THE EVOLUTION OF BRAIN AND MIND: A NON-EQUILIBRIUM THERMODYNAMICS APPROACH[1]

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ABSTRACT. The evolution of human brain and mind presupposes the study of the evolution of organic life-forms and the study of the phylogeny of preconscious animal cognition. Thus this paper takes as its basis the framework of non-equilibrium thermodynamics for biological systems. According to this viewpoint, biological systems seem to violate the Second Law of Thermodynamics: organisms keep themselves alive in their highly organized states because they absorb energy from the environment and process it to produce a state of low entropy within themselves. So it can be said that biological systems are feed of or attract negative entropy in order to compensate for the increase of entropy they create when living (i.e., life is negentropic). The paper then traces the phylogeny of brain and mind from the complexity of negentropic processes in biological systems (metabolism, thermo-regulation, irritability, sensation, perception) to non-human animal mind and human consciousness.

KEY WORDS. Non-equilibrium thermodynamics, evolution, entropy, negentropy, brain evolution, cephalization, encephalization, language, cultural psychology, consciousness.

1. INTRODUCTION

The study of the similarities and differences between the most elementary forms of mind and the more complex ones is highly important, for it allows us to understand the premises for the emergence of the human brain and mind. Such premises are the result of the long evolution of the various forms of organic life. Ignoring such premises may lead to conceive consciousness, for instance, as an absolute and unchangeable entity, an *extra* fact (Chalmers 1996, p. 123) over and above of, or supervenient to, 'physical' facts, as many theorists do. Thus, the evolution of human brain and mind presupposes the study of the development of organic life forms and the evolutionary study of the non-human brain and mind.

In this paper, I will propose an approach to the evolution of the human brain and mind on the basis of non-equilibrium thermodynamics [2], as well as some ideas developed by cultural psychologists (see also Grande-García 2005).

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2. NON-EQUILIBRIUM THERMODYNAMICS OF BIOLOGICAL SYSTEMS

From the standpoint of some physicists, the paradox underlying natural selection is that it proceeds in a blind and purposeless way, but at the same time gives rise to more and more complex designs. This continuous increase of information (i.e., the spontaneous emergence of order) seems to violate the Second Law of Thermodynamics.

According to the theory of information (Shannon 1948/1968), one of the basic principles of cybernetics states that information is statistical, and that is measured on the basis of the laws of probability. In this sense, information is conceived as a measure of freedom of election implicit on selection. As the freedom of election increases, the probability that a certain message is chosen diminishes. The measure of probability is known as *entropy*. According to the Second Law of Thermodynamics, there is a tendency within natural processes towards a state of disorder, or chaos, which takes place with no intervention or control. According to the principles of cybernetics, order (i.e., the decrease of entropy or *negentropy*) is less probable, and chaos (increase of entropy) is most probable.

An organized system, say a living organism, has to be able to maintain order by means of self-control or self-regulation processes, counteracting the natural tendency towards disorder or universal degradation of energy, that is, the tendency towards thermodynamic equilibrium which in biological systems means death. This process is what theorists call *negentropy*, that is, the decrease of entropy or negative entropy.

To put it briefly: entropy is a measure of disorder and, according to the Second Law of Thermodynamics, it can *n*ever decrease. Information proceeds in the opposite direction. This has led theorists (e.g., Brown 2000; Schulman 2002) to propose two 'arrows of time': (i) the behavior of physical systems pointing towards the increase of entropy and, as a consequence, towards the increase of disorder or chaos, and (ii) the behavior of biological systems (see Bounias 2000), pointing towards the opposite direction, resulting in more and more complex structures of order by means of negentropy.

An example will show these ideas. If accidentally you drop a glass from the table, it will smash into pieces. Since there isn't a physical law that forbids the cup to recompose, in practice this never occurs, and we intuitively know that this cannot occur. In this case, order is destroyed and cannot be recreated. This is a manifestation of the Second Law of Thermodynamics. On the other hand, we develop from childhood to adolescence to adulthood, and since there isn't a biological law that forbids it, and as much as we would like to, adults never go back to adolescence and then to childhood. This is a manifestation of the opposite arrow of time: order is created and cannot be undone.

The Austrian physicist Erwin Schrödinger, one of the founders of Quantum Physics, first proposed the idea that biological organization is created and maintained at the expense of thermodynamic order. Thus, life shows two fundamental processes: (i) the creation of order from order (e.g., the offspring has the same order as the parents), and (ii) the creation of order from disorder or chaos (e.g., metabolism, eating, and growing). Living systems violate, *prima facie*, the Second Law of Thermodynamics. In Schrödinger's own words:

> [E]verything that is going on in Nature means an increase of the entropy of the part of the world where it is going on. Thus a living organism continually increases its entropy and thus tends to approach the dangerous state of maximum entropy, which is death. It can only keep aloof from it, i.e., alive, by continually drawing from its environment negative entropy (Schrödinger 1967/1992, p. 71).

