A Syntropic Model of Consciousness

Antonella Vannini

Chalmers divides the problems of consciousness into: *The easy problem*, which deals with the study of neurobiological models of consciousness. Considering the enormous progresses of science it is relatively simple to find neural correlates of the conscious experiences. The easy problems largely deals with the functioning of the brain in the way it transmits and reads sensory signals, in the processing of information, in the control of behaviour, in the mechanisms underlying intelligence and memory, in the capability of reproducing verbal accounts, etc. Nevertheless, according to Chalmers, this approach does not explain the subjective qualities that consciousness has for the subject; in other words this approach is not able to answer the problem of the phenomenal consciousness. *The hard problem* which deals with the explanation of the qualitative and subjective aspects of consciousness, which escape a physicalistic and materialistic analysis.

In the first chapter of this work, models suggested by Antonio Damasio (1999), Gerald Edelman (2000) and Francisco Varela (1996) are described. These models try to explain consciousness using the principles of classical physics. These models show a different attitude towards localization: Damasio suggests neural sites in which consciousness could take place, Edelman suggests that consciousness is a global process of all the brain and Varela considers consciousness as a distributed quality of all the organism and of the interaction of the organism with the environment. In the second chapter, the models of consciousness based on quantum mechanics are reviewed. Using together the criteria of scientific falsification and the criteria of biological compatibility only two models, one suggested by Luigi Fantappiè (1942) and the other one suggested by Chris King (2003), survive the selection. It is interesting to note that these models are not pure quantum mechanical models, as they both originate from the integration of Schrödinger's wave equation (quantum mechanics) with special relativity

Introduction

The introduction to *The Conscious Mind* by David Chalmers (Chalmers, 1996) states that:

"*Consciousness is the biggest mystery. It may be the largest outstanding obstacle in our quest for scientific understanding of the universe. The science of physics is not yet complete, but it is well understood; the science of biology has removed many ancient mysteries surrounding the nature of life. There are gaps in our understanding of these fields, but they do not seem intractable. We have a sense of what a solution to these problems might look like; we just need to get the details right. Even in the science of the mind, much progress has been made. Recent work in cognitive science and neuroscience is leading us to a better understanding of human behaviour and of the processes that drive it. We do not have many detailed theories of cognition, to be sure, but the details cannot be too far off. Consciousness, however, is as perplexing as it ever was. It still seems utterly mysterious that the causation of behaviour should be accompanied by a subjective inner life. We have good reason to believe that consciousness arises from physical systems such as brains, but we have little idea how it arises, or why it exists at all. How could a physical systems such as a brain also be an experiencer? Why should there be something it is like to be such a system? Present-day scientific theories hardly touch the really difficult questions about consciousness. We do not just lack a detailed theory; we are entirely in the dark about how consciousness fits into the natural order*."

Chalmers divides the problems of consciousness into:

- **The easy problem**, which deals with the study of neurobiological models of consciousness. Considering the enormous progresses of science it is relatively simple to find neural correlates of the conscious experiences. The easy problems largely deal with the functioning of the brain in the way it transmits and reads sensory signals, in the processing of information, in the control of behaviour, in the mechanisms underlying intelligence and memory, in the capability of reproducing verbal accounts, etc. Nevertheless, according to Chalmers, this approach does not explain the subjective qualities that consciousness has for the subject; in other words this approach is not able to answer the problem of the phenomenal consciousness.

- **The hard problem** which deals with the explanation of the qualitative and subjective aspects of consciousness, which escape a physicalistic and materialistic analysis.

Chalmers says that "*The really hard problem of consciousness is the problem of experience. When we think and perceive, there is a whir of information-processing, but there is also a subjective aspect. As Nagel has put it, there is something it is like to be conscious organism. This subjective aspect is experience.*" (Chalmers, 1995). Chalmers affirms that easy problems are easy because all that it is needed is to find the mechanisms which allow to explain them, making them compatible with the laws of classical physics. The problem of consciousness is different from the easy problem since, even when all the main functions are explained according to cause-effect processes, it is impossible to arrive at the explanation of consciousness, in the term of subjective experience, according to the laws of classical physics.

In the first chapter of this work models suggested by Antonio Damasio (1999), Gerald Edelman (2000) and Francisco Varela (1996) are described. These models try to explain consciousness using the principles of classical physics. In the second chapter the principles of Quantum mechanics (QM) and its main interpretations will be introduced in order to describe the models of consciousness which are based on QM. In the 1930s, while the field of psychology was dominated by behaviourism, which did not consider consciousness a field for scientific investigation, the most important interpretations of Quantum Mechanics were using consciousness in order to explain the strange behaviours of the sub-atomic world. For example, according to the Copenhagen interpretation the wave function collapses into a particle only when a conscious observation is performed through an act of measurement. In this interpretation consciousness itself creates matter, and it is not matter which creates consciousness.

Quantum models of consciousness described in chapter 2 can be divided in three main categories:

1. models which assume that consciousness creates reality and that consciousness is an immanent property of reality;
2. models which link consciousness to the probabilistic properties of quantum mechanics;
3. models which attribute consciousness to a principle of order of quantum mechanics.

Analyzing the quantum models of consciousness which belong to the first category a tendency towards mysticism can be observed. All these models start from the Copenhagen interpretation of quantum mechanics and assume that consciousness itself determines reality. These models try to describe the creation of reality as a consequence of panpsychism, and assume that consciousness is an immanent property which precedes the formation of reality. The concept of panpsychism is explicitly used by most of the authors of this category. These assumptions cannot be falsified or tested in an experiment.

Analyzing the quantum models of consciousness which belong to the second category, also in this case, it is impossible to falsify the assumptions or test the models using experiments, as they consider consciousness to be linked to a realm, for example that of the Planck's constant, which cannot be observed by modern science.

Analyzing the third group of models which attribute consciousness to principles of order which have been already discovered and used for physical applications (laser, superconductors, etc.) it is possible to imagine experimental tests which could falsify them. However it is important to note that many of these models require conditions which are not compatible with the characteristics of biological systems. The order principles on which most of these models are based require extreme physical conditions such as, for example, absolute zero temperatures (-273 C°).

Using together the criteria of scientific falsification and the criteria of biological compatibility only two models, one suggested by Luigi Fantappiè (1942) and the other suggested by Chris King (2003), survive this selection. It is interesting to note that these models are not pure quantum mechanical models, as they both originate from the generalization of Schrödinger's wave equation (quantum mechanics) with special relativity.

In conclusion, it seems that all the models of consciousness which start from quantum mechanics cannot be translated into experiments, either because they cannot be falsified or because they are not compatible with the requirements of biology. The only two models which offer the possibility to be translated into experiments are those which unite quantum mechanics with special relativity.

The third chapter describes in more detail King and Fantappiè's models, while the fourth chapter is dedicated to the relation between causality and time. The understanding of this relation is fundamental for the understanding of the models of consciousness which are based on the principles of quantum mechanics and special relativity.

1. Consciousness according to classical physics

Many authors are interested in and are studying consciousness and mental states, and there is a wide variety of positions ranging from models based on classical physics (for example the models suggested by Paul Churchland, Antonio Damasio, Daniel Dennett, Gerald Edelman, Francisco Varela and John Searle), to models based on the properties of Quantum Mechanics, such as the dual nature of matter: particle and wave, the collapse of the wave function, non locality and the unified field (John Eccles, Stuart Hameroff, Roger Penrose and Chris King). Nevertheless an authentic understanding of mental phenomena seems to be still far away.

In this chapter Antonio Damasio, Gerald Edelman and Francisco Varela's models of consciousness based on classical physics are described.

These models show a different attitude towards localization: Damasio suggests neural sites in which consciousness could take place, Edelman suggests that consciousness is a global process of all the brain and Varela considers consciousness as a distributed quality of all the organism and of the interaction of the organism with the environment.

1.1 Consciousness according to Damasio

Many authors link consciousness to cognition and thinking, while Damasio links consciousness to emotions and feelings. Damasio's motto could be: "*I feel therefore I am.*" The importance of emotions was clearly stated in *Descarte's Error* (Damasio, 1994); in this book Damasio describes the importance of emotions in order to decide advantageously.

It is necessary to clarify the meaning that the words emotions and feelings have for Damasio.

Usually, in common language, no distinction between emotions and feelings is made, and theses words are used practically in the same way. Damasio, instead, uses these terms in different ways (even if they belong to the same process):

- *Emotions* are a collection of chemical and neural responses, which form a configuration and have the function of leading the organism to choose advantageously. Emotions are relative to the life of the organism, of its body, and the role of the organism in order to survive. The mechanisms which produce emotions are placed in a limited area of the subcortical region, starting from the encephalic trunk; these mechanisms are part of a group of structures which regulate and represent the inner states of the body and can be activated automatically, without any conscious decision. Emotions use the body as a theatre (inner milieu, visceral systems, vestibular and muscle and skeletal apparatus), and influence the way in which many brain circuits work. Emotional responses are responsible for profound changes in the body and in the brain. The collection of these changes forms the underlying substrate of neural configurations which are the feelings and the emotions (Damasio, 1999).
- According to Damasio the mechanism of emotions results in *feelings*. Feelings translate in the language of mind the vital states of the organism: mental maps of the states of the organism. At the origin of feelings there are emotions produced by the body, made of different parts which are constantly recorded by brain structures. Feelings are the perception of a specific state of the body, to which a state of the mind can be associated. Damasio distinguishes between feeling the emotions

and feeling the background. In the case of feeling the emotions Damasio says that the essence of this experience is the experience of the change which takes place at the body level and which is juxtaposed to mental maps and mental images (Damasio, 1994). In other words, an emotion is felt when the variation of a body state is linked to a cognitive content. Background feelings, instead, precede feeling the emotions and originate from background body states. Background feeling is the feeling of life itself. Background feelings corresponds to the state of the body which prevails among emotions, it is our image of the body state when it is not moved by emotions. According to Damasio, without the background feeling, the representation of the self would be disrupted (Damasio, 1994).

In *The Feeling of What Happens* (Damasio, 1999) describes consciousness as the knowledge of feelings: consciousness is experienced as a feeling and, consequently, if it is experienced as a feeling it could probably be a feeling. Damasio says that consciousness is not perceived as an image, neither as a visual, auditive, smell or taste configuration. Consciousness is not seen or heard. Consciousness has no smell or taste. According to Damasio consciousness is a configuration constituted by the non verbal signs of the body states.

Damasio divides consciousness into 3 levels: proto-self, nuclear self and autobiographical self.

The proto-self

Proto-self forms in each moment maps the state of the physical structure of the organism in its various dimensions and it is therefore a collection of coherent neural configurations; it coincides with the basic adjustments of life (Damasio, 1999). This collection of neural configurations is constantly updated and can be found in many locations of the brain at multiple levels, from the encephalic trunk to the brain cortex and in interconnected neuron structures. According to Damasio we are not conscious of the proto-self.

The nuclear self

Damasio suggests that consciousness starts when the maps of the proto-self are changed by the interaction with an object. Nuclear consciousness arises when brain representations generate a non verbal description, based on images, of the way in which the state of the organism is being modified by the interaction with the object. The object with which the organism interacts, can be real or recalled by memory, inside or outside the organism. The interaction with the object triggers an impulse of consciousness. Consciousness would be the consequence of these impulses and the continuity of consciousness would be the result of the constant generation of these impulses by the interaction with thousands of objects, real or recalled, which constantly modify the maps of the proto-self. More objects can interact with the organism at the same time and modify the proto-self and consciousness can arise by multiple interaction with objects (Damasio, 1999).

While the proto-self is a non conscious state, the nuclear self is the first stage of consciousness and coincides with the knowledge of feeling emotions. The biological essence of the nuclear self is the representation of a map of the proto-self which is being modified. This change is caused by the interaction with an object which modifies the perception of the inner states of the body, of the proto-self, causing emotions. The nuclear self is non verbal and can be caused by any object. As there is always ample availability of objects, the conscious experience is continuous and it is therefore experienced as a continuous state. The mechanism of the nuclear self requires the existence of the proto-self.

Nuclear consciousness is the most simple type of consciousness and gives a sense of self to the organism in a specific moment and place ("here and now"). Nuclear consciousness is a simple biological phenomenon which has only one level of organization, it is stable during all the life of the organism, it is not exclusive only to human beings, and does not depend on memory, reasoning or language. Nuclear self arises from the interaction of the organism with an object. It is based on the experience of changes in the organism and it is induced by the interaction with objects. The proto-self is a biological precursor of what, with the nuclear self, becomes the elusive feeling of consciousness.

The nuclear self coincides with feelings, with the ability of the organism to feel emotions which regulate the life of the organism. This happens when the organism processes sensory or memory information, for example when we observe a face or a landscape, or when the mind recalls an object or a specific situations and represents them as images in the process of the mind.

The model of the nuclear self is based on the following elements (Damasio, 1999):

1) The organism, as a unity, is projected in brain maps, in structures which constantly inform about the inner states of the organism. Damasio calls these maps, maps of the first order.
2) Sensory and motion structures, activated by the object, are projected in the maps of the first order, which represent the organism.
3) These projections produce modifications in the maps of the organism.
4) Modifications generate maps of the second order, which represent the interaction between the organism and the object.
5) Neural configurations which are momentarily formed by the maps of the second order can be translated into images.
6) Consciousness would arise from the construction of mental images caused by the interaction of objects with the organism.
7) Both the maps of the organism and the maps of the second order are linked to the body; consequently the images which describe relations among the organism and objects are feelings.

The autobiographical self

The first level of consciousness starts from the re-representation of the non-conscious proto-self while it is being modified by the interaction with an object. The autobiographical consciousness arises from the description of the interactions with the object: we know we exist because our narrated history shows us as actors in the interaction with the object.

Autobiographical consciousness, or extended consciousness, depends on the same mechanism as nuclear consciousness, but it connects the feeling of self to past and future events in an autobiographical narration. The self which derives from this process is a strong and robust self. It is an autobiographical self.

The autobiographical self, or extended consciousness, coincides with the higher level of consciousness. The autobiographical self is based on the ability of the person to keep track of his history. The autobiographical self is based on the autobiographical memory which is formed by implicit memories of a great number of individual experiences of the past and of the foreseen future. The autobiographical memory grows with the increase of life experiences, and can be partially changed in order to accommodate new experiences. Groups of autobiographical memories can be activated as neural configurations and become explicit in the form of images. Each time an object is recalled it generates an impulse of nuclear consciousness, this results in the autobiographical self of which we are conscious. The autobiographical self is based on experiences of the nuclear self which have been recorded in time and which can be activated and transformed into images. The autobiographical self requires the presence of a nuclear self (Damasio, 1999).

Autobiographical consciousness is the most complex level of consciousness. It is a complex biological phenomena, with different levels of organization, which evolve during the history of the organism. Neurological syndromes show that the impairment of the extended consciousness does not effect the capability of the nuclear consciousness to remain intact. On the contrary, the impairment of the nuclear consciousness destroys the higher levels of consciousness.

Extended consciousness would arise from two different types of processes (Damasio, 1999):

1) The first requires the gradual accumulation of memories of a specific class of objects. Each of these autobiographical memories is then treated by our brain as an object, becoming an inducer of consciousness.
2) The second consists in keeping active, at the same time, several images which form together the autobiographical self and which define the object. The autobiographical self can take place only in organisms which are equipped with a good sized memory and a high level of reasoning, but it does not require the use of language.

