Aisthesis
PRATICHE, LINGUAGGI E SAPERI DELL'ESTETICO
rivista on-line del Seminario Permanente di Estetica
spes
anno VIII, numero 1

The aesthetic experience as a characteristic feature of brain dynamics

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1. *Introduction*

In this report I will present essential features of the dissipative quantum model of brain which has been developed in recent years (Vitiello [1995, 2012b]); Freeman, Vitiello [2006, 2008, 2010]). The model describes the collective neuronal activity providing many features of the brain behaviour in terms of its microscopic dynamics and suggests that one characterizing feature of the brain activity is the continuous attempt to reach the equilibrium with the environment in which the brain is embedded. Such an effort in balancing the energy fluxes exchanged between the brain and the world acting one on the other in reciprocal actions/reactions is finalized to a perfect «to-be-in-the-world». *The aesthetical experience* might then consist in such a harmonious fitting of the self in the world (Desideri [2006]; Vitiello [2008]). In this sense, the *aesthetical dimension* appears to be a characterizing feature of the neuronal activity. In order to proceed in my discussion, I need to introduce first few notions on the mechanism of spontaneous breakdown of symmetry in quantum field theory (QFT). Then, in Section 2, I present the scheme of the working brain in the dissipative model. The possibility to describe the act of consciousness is discussed in Section 3 and the aesthetic experience, its meaning and relation with the dissipative character of the brain dynamics, is discussed in Section 4. Finally, Section 5 is devoted to concluding remarks and the perspective of obtaining an integrated ecological vision where coherence plays the role of a paradigmatic law is presented.

1.1. *Spontaneous breakdown of symmetry and generation of ordered patterns*

One of the open problems to be faced in many research sectors of contemporary science is the question of the derivation of the macroscopic behaviour of the system from the properties and the dynamics of its elementary constituents, namely the question of how it happens that a (large) number of atoms or molecules assemble themselves together giving as a result a piece of structured matter with specific macroscopic properties. Even more difficult is the problem of deriving macroscopic properties of living matter from the dynamics of microscopic biologic components. Some help may come from QFT which provides the available theoretical and computational tools, positively tested in the experiments, for the study of solid state physics, elementary particle physics and cosmology. In QFT the challenge is to derive indeed the *macroscopic manifestations* of the underlying quantum dynamics ruling the interactions of the system elementary components (Blasone, Jizba, Vitiello [2011]).

In such a perspective, of particular interest is the study of systems which present at a macroscopic observation some kind of ordered patterns, for example crystals, magnets, etc., and of course living matter. In all the known cases, the ordering turns out to be describable in terms of the persistence of a constant phase difference (*phase locking*) among oscillations of the elementary components, e.g. *in phase* oscillations of the electrical dipoles characterizing the elementary components. In these cases of ordered patterns, the macroscopic behaviour of the system cannot be derived as the *sum* of the behaviours and properties of the elementary components, does not belong to perturbative physics where one adds small contributions (perturbations) in order to obtain a finite result. For example, the magnetization, the electrical properties, the stiffness, etc. are *system* properties of magnets and crystals not of the individual atomic or molecular components. The search aimed to understand how this happens shows that the basic dynamics of the components needs to have the property of nonlinearity producing *long range correlations* among them. These long range correlations form the *tissue*, the ordered patterns and shapes (forms) in which the components are *organized*. Such an ordering is thus of dynamical origin, not created by forcing the components, one by one, to sit in specific positions or oscillating with a given phase and frequency. It is a typical nonlinear phenomenon not derivable by means of the perturbative formalism. The linear dimension or range of the correlations dictates the macroscopic size of the system *as a whole* and is much greater than the typical size of the elementary component. In a quantum framework one may associate to a wave motion a corresponding specific quantum, called, in the case of dynamical generation of ordered patterns, the Nambu-Goldstone (NG) boson or quantum. One can show that the existence of long range correlations, and thus of NG quanta, is a consequence of the breakdown of the symmetry characterizing the component interactions (Umezawa [1993], Blasone, Jizba, Vitiello [2011]). For example, consider a collection of atoms interacting is such a way that their positions can be shifted at will without producing observable changes in the system (symmetry under spatial translations). If such a space translational freedom is inhibited (space translation symmetry is broken) so that the atoms can only occupy definite sites at definite distances (multiples of the lattice length), then a long range correlation arises in the form of an elastic wave connecting the atoms. The NG quantum of such a wave is called the phonon. The resulting crystal ordering of the atoms in their lattice sites thus appears as a dynamical effect of the symmetry breakdown. Crystal ordering is lack of space translational symmetry. In full generality, *order is lack of symmetry*. The macroscopic behaviour (the macroscopic properties) of systems like the crystal, the magnets, etc., can thus be only explained by recurring to the microscopic quantum dynamics. In this sense, they are called *macroscopic quantum systems*.

