# Generalization of thermodynamics allowing negentropic entanglement and a model for conscious information processing

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## Contents

## 1 Introduction

Costa de Beauregard considers a model for information processing by a computer based on an analogy with Carnot's heat engine [9]. I am grateful for Stephen Paul King for bringing this article to my attention in Time discussion group and also for inspiring discussions which also led to the birth of this section. As such the model Beauregard for computer does not look convincing as a model for what happens in biological information processing.

Combined with TGD based vision about living matter [6, 7, 8], the model however inspires a model for how conscious information is generated and how the second law of thermodynamics must be modified in TGD framework [5]. The basic formulas of thermodynamics remain as such since the modification means only the replacement $S \to S - N$, where $S$ is thermodynamical entropy and $N$ the negentropy associated with negentropic entanglement. This allows to circumvent the basic objections against the application of Beauregard's model to living systems. One can also understand why living matter is so effective entropy producer as compared to inanimate matter and also the characteristic decomposition of living systems to highly negentropic and entropic parts as a consequence of generalized second law. ADP-ATP process of metabolism provides a concrete application for the generalized thermodynamics.

# 2 Beauregard's model for computer

Beauregard's model describes computer as information processor analogous to heat engine. The work done by a heat engine is replaced with information generated by the computer and printing makes this information manifest.

1. In Carnot cycle thermal energy is transformed to work and one gets the well known upper bound for the efficiency from second law as $\eta = W/Q_{in} \leq \Delta T/T_{in}$.

2. Beauregard a model for an ideal computer is as a system which performs no work but prints instead. One studies information flow instead of energy flow. Negentropy is identified as a negative of thermodynamical entropy. Incoming negative negentropy flow means coding of program metaphorically at least and outgoing negentropy flow to what results, when this coding is erased in computer memory. The printed text carries the negentropy which in the optimal situation is the difference between incoming and outgoing negentropies. This negentropy is sucked from the incoming negative negentropy flow so that second law holds true.

3. In terms of formulas one has $dW = dQ_{out} - dQ_{in} = 0$ and $dS = dQ_{out}/T_{out} - dQ_{in}/T_{in} = dQ_{in}(1/T_{out} - 1/T_{in}) \geq 0$. In the ideal case that the total entropy does not increase, this entropy growth must be compensated by the reduction of the entropy of the printer by amount $dS$ interpreted as negentropy of the output.

4. This vision about computing is based on second law and identifies information gain as difference between two entropies. System can gain information by feeding disorder to the environment. The best possible situation is that one has no information at all.

## 2.1 Ciriticism of the model

This model seems consistent with thermodynamics and skeptic would argue that what we see around us could be seen as a support for this view about information processing in living systems. One can however argue that the view about information as absence of entropy does not really make sense in living matter.

1. p-Adic physics encourages the belief in genuine information [3]. If living matter is identified as something in the intersection of real and p-adic worlds it is possible to have a genuine information represented as a negentropic entanglement. The number theoretic variant of Shannon entropy gives a natural measure for this information since it can be negative and there is a unique p-adic prime minimizing it. Conscious information is a rule $A \leftrightarrow B$ in which the pairs $a \otimes b$ in the quantum superposition represent the instances of the rule. Schrödinger cat knows that it should not open the bottle by being a little bit dead but negentropically so.

2. Second point is that Boltzmann's kinetic theory leading to the second law is based on the assumption that quantum coherence is not present in the time scales considered. If this assumption fails one cannot treat the system as a thermodynamical system (atoms represent standard example of this). In zero energy ontology and accepting the hierarchy of Planck constants, there are always levels of hierarchy for which second law does not make sense in a given time scale.

3. There is also a direct experimental evidence for the reversal of thermodynamical time and therefore breaking of second law in time scales below .1 seconds, which happens to correspond to the time scale assignable to the CD of electron and to a fundamental biorhythm. The evidence comes from a system consisting of beads on necklace [10].

