assumed to permute the regions of a single connected component of the space-time surface realized as roots of the pair (f_1, f_2) defining the space-time surface. The internal Galois group would act as analytic flows of H transforming the regions as roots to ech other so that the action is analogous to that of a braid group.

1. It is easy to see that the space-time surface in general consists of several disjoint regions if (f_1, f_2) is expressible as the composite $(f_1, f_2) = (g_1(h_1, h_2), g_2(h_1, h_2))$. In this case the space-time surface is union of disjoint surfaces $h_i = r_i$, where r_i correspond to the roots of g_i. The permutations of the roots for a connected component of the space-time surface would realized as analogs of braidings.

2. The space-time regions identified as roots of (f_1, f_2) for a single connected component would have string world sheets as interfaces having hypercomplex time coordinates u, v. Suppose that there are n string world sheets. The number of string world sheets/folds can be larger than n. If folds are between any pair i, j are present then the number of folds cannot be larger than $(n-1)n$: in this case all pairs i, j would have two folds. Circle is a simple example: it has 2 sheets and 2-folds: 1,2 and 2,1.

   Since the M^4 complex coordinates w and roots as its values labelling the string world sheets are in general complex, one can say that the fold is complexified. For a cusp (see this) the two folds can be ordered. Fold would now involve a string world sheet and cusp would combine two folds. At the vertex of the cusp where 3 roots co-incide, two folds would disappear. This suggests that the string world sheets connect at their ends associated with the disappearing folds and form a single string world sheet.

3. Catastrophe theory suggests that all catastrophes and hence also the space-time surfaces can be constructed from complexified cusps. The folds, which appear on a cloth, can be ordered. If so, folds between roots $i, i+1$ and $i-1, i$ are possible and would come from a single cusp but folds with $|i-j \geq 1$ would not be possible. This could give rise to the ordering of the roots w_i. Does this mean that the Galois group is cyclic?

4. This brings in mind twistor amplitudes and planar diagrams, which correspond to Feynman diagrams with no crossing lines and therefore embeddable in plane. Non-planar Feynman diagrams are a problem of the twistor Grasmannian approach [B2, B1] since they have no twistorial representation. The Feynman diagrams with crossing lines can be embedded in the plane with holes, whose boundaries are connected by cylinders as kinds of wormholes.

In string models, the corresponding diagrams involve this kind of wormholes. This suggests that if the 2-D projection of the space-time sheets with constant values of hypercomplex coordinates has a topology with a genus g larger than 0, the space-time surface contains wormholes connecting roots with $|i-j \geq 1$. In this case also the generalized Galois group is non-Abelian. Wormhole contacts defining Euclidean regions (CP_2 type extremals) could be such connections.

To include wormhole contacts as connectors of the Minkowskian space-time sheets, one should allow besides the Minkowskian folds also the presence of the Euclidean CP_2 type extremals with a light-like M^4 curve, possibly geodesic, as M^4 projection. For these Euclidean regions the string world sheet would reduce to this curve since the second hypercomplex coordinate would be constant.

The internal Galois group could relate to the TGD view of topological qubits [L17].

1. The quantum-mechanical transfer of fermions between regions corresponding to roots of (f_1, f_2) does not require a continuous path. Classical transfer requires a path going through a fold at which the two roots as space-time regions meet. Fold corresponds to a boundary of a string world sheet identified as fermion line. Folds are labelled by the values of the complex coordinate w having interpretation as roots.

2. There is a direct analogy to the case of condensed matter majorana fermions suggested to define topological qubits. For a Majorana fermion two branches of the Fermi surface touch each other at point and the energy difference for the branches is zero at this point. Majorana fermions are assigned with these points and they would be located at the ends of a wire [L17]. In the TGD framework the folds would correspond to the seats of topological qubits.

2. Outer Galois group

The element-wise multiplication of the function for pairs (f_1, f_2) is essential for the identification of the outer Galois group and gives an algebra, which is enough for identifying the Galois group as group of automorphisms for the algebraic extension of rationals involved. Outer Galois group permutes the roots of g, which are algebraic numbers in the extension of E and label the disjoint components of the spacetime surfaces. These two Galois groups commute and the outer Galois group relates to the internal Galois group in the same way as the Galois group of an extension of rationals to the Galois group of complex rations generated by complex conjugation.

The outer Galois group is natural for the TGD realization of the Langlands duality, discussed from the TGD point of view in [L9, L14].