Extended consciousness arises when operational memory keeps active, simultaneously, both an object and the autobiographical self. In this process both the past which has been experienced and the future which is being expected are important. Future experiences, which are expected, have a great influence on the process of the autobiographical self. Memories of our desires and of the outcomes which we expect generate a pressure in each moment on our self.

According to Damasio, consciousness was formed in order to cope with the requirements of survival. In order to survive it is necessary to find and acquire energy and prevent all those situations which threaten the integrity of living structures. With no action, organisms like ours would not survive, because they would not find the sources of energy needed in order to renew structures and stay alive, and they would not use energy for their survival. Actions are guided by nuclear and extended consciousness and efficient actions require consciousness based on good images (Damasio, 1999). Actions are at the basis of survival and their power relies on the availability of using good images, the result is that consciousness, which maximises the efficiency of images, would provide enormous advantages for survival, leading to the natural selection of those organisms which are based on conscious processes. The big opportunity which is offered by consciousness is the link between mechanisms which regulate life and the production of images. This link constitutes a real advantage because the survival in a complex environment depends on the choice of the right action.

Localization of consciousness

The link between behaviour and brain became clear more than a century ago when Paul Broca and Carl Wernicke discovered that specific damages in areas of the left brain hemisphere caused language deficits. New techniques of investigation allow to study brain damages, with a three-dimensional reconstruction of the brain, when the patient is still alive. In this way it is now possible to study the behaviour of patients with specific damages. Using this process of investigation, Damasio discovered that neural damages localized in the prefrontal regions of the brain, especially in the ventral and medial sectors and in the right parietal region, are systematically associated with decision making deficits, which are often associated with severe alterations of the perception of emotions and feelings. Family members report that it is possible to recognize an exact “before” and “after” the neurological lesion. These studies show that the reduction of emotions impairs the rational process of decision making. Emotions seem to be an essential element in the process of reasoning. Without emotions all the process of reasoning and decision making is no longer oriented towards advantageous outcomes.

Localization of the proto-self

With emotions, specific regions of the brain send commands to other regions of the brain and to nearly all the regions of the body using two different ways. One is the blood circulation, in which commands are carried by molecules, chemical substances, which act on the receptors of cells which form the tissues of the body. The other is the neural networks in which commands are sent in the form of electro-chemical signals which act on the neurons, on muscular fibres and on organs (such as the surrenal gland) which can free chemical substances in the blood. The result of these chemical and neural commands is a global change in the state of the organism.

Substances such as monoamines and peptides, produced in the regions of the encephalic trunk and of the basal proencephalus, alter the modality in which brain neural circuits process the information, trigger specific behaviours and change the way in which the states of the body are signalled to the brain. In other words, both the brain and the body are influenced by these commands, even though these commands are produced in a limited area of the brain, which reacts to a specific content of the mental process.

According to Damasio, the structures which form the proto-self are (Damasio, 1999):

- Numerous *nuclei of the encephalic trunk* which regulate body states and project the signals which arrive from the body into maps. Along these chains of signals, which start from the body and end in the brain, the encephalic trunk is the first region in which groups of nuclei signal the state of the body.
- *Hypothalamus* and the *basal proencephalus* interconnected with the encephalic trunk areas. The hypothalamus contributes to the representation of body areas keeping an updated representation of the inner milieu: nourishing substances, glucose, concentrations of different ions, concentration of water, pH, concentration of hormones, and so on. The hypothalamus contributes in the regulation of the inner milieu according to these maps.
- *The insular cortex, and the S-II and medial parietal cortexes* situated behind the splenius of the callous body, which are all part of the somato-sensitive cortices. The functions of these cortices, in human beings, are asymmetrical; they contain the most integrated representation of the inner state of the body and of the muscular-skeletal system.

Localization of the nuclear-self

The study of patients with neurological damages shows that when nuclear consciousness is impaired extended consciousness is deactivated. But the opposite is not true, when the extended consciousness is impaired the nuclear consciousness can remain intact (Damasio, 1999).

Nuclear consciousness arises from the interaction of the organism with objects. Objects are shown in the form of neural configurations, in the sensitive cortex specific to its nature. For example, in the case of visual objects, the neural configurations take form in a great number of places in the visual cortex.

According to Damasio, the nuclear self needs a high degree of structural stability in order to offer a continuous reference in the long period. This continuous reference is what the self is required to provide. Representations change in time, but the self does not change, or at least not to the same extent. This stability is an essential requirement for the creation of consciousness. It is therefore necessary to identity structures which are capable to produce this stability.

The enigma of the biological roots of the nuclear self was formulated by Damasio asking what is that thing which is unique, is it always the same thing and provides a skeleton to the mind? The answer to which Damasio arrives is that the stability is given by the borders of the organism. Life exists within borders, which separates the inner milieu from the outer environment. The concept of an organism is based on the idea of the existence of borders. In the case of a cell, the border is the membrane. Life changes continuously, but it can only change within certain limits: life needs borders. It is therefore necessary to study what keeps life within certain borders, together with the neural representations integrated with the inner milieu which describe the inner state of the living organism. Damasio states that without a body no mind can exist.

Damasio states that structures of the second order, associated with the autobiographical self, need to:

1) Receive information through axonic signals coming from the sites involved in the representations of the proto-self.
2) Generate a neural configuration (image) which "describes", with some kind of time sequence, the changes in the maps of the first order.
3) Introduce, directly or indirectly, the general image which derives from the neural configuration of the flow of images. This general image is *thought*.
4) Send signals, directly or indirectly, to structures which process the information in such a way that the image of the object can be amplified.

This succession of representations constitutes a neural configuration which becomes, directly or indirectly, the base for an image, the image of the relation between the object and the proto-self modified by the object. The neural configuration of the second order arises in a transitory form from the interaction of some selected regions. It is not found only in one brain region, and neither everywhere or nowhere. The areas which meet the specifications for structures of the second order are the entire area of the cyngular cortex, the thalamus and some areas of the prefrontal cortex.

Neural configurations of the second order amplify the image of the object and this happens in different ways, it includes the thalamus-cortical modulation and the activation of the cholinergic nucleus and monoaminergic of the basal proencephalus and of the encephalic trunk, which all together influence the cortical elaborations.

These critical elements are set up by a network which is continuously reactivated and which is based on areas of convergence situated in the higher order temporal and frontal cortexes, and in subcortical nuclei such as the amygdala. The pace of this coordinated activity is set by the thalamus, while the prefrontal cortex, which participates in the work memory, maintains the reiteration of these components for long periods.

In conclusion

It is well known that vital functions, such as those of the heart, lungs and intestines, depend on the encephalic trunk, such as the control of sleep and wakefulness. Therefore, in a very small area, many structures are present which signal the chemical and neural states of the body to the central nervous system. These structures also carry signals from the brain to the body. Along these lines many centres control the vital functions of the organism.

An extended lesion of the encephalic trunk which usually causes coma, compromises many structures which regulate sleep and centres which are associated to the proto-self. The brain nucleus which is dedicated to the regulation of life processes and to the representation of the organism share the same areas and are interconnected with the centres which regulate sleep and wakefulness, emotions and attention and, in a word, consciousness (Damasio, 1999).

In conclusion, Damasio notes the essential role of the encephalic trunk: this region would be involved at the same time in the processes concerning sleep, emotions, feelings, attention and consciousness.

This overlapping of functions could seem accidental, but according to Damasio it is reasonable when analyzed according to the model that he has developed. The homeostatic regulation which comprises emotions, requires periods of wakefulness (in order to collect energy), periods of sleep (presumably in order to reconstruct the chemical elements necessary for the neurons), attention (in order to interact with the environment) and consciousness (in order to provide highly planned actions). The anatomic link of these functions with the body is totally evident.

This description is compatible with the classical idea of a locus situated in the higher regions of the encephalic trunk capable of creating particular electrophysiological states in the thalamus and in the cortex. Damasio's description differs from the classical one in two ways: first, it offers a biological foundation to the origin and anatomical location of the proto-self; second, it presupposes that the activity of the proto-self offers an important contribution to the state of consciousness, but that it does not produce the subjective state which defines consciousness in itself.

Damasio suggests that mechanisms which produce consciousness have been selected during evolution because they are useful for the organism in order to survive. Because consciousness was necessary as a biological tool for survival it was not limited to emotions, but it was used by all the other sensory stimuli. At the end, consciousness became applicable to a wide range of sensory states.

Damasio underlines the role of the vagus nerve which enters the brain at a higher level of the encephalic trunk, well over the level in which lesions usually occur. A high number of signals does not propagate through the nervous system, but uses blood flow, which reaches the central nervous system at the level of the encephalic trunk. All the studies of patients with spinal lesions have shown that the higher the lesion the more severe is the impairment. The higher the lesion the less information flows from the body to the brain, blocking in this way the flow of consciousness.

1.2 Consciousness according to Edelman and Tononi

In this paragraph the model of consciousness suggested by Gerald Edelman and Giulio Tononi is briefly described. This model differs from Damasio's model because it introduces the concept of integration and amplification of neural signals and does not require a specific localization of consciousness.

Dealing with the scientific study of the neural basis of the conscious experience, Edelman and Tononi start their book "*A Universe of consciousness*" (2000) with a reference to what Arthur Schopenhauer (1813) defined as the "cosmic dilemma": "*how can the subjective experience be correlated to events which can be described in an objective way?*" According to these authors, the best way to solve this dilemma is the scientific approach in which theories which can be verified are combined with well devised experiments. Consciousness is not a topic of philosophy, but it can be studied using the scientific methodology.

In the last centuries, both philosophy and science have tried explain the dilemma of consciousness. As far as the philosophical approach is concerned, Edelman states that it is quite improbable that philosophy alone will be able to solve the dilemma represented by consciousness and by the body-mind relation; at the most, it will contribute to define how difficult it is to deal with this dilemma. Thought alone, in the form of philosophy, is not sufficient by itself to unveil the origins of the conscious experience; it needs the support of observations and scientific experiments.

In the "science of the mind" a great progress has been made from the first introspective attempts of Tichener and Külpe. Now science can focus the attention on the neural correlates of consciousness, thanks to the technological advances of modern neurosciences. Nevertheless, Edelman and Tononi say that this does not allow to correlate the characteristics of consciousness with intrinsic properties of localized neurons in specific areas of the brain, as consciousness is not an object which can be localized in any part of the brain, but on the contrary a process. The aim of the authors is therefore to identify the neural processes which can explain the essential properties of the conscious experience.

Edelman describes this new perspective in the following way: "*Our analysis leads to several conclusions. First, conscious experience appears to be associated with neural activity that is distributed simultaneously across neuronal groups in many different regions of the brain. Consciousness is therefore not the prerogative of any one brain area; instead, its neural substrates are widely dispersed throughout the so-called thalamocortical system and associated regions. Second, to support conscious experience, a large number of groups of neurons must interact rapidly and reciprocally through the process called reentry. If these reentrant interactions are blocked, entire sectors of consciousness disappear, and consciousness itself may shrink or split. Finally, we show that the activity patterns of the groups of neurons that support conscious experience must be constantly changing and sufficiently differentiated from one another. If a large number of neurons in the brain start firing in the same way, reducing the diversity of the brain's neuronal repertoires, as is the case in deep sleep and epilepsy, consciousness disappears.*"

According to this approach, neural activities which are at the basis of consciousness involve large populations of neurons widely spread in the brain, and particularly the populations of the thalamocortical system. On the other hand no area in the brain is specifically responsible for the conscious experience.

In order to study the neural processes from which consciousness arises, it is necessary, according to Edelman and Tononi, to understand the global way in which the brain functions. For this purpose three main topological organizations of the brain, each one specialized in specific functions, seem to be necessary:

1. The thalamocortical systems, which constitute a group of separated but at the same time integrated circuits. This systems is based on the thalamus, which receives sensorial signals and signals of other nature and is connected to the cortex of the brain. Both the cortex and the thalamus are divided in many different functional areas. The different cortical areas and respectively the thalamus nuclei which are also specialized; for example, some areas process visual information and other auditive signals. These functional areas are separated by the reentry mechanism. The reentry mechanism is a key concept in the model suggested by Edelman. With the term "reentry" a process is characterized by feedback and feedforward signals. Reentry is a recursive exchange of

information, and a parallel exchange of information among interconnected areas in which neural maps are constantly synchronized. The reentry mechanism, typical of the thalamocortical systems, turns perception into a unitary process and behaviour. For this reason the mechanism of the thalamocortical systems seems to be dedicated to the integration of different brain areas into a unified response.

2. These parallel circuits, which link the cortex with the gland of the hippocampus, form a ring which project the information into the cortex through the thalamus. This organization differs from the thalamocortical system; connections are generally unidirectional and not bidirectional, and form long rings, and relatively few interactions exist at the horizontal level. These systems seem to be able to perform a variety of complex motility and cognitive procedures, which are generally functionally isolated among each other. This guarantees the speed and precision of the execution of different tasks.
3. Projections which start from the nuclei of the encephalus trunk and from the hypothalamus. These projections activate when major stimuli arise (strong noise, strong light, strong pain) and project information towards wide areas of the brain, releasing neuromodulators which influence the activity and neural plasticity, and change the strength of the synapses in the neural circuits, producing adaptive responses. These systems are collectively referred to as systems of value because they signal to all the neural system the presence of a major event changing the synaptic strength.

Considering data which comes from neuroimaging studies, Edelman asserts that the neural processes of the conscious experience involve groups of neurons widely distributed (especially of the thalamocortical system) in quick and strong reentrant interactions. These interactions among multiple areas of the brain are necessary for a stimulus to be perceived in a conscious way. This assertion is supported by experiments conducted in conditions of binocular competition, in which a subject, undergoing measurements of brain activities with a MEG, looks at incongruent stimuli: red vertical lines with the left eye through a red lens, and blue horizontal lines with the right eye, through a blue lens. Even though stimuli are presented simultaneously, the subject will be aware alternately of one or the other. Even if both the stimuli are received at the same time, only one is transferred to the conscious experience. The results of these studies show that:

1. The brain areas which are correlated to the conscious experience are widely distributed, but locally specified.
2. The neural processes which support the conscious experience are highly coherent, in the way that the synchronization of distant cortical regions increases when the subject is conscious of the stimulus, compared to when he is not. Coherence is therefore an indicator of the degree of synchronization among areas of the brain, and the values of coherence can be used as the strength of the reentrant interactions among brain areas.

These results show that, in order to have conscious experiences, a quick integration of the activity of brain regions distributed through reentrant interactions is necessary. This aspect of the neural synchronization, even if necessary, it is not sufficient, by itself, for the emersion of consciousness. It seems that consciousness requires neural activities which are not only integrated, but also differentiated, that is to say a neural activity which changes continuously and which differs in time and space. In order to support this assertion Edelman shows that two phenomena which are characterized by the disappearance of consciousness are epilepsy and slow wave sleep. These phenomena are both characterized by the synchronization of neural populations where the majority of neural groups discharge in a synchronous way, with the consequent elimination of differences. Brain states become extremely homogeneous, and with the reduction of the repertory of brain states consciousness is lost.