    (a) Standard physics explanation would be in terms of fluctuation in the value of entropy. Fluctuation theorem [12] allows to deduce a precise expression for the ratio of probabilities of entropy fluctuations of same magnitude but opposite sign as $exp(A)$ where $A$ represents the magnitude of the fluctuation. The appearance of .1 second time scale however forces to challenge this interpretation.

    (b) In TGD framework one possibility is that the spontaneous local reversal of the arrow of geometric time induced from that of experienced time implies that second law with reversed arrow of geometric time is operating. Second possibility is that genuine increase of negentropy is in question.

## 2.2 Problems of Beauregard's model if interpreted as a model for information processing in living systems

Beauregard's model for what he calls "printer" looks problematic for several reasons.

1. Living matter and computers are in good approximation at the same temperature as environment and temperature $T$ and volume $V$ are not changed during the process so that free energy $F$ is minimized rather than thermodynamical negentropy. This kind of systems are not analogous to steam engines for which one has has incoming steam at higher temperature. Beauregard's analog of Carnot engine satisfies $dW = dQ_{out} - dQ_{in} = 0$ and indeed gives for $T_{in} = T_{out}$ the trivial result $dN = 0$. No information is generated. Even worse, living systems are typically at higher temperature than environment so that the heat engine analogy does not seem to work well.

2. In the analog of steam engine one actually assumes that the entropy difference for outgoing and incoming beams corresponds to a positive negentropy assignable to the printing. One can however treat the printer and computer as a single system in which case one can draw only one conclusion from standard thermodynamics: this negentropy corresponds to work done by the combined system and one has just the ideal steam engine but the work interpreted as printout. Something however distinguishes between printer and steam engine.

# 3 TGD based variant of Beauregard's model and generalization of thermodynamics

The TGD inspired variant of Beauregard's model leads naturally to a generalization of the second law of thermodynamics taking into account the possibility of negentropic entanglement.

## 3.1 Questions

Something distinguishes between printer and steam engine and standard thermodynamics is not able to express this difference. What this something is? The proposal to be discussed is that the positive entanglement negentropy assignable to rational (or even algebraic) entanglement generated in the process in which conscious information is created. It is best to proceed by making questions.

1. The work done by steam engine is "useful" work. What does this mean? Something which does not have meaning for us but is a prerequisite for having meaning. Perhaps metabolic energy at the basic level. This work can be eventually transformed to metabolic energy needed to build mental images generated by the text.

2. What metabolic energy is? In TGD Universe there are two kinds of entanglements: the entropic bound state entanglement and negentropic entanglement which is rational or even algebraic and possible in the intersection of real and p-adic worlds. Bound state entanglement is stable under NMP [3] by binding energy. This kind of entanglement is like a marriage based on social conventions, a jail.

   Negentropic entanglement does not involve binding energy and can be compared to a marriage based on freedom and love. The positive energy associated with the negentropic entanglement has wrong sign to be interpreted as binding energy and is identifiable as metabolic energy. This identification could explain the long standing mystery of the high energy phosphate bond central for the functioning of ATP and ADP. ATP-ADP process would be basically a transfer of negentropic entanglement and thus information to the living system and at work at all levels in living matter.

3. What is the process giving meaning to the text? This process must generate negentropic entanglement. The corresponding entanglement negentropy is something independent of thermodynamic entropy and the safest assumption is that the generation of negentropic entanglement is accompanied by the generation of thermodynamical entropy at least compensating it so that second law in a generalized form continues to hold true.

## 3.2   What happens in quantum jump?

Quantum jump involves $U$ process and state function reduction cascade [3]. Negentropy Maximization Principle implies second law for the standard view about state function reduction: second law states that the ensemble entropy increases by the randomness of the outcome of the state function reduction process. When negentropic entanglement is present the situation is not so clear. Before proceeding to consider the modification of the second law one must define more precisely what $U$ process is.

