On the brain-mind visual experiences

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***Abstract*—Within the frame of the dissipative quantum model of brain we present a theoretical analysis of brain-mind visual experiences made during dreaming, meditation, caused by the action of psychoactive substances, or under conditions of low degree of openness of the brain on its environment. The brain-mind visual experiences we refer to are visual activities not connected to the actual seeing as in the awake state. The movie-like sequences of images in brain-mind visual experiences have their origin in the criticality of the low level of openness of the brain dynamics. They are described as trajectories through the memory space constructed during the subject perceptual experiences. Truthfulness and realism felt in brain-mind visual experiences find a description in terms of the entanglement between the doubled degrees of freedom in the dissipative model. We conjecture that brain-mind visual experiences may be present also in subjects under anesthesia, in some coma states and in general under conditions of reduced openness of the brain on its environment. Our presentation develops mostly at a descriptive, qualitative level. The mathematical formalism on which it is grounded is summarized in the Appendix to facilitate the reading of the main text. Laboratory observations of the criticality of the brain functional activity are in agreement with the dissipative model and are briefly recalled in the course of the presentation. Nevertheless much work is still needed at theoretical and experimental level.**

***Index Terms*—brain-mind visual experiences, dreams, meditation, coma states, psychoactive substances, models of cortical dynamics in perception, cognitive behavior.**

I. Introduction

In this work we report on some recent studies [1] of brain-mind visual activity experienced under conditions of low degree of openness of the brain on its environment. These brain states of low level of openness may be due, for example, to psychoactive substances, or during dreaming, meditation, perhaps also under anesthesia, in some of the coma states, etc.. We refer to such experiences as brain-mind visual experiences to recall that they are not the ones connected to the actual seeing as in the awake state.

Our study is carried on within the dissipative quantum model of brain [2], [3], [4], [5] whose agreement with laboratory observations have been reported in [6], [7], [8], [9], [10]. The model has been also used [11] in the analysis of neural networks. Quantum dynamical features of neural nets are of course of great interest in computational neuroscience and in quantum computational applications (quantum computation) [12], [13], [14].

In our theoretical analysis movie-like sequences of images in brain-mind visual experiences are described in terms of trajectories in the memory space constructed during the perceptual history of the subject. The brain-mind visual activity appears to be due to the brain dynamical criticality described by the dissipative model in agreement with observations [4], [6], [8], [10], [15]. Much theoretical and experimental work is however still to be done.

Beyond its connection to neuroscience and psychology in general, our study is motivated by the increasing research interest in psychoactive natural or chemically synthesized substances able to affect mood, sleeping, thoughts, etc. and by the studies of dreams and dream-like brain activities [16].

In section II we summarize the main features of the dissipative model. In section III, the consequences of the degree of openness of the brain on its environment are analyzed. In Section IV and V, brain-mind visual experiences and the feelings of truthfulness and realism associated with them are discussed. Section VI is devoted to the conclusions. A summary of the dissipative model mathematical formalism underlying the main text descriptive discussion are presented in the Appendix.

II. Basic ingredients of the dissipative quantum model of brain

A. The Ricciardi and Umezawa model

The motivations behind the study of the brain as a many-body system proposed by Ricciardi and Umezawa [17], and further developed by Stuart, Takahashi and Umezawa [18], [19], [20], may be traced back to the experimental work by Lashley leading him to conclude that "all behavior seems to be determined by masses of excitation, by the form or relations or proportions of excitation within general fields of activity, without regard to particular nerve cells" [21], [22]. The description of brain functions, especially of memory storing and recalling, is obtained in the Ricciardi and Umezawa model by use of long-range correlation waves dynamically generated through the mechanism of spontaneous breakdown of symmetry in quantum field theory (QFT). The modes associated with these long-range waves are the Nambu-Goldstone (NG) modes [23] and are named dipole-wave-quanta (dwq). The symmetry that gets broken is the rotational (spherical) symmetry of the electrical dipoles characterizing all the brain elementary constituents (the water molecules and all other biomolecules)

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[24], [25]. It needs to be stressed that neurons, glia cells and other bio-units are considered to be classical object in the model. The quantum variables are the vibrational modes of the electrical dipoles. In this respect, the model is radically different from other quantum models existing in literature [5].