In order to study the mechanisms underlying this integration of separated functional areas, Edleman studied the concept of reentry in a large scale simulation of the visual system in which no higher level structure coordinates the answers of the model. This simulation was created taking into account the functional separation of the visual cortex: the neural units inside each separate area of the model respond to different properties of the stimuli. For example, V1 group of neurons respond to the elementary characteristic of the object, such as the orientation of the borders in a specific position of the visual field; IT group of neurons (inferotemporal) respond to class of objects with a specific form, independently from their position in the visual field. This model was tried in different visual tasks, some of which required the integration of signals produced from the activity of multiple areas working separately. For example, one task required the discrimination of a red cross from a green cross and from a red square, all presented simultaneously in the visual field. These simulations have shown that the integration (which emerged very quickly, after 100-250 milliseconds from the presentation of the stimulus) did not occur in a specific area, but as an average coherent process, and as the result of the interaction of reentry interactions among groups of neurons distributed in many areas. Simulations have shown that reentry can solve the problem of the global and general synchronization. Reentry is therefore the key neural mechanism which allows to obtain the integration of the whole thalamocortical system; this integration can generate a unitary behavioural answer.

At this point, Edelman asks what integration is and how it can be measured. For this purpose he introduces the concept of "functional aggregates", which describe a subset of elements which interact strongly among themselves and in a weak way with the rest of the system, and which cannot be divided into independent components. In order to obtain a measure of the integration of a system, Edelman uses the concept of statistical entropy, a logarithmic function which reflects the number of possible ways that the system can assume, weighed according to their possibility of occurring. If the neural system is isolated (that is to say if it does not receive any signal from outside and inside) neural groups do not interact; any possible state of the system can occur, each one with the same probability. In this situation entropy is at the maximum and coincides with the sum of all the single entropies of each element. On the contrary, if in the system some sort of interaction is present, the number of possible states is inferior to what would be expected by the possible states which can occur when the parts are separated. This integration measures the reduction of entropy caused by the interaction of the elements of an integrated system.

Edelman and Tononi's are against any form of localization and this approach is well expressed in the *dynamic nucleus* hypothesis, according to which the activity of a group of neurons contributes directly to the conscious experience if it is part of a functional aggregate characterized by strong reciprocal interactions among a set of neural groups and in a time span in the order of a hundredth of milliseconds. Conscious experience requires functional aggregate to be very differentiated, as is shown by the high indexes of the neural complexity. The adjective "dynamic" refers to the fact that, even if a high integration is observed within nuclei, its composition changes constantly in time. The dynamic nucleus, generated largely, but not exclusively, from the thalamocortical system, is therefore a process, and it is defined according to the neural interactions and not by specific localizations.

In order to arrive at a general theory of consciousness and explain how the brain developed, Edelman suggests a theory based on Darwin's natural selection, known as *Neural Darwinism,* or *The Theory of Neuronal Group Selection (TNGS).* According to this theory, higher brain functions would be the result of a selection which occurred during the phylogenetic evolution of the specie, and the anatomical and functional variations since the birth of the organism. Since birth, brain is characterized by an excess of neurons and organizes itself according to a process which is very similar to Darwin's natural selection. According to the degree of utilization, some groups of neurons die, and others survive and are reinforced. Selection is operated not at the level of the single neuron, but at the level of groups of neurons, which can range from a few hundred to several million cells. TNGS, which describes the evolution of the central nervous system and accounts for its high variability (fundamental for the differentiation of the states of consciousness), is based on three principles:

1. *Selection during development:* during the development of the embryo neurons extend ramifications in many directions. Ramifications give place to variability in the connectivity providing an immense array of neural circuits. Some of these patterns will be reinforced according to their activities and neurons of these specific groups will connect more strongly.
2. *Selection with experience:* in addition to selection during development, a process of synaptic selection is the result of behavioural experience.
3. *Reentry:* reentry favours the synchronization of the activity of neural groups belonging to different brain maps, connecting them in circuits which emit signals. Reentry is the central mechanism which allows the space and temporal coordination of different sensory and motory events.

In conclusion, the neural Darwinism theory represents the example of a unifying research program, which goes from neurobiology to philosophy, even though there is not much empirical evidence which sustains it is at the moment and it is criticized by the supporters of different theories and models.

1.3 Consciousness according to Francisco Varela

The model suggested by Francisco Varela represents one of the most "global" models among those, in the field of neurosciences, which deal with the phenomena of consciousness. Varela starts his study of consciousness in a paper published with Humberto Maturana entitled "*Autopoiesis and Cognition: The Realization of the Living*" (Maturana and Varela, 1980). The term autopoiesis comes from Greek and means to "produce itself". According to Varela and Maturana autopoiesis is the common element among all the living systems. An autopoietic system is, according to the authors, an independent unit capable of compensating, in a dynamic way, the perturbation which tends to destroy it. When these units interact and organize themselves in a greater autopoietic system, without loosing their individual identities, different orders of autopoiesis are obtained, such as the transition from the cell to the neural system. Autopoiesis has to do with the question "*what is life?*" and tries to define life, beyond the individual differences of living organisms, using the common denominator, the so called minimal cell, which has in itself all that is common to living systems, discriminating in this way between life and non life.

Autopoiesis is interested in the processes linked to life, in the belief that these processes can lead to the definition of what consciousness is. For Maturana and Varela, consciousness emerges from the characteristics of unity and autonomy of the cells: the living system tries to preserve its identity against all the fluctuations of the environment. Varela asserts that consciousness coincides with the identity of an autopoietic system.

In his last year of life Francisco Varela suggested a research program called neurophenomenology (Varela, 1996) which has the purpose of unifying cybernetics, neuropsychology, theoretical biology, immunology, epistemology and mathematics in order to describe the phenomenology of consciousness.

In the paper "*From autopoiesis to neurophenomenology*" (Rudrauf, 2003) Varela suggests a general reference frame which unites all living systems: the concept of autonomy. According to Varela, the biological roots of individuality need to be located in the unitary nature, in the coherent unity of living systems from which autonomy derives. From the autonomy of living systems, and from their being a unity, identity takes form. Identity defies all the natural tendencies which try to destroy it, such as the law of entropy. The living system takes the form of a constant unity which is self-contained and which shows its identity and autonomy from the inside. According to Varela this unity is the result of processes of co-dependence among the different parts of the system.

Not to fall into vitalism, Varela underlines that his approach is totally mechanistic, as it is based on the principle of cybernetics and on the general theory of systems. Nevertheless, the model which he developed is different from that of Cartesian machines, based on input and output cycles. Living systems are characterized by the self replication of themselves, while a machine is not capable of replicating itself. Varela asserts that the origin of life has to be found in the ability of self-reproduce typical of living systems; for this reason he considers autopoiesis the mechanism at the basis of life. According to Varela, the notion of autopoiesis is necessary and sufficient in order to define what life is. From autopoiesis an approach takes form centred on the system, on autonomy and self sufficiency of the organization. In this way, a transition from Cartesian machines and living systems, which are no more than machines with autonomy and unity, is performed. The finalized behaviour which is observed in living systems is considered a distortion of the observer, which emerges when he tries to summarize the behaviour of living systems. Varela emphasizes that cognition and behaviour are mechanical processes and that life is not moved by final causes.

According to Varela, living systems are mechanical and their properties have to be found in the interactions among processes. In this perspective, what appears as intentional behaviour is no more than the presence of specific mechanisms. Therefore also consciousness has to be considered as a consequence of mechanical processes. For example, an intentional act is a succession of mechanical actions which converge towards specific states, a transitory persistence in the relation between the living system and the environment. In Varela's vision persistence and stability are the elements from which consciousness takes form. In conclusion, mind develops from the interaction between the living system and the environment.

For Varela mind is not localized in the brain, but in all the organism, in the processes which link the living system with the environment. Considering that mind is generated by this interaction between the living system and the environment, it is impossible to say if it is inside or outside the body; for this reason, it is not possible to localize the mind. Varela suggests that the mind has the property of existing or not existing and that this depends on the processes and the interactions of the living system with the environment. Even if Varela expresses an immaterial vision of consciousness he continuously stresses the fact that consciousness and mind originate from mechanical processes, and that they are virtual mechanical entities. On the basis of this model, mind would be the consequence of the pattern of processes, which involve our physical body in interaction with the environment.

Consequently, an observer who studies the mind should put together the subjective experiences of the individual, gathered through subjective reports on the basis of different introspective methods for which he has been trained, with the description of how these physical processes propagate inside the living system in a dynamical way. Consciousness is for Varela the result of a dynamical and global process and should be studied as such. In this way he arrives at the conclusion that Chalmers' hard problem, the question about the relation between our subjective experience and the physical processes which can be observed in an objective way, requires the birth of a new experimental neuroscience of mind in which the subjective experience is integrated with the objective observation.

2. Consciousness according to Quantum Mechanics

In the 1930s, while the field of psychology was dominated by behaviourism, which did not consider consciousness a field for scientific investigation, the most important interpretations of Quantum Mechanics were using consciousness in order to explain the strange behaviours of the sub-atomic world. For example, according to the Copenhagen interpretation the wave function collapses into a particle only when a conscious observation is performed through an act of measurement. In this interpretations consciousness itself creates matter, and it is not matter which creates consciousness.

2.1 A short introduction to quantum mechanics

Quantum Mechanics (MQ) or quantum physics originated at the beginning of the 20th Century in order to explain the behaviour of the microscopic world at the atomic level. In this chapter Quantum

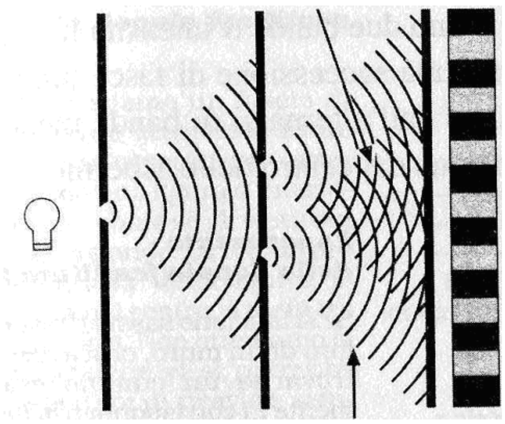
Mechanics will be introduced shortly and some interpretations described, with particular attention to John Cramer's transactional interpretation in which the dual solution of energy is used and the concept of retrocausality introduced.

2.1.1 The double slit experiment: light as a wave

On 24 November 1803 Thomas Young presented, at the Royal Society of London, the double slit experiment demonstrating that light is a wave:

"*The experiment I am about to relate (...) may be repeated with great ease, whenever the sun shines, and without any other apparatus than is at hand to every one*".

Young's experiment was very simple in design: a narrow ray of sunlight shines through a pinhole in a cardboard, the light then goes through two pinholes in a second cardboard, and then ends on a white flat surface creating patterns of lines, light and dark. (Fig. 1) which Young explained as a consequence of the interference among light waves. White lines (constructive interference) are shown when light waves add up, whereas dark lines (destructive interference) are shown when they do not add up.



Diffraction waves

Fig. 1 – *Thomas Young's double slit experiment*

Young's experiment was generally accepted as the demonstration of the fact that light propagates as waves. If light would have been made of particles, the interference pattern would not have shown up, but only two well localized dots of light would have been observed in association with the pinholes in the cardboard. Instead, in the double slit experiment, the brightest line is located between the two pinholes, in what would have been expected to be a dark area (Fig. 2).

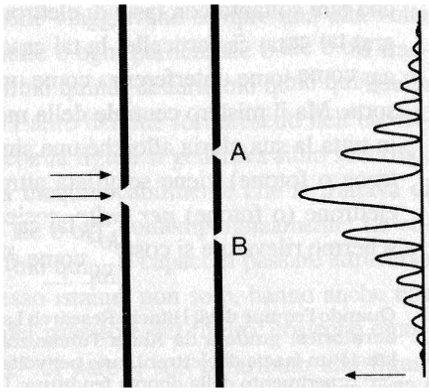


Fig. 2 – *Light patterns in Young's experiment*

Young's experiment has been considered the fundamental demonstration of the wave properties of light until Quantum Mechanics started to disclose the dual nature of matter: waves and particles at the same time.

2.1.2 The birth of Quantum Mechanics

At the end of the 18th Century Lord Rayleigh and Sir James Jeans tried to extend the equipartition theorem of classical statistical mechanics in order to describe thermal radiations.

In classical statistical mechanics, the equipartition theorem is a general formula that relates the temperature of a system with its average energies. The idea is that energy is shared equally among its various forms.

When applied to waves the equipartition theorem predicted that a body would emit radiations with infinite power, as it would all concentrate in the ultraviolet wavelength. This prediction was named the "ultraviolet catastrophe", but fortunately it was not observed in nature. This paradox was solved on 14 December 1900 when Max Planck presented a work, at the German Physical Society, according to which energy is quantized. Planck assumed that energy does not grow or diminish in a continuous way, but according to multiples of a basic quantum, which Planck defined as the frequency of the body (v) and a basic constant which is now known to be equal to $6{,}6262 \cdot 10^{-34}$ joule·seconds and which is now named Planck's constant. Planck described thermal radiations as composed of packets (quantum), some small others larger according to the frequency of the body. Below the quantum level, thermal radiation disappeared, avoiding in this way the formation of infinite peaks of radiation and solving in this way the ultraviolet catastrophe paradox.

December 14 1900 is now remembered as the starting date of quantum mechanics.

2.1.3 The photoelectric effect and light as particles: the photons

When light or electromagnetic radiation reach a metal, electrons are emitted, this is named the photoelectric effect. The electrons of the photoelectric effect can be measured, and these measurements show that:

- until a specific threshold is reached the metal does not emit any electrons;
- above the specific threshold electrons are emitted, and their energy remains constant;
- the energy of the electrons increases only if the frequency of light is raised.

Classical light theory was not able to justify this behaviour, for example:

- Why does the intensity of light not increase the energy of the electron emitted by the metal?
- Why does the frequency affect the energy of the electrons?
- Why are electrons not emitted below a specific threshold?

In 1905 Einstein answered these questions using Planck's constant and suggested that light, previously considered an electromagnetic wave, could be described as quantum packets of energy, particles which are now called photons.

Einstein's interpretation of the photoelectric effect played a key role in the development of quantum mechanics, as it treated light as particles, instead of waves, opening the way to the duality wave/particles.

The experimental proof of Einstein's interpretation was given in 1915 by Robert Millikan who, ironically, had been trying, for 10 years, to prove that Einstein's interpretation was wrong. In his experiments Millikan discovered that all the alternative theories did not pass the experimental test, whereas only Einstein's interpretation was shown to be correct. Several years later Millikan commented: "*I spent ten years of my life testing that 1905 equation of Einstein's and contrary to all my expectations I was compelled in 1915 to assert its unambiguous experimental verification in spite of it unreasonableness since it seemed to violate everything that we knew about the interference of light.*"

2.1.4 The double slit experiment and the dual nature of matter: waves and particles

Young's experiment can now be performed using single electrons. Electrons used in a double slit experiment produce an interference pattern and therefore behave as waves, but at their arrival they give place to a point of light, behaving as particles. Do electrons travel as waves and arrive as particles?

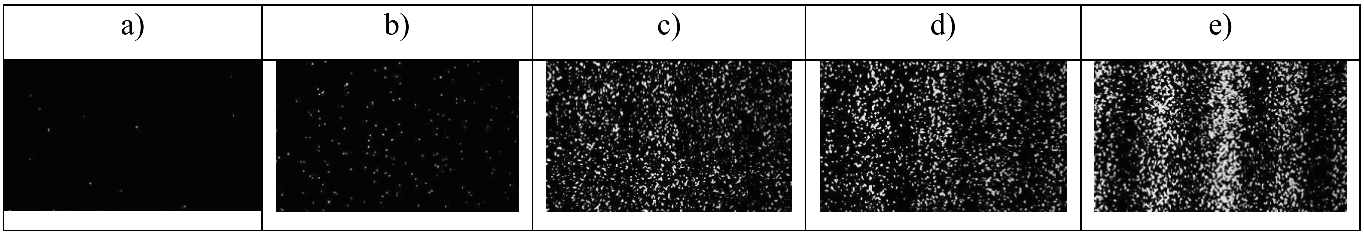


Fig. 3 – *Double slit experiment using electrons*
a) 10 electrons; b) 100 electrons; c) 3.000 electrons; d) 20.000; e) 70.000 electrons.

