



Review Article

Dissipation, consciousness and the unconscious[☆]Chiara Fioretti^{a,1}, Gabriele Pulli^{b,1}, Giuseppe Vitiello^{c,*,1}^a Dipartimento di Scienze Umane, Filosofiche e Educazionali, Università di Salerno, Via Giovanni Paolo II, 132, Fisciano 84013 Salerno, Italy^b Dipartimento di Scienze del Patrimonio Culturale, Università di Salerno, Via Giovanni Paolo II, 132, Fisciano 84013 Salerno, Italy^c Dipartimento di Fisica "E.R. Caianiello", Università di Salerno, Via Giovanni Paolo II, 132, Fisciano 84013 Salerno, Italy

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ABSTRACT

In this paper, we review the dissipative quantum model of brain and some of its recent developments. The model emphasizes the fact that the brain is open to its environment, with outgoing and incoming flows of energy, matter, and information. For a living brain, these flows are always active; they can be enhanced or reduced, never fully eliminated. This characteristic is crucial for understanding brain activity, which is indeed described by the dissipative dynamics, and is fundamental to generating the phenomenon of consciousness. We briefly discuss several results derived from the dissipative model, including the hidden territory of the unconscious, the process of constructing meanings out of information, the dynamic nature of memory, which reveals to be memory of meanings rather than memory of information, the nature of mental activity, the observed chaotic activity of the brain, its fractal self-similarity, its social dimension, the formation of linguistic forms and concepts. Additionally, we address the concept of the brain's entanglement with its environment, and of free will, limited to the formal frame of the Bayes rule derivation.

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1. Introduction

In the second half of the past century, quantum field theory (QFT) was gaining extensive experimental validation in both non-relativistic physics, such as many-body physics in condensed matter, for example, in superconductivity, and in its relativistic formulation of elementary particle physics, which ultimately contributed to the development of the Standard Model. In light of the unsatisfactory state of neuroscience research, in 1967 Ricciardi and Umezawa (RU) proposed utilizing the conceptual and mathematical frameworks of many-body physics to enhance the understanding of the brain (Ricciardi and Umezawa, 1967).

In their model, the authors did not explicitly consider the fact that the brain is in a continuous exchange of energy, matter, and information with its environment, although it was clear in the model that the brain is under the influence of external stimuli. The extension to the dissipative dynamics of the exchanges between brain and environment has been studied in its details in the dissipative quantum model of brain (Vitiello, 1995, 2004b), and its developments (Sabbadini and Vitiello, 2019; Bernal-Casas and Vitiello, 2023; Fioretti et al., 2025), whose review is presented in this paper.

In the following and in Section 2 we first introduce the main features of the RU model and the research and cultural frame in which it was formulated.

In their analysis, Ricciardi and Umezawa (RU) did not oppose QFT techniques to those based on biochemistry commonly used in neuroscience. Rather, they wanted to explore the dynamics underlying neuronal activity that could account for the brain's extraordinary functional efficiency, which was otherwise impossible to explain, then as now, solely as resulting from the intrinsic randomness that regulates biochemical interactions: The detailed study of nerve cells and their connections in the brain structure is certainly *necessary*, but it is *not sufficient* to explain the high efficiency of brain activity. Schrödinger had already emphasized in his 1944 lectures in *What is Life?* (Schrödinger, 1944) that in biological systems, regularities “only on average” emerging from “statistical mechanisms” (p. 78) are not sufficient to explain the “enigmatic biological stability” (p. 47), so that the “expectation of the classical physicist (...) far from being trivial, is wrong” (p. 19). These observations on biological systems in general are even more pertinent in the case of the brain. In the same years, laboratory observations induced Karl Lashley to raise the alarm in the form of a “dilemma” (Lashley, 1942) (p. 306):

[...] Here is the dilemma. Nerve impulses are transmitted [...] from cell to cell through definite intercellular connections. Yet, all behavior seems to be determined by masses of excitation [...] within general fields of activity, without regard to particular nerve cells. [...] What sort of nervous organization might be capable of responding to a pattern of excitation without limited specialized path of conduction? The problem is almost universal in the activity of the nervous system.

Ignoring these issues constitutes a serious limitation for neuroscience and biology studies in general, aggravated by the fact that sometimes the interests of the chemical-pharmacological industry and also the academic competition support the closure of exploring paths not strictly related to mechanistic analysis. For biology, but the argument also applies to the brain, Schrödinger censures this attitude, noting that “...it needs no poetical imagination but only clear and sober scientific reflection to recognize that we are here obviously faced with events whose regular and lawful unfolding is guided by a mechanism entirely different from the probability mechanism of physics” (Schrödinger, 1944) (p. 79).

Walter Freeman notes that laboratory observations rule out the possibility that perception can be attributed solely to the properties of individual neurons, as it happens in the “microscopic approach that currently dominates neuroscience research. We have found that perception depends on the simultaneous, cooperative activity of millions

of neurons spread throughout expanses of the cortex” (Freeman, 1991) (p. 78).

In the 1967 work by Ricciardi and Umezawa, as well as in subsequent works by Umezawa, Stuart, and Takahashi in 1978 (Stuart et al., 1978) and 1979 (Stuart et al., 1979), it is observed that artificial neural network models are extremely useful in applications of computation and control theory. However, “in the case of natural brains, it might be pure optimism to hope to determine the numerical values for the coupling coefficients and thresholds of all neurons by means of anatomical or physiological methods, ...” (Ricciardi and Umezawa, 1967) (*Kybernetik*, p. 45), given that we are dealing with myriads of complex components, approximately 10^{11} neurons, each connected to 10^4 other neurons, 10^{15} synapses, not counting glial cells; all in a bath of water molecules, which in number constitute over 90% of the molecules present. Ricciardi and Umezawa, therefore, ask (Ricciardi and Umezawa, 1967) (*Kybernetik*, p. 45):

[...] Is it essential to know the behaviour in time of any single neuron in order to understand the behaviour of natural brains? Probably the answer is negative. The behaviour of any single neuron should not be significant for the functioning of the whole brain, otherwise higher and higher degree of malfunctioning should be observed, unless to assume the existence of “special” neurons, characterized by an exceptionally long half-life: or to postulate a huge redundancy in the circuitry of the brain. However, up to our knowledge, there have been no evidences which show the existence of such “special” neurons, and to invoke the redundancy is not the best way to answer the question.

Interestingly, the remarks by Ricciardi and Umezawa are on the same line as the observations by Lashley on the “masses of excitation” and the “general activity fields”, confirmed also by using modern experimental techniques, e.g., of fMRI. These features find their QFT description in terms of “collective modes” of the elementary components of the brain (cf. Sections 2 and 3).

On the other hand, the profound difference between artificial neural networks (today we would refer to the artificial intelligence (AI)) and the natural brain was well described by John von Neumann in 1958 (von Neumann, 1958) (p. 80–81): “The mathematical or logical language actually used by the central nervous system is characterized by a less logical and arithmetical depth than that to which we are normally accustomed. [...] We need great numerical precision in many logical steps to achieve what brains accomplish in very few steps”.

Considering the current great interest in developing powerful computing techniques and devices (from quantum computers to AI tools and strategies), and the reciprocal influences with neuroscience studies (Khrennikov, 2020, 2025), it is remarkable that the 1960s also saw the inheritance of research on neural networks developed in the previous decades, and intense studies were being conducted along the lines of cybernetics proposed by Norbert Wiener (Vitiello, 2001, 2024; Umezawa, 1995). Eduardo Caianiello, who conducted research in both QFT and neural networks, founded the Institute of Theoretical Physics at the Federico II University of Naples. This institute also included a Cybernetics Section, organized together with the neurophysiologist Valentino von Braitenberg, a guest at the Institute since its founding. The inaugural lecture of the associated School of Advanced Studies in Theoretical and Nuclear Physics was given in April 1958 by Werner Heisenberg. Umezawa observes that the Institute, where he had been a guest since 1963, provided him with a highly stimulating environment, precisely because, in addition to the theoretical physics sections, there was also a brain sciences section. Referring to his years at the Naples Institute, Umezawa observes (Umezawa, 1995) (p. 109):

At that time [1963], practically the entire Japanese high-energy physics was overwhelmed by the dispersion theory due to a strong influence of American physics, and there was little room left for quantum field theory. ... I found it very difficult to continue my work in Japan. Therefore, I felt very relieved when I moved to Naples. With a strong respect for independent thinking, which is an European tradition, Naples provided me with an ideal place for coming into a new development in quantum field theory.

The search for links among cybernetics, studies of the natural brain, and many-body physics is deeply rooted in that cultural atmosphere (Vitiello, 2001, 2024; Umezawa, 1995; Vitiello, 2011). It is then not surprising that the proposal to study the brain as a many-body problem could spring out from such an environment (Ricciardi and Umezawa, 1967; Vitiello, 2001).

As already mentioned, in the RU brain model, and in its successive elaborations by Umezawa, Stuart, and Takahashi (Stuart et al., 1978, 1979), the analysis of the fact that the brain is open to its environment, of which, of course, the authors were well aware, was left, in a first approximation, to a future formulation of the model. Later, it was shown (Vitiello, 1995) that neglecting the dissipative character of brain dynamics is at the origin of the very small memory capacity of the RU model. Once a memory is recorded, a subsequent external input produces the recording of another memory, which “overprints” on the one previously recorded, thus deleting it. It has been shown that such an overprinting phenomenon is avoided in the dissipative model (Vitiello, 1995), where the memory capacity is greatly enhanced by considering, indeed, the “openness” of the brain. Moreover, it results that the phenomenon of consciousness originates in the dialogical correlation, the ‘bridge’, between the brain and its environment.

The plan of the paper is the following. In Section 2, more aspects of the RU model are described. In Section 3, the openness of the brain is further discussed, also in relation to the available canonical formalism, which requires ‘closing’ the system (the brain, in our case) by including in the formalism the environment in which the system is embedded. The dissipative quantum model of the brain is introduced in Section 4, and in Sections 5 and 6, the features of the memory and of consciousness and the unconscious are discussed. In Section 7, the intentionality and the free will are related to the Bayes rule, which is intrinsic in the memory state structure as formulated in the dissipative model. Section 8 is devoted to the discussion and description of the mental activity. In Sections 9 and 10 the operational and empirical grounding of the model is discussed and a schematic comparison with other brain’s model is presented, respectively. Finally, in Section 11, conclusive remarks are reported, also commenting on the aesthetic experience, on linguistic forms and the formation of concepts, and on the social dimension of the brain’s functional activity. In the Appendix, laboratory settings and measurements related to the dissipative model are briefly described.