   The simplest view about quantum jump is as a unitary $U$-process followed by as a cascade of state function reductions proceeding from top to bottom. But what is the top?

1. In positive energy ontology it would be entire Universe. Quantum classical correspondence suggests that one should be able to assign to quantum jump a duration of geometric time. For this proposal this time is most naturally infinite.

2. The vision about fractal hierarchy of selves and quantum jumps together with ZEO suggests a more refined view about quantum jump in which. $U$-process and subsequence state function reduction cascade could occur independently for disjoint $CD$s. For a given $CD$ the new sub-$CD$s (representing mental images of the corresponding self) can be created and old destroyed so that the only constraint would be that only disjoint $CD$s can perform quantum jumps independently. For this option the duration of geometric time assignable to the quantum jump would naturally correspond to the temporal distance between the tips of $CD$: p-adic length scale hypothesis and number theoretical vision suggest that this distance comes as an octave of $CP_2$ time scale (prime or integer multiple is the more general option). For infinitely large $CD$ this would mean infinite duration. This picture is consistent with the TGD view about how the arrow of subjective time induces the arrow of geometric time [13].

## 3.3   Modification of thermodynamics to take into account negentropic entanglement

What does the presence of this negentropic entanglement mean from the point of view of thermodynamics? There are two obvious options to consider. The optimistic option is just the standard thermodynamics saying nothing about negentropy generation. The pessimistic option is that the generation of negentropy must be accompanied by a generation of at least the same amount of entropy: the good news is that this entropy can be carried by different system and it is possible to have genuinely negentropic systems. The following consideration is restricted to the pessimistic option which seems to be more realistic view about the world we live in.

1. One must generalize the basic expression for energy differential

$$dE \;\; = \;\; TdS - dW \to T(dS - dN) - dW \;\; . \tag{3.1}$$

   This means that there are two kinds of energies given out by the system. The useful work $dW$ and negentropic energy $TdN$. For steam engine only $dW$ is present. For ideal system only negentropic energy would be present.

2. What happens to the second law? The pessimistic guess is that generation of negentropy requires a generation of at least same amount of entropy so that one would have

$$\Delta S - \Delta N \geq \;\; 0 \;\; . \tag{3.2}$$

   Here $S$ can be interpreted as a sum of two terms. The first part corresponds to the ensemble entropy generated by the randomness of ordinary quantum jumps, and second part to the entropy assignable as maximal entanglement entropy assignable to the decompositions of bound state to two parts. $N$ corresponds to maximal negentropy for the decompositions of negentropic subsystem to pairs. One can criticize these definitions and a possible modification of could be as as the average for the entanglement entropies over this kind of decompositions.

3. Quite generally, Clausius inequality allowing to deduce extremization conditions for various thermodynamical potentials generalizes to

$$T_0(\Delta S - \Delta N) - \Delta E - P_0 \Delta V \geq 0 \ . \tag{3.3}$$

where $T_0$ and $P_0$ and temperature and pressure of heat bath. Living systems would be entropy producers and this seems to conform with what we see around us.

For instance, for a system in constant volume one would have

$$\Delta S - \Delta N - \frac{\Delta E}{T} \geq 0 \ . \tag{3.4}$$

so that systems developing negentropy would also generate thermodynamics entropy. For a system in heat bath one has $T = T_0$ and Clausius inequality gives

$$\Delta F = -\Delta W \tag{3.5}$$

stating that increase of free energy at constant temperature requires work done on the system ($dW < 0$): otherwise $\Delta F \leq 0$ holds true.

By using the variable $S - N$ instead of $S$ all formulas reduce formally to standard thermodynamics except that $S$ can be negative. This is absolutely crucial for distinguishing TGD counterpart of Beauregard's printer -identifiable as conscious reader rather than printer - from Carnot engine.

## 3.4   The analog of Carnot cycle for information processing in living matter

Consider now Carnot heat engine and its information theoretic analog in this framework.