In the 1960's, the (Russian born) Belgian physicist Ilya Prigogine proposed an intuitive hypothesis: living organisms function as *dissipative structures*, structures that form as patterns in the energy flow and that are capable of self-organizing in the face of environmental fluctuations (Prigogine and Stengers 1984). According to Prigogine, systems can be divided into: (i) *conservative systems*, which are governed by the three conservation laws for energy, translational momentum and angular momentum, and which give rise to reversible processes, and (ii) *dissipative systems* (Prigogine et al. 1968), subject to fluxes of energy and/or matter, and which give rise to irreversible processes (Prigogine et al. 1977; Sanfeld and Velarde 2004). In other words, these systems maintain their structure by continuously dissipating energy. Such dissipative structures are permanently in states of non-equilibrium. Life maintains itself far from it. The flow of matter and energy "through" the body of the living organisms is what makes possible for them to maintain a (relatively) stable form. Professors Bruno Estañol and Eduardo Césarman define life as the "capacity of dissipative thermodynamic systems to maintain a self-sustained steady state with a great dynamic stability" (Césarman and Estañol 1994, p. 54; Estañol and Césarman 1996, p. 61). In order to stay alive, living systems have to be always in this state far from equilibrium.

For these reasons living systems *seem* to violate the Second Law of Thermodynamics. But in fact they don't. According to Zotin and coworkers (Zotin et al. 2001) the bioenergetic progress includes only a part of all organisms. The biosphere as a whole evolves in accordance with thermodynamic laws towards the equilibrium state. However, some groups of organisms evolve in an opposite direction, but in such a way that the sum of all energetic processes obeys the thermodynamic laws. Secondly, thermodynamics of non-equilibrium processes includes the so-called 'Principle of fastest descent', according to which the movement of an open system towards an equilibrium state occurs along the fastest way. Thus, the movement of a complex system to an equilibrium or stationary state should be accompanied by the development of subsystems that move in an opposite direction with an increasing dissipation function. This means in the case of the biosphere that organisms with higher rates of metabolism appeared. The birth of such organisms accelerates the movement of the biosphere as a whole towards the equilibrium state.

In the course of the evolution of species, this bioenergetic progress is thus determined by the principles of non-equilibrium thermodynamics. The question, however, arises whether an unlimited increase of metabolism is possible or whether there are obstacles that have to be overcome for the further energetic progress. Yet a continuous increase of animal metabolism is impossible. For instance, an increase of body temperature caused by growing heat production rates would result in the denaturation of some essential proteins and in the death of the organism. For such reason, Zotin et al. (2001) suggest that there are 'heat barriers' against the bioenergetic progress and further increases of standard metabolism cannot overcome these barriers.

Now, the reason why non-equilibrium thermodynamics identifies the Second Law as the major driving force of biological order (and as I propose in this paper, even psychological order) is that it is the only physical law that distinguishes past from future, and the only one that can explain irreversible processes: evolving processes in biological and physical orders (Bosatta and Ågren 2001; Demetrius, 1997). The temptation to use this approach to account for biological evolution is irresistible. Albeit we must be careful, for the implications of non-equilibrium thermodynamics, and specially the law of entropy (beginning with the very definition of the term 'entropy'), are far from being well understood.

Since the advent of non-equilibrium thermodynamics, a wealth of concepts has originated: attractors, fractals, and chaos theory, among others. Catastrophe and chaos theories turn out to be merely special cases of non-linear non-equilibrium systems. Now let me apply this approach to the evolution of human brain and mind.

3. NEGENTROPY AND THE PHYLOGENY OF BRAIN AND MIND [I]: FROM METABOLISM TO ENCEPHALIZATION

In cells, the specific negentropic process is *metabolism*, i.e., the set of chemical reactions by means of which cells transform energy, keep their identity, and reproduce. All life forms, from unicellular algae to mammals, depend on the simultaneous carrying-out of hundreds of metabolic reactions that are regulated with absolute accuracy, from birth and maturation to death. Cells have a series of enzymes or specialized catalysts that activate, control, and finish all of these reactions. Each enzyme in turn is coordinated with many other enzymes or catalysts produced within the entire organism (Alberts et al. 2002).

Because living systems continually metabolize molecules and originate potentially toxic waste products, using important substances that are necessary to restore, they have to be able to maintain their internal environments stable. This is achieved by *homeostasis*, which involves a necessary energy consumption to maintain a state of dynamic balance. This means that, even though the external conditions are continually tied down to an increase of entropy, homeostatic processes (conceived as negentropic processes) guarantee that the effects of such changes on organisms are kept to a minimum. If balance is altered and homeostatic processes are unable to recover it, then the organism might fall ill and in time, it might die.

The complexity of negentropic processes in living systems depends upon their energetic freedom in relation with the environment. As this energetic freedom increases, the measure of probability that the organized matter of the environment be chosen at random, diminishes. Such energetic freedom (of election) constitutes motor activity proper.