If electrons were particles we could conclude that they would go through one of the two slits, but the interference patters shows that they behave as waves going through the two slits at the same time. Quantum entities seem to be capable of going through the two slits at the same time and know how to contribute to the interference pattern.

According to Richard Feynman: "*Double slit experiment is a phenomenon which is impossible, absolutely impossible, to explain in any classical way, and which has in it the heart of quantum mechanics. In reality, it contains the only mystery, the peculiarities of quantum mechanics.*" (Feynman 1977)

2.1.5 Copenhagen Interpretation

The interpretation of Copenhagen was formulated by Niels Bohr and Werner Heisenberg in 1927 during a joint work in Copenhagen, and explains the double slit experiment in the following way:

- Electrons leave the electronic cannon as particles;
- They dissolve into waves of superposed probabilities, in a superposition of states;
- The waves go through both slits and interfere creating a new state of superposition;
- The observation screen, performing a measurement, forces the waves to collapse into particles, in a well defined point of the screen;
- Electrons start again to dissolve into waves, just after the measurement.

Essential components of the Copenhagen interpretation are:

- The Uncertainty principle formulated by Heisenberg, according to which a quantum entity cannot have a precisely defined moment and place at the same time.
- The Complementarity principle which states that a single quantum mechanical entity can either behave as a particle or as a wave, but never simultaneously as both; that a stronger manifestation of the particle nature leads to a weaker manifestation of the wave nature and vice versa..

- Schrödinger's wave equation, reinterpreted as the probability that the electron (or any other quantum mechanical entity) is found in a specific place.
- The superposition of states, according to which all the waves are superposed together until a measurement is performed.
- The collapse of the wave function which is caused by the observation and the act of measuring.

According to the interpretation of Copenhagen consciousness, through the exercise of observation, forces the wave function to collapse into a particle. This interpretation states that the existence of the electron in one of the two slits, independently from observation, does not have any real meaning. Electrons seem to exist only when they are observed. Reality is therefore created, at least in part, by the observer.

When Erwin Schrödinger discovered how his wave function had been reinterpreted into a probability function with mystical implications, he commented: *"I don't like it, and I am sorry I ever had anything to do with it".* Einstein immediately refused the interpretation of Copenhagen stating that the use of the observer, of consciousness and probability proved the incompleteness of the interpretation. According to Einstein a scientific theory had to use causality: "*God does not play dice with the universe!*"

2.1.6 EPR

In 1924 Pauli discovered that electrons have a spin, and that in a specific orbit only two electrons, with opposite spins, can find place (Pauli's exclusion principle). According to this principle any couple of electrons, which shared the same orbit, remain entangled showing opposite spins independently from their distance.

According to Einstein, causality is always local and information can only travel at speeds lower or equal to the speed of light, never faster. Starting from these assumptions Einstein refused the idea that information relative to the spin of entangled electrons could travel faster than light. In 1934, he formulated these considerations in the EPR paradox (named after the initials of Einstein-Podolsky-Rosen) which remained unanswered for more than 50 years.

2.1.7 Aspect's experiment

EPR had been presented as a conceptual experiment, in order to demonstrate the absurdity of the interpretation of Copenhagen, raising a logical contradiction. No one expected that the EPR experiment could be really performed.

In 1952 David Bohm suggested to replace electrons with photons in the EPR experiment, and in 1964 John Bell showed that the change introduced by Bohm opened the way to the possibility of a real experiment. At that times even Bell did not believe that the experiment could be performed, but 20 years later several groups had developed the precision of measurements required and in 1982 Alain Aspect published the results of an experiment which showed that Einstein was wrong and that non-locality was real.

Aspect's experiment measured the polarization of photons. It is possible to force an atom to produce two entangled photons, which go in opposite directions. Each photon, of an entangled pair, have opposite polarization. The interpretation of Copenhagen predicts that when the measurement is performed on one photon it instantaneously determines the state of the second photon. This is what Einstein named "*a spooky action at a distance*".

Aspect measured the polarization of photons according to an angle which he could regulate. According to non-locality changing the angle with which the polarization of a photon is measured would instantaneously change the measurement effected on the second entangled photon. The experiment was conducted on series of entangled pairs of photons. Bell's theorem stated that if locality is true, the measurements of polarization performed on the photons moving through the first apparatus, which could be regulated changing the angle, should always be higher than the measurements performed on the second set of entangled photons (Bell's inequality theorem). Aspect obtained opposite results violating Bell's theorem and showing that non-locality is real. Einstein's good sense lost the competition against the unreasonableness of quantum mechanics. Aspect's experiment, proved that in nature instantaneous correlations, where information propagates faster than the speed of light, are real and possible.

2.1.8 Wheeler's delayed choice experiment

When, in a double-slit experiment, a detector is used to measure which slit the photon goes through, the interference pattern disappears.

In 1978 John Archibald Wheeler proposed a variation of the double-slit experiment in which the detectors could be activated after the passage of the photon through the slits. In the delayed choice experiment the detector is located between the slits and the screen on which the interference pattern is observed. Quantum theory tells that when the detectors are turned on the interference pattern disappears, forcing the waves to collapse and the photons to go through the slits as particles. This should happen also if the detection is activated after the transition of the photons through the slits.

The delayed choice experiment became possible thanks to the speed of computers which can choose randomly when to activate the detectors between the double slit and the screen. The result is that this choice effects the way in which the photon has gone through the slit (wave/particle), and that this effect operates backwards in time. The first two experiments which verified this model were performed independently in the 1980s in the University of Maryland and Munich, Germany. These experiments showed that the decision to activate the detectors affected the nature of photons backwards in time.

Wheeler, noted that it is possible to devise a double slit experiment at the cosmic level using light coming from quasars and a galaxy which operates as a gravitational lens on the way to Earth. This light would generate an interference pattern showing that light has travelled as waves. But if a measurement would be performed before the screen on which the interference pattern takes form, the pattern would dissolve and the photons would change from waves into particles. In other words our choice on how to measure the light coming from a quasar influences the nature of the light (particle/quasar) emitted 10 billion years ago. According to Wheeler this experiment would show that retrocausal effects operate at the quantum level.

2.1.9 The transactional interpretation

The transactional interpretation of quantum mechanics was presented in 1986 by John Cramer, physicist of the Washington State University. In this interpretation the formalism of quantum mechanics remains the same, but the difference is how this formalism is interpreted. Cramer was inspired by the absorber-emitter model developed by Wheeler and Feynmen which used the dual solution of Maxwell's equation. As is well known also the generalization of Schrödinger's wave equation into a relativistic invariant equation (Klein-Gordon 1926) has two solutions, one positive, which describes waves which propagate forward in time, and one negative, which describes waves which propagate backwards in time. This dual solution allows to explain in a simple way the dual nature of matter (particles and waves), non locality and all the other mysteries of quantum mechanics and permits to unite quantum mechanics with relativity.

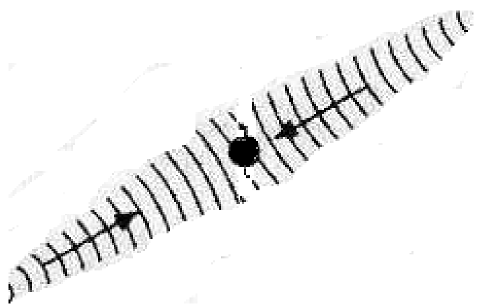


Fig. 4 – *Transactional Interpretation. The transaction between retarded waves, coming from the past, and advanced waves, coming from the future, gives birth to a quantum entity with dual properties wave/particle. The wave property is a consequence of the interference between retarded and advanced waves, the particle property is a consequence of the point in space where the transaction takes place.*

The transactional interpretation requires that waves can really travel backwards in time. This assertion is counterintuitive, as we are accustomed to the fact that causes precede effects. It is important to underline that the transactional interpretation takes into account special relativity, which describes time as a dimension of space, in a way which is totally different from our intuitive logic. The interpretation of Copenhagen, instead, treats time in a classical Newtonian way, and this is why it required the introduction of consciousness, in a mystical way, as a means to solve the contradictions which it was encountering.

2.1.10 Other interpretations of Quantum Mechanics

Other interpretations of quantum mechanics, beside the Copenhagen Interpretation (CI) and the Transactional Interpretation (TI), exist:

HVT (Hidden Variable Theories): it is based on the consideration that all the interpretations of Quantum Mechanics are incomplete, and that a deeper level of reality (a sort of sub-quantum world) which contains additional information on the nature of reality should exist. This information is present in the form of hidden variables. If physicists would know the values of the hidden variables they would be able to predict in a precise way the results of specific measurements, and should not limit themselves to the "probability" of obtaining certain results.

De Broglie-Bohm GWI (Guide Wave Interpretation): in this interpretation, originally suggested by L. De Broglie and then improved and supported by D. Bohm, a wave which guides its movement is associated to each particle, like a radar which guides a boat. Mathematically this wave is described by the Schrödinger wave equation corrected by a factor which considers the guiding property of waves on the movement of particles. Differently from the Copenhagen Interpretation these guiding waves would be real and would permeate all the universe, guiding any particle.

MWI (Many Worlds Interpretation): suggested by Everett at the beginning of 1950, and supported by Wheeler, states that each time a choice is operated at the quantum level (for example if an electron can choose the slit in the double slit experiment), the universe divides in two and continues dividing according to all the choices which are operated.

2.2 Chronological order of Quantum models of Consciousness

A review of quantum models of consciousness was presented by the author in QuantumBiosystems (Vannini 2008). These models can be divided in three main categories:

1. models which assume that consciousness creates reality and that consciousness is an immanent property of reality;
2. models which link consciousness to the probabilistic properties of quantum mechanics;
3. models which attribute consciousness to a principle of order of quantum mechanics.

1) Consciousness creates reality	2) Probability	3) Order principle
1930 - Bohr 1987 - Herbert 1989 - Penrose Hameroff 1993 - Stapp 2004 - Järvilehto 2007 - Mender	1925 - Lotka 1963 - Culbertson 1970 - Walker 1980 - Bohm 1989 - Lockwood 1990 - Pitkänen 1992 - Kaivarainen 1998 - Bondi	1941 - Fantappiè 1967 - Umezawa Ricciardi 1968 - Fröhlich 1971 - Pribram 1986 - Eccles 1989 - Marshall 1989 - King 1995 - Yasue 1995 - Vitiello 2003 - Flanagan 2003 - Pereira 2005 - Hu 2005 - Baaquie and Martine 2008 - Hari

Table 1: classification of quantum models of consciousness

In table 1 each model is associated to one of these three categories. Analyzing the quantum models of consciousness which belong to the first category a tendency towards mysticism can be observed. All these models start from the Copenhagen interpretation of quantum mechanics and assume that consciousness itself determines reality. These models try to describe the creation of reality as a consequence of panpsychism, and assume that consciousness is an immanent property which precedes the formation of reality. The concept of panpsychism is explicitly used by most of the authors of this category. These assumptions cannot be falsified or tested in an experiment.

Analyzing the quantum models of consciousness which belong to the second category, also in this case, it is impossible to falsify the assumptions or test the models using experiments, as they consider consciousness to be linked to a realm, for example that of the Planck's constant, which cannot be observed by modern science.

Analyzing the third group of models which attribute consciousness to principles of order which have been already discovered and used for physical applications (laser, superconductors, etc.) it is possible to imagine experimental tests which could falsify them. It is though important to note that many of these models require conditions which are not compatible with the characteristics of biological systems. The order principles on which most of these models are based require extreme physical conditions such as, for example, absolute zero temperatures (-273 C°).

Using together the criteria of scientific falsification and the criteria of biological compatibility only the models suggested by Luigi Fantappiè and Chris King survive this selection. It is interesting to note that these models are not pure quantum mechanical models, as they both originate from the generalization of Schrödinger's wave equation (quantum mechanics) with special relativity.

In conclusion, it seems that all the models of consciousness which start from quantum mechanics cannot be translated into experiments, either because they cannot be falsified or because they are not compatible with the requirements of biology. The only two models which offer the possibility to be translated into experiments are those which unite quantum mechanics with special relativity.

3. Consciousness according to the dual solution of the wave equation

In the Copenhagen Interpretation of quantum mechanics, the collapse of the state vector (the collapse of a wave into a particle) occurs at the same time at all positions in space. This collapse would seem to require faster-than-light propagation of information, violating in this way the limit of the speed of light posed by special relativity in the propagation of causality. This was Einstein's original objection to quantum mechanics, which was later formulated into the Einstein/Podolsky/Rosen (EPR) paradox. Analyzing the EPR paradox, Schrödinger concluded that the problem lies in the way time is used in quantum mechanics. The Schrödinger wave equation, which was the focus of most of the discussion surrounding EPR, is not relativistically invariant and treats time in an essentially classical way. For example, it assumes that there can be a well-defined "before" and "after" in the collapse description.

The relativistically invariant version of the wave equation was produced by Klein and Gordon in 1926. In order to convert the Schrödinger wave equation into a relativistically invariant relation, Klein and Gordon had to insert the energy/momentum/mass relation (special relativity):

$$E^2 = c^2p^2 + m^2c^4$$

where E is the total energy of an object, p the momentum, m the mass and c the speed of light

in Schrödinger's wave equation (quantum mechanics) obtaining a relativistically invariant equation known as the Klein-Gordon equation:

$$E\psi = \sqrt{p^2 + m^2}\psi$$

The solution of Klein and Gordon's equation depends on a square root which always leads to a dual solution: one positive in which waves propagate from the past to the future (causality), and one negative according to which waves propagate backwards in time, from the future to the past (retrocausality). This dual solution is well expressed in the d'Alambert operator in the form of: retarded waves (which propagate forward in time) and advanced waves (which propagate backwards in time). The Schrödinger wave equation has, in contrast, only the retarded wave solution.

In the 1930s the negative solution was rejected as it was considered impossible, even though experimental evidence supported this solution, as for example the neg-electron theorized by Dirac in 1928 and experimentally observed by Carl Anderson in 1932 and named positron. But, as proposed in Cramer's Transactional Interpretation (Cramer, 1986), and in Costa de Beauregard's Advanced-Action Interpretation (Costa de Beauregard, 1953), the EPR paradox disappears if advanced waves are considered to be real physical entities.

3.1 Chris King's model of supercausality

Chris King starts his paper "*Chaos, Quantum-transactions and Consciousness*" (King, 2003) from Einstein's energy-momentum-mass equation, and states that all quantum objects are constantly faced with bifurcations which force the system to operate choices.

The question about when a structure moves from the laws of quantum mechanics to the laws of classical physics is still under discussion, but it seems that this transition takes place gradually around 200 Angström (1 Angström equals the size of an helium atom). Synaptic vesicles and microtubules have dimensions which are lower than 200 Angström, it is therefore possible to consider these structure as "quantum" objects which constantly choose in response to past and future causes (Arndt, 2005).