In the model, inputs received by the brain induce the breakdown of the symmetry, causing the dynamical formation of ordered patterns in the ground state (the vacuum) through coherent boson condensation of dwq. Memory recording consists in such a condensation process. Memory recall is obtained by excitation of condensed bosons out of the ground state induced by a stimulus similar to the one that caused the condensation (a "replication" signal). The brain thus "reads" the printed information by using as a probe the replication signal.

One of the negative features of the Ricciardi and Umezawa model was the extremely reduced memory capacity, due to the overprinting in the ground state of a new memory over the previously recorded one. This difficulty is solved by considering that the brain is an open, *dissipative* system exchanging energy and information with its environment. A huge memory capacity is obtained by extending the Ricciardi and Umezawa model to the dissipative dynamics [2].

B. The dissipative quantum model of brain

The brain activity is driven by the action-perception cycle [4], [6], [26], [27] in a dynamical regime of persistent *criticality*. At each time t the minimization of free energy [2] is pursued.

Since out-going fluxes are *time-reversed* fluxes with respect to the in-going ones, and vice-versa, the environment behaves as the time-mirror image of the brain, its *Double*. The dissipative brain dynamics is characterized by irreversible time-evolution: in fact, once information has been recorded, the brain cannot be brought to the state in which it was *before* information printing occurred. Thus, the process of getting information introduces *the arrow of time* into brain dynamics. It introduces a partition in time evolution, i.e. the *distinction* between past and future, a distinction which did not exist *before* information recording. Time emerges as an observable in the time mirroring with the Double.

Dissipation implies that the evolution of memory states is controlled by entropy variations [2], which reflects indeed the irreversibility of time evolution (breakdown of time-reversal symmetry).

In the QFT of the dissipative systems, the environment is described by doubling the system degrees of freedom, say A_k: $A_k \to A_k \times \tilde{A}_k$, where $\tilde{A}_k$ denote the environment degrees of freedom and k the momentum. A_k and $\tilde{A}_k$ describe the dipole correlation modes and their time-reversed copies, respectively.

It has been proposed that the act of consciousness resides in the *dialog* with the Double [2], [3], thus establishing couplings or links, say in number of n, with the environment within processes of *identification* vs *distinction* between the self and its Double. The number of links n thus provides a measure of the "openness" of the brain over the world.

The dwq may undergo a number of fluctuating interactions and their characteristic frequency may consequently change in time. It has been shown [28] that dissipation and time-dependence of frequency lead to the dynamical organization of amplitude modulated (AM) and phase modulated (PM) assemblies of (myriads) of neurons synchronously oscillating, as actually observed in laboratory [26], [29]. The sizes of the domains are related with the emergence of finite life-times for the memories. The dynamical generation of these time-scales are in agreement with physiological observation of recruitment of neurons in the brain functional activity and with the decay behavior of memories [2], [26].

As mentioned, the breakdown of symmetry implies the *coherent* condensation of dwq in the ground state, which thus stabilizes the ordered patterns. QFT guaranties the existence of infinitely many distinct state spaces, and thus *infinitely many distinct ground states*. "Distinct" means orthogonal (in the QFT jargon, unitarily inequivalent representations), thus not interfering states, which in turn means non-interfering, distinct memories. We refer to them as the "memory states" and to their collection as the "memory space". Each memory state is identified by a macroscopic variable, called the order parameter and related with the density of condensed dwq in the vacuum. Its value represents the "memory code" $\mathcal{N}$.

The label $\mathcal{N}$ in the vacuum $|0>_{\mathcal{N}}$ specifies the set of integers $\{\mathcal{N}_{A_k}\}$, for any k, which defines the initial value of the A_k mode condensate, i.e. the information *code* recorded at time $t_0 = 0$. The balance of the energy flows exchanged between the system and the environment requires that $\mathcal{N}_{A_k} - \mathcal{N}_{\tilde{A}_k} = 0$, for any k . Such a condition, however, does not uniquely fix the code $\mathcal{N} \equiv \{\mathcal{N}_{A_k}\}$, for any k. Also $|0>_{\mathcal{N}'}$ is an available memory state, provided that $\mathcal{N}' \equiv \{\mathcal{N}'_{A_k}; \mathcal{N}'_{A_k} - \mathcal{N}'_{\tilde{A}_k} = 0\}$, for any k, so to ensure the energy flow balance: $|0>_{\mathcal{N}'}$ corresponds to a different information of code $\mathcal{N}'$ (see the Appendix).