Let me remark that the agent triggering the symmetry breakdown process is a *weak stimulus*, which can be switched off after symmetry breakdown has occurred. For example, a weak external magnetic field may trigger the magnetic ordering in a metal able to sustain the magnetized state. After the magnetization has been obtained, the weak external field may be switched off without producing the loss of the magnetic properties. The system is driven to and persists in the ordered state by its *internal* dynamics. This is expressed by saying that the symmetry has been «spontaneously» broken. On the contrary, if one «forces» the system by imposing an external constraint so to break the symmetry, then one talks of «explicit» symmetry breaking.

We thus see that a *change of scale*, from the microscopic to the macroscopic scale is dynamically produced due to the mechanism of the symmetry breakdown and the consequent generation of NG bosons, namely of long range correlations. The NG bosons are collected (*condensed*) in the least energy state (called the vacuum) of the system and their being *in phase* is expressed by saying that they form a *coherent* state. Coherence is thus generated as the result of the spontaneous breakdown of the symmetry triggered by a weak external stimulus and characterizes the macroscopic behaviour of the system. Coherence is observed in many systems in nature and in a wide range of temperature, from thousands of degrees (diamond crystal melting point is 3545 ºC) to very low temperature (below -252 ºC in superconductors).

A final observation concerns the fact that NG bosons are real quantum particles interacting with other components of the system. They thus enter in the list of the system elementary components, they belong to the system *structure*. They are, however, also responsible of the system *function*, e.g. the magnetic, the crystalline function. We thus arrive to the conclusion that in macroscopic quantum systems structure and function cannot be separated, their distinction vanishes.

2. *The dissipative brain*

The observations and remarks in the previous Section may be applied to the study of the brain. This is an open system in continuous interaction with the environment. Such an interaction can never be switched off without producing serious damage to the brain. The brain receives from the environment soft or weak stimuli through the perception channels. The stimulus is considered to be weak as far as it does not hurt the reception gates and as far as it does not reduce the brain in a slavery state, as it happens under a highly stressing situation or, e.g., due to electroshock.

In 1967, Umezawa and Ricciardi (Ricciardi, Umezawa [1967]; Stuart, Takahashi, Umezawa [1978, 1979]) proposed to treat the brain as a condensed matter system and to assume that the stimuli from the external world may trigger the breakdown of the symmetry of the brain microscopic dynamics with the result of producing memory re-coding as a boson condensation phenomenon. Memory recollection was described as the process of producing excitations out of the condensed state. The main motivation of their proposal was the hope that by treating the brain as a many-body system, namely a QFT system, they could solve the «Lashley dilemma» of the rapid generation of long range neuronal correlations. Indeed, already in the 40s' Lashley (1948) noticed that «nerve impulses are transmitted […] form cell to cell through determinate intercellular connections. Yet, all behavior seems to be determined by masses of excitation […] with-in general fields of activity, without regard to particular nerve cells. […] The problem is almost universal in the activity of the nervous system». In fact, «here is the dilemma. […] What sort of nervous organization might be capable of responding to a pattern of excitation without limited specialized path of conduction?». The price to be paid in the Umezawa-Ricciardi (UR) approach was to use QFT, indeed, since in such a framework one knows how long range correlations arise among the elementary components of a system (in those years the spontaneous symmetry breakdown was introduced as the basic mechanism in the formulation of the standard model of elementary particles, whose experimental confirmation we still witness in present days with the observation of the Higgs particle; those were also the years in which the QFT formulation of superconductivity, based as well on the spontaneous breakdown of symmetry, was receiving great experimental support). The UR model contained, however, a couple of obscure points. In the model it was clear that *the neurons, the glia cells and any other biologically characterized units are not quantum objects*. It was not clear, however, which one were the quantum variables, which one was the symmetry to be broken by the external stimulus or input. Moreover, although, of course, the authors knew well that the brain is an open system, it was treated as a closed system, and finally the memory capacity was too small. The model was not able to accommodate the huge memory capacity of the brain.