A clear example of a greater complexity in negentropic processes in living systems is the regulation of body temperature. In *poikilothermic* organisms (e.g., insects, reptiles, amphibians, fish), the body temperature varies according to the environmental temperature: in order to avoid the loss of organic humidity caused by evaporation, the body temperature is always a little lower compared with that of the environment (Woods et al. 2003). Since the metabolic rhythm diminishes as the external temperature drops down, poikilotherms show motor difficulties when temperatures are low. To avoid an excessive body temperature, they look for fresh and dark places during the day. But all over the long winter periods in the northerly and southern regions of the planet, a toad or a salamander, for instance, stay metabolically immobile. Certain species of toads can even hibernate literally frozen. On the contrary, *homoeothermic* organisms such as birds and mammals struggle for their existence thanks to their freedom to move, because they are able to maintain a constant body temperature (37-40 centigrades) (Cossins and Bowler 1987).

Poikilothermic regulation and homoeothermic regulation are two qualitatively different stages in the development of negentropic processes in living matter. So life means differentiation with respect to the external environment, that is, self-regulation that reduces the direct exchanges between organisms and the environment. The more self-regulated an organism, the more physico-chemically fragile it is. For that reason a greater complexity in the negentropic processes in living systems—in terms of the self-regulation of energy degradation—ends up in autonomous systems that maintain the level of individual-environment energetic exchange.

As a result of a greater complexity in the negentropic processes, we now get to the level of nervous functions in the zoologically higher biological systems. Such a complexity is represented in the property of organisms to react actively to objects and phenomena in the external environment.

The elementary form of this new stage in negentropic processes is *irritability*, i.e., the selective reaction of living systems to specific external influences (e.g., light, temperature, etc.). As the evolution of living organisms reached a higher level, irritability gave rise to a qualitatively new property, namely *sensibility*, that is, the ability of organisms to react not only to the direct action of vital ('biotic') stimuli for their survival, but also, to react to such stimuli which, not being directly biological ('abiotic'), signal the appearance of biologically relevant stimuli (e.g., food). The abiotic stimuli are presented to organisms under the form of properties or isolated qualities of objects from the external environment. The crucial aspect of this evolutionary stage is that organisms are now capable to guide themselves in the external environment and to react actively at any change on it, that is, organisms were now capable to generate individually variable forms of behavior that did not exist in the vegetable realm.

The negentropic processes characteristic of elementary irritability and sensibility to biotic and abiotic stimuli are sufficient for the maintenance of unicellular organisms. Among such organisms we find two types of cellular organization. They are *prokaryotes* if the genetic material is not surrounded by membranes that isolate them from the rest of the cell. This happens in green-blue bacteria and algae or *cyanobacteria* (Stanier and Cohen-Bazire 1977). The cells of *eukaryotic* organisms, on the contrary, have their genetic material separated from the cytoplasm, by means of a double membrane, that constitutes the nucleus (Alberts et al. 2002; Vidal 1984). Unicellular organisms such as protozoa belong to this kind of cellular organization.

The passage from unicellular to multicellular forms represents a qualitative leap towards the multiplicity of forms seen in the animal kingdom and therefore, towards new and more complex negentropic processes. For now multicellular organisms obtain energy by means of food digestion, and have cells organized in tissues. Contrary to plants that produce nutrients from inorganic substances by means of photosynthesis, or mushrooms that absorb the organic matter in which they usually are immersed, animals get their food actively and digest it in their internal environments. Associated to such nutrition process there exist many other characteristics that distinguish the majority of animal species from other life forms.

Specialized tissues allow them to move in search for food or, if they remain steady in a certain place almost all of their lives (such as sessile animals), to pull it towards them (Freeland et al. 2003).

The emergence of multicellular organisms gave rise to cells specialized in the reception of stimuli that affect the body of those organisms, and to the first contractile cells whose executive function would be assumed by the muscle cells in later stages of phylogeny. Such specialization makes necessary the presence of a coordination system, which arises when in the places of the old stimulation gradients in unicellular organisms, minuscule channels of the most excitable protoplasm that constitutes the most elementary form of nervous system—known as reticular or diffuse nervous system—begins to be singled out. In the phylum *cnidaria* (a clear example is hydra) a specialized level of cellular organization represented in a tissue organization, is already present. In the ectoderm (external layer) of such organisms there are certain sense cells that comprise the afferent apparatus of a nervous coordination system. The most outstanding characteristic of this coordination system is the communication between these sense cells with a nerve net. This net is a relatively diffuse structure, with certain limitations related to the range of responses it can produce: stimulation of the epithelial-muscular cells or stimulation of the specialized defensive structures. At the level of the nerve net, it is not possible for such organisms to execute refined muscular movements yet. However, in addition to the nerve net, certain cnidarians have a nerve ring that allows neuromuscular responses of greater complexity (Koizumi 2002).