The condensed states $|0>_{\mathcal{N}}$, for any $\mathcal{N}$ turn out to be finite temperature (squeezed) coherent $SU(1,1)$ states. The condensed modes $\{A_k, \tilde{A}_k\}$ are entangled modes due to their phase mediated long-range correlation [30].

In conclusion, many sequentially recorded information may *coexist* without interference since (infinitely) many vacua $|0>_{\mathcal{N}}$, for all $\mathcal{N}$, are independently accessible in the sequential recording process. The "brain (ground) state" is represented by the collection of the full set of memory states $|0>_{\mathcal{N}}$, for all $\mathcal{N}$. The dissipative dynamics allows to achieve a huge memory capacity.

III. Higher or lower degree of openness of the brain on its environment

We present now few remarks on the higher or lower level of coupling of the brain with its environment.

The time-dependence of Ω_n of the coupled systems A and $\tilde{A}$ (see (2) in the Appendix) implies that energy is not conserved in time and therefore that the $A - \tilde{A}$ system is not a closed system. From (1) (in the Appendix) we see that as $n \to \infty$, Ω_n approaches to a time independent quantity. Energy is thus conserved in such a limit, i.e. the $A - \tilde{A}$ system gets closed as $n \to \infty$. When n is not very large (infinity), the system A (the brain) has not fulfilled its capability to fully couple with its environment.

Memory recording may occur provided Ω_n is real. Upon restoring the suffix k, the reality condition is seen to be satisfied for times t such that $0 \leq t \leq T_{k,n}$, with $T_{k,n}$ given by

$$T_{k,n} = \frac{2n+1}{L} \ln\left(\frac{2\omega_{0,k}}{L}\right).$$

Thus, memory recording can occur in limited time intervals which have $T_{k,n}$ as the upper bound, for each k. For times $t > T_{k,n}$ memory recording cannot occur. For fixed k, $T_{k,n}$ grows linearly in n, which means that the time span useful for memory recording (the ability of memory storing) grows as n grows, i.e. more the system is open to the external world (more are the links), higher is its ability of learning. It is possible, for example, that the ability in information recording may be different under different circumstances, at different ages, and so on. A higher or lower *degree of openness* to the external world produces a better or worse ability in learning, respectively.

Let us now fix n and analyze the $T_{k,n}$ behavior in k. We remark that ${\Omega_{k,n}}^2(t) \geq 0$ at any given t implies $k \geq \tilde{k}(n,t) \equiv k_0 e^{Lt/2n+1}$, with $k_0 \equiv L/2c$ at any given t (note that $\omega_{0,k} = kc$). A threshold $\tilde{k}$ thus exists for the k modes, which only depends on the internal parameters, a kind of subjective "sensibility" to external stimuli. As n grows, the threshold $\tilde{k}$ on k in the memory process is lowered and a richer spectrum of k modes is involved.

Note that the condition on k excludes modes of wave-length $\lambda > \tilde{\lambda} \propto 1/\tilde{k}(n,t)$ for any given n and t. We have thus an infrared cut-off, by which infinitely long wave-lengths are not allowed. Then the QFT infinite volume limit is not reached and the unitary inequivalence among ground states is "softened". The important consequence is that at given t's transitions through different vacuum states (which would be unitarily inequivalent vacua in the infinite volume limit) become possible. We may have then "association of memories" and "confusion" of memories. We will comment more on this point in the following.

The existence of the $\tilde{\lambda}(n,t)$ cut-off also means that in the memory recording processes the (coherent) domain sizes are less or equal to $\tilde{\lambda}$, and that, for a given n, such a cut-off reduces in time. On the other hand, a growth of n opposes to such a reducing.

Modes with larger k have a "longer" life-time. In other words, each k mode "lives" with a proper time $\tau_{k,n}$, so that the mode is born when $\tau_{k,n}$ is zero and it dies for $\tau_{k,n} \to \infty$.

