Competition between Maxwell's demons and some consequences

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We consider the problem of the competition between two Maxwell's demons. The presence of a more clever demon in one of two subsystems allows it to drain more order than the other. We suggest that this principle plays an important role in the evolution of organized systems. Examples from biological, social and economical sciences are proposed.

Keywords: Maxwell demon, information and entropy, competition between organized systems

Se considera el problema de la competencia entre dos demonios de Maxwell. El demonio mas inteligente puede obtener mayor cantidad de orden que el otro. Se sugiere que esto puede jugar un papel importante en la evolución de los sistemas organizados. Se proponen ejemplos de las ciencias biológicas, sociales y económicas.

Descriptores: Demonio de Maxwell, información y entropía, competencia entre sistemas organizados

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1. Introduction

In the second half of the XIX Century there were proposed, among others, two basic ideas by two outstanding scientists: First, Charles Darwin [1] in *The Origin of Species* proposed the natural selection law, mediated by the struggle for life and the survival of the fittest individual and species. Second: James Clerk Maxwell [2] in his *Theory of Heat* wrote that if we consider a gas in a box with a partition and a being or demon able to open and close a window, selecting the molecules according to their speeds, it would be possible to create a difference of temperature in both halves of the box, and to let a cyclic motor to work, violating the second law of thermodynamics. The paradox of the Maxwell's demon took several decades to be fully understood and solved, and for it was essential the introduction of the new concepts of information, negentropy and order. To decide which molecules pass and which must not pass, the demon must get information, and this can be only possible by increasing its own entropy or the entropy of another system. Thus, the second law is not violated. If the demon has, say, M degrees of freedom (or accessible states) available, and makes one specific choice, the information gained is just $I = k \ln M$, where usually $k = \ln 2$. In the discussions and solution of the Maxwell's demon paradox we must mention, among others, the names of Wiener, Slater, Szilard, Smoluchowski and Brillouin [3, 4]. The concept of information was essentially due to Shannon [5], and the negentropy concept is due to Schrödinger [6] and Brillouin [3].

In recent years the concepts of information, order and entropy have been widely used and even gave rise to a new evolutionary paradigm (see Ayres [7]) and the notion of *complex* systems has increasing interest, and more specifically, the notion of *complex adaptive systems* (see *i.e.* Gell-Mann [8]), has been introduced, capable of creating some schema from the inflow of data coming from themselves or from external sources of information.

Maxwell's demon concept has wide applicability in living systems, either as acting mechanisms at cell or intra-cell level, or even as the individual itself. We want to argue that a generalization of the Maxwell's demon concept, in the sense of a system or device able to make a "convenient" choice from a set of several possible alternatives available (degrees of freedom), but applied specifically to the interaction among organized systems, plays an important role not only in the Darwinian evolution and natural selection, but also in biology and in social and economical evolution of human society.

Our generalization conceives as a Maxwell's demon every system able to create order from disorder or, generalizing the concept, able to increase its order, by draining it from another (usually less) ordered system, or even to keep its order by threatening or limiting the degrees of freedom of other ordered system or even by destroying it. We understand the above-mentioned complex adaptive systems as an advanced and specialized version of Maxwell's demons.

As pointed out by Wiener [9], the fate of the demon is to be finally disordered, it falls into *"a certain vertigo*, and is incapable of clear perceptions"; it dies as a consequence of the second law. But at the level of individuals capable of self-reproduction, the demon works enough time before dying, to be self-reproduced.

But it may also happen that the demon would receive an excess of information, being unable to process it, *i.e.*, there is some bound in every system to its capacity to assimilate the inflow of information. We name useful information to that being assimilated; the excess is *garbage information* [7]

Evolution is a consequence of interaction among highly organized systems with the environment and especially among themselves. This led Lotka [10] to attribute long ago an essential role to the flow of *free energy* to organized systems. However, a distinguishing feature of any two interacting organized systems is that in general, they have not the same order or negentropy content, (we are always considering specific quantities, *i.e.* negentropy per unit volume or mass) and on the average, as a result of the interaction, negentropy flows from the less organized to the more organized system, in opposite direction to the stated by the second law of thermodynamics.

We recall that in thermodynamics we have the entropy law, which is realized whenever we put in contact two systems at different temperatures. Heat flows from the system A to the system B, once the thermal contact is established if

$$T_A > T_B. \tag{1}$$

For most systems, entropy is a monotonic function of temperature, if other parameters are kept fixed. If we consider two such systems, the second law can be understood as a flux of negentropy from the most ordered system (the colder one) to the less organized (the hotter one). Sometimes this is understood as the *principle of degradation* of energy (in the sense of disordering it).