The most remarkable characteristic of these organisms is the lack of a top structure or organ which guides their activity. Without such an organ, the stimulation spreads equally throughout their reticular nervous system. Therefore, the lack of a top organ that not only might be able to receive and coordinate information, but also to reprocess and code it creating a behavioral scheme, restricts the locomotor capacities of those organisms with a diffuse nervous system. This is the path towards more complex nervous systems (Holland 2003; see also Koch and Laurent 1999).

With the development of more advanced nervous systems, negentropic processes reached higher levels of complexity, for in highly developed living systems randomness diminishes, the organism has a large energetic freedom, and the relationships between the organism and the environment become more complex with the emergence of a top organ capable of creating behavioral schemes. The emergence of such a top structure is called *cephalization*.

This new form of nervous system can be found in its more elementary form in the *ganglionic* nervous system of the phylum *platyhelminthes*, such as *planarian*, which now show a clear level of tissue organization. In the anterior end of this kind of nervous system, two lobes of concentrated nerve tissue can be seen, which combined, make a ganglion that constitutes the encephalon. From this ganglion two bundles of neurons, called nerve cords, are prolonged back. Such structures form a central nervous system (CNS) able to process information coming from the sense cells, and allow more complex behavioral schemes than the ones seen in less developed organisms. The CNS of mollusks (e.g., snails and clams) is even more complex due to the process of cephalization, which in these organisms is highly advanced, and to the presence of additional ganglia, spread throughout their whole CNS.

An even more complex kind of CNS is that of *arthropods* (crustaceans, insects, spiders). Insects, particularly, show a highly degree of cephalization (Arendt and Nübler-Jung 1999). Ocellus or compound eyes in certain species are the most noticeable organs in the anterior region of this CNS. Such animals show a ladder-type CNS in their ventral side, that is, a double nerve cord that can have some or many ganglia spread all through it. The coordination of the delicate appendix movements of arthropods depends, in a large measure, from the ganglia in each segment of the CNS, which allow a considerable decentralization of the locomotor functions.

As cephalization gets more complex, we see a completely new mode in negentropic processes represented by the ability of more complex organisms to self-regulate the information from the external environment under the form of isolated elementary percepts (i.e., *sensation*), which in a certain stage in phylogeny became the self-regulation of information under the form of concrete objects, i.e., *perception*. This step forward in the development of brain functions allowed animals to be able to distinguish and generalize objects and phenomena of the surrounding environment into full images or representations.

In this stage we find most of the modern vertebrates. The development of this stage is closely related to the transit of vertebrates to a ground life or 'terrestrialization' as Nishihara (2004) calls it, which made necessary the emergence of new abilities in organisms for guiding themselves in the changing conditions of the external environment. This led to the emergence of CNS with a top organ (brain) which is not only capable of receiving information from the environment and put innate behavioral schemes into operation, but also to analyze such information and to activate new individually variable behavioral schemes (Brown 2001; Geary 2005).

During the course of the development to more complex forms in negentropic processes in non-human animals we can see radical changes in the evolution of CNS. An outstanding feature of such evolution has been a general tendency, during the last 100 million years (and of two million years during anthropogenesis), to the increasement in the size of the brain of the vertebrates, i.e., *encephalization* (see Gibson 2002; Reader and Laland

2002; Roth 2000). Now then, how has the evolution of the brain been related with changes in behavioral and cognitive capacities?

The study of encephalization during animal evolution has the initial difficulty that brains don't fossilize. But alternative methods have been used. One of these methods consists in the creation of a mold from the space that the cranial cavity of a fossil skull occupied. These molds (called endomodels) provide a good indication of the size and form of the brain of early vertebrates. Another method consists in studying modern animals that show several degrees of similarities and differences with respect to ancient ones. For example, contrary to mammals, modern frogs seem to show a lot of similarity with the vertebrate animals of 300 millions of years ago, while some mammal species (e.g., the opossum) show a greater similarity to fossil mammals of 50 million years ago than other species, like the dog. However, fossil record should not be seen as a linear sequence, for a special evolutionary development would not have been present in mammals even though it was given before the first mammal evolved. Some highly developed species of sharks, for instance, evolved with bigger brains than those of primitive ones, but this doesn't justify the larger brains found in mammals, for the evolutionary line of mammals split up from that of sharks before the sharks of larger brains (e.g., white shark) evolved (see Turner and Miller 2005).

The ethological and zoological research shows that even the most primitive vertebrates that exist today, as the lampreys, have brains of great complexity. Lampreys make a group of almost forty species of jawless fish which resemblance eels and inhabit fresh water currents and lukewarm and sub-artic ocean regions around the globe. These organisms not only have a spinal cord with a basic structure, a posterior encephalon and a mesencephalon, but also possess a diencephalon and telencephalon. The telencephalon shows brain hemispheres and other subdivisions present in the mammal brain.