2. The many-body model of the brain

In discussing some additional features of the Ricciardi and Umezawa many-body model of the brain, it may be interesting to report Umezawa’s description of the origin of his interest in brain studies. In 1995, he wrote (Umezawa, 1995) (p. 122):

Since I was deeply involved in the subject of order and long-range correlation in many-body systems [...], I naturally asked myself the question “is there any long-range correlation” associated to brain. If there is long-range correlation, each constituent of the system should be trapped by this correlation and its individual behavior should not be freely exhibited and should instead be controlled by the correlation. In that case, we do not observe individual cells, but the quasi-cells (in analogy to the term quasi-particle). My argument followed the following logic. In any material in condensed matter physics any particular information is carried by certain ordered pattern maintained by certain long-range correlation mediated by some massless quanta. It looked to me that this is the only way to memorize some information; memory is a printed pattern of order supported by long-range correlations. Later, I noticed that this could provide a remarkable mechanism for memory recollection. Suppose that an ordered pattern was printed on the brain by a condensation mechanism in the vacuum which was induced by certain external stimuli. Though an order is stored, the brain is not conscious of this because it is in the ground state. However, when a similar external stimulation comes in, it easily excites the massless boson associated with the long-range correlation. Since the boson is massless,

any small amount of energy can cause its excitation. During the time of excitation, the brain becomes conscious of the stored order (memory). This explains the recollection mechanism. The stability of memory is associated with the concept of vacuum.

In technical, formal terms, the above description says that the dynamical mechanism of spontaneous breakdown of symmetry (SBS) is at the basis of the RU many-body brain model.

To see how the SBS operates, consider that, in general, the field equations describing the temporal evolution of the system have symmetry properties with respect to certain transformations. Let $|0\rangle$ denote the minimum-energy state (the ground state, or vacuum) of the system. When $|0\rangle$ does not have the same symmetry properties of the field equations, one says that spontaneous breakdown of symmetry (SBS) occurs (Itzykson and Zuber, 1980; Umezawa, 1983; Blasone et al., 2011). This may be caused by an external or endogenous stimulus or perturbation, even a very weak one, to which the system is subjected.

The ‘breakdown’ is called spontaneous because the system places itself in the $|0\rangle$ state, due to its internal dynamics, under given boundary conditions, such as, e.g., temperature. The Goldstone theorem in QFT (Umezawa, 1983; Blasone et al., 2011; Goldstone et al., 1962; Nambu, 1960), widely confirmed by experimental observations, states that when SBS occurs, long-range correlations between its elementary components are dynamically generated, thus producing ordered structures.

Ordering is possible as long as the correlations do not interfere negatively, that is, as long as they are phase coherent. The de Broglie relation allows us to describe long-range correlations in terms of so-called Nambu–Goldstone (NG) quanta (Goldstone et al., 1962; Nambu, 1960). They are boson quanta and obey the Bose–Einstein distribution; they can thus be condensed in large numbers into the same ground state, resulting in a coherent state. The net of coherent long-range correlations describes the “collective” behavior of the correlated systems’s components. Examples of NG quanta are the magnons in the ferromagnet and the phonons in the crystal (Umezawa, 1983).

A measure of the degree of the ordering is provided by the “order parameter” (for example, the magnetization in the magnets), which is a classical field, i.e., not subject to quantum fluctuations, although it is generated by the quantum dynamics. The order parameter is responsible of the macroscopic behavior of the system (think, for example, of the orientation in an external magnetic field of the needle of a compass, which is controlled by its magnetization).

In conclusion, the SBS and the resulting formation of coherent structures in the ground state, described by the order parameter field, allow the transition from the dynamical quantum (microscopic) level to the classical (macroscopic) level. One then speaks of “macroscopic quantum systems”, in the sense that quantities characterizing the classical behavior (for example, the order parameter) can only be described by resorting to the quantum dynamics of the microscopic level.

Within such a frame, in the RU model, “memory recording” is described by the dynamical process of condensation of the NG quanta (Ricciardi and Umezawa, 1967; Sivakami and Srinivasan, 1983). The corresponding long-range correlations are not modeled in terms of “rigid connections” (wiring); rather, they describe the “general fields of activity, regardless of particular nerve cells...”, the configurations “without a limited and specialized conduction pathway”, mentioned by Lashley in his dilemma.

In this respect, the RU model is also in agreement with Walter Freeman laboratory observations (Freeman, 2005b) showing that bioelectric waves in the brain can be stopped by cold treatments, electric shocks, or drugs, without memory loss after recovery. Moreover, memory is not lost in many ablation experiments or when a brain is cut in many directions so that certainly some pre-existing networks are destroyed (Freeman, 2005b). From these observations, it follows that memories do not reside in neural circuits and nets (they are not wired). In this sense, Karl Pribram (Pribram, 1991) suggested using

the concepts of hologram and phase coherence developed in laser physics (Klauder and Sudarshan, 1968).

It has to be remarked that in the RU model (and in the dissipative quantum model illustrated below), neurons, glial cells, and other biological components are considered to be classical structures, unlike in other models in the literature on the quantum brain and consciousness (Atmanspacher, 2015).

The question of which one is the symmetry undergoing the spontaneous breakdown and what the quantum variables are in the RU model is left by the authors to be defined at a later research stage.

Finally, as already mentioned in the Introduction, the RU model has a very limited memory capacity, contrary to what is observed in the natural brain. This difficulty is overcome in the dissipative quantum model of the brain (Vitiello, 1995) (cf. Sections 3 and 4).

One more remark is that in QFT, the term coherence refers to (Glauber-like) coherent states resulting from coherent Bose–Einstein condensation, and therefore it does not have the same meaning it has in quantum mechanics (QM), where it refers, together with the decoherence phenomenon, to the probability amplitudes in the superposition of the wave functions. In this connection, it is useful to mention that long-lived coherence in QFT is notoriously observed over a wide temperature range, below critical temperatures T_C , surviving noisy perturbations and thermal fluctuations; e.g., coherent ordering in magnetized iron, is lost at $T_C = 770$ °C; diamond crystal melts at $T_C = 3545$ °C; sodium chloride (kitchen salt) melts at $T_C = 804$ °C; superconductivity of niobium compounds vanishes at $T_C = -153$ °C; in copper and bismuth compounds, at $T_C = -252$ °C.

In the following sections, we consider some aspects of the dissipative dynamics of biological systems and the brain, whose time-evolution goes through physically different dynamical regimes (*phase transitions*) and is described by trajectories in the manifold of the infinitely many unitarily inequivalent representations of the canonical (anti-)commutation relations in QFT (Del Giudice et al., 1988a).

3. Biological systems and the brain are open systems

In 1983, Del Giudice and collaborators, inspired by the work of Herbert Fröhlich (Fröhlich, 1968), proposed to study biological systems by using the QFT formalism of SBS. They considered the spherical rotational symmetry of the electric dipoles of water molecules and other biomolecules (Del Giudice et al., 1983, 1985, 1986). Among the many contributions on this research line, see, e.g., Del Giudice et al. (1988b), Preparata (1995), Del Giudice and Vitiello (2006), Bono et al. (2012), De Ninno et al. (2014), and the more recent ones on liquid water (De Ninno and De Francesco, 2018; De Ninno and Gamberale, 2025).

Natural questions then arise: Why is so much attention given to the role played by water in biological systems? Are there plausible alternatives? What is the uniqueness and necessity of choosing water in the study of living matter?

To answer these questions, we list several important facts showing by themselves that water does not have a marginal role in the biological system activity.

It is a fact that chemical and electrochemical activity, as well as the configurations of many macromolecules, such as protein folding, are not possible in the absence of water.

Water molecules constitute the great majority of molecules in biological systems; in the human body, they are more than 70% by weight and more than 90% by number of molecules.

In biological systems, cell membranes maintain an electric potential difference of approximately 100 mV. Their thickness is of 10^{-6} cm. There is therefore an electrical field of the order of 10^5 V/cm, so strong that it may cause breakdown of a layer of ordinary matter, unless special precautions are taken (Fröhlich, 1968) (the dielectric breakdown of, e.g., silicon is at 0.4×10^5 V/cm). Biological systems thus exhibit extraordinary dielectric properties, and in the said electrical field, water molecules may enter into a collective state of coherent

correlations, which, although with short lifetime (fortunately, “water forgets”), opposing local thermal fluctuations, may produce an environment favorable to reducing the randomness that governs the kinetics of chemical reactions.

Under such conditions, electric dipole–dipole interactions between aromatic ring structures in DNA and enzymes are found to be dipole-mediated by their water environment (Kurian et al., 2018). See also recent studies on hydrated DNA (Pietruszka, 2025),

It has been experimentally observed that “a change in the hydration state can lead to dramatic changes to the DNA structure” (McDermott et al., 2017), confirming that such a water chiral superstructure (called chiral spine of hydration) constitutes a detailed mold or “electromagnetic image”, that, in the jargon of biochemistry, allows enzymes to “scan” or “read” the double helix.

By using scanning dielectric microscopy, recent observations (R. Wang et al., 2025) show that water exhibits high polarizability and conductivity properties when confined between plates separated by a distance of the nanoscale order of 1–2 nm. The acquired large dielectric constant, of the ferroelectric-like values, is attributed to strongly disordered hydrogen bonding induced by the few-layer confinement.

Recent experimental analysis of cancer tissues shows structural changes in collagen and water structures, confirming the role of water in the biological cellular organization (Mourkh, 2025).

Going into more details, the list may continue, always fully justifying the attention given to the role played by water. The uniqueness and necessity of choosing water are reinforced by the actual absence of plausible alternatives, in quantity and properties, able to play the same roles played by water.

Water molecules may undergo the dynamical process of the spontaneous breakdown of the rotational symmetry (cf. Section 2) of the molecular electric dipoles, allowing the formation of long-range coherent correlations between them (the associated NG bosons are called dipole-wave quanta (DWQ)). Coherent dipolar dynamics generates collective molecular dynamics and the polarization density $P(x,t)$ (the order parameter), which, together with the lowered ionization potential threshold of the coherent domains (electron release) (Del Giudice et al., 1986; Preparata, 1995; De Ninno and Gamberale, 2025), favors ordered biochemical reactions, from the subcellular and cellular levels to the tissue, organ, and organism levels.

The ‘plasticity’ of biological systems arises from the fact that the lifetime of coherent molecular correlations mediated by water is very short. In the brain, the neuronal correlation time scale is of the order of milliseconds (ms).

A remarkable result obtained within such a scheme is the explicit computation of the inner diameter of the microtubules in the cell’s cytoskeleton. It turns out to be approximately 150 Angstroms (Del Giudice et al., 1986), in full agreement with the experimentally observed value. As far as we know, in the literature, this is the only existing theoretical computation of the inner diameter of the microtubules. It solely involves the existence of long-range dipolar correlations in water and the filamentary propagation of the electrical field in the water coherent medium. It therefore confirms the theoretical consistency of the scheme and its adequacy with the experimental observations.

In 1992, Jibu and Yasue proposed (Jibu and Yasue, 1995) to consider the water as one of the relevant constituents in the RU model. Independently, the dissipative quantum model of brain was formulated (Vitiello, 1995).

From what was said above, it was a natural choice to identify the quantum variables as the fluctuations of the molecular electric dipoles, and the symmetry to be broken with the dipole’s spherical symmetry. Such choices, implying the formation of collective modes over coherent domains, also account for the laboratory observation of *masses of excitations within general fields of activity without regard to particular nerve cells*, reported by Lashley in his dilemma (cf. Section 1), and confirms the observation by Umezawa that *the behavior of any single*

neuron should not be significant for the functioning of the whole brain (cf. Section 1).