The opposite case is typical in living systems, which contains a large amount of dynamical order kept at the expense of its environment [6], since they are essentially open systems in the thermodynamical sense. In this sense, the cell membrane acts as a true Maxwell demon in the roots of the plants, absorbing the proper substances needed from the environment. Also, at the expense of solar radiation negentropy, biological order is started to be built in photosynthesis [11].

Let us consider now the case of *two* interacting highly organized systems, how to define then a parameter which characterizes the flow of negentropy from one of the systems to the more ordered one?

We thus face the new problem of the competition of Maxwell demons (see Fig. 1). For simplicity, we will consider binary interactions among demons. If we conceive not *one* but *two* Maxwell demons 1 and 2, in a box with a partition, one demon on each side, trying to leave the slower molecules on its side (to decrease its environment temperature and increasing that of its partner), the result of their action would cancel if the amount of phase space available to both demons is equal, so that the ordering action of one of them is canceled exactly by the other. We are assuming as a fundamental hypothesis

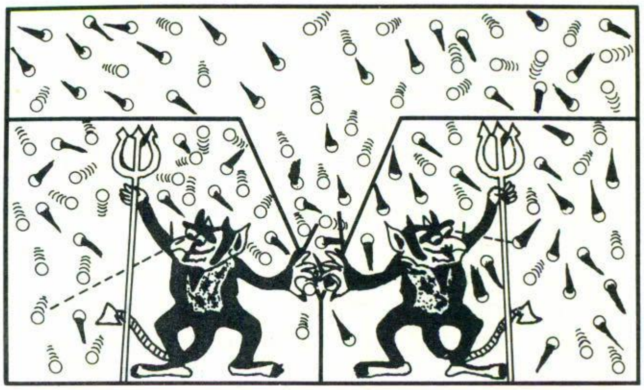

FIGURE 1. The competition between two Maxwell's demons, in which each one of them tries to reduce the temperature in its side by choosing the slower molecules.

that both demons are exactly equal each other and operate at the same rate. But it may happen that the demons act in a system which exchange particles with a reservoir in equilibrium. Then if one of the demons, say 1, has available a wider region of phase space than the other one $\Delta\Gamma_1 > \Delta\Gamma_2$, remaining equal in any other respect (say, demon 2 is blind to some intervals of frequencies, and is unable to detect the light scattered into such intervals), the ordering action of demon 1 would prevail on the other since it is able to obtain an information $I = \sum_i \ln \Delta(\Gamma_1/\Gamma_2) > 0$, where i extends over a large number of both demon's operations (in which it succeeds, that is, we discount the failures) and it will finally succeed in leaving on its side the colder gas and heating its partner side. *In general, the demon's efficiency is associated with the disposal of a wider phase space, i.e. a larger number of degrees of freedom, which enables it to make a more profitable choice, i.e. to get more information.* The greater the information available to the Maxwell's demon, the more efficiently it operates, under equal conditions. If the demons are unequal, it may happen that both of them have available equal regions of phase space but one of them, say demon 2, is unable to react quickly (or fails more frequently) and makes its good choices at a slower rate than demon 1. Then

$$I_1 = \sum_i \ln \Delta\Gamma_1 > I_2 = \sum_j \ln \Delta\Gamma_2, \tag{2}$$

where $i = 1, \ldots, N$, $j = 1, \ldots, M$ and $N > M$. The average result for demon 2 is equivalent to having available a smaller region of phase space than 1. In extreme cases this may happen if the available phase space changes at each operation. Then if it holds that

$$I_1 = \sum_i \ln \Delta\Gamma_{1i} > I_2 = \sum_j \ln \Delta\Gamma_{2j}, \tag{3}$$

we state that demon 1 is more efficient than demon 2. Each demon has reduced the entropy of its corresponding halfbox (at the expense of increasing the entropy of the reservoir + some external source) but in such a way that the demon 1 got the lower entropy.

We turn to the case in which both demons operate not in a gas initially at equilibrium, but in some organized medium which is a large source of negentropy of total amount F, such that at the end $\Delta I_1 + \Delta I_2 \simeq F$. If $\Delta I_1 > \Delta I_2$, it was demon 1 which obtained maximum profit. This may be the case if the source of negentropy are the bodies of the demons, serving potentially as source of food for the other demon. We have an example in the case of the shark *vs.* a weaker fish, the phase space refers partially to the physical phase space: the shark dominates by reducing the degrees of freedom of the weaker fish, whose body is a source of negentropy for the shark. Consider also the example of the mongoose-snake play, discussed by Wiener [9] which illustrates how the mongoose elaborates its strategy by getting information from the snake's pattern of behavior. The mongoose acts as a predator whenever the conditions permit it to operate freely as a more clever or more efficient Maxwell's demon—we suppose no external effects, as the attack from a third animal, interfere in the game. The mongoose wins the game with the snake because it is more clever. Both animals have some "phase space of possibilities" to make a choice of actions at each instant, but the mongoose has a wider phase space than the snake or acts more efficiently, and even increases its available phase space during quarreling, by learning from its enemy.