The differences in the brains of vertebrate species don't consist in their basic subdivisions but in their relative sizes and design. The question now is at which stages in the evolution of vertebrates certain regions of the brain begun to be relevant. Lampreys have a couple of large optic lobes in their mesencephalon, which is likely to indicate their higher level of visual integration. In the frog the relatively big optic lobules in the mesencephalon is the major visual region of the brain. But in birds and mammals the complex visual perception requires an enlargement of the telencephalon (see Lefebvre et al. 2004; Reader 2003).

Reptiles were the first vertebrates that exhibited relatively large brain hemispheres. They were also the first vertebrates with a brain cortex, but without strata, as in the mammal brain. Part of the brain cortex of reptiles seems to be homologous to the mammal hippocampus. The hippocampus of the mammal brain is known as *paleocortex* because it is ancient in an evolutionary sense. Primitive mammals, like the opossum, have a relatively big amount of paleocortex and other structures that together form the limbic system. The term 'limbic' reflects the fact that this system constitutes a border around the mid-brain structures (the Latin word *limbus* means 'boundary').

All mammals have a neocortex with six layers. In highly evolved mammals the neocortex constitutes more than half of the volume of the entire brain (see Barton 1996). In many primates, such as pongids, the neocortex is deeply wrinkled, recovering the brain with a great amount of cortical surface. In higher mammals the brain cortex is the major organ devoted to an array of functions, for example the perception of objects in the external environment. The brain areas which in certain species were responsible for perceptual functions (e.g., the optic lobes of the lamprey's mesencephalon, or the optic region in the frog) have ended up in modern mammals to be the visual areas or relay stations that project to the brain cortex (Kaas 2004).

4. NEGENTROPY AND THE PHYLOGENY OF BRAIN AND MIND [II]: FROM MOTOR SCHEMES TO CONSCIOUSNESS

As a result of the emergence, development, and complexity of brain structures, negentropic processes in living systems reached an entirely new level in the self-regulation of organism-environment energetic exchange. For now brain cortex, as a top organ, not only receives and codes information from the environment and activates innate behavioral schemes, but also allows animals to analyze and synthesize the information coming from the external environment, guide their behavior in its constant changes, and form new individually variable behavioral schemes in correspondence with such changes (Krubitzer 1998; Rakic 1998). The essence of these qualitatively new processes is that, as a result of the active guidance to the changing and demanding conditions of the environment, stimuli of vital importance begin to stand out, motivating the emergence of new behavioral schemes that will aid animals to attain the necessary target, to avoid an imminent danger and, finally, to adapt themselves to the external environment. These mechanisms have been studied under the form of conditioned reflexes and complex dynamic motor schemes. Thus, in the process of their guiding activity within the external environment, the motor mechanisms of animals are not a simple chain of movements mechanically assimilated, but rather complex processes of adaptive activity.

When we arrive to a critical point in the evolutionary scale of vertebrate animals, we even find new forms of individually variable behavior, especially in primates. The major aspect of the intelligent behavior of these animals is that, in the process of their guiding activity, the discovery of the necessary solution to problems put forward by the external environment, does not remain in simple motor trials, but rather it begins to precede them, which leads to a new mode of simulated guiding activity, i.e., movements are only an executive link in such an activity that is preceded by complex simulated action schemes or programs (Grande-García 2007 [3]).

There is a whole range of data that demonstrates the complexity of primate cognition (for recent reviews see Bekoff et al. 2002; Díaz and Vargas Pérez 2005; Griffin 2001). For example, some studies using tasks based on a Piagetian framework (e.g., Parker 2002), have found that various species of monkeys and apes achieve sub-stage five of the sensory motor stage (trial-and-error discovery of instrumental means, imitation of novel behaviors). It is also claimed that great apes complete sub-stage six (insightful discovery of instrumental means, deferred imitation), which Piaget considered to be the hallmark of the appearance of mental representations or images (Piaget and Inhelder 1969), yet the data on this point is still disputed.

There is also growing data that apes and some species of monkeys engage in behaviors that have many of the features of deliberate deception (Cheney and Seyfarth 1990; Güzeldere et al. 2002).

There is broad indication for the ability to use tools. The most extensive tool users and tool makers among primates are chimpanzees, which appear to be the only primate species, other than the human species, that uses material artifacts as a significant part of life in the wild (Bermejo et al. 1989; McGrew 1988). The major tools used by chimpanzees are for subsistence (e.g., using a chewed leaf to sponge up water, using a stone to crack nuts); however, sticks and stones have been used as weapons and for self-stimulation (tickling) (McGrew et al. 1979).

In their well-known work with chimpanzees, Jane Goodall in Gombe (1967; Goodall and Lickley 2002) and Jordi Sabater Pí in the Okorobikó mountains in Rio Muni (Sabater Pí 1974), described how these primates stripped leaves from branches to use as probes for ants and to make fishing rods for termites. And although it is known that these animals make tools modifying natural objects (e.g., cutting leaves to fish out termites), there have also been some reports of chimpanzees using a variety of tools to acquire honey, remove nuts from their shells, pick bits of brain from skulls and clean the cranial cavities of prey (McGrew et al. 1979).