King quotes Eccles, Penrose and Hameroff who proved the existence of quantum structures in living systems and arrives to the conclusion that life is moved not only by mechanical causes but also by final causes (attractors). According to King, a new and innovative description of the relation between mind and brain derives from this constant state of choice in which living structures are immersed. This constant state of choice would force living systems into a state of free will which would be common to all the levels and structures of life, from molecules to macrostructures, and organisms. This constant state of free will, would originate chaotic dynamics which, when attractors are inserted, organize in fractal structures which have the property of amplifying and selecting small perturbations. The classical example is the Lorenz attractor.

Starting from these premises King suggests two separate levels of explanation of consciousness. In the first level, information flows from the mind to the brain, through free will; in the second level, information flows from the brain to the mind, thanks to the selection and amplification of signals performed by fractal structures. King considers the mind to be immaterial, and its organization would be the consequence of the cohesive properties of *-E* (entanglement and nonlocality).

King suggests that, in order to understand what consciousness really is, it is necessary to start from free will, because at this level it becomes necessary to definitely refuse any attempt to use mechanical approaches. King describes:

- *Free will* as the process which the mind uses to act on the brain. Free will originates from bifurcations and supercausality which force living systems to operate choices. According to Fantappie's hypothesis retrocausality and anticipation (*-E*) are strongly correlated to emotions whereas rationality and memory would be a result of *+E*. In our daily life bifurcations would therefore be experienced in the form of the antagonism emotions/rationality. This constant antagonism would force humans into a state of free will and choice.
- *Consciousness* is the aptitude of the brain to act on the mind, selecting and amplifying sensorial perceptions, thanks to the properties of chaotic dynamics and fractal structures.

Sir John Eccles underlined the importance of free will in the cognitive processes of people: all sane people are considered to have the ability to modify and control their own actions through will and intentionality. Free will is usually considered to be at the basis of all the actions of human beings, but it absolutely contradicts the assumption that only classical causality and determinism are real (Hooper and Teresi, 1986). For this reason, when starting the study of consciousness from free will, it becomes impossible to agree with the assumptions of deterministic models, such as the computational one, which describe the brain as a complex machine.

According to King:

- free will allows the flow of information from the mind to the brain;

- fractal structures and chaotic dynamics select and amplify the signals of the physical world allowing the flow of information backwards, from the brain to the mind. Attractors and chaotic dynamics are at the basis of fractal geometry which describes how complex structures originate, organize and cooperate shifting from chaos to order.

In this description, supercausality is the new paradigm which permits to overcome the limits of the traditional theories of consciousness.

The model of consciousness described hypothesizes that it should be possible to observe:

1. living structures at the quantum level;
2. fractal structures in the organization of the different levels of the brain, from the neuronal level to the main structures;
3. chaotic dynamics in the brain processes.

First hypothesis: quantum structures

The question about when a structure shifts from the laws of microcosm (quantum physics) to the laws of macrocosm it is still discussed, but it seems that it is gradual at around 200 Angström (Arndt, 2005). In 1935 Eddington observed that synaptic vesicles had dimensions inferior to 200 Angström (Eddington, 1935) and, therefore, he hypothesized quantum-mechanic actions on living systems. These considerations were formulated again in 1970 by Eccles, who arrived at the conclusion that synaptic vesicles can be considered quantum objects, which can be therefore activated in non-determinist ways, following in this way the principle of free will which leads the system to global non deterministic instability (Eccles, 1970). In 1987 Hameroff supported these considerations observing the fact that microtubules show dimensions which are inferior to 200 Angström, a fact which implies non deterministic quantum processes. According to Hameroff microtubules are quantum objects (Hameroff, 1982).

Second hypothesis: fractal structures

The second hypothesis requires that the brain be organized on the basis of multi-fractal structures organized at different levels: the global level of the nervous system, the cellular level and that of the molecules. Fractal structure would allow the selection and amplification of signals, and the transition of the information from the lower to the higher levels, producing the "butterfly effect" which has been described by Lorenz in meteorology. In this way the instability of the highest neurodynamic level, could be influenced by the instability of the cellular level, which could be influenced by the instability of the molecules and of the quantum level. A wide range of empirical evidence show that the brain, neurons, cells and their components are fractal structures. A wide range of evidence can be found in the volume "*Fractals of brain, fractals of mind*" by Mac Cormac and Stamenov (1996). The fractal structure of living systems, and particularly of the brain, is now well known and supported by empirical evidence.

Third hypothesis: chaotic dynamics

Walter Freeman, worked for over thirty years studying the chaotic dynamics of the brain. In one of his books "*How brains make up their minds*" Freeman underlines the enormous complexity of the brain, and the inability of the linear causal model to describe and explain its complexity (Freeman, 2000). The brain is a highly dynamic and complex system: it contains approximately 10 billion neurons, connected in a complex non-continual network consisting of more than 1000 billion synapses. According to Freeman, the functioning of such a network can be understood only by using models derived from the modern theory of non-linear dynamical systems, based on the properties of self-organization and emerging phenomena. Even simpler systems, such as the surface of a fluid or a mix of chemical products, which are characterized by a high number of interacting substances, can generate macroscopic and global properties under particular circumstances which do not exist at the level of the basic substances, and which are therefore indicated as "emerging phenomena". These properties depend upon patterns which result from non-linear interactions among elementary substances. From a physical point of view, these non-linear interactions can be traced back to feedback loops in which the components of a system are connected circularly in such a way that each element stimulates the following until the last one stimulates the first. Thanks to this circular organization, the behaviour of each element is influenced by all the others. This permits the system to self-regulate until it reaches a dynamic equilibrium where the elements which are part of the system are affected by the global state generated together.

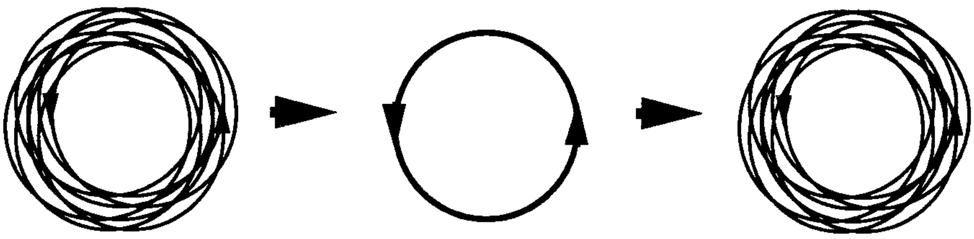


Fig. 1. Chaotic dynamics in the recognition of odours (Skarda and Freeman, 1987).

This circular interaction, or ring, permits the system to self-organize spontaneously without any external agent controlling the organization. In his studies of brain dynamics, using rabbits which were left free to smell the environment, Freeman found chaotic processes in the recognition of odours. Using EEG, Freeman measured neural activity during and after the odour stimuli, and represented them in space using a computational model. Freeman showed that the forms which were obtained, which were irregular but structured, represented chaotic attractors (or strange attractors, as described in the fifth chapter). Each attractor corresponded to the behaviour shown by the system as a consequence of a particular stimulus, such as a well known odour. In other words, a reaction to external simulation gives place to a global activity (registered by EEG) which is chaotic, but ordered and structured; if the stimulations change even slightly, the neurons instantly produce another configuration, which is complex but still ordered. According to the author, these chaotic dynamics can also be observed in other forms of perception. In conclusion, Freeman says that "*The great advantage that chaos can give to the brain is that chaotic systems can produce continually new types of activities. In our opinion these activities are essential to the development of groups of neurons different from those already established. More generally, the ability to create new types of activity may underlie the ability of the brain to reach for intuitions, and solve problems through trial and error*".

Chaotic dynamics are defined as non deterministic, and reactive (Schuster 1986, Stewart 1989). Reactive means that the system is capable of selecting and amplifying even the slightest perturbation, changing a chaotic system into a reactive system. At the same time a system of this kind cannot be predicted with computational techniques, because of free will which acts at each level of the system. The interaction of the chaotic and fractal properties repeated at the different levels (molecules, cells, neurons and nervous system) is indicated as the multi-fractal model. This model implies that all the components, from the molecular one to the global brain structures, can reciprocally activate each other. The fractal nature of their connections, the sophistication of neurons and synaptic junctions, leads to a modular and flexible structure. According to King, the anticipatory properties of these systems, their flexibility and ability of performing decisions, justifies why this model has been selected during evolution. The advantage of conscious processes in terms of anticipation, flexibility, learning and self-organization are fundamental for the survival of the living system and therefore free will and consciousness have emerged, surpassing any eventual computational systems.

3.2 The model of Luigi Fantappiè

In July 1942 Luigi Fantappiè presented at the Pontificial Academy of Science the "*Principals of a unitary theory of the physical and biological world based on quantum mechanics and special relativity*" in which he showed that retarded waves (diverging waves), with causes placed in the past, corresponded to chemical and physical phenomena governed by the law of entropy, while anticipated waves (converging waves), with causes placed in the future, correspond to a new category of phenomena governed by a law which is symmetrical to entropy and which Fantappiè named syntropy. Analyzing the mathematical properties of the anticipated waves Fantappiè arrived to the conclusion that these properties coincide with the qualities of living systems: finality, differentiation, order and organization.

The second principle of thermodynamics states that in each transformation of energy (for example when heat is transformed into work), a part of energy is dispersed in the environment. Entropy measures how much energy has been dissipated in the environment. When energy is distributed in a uniform way (for example no variations in heat exist), a state of equilibrium is reached and it is impossible to transform energy into work. Entropy, therefore, measures how much a system is near to the state of equilibrium and which is the degree of disorder in the system. Entropic phenomena show the following characteristics:

1) *causality*: diverging waves cannot exist in the absence of causes which have generated them;
2) *tendency towards homogeneity*: entropic phenomena tend to level out in the sense that they evolve from differentiation to homogeneity, from complex to simple. With time homogeneity and the uniformity of the system grow: the entropy of the system grows.

The qualities of syntropic phenomena are the following:

1) Entropy diminishes.
2) Syntropic phenomena are anti-dissipative and attractive. Converging waves concentrate energy and matter in always smaller spaces.
3) Because the concentration of matter and energy cannot be indefinite, entropic phenomena should compensate the concentration of energy and matter. In syntropic phenomena an exchange of matter and energy with the environment is therefore expected.
4) Syntropic phenomena are generated by "final causes", attractors, which absorb converging waves. These "final causes" are strictly connected with the existence of the syntropic phenomena: in this way it is possible to introduce a concept of "scientific finalism", where finalism is equal to "final cause".

As a consequence of the fact that the universe is expanding, macrocosm is governed by the law of entropy which forces time to flow from the past to the future (Eddington, 1927) and causes to precede effects (mechanical causation: cause➔effect). On the contrary, in the microcosm expansive forces (entropy) and cohesive forces (syntropy) are balanced, and time and causes flow in both directions (cause➔effect🡐cause), giving way to syntropic processes. Einstein's famous *Übercausalität*: supercausality.

The law of entropy implies that systems can evolve only towards disorder and destruction of all forms of organization; for this reason various biologists (Monod, 1974) have reached the conclusion that the properties of life cannot originate from the laws of the macrocosm, as these are governed by entropy and evolve towards heat death, disorder, and the annihilation of all forms of organization. Supercausality, and especially syntropy, which is observed in the microcosm, imply the qualities of order, organization, and growth which are typical of living systems.

Consequently Fantappiè suggests that life qualities could be a consequence of the properties of the microcosm, of quantum physics. But, as soon as the syntropic system grows beyond the dimensions of microcosm and enters the macrocosm level it starts conflicting with the law of entropy, which governs the macrocosm level and tends to the destruction of any form of organization and structure. In this way the fight for survival, in the form of conflicts with the law of entropy, starts.

The conflict between life and entropy is well known and it has been discussed continuously by biologists and physicists. Schödinger (Nobel prize 1933 for physics), answering the question about what allows life to contrast entropy, concluded that life feeds on "negative entropy" (Schödinger, 1988); the same conclusion was reached by Albert Szent-György (Nobel prize 1937 for physiology and discoverer of vitamin C) when he used the term syntropy in order to describe the qualities of negative entropy as the main property of living systems (Szent-György 1977). Albert Szent-Gyorgyi states that "*it is impossible to explain the qualities, organization and order of living systems starting from the entropic laws of macrocosm*". This is one of the paradoxes of modern biology: the properties of living systems oppose the laws which govern the macro level of reality.

The hypothesis of a fundamental conflict between life (syntropy) and environment (entropy) leads to the conclusion that living systems need to satisfy conditions in order to survive. For example.

1. acquire syntropy from the microcosm;
2. combat the dissipative and destructive effects of entropy;

In order to combat the dissipative effects of entropy, living systems need to acquire energy from outside and protect themselves from the dissipative effects of entropy. These conditions are known under the name of "**material needs**", and include:

- In order to combat the dissipative effect of entropy:
    - The need to acquire energy from outside, for example with food;
    - The need to reduce the dissipation of energy, for example with a shelter (housing) and clothes;
- In order to combat the continuous production of waste, which is the consequence of the destruction of structures under the effect of entropy:
    - The need for hygienic and sanitary standards and waste disposal.

The satisfaction of material needs leads to a state of well-being which is characterized by the absence of pain. The partial satisfaction, instead, leads to suffering in the form of hunger and illnesses. The total non-satisfaction leads to death.

Satisfying material needs does not stop entropy from destroying the structures of the living systems: cells die, and structures are destroyed; the living systems are therefore continuously called to repair the damages caused by entropy. In order to mend these damages syntropy is needed, as it is the only property which allows to create order and organization and to counterbalance the destructive effects of entropy.

Fantappiè suggests the existence of a structure which would support the vital process of an organism feeding on syntropy, such as the Autonomic Nervous System (ANS). ANS would acquire syntropy from the microcosm, feeding in this way the regenerative processes of living systems. Because advanced waves (syntropy) converge energy:

- When syntropy is acquired feelings of heat (concentration of energy), associated with feelings of well-being, would be experienced in the thorax area (typical of the ANS).
- When syntropy is not acquired feelings of cold and emptiness would be experienced in the thorax area, associated with feelings of pain and suffering.

According to this model, when the need to feed on syntropy is not satisfied feelings of emptiness, cold and pain in the thorax area are experienced. When this need it totally non satisfied ANS would not be capable of feeding regenerative processes and the damages produced by entropy would not be repaired, leading the system to death.

The hypothesis that neurophysiological parameters of ANS should show behaviours of anticipation originates from the description of ANS as a system which feeds the living system with syntropy in order to support the vital functions of the living system. This is the hypothesis which has guided the research activity.

The fundamental elements of this model are (Fantappiè, 1942, 1955a):

- When the negative solution of Klein-Gordon's equation is interpreted it implies necessarily that at the atomic level of quantum mechanics time is unitary (past, present and future coexist).
- In 1927 Sir Arthur Eddington introduced the expression "*the arrow of time*", showing that entropy forces events to move in one particular direction: from a situation of high potentials to one of low potentials: from past to future. At the macrocosm level entropy prevails (Frautschi, 1981) and this fact causes time to move forward, in the direction familiar to us, from the past to the future.
- The law of entropy tends to destroy and level structures and leads to death.
- As a consequence of the incompatibility of life with the law of entropy, which governs the macrocosm, Fantappiè suggests that life originates in the quantum level, at the atomic scale, where the law of syntropy can prevail.
- Syntropy leads to the formation of structures which rapidly grow beyond the level of quantum mechanics and enter the macrocosm level. However macrocosm is governed by the law of entropy which destroys any form of structure, organization and order.
- Consequently, in order to survive, syntropic systems (life) need to counterbalance the deadly effects of entropy.
- Fantappiè associates the anabolic processes of life to syntropy and the catabolic ones to entropy and suggests the existence of structures which operate a bridge between the syntropic properties of microcosm and living systems. These structures have been documented by many researchers, among whom Eccles (1989), Penrose (1994), Bondi (2005) and Hameroff (2007). Fantappiè notes the strange symmetrical properties of water, which in many ways are opposite to those of other

liquids. For example when water solidifies instead of becoming heavier it becomes lighter. Fantappiè suggests that water might operate a bridge between the micro and the macro level, allowing syntropy to flow from the microcosm. For this reason water is essential for living systems.