In conclusion, the biological system is far from thermodynamic equilibrium (Del Giudice et al., 1983, 1985, 1986), as indeed recognized by biology, always requiring an external input to maintain its time evolution along trajectories minimizing the free energy $F = U - TS$ at every time t (U is internal energy, S is entropy, T is temperature). Thus, for the states considered to be stationary at every t , it has to be $dF = 0$, i.e., $dU = TdS$, with readjustments (transfers) of energy, $dU \leftrightarrow TdS$, from kinematic (disordered) configurations to ordered ones, and vice versa.

This is even more true for the brain, which is in a continuous exchange of energy and information with its environment. Minimization of free energy, e.g., plays a relevant role in the asymmetric left and right hemisphere configuration (lateralization) of the brain Vallortigara and Vitiello (2024). Moreover, EEG, ECoG, fNMR, and similar methods reveal that myriads of neurons enter into domains of coherent oscillations, modulated in amplitude (AM) and phase (PM) (Freeman, 1975, 2000; Freeman and Quian Quiroga, 2016). They form in a few milliseconds (ms), persist for a period of 80–120 ms, have carrier frequencies in the 12–80 Hz range (the beta-gamma range), and resynchronize with frequencies in the theta-alpha band (3–12 Hz) (Freeman, 1975, 2000; Freeman and Quian Quiroga, 2016). They extend from a few mm to 19 cm in linear dimension in humans and across much of the hemisphere in rabbits and cats.

For an analysis formally near to the QFT approach to biological systems mentioned above, see Ref. Keppler (2023) and for the compatibility between variability and stability, see Ref. Fingelkurts and Fingelkurts (2004).

In neuroscience laboratories, it is observed that cortical domains abruptly jump from a receiving state to an active transmitting state (Freeman, 2000). Analysis of the observed time and space scales excludes that they are generated by the propagation of chemical vectors, which would be too slow (Freeman, 2005b). Thus, long-distance correlations are not created by the exchange of neurotransmitters, whose propagation is therefore not the cause, but rather the effect of the formation of correlated domains; long-range correlations also support the ephaptic connection between neurons (Anastassiou et al., 2011; Grundfest, 1959). Ion gradients across cell membranes provide the energy required for ephaptic neuronal communication.

Moreover, electric current densities and magnetic fields sustained by extracellular dendritic diramations are too weak to be responsible for the rich neuronal texture (Freeman, 2000). Neuronal radio waves (combined propagation of the electric and magnetic fields) are also excluded due to the imbalance between the electrical permittivity and magnetic permeability (80:1) of neural tissue. EM waves are also excluded due to the low frequency (<100 Hz) and wavelengths (of the order of kilometers) at EEG frequencies (Freeman, 1975, 2000; Freeman and Quian Quiroga, 2016) (for a comprehensive view of Freeman neuroscience observations see Kozma (2016).

The openness of the brain needs to be described by dissipative dynamics (the term ‘dissipative’ refers to both outgoing and incoming flows).

For a ‘closed’ (non-dissipative) system, energy conservation is ensured by symmetry under continuous time translations (Noether’s theorem) (Itzykson and Zuber, 1980), which means that the origin of the time axis can be freely translated (its position on the time axis is conventional). This is not so for biological systems and the brain, whose birth (origin) occurs at a well-defined time (they are *aging* systems). For these systems, symmetries under continuous time translations and under time reversal are broken: dissipation implies that time evolution is intrinsically irreversible, and the arrow of time cannot be reversed. Obtaining information from the world introduces, in fact, the division of the time axis into “before” and “after” the information has been obtained (*Now, you know it!...*), thus introducing “the present” (the *Now*), which distinguishes the past from the future.

The classical and quantum canonical mathematical formalism (the only one available to us!) is developed solely for closed systems. This implies that the open system under study (the brain) can be mathematically modeled only provided we ‘close’ the system by considering also the environment, so that the couple (system, environment) behaves as a closed system (this is a well-known computational strategy, commonly used in thermodynamics). The reciprocal exchange of energy and information between the two in the couple is, of course, not excluded.

In practice, one may satisfy such a mathematical constraint by ‘doubling’ the degrees of freedom: each one of those describing the system, say A_k , is associated with a corresponding degree of freedom of the environment, \tilde{A}_k . The index k denotes the momentum or other kinematic or charge variables. A similar strategy is used in finite-temperature QFT (Takahashi and Umezawa, 1975), in the study of unstable particles and quantum dissipation (Celeghini et al., 1992). Since the flows outgoing from the system $\{A_k\}$, is ingoing into the environment $\{\tilde{A}_k\}$, for any k , and vice versa, the set $\{(A_k, \tilde{A}_k)$, for any $k\}$ is a closed set.

It should be remarked that, in the dissipative model, the doubled degrees of freedom \tilde{A}_k are not just mathematical tools or artifacts. They describe physically existing degrees of freedom of the (brain-environment) system. They are found to play a relevant role, at different dynamical levels, in memory recording and recalling, in the unconscious activity, in the mental activity, etc. Moreover, tilde-modes also play a role in the description of the noisy background in relation with entanglement and chaos (Pessa and Vitiello, 2005; Srivastava et al., 1995).

The mathematical constraint of ‘closing’ the system is thus satisfied by describing the environment as the “time-reversed” image of the system (outgoing from the brain is ingoing into the environment, and vice versa, as in any administrative accounting between expenses and gains or introits). Although this is a simplified picture of the very complex nature of the environment, it provides, however, its *exact* description from the standpoint of the energy fluxes balancing. In conclusion, in the dissipative model, the environment is described as the image of the system (the brain) in the ‘mirror of time’, it is its *Double* (Vitiello, 1995).

4. The dissipative quantum model of brain

A specific feature of relativistic and non-relativistic (many-body) QFT is the existence of infinitely many physically inequivalent state spaces (unitarily inequivalent representations of the canonical (anti-)commutation relations) that describe different *phases* or dynamical regimes accessible to the system under different boundary conditions (Umezawa, 1983; Blasone et al., 2011). This is in contrast to quantum mechanics (QM), where the Stone–von Neumann theorem states that all the state spaces are unitarily equivalent (von Neumann, 1955).

In QFT, each one of the “orthogonal” (unitarily inequivalent) spaces of states has its own minimum-energy state (the ‘vacuum’ or ground state), characterized by a different condensation density of Nambu–Goldstone (NG) quanta, the DWQ in the dissipative quantum model (cf. Section 3). Memory is recorded by the condensation of DWQs (Vitiello, 1995).

Let $|0(\theta(t))\rangle$ denote the ground state where pairs (A_k, \tilde{A}_k) , for each k , respectively denoting the DWQ and its doubled image (cf. the previous section), are condensed, and $\theta(t)$ is related to the condensation density at time t (see below, Eq. (6)). $|0(\theta(t))\rangle$ is the memory state at time t and finite volume V , whose expression is

$$|0(\theta(t))\rangle = \prod_k \frac{1}{\cosh(\Gamma_k t - \theta_k)} \exp\left(\tanh(\Gamma_k t - \theta_k) A_k^\dagger \tilde{A}_k^\dagger\right) |0\rangle, \quad (1)$$

(we omit mathematical derivations to make the reading more fluid, see Vitiello 1995 for details). It is a generalized $SU(1, 1)$ coherent

state (Perelomov, 1986), normalized at any t , $\langle 0(\theta(t))|0(\theta(t))\rangle = 1$, with $\theta_k(t) \equiv \Gamma_k t - \theta_k$; Γ_k controls the condensate lifetime of momentum k , and θ_k the condensation density at initial time $t_0 = 0$. The (vacuum) state $|0\rangle \equiv |0, \vec{0}\rangle \equiv |0\rangle \times |0\rangle$ is annihilated by $A_{\mathbf{k}}$ and $\tilde{A}_{\mathbf{k}}$, $A_{\mathbf{k}}|0\rangle = 0 = \tilde{A}_{\mathbf{k}}|0\rangle$, for any \mathbf{k} . The operators $A_{\mathbf{k}}$ and $\tilde{A}_{\mathbf{k}}$ have the usual canonical commutation relations (CCR).

The state $|0(\theta(t))\rangle$ is the time evolution at t of the memory state at t_0 , $|0(\theta(t_0))\rangle \equiv |0(\theta)\rangle_0$:

$$|0(\theta(t))\rangle = \exp\left(-it\frac{\hat{H}}{\hbar}\right)|0(\theta)\rangle_0, \quad (2)$$

where the Hamiltonian is (Vitiello, 1995) $\hat{H} = \hat{H}_0 + H_I$, with

$$\hat{H}_0 = \sum_{\mathbf{k}} \hbar\omega_{\mathbf{k}}(A_{\mathbf{k}}^\dagger A_{\mathbf{k}} - \tilde{A}_{\mathbf{k}}^\dagger \tilde{A}_{\mathbf{k}}); \quad H_I = i \sum_{\mathbf{k}} \hbar\Gamma_{\mathbf{k}} (A_{\mathbf{k}}^\dagger \tilde{A}_{\mathbf{k}}^\dagger - A_{\mathbf{k}} \tilde{A}_{\mathbf{k}}). \quad (3)$$

It is $[\hat{H}_0, H_I] = 0$, and $\hat{H}_0|0(\theta)\rangle_0 = 0$. Notice that $|0(\theta(t))\rangle$, for any t , is not invariant under H_I , expressing formally the breakdown of the symmetry under continuous time translations and time-reversal, in agreement with the dissipative character of the dynamics (cf. the discussion in Section 3).

In the infinite volume limit, at different times and/or θ it is (Vitiello, 1995):

$$\langle 0|0(\theta(t))\rangle \rightarrow 0, \text{ for } V \rightarrow \infty, \quad \forall t, \quad (4)$$

$$\langle 0(\theta'(t'))|0(\theta(t))\rangle \rightarrow 0, \text{ for } V \rightarrow \infty, \quad (5)$$

$$\forall t, t', \text{ with } t \neq t', \quad \text{and/or } \forall \theta, \theta', \text{ with } \theta \neq \theta',$$

meaning that, in the infinite volume limit, it does not exist any unitary operator (any generator) connecting states at different times and/or θ s: the evolution in time of $|0(\theta(t))\rangle$ is “non-unitary”, consistently with the breakdown of continuous time translation and time-reversal transformations.

The number $\mathcal{N}_{A_{\mathbf{k}}}(\theta(t))$ of $A_{\mathbf{k}}$ bosons condensed in the state $|0(\theta(t))\rangle$ is

$$\mathcal{N}_{A_{\mathbf{k}}}(\theta(t)) = \langle 0(\theta(t))|A_{\mathbf{k}}^\dagger A_{\mathbf{k}}|0(\theta(t))\rangle = \sinh^2(\Gamma_{\mathbf{k}}t - \theta_{\mathbf{k}}), \quad (6)$$

satisfying, due to the minimization of free energy, the Bose–Einstein distribution at any t (Vitiello, 1995; Celeghini et al., 1992): $\sinh^2(\theta_{\mathbf{k}}(t)) = 1/(\exp(\beta(t)\omega_{\mathbf{k}}) - 1)$. In deriving Eq. (6), one finds that $\mathcal{N}_{A_{\mathbf{k}}}(\theta(t))$ is determined by the contributions of tilde-operators (the environment) to the state $|0(\theta(t))\rangle$, thus showing that they have an active role in the memory recording process, and formally confirming that the Self is always in relation with its Double (cf. Section 6, where the metaphoric sense of the Self and the Double in relation to the model formalism is commented on).