It has also become commonplace for primatologists to claim the existence of culture among chimpanzees in the wild (Whiten and Boesch 2001). It has even been argued for the actuality of cultural traditions on the basis of observations of stable differences among different troops in the way that they fish out termites or use leaves to get water (Whiten et al. 2001).

Moreover, some primatologists claim evidence for the active teaching of tool use among chimpanzees (Whiten and Boesch 2001).

Now, in spite of all these data that demonstrate the progressive development and the growing enhancement of the complex non-human animal mind, the biological laws that determine their evolution impose even to their higher evolved representatives limits impossible to overcome, that are manifest in the common characteristics of the preconscious animal mind, distinct from the human conscious mind. On the basis of the ideas developed by cultural psychologists (e.g., Cole 1996; González Rey 2002; Leontiev 1973/2005*a*; Luria 1977; Medina Liberty 2005; Vygotsky 1978), three main features that differentiate non-human animal mind from the human conscious mind, can be stated:

(1) *The limited character of the source of non-human animal behavior*: The entire structure of the non-human animal behavior obeys two main forms of manifestation: (i) the unconditioned reflexes resulting from the experience of the entire species, and (ii) the conditioned reflexes resulting from the individually variable experience of a single animal. These are the two sources from which the entire animal behavioral structure arises, which implies that in spite of the great variety and enhancement in the natural adaptation to the external environment achieved by higher vertebrates, none of them overcomes the limits of the biological laws that impose these forms of behavior. On the contrary, the source of the human mind is not inevitably tied to biological motivations, but rather it is given by cultural heritage; that is, it is set in the wealth of creations engendered by society, such as art, science, technique, etc. When this cultural heritage is internalized by each individual by means of their psycho-social activity and the assimilation of language, the human individual is now able to overcome the boundaries of her/his own individual experience and to assimilate the one from previous generations. This gave rise to enormous possibilities for the development of higher psychological processes as thinking and consciousness.

(2) *Every non-human animal behavior has a biological motivation*: their behavior arises, is set, works by virtue of biological needs, and is constrained to such necessities. Among non-human animals (not even in the most evolved ones) there is never an activity that does not imply a concrete biological sense, that is, an activity that is not guided to the satisfaction of a biological requirement. On the contrary, human motivations have a content and a form of satisfaction basically social. The satisfaction of human primary physiological necessities is even mediated and restructured by sociocultural factors. For example, if human sexual or eating necessities responded only to the determination of merely biological factors, how to explain then the emergence of clinical disorders such as

sexual impotence, anorgasmia, precocious ejaculation, paraphilias, anorexia, and bulimia [4]? What's more, the process of sociocultural learning itself (unique of the human species) not only restructures the basic biological needs, but also creates necessities and motivations of a higher level (e.g., cognitive, aesthetic, affective, etc.), specific of the human mind and beyond the biological level.

(3) *Non-human animal mind is guided by direct experience*: Anthropoid apes are at the top of the highest forms of non-human animal mind, characterized by a two-phase structure of activity: (i) a readiness stage of simulated action schemes, and (ii) a subsequent stage of action performance. Nevertheless, although the features and peculiarities of the developed mind of anthropoid apes have originated, and originates, interpretations that border on anthropomorphism, all their activity is determined by the impressions from the environment and/or by the principles of the direct individual experience. This imposes a qualitative limit to the non-human animal mind, tying it, at the most, to a situational and concrete representation of reality. On the contrary, the human mind implies an activity that presupposes the use of linguistic instruments, i.e., language. The acquisition of the syntactic structure and the semantics of language is what, in fact, allows the human being to designate the objects, qualities, actions, and relationships of the external world, to abstract their crucial properties, to form concepts and categories, and to access logical-abstract thought and goal-oriented conscious activity (Gal'perin, P. Ia. 1992; Leontiev 1973/ 2005*b*; Mithen 1999; Vygotsky 1934/1986).

Consequently, the transition from non-human to human mind involves a qualitative leap towards an entirely new negentropic activity. The immediate consequences of entropy that increases and drives non-human animals towards the energetic balance are counteracted by a series of negentropic activities whose aim is the adaptation of organisms to the external environment. Human being shares with the rest of living systems most of these negentropic activities that we have been tracking from the cellular level to the primate mind. But at the human level we find new forms of negentropic activities that are manifest in the accumulation of energy under the form of material production, that is, under the form of human labor.

Thus, in the human organism the energetic freedom increases, diminishing the measure of probability that the organized matter of the environment no longer depends directly on those negentropic activities characteristic of all living systems (including the human being), which are based on transformations and adaptations of organs, apparatuses, or systems, rather, it depends on the active transformation of the environment by means of socially produced instruments, specifically language.