Since only the modes allowed by the reality condition are present at certain time t, being the other ones decayed, a hierarchical organization of memories depending on their life-time is produced. Among coexisting memories with a specific spectrum of k mode components, some of them "die" before, some other ones persist longer according to the number of the smaller or larger k components in the spectrum, respectively [28].

We also observe that k components with different life-times may produce the corruption of the spectral structure of the the memory information with consequent deformations of the memory code. At some time $t = \tau$, larger than the memory life-time, $|0>_{\mathcal{N}}$ reduces to the "empty" vacuum $|0>_0$ with $\mathcal{N}_k = 0$ for all k and the information has been *forgotten*. At $t = \tau$, a new information may be recorded in $|0>_0$. In order to avoid to completely forget an information, its code needs to be restored by *brushing up* the recorded subject (external stimuli maintained memory) [20].

In conclusion, memories with a spectrum containing a larger number of higher k components persist longer and are also more "localized" than shorter term memories, i.e. those with a spectrum more populated by smaller k components, which extend over larger domains.

Summing up, more neuronal connections will form in the brain which is more connected to its environment. Here we do not refer to structural or anatomical neuronal connectivity, but to the functional one, which is highly dynamic with modulation time-scales in the range of hundreds of milliseconds [6], [26], [27], [31]. These functional neuronal connections may change in a short time and new configurations of connections may extend over domains including a larger or a smaller number of neurons. Such a dynamical picture is in fact observed in brain activity. It finds a possible description in the dissipative model, where coherent domain formation, size and life-time are highly dynamic and depend on the number of links that the brain sets with its environment and on internal parameters, as described above.

IV. THE BRAIN-MIND VISUAL EXPERIENCES

Weak inputs may be shown to drive the system through memory states. Trajectories in the memory space are found to be classical chaotic trajectories [32] and thus slight occasional (random) perturbations may lead to diverging paths going through completely different sequences of memory states. Deterministic chaos generated by noisy neural fluctuations plays indeed an essential role in the brain functional activity [15], [27], [29], [31], [33], [34], [35]. As stressed by Freeman [27]:..."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... This changeability is a prime characteristic of many chaotic systems ... 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 ...".

According to the dissipative model, "abrupt shifts" (in Freeman's words) from one activity pattern to another one are favored when unitary inequivalence among vacua is softened. As said, this may happen in the case of low openness of the brain on its environment (*criticality*, phase transitions). Phase transitions among memory states allows "association" of memories. This may be a not completely negative event provided that “confusion” of memories is avoided.

On the other hand, the opposite case of strict inequivalence is obtained when the number of links n with the environment is maximum. Such a case corresponds to ”fixation” or ”trapping” in some specific memory state.

In conclusion, memory states constitutes a manifold of coherent states, the landscape of attractors, in the language of nonlinear dynamical systems. Itinerant classical chaotic trajectories may develop, triggered by the smallest of perturbations. Different degrees of openness of the brain may lead to different scenarios. This agrees with observations made by use of EEG, ECoG, fNMR, and other techniques, showing indeed that cortical activity goes through the formation of AM and PM neuronal assemblies, “multiple spatial patterns in sequences during each perceptual action that resemble cinematographic frames on multiple screens” [9], [36], [37].

The dissipative model predicts that the brain reduced openness leads to the ‘smoothing’ of the physical inequivalence among memory states with a greater possibility of phase transitions. The increase of the criticality is at the origin of the movie-like sequences of images in the brain-mind activity. When the brain is almost closed on itself, with quite a small number of links n with the environment, almost dominated by criticality, a “flow” of memories may occur leading to “travel” through memory states.

On the contrary, the ‘normal’ states of openness are the ones of “presence”, awareness of the *Now*, “attention” on what is going on around us.

As mentioned, reduced brain openness may be caused by physical or chemical agents, e.g. DMT, Ayahuasca or other psychoactive substances. Then, “bits” or “debris” of memories represented by deformed or corrupted memory codes $\mathcal{N}$ in their components $\mathcal{N}_{A_{\mathbf{k}}}$ (and $\mathcal{N}_{\tilde{A}_{\mathbf{k}}}$), for few or many k's, might be recalled outside their original recording context, assembled in some emerging new contexts, flowing in movie-like sequences.