- In order to counterbalance the deadly effects of entropy life needs to feed on syntropy: negative energy, waves and energy which moves backwards in time.
- Fantappiè suggests that structures which support the vital functions of life feed on syntropy, and sees this task in the Autonomic Nervous System (ANS).
- Fantappiè arrives, therefore, to the conclusion that the physiological parameters of ANS (such as skin conductance and heart rate parameters) should show anticipatory behaviour as a consequence of the fact that ANS feeds on syntropy, an energy which moves backwards in time.

4. Empirical evidence

In the last decade a growing number of studies have shown the existence of pre-stimuli reactions in the parameters of skin conductance and heart rate. Anticipatory pre-stimuli reactions are neurophysiologic responses activated before the stimulus takes place. These anticipatory reactions are activated before the subject can receive indications or cues about the stimulus. In scientific literature, various experiments show the existence of anticipatory effects, for example:

1. *Anticipatory reaction of skin conductance.* In 2003 Spottiswoode and May of the Cognitive Science Laboratory replicated Bierman and Radin (1997) experiments which show an increase in skin conductance 2-3 seconds before emotional stimuli are presented. Spottiswoode and May replicated these results obtaining a statistical significance of $p=0.0005$, and performed controls in order to exclude all possible artifacts and alternative explanations. These results support the hypothesis that the autonomic nervous system reacts in advance of stimuli (Spottiswoode and May, 2003).
2. *Electrophysiological responses.* McCarty, Atkinson and Bradely in *"Electrophysiological Evidence of Intuition"* (2004) show the existence of strong anticipatory reactions of the electrophysiological parameters of the heart.
3. *Pre-stimuli heart rate differences.* In his article "*Heart Rate Differences between Targets and Non*

Targets in Intuitive Tasks", Tressoldi and coll. report results of two experiments aimed at investigating pre-stimuli heart rate changes. Results support the hypothesis that heart rate changes before stimuli are applied (Tressoldi 2005).

On the basis of this evidence, Tressoldi suggests that in decision making two processes are active:

– *Cognitive (implicit and explicit)*, which follow the classical flow of information, from the past to the future, and which are based on the use of memory, learning and experience;
– *Intuitive,* based on the perception of emotions, which follow the backwards in time flow of information, from the future to the past, and which use the signals arriving from ANS.

In order to falsify Fantappiè's model it was decided to use a modified design of Tressoldi's experiment.

Phase 1 *Presentation of stimuli and measurement of heart rate*				**Phase 2** *Choice*	**Phase 3** *Random selection*
Blue	Green	Red	Yellow	Blue/Green/Red/Yellow	Red
Non target	***Non target***	***Target***	***Non target***		***Target***
4 seconds HR01 HR02 HR03 HR04	*4 seconds* HR01 HR02 HR03 HR04	*4 seconds* HR01 HR02 HR03 HR04	*4 seconds* HR01 HR02 HR03 HR04		***Feedback***

Tab. 1 – Phases of an experimental trial:
1. *colours are presented on full screen for exactly 4 seconds and the heart rate (HR) is measured each second;*
2. *the experimental subject chooses one of the colours trying to guess the colour which will be selected by the computer;*
3. *the computer selects, using an unpredictable random algorithm, one of the 4 colours (target) and shows it in full screen (feedback).*

Each trial of the experiment was divided in 3 phases (table 1):

1. <u>*Presentation phase*</u>*:* 4 images are presented one after the other on the screen of the computer. The first one is blue, the second one is green, the third one is red and the fourth is yellow. Each image (colour) is shown for exactly 4 seconds. The subject is asked to look at the images, and during the

presentation the heart frequency is measured at fixed intervals of 1 second. For each image 4 measurements of the heart frequency are saved: one for each second. The presentation of the image is perfectly synchronized with the heart rate measurement. When necessary the synchronization is re-established showing a white image before the presentation of the colour.

2. *Choice phase:* at the end of the presentation of the 4 colours, an image with 4 colour bars is shown (blue, green, red and yellow) in order to allow the subject to choose (using the mouse) the colour which he thinks the computer will select. In other words, the subject is asked to guess the colour which the computer will select.
3. *Random selection of the target and feedback:* as soon as the subject chooses a colour the computer selects the target colour, using a random (and therefore unpredictable) process, and shows the selected colour full-screen on the computer (*Feedback*). The presentation of the target acts as a feedback which informs the subject of the result of his/her attempt to guess.

According to Fantappiè's hypothesis, in the presence of anticipatory behaviour (retrocausality), differences should be observed in phase 1 between heart rate frequencies when the colour is target (chosen by the computer in phase 3) or non target (not chosen by the computer in phase 3).

Four experiments were performed:

1. The first experiment involved 24 subjects. For each subject the trial was repeated 60 times. Results showed a strong and statistically significant difference in heart rate frequencies measured in phase 1 when the colour is target compared to when the colour is not target. The effect appeared with the blue and green colours.

2. The second experiment was devised in order to answer the following questions:

    a. The retrocausal effect shows only with the blue and green colours?
    b. The retrocausal effect shows only when colours are used?
    c. The retrocausal effect appears only when feedback is shown by the computer?

The experiment consisted of 5 different trials: in 3 trials the sequence of the colours was changed, in order to answer question 1: "*Does the retrocausal effect show only with blue and green colours?*"; in the fourth trial the feedback was not shown, in order to answer question 3: "*Does the retrocausal effect appear only when feedback is shown by the computer?*"; in the last trial colour stimuli were replaced with black numbers on a grey background, in order to answer question 2: "*Does the retrocausal effect show only when colours are used?*" The sample was of 23 subjects, and the 5 trials were repeated 20 times for each subject. In the results the effect does not show only with the blue and green colours, but also with the other colours; the effect emerged also when numbers were used, and is not necessarily associated with colours; the effect is absent when the computer, after choosing the target does not show it (but shows a grey full screen); the effect is stronger near the feedback (*position effect*). In order to study possible statistical artifacts, targets were used which were not correlated with the stimuli selected by the computer during the execution of the experiments. These uncorrelated targets did not show any statistically significant result.

3. In the second experiment, the absence of the feedback happened always in the fourth trial, and this could constitute an artifact. In the third experiment the sequence of the colours in phase 1 was always the same, but the feedback was hidden at random, in an unpredictable way. Results show that the retrocausal effect of the heart rate appears only when the computer shows the feedback. The feedback of the computer, in phase 3, can therefore be considered the cause of the retrocausal effect which is measured in phase 1.

Tressoldi suggests the hypothesis that somatic markers (SM), such as those described by Damasio (Damasio, 1994), can explain pre-stimuli effects observed in these experiments. Tressoldi extends Damasio's model of decision making, based on the dual system of information processing:

- *Conscious systems*, or declaratory, which use verbal processes of reasoning in order to formulate decisions;
- *Emotional systems*, unconscious, non-declaratory, which use a different neurophysiological network in which somatic markers, which can be measured through skin conductance and heart rate

frequencies, seem to play a key role;

and proposes that Somatic Markers (emotional signals) can be the consequence not only of learning but also of the flow of information which moves backwards in time.

Damasio did not consider the possibility that the anticipatory reactions observed in gambling could be the result of *retrocausality* and not only of learning. The design of his experiments is based on implicit rules which do not allow to distinguish retrocausal and learning effects in the anticipatory reaction of skin conductance.

The fourth experiment used the same sequence of colours as the first experiment, but in phase 3 a colour had a 35% chance of being extracted (lucky colour), and another colour had a 15% chance of being extracted (unlucky colour) and the last two colours had a 25% each chance of being extracted (neutral colours). The aim of the experimental subjects was to try to guess the target extracted by the computer. Subjects were not informed that colours had different chances of being extracted. In each trial 16 heart rate frequencies were measure in phase 1, the experiment consisted of 100 trials and the sample was of 30 subjects.

The design used in the fourth experiment allows to distinguish in a precise way the retrocausal effect from the learning effect:

- when differences are observed in heart rate frequencies (measured in phase 1) in association with the random (unpredictable) choice of the computer in phase 3, these differences can be attributed only to a retrocausal effect;
- when differences are observed in heart rate frequencies (in phase 1) in association with the choice (lucky, unlucky or neutral) operated by the subject in phase 2, these can be interpreted as a learning effect.

The hypotheses of the fourth experiment were the following:

1. *Retrocausal hypothesis*, in the form of differences of heart rate frequencies measured in phase 1 in association with the colour selected by the computer in phase 3;
2. *Learning hypothesis*, in the form of heart rate differences measured in phase 1 in association with the choice operated by the subject in phase 2. As a consequence of the fact that this would be a learning effect it should be strong in the last trials of the experiment.
3. *Interaction hypothesis*, because both the retrocausal and learning effect would show on the heart rate frequencies an interaction would be expected.

The results of the fourth experiment show:

1. A strong retrocausal effect with all the colours: blue (Chi Square 117.63) $p<1/10^{27}$, green $p<1/10^{12}$, red $p<1/10^{13}$ and yellow $p<1/10^{11}$. It is important to remember that p indicates the error probability which we accept when we state that the effect exists: therefore the smaller is the value of p the more significant is the result.
2. The retrocausal effect was strong from the first trials of the experiment.
3. A strong learning effect (p=0.00000000023). This effect shows in a strong way in the last block of trials, as expected by the learning hypothesis.
4. An interaction of the two effects in the middle part of the experiment in which both effects disappear and then emerge again (p=0.000000000000076).

5. Conclusions

Fantappiè and King's models overlap in many point, but they also differentiate in some important elements.

9.1.1. Fantappiè's model

Wheeler, Feynman (1949) and Fantappiè (1942) showed that advanced waves behave as absorbers whereas retarded waves behave as emitters. In 1941 Fantappiè discovered that, according to the law of syntropy, living systems are a consequence of advanced waves and would behave as energy absorbers; he then arrived at the conclusion that the energy balance of living systems should, therefore, always be positive, in favour of absorption. The assertion that living systems absorb energy is consistent with the realization that nearly all the energy used by humanity derives from biological masses: wood, coal, petrol, gas and bio-fuels.

This distinction between absorbers and emitters provides an interesting insight into one other basic property of life: the "feeling of life". According to Damasio the "background feeling" which is the equivalent of the "feeling of life" is the fundamental element of consciousness and life. Likewise, Fantappiè asserts that "advanced waves are the essence of life itself". If both Damasio and Fantappiè are right, it would follow that the feeling of life, consciousness, is a direct consequence of advanced waves, since life itself is, according to the law of syntropy, a consequence of advanced waves. A more intuitive understanding of the link between advanced waves and consciousness may come when considering the "feeling of life" as a consequence of converging waves/absorbers, rather than a consequence of diverging waves/emitters (retarded waves). The equivalence "feeling of life = advanced waves" leads to the conclusion that systems based on the positive solution (entropy), as for example machines and computers, would never show the "feeling of life" independently from their complexity, while systems based on the negative energy solution (syntropy), as for example life itself, should always have a "feeling of life", independently from their complexity.

According to these considerations, Fantappiè's model could result compatible with the model suggested by Damasio, and it could even represent an extension and specification of this model. The background feeling described by Damasio would coincide with the feeling of life described by Fantappiè and would take the form of emotions and feelings, localized in the ANS area. The only major difference with Damasio's model is that Fantappiè's hypothesis suggests that emotions and feelings would be, at least in part, the consequence of future states. In his clinical observations, Damasio constantly noted the importance of the future: *the memories of the future, events which are expected, have in each moment a great impact on the autobiographical self. Desires, goals and aims have a strong importance* (Damasio, 1999); *subjects with decision-making deficits show behaviour which could be defined as short-sighted towards the future* (Damasio, 1994).

In conclusion, syntropy could constitute the element which is missing in Damasio's model in order to answer Chalmer's hard problem.

9.1.2 King's model.

Also King's model starts from the dual solution of the Klein-Gordon equation. According to King, the constant interaction between information coming from the past and information coming from the future would place life in front of bifurcations. This constant antagonism between past and future would force humans into a state of free will and consciousness. Consequently consciousness would be a property of all living structures: each cell and biological process would be forced to choose between information coming from the past and information coming from the future (King, 1996).

For example metabolism is divided into:

- Syntropic processes: *anabolism* which includes all the processes which transform simple structures into complex structures, for example nutritive elements into bio-molecules, with the absorption of energy.
- Entropic processes: *catabolism* which includes all the processes which transform higher level structures into lower level structures, with the release of energy.

As a consequence of this constant state of choice, King suggests that all levels of life are faced with bifurcations and that chaotic variations are the result.

In 1963 the meteorologist Lorenz discovered the existence of chaotic systems which react, in each point of their states, to small variations. Studying, for example, a simple mathematical model of meteorological phenomena, Lorenz found that a small perturbation could generate a chaotic state which would amplify, making weather forecasting impossible (Lorenz, 1963). Analysing these unforeseeable events, Lorenz found the existence of an attractor which he named the "chaotic attractor of Lorenz": this attractor causes microscopic perturbations to be amplified, and interfere with the macroscopic behaviour of the system. Lorenz described this situation with the words: "*The flap of a butterfly's wings in Brazil can set off a tornado in Texas*".

Lorenz's discovery started the science of chaos, which is centred on attractors. In this regard it is interesting to note the contradiction in the way the words "order" and "disorder" are used. In thermodynamics disorder is a property of mechanical deterministic systems, governed by entropy with causes in the past, while order is a property of syntropy and attractors, in which causes are placed in the future. In the science of chaos, on the contrary, order is associated with deterministic systems (entropic systems), while disorder is associated with attractors (syntropic systems). The origin of this contradiction can be found in the fact that in the science of chaos, "ordered" systems are those which can be predicted (a property which is true only within entropic systems), while "disordered" systems are those which cannot be predicted (a property which is true within syntropic systems). The science of chaos links order to entropy and disorder to syntropy; but, as was seen already, as a consequence of the second law of thermodynamics, entropy is linked to disorder and syntropy is linked to order. The fact that syntropic phenomena are attracted by the future and cannot be predicted in a precise and mathematical way is associated at the micro-level with chaos and disorder.

It is interesting to note that the forms of order which syntropy generates at the macro-level are accompanied, at the micro-level, with chaotic / non-deterministic processes.

Fractal geometry, which was started in the 1970's by Mandelbrot, shows that by inserting attractors in a geometrical system, complex and ordered figures are generated. In fractal geometry an attractor is an operation, a function which tends to a limit which will never be reached (Mandelbrot, 1987). For example, if we repeat the square-root of any positive number except one, the result will tend to one, but never reach it. The number one is therefore the attractor of the square-root of positive numbers. In the same way, if we square a number superior to one the result will tend to infinity, and if we square a number inferior to one the result will tend to zero. Fractal figures are a result of the interaction of attractors introduced into a geometrical figure; fractals show, in a visual way, what happens when syntropy and entropy interact together.