Similarly, $\mathcal{N}_{\tilde{A}_{\mathbf{k}}}(\theta(t)) = \sinh^2(\Gamma_{\mathbf{k}}t - \theta_{\mathbf{k}})$, since $|0(\theta(t))\rangle$ is a condensed state of pairs of $A_{\mathbf{k}}$ and $\tilde{A}_{\mathbf{k}}$, $\forall \mathbf{k}$, at any t . Thus, $(\mathcal{N}_{A_{\mathbf{k}}} - \mathcal{N}_{\tilde{A}_{\mathbf{k}}}) = 0$, $\forall \mathbf{k}$, is constant in time. The ‘memory code’ $\mathcal{N}(\theta) \equiv \{\mathcal{N}_{A_{\mathbf{k}}}(\theta(0)) = \mathcal{N}_{\tilde{A}_{\mathbf{k}}}(\theta(0)), \forall \mathbf{k}, \text{ at } t = 0\}$ characterizes the memory recorded at initial time $t = 0$.

At $t = \tau$, where τ is the largest among the values $\tau_{\mathbf{k}} = \theta_{\mathbf{k}}/\Gamma_{\mathbf{k}}$, for all \mathbf{k} , the memory recorded in $|0(\theta)\rangle_0$ is “forgotten” (the (A, \tilde{A}) condensation vanishes, cf. Eq. (6)). It may be restored by a “replication” of the initial stimulus (Vitiello, 1995; Stuart et al., 1979) or even by a different one, or by constructing a different $|0(\theta')\rangle_0$ from $|0\rangle$. It is also remarkable that, since the parameters $\Gamma_{\mathbf{k}}$ s depend in general on specific properties of the brain and on different boundary conditions, different time scales τ can be allowed, i.e., the model may describe memories with long and short lifetimes (Vitiello, 1995; Alfinito and Vitiello, 2000). Memories with a very long lifetime, say ‘permanent’ memories, e.g., so-called genetic memories on which vital functions may depend, are also allowed. One can also show (Alfinito and Vitiello, 2000; Pessa and Vitiello, 2005) that condensation domains smaller in dimensions correspond to longer lifetime memories, and larger domains to shorter lifetime ones.

In the state $|0(\theta(t))\rangle$, $A_{\mathbf{k}}$ and $\tilde{A}_{\mathbf{k}}$ are entangled modes (Vitiello, 2004b; Sabbadini and Vitiello, 2019; Pessa and Vitiello, 2005), as shown by the non-zero value of the covariance, $\text{cov}(N_{A_{\mathbf{k}}}, N_{\tilde{A}_{\mathbf{k}}})$ (Haroche and Raimond, 2006; Auletta et al., 2009; Gerry and Knight, 2005):

$$\text{cov}(N_{A_{\mathbf{k}}}, N_{\tilde{A}_{\mathbf{k}}}) \equiv \langle N_{A_{\mathbf{k}}} N_{\tilde{A}_{\mathbf{k}}} \rangle - \langle N_{A_{\mathbf{k}}} \rangle \langle N_{\tilde{A}_{\mathbf{k}}} \rangle = \frac{1}{4} \sinh^2 2\theta_{\mathbf{k}}(t) \neq 0, \quad (7)$$

for $t < \tau$. The expectation values $\langle *** \rangle$ are computed in the state $|0(\theta(t))\rangle$. The covariance is zero for uncorrelated modes, since then $\langle N_{A_{\mathbf{k}}} N_{\tilde{A}_{\mathbf{k}}} \rangle = \langle N_{A_{\mathbf{k}}} \rangle \langle N_{\tilde{A}_{\mathbf{k}}} \rangle$. The entanglement is revealed by the impossibility to factorize the expectation $\langle N_{A_{\mathbf{k}}} N_{\tilde{A}_{\mathbf{k}}} \rangle$ in single-mode states. We thus conclude that the brain and its environment are entangled systems, confirming the substantial characterization of the brain as an open system. The covariance provides a measure of the correlation between the brain and its environment.

The dissipative model has a huge memory capacity, a feature that does not exist in the RU model, as mentioned in Sections 1 and 2, and is a characterizing feature of the dissipative model. Indeed, a large number of different memories can be recorded, with memory codes $\mathcal{N}(\theta)$, $\mathcal{N}(\theta')$, $\mathcal{N}(\theta'')$, ...; with $\theta \neq \theta' \neq \theta''$..., each one in a different θ -representation among the infinitely many of them, each other unitarily inequivalent. Moreover, unitarily inequivalence holds for states at different θ s even at the same time t , $\theta(t) \neq \theta'(t) \neq \theta''(t)$, etc. (see Eq. (5)), so that different memory states may coexist at the same time t .

The unitarily inequivalence among the state spaces (Hilbert spaces) acts as a “protection” against *confusion* of memories (interferences between different memory codes). In realistic cases, however, the smoothing of the unitary inequivalence, due, e.g., to boundary effects, defects, impurities (Vitiello, 1995; Blasone et al., 2011; Del Giudice et al., 1985, 1986; Freeman et al., 2012), may cause “association” of memories and/or “paths” through (connecting) memories in the space of the memory states.

5. Memory of meanings

It is possible to prove (Pessa and Vitiello, 2005; Vitiello, 2004a) that small variations in the boundary conditions lead to a time evolution of $|0(\theta(t))\rangle$ characterized by diverging, classical chaotic trajectories in memory space. This accounts for laboratory observations of chaotic activity in the brain. Freeman observes (Freeman, 1991), p. (78–79):

[...] *The brain transforms sensory messages into conscious perceptions almost instantly. Chaotic, collective activity involving millions of neurons seems essential for such rapid recognition. [...] Our studies have led us as well to the discovery in the brain of chaos - complex behavior that seems random but actually has some hidden order. The chaos is evident in the tendency of vast collections of neurons to shift abruptly and simultaneously from one complex activity pattern to another in response to the smallest of inputs. [...] In fact, we propose it is the very property that makes perception possible. We also speculate that chaos underlies the ability of the brain to respond flexibly to the outside world and to generate novel activity patterns, including those that are experienced as fresh ideas.*

The activity of thinking is indeed closely linked to wandering, exploring without a definite task, opening new, unexplored paths, often leading to the pleasant prize of the *surprise*. We come back to this point in Section 6.

Finally, as it happens in the RU model, also in the dissipative quantum model, the excitation from the ground state of the condensed modes $A_{\mathbf{k}}$ of the memory code $\mathcal{N}(\theta)$ induces the recall of the corresponding memory. Since the number of $A_{\mathbf{k}}$ modes for each \mathbf{k} is very large, the recall stimulus (the replication signal Vitiello, 1995; Stuart et al., 1979) does not need to be the same as the stimulus responsible for the recording of that memory. It is enough (Pessa and Vitiello, 2005) that the difference between the set of recalled $A_{\mathbf{k}}$ and those of the code \mathcal{N} be a zero measure set. This is why a memory can be recalled also by a stimulus not exactly equal to the recording one. The recording and the recalling stimuli can also be very weak. The important point is

that the recording stimulus can induce SBS, and the recalling stimulus can get a ‘response’ from the system. Then we say that the stimuli are ‘in-phase’ with it, or ‘significant’ for it.

The memory state $|0(\theta)\rangle$ is a least energy state and thus the dynamics activated by the external stimulus proceeds toward this state as toward an “attractor”, so that at any time t the collection of all the memory states appears as an “attractor landscape”. The recording stimulus may induce the system to move to one of the existing attractors compatible with the code $\mathcal{N}(\theta)$ of the incoming information or, neglecting nonessential information details in a process of *abstraction*, selects another fundamental state, thus generating a new attractor in a process of *generalization* that identifies the category to which the stimulus belongs. The formation of a new attractor is thus never a simple addition to the attractor landscape. Rather, the new attractor triggers the re-configuration of the whole net of relations among the attractors, thus *integrating* the information incoming from the perceptive experience into the global landscape (the memory space).

The *meaning* emerges from this process of information integration, with or without the formation of a new attractor, and consequent rearrangement of the whole net of relations among the attractors in the updated landscape. The input is in itself meaningless; rather, the meaningfulness belongs to the “context” in which the perceptual experience occurs. The continuous process of rearrangement of the landscape of the attractors faithfully describes laboratory observations that the brain never acquires new information without placing it in context: the green of the traffic light is *not* the green of the poster in my office, even if they are *physically the same* (their frequencies in their respective spectral composition are the same). The credibility of a meaning is verified by the adequacy of the resulting action, which is the content of pragmatic information (Atmanspacher and Scheingraber, 1990).

Learning consists of the process of updating the pre-existing landscape of attractors, and the flow of information exchanged with the world then becomes *knowledge*. This creates a perspective; it measures (provides *comprehension* of) the global experience accumulated in past perceptual experiences, and creates expectations that guide the subject in the *intentional* search for satisfying experiential situations (such as searching for food where it was found in the past). Our actions are thus conditioned by the knowledge, and at the same time, they verify the reliability of expectations, thus testing (experimentally) the very credibility of knowledge. The “intentional arc” (Merleau-Ponty, 1945/1962; Dreyfus, 2007), that thus closes, appears to be the manifestation of the action-perception arc described in neurology (Bernal-Casas and Vitiello, 2023; Freeman, 1997).

The continuous updating of the integrated, but never definitive correlation net in the memory space (the landscape of the attractors), triggered by the information incoming from the perceptive experience, describes the dynamical setting, or scenario, a sort of global workspace (Baars, 1997), where the continuous dialogue Self-Double evolves (cf. also Section 6). All of it is far from the equilibrium, in a continuous flow of phase transitions, each phase describing the configuration of the correlation net among the attractors at each time t . Most remarkable is that each ‘node’ of the net (each attractor $|0(\theta(t))\rangle$), in the landscape of the attractors, evolves in time according to the equation (Vitiello, 1995)

$$\frac{\partial}{\partial t}|0(\theta(t))\rangle = -\left(\frac{1}{2}\frac{\partial S}{\partial t}\right)|0(\theta(t))\rangle, \quad (8)$$

namely, time-evolution is controlled by the entropy variations, a feature that indeed reflects the irreversibility of time evolution (the *arrow of time*) characteristic of dissipative systems.

The conclusion is that brain activity consists of constructing meanings out of information. *Memory, and with it knowledge, is then memory of meanings, rather than memory of information* (Vitiello, 2018).

6. The root of consciousness and the unconscious

In the Hamiltonian H_I in Eq. (3), the coupling terms between the A modes and their ‘mirror modes’ \bar{A} formally represent self-interaction terms of the A system, describing a sort of self-recognition process (like experiencing the echo (\bar{A}) answering our own voice (A) in the mountains) and, according to our discussions in the previous sections, the dynamical processes described by H_I underlie the neuronal functional activity. In the dissipative model, we refer to these processes as “the dynamics of the Self in relation to its Double”. Contents and metaphorical images, specific to psychological approaches, in this way enter our discussion, including the richness, but also the ambiguities (!) of associations and translations between different levels of languages (the physical and the psychological).