2.1. *Dissipation, the brain and its Double*

In the first half of the 80s', stimulated by the suggestion coming from the work on highly polar states in biological systems by Herbert Fröhlich (Fröhlich [1968]), it was proposed that a dominant symmetry in living matter is the electrical dipole rotational symmetry of water molecules (Del Giudice *et al.* [1985, 1988]). Water is about 70 % in weight of the human body and more than the 90% in number of the constituent molecules. Thus one cannot disregard the water role in the study of living matter and the spontaneous breakdown of rotational dipole symmetry must be considered. In the following years it was proposed (Jibu and Yasue [1992, 1995]; Jibu, Pribram and Yasue [1996]; Vitiello [1995]) that in the UR model the external stimuli break the dipole rotational symmetry. The quantum variables are thus identified with the vibrational dipole quanta and the recorded memory is specified by the number N_A of NG quanta condensed in the least energy state. In 1995 it was also proposed (Vitiello [1995, 1998a,b]) to modify the UR model by taking into account the unavoidable fact that the brain is permanently entangled with the environment. It is a *dissipative* system, whose dynamics is characterized by incoming and outgoing fluxes of energy, under various forms, exchanged with the environment. This modification requires a drastic change in the QFT formalism used in the UR model. In *the dissipative quantum model* it is required that the brain and the environment in which it is embedded be treated at once in order to deal with a *closed* system. In other words, the mathematical formalism requires the balance of the energy fluxes between the brain and the environment. Technically this is achieved by *doubling* the brain degrees of freedom. From the mathematical point of view, the brain system is interacting with its *Double*, namely the environment is described in the same way as the brain system is described. The only difference is that, of course, fluxes ingoing in the brain are outgoing fluxes from the environment (Double), and vice-versa. This is formally obtained by inverting the time direction (*the arrow of time*) for the environment, namely exchanging «in» with «out»: the Double is then the time-reversed image of the brain system. It is like having a «mirror in time» in which the self reflects in its Double image. In conclusion, the system «brain/environment» is treated as the closed system «brain and its Double».

It must be remarked that in the QFT of dissipative systems, and thus also of the brain, the vacuum state is characterized by the balance between the number N_A of the brain NG bosons and their Double image, N_B, i.e. $N_A – N_B = 0$. This implies that infinitely many vacua are then possible, depending on the infinitely many values that N_A and, correspondingly, N_B may take so that their difference is vanishing. Since in the dissipative quantum model different memories are specified by different N_A's, we see that infinitely many memory states may be allowed: dissipation is discovered to be the key to solve the memory capacity problem which was instead unsolved in the UR (non-dissipative) model.

It should be observed also that the ortogonality among the vacuum states, guaranties the *protection* of memories in a strict mathematical sense. In the real brain, however, ortogonality is not so strict due to finite volume effects and some *confusion* of memories is possible. This is a fortunate occurrence since then «passages», or «trajectories» from memory to memory become possible. Moreover, since the dynamics is a dissipative one, the possibility to forget is implied by the model, and also different decay rates of memories, namely short and long lived memories, are predicted. More features observed in brain functioning may be described by the model, which for brevity here are not reported (see Vitiello [2001]; Freeman, Vitiello [2006, 2010]).