1. The basic equation for Carnot engine is

$$dW = dQ_{in} - dQ_{out} \geq 0 \ . \tag{3.6}$$

Optimal efficiency corresponds to $dS_{out} = dS_{in}$.

2. For the information theoretic analog one would have

$$dW = 0 \ , \tag{3.7}$$

and

$$dN = dS_{out} - dS_{in} \geq 0 \ . \tag{3.8}$$

The interpretation would be that incoming entropy flow leaves the computer in a state of higher entropy and the difference corresponds to information $dN$ feeded to say printer. The increase of entropy would have interpretation in terms of erasing of data from computer memory.

The problematic aspect of the model is that it requires $T_{in} > T_{out}$ in order to have $dN > 0$. For living systems one has however typically $T_{in} < T_{out}$. Already for $T_{in} = T_{out}$ the situation trivializes since one has

$$dN = 0 \tag{3.9}$$

by $dW = 0$ and $dS = dQ/T$.

3. Now however a more general condition

$$T_{in}d(S_{in} - N_{in}) - T_{out}d(S_{out} - N_{out}) \geq 0 \qquad (3.10)$$

holds true and allows to generate conscious information provided it is compensated by thermodynamical entropy. Note that the temperature of the environment can be even lower than the temperatures of the system.

It is also possible to transform information to work as the expression for the differential $dF = -SdT - TdN - dW$ of the generalized free energy $E = E - TS$ shows. The increase of $dW$ for the work done by the system is compensated by the reduction of information $dN$ so that system loses negentropy in the process keeping dF constant. The loss of negentropy coiuld be interpreted in terms of a loss of metabolic energy which corresponds to negentropic entanglement for AMP, ADP, and ATP molecules.

4. Beauregard calls the information engine printer. What does this "printing" correspond from the point of view of negentropic entanglement? Is the negentropic entanglement is generated during physical printing or during the reading? If the negentropic entanglement is generated before reading, there must be some other conscious entity for which the text has meaning. This seems un-necessary assumption so that ordinary computers would not generate negentropic entanglement. For the second and much more reasonable looking option the above process takes place during the reading and the "printing" as a name for the above process is misleading: conscious reading is in question.

## 3.5   Some clarifying comments

Some clarifying comments about biological implications are in order. Many of them are inspired by the questions of Stephen Paul King in Time discussion group.

1. There is no need to restrict the consideration to equilibrium systems. First of all, the environment and living system are in general at different temperatures and temperature difference is typically of wrong sign for the model of Beauregard to work in this context. Beauregard's model is of course a model for computation, not for the generation of negentropic mental images. Maybe cognitive machine might be proper term for what the modified model could describe.

2. Quite generally, self-organization requires a feed of energy to the system so that one has flow equilibrium. In the case of living system this feed of energy is metabolic energy associated with the negentropic entanglement transferred to the system in the ATP-ADP process. Self-organization driven by negentropic entanglement leads to standardized negentropic mental images automatically as asymptotic self-organization patterns in 4-D sense ($CD$s within $CD$s within ...).

3. No explicit assumptions about computational aspects of the process has been made. Just a generation of conscious information identified in terms of negentropic entanglement is assumed. The basic character quantum jump as $U$-process followed by the cascade of state function reductions represents a fractal hierarchy of what can be seen as quantum computations and are distinguished from classical computations in that the process proceeds from top to bottom rather than being a local process. The result of computation is represented using statistical ensembles defined by sub-$CD$s at various levels of the hierarchy and is in principle communicable by classical fields (say EEG patterns in the case of brain) to higher levels of self hierarchy which in turn can induces the same distributions so that communication of the objective aspects of the experience with the mediation of "medium" is possible. The presence of the "medium" seems unavoidable. Magnetic body would be this medium in TGD inspired biology.