In this sense, in the dissipative model, the concepts of Self and Double are also referred to as phenomenological or psychoanalytic metaphors. They are rooted, however, in the model’s concrete mathematical formulation. A merit of the dissipative quantum model is that it enables the grounding of metaphoric extensions in precise QFT entities. Incidentally, note that this is, in general, typical of quantum theories (QM and QFT). For example, in a context completely different from the one discussed in this work, the equality sign in the de Broglie relation, $\lambda = \hbar/p$, allows to express in terms of the wave language the contents of the momentum language, and vice versa (which is exactly the meaning of the word ‘metaphor’), including, however, the associated ambiguities (how to distinguish the particle content in a wave interference pattern?).

The ‘closure’ of the system implies that our ‘being-in-the-world’ is subject to perceptual constraints, in the persistent attempt of balancing reciprocal exchanges of energy, matter, and information; a never-ending *dialogue* between the Self and its Double.

In the dissipative model, the internal/external boundary is therefore (metaphorically, but concretely supported by the model’s mathematical formulation!) conceived as a “bridge”, not a barrier, between the Self and its Double. The identity of the Self is a dynamical relational identity. The mutual influences of one on the other require a continuous updating of their relationship. Each is exposed to the gaze of the other.

It is in such an unavoidable mirroring process (dialogue), which occurs in the present, the *Now*, on the surface of the “mirror of time”, not in the past neither in the future, that the act of consciousness likely finds its origin (Vitiello, 1995, 2001), deeply rooted in the entanglement between “the two” (cf. Sections 3 and 4). The self-questioning property of consciousness (Desideri, 2004) seems to have its realization in these Nows, . . . “when at the precise instant an image suddenly stands out and the eye stops” forcing “the time to stop his course” (Prete, 2004), “and suddenly, all at once, the veil is torn away, I have understood, I have seen” (Sartre, 1990). This *surprise*, the *astonishment* felt in the “unveiling the Double” (Vitiello, 2001) actually characterizes our being-in-the-world.

The act of consciousness repeats itself in a “new” Now, not a time-translation of the previous one, in a continuous succession of different Nows. From each of them, different chaotic paths, time-lines, often with different time scales, develop (ten minutes is too long time interval or too short one, depending on what we are waiting for), exploring the space of the memory, redesigning the “identity” of the Self, which in this way survives the deleting action of oblivion (Vitiello, 2004b). It is interesting that in his analysis of the relation between elements of reality and the mental activity (Whitehead, 1929), Whitehead says that “The actual entity is the enjoyment of a certain quantum of physical time” (p. 401 in Whitehead 1929), where his ‘quantum of physical time’ might be seen as the ‘Now’ just mentioned, and his ‘enjoyment’ as the ‘act of consciousness’ redesigning, as said above, the ‘identity’ of the Self (the actual entity). In this view, as suggested in Khrennikov (2003), consciousness can be considered, in principle, as a representation of Whitehead’s field of feeling (enjoyment).

On the other hand, the \tilde{A} modes (the environment, the Double) cannot be eliminated from the brain dynamics, and thus they play a role also in the unconscious brain activity (Vitiello, 1995), as we will see below. In conclusion, consciousness and the unconscious have their roots in the dissipative character of the brain's dynamics.

Theories on the origins of the Self consistently emphasize the formative role of the environment. Among the most influential contributors, Donald Winnicott in 1971 proposed (Winnicott, 1971) that the emotional development of the individual — and the very emergence of the Self — depend fundamentally on the early relational environment, embodied by the primary caregiver. In the earliest months of life, the infant exists in a state of absolute dependence, where the boundaries between Self and mother are indistinct. The mother functions as both filter and container for the infant's experiences, shaping the first representations of the external world and of the Self. Through her attuned responses, she becomes the Mother–Environment, the infant's primary medium of existence. Winnicott's ideas marked a decisive shift in psychoanalytic thought, moving away from drive theory to focus on the relational and environmental dimensions of development. Together with other Independent psychoanalysts — such as Bowlby, Bion, and later Bollas — he emphasized that the Self arises through a dynamic interaction with the caregiving environment. The mother's handling, gaze, and emotional presence create an affective dialogue, described by Stern (1985) as a “dance”, that supports the child's transition from undifferentiated union to a sense of individuality. The gradual movement from absolute to relative dependence allows the child to distinguish between “Me” and “Not-Me”, thereby constructing an integrated sense of existence. Transitional objects later mediate this separation, symbolizing both continuity and independence from the maternal environment. What occurs in the infant's complex journey toward Self-development when the relationship with the environment is marked by disruptions in the dyadic bond and affective deprivation? Donald Winnicott examined this question extensively. As both pediatrician and psychoanalyst, he identified in certain patients a deep, primitive sense of nonexistence — a “voided Self” (Balint, 1963) — emerging from repeated encounters with a psychically absent or “dead” mother who fails to function as an integrating object–environment, a necessary foundation for the infant's sense of being. This persistent exposure to a non-responsive, non-nurturing mother constitutes a form of cumulative trauma, arising from the mother's inability to meet the child's emotional needs within a relational field dominated by her own internal conflicts and unmet desires. When maternal care is insufficient in its protective and containing functions, the consequences can be profound: in extreme cases, psychosis or cognitive impairment may develop, while physical or emotional separations often give rise to depressive states rooted in a fragile or inconsistent sense of existence. Within the framework of the dissipative model (Vitiello, 2001), such traumatic outcomes can be understood as resulting from varying degrees of “closure” within the child's system — an adaptive constriction that impedes the natural flow of relational and affective exchanges necessary for psychic growth. The trauma resulting from maternal absence — and the consequent impossibility of experiencing the environment as a Double capable of signifying both the world and the Self—is consigned to implicit memory, remaining inaccessible to consciousness yet embedded within the unconscious (Winnicott, 1989). In this framework, the Double delineates the “space” we might identify as the unconscious, conceived by Winnicott (1971, 1958) as a transitional space. Within this psychic area, experiences excluded from conscious awareness can find symbolic expression and, through processes such as artistic creation, be gradually integrated and repaired within the Self. The environment, functioning as the Self's Double, thus serves as a containing and reflective structure that enables the internal exploration of unconscious material and the formation of meaning. Consequently, the unconscious should not be understood merely as a muted dialogue with the Double (Vitiello, 2024) (p. 89), but rather as a dynamic transitional field where implicit or unexperienced traumas

can encounter representation and transformation through contact with the Double itself.

If the brain is in continuous relation with the environment in which it is immersed, when it isolates itself, even partially, from this environment, its functions are compromised, starting with the temporal function; a loss of the sense of time occurs. This finds confirmation in the main characteristic that Freud identifies in the unconscious when he states that “The unconscious is quite timeless” (Freud, 1901) (p. 275n). If consciousness is the dialogue of the brain with its Double (its environment), the unconscious, as said, is what occurs when it becomes impossible (traumatic) experiencing the environment as its own Double, and the dialogue with it is silenced.

If the brain receives innumerable stimuli from the environment, Freud observed that “Protection against stimuli is an almost more important function for the living organism than reception of stimuli” (Freud, 1920) (p. 27). The organism, therefore, is equipped with a shield that protects against stimuli. Moreover, Freud adds: “We describe as ‘traumatic’ any excitations from outside which are powerful enough to break through the protective shield” (Freud, 1920) (p. 29). And perhaps even the greatest joy has this same characteristic of an unexpected, even unthinkable event, still undomesticated: a kind of positive trauma. In any case, the fact that the brain is an open system is reflected in Freud's work. If, however, partial isolation from the world occurs, e.g., during sleep, or due to the effects of drugs, the orthogonality between memory states may be partially lost. Then, in such a state of reduced openness, confusion and association of memories may occur, and their ordering in the flow of time may be different from the one in which they were generated, which typically characterizes dreams (Re and Vitiello, 2020).

7. The Bayes theorem. intentionality and free will

The state $|0(\theta)\rangle$ in Eq. (1) can be written as (Takahashi and Umezawa, 1975; Celeghini et al., 1992; Umezawa et al., 1982)

$$|0(\theta)\rangle = \sum_{n=0}^{+\infty} \sqrt{W_n} (|n\rangle \otimes |\tilde{n}\rangle), \quad (9)$$

where $n = \tilde{n}$ denotes the set $\{n_k\}$, with $n_k \equiv n_{A_k}$, and

$$W_n = \prod_k \frac{\sinh^{2n_k} \theta_k}{\cosh^{2(n_k+1)} \theta_k}, \quad 0 < W_n < 1, \quad \sum_{n=0}^{+\infty} W_n = 1. \quad (10)$$

The entropy S_A is given by

$$S_A \equiv \langle 0(\theta) | S_A | 0(\theta) \rangle = - \sum_{n=0}^{+\infty} W_n \ln W_n, \quad (11)$$

and similarly for the entropy $S_{\tilde{A}}$. The minimization of the free energy $d\mathcal{F}_A = dE_A - (1/\beta)dS_A = 0$, holds at any t , and the changes in the energy $E_A \equiv \sum_k E_k \mathcal{N}_{A_k}$ and in the entropy are given by

$$dE_A = \sum_k E_k \dot{\mathcal{N}}_{A_k} dt = (1/\beta)dS_A, \quad (12)$$

provided $\partial\beta/\partial t = -(1/k_{\tilde{A}}T^2)(\partial T/\partial t) \approx 0$. The heat variation is $dQ = \frac{1}{\beta}dS_A$. For brevity, we do not discuss here the computation of the energy supporting the cortical activity (see Capolupo et al. 2013 for details).

From Eq. (9), we see that the probability of finding n_k quanta A_k in the $|n_k\rangle$ component of $|0(\theta)\rangle$ given \tilde{n}_k quanta \tilde{A}_k in the $|\tilde{n}_k\rangle$ state is:

$$P(n_k | \theta_k) = W_{n,k} = \frac{\tanh^{2n_k} \theta_k}{\cosh^2 \theta_k}, \quad \forall \mathbf{k}. \quad (13)$$

Since A_k and \tilde{A}_k come in pairs $\forall \mathbf{k}$ in $|0(\theta)\rangle$, and θ_k is conditioned to satisfy the Bose–Einstein distribution, we have: $P(n_k | \theta_k) \equiv P(n_k | \tilde{n}_k) \equiv P(\theta_k | \tilde{n}_k) \equiv P(\theta_k | n_k)$ and

$$P(\theta_k | n_k) = \frac{\tanh^{2n_k} \theta_k}{\cosh^2 \theta_k}, \quad \forall \mathbf{k}. \quad (14)$$

Moreover, by construction, the probability of finding n_k particles in $|\theta(\beta)\rangle$, with the Bose–Einstein distribution, equals the probability $P(\theta_k)$ of finding the specific θ_k , and $P(n_k) = P(\theta_k) = P(\bar{n}_k), \forall k$. We thus obtain (Bernal-Casas and Vitiello, 2023) the Bayes’ relation

$$P(n_k|\theta_k) = \frac{P(\theta_k|n_k)P(n_k)}{P(\theta_k)}. \quad (15)$$

In many decision-making problems, in administrative and management environments, and various scientific applications, Bayes’ rule is widely used to evaluate which action, among multiple possibilities, should be taken, thereby realizing the desired task with the highest Bayes probability. In our present context, it provides the formal description of the *intentionality* process guiding the brain’s actions. Remarkably, Bayes’ rule is built into the memory state describing the entanglement Self-Double. In this formal sense, it suggests which one is the set of possibilities available to us to operate intentionally on the world with some probability of success, it delineates the domain of choices on which we can realistically exercise our will, the limits of our *free will* (Bernal-Casas and Vitiello, 2023). Within such boundaries, the freedom in the choice of the action we operate becomes an “active response” to the world, implying ‘responsibility’ and thus it becomes an *ethical* response (Vitiello, 2004b). Then, the social dimension manifests itself. The Self and the Double recognize themselves as parts of a larger community, the “societies of brains” (Freeman, 1995), where the brains’ openness unveils the reciprocal physical dependence, with one non-existent without the others.