3. *The dialogue with the Double and Consciousness*

From the discussion presented above we see that the dissipative quantum model leads us to a thermodynamic model of cortical neurodynamics expressed at the classical level as the manifestation of the dissipative dynamics at the quantum level (Freeman [2004]; Vitiello [1995, 2001]; Freeman, Vitiello [2008]). The vividness and emotional intensity of memories requires a very densely packed exchange of energy with the environment (Capolupo, Freeman, Vitiello [2013]), which accounts for the so-called «dark energy» (Raichle, Gusnard [2002]; Laughlin et al. [1998]) in knowledge retrieval. The brain constructs within itself an understanding of its surround by repeated trial-and-error. Dissipation characterizing brain dynamics is thus also intrinsic to knowledge construction. We are embedded in the intricate net of perceptions, trades and reciprocal actions and reactions involving ourselves and our environment, which constitute our «experience» of the world (Desideri [2004]). In the dissipative model, such a highly dynamic life of the brain is described in terms of a continuous undergoing through *phase transitions* between different dynamical regimes, and thus as a *far from the equilibrium* process, approaching to and departing from the stationary point where variations of free energy are vanishing (Freeman et al. [2012]). I have postulated that the act of *consciousness* resides in such a restless dialog of the self with its Double (Vitiello [1995, 2001]). Consciousness then belongs to the bridge which connects, does not separate the self and its Double. It lives in the present since the present stays on the surface of the mirror in time in which, as said in the previous Section, the self reflects in its Double, and vice-versa. It is interesting to observe that the word συνειδώς, which means to «see together», in the act of «immediate vision», was used by the ancient Greeks to denote the consciousness (to be conscious of), thus stressing the «present» as the time dimension of the consciousness (the verb οράω is used instead for the act of lasting vision (Bonazzi [1936]). Consciousness is thus an act of sudden knowledge, an intuitive one, an *unum* not susceptible to be divided into rational steps, thinkable but «non-computational», as the present is (Vitiello [2004a]), and it is non-separable from our body. Our «to-be-in-the-world» manifests itself as a constraint to «listen» to it through our perceptions (Desideri (1998)), from one side, and as a constant self-referential *emotional* experience flowing through our body (Vitiello [2004a]; Desideri [2014a]), from the other side; in a continuous re-composition between subjectiveness and objectiveness, between the self and its Double, apparently separated, but actually definitely entangled in the consciousness acts. The relations between the self and its surround constitute then the *meanings* of the flows of information exchanged during their interactions. In this way the brain builds the knowledge of its own world, i.e. its Double (Vitiello [2001]).

3.1. *Information and meaning*

I have been mentioning about meanings and it is perhaps useful to say one more word on the way information, in the Shannon sense, and meaning enter in the dissipative quantum model of brain. As already stressed, the brain is open on the world through many perception gates and channels of which our body is extremely rich. Then a first comment is that, once the brain gets an information through a perception experience, it is no more the same as it was before getting that information; «now you know!» is a warning message addressed to someone who comes to know something: «now you know; you are no more the same person as you were before». This means that the *act of getting* information breaks the time-reversal symmetry, it introduces a partition on the time axis making a distinction between «before» and «after», it introduces the *arrow of time* in the brain dynamics, which is in fact a dissipative dynamics. The *perception* of the stimulus (information) introduces by itself, *independently of the specific information*, the breakdown of time-reversal symmetry in the «internal» brain dynamics.