Human labor consists in the active process of transformation of nature that, at the same time, makes possible the development of the human being itself, as the socialist thinkers Karl Marx and Friedrich Engels pointed out in the nineteenth century (Marx and Engels 1846/1959). If the non-human animal takes what nature offers and modifies it using its natural organs, human labor, on the contrary, involves the transformation of the crude thing and the creation of a new product, no longer natural but cultural. On account of this peculiarity of labor (that is radically distinct from animal activity) only at the human level we can find cultural products (machines, buildings, language, etc.). This implies that when human labor materializes in any product, it allows the progressive accumulation and the constant development of such product along the subsequent generations.

Labor is never a direct but an indirect process that presupposes the mediation of cultural instruments interposed between the human being and his labor object. Now, cultural instruments manifest under the form of labor tools external to the subject (e.g., a hammer, a computer, a microscope) or under the form of inner functional structures within the subject, like operational capacities by means of linguistic signs (e.g., scientific theories, artistic productions, etc.). Independently of the prevailing form (manual or intellectual) that the labor of a person acquires, she/he will always need cultural instruments provided by the human society. In this sense, every *individual* human activity is always, from the *start, a social* one since it is supported by the collective labor of past and present generations and under specific historical-social conditions (Cole 1996). Naturally, this does not invalidate at all the great merit and the individual talent of a particular human being in a certain activity (scientific or artistic creation, for instance), but rather it allows a better understanding of the essence of human creativity as a process that takes what culture provides it in a certain field of knowledge, and transforms it into something new: a theoretical model, a piece of art, a work of engineering, of architecture, etc., and leads the cultural patrimony at a new level so it can continue its development.

Moreover, human labor has another fundamental feature that consists on being a social activity that presupposes communication and exchange of experiences between the members of a society that participate in the productive process (Medina Liberty 2004). This means that the productive activity itself gradually created the need for a new kind of communication that eased the emergence of human language. As Colombian psychologist Alberto Merani (1977) points out, using language for life itself, human being transforms it into a social instrument; turning it into tongue and speech, he transforms it into a labor means and a labor object, thus emerging new means of production. Further, the action of language in turn becomes, as any other kind of labor, a productive labor, that is, becomes a negentropic activity.

This new historically formed mode of life, which is a uniquely human patrimony, had enormous consequences for the general structure of human activity, hence, for the formation of consciousness. Thus the well-known thesis of Karl Marx according to which: "[it] is not the consciousness of men that determines their existence, but, on the contrary, their social existence determines their consciousness" (Marx 1904/1959, p. 43). At the same time this new mode of life had also consequences in the anatomical and physiological restructuring of the emerging human being, and above all in the reorganization of the human brain (Mithen 2000).

Accordingly, the activity of non-human animals implies the satisfaction of an entirely biological necessity, that is, their whole behavioral activity is guided by stimuli with a biological significance and it tends towards the object that satisfies a necessity that is also biological. Therefore, the non-human animal mind is characterized by the fact that the target of animal activity is always fused with the biological motivation that drives it. Consequently, the non-human animal mental representations are always syncretic and undifferentiated: if the motivation and the target of animal activity are fused with the object that satisfies it, then the non-human animal cannot differentiate between the model, reflex or mental representation, and the independent existence of the object itself. That is, non-human animals cannot distinguish and differentiate themselves as something different from what surrounds them.

In the human being, on the contrary, the development of the productive activity was the factor that allowed rupturing the fusion between the motivation and the target of activity, interposing actions and operations that made possible that both the motivation and the target of behavior became conscious. This allowed the human being to maintain an anticipated goal-oriented activity under the form of a *conscious model of reality* (Leontiev 1973/2005*b*; Luria 1982). This fact permitted the human being to self-regulate his activity by means of behavioral conscious schemes in order to anticipate or simulate (Grande-García 2007) the consequences of his activity and, consequently, of regulating it much more effectively, which considerably enhanced the human ability to interact with the external environment.

Human being's growing capacity to consciously form anticipated models of possible activities had a very positive effect on human activity in general, for it begun to lose its direct and immediate character to a given external circumstance and started to be carried out on the basis of an active guidance that not only comprises the individual's past experience and the present objective situation, but also considered the possible future course of such external circumstance.

The ability to simulate anticipated behavioral schemes as conscious representations allowed the human being to develop his capacity to form deductions, conclusions, and logic and causal judgments, regarding the events he experienced. Being so, the human's prevalent socio-labor activity (as a better means for survival) made possible the formation and the progressive development of the human mind and its ability to distinguish its own activity from external objects and phenomena, that is, the human being was now able to expand his knowledge by virtue of the capacity to establish links and relations between him and the things around him. Thus, slowly but progressively, the emerging human being was able to distinguish the external environment as an independent reality and to represent it as a conscious mental model.

Concerning this point and based on Pavlov's conditioned reflex theory, and the works of Alexander Luria and others, the Hungarian physiologist G. Ádám (1980, esp. pp. 147-166) suggested that impulses become conscious when assuming a secondary signal character, i.e., when gaining verbal expression—according to Pavlov's thesis of language as a secondary signaling system. The human being is able to distinguish the external environment as an independent reality not only because he perceives stimuli, but also because he *knows*[5] them. Thus, according to Ádám, consciousness means the simultaneous presence in the higher centers of the brain of the external events arising as a result of primary environmental stimuli (sensation and perception) and those due to abstract, verbal signals.