Our discussion leads us to conjecture that, similarly, flows of images may occur under anesthesia, in deep meditation stages, in some altered state, e.g. induced by or related with slow breathing techniques [38], or in general when the brain openness is actually reduced, as in some coma states. Even the persistent influence of rhythmically modulated visual stimuli, or else musical rhythms may become in some cases dominant to the point of excluding other inputs thus reducing the brain openness (as e.g. in hypnosis).

Of course, the most common brain-mind visual experiences of movie-like sequences of images is the one we have in dreams or dream-like and sleeping states [16], [39], [40], [41], [42], [43], [44], [45], [46]. According to our discussion, in such cases it is again the criticality of the brain dynamics, due to quite small number of links with the external world, at the origin of sudden shifts, abrupt changes of scenarios often accompanied by the feeling of being flooded by a succession of emotions. The “debris” or “pieces” of memories, “might even be felt in the dream with the flavor of new, never lived situations, as not belonging to our past, in that intricate blend or mix,...presenting sometimes an obscure core, as the center of a vortex, which Freud [47] has called the dream navel” [3].

In the EEG of normal brain activity, “null spikes”, a kind of black-out of the signal, separate two behavioral frames in the brain activity [6]. When coherence weakens, “the wave packet terminates with a null spike, which clears the field and opens the way for the next wave packet” [10]. In the dissipative model null spikes are represented by singularities in the phase transitions between different configurations of correlations in the attractor landscape, namely different scenarios in the brain functional activity [10]. In brain-mind visual experiences null spikes correspond to the closing a movie-like flow, clearing the field and opening another movie-like flow.

It is remarkable that pain is not experienced in dream states, where correlated domains are small. This seems to be consistent with the fact that, on the other hand, lowering of the pain threshold is obtained under the action of drugs, such as morphine, which may reduce indeed the extension of neuronal connections.

In the dream condition of quasi-closure, although the low level or absence of awareness of the environment changes, and thus of reactive feedback, the smallest of the perturbations may still induce chaoticity in brain behavior. The subject, failing to distinguish his Double from himself, in a process of reciprocal identification, enters into the role of “spectator of himself” in the brain-mind visual experiences.

V. Truthfulness and realism appearance in brain-mind visual experiences

In brain-mind visual experiences, recollections of memory states may present rearranged sequences of images generating contexts which, although new with respect to the original recording contexts, are nevertheless felt by the subject as “true” and “real”. In this section we analyze the origin of truthfulness and realism feelings in dreams and other brain-mind visual experiences.

Intentionality is a characteristic ingredient in the action-perception cycle in the brain functional activity [37], [48]. The brain response to a perceptual input is an intentional action aimed to its best to-be-in-the-world, with consequent new perceptual experience and, in a cycle, new intentional action [4], [49]. As observed by Pribram [22], [50], [51] there is always an “intention” content in the action. From his laboratory observations Freeman concludes that neuronal activity acts “as a unified whole in shaping each intentional action at each moment” [52], and in the action-perception cycle “intended actions” follow the “active perception”. We indeed operate an “active selection” among the perceptual inputs by focusing “only on those that we judge worthwhile to expend some energy for, the ones to which we attribute a “value”, which involve our “emotion”...” [3].

In a given perceptual experience, the brain eliminates unnecessary details in a process of generalization and, by abstraction, proceeds to the association of a category. A specific attractor in the attractor landscape is thus identified for such a perceptual experience. If such an attractor does not already exist (not already created in a previous experience), it is newly constructed. The whole attractor landscape is thus reshaped at any new experience, either due the inclusion of new attractors, or to the rearrangement of the intricate net of correlations among attractors. This amounts to the construction of the *meaning* of that specific perceptual experience and sometimes of the whole perceptual history of the subject. Meanings are associated with correlations dynamically generated in the landscape of the attractors during the brain perceptual history. Memory is thus not memory of information, but memory of the meaningful net of dynamical correlations shaped in its recording.