Fractal geometry reproduces some of the most important structures of living systems, and many researchers are arriving at the conclusion that life processes follow fractal geometry: the outline of a leaf, the growth of corals, the form of the brain and the nervous terminations.

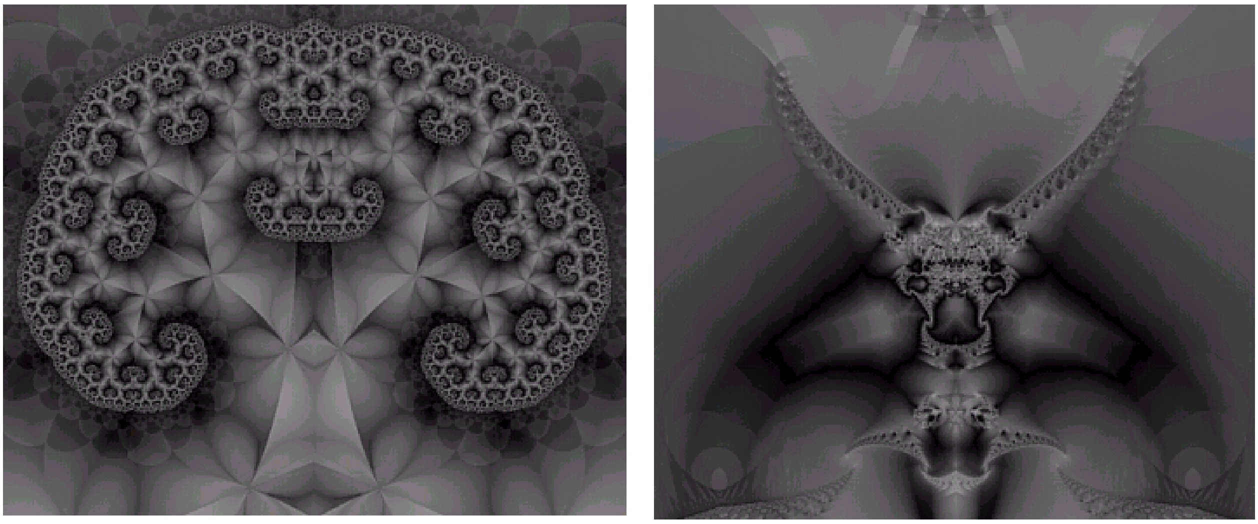


Fig. 2 - Note the similarity of these fractal images with brain structures (http://fractalarts.com/).

An incredible number of fractal structures has been discovered, for example:

1. Blood arteries and coronary veins show ramifications which are fractals. Veins divide into smaller veins which divide into smaller ones. It seems that these fractal structures have an important role in

the contractions and conduction of electrical stimuli: the spectral analysis of the heart frequency shows that the normal frequency resembles a chaotic structure;

2. Neurons show fractal structures: if neurons are examined at low magnifications, ramifications can be observed from which other ramifications depart, and so on;
3. Lungs follow fractal designs which can easily be replicated with a computer. They form a tree with multiple ramifications, and with configurations which are similar at both low and high magnifications.

These observations have lead to the hypothesis that the organization and evolution of living systems (tissues, nervous system, etc.) can be guided by attractors (causes placed in the future) in a similar way to that which happens in fractal geometry.

Fractal structures of the human body grow in complexity following the evolution of life. Fractal structures in living organisms probably evolve through limited information which forms part of a complex algorithm, and guides living organisms in their evolution.

The existence of non-local processes is one of the main qualities of the inversion of the time arrow, and could be considered one of the basic qualities of syntropic processes and attractors. Living systems and brain processes are typical expressions of syntropic properties, so it is consistent to consider non-locality a quality of living systems, and in particular of brain processes.

King states that the supercausal model derived from quantum physics shows that free will is a consequence of the fact that cells are constantly forced to choose between information which comes from the past (diverging waves, emitters/entropy) and information which comes from the future (converging waves, absorbers/syntropy). This constant state of choice gives form to chaotic behaviour on which the conscious brain feeds, a process which is syntropic and not reproducible in a laboratory, or through computational techniques. Chaos is a consequence of the fact that processes are non mechanical and unpredictable. Order is a consequence of the fact that through the presence of attractors the system inevitably evolves towards a reduction of entropy and an increase of differentiation and organization. This fact is particularly evident in brain processes, processes in which chaos, complexity and order coexist. King states that "*The interaction of non contiguous causes shows in the form of an* *apparently chaotic situation which can therefore be studied only in a probabilistic way. In other words, the chaotic processes which are observed in the neuronal system can be the result of behaviour which is apparently random and probabilistic, since they are non local in space and time. This would allow neuronal networks to connect in a sub-quantum way with non local situations and explain why behaviour results in being non deterministic and non computational.*"

9.1.3 Differences between the two models

According to Fantappiè the "feeling of life" is a property of anticipated waves, while for King consciousness is a consequence of bifurcations and the use of free will. In both cases the feeling of life and consciousness are a consequence of the extension of physics to the negative solution of energy and waves. According to this approach, models which are based only on the positive solution (classical physics), such as computers and mechanical systems, will never be able to answer Chalmers' hard problem about the subjective experience, the feeling of life and consciousness.

Many authors arrive to similar conclusions:

- Eliano Pessa (1992) underlines: "*how is it possible that perception processes in human beings are so fast when they imply so many different operations and phases of data analysis? How is it possible that, except for exceptional cases, human beings recognize in a correct way, despite the fact that in this complex data analysis, in which each phase depends in a crucial way from the results obtained by the previous phase, an error can easily arise and compromise all the computation? The computational approach does not answer these questions.*"
- In the same way Gigerenzer (2009): "*according to the computational approach, when a baseball player catches a ball he should solve a complex system of differential equations: compute the trajectory of the ball, estimate the initial distance, the initial speed, the angle, the direction and speed of the wind in each point of the trajectory, and perform all these calculations in fractions of a seconds. The brain behaves as if it is able to solve instantaneously several differential equations of which the values, the information necessary for the computation, are unknown, but without*

compromising the ability to play. If we ask a baseball player how he manages to catch the ball, generally he is not able to answer." Trainers know that the best performances are achieved when the player uses intuition. When he is asked to use cognitive processes his abilities are usually reduced.

- The biologist Rosen (1985), in the book "*Anticipatory systems*" notes that one of the fundamental characteristics of living beings is that of anticipating future events: *It is obvious that one of the most peculiar characteristics of living systems is its dependency on future states and not only on past states"* and arrives at the conclusion that this ability, well known in the field of biology, cannot be reduced to computational processes or predictive models.
- Damasio, in the Destartes' Error, underlines the role of emotions in decision making and the fact that when emotional signals are not perceived properly, because of brain injuries, subjects develop decision making deficits. Damasio uses the expression "short sight towards the future" in order to describe decision making deficits which arise when subjects are not able to perceive emotional feelings. A broad literature now links these emotional signals (somatic markers) to decision making processes and shows that the most efficient decisions are usually guided by emotional signals.

In the volume *Filters and Reflections. Perspectives on Reality* published by the International Consciousness Research Laboratory (ICRL) of Princeton, a "supercausal" model of consciousness based on Fantappiè's and Chris King's hypothesis of a continuous interaction of information coming from the past and information coming from the future is suggested (Vannini and Di Corpo, 2009). According to this model the mysteries of cognitive processes, such as binding, can be explained as a consequence of the properties of anticipated waves, properties which we constantly use in our daily life without being aware of it.

It is obvious that the opening of science to the negative solution of energy results in a change of paradigm. Scientists who have proposed this change, in spite of the experimental evidences which support it, have experienced forms of exclusion and censorship within the academic world. These reactions are described by Fantappiè and many other researchers and scientists.

Nevertheless it is also true that the only criteria which allows to distinguish between what it is true and what it is false is the experimental method, the scientific method. If the scientific method supports this change of paradigm it will inevitably take form.

After four hundred years it seems that the experimental method has not yet entered fully into our academic culture. As was shown, physicists tend to refuse any evidence which contradicts classical causation. The law of syntropy redefines the concept of causality, adding to classical causation, which moves from the past to the future, also causes which move backwards, from the future to the past. If this redefinition of causality is true, as it seems to be according to the results of the experiments discussed in this work, and which other researchers have found in independent research work, the consequences are “tremendous”, as Fantappiè says, not only in the field of physics, but also in biology, psychology and in the social sciences.

Bibliography

Amir D. Aczel (2004) *Entanglement: il più grande mistero della fisica,* Raffaello Cortina Editore, Milano 2004;

Anderson C.D. (1932) *The apparent existence of easily deflectable positives*, Science, 76:238 (1932);

Arcidiacono G. ed S. (1991) *Entropia, Sintropia ed Informazione,* Di Renzo Editore, Roma 1991;

Armour J.A. (2004) *Cardiac neuronal hierarchy in health and disease*, American journal of physiology, regulatory, integrative and comparative physiology. Aug. 2004; 287 (2), p. 262-71;

Arndt M. e Zeilinger A. (2005) *Probing the limits of the quantum world*, PhysicsWorld, Marzo 2005, p. 35-42;

Arntz W., Chasse B. e Vincente M. (2006) *Bleep,* Macro Edizioni, Cesena 2006;

Aspect A. (1982) *Experimental Realization of Eintestein-Podolsky-Rosen-Bohm Gedanken-experiment,* Physical Review Letters, vol. 49, 91, 1982;

Atmanspacher H., Bishop R. (2002) *Between Chance and Choice*, Imprint Academic, UK, p. 92.

Baaquie B., Martin F. (2005) *Quantum Psyche. Quantum Field Theory of the Human Psyche*, NeuroQuantology, Vol 3(1): 7-42;

Baggott J. (2003) *Beyond measure*, Oxford University Press, p. 171;

Bechara A., Tranel D., Damasio H. e Damasio A.R. (1996) *Failure to Respond to Anticipated Future*

Outcomes Following Damage to Prefrontal Cortex, Cerebral Cortex, 1996, vol. 6, no. 2, p. 215;

Bechara A., Damasio H., Tranel D. e Damasio A.R. (1997) *Deciding Advantageously before Knowing the Advantageous Strategy*, Science, 1997, vol. 275, p. 1293;

Bechara A., Damasio H., Tranel D. e Damasio A.R. (2005) *The Iowa Gambling Task and the somatic marker hypothesis: some questions and answers*, Trends in Cognitive Sciences, vol. 9: 4, April 2005;

Bierman D.J. e Radin D.I. (1997) *Anomalous anticipatory response on randomized future conditions.* Perceptual and Motr Skills, 84, 689-690;

Blanchard E.B., Wulfert E., Freidenberg B.M., et al. (2000) *Psychophysiological Assessment of Compulsive Gamblers' Arousal to Gambling Cues: A Pilot Study*, Appl. Psychophysiol. Biofeedback, 2000, vol. 25, no. 3, p. 155;

Bohm D. (1980) *Wholeness and the implicate order*, Routledge, Oxford 1980;

Bohm D. e Hiley B.J. (1993), *The Undivided Universe*, Routledge, London, p. 275-276;

Bondi M. (1998) *The role of synaptic junctions in the identification of human consciousness*. Biology Forum, Vol. 91: 329-334;

Bondi M. (2005) *Quantum Electrodynamics and Unified Synaptic Channel in the identification of Consciousness,* NeuroQuantology, Vol. 3(2): 119-133;

Capra F. (1992) *Il punto di svolta,* Feltrinelli, Milano 1992;

Cattell R.B. (1976) *The scientific use of factor analysis in behavioural and life sciences*, Plenum Press, New York 1976;

Chalmers D. (1995) *Facing up to the Problem of Consciousness*, in *Journal of Consciousness Studies*, 1995, 2, 3, pag. 201;

Chalmers D. (1996) *La mente cosciente*, McGraw-Hill Italia, Milano 1996;

Cleeremans A. (2003) *Implicit Learning,* Encyclopedia of Cognitive Science, Nature Publishing, London 2003;

Corbucci M., Iacarelli G. e Cavalieri G. (2005), *Il trasmettitore a SPIN*, Scienza e Conoscenza, novembre 2005, p. 16-21.

Cramer J.G. (1986) *The Transactional Interpretation of Quantum Mechanics*, Reviews of Modern Physics, Vol. 58: 647-688;

Cramer J.G. (2006) *What's done is done… or is it?*, New Scientist, 30 September 2006, pp. 6-10;

Culbertson J. (1963) *The minds of robots*, University of Illinois Press 1963;

Culbertson J. (1976) *Sensations, memories and the flow of time*, Cromwell Press, Trowbridge, UK 1976;

Damasio A.R. (1994) *Descarte's Error. Emotion, Reason, and the Human Brain,* Putnam Publishing, 1994;

Damasio A.R. (1999) *The Feeling of What Happens. Body and Emotion in the Making of Consciousness*, Heinenann, London 1999;

De Beauregard O. (1953) *Comptes Rendus* 236, 1632-1634;

De Beauregard O.C. (1957), *Théorie synthetique de la relatività restrinte et des quanta*, Gauthier – Villars, Paris 1957 ;

De Beauregard C. (1977) *Time Symmetry and the Einstein Paradox*, Il Nuovo Cimento (42B);

Dummett M. (1954) *Can an Effect Precede its Cause*, Proceedings of the Aristotelian Society (Supp. 28);

Eccles J.C. (1970), *Facing reality,* Springer, New York 1970;

Eccles J.C. (1989) *Evolution of the brain*, Routledge, Oxford 1989;

Eccles J.C. (1994) *The self and its brain*, Springer, Berlin, Germany 1994;

Eddignton A. (1927) *The Nature of the Physical world*, Ann Arbor Paperbacks, University of Michigan Press, Ann Arbor 1958;

Eddington A. (1935) *New Pathways in Science.* Cambridge Univ. Press 1935;

Edelman G.M. e Tononi G (2000) *A Universe of Consciousness*, Basic Books, 2000;

Einstein A. (1916) *Relatività, esposizione divulgativa,* Universale Bollati Boringhieri, Torino 1967;

Ercolani A.P., Areni A. e Leone L. (2002) *Statistica per la psicologia. Statistica inferenziale e analisi dei dati*, Il Mulino, Bologna 2002;

Fantappiè L. (1942) *Sull'interpretazione dei potenziali anticipati della meccanica ondulatoria e su un principio di finalità che ne discende*. Rend. Acc. D'Italia, n. 7, vol 4;

Fantappiè L. (1943) *Teoria unitaria de la causalidad y findalidad en los fenomenos fisicos y biologicos, fundata en la mecanica ondulatoria y relativista*. Rev. Mat. Hispano-Americana, s. 4, t. 3;

Fantappiè L. (1944a) *Principi di una teoria unitaria del mondo fisico e biologico.* Humanitas Nova, Roma 1944;

Fantappiè L (1944b) *Principi di una teoria unitaria del mondo fisico e biologico*, Di Renzo Editore, Roma 1991;

Fantappiè L. (1945) *La nuova teoria unitaria dei fenomeni naturali*. Orientamenti culturali, Roma, vol. I, f. 6, 1945;

Fantappiè L. (1947a) *Visione unitaria del mondo e della vita. Conferenza*, ed. Studium Christi, Roma 1947;

Fantappiè L. (1947b) *Una nuova teoria unitaria*, Rec. Responsabilità del Sapere, anno I, f. 1-2, Roma 1947;