# 4   About implications of generalized second law

Generalized second law allows to sharpen the basic picture about implications of the second law.

## 4.1  Biological implications

Living matter involves also another aspect made possible by the generalized second law obtained by the replacement $S \rightarrow S - N$. Subsystem can have also negative net entropy and split to two highly negentropic and entropic pieces. In the extreme situation this is nothing but excretion, which is absolutely essential element of being alive but sometimes forgotten from the lists of properties distinguishing living matter from inanimate matter. It is not at all clear whether this is possible for standard non-equilibrium systems defining information as a reduction of disorder. At all levels of the fractal hierarchy division into negentropic and entropic subsystems is expected.

This picture seems to be in accordance with basic chemistry of energy metabolism.

1. The process creating both negentropy and entropy would be standardized in living matter and mean a generation of high energy phosphate bonds assignable to AMP, ADP, and ATP containing 1, 2, and 3 phosphates respectively besides the sugar residue. Sugar residue is basic nutrient and would provide the stored metabolic energy transformed to the negentropic energy of the high energy phosphate bonds if the proposed view is correct. Also other DNA nucleotides such as G can appear besides A but in metabolism A has a preferred role.

2. The basic metabolic cycle provides ADP with an additional phosphate energizing it to ATP and the reverse process transfers the metabolic energy and also negentropic entanglement to the acceptor molecule. Also ADP can provide metabolic energy by transforming to AMP when ATP is not available in sufficient amounts. That the catabolism of AMP creates urea excreted out of the system fits with the general picture. The catabolism for nutrients would create the entropy compensating for the negentropy of the high energy phosphate bonds.

3. The backbone of DNA is made of sugar and phosphate residues and corresponds to a sequence of $XMP$, $X = A, T, C, G$ with each XMP presumably containing single high energy phosphate bond serving as a storage or potential source of negentropy. This conforms with the view that DNA carries conscious information.

Negentropic and entropic entanglement are assumed to generate mental images with opposite emotional colors. This connects information processing with emotions. From neuroscience point of view this is not a news: peptides are molecules of emotions on one hand and molecules of information on the other hand [11]. The well-known specialization of the left and right hand sides of the amygdala to experience positive and negatively colored emotions could be seen as one instance of this connection and representing also an example about fractal negentropic-entropic differentiation.

## 4.2  The interpretation of generalized second law in a wider context

Leaving the narrow confines of thermodynamics one could try to interpret the generalized second law in a wider context.

1. The generalized second law unavoidably brings in mind the Good-Evil dichotomy. Good deeds seem to induce evil deeds. Maybe this kind of polarization effect is indeed unavoidable in the situations for which thermodynamics applies. The crucification of a man whose sole crime was to suggest that we should love also our enemies expresses this paradoxical truth in very deep manner. Thermodynamical approximation can however fail and the hierarchy of Planck constants and zero energy ontology predict that this occurs. Maybe the Eastern teachings promising a way out from the cycle of endless suffering are inspired by experiences in which no Good-Evil polarization takes place. The ATP-ADP cycle generating negentropy and at least same amount of entropy has more than obvious analogy with the Karma's cycle.

2. One cannot avoid associations with the basic teachings of Christianity. $U$ process would correspond to Genesis creating the paradise. Eating the fruits from the tree of Good and Bad Knowledge would correspond to the emergence of cognition producing islands of negentropy and entropy and meaning a banishment from paradise. "With hard work of you hands must you will get your bread" would correspond to endless fight for getting metabolic energy transformed to energy associated with the negentropic entanglement.

Heaven and hell would be the islands of negentropy and entropy resulting during the state function reduction process. The next U-process re-creating the heaven and and Earth would be the new Genesis and the moment of mercy meaning a new possibility to be used or lost for both saints and sinners. If $U$-process is local in the sense that it can occur independently for disjoint $CD$s, the situation is rather comforting since salvation possibly brought by the next moment of recreation requires only a finite time of waiting.

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