We stress that the concept of free will here considered is defined by, and limited to, the mathematical formalism of the Bayes’ rule derivation, and its formal description of intentionality. We avoid, since they are outside the scope of this review and of the dissipative model, any philosophical interpretation of, or discussion on, the free will concept presented here, as well as any comparison with competing views on free will in the essentially qualitative ongoing debates.

We also remark that the parameter θ_k constitutes the link between the entanglement (cf. Eq. (7)), the Bayes’ rule, and the free energy minimization (cf. Eq. (6)) that plays a relevant role in the dissipative model (Vitiello, 1995) and in many successive analyses on brain modeling (Bernal-Casas and Vitiello, 2023; Friston et al., 2006; Friston, 2010). It is also possible to show (Bernal-Casas and Vitiello, 2023) that the shift to a different value θ' , due to any possible cause, is dynamically ‘corrected’ by the process of minimization of the free energy, thus reaching a specific ‘target’ state $|\theta(\theta)\rangle$. The difference between the two configurations, θ'_k and θ_k , is computed to be of the order of $\sinh(2\theta_k)\delta\theta_k$, for any k , and small positive $\delta\theta_k$, with $\delta\theta_k \equiv \theta'_k - \theta_k$. In terms of energy and entropy variations, the difference is

$$dE'_A - dE_A = \frac{1}{\beta}(dS'_A - dS_A). \quad (16)$$

Without reporting formal details for brevity, we observe that memory states have self-similar fractal structure (Vitiello, 2009) in agreement with experimental observations (Freeman, 2005a; Gireesh and Plenz, 2008). Since there is an isomorphism between fractal self-similarity and the coherent nature of dynamics (Vitiello, 2012), the fractal structure also signals the coherent properties of the state $|\theta(\theta(t))\rangle$.

8. Brain and mind

Consistent with experimental data, the dissipative quantum model describes a continuous field of collective neuronal activity coexisting with the activation of discrete neuronal pulses. In multi-channel recordings of echocortigram (ECoG) signals, one observes the formation of conical phase gradients (phase cones) that implode and explode (Freeman, 2004b). The position of the apex and the opening of the phase cone (phase gradient) is fixed within a frame but varies randomly from one frame to the next. The gradient is negative (explosion) or positive (implosion) and often exhibits a clockwise or counterclockwise swirling

rotation. The dissipative model describes the dynamic origin of such cones in terms of reciprocal time reversal and predicts the existence of singularities associated with the apex of the cone in the process of non-instantaneous phase transitions (Freeman et al., 2012; Freeman and Vitiello, 2010).

In neurodynamics, there could be an explanation for the explosive gradient, for example, in terms of a pacemaker. However, there is no explanation for the imploding gradient, nor for why both the positive and negative gradients occur, one or the other at random. In the dissipative model, the imploding and exploding phase cones are described, respectively, by retarded Green’s functions, which express what happens at time t_0 (the present) in terms of what happened at a past time $t < t_0$; and by advanced Green’s functions, expressing events at t_0 in terms of events at a future time $t > t_0$. Actions are attributable to brain activity in thermodynamic time, i.e., forward in time, according to the arrow of time; the Double searches and reconstructs the perceptions acquired in the past (backward in time, *this is the mind*), for the purpose (*intentionality*) of planning the action deemed necessary for survival, for being-in-the-world. Going backward in time, in the reconstruction of a past perceptual experience, the Double “provides the *imagination* from which to construct the hypothesis to be tested by action”. Neuronal activity forward in time guides the “intentional” action and is planned considering the hypothesis provided by the Double. “It is the Double that imagines the world outside, free from the shackles of thermodynamic reality” (Freeman and Vitiello, 2016). Brains test the hypothesis using the action-perception cycle. The experience that an action, in repeated trials, is infallibly followed by changes in the environment creates the perception of time and simultaneously of causality (Freeman and Vitiello, 2016, 2007b). Neuronal activity, therefore, evolves “along parallel timelines”, (Freeman and Vitiello, 2016) one corresponding to the reconstruction of the past in memory (*the mind, mental activity*), the other directed to the future with the intention of achieving a specific goal and planning the actions to be undertaken.

The entanglement of the pairs (A, \bar{A}) in the state $|\theta(\theta(t))\rangle$ indicates that the relationship, the dialogue between the Self and its Double, cannot be interrupted (disentangled). It therefore translates into the entanglement between *brain activity* and *mental activity*, without the possibility of being separated. There is not a double level of existence, matter and mind, but a single indivisible entity. In the dissipative model, mental states cannot be separated from the brain, and vice versa.

Finally, we remark that through the heart’s electromagnetic (EM) field, and the nervous system, there is a communication between heart and brain, supported, according to the neuro-visceral integration model (Thayer et al., 2009; Dal Lin et al., 2015, 2021b), by the exchange of complex hormonal signals. Such a dialogue between the heart, the brain, and the whole organism is at the origin of adaptive responses (the feeling of harmony with the world, the aesthetic experience (Desideri, 2018; Vitiello, 2015) (cf. Section 11)), or of illness states (conflictual relations with the Double).

9. Operational and empirical grounding of the dissipative quantum model

In our review of the dissipative quantum model, it might be useful to list, without further discussion for brevity, specific results of the model that are consistent with, or predict, current experimental observations, and/or have been explicitly observed using EEG and ECoG, and are confirmed by similar and other tools in neuroscience. This will also confirm the operational and empirical grounding of the dissipative model. Some of the listed results have already been discussed in the previous Sections. For the reader’s convenience, we have also included them in our list below. Details of each item in the list can be found in the quoted bibliography.

Our listing starts with two main features of the ECoG data explained by the dissipative model (Freeman and Vitiello, 2007b, 2008),

the dynamical formation of spatially extended domains of neuronal synchronized oscillations and their rapid sequencing:

- the textured patterns of amplitude modulated (AM) and phase modulated (PM) oscillations in distinct frequency bands correlated with categories of conditioned stimuli, i.e., coexistence of physically distinct AM patterns

- the remarkably rapid onset of AM patterns into (irreversible) sequences that resemble cinematographic frames

Other predictions of the model in agreement with experimental observations (Vitiello, 2009; Freeman and Vitiello, 2007b, 2008) include:

- very low energy is required to excite AM correlated neuronal patterns

- AM patterns have large diameters with respect to the small sizes of the component neurons

- duration, size and power of AM patterns are decreasing functions of their carrier wave number k

- there is lack of invariance of AM patterns with invariant stimuli, but constancy with the unchanging meaning of the stimuli

- there is fractal self-similarity in brain background activity in agreement with power-law distributions of power spectral densities derived from ECoGs data (Vitiello, 2009; Freeman et al., 2008)

- there is heat dissipation at (almost) constant in time temperature (Freeman and Vitiello, 2010, 2007b, 2008)

- time evolution characterized by diverging, classical chaotic trajectories in the memory space in agreement with laboratory observations of chaotic activity in the brain (Freeman, 1991)

- the occurrence of near-zero down-spikes in phase transitions

- the whole phenomenology of the occurrence of phase gradients and phase singularities in the formation of vortices

- the constancy of the phase field within the frames

- the insurgence of a phase singularity associated with the abrupt decrease of the order parameter and the concomitant increase of spatial variance of the phase field

- the occurrence of phase cones and random variation of sign (implosive and explosive) at the apex

- the phase cone apices occur at random spatial locations

- the apex is not initiated within frames, but between frames (during phase transitions)

As said, the above-listed items, some of which have been discussed in the previous sections, have been derived from the dissipative model and are confirmed by experimental precision measurements with spatial, temporal, and spectral resolution of the ECoG and EEG, by using, e.g., ECoG with arrays of $8 \times 8 = 64$ channels with close spacing of 0.5–0.8 mm; digitizing rates of 500 Hz (see, e.g. Freeman and Vitiello 2010). For more details see the Appendix and the quoted published references.

In addition, as discussed in several points in this review, we stress that the model is consistent with the observed very large memory capacity, predicts memories with different lifetimes, and that the brain is an aging system. The model derives, not as the classical limit, but as a dynamical output, the “classicality of functionally self-regulated and self-organized background activity of the brain” (recall that in the dissipative model, neurons, glial cells, and other biological components are considered to be classical structures, cf. Sections 2 and 3). Moreover, as mentioned in Section 11, we will see that the dissipative model provides a formal framework for the heart-brain communication system, which is object of much attention in recent studies. The model also finds application in linguistics, aesthetics, social and cultural aggregations.

The whole picture can be summarized, quoting from Ref. Freeman and Vitiello (2010), as follows:

[...] *The foremost problem in studies of perception is to explain how brains seek, presage, and amplify microscopic activity driven by sensory receptors, retrieve and mobilize the relevant prior knowledge about the stimuli, and disseminate the selected knowledge in preparing an appropriate intentional action. Experimental data show that the cortex maintains by mutual excitation robust spontaneous background activity that is parsed by*

inhibitory feedback into oscillations that are both spatially and spectrally distributed. [...]

The fact that the dissipative many-body model naturally leads to equations describing mesoscopic fields and currents and to soliton-like “classical” solutions (the vortex) [...], and to microscopic/mesoscopic thermodynamic interplay [...] is certainly a remarkable offspring of the many-body model. The model appears to provide an efficient way for describing and organizing in a unified and consistent framework a large body of brain function data. [...]

Finally, we observe that the description of the singularities appearing in the process of phase transitions turns out to be remarkably crucial in the understanding of the nature of the engagement of the subject with the environment in the action-perception cycle. By the continual updating of the meanings of the flows of information exchanged in its relation with the environment, the brain proceeds from information to knowledge in its own world as it is known by itself (Heidegger’s Dasein (Heidegger, 1975/1988)), that we describe as its Double (Vitiello, 2001).

10. Comparing the dissipative quantum model with other models and computational neuroscience frameworks

The dissipative model, like the RU model (cf. Section 2), is not in opposition to the biochemical and computational approaches commonly used in neuroscience. Rather, it explores the dynamical foundation and the physical processes underlying and supporting the neuroscience rich phenomenology, which is the object of study for biochemical and computational models (Vitiello, 1995; Freeman and Vitiello, 2007b). Thus, the model is “a direct attack on explaining the link between micro dynamics [...] and mesoscopic dynamics of [neuronal] populations that produce observable data, structures and patterns” (Freeman and Vitiello, 2010).

Referring in particular to its QFT formalism, in Freeman and Vitiello (2008) it is remarked that “the dissipative quantum model is [...] different in a substantial way from brain models formulated in the Quantum Mechanics frame” (Stapp, 2003; Penrose, 1994; Hameroff and Penrose, 1996).