Fantappiè L. (1948) *Il problema sociale alla luce della nuova teoria unitaria*. Responsabilità del Sapere, anno II, f. 9, Roma, 1948;

Fantappiè L. (1955a) *Conferenze scelte,* Di Renzo Editore, Roma 1993;

Fantappiè L. (1955b) *L'eterno nel tempo,* Pro Civitate Christiana, Assisi 1955;

Faye J., Scheffler U. e Urchs M. (1994). *Logic and Causal Reasoning*. Wiley-VCH. ISBN 3050025999;

Feynman R. (1949) *The Theory of Positrons*, Physical Review 76: 749;

Feynman R. (2001) *Meccanica Quantistica,* in *La fisica di Feynman,* Vol.III, Zanichelli, Bologna 2001;

Flanagan B.J. (2003) *Multi-Scaling, Quantum Theory, and the Foundations of Perception*, NeuroQuantology, Vol. 1(4): 404-427;

Frautschi S. (1982) *Entropy in an expanding universe*, Science, vol. 217, Aug. 13, 1982, 593-599;

Freeman W. (2000) *Come pensa il cervello*, Einaudi, Milano 2000;

Fröhlich H. (1968) *Long range coherence and energy strorage in biological systems*, Int. J. Quantum Chemistry, Vol2: 641-649;

Galileo Galilei (1979) *Il Saggiatore,* a cura di Libero Sosio, Feltrinelli, Milano 1979;

Gamow G. (1990) *Trent'anni che sconvolsero la fisica,* Zanichelli, Bologna 1990;

Ghirardi G.C. (2003) *Un'occhiata alle carte di Dio,* Il Saggiatore, Milano 2003;

Gigerenzer G (2009) *Decisioni Intuitive*, Raffaello Cortina Editore, Milano 2009;

Gribbin J. (2004) *Q come Quanto: dizionario enciclopedico illustrato di fisica quantistica,* Macro Edizioni, Cesena 2004;

Hameroff, S.R. (1982) e Watt R.C., *Information processing in microtubules,* J. Theor. Biol., 98:549-561;

Hameroff S.R., Penrose R. (1995) *Orchestrated reduction of quantum coherence in brain microtubules: A model for consciousness*. Neural Network World, Vol. 5(5): 793-804;

Hameroff S. (1998) *Quantum computation in brain microtubules: the Penrose-Hameroff model of consciousness*, Phil. Trans. R. Soc. Lond Vol. 356: 1869-1896;

Hameroff S. (1998) *Consciousness, the brain and spacetime geometry*, in The Annals of the New York Accademy of Sciences, Special Issue Cajal and Consciousness;

Hameroff S., Penrose R. (2003) *Conscious events as orchestrated space-time selections*, NeuroQuantology, Vol. 1(1): 10-35;

Hameroff S. (2007) *Orchestrated reduction of quantum coherence in brain microtubules*, NeuroQuantology, Vol. 5(1): 1-8;

Hari S. (2008) *Eccles's Psychons Could be Zero-Energy Tachyons*, NeuroQuantology, Vol. 6(2): 152-160;

Herbert N. (1987) *Quantum Reality: Beyond the New Physics*, American Journal of Physics, Vol. 55(5): 478-479;

Herzog T. J. et al. (1995) *Complementarity and the Quantum Eraser*, Physics Review Letters 75 (17): 3034–3037;

Hu H. e Wu M. (2004) *Spin as Primordial Self-Referential Process Driving Quantum mechanics, Spacetime Dynamics and Consciousness*, NeuroQuantology, Vol. 2 (1): 41-49;

Ioannidis J.P.A. (2005), *Contradicted and Initially Stronger Effects in Highly Cited Clinical Research*, JAMA. 2005; 294: 218-228;

Jahn R. e Dunne B. (1997) *Science of Subjective,* Journal of Scientific Exploration, Vol. 11, No. 2, pp. 201–224, 1997;

James S., Spottiswoode P. e May C. (2003) *Skin Conductance Prestimulus Response: Analyses, Artifacts and a Pilot Study,* Journal of Scientific Exploration, Vol. 17, No. 4, pp. 617-641;

Janis I.L. e Mann L. (1977) *Decision-making: a psychological analysis of conflict, choice, and commitment*, New York: Free Press 1977;

Järvilehto T. (2004) *Consciousness and the Ultimate Essence of Matter*, NeuroQuantology, Vol. 2(3): 210-218;

Jibu M. e Yasue K. (1995) *Quantum brain dynamics and consciousness*, in Advances in Consciousness Research, Vol.3, John Benjamins Publishing Company, Amsterdam;

Kaivarainen A. (1992) *Mesoscopic theory of matter and its interaction with light. Principles of self-organization in ice, water and biosystems*, Finland: University of Turku;

Kaivarainen A. (2005) *Hierarchic Model of Consciousness*, NeuroQuantology, Vol. 3(3): 180-219;

King C.C. (1989) *Dual-Time Supercausality*, Physics Essays, Vol. 2(2): 128-151;

King C.C. (1990) *Did Membrane Electrochemistry Precede Translation?* Origins of Life & Evolution of the Biosphere Vol. 20: 15-25;

King C.C. (1991) *Fractal and Chaotic Dynamics in the Brain*, Prog Neurobiol, Vol. 36: 279-308;

King C.C. (1996a) *Fractal neurodyamics and quantum chaos: Resolving the mind-brain paradox through novel biophysics*, In E. Mac Cormac and M. Stamenov (Eds.), Fractals of brain, fractals of mind, Advances in Consciousness Research, 7, John Benjamin Publishing Company, Amsterdam;

King C.C. (1996b) *Quantum Mechanics, Chaos and the Conscious Brain*, J Mind and Behavior, Vol. 18: 155-170;

King C.C. (2003) *Chaos, Quantum-transactions and Consciousness*, NeuroQuantology, Vol. 1(1): 129-162;

Kuhn T. (1978) *La struttura delle rivoluzioni scientifiche,* Einaudi, Torino, 1978;

Laplace P.S. (1795), *A philosophical Essay on Probabilities,* Springer-Verlag, New York, 1995;

LeDoux J. (1996) The emotional brain: the mysterious underpinnings of emotional life, New York: Simon and Schuster 1996;

Lockwood M. (1989) *Mind, brain and the quantum*, Basil Blackwell, Oxford 1989;

Lorenz E. (1963) *Deterministic Nonperiodic Flow*, Journal of the Atmospheric Sciences, 1963, Vol.20, No.2, pp.130-140;

Lotka A.J. (1925) *Elements of Physical Biology*, Williams & Wilkins Co, Baltimore, reprinted in 1956 as Elements of Mathematical Biology, Dover Publications, New York;

Luisi Pier Luigi (2003) *Autopoiesis: a review and a reappraisal,* Naturwissenschaften, 90:49–59;

Mac Cormac E.R. e Stamenov M.I. (1996) *Fractals of Brain, fractals of mind,* in *Advances in counsciousness research,* Vol.7, John Benjamins Publishing Company, Amsterdam 1996;

Mandelbrot B.B. (1987) *Gli oggetti frattali*, Einaudi, Torino 1987;

Mann L. (1992) *Stress, affect, and risk taking*, in *Risk-taking behaviour* (Frank YJ, ed.), pp. 202-230. Chichester: Johm Wiley & Sons 1992;

Marshall, I.N. (1989) *Consciousness and Bose-Einstein Condensates*, New Ideas in Psychology, Vol. 7 : 73–85;

Marshall I.N., Zohar D. (1994) *Quantum Society*, William Morrow, New York 1994;

Maturana H. e Varela F. (1980) *Autopoiesis and Cognition: The Realization of the Living*, Boston Studies in the Philosophy of Science, vol. 42, 1985;

Maturana H e Varela F. (1984) *L'albero della conoscenza*, Garzanti Editore, Milano 1987;

McCratly R., Atkinson M. e Bradely R.T. (2004) *Electrophysiological Evidence of Intuition: Part 1*, Journal of Alternative and Complementary Medicine; 10(1): 133-143;

McCratly R., Atkinson M. e Bradely R.T. (2004) *Electrophysiological Evidence of Intuition: Part 2*, Journal of Alternative and Complementary Medicine; 10(2):325-336;

Mender D. (2007) *Decentering the subject of physics*, NeuroQuantology, Vol. 5(1): 175-181;

Monod J. (1974) *Il caso e la necessità*, Oscar Mondatori, Milano 1974;

Nambu Y. (1950) *The Use of the Proper Time in Quantum Electrodynamics*, Progress in Theoretical Physics (5);

Newton I. (1686), *Principi matematici della filosofia naturale*, a cura di A. Pala, UTET, Torino, 1965;

Newton I. (1704), *Scritti di ottica*, a cura di A. Pala, UTET, Torino 1978;

Olivetti Belardinelli M. (1991) *La costruzione della realtà,* Bollati Boringhieri Editore, Torino 1991;

Peijnenburg J. (1999) *Shaping Your Own Life*, Metaphilosophy vol. 37;

Penrose R. e Isham C. (1989) *Quantum Concepts in Space & Time* , Oxford University Press.1989;

Penrose R. (1989b) *The Emperor's New Mind*, Oxford Univ. Press 1989;

Penrose R. (1994) *Ombre della mente*, Rizzoli, Milano 1994;

Penrose R. (1999) *The Large, the Small and the Human Mind*, Carmbridge University Press, 1999, Cambridge, UK, p. 132;

Penrose R. (2005) *Il grande, il piccolo e la mente umana*, Cortina Editore, Milano 2005;

Penrose R. (2005b) *La strada che porta alla realtà: le leggi fondamentali dell'universo,* Rizzoli, Milano 2005;

Pereira A. (2003) *The Quantum Mind/Classical Brain Problem*, NeuroQuantology, Vol. 1(1): 94-118;

Pessa E. (1992) *Intelligenza Artificiale*, Bollati Boringhieri, Torino 1992;

Pitkänen M. (1990) *Topological Geometrodynamics*. Internal Report, HU-TFT-IR-90-4 (Helsinki University);

Pitkänen M. (2003) *TGD (Topological Geometro Dynamics) Inspired Theory of Consciousness*, NeuroQuantology, Vol. 1(1): 68-93;

Poli M. (1994) E. Prato Previde, *Apprendere per sopravvivere,* Raffaello Cortina Editore, Milano 1994;

Poincaré H (1908) *Le raisonnement mathématique,* in *Scinece et méthode,* Flammarion, Paris;

Pribram K. (1971) *Languages of the Brain*, Prentice Hall, New Jersey 1971;

Pribram K. (1990) *Brain and Perception*, Lawrence Erlbaum, Oxford 1990;

Prigatano G.P. (2003), *Challenging dogma in neuropsychology and related disciplines,* Archives of Clinical Neuropsychology 18 (2003) 811-825;

Prigogine I. (1979), *La nuova alleanza,* Longanesi Editore, Milano 1979;

Radin D. (2006), *Entangled Minds,* Paraview Books, New York 2006;

Reber, A.S. (1989) *Implicit Learning and Tacit knowledge,* Journal of Experimental Psychology: General, 118, 219-235;

Ricciardi L.M. e Umezawa H. (1967) *Brain and physics of many body problems*, Biological Cibernetics, Springer, Berlin, Vol. 4(2): 44-48;

Rifkin J. (1982) *Entropia*, Mondatori, Milano 1982;

Rosen R. (1985) *Anticipatory Systems*, Pergamon Press, USA 1985;

Rudfrau D., Lutz A., Cosmelli D., Lachaux J.P. e Le VanQuyen M. (2003) *From autopoiesis to neurophenomenology: Francisco Varela's exploration of the biophysics of being,* Biol Res 36: 27-65, 2003

Sartori L. (2004) Martinelli M., Massaccesi S. e Tressoldi P. E., *Psychological correlates of ESP: heart rate differences between targets and non targets in clairvoyance and precognition forced choice tasks,* atti della Convention 2004 della Parapsychological Association, p. 407-412;

Schrödinger E. (1988) *Che cos'è la vita*, Sansoni, Firenze 1988;

Sharpe L., Tarrier N., Schotte D. e Spence S.H. (1995) *The Role of Autonomic Arousal in Problem Gambling, Addiction*, 1995, vol. 90, p. 1529;

Skarda C.A. e Freeman W.J. (1987) *How brains make chaos in order to make sense of the world*, Behav. Brain. Sc., vol. 10, pp. 161--195, 1987. Stuart Mill J. (1943), *A System of Logic,* Sistema di logica deduttiva e induttiva, UTET, Torino 1988.

Slater J.C. (1980) *Teoria Quantistica della materia,* Zanichelli, Bologna 1980;

Spottiswoode P. e May E. (2003), *Skin Conductance Prestimulus Response: Analyses, Artifacts and a Pilot Study,* Journal of Scientific Exploration, Vol. 17, No. 4, 617-641;

Stapp H.P. (1993) *Mind Matter and Quantum Mechanics*, Springer-Verlag, Berlin 1993;

Stapp H.P. (1999) *Attention, intention, and will in quantum physics*, Journal of Consciousness Studies, Vol. 6(8/9): 143-164;

Szent-Gyorgyi, A. (1977) *Drive in Living Matter to Perfect Itself*, Synthesis 1, Vol. 1, No. 1, 14-26;

Taylor J. (2001), *Hidden Unity in Nature Laws*, Cambridge University Press, 2001, Cambridge, UK, p. 337;

Szilard L. (1992) in W. Lanouette, *Genius in the Shadows,* Charles Scribner's Sons, New York;

Tressoldi P. E. (2005) Martinelli M., Massaccesi S., e Sartori L., *Heart Rate Differences between Targets and Nontargets in Intuitive Tasks*, Human Physiology, Vol. 31, No. 6, 2005, pp. 646–650;

Vannini A. (2005) *Entropy and Syntropy. From Mechanical to Life Science*, NeuroQuantology, vol. 3, n.2, pp. 88-110;

Vannini A. (2008) *Quantum Models of Consciousness*, Quantum Biosystems, 2008, 2, pp. 165-184;

Vannini A. e Di Corpo U. (2009) *A Retrocausal Model of Life*, in *Filters and Reflections. Perspective on Reality*, ICRL Press, Princeton, NJ, USA, pp. 231-244;

Varela F. (1996) *Neurophenomenology: A methodological remedy for the hard problem*, in Journal of Consciousness Studies, 3(4): 330-349;

Varela F., Thompson E e Rosch E. (1992) *The embodied Mind,* The MIT Press, Cambridge, Mass, USA;

Vitiello G. (2003) *Quantum Dissipation and Information. A route to consciousness modelling,* NeuroQuantology, Vol. 1(2): 266-279;

Vitiello G. (2001) *My Double Unveiled – The dissipative quantum model of brain* – Benjamins Publishing Co., Amsterdam 2001;

Walker E. (1970) *The Nature of Consciousness*, Mathematical BioSciences Vol. 7: 131—178;

Wheeler J. e Feynman R. (1945) *Interaction with the Absorber as the Mechanism of Radiation*, Review of Modern Physics (17);

Wheeler J.A. e Feynman R.P. (1949) *Classical Electrodynamics in Terms of Direct Interparticle Action.* Reviews of Modern Physics 21 (July): 425-433;

Wheeler J.A. e Tegmark M. (2001) *100 years of the quantum,* Scientific American, Febbraio 2001, pp. 68-75;

Zajonic R.B. (1984) One the primacy of affect. Am Psychol 39:117-123.