As a second comment, I recall that in the dissipative model the memory states are states of minimum energy. They behave thus as «dynamical attractors» and at a given time the brain state is described by the collection of such memory states, namely as the *attractor landscape*. Going from memory to memory is then described by trajectories in such a landscape of attractors. These trajectories can be shown to be chaotic trajectories (Vitiello [2004b]) and therefore quite sensible to tiny fluctuations in the initial conditions. This shows that an important role is played by noise and weak perturbations in the dissipative brain dynamics, which explains the observed relevance of small stimuli to the brain functioning and reactions. One can observe (Freeman [1975, 2001]; Rolls [2014]) that the same stimulus in different contextual conditions may lead to different brain reactions or answers, provided that the stimulus is a weak one. The brain activity is actually only triggered, not controlled, by weak stimuli. Moreover, any new stimulus produces symmetry breakdown and thus, as explained above, the recording of a new memory; it originates the formation of a new attractor in the landscape of attractors. From one side, the new information is submitted to a process of *abstraction*, by eliminating unessential details, and of *generalization*, by recognition of the category to which the stimulus belongs. On the other side, the inclusion of the new attractor in the landscape never results in a pure *addition* of the new attractor to the pre-existing set of attractors; rather it produces a fully *rearrangement* of the whole attractor landscape, so to «situate» the new memory in the «context» of the whole set of memories acquired in the previous perception experiences of the brain. It is in such a *contextualization* process that the new «information», which is void of meaning in the Shannon sense, becomes *meaningful*, entering in and changing the already acquired perceptual experience of the brain[1]. In this specific sense, *memory is not recording (and/or recollection) of infor-*

[1] Consider for example the perception of the red color by the retina. The (Shannon) information consists in giving the specific value of the red wavelength λ . However, the red of the stoplight and the red of the book cover on my desk (*same* wavelength λ!) have *different* meanings. Inci-

mation in the Shannon sense[2]. Memory is recorded through the mechanism of creation of a coherent state with a specific N_A, as explained above. The process of formation of the meaning consists in the process of dynamical generation of the coherent state and its contextualization in the attractor landscape. *Memory recording is thus always formation of meanings.* The rearrangement of the attractor landscape constitutes the *learning* process. The flux of information exchanged with the environment becomes *knowledge* through such a learning process. The *growth of knowledge* is realized at each rearrangement process of the attractor landscape, namely at each new formation of meaning, since in each rearrangement process the past story of the perception experiences is fully taken into account. This generates the *vision of the world* and creates *expectations* which drive the brain in the *intentional* search of situations considered satisfactorily on the basis of previous experiences. This in turn determines our *actions,* which at once also provide a *test* for our expectations thus making our knowledge *reliable* or not. Verifiability of our vision of the world makes it trustable (*credible)*. The Galileo paradigm finds in the functioning of the brain its alive realization.

4. *The aesthetic experience*

The relation with the Double appears in conclusion always new in its dynamic realization and our action is «intentionally» oriented towards the optimal «balance» in our trade with the Double. In this process the brain continuously puts under discussion the previously reached equilibrium and the whole state of its attractor landscape. The successive formation, disassembly, reconstruction of the coherent assemblies of neurons, following each other as in a cinematographic sequence of frames, are described by the chaotic trajectories in the attractor landscape. Intentionality emerges as a continuous balancing effort out of the dissipative brain dynamics, never definitely satisfied, but always pursuing a new equilibrium, a process made possible by the maintenance of the cortex in a state of criticality, a readiness from expectancy to realization and back again repeatedly in tracking changes in the environment (Capolupo, Freeman, Vitiello [2013]; Freeman *et al.* [2012]). The constant effort is thus finalized to give a meaning to our «being-in-the-

dentally, I observe that one of the limits of the program of Artificial Intelligence has been the impossibility to fully account and/or simulate the contextualization of given recorded information (Freeman (2001); Dreyfus (2007)).

[2] The brain is not an encyclopedia! The brain functioning shows how fallacious is the enlightenment illusion that encyclopedia (*naturalism*) is knowledge. Naturalism is a necessary but not sufficient step to knowledge (Vitiello (2001)).

world» with the intent of getting the «maximal grip» on the world. The continuous reciprocal *emotional exposure* and *complementarity* between the self and its Double may then acquire the aspects of the search for *survival* (Dreon [2015]; Dissanayake [2015]). In this way, the dissipative quantum model formally describes the *perception-action arc* of neuroscience or the *intentional arc* in the Merleau-Ponty's (Merleau-Ponty [1945]) phenomenology of perception.