The intentional action in response to an input finds its origin and motivation in the hypotheses that the brain can formulate and that are indeed tested by the action to which they lead. Since the Double carries the time-reversed image of the brain perceptual history, the hypotheses are provided by the Double through the reconstruction of past perceptual experiences, which in [53] has been postulated to be the "mental" activity. Knowledge is constructed in this way, on the basis of confidence (truthfulness) and significance (realism) of the action and on the feeling of emotional and perceptual states in the relation with the Double [54], [55]. The "confidence" level arises from the experience of changes in perception following repeated trials, which creates the perception of the flowing of time and of causation [53], [54]. "Realism" rests on the recognition of our identity, depicted by our memory consistent with our map of values. Memory (non-oblivion) and truth indeed coincide in the ancient Greek $\alpha\lambda\eta\theta\epsilon\iota\alpha$ [3].

In brain-mind visual experiences, brain states are quasi-closed states. Their greatly reduced openness is at the origin of the lack of synchronization to a reference clock. This may allow the loss of the time ordering of the events as originally recorded in the waking state, the mixtures of memory traces and the emergence of new scenarios. Nevertheless, intentionality and meaningfulness are univocally associated with the identity of the subject, to "affectivity [which] is the primordial form of subjectivity" [56], so that they constitute a deep red thread also in brain-mind visual experiences, someway related to the 'unconscious wish' component of dreams postulated by Freud [47]. All of it happens in that frontier region where "emotion processes occur below the threshold of conscious awareness" going "from vague-unconscious to crisp-conscious" [57], [58] and to some form of control by the dreamer on the dream scenarios in the lucid dreaming phenomenon [16], [59]. The feelings of truthfulness and realism of new scenarios in brain-mind visual experiences are then due to the fact that traces of memories are actually traces of meanings, sewed together with that red thread of intentionality, thus carrying the seal of the subject identity. Perhaps this is why hidden, or more or less veiled meanings also appear in chaotic trajectories through memory traces and in their rearrangements into new scenarios, disjoint from the awake experience.

The process of feedback-adjustment-feedback in the continual matching (dialog) with the Double, within the intentional context of the action, is described by the entanglement of the A_k and $\tilde{A}_k$ modes [30], which plays the role of a "truth-evaluation" function. Observations of the A_k modes indeed depend on the $\tilde{A}_k$ modes, which thus constitute the address for the A_k modes, and vice-versa. Brain modes and mental (Double) modes cannot be separated, there is no separation between mental activity and brain activity. Truthfulness and realism in brain-mind visual experiences are thus further strengthened by the quasi-full matching between the self and its Double in the low level of openness of brain states. The transition from the subject quasi-closure states to the awake openness states is induced by the "waking up" experience restoring the awareness of the distinction between the self and its Double (*It was only a dream!...*).

In the visual scenarios, fed with "pieces" or "debris" of memories, it may even happen that, due to a profound intentional component, some feelings or contexts might "appear" (anticipated) in the brain-mind visual experiences and then re-appear in future perceptual experiences. These are not brain capabilities of 'prediction' or 'precognition'. It only means that in brain-mind visual experiences the blend of complex nets of correlations may find some natural resemblance to perceptual experiences in a future waking state.

VI. Conclusions

In the formalism of the dissipative quantum model of brain, the space of the memory states is constructed by resorting to the existence in QFT of infinitely many unitarily inequivalent representations of the canonical commutation relations. Under convenient boundary conditions, paths or trajectories through memory states are classical chaotic trajectories. As experimentally confirmed in condensed matter physics, long range correlation waves in the collective microscopic dynamics lead to macroscopic system properties. A possibility which is out of reach in other approaches solely grounded on short range interactions.

Within such a framework, we have shown that dynamical criticality consequent to the brain quasi-closeness on its environment is at the origin of brain-mind visual experiences. These may occur in brain non-ordinary states, in dreaming activity, meditation and other low openness functional activities caused, e.g., by psychoactive substances. Brain-mind visual experiences appearing as movie-like sequences of images, with more or less familiar, or more or less unexpected scenarios are thus described in terms of chaotic trajectories through the memory space.

The role of intentionality in brain functional activity and the persistency at deep level of its traces in brain low openness states has been also considered. The origin of the truthfulness and realism felt in brain-mind visual experiences appears to be the result of the entanglement between the self and its Double.

We conjecture that our conclusions might be extended also to anesthesia and to some pathological cases, such as some of the coma states.