As another example, consider, for instance, a chess game. We have two players, each one being able to "open the demon's window" by moving the adequate piece in each step of the game in equality of other conditions. It is the greater ability of *one* of the players which decides who wins the game and this ability is determined by the choice of the appropriate play at each step of the game, out of a large number of possible outcomes analyzed in the mind of the player. At each step he considers (conscious or not of it) the number M_1 of his possible plays after every play done by his partner; he must consider then the number $M_1 \times M_2$ of his possible next plays, and so on to $\Gamma = \prod_i M_i$. On the average, the player able to imagine the larger Γ would get the larger information $k \ln \Gamma$ and is able to do the best choice to win the game. Then that player disorganizes and makes a *depredation* on the other. It is this fact which has permitted a computer to defeat a chess Grandmaster the first time in 1988 (see [12] and references therein).

In the language of Darwin, how to characterize the "more apt" individual or system? In the evolutive scale, one parameter characterizing frequently the more apt is the strength. The stronger animal dominated the weaker ones. The shark depredated other fishes mainly by force. The Maxwell's demon used "force" to operate. But as evolution advanced the role of intelligence increased. The tendency was the domination due to the presence of a "more clever" Maxwell's demon, in the sense of a more efficient *learning machine*, following Wiener terminology [9].

We want to define now the quantity C characterizing the "cleverness", or efficiency of the demon, that is, its ability to learn and to make a choice on the basis of this learning. This means either the ability of getting the maximum information in the sense of either using a maximum number of degrees of freedom or "volume of phase space" of possibilities and alternatives, enabling it to make the more advantageous choice, or using more efficiently (by a quick adequate choice) the obtained information. Thus cleverness means not only to have at its disposal a larger number of degrees of freedom, but also the ability to make the adequate choice or decision at each time. From (3) we define the cleverness of the demon i as some increasing function of I_i/N, which in a first approximation can be considered as linear, through a coefficient k,

$$C_i = kI_i/N, \tag{4}$$

thus, cleverness is defined from the average ability of the demon to get information from a source, and it may lead to comparison of the relative ability of two demons in extracting information from some common source. For each demon, the source may be also some organized system containing the other demon.

We can state the *principle of depredation* (as opposite to the degradation one) as follows: When two highly organized systems A and B with Maxwell's demons a and b being part of them and guiding their interaction, are put in contact, order or negentropy is expected to flow from A to B, whenever

$$C_a < C_b. \tag{5}$$

The quantities $C_{a,b}$ are not in general, absolute quantities as temperature, but must be defined for each pair of interacting Maxwell's demons. For demons of different kind it would be better to define the relative cleverness, by dividing by the initial negentropy "investment" I' of each demon, *i.e.* $c_i = C_i/I_i'$, where I_i' must be defined in each case. Then in place of (5) we must have $c_a < c_b$.

We want to stress that the principle of depredation, describing the fight or competition among two different Maxwell's demons is close to problems like the gambler's ruin and some related problems [13].

We would like to emphasize that in the previous paragraphs we have been far to pretending to give a final theory, or to give a detailed solution to a specific problem. Our attempt has been, however, at the light of information theory and thermodynamics, and from the discussion of the problem of the competition between Maxwell's demons, to point out a set of consequences which manifest regularly characterizing the interaction and evolution of living systems, human societies and organizations, in spite of their complexity. Below, we want to mention some examples and complementary concepts. Before doing that, we want to point out that in recent years a new interdisciplinary science, the *Synergetics*, has been developed, mainly by Hermann Haken and collaborators [14], which investigate certain systems composed from a large number of degrees of freedom, in which usually a set of *few* degrees of freedom or collective modes play an important role in describing the system's behavior. Synergetics uses a wide number of physical and mathematical concepts (*i.e.* from thermodynamics, statistical physics, information theory, nonlinear equations, probability theory, etc.), leading to a general method of attacking several problems of physics, chemistry, biology, economy, and sociology. We mention the laser, macroscopic patterns in chemistry, formation of public opinion in sociology, among the problems studied by synergetics. In all these problems, dynamics play a crucial role in its formulation. Quoting Professor Haken's words *"...it is the growth (or decay) rates of collective 'modes' that determine which and how macroscopic states are formed. In a way, we are led to a generalized Darwinism which even acts in the inanimate world, namely, the generation of collective modes by fluctuations, their competition and finally the selection of the 'fittest' collective mode or a combination thereof, leading to macroscopic structures."*

We would like to suggest that whenever the problem under study involves the interaction of intelligent "modes", trying to get a positive balance of negentropy or information in the process, our previous ideas might be considered *in addition* to the usual assumptions and methods of synergetics.