Since the flux of perceptions cannot be stopped (the brain cannot be closed!), each rearrangement process of the attractor landscape consequent to a new perception provides an *always new* vision of the world, so that the dimension of the functioning of the brain is the one of the *surprise,* of the *astonishment* (Vitiello [2004a]): «and suddenly, all at once, the veil is torn away, I have understood, I have *seen*» (Sartre [1948]); and of the *Now*, the magic dimension of the present, the time that stops his course in the photographer «surprise»: «when at the precise instant an image suddenly stands out and the eye stops» forcing «the time to stop his course» (Prete [2003]). It is then through such features that the brain in the dissipative model turns out to be characterized in its functioning by the *aesthetical experience*, which consists in the harmonious «to-be-in-the-world», flavoured by the «emotion» of the perception, the *pleasure of exploring*, the satisfying accomplishment of our *trade and play* with our Double (Vitiello [2001]; Desideri [2006, 2011, 2014]), which, however, is never definitive. The aesthetical experience arising from pursuing the perfect harmony of the self in the world continuously renews itself since the dialog of the self with its Double is of dynamical origin, never concluded or terminated, always opening new horizons to be explored. The *aesthetical dimension* thus appears as the one that describes the entire landscape texture of our perceptual experiences (Desideri [2006]). From what said above, it also enters the construction of knowledge, in this way establishing a link with Spinoza's «intuitive science» (Diodato [1997, 2012]). The aesthetical experience appears to be not a particular experience, neither a generic one (Desideri [2006]), but the experience that arises from the optimal exchange between the self and its Double, determining itself in the aesthetical judgment which involves always *solely* the first person (Desideri [2006]), and thus is never matter of discussion, rather, opposing often to previously consolidated views, carries the flavor of being *eversive*.

4.1. *Errare e pensare*

Perhaps, these features, together with the relevance of weak fluctuations and noisy stimuli, are responsible of the degrees of freedom which make *imagination* to be possible and allow those *different views* (Desideri [2006]) of the world corresponding to the different unpredictable paths in the attractor landscape. This sheds light on the fact that mirror neurons (Rizzolati, Craighero [2004]) and mirror circuitry cannot be at the basis of the complexity and novelty of behaviors, of *creativity*. Pure mirroring is not enough, a *mimesis* (after Aristotle) is necessary in order to produce a *variation* of the observed action, an extension by imagination (Diodato [2013]) of the *meaning* of the world, of its *significance* (Desideri [2014]) and to that aim the undetermined bounds of imaginations are necessary (Desideri [2006]). In this way, the stimulus-answer mechanism is unlocked from the causal monism involved in the adaptationist paradigm (Desideri [2014]; Dreon [2015]). From the physicist point of view it is satisfactory that the mathematical structure of the dissipative quantum model of brain carries in itself such an important role of fluctuations, noise and chaoticity as characterizing features of brain functioning (Vitiello [2004a,b]). This happens to such a degree that even the *act of thinking*, usually almost synonymous of «rationality», namely of «logical consequential necessity» in its chain of steps or stages, acquires a new perspective in the model, so that «to think» appears much better grounded on the *erratic*, gratuitous walk described by chaotic trajectories in the attractor space: perhaps, as in the tragedy *Oedipus at Colonus* by Sophocles, one can finally come to *see*, to *know* only after *wandering*. The fact that strict consequential necessity is missing in the acts of consciousness and in brain activity gives us the «privilege» of being able to «make mistakes», namely to follow unexplored paths, eluding conformity and homologation, thus opening the possibility to «invention» and «novelties», contrarily to mechanical machines which by definition are «broken» if their functioning deviates from planned steps (Minati, Vitiello [2006]). Thus, *errare e pensare* (to err and to think) get along much more and much better than one may suspect. Maybe, pensare *is* errare. In 1958 von Neumann (von Neumann [1958]) did observe that [...] «the mathematical or logical language truly used by the central nervous system is characterized by less logical and arithmetical depth than what we are normally used to. [...] We require exquisite numerical precision over many logical steps to achieve what brains accomplish in very few short steps». The dissipative quantum model describing the sequential phase transitions in brain functioning and Freeman's studies on chaoticity in brain activity (Freeman [1975,1990,1996]; Freeman, Quian Quiroga [2013]) provides a way to the understanding of such a view.