Anyhow, the production of labor instruments gave the human being another advantage as important as the previous one: In the products of the human labor the experiences and knowledge that the members of the species have achieved in the collective practice are gathered, which allows their passage to future generations which, in turn, pass them again in a larger scale and so forth. This means that from productive labor emerged the uniquely human social, material, and cultural inheritance, which has been uninterruptedly transmitted along the human history and had assured the continuity of the progresses of human conscious mind. As the British archaeologist Steven Mithen (1999, p. 295) says, "it is seriously unfinished business."

NOTES

1 A first version of this paper appeared in my undergraduate thesis (see Grande-García, 2001). I would like to thank professors Hilda S. Torres Castro and Alberto Miranda Gallardo (Department of Psychology, Facultad de Estudios Superiores Zaragoza, UNAM) for inviting me to participate in the Philosophy of Psychology Seminar where I presented a reviewed version of the paper. I am also grateful with professors Ramón Abascal Rivera, Armando Cíntora Gómez, Sergio Díaz Ramírez, Alejandro Escotto Córdova, Carlos Hernández Mercado, Rubén Lara Piña, Sílvio Pinto, Ana María Rosado and Jesús Silva Bautista, for helpful discussions on the topics covered by this paper. Finally, and no less important, I would like to thank the editor of *Ludus Vitalis*, Fernando Zambrana, for his kind attentions at all moments prior to the publication of this paper.

2 The idea of thermodynamics and cybernetics to account for any self-regulatory system, and specifically living systems, is not new, and has been a tradition in Western science (e.g., Lotka, 1922; von Bertalanffy, 1950; Wiener, 1961). Thermodynamics and cybernetics have been used to explain the physical basis of biological evolution (e.g., Sella and Hirsh, 2005; Wicken, 1983, 1998; Wiley and Brooks, 1982). Jean Piaget (1967) used this approach to account for cognitive processes as self-regulatory activities which in his view continue, in a higher level, the self-regulatory activities in the organic level. Arturo Rosenbleuth (1954, 1971) developed a dual-aspect model combining cybernetics with psychology to solve the mind-body problem (see also Césarman and Estañol, 1996; Merani, 1977). So, this approach has been recently extended to psychology (e.g., La Cerra, 2003; Tooby et al., 2003), and particularly to the study of consciousness (e.g., Goerner and Combs, 1998; Roederer, 2003; Vandervert, 1995).

3 According to contemporary motor research (Jeannerod, 1999; Prinz, 2003), movement is not the main aspect of the motor system, but *action* is. Action is defined by a goal and an expectation; movements are the overt and final result of an action. So, action has two aspects: (i) an inner or overt one (movement proper), and (ii) an external or covert one (which corresponds to the motor representations of goal and expectation of an action, also called 'motor imagery'). This theoretical constraint has a logical consequence, namely, that a movement necessary involves a covert counterpart, but motor imagery or covert aspect of an action, does not imply an overt counterpart, i.e., a movement.

4 Some authors have argued for a reformulation of mental disorders from an evolutionary perspective (e.g., Demaret, 1983; Nesse, 1999; Price, 1967). According to this approach, mental diseases seem to have some adaptive function. For example, anxiety and depression are maybe defense mechanisms as physical pain is, while some eating disorders seemed to have evolved as feminine strategies to attract and retain males. I thank Professor Sergio Díaz Ramírez (Department of Psychology, Facultad de Estudios Superiores Zaragoza, UNAM) for making me notice this point.

5 In fact this is the original meaning of the term 'consciousness'. According to Zeman (2002, p. 14), consciousness comes from the combination of two Latin words: *scio*, meaning 'I know', and *cum*, meaning 'with'. Now, according to Natsoulas (1991) the ancient Romans used the terms *conscio*, *conscious*, and *conscientia*, to refer to an external, interpersonal, cognitive relationship be-

tween people. The English adjective 'conscious' (in Spanish, 'consciente') comes from these Latin locutions. Nevertheless, the etymology for the Spanish adjective 'consciente' is different from the English one, for it comes from the Latin voice *consciens*, -entis, and this in turn from the voice *conscire*, meaning 'to know perfectly'. But the prefixes that compose the Spanish words 'conciencia' and 'consciente', and the English words 'consciousness' and 'conscious' respectively, come from the same Latin voices that I mentioned earlier (i.e., *scio* and *cum*). The voice *cum* appears then to allude to knowledge that can be shared, rather than to 'to have knowledge' (i.e., 'with knowledge'). So, in this sense and because Latin had more meanings to the words *conscio*, *conscious*, and *conscientia*, the word 'consciousness' might mean, etymologically: (i) 'I know together with someone else', i.e., 'I share with someone else the knowledge that', or (ii) 'I know well or better than I know'.

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