Trying to find realizations of the principle of depredation in the biological context, it may be argued that such principle acts in first instance in feeding, when living systems feed from the sorrounding media or from other species that are dominated or exploited by them. The case of the shark is a typical one. At human scale agriculture and domestication of animals is the next step, since men restrict the degrees of freedom of the corresponding species, to get some profit from them; (even wars and slavery are successive steps and domination of some human groups by others are usually manifestations of it). We must point out, however, that not all interactions among different biological and social species are of this sort. There exists the possibility of an association among species for mutual convenience; symbiosis is one of such examples.

We would like to suggest that in modern social and economical organizations the principle of depredation is present very frequently. Negentropy flux is usually made by trade, business, or exchange of information. Given two organizations (one from a more developed country and another from a less-developed one), most interactions are characterized on the average, by a net flux of negentropy from the less-developed to more the developed one. This is due to the existence of "more clever" Maxwell's demons in the sense described above, which manage to get (on the average, since there are specific cases in which the situation is just the opposite) more profit for themselves than for their partners in any transaction, by simply obeying the established rules.

Thus for instance, for two interacting enterprises E_B, E_A, the first having more advanced technology and organization, it is usual that under competition or association, the second becomes either destroyed or absorbed by the first.

We must point out here that **money** is a quantity measuring value of goods and services. Value is in general a *measure of the information or negentropy content of goods and services.*† We suppose a complex functional dependence of value V with regard negentropy N, $V = f(N)$, but in a first approximation, we take this relation as linear $V = \alpha N$.

Economical transactions as trade and financial business, means an exchange of the stored negentropy in goods and services by the negentropy content of money, (and even money tends to be more and more handled as information [7]). The efficient Maxwell's demon manages always to get a positive balance of negentropy (in money form) in the transaction. Having two enterprises E_1, E_2 we may conceive either their mutual interaction, or their interaction through some "economical medium", which may include the market of consumers and other enterprises. Each enterprise has a balance of negentropy, a net profit (positive or negative) along its interaction for some interval of time, say, N times. To compare enterprises of different sizes, it is better to use the relative profit, the quotient of the absolute net profit by the total disbursements in the N interactions $p_i = P_i/D_i$. Let us assume that the first one obtained a profit p_1 greater than the profit p_2 of the second, which may be negative. We understand this as meaning the cleverness inequality $c_1 > c_2$. The meaning of this inequality is that in a direct economical interaction between both enterprises, we must expect on the average a net influx of profit from 2 to 1. At the end, the second enterprise, being less efficient, would be depredated by the first.

Goods (and even services) can be characterized by their informational content [7], and one of the characteristics of *development* is the fact that goods and services increase in diversity (and in its availability) and in their content of information per unit of product or service, then these products have *more value*; *e.g.* become more expensive. As an example, compare the abacus and the mechanical calculating machine with the modern computers, or the old diligences with the modern automobiles. But even cars and computers change from year to year to more advanced technologies and higher informational content.

We can thus take as one characteristic of development the average negentropy produced per individual-year in a country. If we call N_i the average negentropy stored outside the individual to make (at least potentially) his life richer and more comfortable, development occurs if

$$dN_i/dt > 0. \tag{6}$$

Developed countries (D) when compared with developing ones (D_g) show manifestly a larger value of N_i and dN_i/dt. This fact allows them, on the average, to have the more potentially efficient Maxwell's demons, and obviously $C_D > C_{D_g}$.

We must stress that in usual biological (non-human) beings (a bee-hive, for instance), there is, at least approximately, an upper bound U for the development $U > dN_i/dt$, where dU/dt is a zero of order T, T being the lifetime of the individual. This means, we are unable to observe any change in N_i when observing several generations of a bee-hive. The human beings as well as the society and the economy does not exhibit up to now upper bounds for their development: $dU/dt \geq 0$, and the density of (useful) information may be increased without limit in a time of order T.

We want to state that the principle of depredation must not be considered as a fatalistic one. On the contrary, we must consider it as a fact to be taken into account in the struggle for life and development, which must be necessarily faced. It is only a requirement *to learn* how to be the more clever and more efficient Maxwell's demon, to win the game.

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