It might be useful to clarify such a ‘substantial’ difference by comparing, although in a schematic way, the dissipative model with other quantum models, and even with classical and computational approaches, e.g., SOC (Self-Organized Criticality) approaches, or computational neuroscience frameworks. For a comprehensive discussion on the most popular quantum models, on their grouping in different classification categories see also Atmanspacher (2015). Here, for brevity, we limit our comments to the general common features of these models.

First of all, we recall that, in contrast with QM models, the dissipative model incorporates the environment, and thus dissipation, with consequent non-unitary (irreversible) time evolution. This is formally described in terms of QFT, where spontaneous symmetry breaking (SBS) occurs, allowing the representation of brain activity patterns in terms of distinct (unitarily non-equivalent) quantum states of lowest energy (vacua). The act of consciousness then emerges at the classical interface between the brain and the environment (its *Double*). All this is extraneous to QM models, necessarily characterized, as QM is, by unitary, thus reversible, evolution, facing difficulties such as quantum decoherence and quantum-to-classical scale differences.

We might then include these and other features of the QFT dissipative model (QFTdm) in a schematic list, contrasting with other quantum models (QMm). Some of the items are discussed in the previous sections and are included in the list for the reader’s convenience:

- in QFTdm, the brain is a physical, realistically open system, in continuous interaction with its environment, exchanging energy, matter, information (dissipation), implying non-unitary dynamics $\langle - - \rangle$
- in QMm, the brain is, in most cases, treated as an isolated system, with unitary dynamics.

-in **QFTdm**, time evolution is irreversible (non-unitary) (the arrow of time) $\langle \dashrightarrow \rangle$ in **QMm**, time evolution is reversible (unitary).

-in **QFTdm**, we have non-linear dynamical equations, no superposition of solutions; coupling with the environment, self-coupling, self-recognition, self-organization $\langle \dashrightarrow \rangle$ in **QMm**, linear Schrödinger equation for probability amplitudes, superposition principle, collapse of wave-function, decoherence.

-in **QFTdm**, there is spontaneous breakdown of symmetry (SBS) triggered by perceptual stimuli; formation of multiple, distinct (unitarily inequivalent) ground states with different long-range correlations (different densities of coherent NG condensates) responsible of collective assemblies of neurons (“textured patterns”), representing different brain states (e.g., memories or representations of perceptual inputs). $\langle \dashrightarrow \rangle$ in **QMm**, unicity of the ground state (the von Neumann theorem), collapse of the wave function, decoherence. No explanation of multiple, coexisting, different memory states; mostly considering quantum states within individual neurons, fragile coherence (QM decoherence) within and between neurons.

-in **QFTdm**, memory capacity is huge; it allows new memories forming from perceptual experiences without destroying old ones $\langle \dashrightarrow \rangle$ in **QMm**, memory capacity is very limited, or not discussed; new memory overwrites the previously stored one.

-in **QFTdm**, temperature and temperature effects are included in the QFT formalism; compatible with QFT coherent structure of memory states $\langle \dashrightarrow \rangle$ in **QMm**, temperature and temperature effects are absent (as they are in the QM formalism); when introduced they favor the QM decoherence.

in **QFTdm**, the space of brain states admits chaotic classical trajectories, in agreement with laboratory observations (Freeman, 1991) (cf. Section 5) $\langle \dashrightarrow \rangle$ in **QMm**, observed chaoticity is unexplained.

in **QFTdm**, fractal self-similarity, scale-free neuronal activity is formally derived, in agreement with laboratory observations (Freeman, 2005a; Gireesh and Pleniz, 2008) (cf. Section 7) $\langle \dashrightarrow \rangle$ in **QMm** scale-free self-similarity remains essentially unexplained.

-in **QFTdm**, the “present”, the “Now”, distinguishing the past from the future, is allowed. “Getting the information” implies the breakdown of time-reversal symmetry (“Now, you know it!”; irreversible time evolution); breakdown of time translational symmetry (Noether theorem), aging systems, time evolution as “cinematographic sequences” of frames (photograms) $\langle \dashrightarrow \rangle$ in **QMm**, the present, past, and future are not uniquely defined (time evolution is reversible).

-in **QFTdm**, the act of consciousness as the dialogue with the environment (the Double); it occurs solely in the present $\langle \dashrightarrow \rangle$ in **QMm**, consciousness mostly associated with the quantum-to-classical reduction, wave-function collapse process, as e.g., in the Hameroff-Penrose model, where consciousness is associated with the collapse of the wave-function describing the superposition of quantum states of dimers on the microtubules.

-in **QFTdm**, transition from quantum to classical states is dynamically induced by coherence and by the classicality of the order parameter field, generated by coherent states at the quantum level, but classically behaving since free from quantum fluctuations $\langle \dashrightarrow \rangle$ in **QMm**, quantum to classical transitions are mostly treated by statistical averaging, leaving open the question of how to explain the “enigmatic functional stability” of the system at classical level (cf. the Schrödinger objection, Section 1).

-in **QFTdm**, the mind and mental states are related to material substrate (imploding and diverging phase cones observed in neuronal activity, see Section 8); mind and brain (matter) are not separate or separable entities $\langle \dashrightarrow \rangle$ in **QMm**, several different positions (cf. Atmanspacher 2015), dualistic conjecture (matter level separated by mind level), and matter and mind are regarded as dual (separate) aspects of one underlying reality.

The list may continue, but for brevity, we invite the reader to consult good accounts on the QM approaches and the dissipative model, e.g., Atmanspacher (2015), and the bibliography there reported.

Of course, the QFT formalism also makes a substantial difference from classical and computational approaches. For example, SOC approaches may describe many observed features, such as fractal self-similarity, avalanche-like neuronal assembly, and non-linear features. However, although they are usefully applied to many different physical systems, showing the complexity of some behaviors common to them, notwithstanding their physical differences, they lack any derivation from, or connection to, the physics at the microscopic level, which is the starting point of the dissipative quantum model analysis. In contrast, SOC approaches offer many more possibilities for numerical and computational side than the dissipative model.

In general, numerical simulations and computational approaches represent an important applicative sector, different from the possibilities offered by the dissipative model, which, of course, was born in a different perspective than the computational one.

On a different side and different level, as mentioned in Section 6, a possible similitude could be seen, although not an immediate one, between the “global workspace” in the Baars model (Baars, 1997) and the continual updating of the landscape of the attractors, and its exploration in the dissipative model. However, again, the basic starting point in the two cases is a completely different one. In the dissipative model, the link to the physical substrate is central, while the global workspace approach is not explicitly related to the brain’s physical matter components, resting instead on the cognitive dimension; as for consciousness, which, in contrast, emerges from the physically unavoidable condition of the dissipation in the dissipative model.

Another classical approach that might be considered is the one by Tononi, relating consciousness to the notion of integrated information theory (IIT) (Tononi, 2008; Oizumi et al., 2014), so that consciousness consists of the neuronal structured aggregation resulting from the integration of the information reaching the brain. In the IIT approach, the neuronal physical interaction is assumed to be at the origin (the cause) of the information integration, and reveals itself in neuronal assemblies structures. These are assumed to be observable (measurable) expressions of consciousness. The differences with the dissipative model are evident. Also in the case of the IIT approach, the act of consciousness is not grounded in the dynamical interaction brain-environment, rather it is in some sense identified with a “neuronal correlate” resulting from, and representing the information integration. What actually matters is not the interaction with the environment, but the intrinsically internal neuronal structures

Finally, it is intriguing the possibility of a connection between the notion of the Now in the dissipative model and the ‘quantum of physical time’ in Whitehead’s observation (Whitehead, 1929): “The actual entity is the enjoyment of a certain quantum of physical time” (p. 401). Is there any possible way to relate Whitehead’s field of feeling (enjoyment) to the act of consciousness realizing in the Now? (Khrennikov, 2003) (cf. Section 6).

11. Concluding remarks

In conclusion, a unified view of cognitive and biochemical activity emerges from our discussions (Dal Lin et al., 2020, 2021a). As emphasized in the previous sections, a central role in our analysis is the one played by the brain’s persistent openness to its environment, implying the dissipativity of its dynamics. Brain’s openness is the source of consciousness and of many properties of the brain’s functional activity. The dynamics of knowledge, feeling, and the same being-in-the-world unfold in the dialogue between the Self and its Double. The unconscious belongs to that transitional space where traumatic experiences, implicit or realistic in the relations with the Double, are confined.

The brain closure is lethal. Isolation can lead to depression, loss of interest in the world, narcissistic identification with it, or, conversely, the adoption of different and coexisting worldviews, associated with numerous Doubles and multiple personalities (dissociative identity disorder (DID)) (Turner, 2022).

The memory space is described in the dissipative model by the landscape of the memory states $|0(\theta(t))\rangle$, acting as attractors due to their being the lowest energy states. As observed in Section 5, classic, chaotic trajectories describe time evolution in the memory space. Small variations in boundary conditions determine divergent deterministic trajectories, which allow the brain to immediately respond to rapidly changing or unexpected stimuli. The activity of thinking is closely connected to such a chaotic wandering through the landscape of the attractors. *Imagination*, produced by the mental activity, offers to the brain activity the possibility to plan actions unforeseen on a purely logical basis. It therefore has an active role in determining trajectories in the landscape of attractors, corresponding to “a different kind” of seeing, resulting in the “aesthetic experience”, a “dimension that permeates the entire field of our experience” (Desideri, 2007), not limited to the artistic field.

Aesthetics, therefore, is not a ‘particular’ experience in any way, nor just any experience, but an experience that, looking within itself, recognizes “the perfect exchange between inside and outside”, a “favorable connection” between “me and the object”, and in acknowledging it, determines the aesthetic judgment that “always implies the first person” (Desideri, 2007). *Beauty is my beauty*.

The path in the landscape of attractors is determined by its specific initial conditions. In this sense, these are pregnant with meaning (Desideri, 2007), anticipating, so to speak, the path in its evolution, thus defining an orientation, that of “casting a new look on the world”, not extraneous to, but rather concurrent with, the cognitive dimension (Desideri, 2007). The determinism of the path attributes the character of irrefutability to this different vision, which therefore does not represent a belief, a hypothesis that can be discussed and proven false, aesthetic emotion is not an opinion (Desideri, 2007); the path that pertains to it, born from impalpable perceptual fluctuations, and therefore by their very nature unpredictable, is divergent from every other path in the chaotic dynamics of the landscape of attractors. For this reason, the aesthetic experience is always new, *subversive* with respect to the consolidation of landscapes already explored. Since the balance of flows, which it expresses and which it delights in, is never definitive because it is dynamical, the orientation it expresses “always awaits renewal” (Desideri, 2007), in a tension that gives aesthetic experience a “performative value” within the intentional arc, and directs it toward an “emotional response” to the perceptual experience from which it arises. Interestingly, Diodato (1997) identifies, within a Spinozian perspective, a connection between aesthetics and “intuitive science”, “knowledge of an aesthetic nature [...] at the same time corporeal and mental”.

As already observed in Section 7, the brain’s openness is, of course, also openness to other brains, in a “social brain” community. The “phase correlations between brains” is intrinsic to the brain’s functional activity (Freeman, 1995). The brain’s social dimension identifies the communities, defines their culture, their organization, economy, their history, and their language.