4.2. *The social brain*

The aesthetical experience also implies the «active response» of the self to the world and the reciprocal action of the world on the self, and in turn active responses imply responsibility and thus they become moral, ethical responses through which the self and its Double become part of the larger social dialog. An interpersonal, collective level of consciousness thus arises; the transition from the individual to the social assumes the character of a new dynamical regime where a «social brain» emerges, a larger stage where a common «culture» is originated from the many individual aesthetical experiences. Cultural atmospheres are then the manifestations of long range correlations among individuals who get mutually dependent, each other bounded (entangled) in their very existence, each one simply non-existing without «the others». In this way, one's construction of knowledge, the meanings formed at personal levels produce a higher level of knowledge, structured levels of meanings in a shared common view of the world; new cultural trends, whose novelty may even acquire a *revolutionary* character, or simply new «fashions», may swap over a large assembly of people, which thus become a *community*. In such a frame, aesthetical experience unavoidably implies disclosure, *language*, to *manifest* «signs», including artistic *communication* (Vitiello [2008]; Cometti [2015]), which typically does not carry information, but meanings, with the additional essential aspect of «vagueness», crucial to leave open the doors to dynamical formation of further meanings.

Concerning hierarchically structured levels of activity, it has to be remarked that the coherent structure of the brain background state manifests itself in the self-similarity properties of fractal structures (Freeman, Zhai [2009]; Gireesh, Plenz [2008]; Petermann *et al.* [2009]). Laboratory measurements indeed show that recurrence intervals, durations and diameters of neocortical electroencephalogram (EEG) phase patterns have power-law distributions. The power spectral densities of electrocortigrams (ECoG) conform to power-law distributions over distances ranging from hypercolumns to an entire cerebral hemisphere (Freeman, Vitiello [2006, 2010]; Vitiello [2009a, 2012b]). These facts and the observation that fractal structures and self-similarity occur in a large number of natural phenomena and systems leads us to ask the question whether a unified physical understanding at the ecological scale is possible (Vitiello [2009a, 2012b]). We briefly discuss such a possibility in the following Section.

5. *Concluding remarks. Towards an integrated ecological vision*

In conclusion the brain is a dissipative system embedded in the environment and its harmonious relation with the world defines the aesthetical experience. This is the primary experience of our to-be-in-the-world, deeply rooted in our being, not a generic one, neither a peculiar one. The dissipative dynamics of the brain leads to the coherent structure of the brain ground state. Coherence is the product of the spontaneous symmetry breakdown induced by the external inputs to which the brain is unavoidably exposed. The openness of the brain results in a continuous dialog with the world, which is described in the dissipative model as its Double. In such a dialog, the brain constructs *meanings* and *knowledge*. As a result from new perceptual experiences, new attractors are formed in the attractor landscape which then undergoes a fully rearrangement, thus putting under new, unforeseen light the vision of the world. The generation of coherence in the brain dynamics turns out to be generation of meanings leading indeed to an ordered (i.e. meaningful) vision of the world, knowledge.

Coherence is the result of the process of spontaneous breakdown of symmetry. This is a very general dynamic process, present in most of the known natural phenomena. It is therefore worthwhile to consider such a process in a more general setting than the one of brain studies discussed above.

In elementary particle physics, in condensed matter physics, in cosmology one observes the formation of ordered patterns with various ordering configuration, e.g. different crystal ordering, ferromagnets, ordered time sequences, e.g., of chemical reactions, etc... These patterns are the macroscopic manifestations of the coherent dynamics underlying at the level of the elementary constituents of the system. Such a microscopic dynamics is described by the unifying formalism of spontaneously broken symmetry in quantum field theory. The observed ordered configurations or patterns thus appear to be *macroscopic quantum systems,* namely quantum systems not in the trivial sense of being made of quantum components, such as atoms and molecules, but in the sense that their macroscopic properties cannot be described without making recourse to the quantum dynamics. When symmetry is spontaneously broken this is characterized by the *coherent condensation* phenomenon, i.e. the simultaneous presence in the least energy state (called ground state or vacuum) of quanta (bosons) carrying the same quantum characterization (same quantum numbers) and a well specified and constant phase difference (*phase locking*).