Finally, we mention that according to the dissipative model the formation of extended neuronal correlation domains may be inhibited by a rapid succession of strong perceptual inputs. They might dominate the emotional state of the subject so to prevent to focus his attention on any of the inputs. Neuronal recruitment of signals may also be exceedingly enhanced by some chemicals. The inflation of competitive domains formed in a short time interval will then amount to lack of information "in the average", with consequent deficiency in a coherent response of the subject and in his relational activity [3].

Much theoretical and experimental work has still to be done in support of the preliminary results and analysis here presented.

APPENDIX
A SUMMARY OF THE DISSIPATIVE QUANTUM MODEL OF BRAIN FORMALISM

In order to balance the flow of the energy exchanged between the brain and its environment, one needs to double the system degrees of freedom [2]. On a formal basis this is also required in order to set up the canonical formalism, at classical and quantum level.

Let A_k ($A_k^\dagger$) and $\tilde{A}_k$ ($\tilde{A}_k^\dagger$) be the annihilation (creation) operators for the dipole wave quanta (dwq) (the Nambu-Goldstone (NG) modes) and their doubled modes, respectively. The $\tilde{A}$ system represents the bath or environment.

At the classical level the A_k and $\tilde{A}_k$ modes are associated with *damped* oscillator modes and their time-reversed image, respectively. The classical equations are

$$\begin{aligned} \ddot{u} \, + L \, \dot{u} \, + {\omega_n}^2(t) u \, &= 0, \\ \ddot{v} \, - L \, \dot{v} \, + {\omega_n}^2(t) v \, &= 0, \\ \omega_n(t) \; &= \; \omega_{0,k} \, e^{-\frac{Lt}{2n+1}}. \end{aligned} \tag{1}$$

The specific t-dependence of $\omega_n(t)$ is dictated by phenomenological reasons (fitting observed brain response to external stimuli [8], [26]). $\omega_n(t)$ approaches to the time-independent value $\omega_{0,k}$ for $n \to \infty$. L and $\omega_{0,k}$ are characteristic parameters of the system; they parameterize subjective attitudes. By using $u(t) = (1/\sqrt{2}) r_n(t) e^{-Lt/2}$, $v(t) = (1/\sqrt{2}) r_n(t) e^{Lt/2}$, the damped/amplified oscillator equations are reduced to the single parametric oscillator

$$\ddot{r}_n + \Omega_n^2(t) r_n = 0 \ ,$$

Ω_n is the common frequency:

$$\Omega_n(t) = \left[\left(\omega_n^2(t) - \frac{L^2}{4} \right) \right]^{\frac{1}{2}} . \tag{2}$$

For the mathematical formalism of the quantization procedure see [2], [28].

Let $\mathcal{N}$ be the *memory record* of the input printed in the vacuum state $|0\rangle_{\mathcal{N}}$ at $t_0 = 0$, representing the memory state at $t_0 = 0$. The code $\mathcal{N}$ is the set of the numbers $\mathcal{N}_{A_k}$ of modes A_k, for any k, condensate in $|0\rangle_{\mathcal{N}}$. $\mathcal{N}_{A_k}(t)$ is given, at each t, by [2]:

$$\mathcal{N}_{A_k}(t) \equiv {}_{\mathcal{N}}\langle 0(t)| A_k^\dagger A_k |0(t)\rangle_{\mathcal{N}} = \sinh^2\bigl(\Gamma_k t - \theta_k\bigr) \ .$$

A similar expression is obtained for the modes $\tilde{A}_k$. $|0(t)\rangle_{\mathcal{N}}$ denotes the time-evolved of $|0\rangle_{\mathcal{N}}$. Γ is the damping constant, related to the memory life-time, and θ_k fixes the code value at $t_0 = 0$. $|0\rangle_{\mathcal{N}}$ and $|0(t)\rangle_{\mathcal{N}}$ are normalized to 1. $|0(t)\rangle$ is a generalized $SU(1,1)$ squeezed coherent state, where the A and $\tilde{A}$ modes are entangled. In the infinite volume limit it is

$$\begin{aligned} &{}_{\mathcal{N}}\langle 0(t)|0\rangle_{\mathcal{N}'} \underset{V\to\infty}{\longrightarrow} 0 \quad \forall\, t \neq t_0, \ \ \forall\, \mathcal{N}, \mathcal{N}' \ , \\ &{}_{\mathcal{N}}\langle 0(t)|0(t')\rangle_{\mathcal{N}'} \underset{V\to\infty}{\longrightarrow} 0, \quad \forall\, t\,, t' \,\text{with} \quad t \neq t' \ , \ \forall\, \mathcal{N}, \mathcal{N}' \ . \end{aligned}$$