1. A simpler version of the outer Galois group is associated with dynamical complex analytic symmetries $g : C \to C$: $(f_1, f_2) \to (g_1 \circ f_1, f_2)$. Here g_1 does not have a parametric dependence on f_2. The outer Galois group relates to each other *disjoint* space-time surfaces. When g reduces to map $g : C \to C$, one can assign to it an ordinary Galois group relating to each other the disjoint roots of $g \circ f$ realized as disjoint 4-surfaces $(f_1, f_2) = (r_1, 0)$.

2. The notion of outer Galois group generalizes to the general situation $g = (g_1, g_2)$. Also now the roots of $g \circ f$ are disjoint space-time surfaces representing roots as pairs of algebraic numbers $(f_1, f_2) = (r_{i,1}, r_{i,2})$. Is it possible to assign to the roots the analog of the Galois group?

   This group should act as a group of automorphisms of some algebraic structure. This structure cannot be a field but algebra structure is enough. These arithmetic operations would be component-wise sum $(a, b) + (c + d) = (a + c, b + d)$ and componentwise multiplication $(a, b) * (c, d) = (ac, bd)$. The basic algebra would correspond to the points of $(x, y) \in E^2$ or rationals and the extension would be generated by the pairs $(f_1, f_2) = (r_{i,1}, r_{i,2})$. This structure has an automorphism group and would serve as a Galois group. The dimension of the extension of E^2 could define the value of the effective Planck constant.

   Also the notion of discriminant can be generalized to a pair (D_1, D_2) of discriminants using the component-wise product for the differences of root pairs. Could D_i be decomposed to a product of powers of algebraic primes of the extension of E^2?

3. Some implications

The number theoretic notions have profound implications.

1. In [L9] the idea that the space-time surfaces can be regarded as numbers was discussed. For a given g, one can indeed construct polynomials having any for algebraic numbers in the extension F of E defined by g. g itself can be represented in terms of its n roots $r_i = (r_{i,1}, r_{i,2})$, $i = 1, n$ represented as space-time surfaces as a product $\prod_i (f_1 - r_{i,1}, f_2 - r_{i,2})$ of pairs of monomials. One can generalize this construction by replacing the pairs $(r_{i,1}, r_{i,2})$ with any pair of algebraic numbers in F. Therefore all algebraic numbers in F can be represented as space-time surfaces. Also the sets formed by numbers in F can be represented as unions of the corresponding space-time surfaces.

2. This picture also leads to a vision about physics laws as being analogous to laws of logic and time evolution of the physical system as analogous to a proof of theorem [L15]. Different meta levels defined by the maps $g : C^2 \to C^2$ are analogous to hierarchy of statements about statements in mathematics. This applies also to the more general maps. The interpretation is that the surfaces at the higher levels of the meta hierarchy represent statements about the surfaces $(f_1, f_2) = (0, 0)$ at the lowest level of the hierarchy.

3. The creation of algebraic complexity, i.e. increasing the value of h_{eff}, requires metabolic energy. The value of h_{eff} tends to spontaneously decrease, which gives rise to a dissipation as a competing effect and one should understand how these two tendencies relate to each other.

4. Negentropy Maximization principle [L7] states that the algebraic complexity measured by the sum of p-adic negentropies increases in a statistical sense during the number theoretic evolution and NMP states this fact. Also the ordinary entropy increases as a result of the increase of the negentropy and this conforms with the view of Jeremy England [I3] [L1]. The maximum value for h_{eff} partially characterizes algebraic complexity. Also Galois groups, the degree(s) of the polynomials defining the space-time surface, and ramified primes (when they are defined) characterize the complexity. Galois groups generalize the group Z_2 assigned with condensed matter fermions in topological quantum computation [L17].

2.2 The TGD view of Maxwell's demon

The basic vision is as follows.

1. A field body can act as a Maxwell's demon. As a carrier of potentially conscious information realized as memories about previous SSFRs [L10], the field body can transfer negentropy, basically energy, to lower levels and seemingly help to break the second law. As a result, an additional term from information to the basic equation expressing the second law. The h_{eff} for the field body however decreases in the process.

   Also the classical fields associated with the field body can do work on the biological body and the classical gravitational/electric fields are characterized by gravitational/electric Planck constants [L4, L6].

2. In presence of the field bodies, perhaps assignable to the hierarchy of abstractions defined by the maps g, more work can be obtained from the system than the second law would otherwise allow. This is only apparent because the h_{eff} of the field body decreases so that the algebraic complexity measuring the level of consciousness decreases. Therefore h_{eff} must be increased to its original value. Metabolic energy is needed for this purpose.

Consider now the TGD view of Maxwell's demon as a conscious entity in light of the recent results not yet taken into account in the discussion of [L12].