A further support to a unified view of natural phenomena (Vitiello [2012a, b]) comes from the observation that Nature *loves* fractals. They are commonly described as geometric structures characterized by self-similarity properties. In other words, they exhibit at different scales of observation always the same modular geometric structure. They are said to be *scale free* systems for such a reason. Their geometric appearance, their form seems to be conditioned by some physical constrains (although in a different context see Tedesco [2014]). Recently, however it has been found (Vitiello [2009a, 2012b]) that the process of growth of fractals is controlled by the process of coherent boson condensation at a microscopic level. It has been shown indeed that fractal self-similar structures (including logarithmic spirals) are isomorph to the coherent states in QFT (the reverse of this statement is also true: coherent states are described by self-similar properties). This fact opens then a wide window on the scenario of natural phenomena where fractals appear. It seems that then some light can be shed on the understanding of the reasons at the basis of the extremely frequent recurrence of fractals in Nature, from solid state physics to earth science, biology, medical sciences, clustering of galaxies, etc. (Peitgen, Jürgens and Saupe [1986]; Selvam [1998]; Bunkov, Godfrin [2000]; Fodor, Piattelli-Palmarini [2011]), scale free processes observed in brain activity (Freeman, Zhai [2009]; Gireesh, Plenz [2008]; Petermann et al. [2009]; Vitiello [2009a]). Self-similar recurrences and related Fibonacci-type sequences seem to play a role even in language studies (Piattelli-Palmarini, Uriagereka [2008]; Medeiros, Piattelli-Palmarini [2013]). The «emergence of fractal dislocation structures» has been observed (Chen [2010]) in a crystal submitted to deforming stress actions at low temperature, which provides a further example of formation of fractal induced by (non-homogeneous) coherent phonon condensation in the crystal state. Moreover, self-similar structures are diffused in living and non-living matter not only in far apart sites in the world (in the Universe, we should say considering galactic clustering and shapes), but also they persistently occur during the billions of years of the evolution of the Universe. The discovery of the isomorphism above mentioned thus suggests that the dynamical law of coherence acts persistently, in space and in time, at a fundamental level, as a basic *law of form* ruling *morphogenetic processes.* The analysis of such a law shows that it is characterized by nonlinearity and dissipation, which also implies the appearance of the *arrow of time* (breakdown of time-reversal symmetry) (Vitiello [2012a, b]) with the consequent non-equilibrium dynamics controlled by entropy variations.

In view of what discussed above concerning the formation of meanings, one might say that the *appearance of forms* through coherence becomes the *formation of mean-*

ings. Nature is then not a collection of multi-coded *isolated* systems, rather it is unified by the dynamics of coherence which thus becomes a *dynamic paradigm* ruling the natural phenomena. In this sense, coherence is by itself the primordial origin of *codes*. These thus appear to be expressions of meanings (semantic level), not of pure information (syntactic level) (Vitiello [2012b, c]). This view seems to be confirmed by the PCR (polymerase chain reaction) processes commonly used in biology and by recent experiments (Montagnier *et al.* [2010]) on the electromagnetic properties of aqueous solutions of DNA of viruses and bacteria. The possibility to duplicate and reproduce through PCR the DNA macromolecular chain (the genetic code) is due to the fractal self-similar property of the electromagnetic signal emitted by the aqueous solutions of DNA, which thus, according to the isomorphism above mentioned, appears as the carrier of the coherence (meaning) of which the DNA code is expression. Perhaps, modifications in the signal coherence (as in the dynamically deformed squeezed states (Vitiello [2012a, 2014]) may play an important role in the dynamical origin of epigenetic modifications, which, in such a view, then signal the appearance of *new meanings* associated to deformed coherent signals. DNA appears in conclusion to be the *vehicle* through which coherence and its dynamical deformations propagates in living matter.

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