Remarkably, the dissipative model formalism also applies to linguistic analysis within the Chomsky Minimalist Program (Chomsky, 1995). It describes (Piattelli-Palmarini and Vitiello, 2015, 2017b,a) the transition from the regime of lexical elements (atomistic components) to the one of collective structures (words, sentences, etc.), able to establish “meaningful” communications (not just written or spoken signs). In particular, the “manifold of concepts” is generated from the syntactic level of lexical elements through a dynamical process, not just assembling little lexical elements, words, etc. It can be shown that coherence of the collective mode protects the semantic content against “atomistic defects”: e.g., partially corrupted, deformed, or missing words, grammatical defects, etc., do not affect the meaning, provided, of course, they occur below a criticality threshold. Moreover, self-similar structures observed in linguistics are also obtained, as it happens in the brain’s functional activity. Obtaining these results within the formalism

of the dissipative model of the brain suggests that the basic mechanisms of linguistics are rooted in the same functional activity of the brain.

Finally, within the frame of open systems, the study of the stability conditions, of transformations, and even revolutions in social dynamics, may be of great interest (Khrennikov, 2020, 2025, 2024) for the understanding of social and economic ‘phase transitions’. There are also projects, such as Cognitive Warfare, planned by military organizations, which are thought (Montocchio, 2021) to become “a permanent, self-sustaining mode of action to achieve, in the long term, the desired end state: destabilization of a political leader, a military commander, an entire general staff, a population, or an Alliance. [...] Cognitive warfare is, to date, the most advanced form of human mental manipulation that allows for the influence of individual or collective behavior to gain a tactical or strategic advantage. [...] the human brain becomes the battlefield. The goal pursued is to influence not only what the targets think, but also their way of thinking and, ultimately, how they act”.

Unfortunately, currently, social, economic, and financial crises are being addressed by privileging the market for the products of the dominant industrial complexes, promoting high-profit production, such as weapons, controlling migration fluxes, directing them towards cheap labor and slavery, and extending massive use of AI in any field, with the resulting centralization of decision-making processes.

Our effort, in opposition to all this, and our strong commitment, is, of course, aimed at defending the “Human” and its prevalence over every other objective. If it is ever possible to build a machine endowed with consciousness, then it must possess “the best of the human model: an unpredictably erratic way of thinking, capable of learning but unfaithful, always doubtful, suspicious, totally rooted in the world, yet irreducibly free. And it will have to be called Spartacus” (Vitiello, 2004b).

The authors dedicate this paper to the memory of Walter J. Freeman III, ten years after his passing.

CRediT authorship contribution statement

Chiara Fioretti: Writing – review & editing, Writing – original draft, Conceptualization. **Gabriele Pulli:** Writing – review & editing, Writing – original draft, Conceptualization. **Giuseppe Vitiello:** Writing – review & editing, Writing – original draft, Validation, Supervision, Conceptualization.

Declaration of generative AI use

The authors declare that generative AI, AI technology, and AI tools have not been used at any stage of production of the manuscript.

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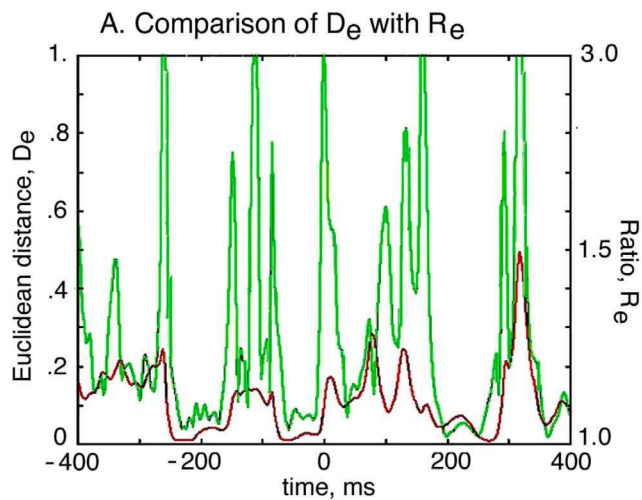


Fig. 1. Spikes: D_e stability measure. Curve: R_e boson density (Freeman, 2004a).

Appendix. Excerpts from “the dissipative quantum model of brain and laboratory observations”

We report some excerpts from the paper “The dissipative quantum model of brain and laboratory observations” (Freeman and Vitiello, 2007a), describing laboratory settings and measurements related to results and predictions of the dissipative model:

“The mesoscopic neural activity of neocortex appears to consist of the dynamical formation of spatially extended domains in which widespread cooperation supports brief epochs of patterned oscillations. These “packets of waves” have properties of location, size, duration and carrier frequencies in the beta-gamma range (12–80 Hz). They resynchronize, through a sequence of repeated collective phase transitions in cortical dynamics, in frames at frame rates in the theta-alpha range (3–12 Hz). The formation of such patterns of amplitude-modulated (AM) synchronized oscillations in neocortex has been demonstrated by imaging of scalp potentials (electroencephalograms, EEGs) and of cortical surface potentials (electrocorticograms, ECoGs) of animals and humans from high-density electrode arrays (Freeman and Vitiello, 2007b; Freeman et al., 2003b,a; Freeman, 2004a,c).”

“The AM patterns appear often to extend over spatial domains covering much of the hemisphere in rabbits and cats (Freeman, 2005c, 2006), and over the length of a 64×1 linear 19 cm array (Freeman et al., 2003b) in the human cortex with near-zero phase dispersion (Freeman et al., 2003c; Freeman and Rogers, 2003). Synchronized oscillation of large-scale neuronal assemblies in beta and gamma ranges has also been detected by magnetoencephalographic (MEG) imaging in the resting state and in motor task-related states of the human brain Bassett et al. (2006). In this paper, we compare the predictions of the dissipative quantum model of brain Vitiello (1995, 2001) with these neurophysiological data (Freeman and Vitiello, 2007b, 2008).”

“High-density electrode arrays (typically 8×8 in a 2D square) fixed on the scalp or the epidural surface of cortical areas, and fast Fourier transform (FFT) have been used to measure AM pattern textures for which high spatial resolution is required (Freeman et al., 2003b, 2000). The set of n amplitudes squared from an array of n electrodes (typically 64) defines a feature vector, $A^2(t)$, of the spatial pattern of power at each time step. The vector specifies a point on a dynamic trajectory in brain state space, conceived as the collection of all possible brain states, essentially infinite”.

“Measurement of n EEG signals defined a finite n -dimensional sub-space, so the point specified by $A^2(t)$ is unique to a spatial AM pattern of the aperiodic carrier wave. Similar AM patterns form a cluster in n -space, and multiple patterns form either multiple clusters or trajectories

with large Euclidean distances between digitizing steps through n -space. A cluster with a verified behavioral correlate denotes an ordered AM pattern. The vector $A^2(t)$ is taken to be the best available numeric estimator of our order parameter, because when the trajectory of a sequence of point senders into a cluster, that location in state space signifies increased order from the perspective of an intentional state of the brain, owing to the correlation with a conditioned stimulus.”

“We use the reciprocal of the absolute value of the step size between successive values of $D_e(t) = |A^2(t) - A^2(t-1)|$ as a scalar index of our order parameter. Pattern amplitude stability was proved by small steps in Euclidean distances, $R_e(t)$, between consecutive points (higher spikes in Fig. 1). Pattern phase stability was proved by calculating the ratio, $R_e(t)$, of the temporal standard deviation of the mean filtered EEG to the mean temporal standard deviation of the n EEGs (Freeman, 2004a,c) (lower curve in Fig. 1). By these measures, AM/phase-modulated patterns stabilized just after the phase transitions and before reaching the maximum in the spatial AM pattern amplitude. $R_e(t) = 1$ when the oscillations were entirely synchronized. When n EEGs were totally desynchronized, $R_e(t)$ approached one over the square root of the number of digitizing steps in the moving window. Experimentally, $R_e(t)$ rose rapidly within a few ms after a phase discontinuity and several ms before the onset of a marked increase in mean analytic amplitude, $A(t)$.”

“The succession of the high and low values of R_e revealed episodic emergence and dissolution of synchrony; therefore, R_e was adopted as an index of cortical efficiency (Haken, 1996), on the premise that cortical transmission of spatial patterns was most energy-efficient when the dendritic currents were most synchronized.”

“Resynchronized oscillations in the beta range near zero lag commonly recurred at rates in the theta range and covered substantial portions of the left cerebral hemisphere under observation (Freeman et al., 2003a) (exceeding the length of the recording array (19 cm) in human brain). We conclude that a specific value of the phenomenological order parameter $A^2(t)$ may be assumed to correspond to a specific value of N of the order parameter predicted by the dissipative model: the observation of the AM pattern textures and of their sequencing finds thus a description in the dissipative model. The time evolution in the brain space described by the space of the representations of the CCRs gives the image of a quantum origin of the trajectories described by the time dependent vector $A^2(t)$ in the brain state space as phenomenologically described above.”

“A further agreement of the dissipative model with observed features is recognized by considering the common frequency $\Omega_k(t)$ for the a_k and \bar{a}_k modes (cf. Eq. (8) in Alfinito and Vitiello (2000)): the duration, size, and power of AM patterns are predicted to be decreasing functions of the carrier wave-number k , as indeed confirmed in the observations. Carrier waves in the gamma range (30–80 Hz): durations seldom exceeding 100 ms, diameters seldom exceeding 15 mm; low power in the $1/f^\alpha$ relation. Carrier frequencies in the beta range (12–30 Hz): durations often exceeding 100 ms; estimated diameters large enough to include multiple primary sensory areas and the limbic system; greater power by $1/f^\alpha$.”

“Eq. (2) [Eq. (12) in the present paper] shows that the change in time of the condensate, i.e., of the order parameter, turns into heat dissipation dQ . Therefore, the ratio between the rate of free energy dissipation to the rate of change in the order parameter is a good measure of the ordering stability. This is in agreement with observations. Indeed, in terms of the laboratory observables, the rate of change of the order parameter is specified by the Euclidean distance $D_e(t)$ between successive points in the n -space. Typically, $D_e(t)$ takes large steps between clusters, decreases to a low value when the trajectory enters a cluster, and remains low for tens of ms within a frame. Therefore, $D_e(t)$ serves as a measure of the spatial AM pattern stability. Empirically (Freeman, 2005c, 2006) it was found that the best predictor of the onset times of ordered AM patterns was, as suggested by the dissipative model, the ratio $H_e(t)$ of the rate of free energy dissipation

to the rate of change in the order parameter, because $D_e(t)$ falls and $A^2(t)$ rises with wave packet evolution: $H_e(t) = A^2(t)/D_e(t)$.”

This index is named the pragmatic information index after Atmanspacher and Scheingraber (Atmanspacher and Scheingraber, 1990). Our measurements showed that typically the rate of change in the instantaneous frequency $\omega(t)$ was low in frames that coincided with low $D_e(t)$, indicating stabilization of frequency as well as AM pattern. Between frames $\omega(t)$ increased often several fold or decreased even below zero in interframe breaks that repeated at rates in the theta or alpha range of the EEG (Freeman et al., 2003a) (phase slip Pikovsky et al., 2001).”

Data availability

No data was used for the research described in the article.

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