1. Consider first the notion of a cognitive measurement [L12]. The Galois group for $g_1 \circ g_2 \circ ...$, $g_i : C \to C$ is characterized by a hierarchy of coset groups defined by the hierarchy of its normal subgroups. The irreps of the Galois group can be decomposed to tensor products

of the coset groups and the entanglement between the coset groups can be measured in cognition SFRs.

In particular, the hierarchy formed by functional composition of polynomials $g : C \to C$ is accompanied by a hierarchy of extensions of extensions ... of E and the hierarchy of normal subgroups for the Galois groups.

2. Prime groups are simple groups having no normal groups and prime polynomials do not allow functional decomposition $P \circ Q$. If the degree of the polynomial is prime this is the case but this is not a necessary condition. Space-time surfaces of this kind are fundamental objects and the polynomial in question would have prime degree with respect to the 3 complex coordinates of H. The composites formed of maps g and of these fundamental function pairs f would define cognitive representations of the surface defined by f as kind of statements about statements. An interesting question is whether these surfaces could correspond to elementary particles. The primes orders of polynomials involved do not probably correspond to p-adic primes assigned in p-adic mass calculations to elementary particles and identified as ramified primes [L5].

3. What happens when the value of h_{eff} descreases? Does it decrease only apparently? If the highest levels in the tensor product of irreps of the coset groups become singlets, these levels effectively drop away. Or could the space-time surface itself become simpler as some maps g in the composite $g_1 \circ g_2$... become identity maps? Field body would lose some of its levels. Indeed, in the TGD based view of biocatalysis, the temporary reduction of h_{eff} is essential for the biocatalysis [L16].

2.3 How could the time reversal in BSFR relate to the second law?

Time reversal in BSFRs represents new physics. What are the implications?

1. Entanglement entropy and p-adic negentropies are associated with a pair of systems. Thermodynamic entropy is associated with an ensemble. A single BSFR cannot reduce ensemble entropy. It reduces entanglement entropy. Quantum entanglement with the environment is the cause of BSFR. Ensemble entropy, however, corresponds to entanglement entropy after a quantum measurement when quantum entanglement has disappeared.

2. In the ZEO based theory of consciousness, falling asleep (or biological death) corresponds to a BSFR and waking up to another BSFR. Sleeping restores resources and heals. What does this mean? Does the field body gain new metabolic energy resources that appear after the second BSFR? Does the BSFR violate the second law or does the energy needed come from outside the process as metabolic energy?

   During sleep, metabolic energy is not used for normal bodily purposes such as movement and sensation. It could go to the field body to restore the values of h_{eff} to their original values. For example, protons are transferred back to dark protons by the Pollack effect. That would require metabolic energy. This would be visible as the presence of an unknown energy sink during sleep. Metabolic energy consumption would not be reduced.

   During sleep, the second law applies in the opposite direction of time. This would only allow for an *apparent* violation of the second law.

3. BSFR would correspond to the loss of entanglement between the system and the environment, which for an ensemble means an increase in ordinary entropy. The produce thermodynamic entropy would be equal to as entanglement entropy transformed into ensemble entropy in BSFRs. Thermodynamic entropy for the ensemble would increase for both arrows of time in BSFRs.

4. The subsystems as smaller space-time sheets topologically condensed on the space-time sheet of the system can form a thermodynamic ensemble. The entropy of this ensemble increases in both directions of time. If it is possible to observe its increase occurring in the opposite direction of time, it would look like a decrease in entropy in the standard time direction and give rise to apparent violation of the second law. In the Pollack effect [I2, I1, I5, I4] this kind

of effect is observed for the negatively charged exclusion zones at EZs throw impurities out. This looks like time reversed diffusion and can be understood in the ZEO [L16].

In the case of SSFRs it is not meaningful to talk about an ensemble. The SSFRs cannot not therefore affect the ensemble entropy. The sequences of SSFRs define the analog of an adiabatic time evolution.

5. In biosystems the metabolic energy input makes it possible to maintain the h_{eff} distribution. At lower levels, entropy of the field body however increases gradually and eventually leads to death. Is it possible to maintain the metabolic energy feeds or are the metabolic energy currents gradually reduced during the evolution so that there is no metabolic energy feed increasing the complexity for subsystems anymore? This would be reduction of gradients leading to thermal equilibrium and loss of information. Could this be the TGD counterpart of heat death?

   Could the pairs of BSFRs solve the problem by allowing a fresh start with the original arrow of geometric time with the field body having a pure state and low entropy after the second BSFR? Sleep begins and ends with a BSFR. Sleeping overnight indeed allows one to wake up full of energy which is dissipated during the day. Could BSFRs generate the necessary gradients needed to avoid heat death? Could BSFRs take care that the system's form kind of flip flops exchanging metabolic energy by dissipating.

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