These equations hold also for $\mathcal{N} \neq \mathcal{N}'$, $t = t_0$ and $t = t'$, respectively. They show that in the infinite volume limit, the vacua with same $\mathcal{N}$ at $t \neq t'$, for any t and t', and, similarly, at equal times, but different $\mathcal{N}$s, are orthogonal (vacuum) states and their corresponding Hilbert spaces are unitarily inequivalent spaces. Time evolution therefore occurs through a sequence of *phase transition* (*criticality*). In a similar way criticality characterizes transitions (trajectories) through the memory states (a sequence of phase transitions).

The number $\left(\mathcal{N}_{A_k} - \mathcal{N}_{\tilde{A}_k}\right)$ is a constant of motion for any k. The constraint $\mathcal{N}_{A_k} - \mathcal{N}_{\tilde{A}_k} = 0$, for any k, ensures then the wanted balance of the energy flows between the system and the environment.

An infinite number of memory states may exist, each one of them labeled by a different code $\mathcal{N}$. Infinitely many vacua $|0\rangle_{\mathcal{N}}$, for all $\mathcal{N}$, are indeed independently accessible in the recording process of sequential inputs. They may coexist without destructive interference.

The collection of the full set of states (the space of the memory states) $|0\rangle_{\mathcal{N}}$, for all $\mathcal{N}$, such that the constraint $\mathcal{N}_{A_k} - \mathcal{N}_{\tilde{A}_k} = 0$, for any k, and for all $\mathcal{N}$ is satisfied, represents the "brain (ground) state".

The constraint $\mathcal{N}_{A_k} - \mathcal{N}_{\tilde{A}_k} = 0$, for all k, for all $\mathcal{N}$, expresses the so-called thermal state condition in the real time formalism of thermal field theory (thermo field dynamics (TFD)): $(A_k^\dagger A_k - \tilde{A}_k^\dagger \tilde{A}_k)|0(t)\rangle_{\mathcal{N}} = 0$, for all k [60]. The state $|0(t)\rangle_{\mathcal{N}}$ may be written as:

$$|0(t)\rangle_{\mathcal{N}} = \exp\left(-\frac{1}{2} S_A\right) |\mathcal{I}\rangle = \exp\left(-\frac{1}{2} S_{\tilde{A}}\right) |\mathcal{I}\rangle,$$

with $|\mathcal{I}\rangle \equiv \exp\left(\sum_k A_k^\dagger \tilde{A}_k^\dagger\right)|0\rangle$, $\ A_k|0\rangle = 0 = \tilde{A}_k|0\rangle$ and

$$\begin{aligned} S_A \equiv \sum_k \Big\{ & A_k^\dagger A_k \ln \sinh^2\bigl(\Gamma_k t - \theta_k\bigr) \\ & - A_k A_k^\dagger \ln \cosh^2\bigl(\Gamma_k t - \theta_k\bigr) \Big\} \end{aligned}$$

denotes the entropy operator. $S_{\tilde{A}}$ is given by a similar expression with $\tilde{A}_k$ and $\tilde{A}_k^\dagger$ replacing A_k and $A_k^\dagger$, respectively [2]. We shall simply write S for either S_A or $S_{\tilde{A}}$. We have

$$\frac{\partial}{\partial t} |0(t)\rangle_{\mathcal{N}} = - \left(\frac{1}{2} \frac{\partial S}{\partial t} \right) |0(t)\rangle_{\mathcal{N}},$$

showing that time-evolution is controlled by entropy variations, which reflects the irreversibility of time evolution characteristic of dissipative systems (breakdown of time-reversal symmetry, *the arrow of time*). The $\tilde{A}$ modes account for the noisy background. Trajectories of initial condition $\mathcal{N} = \{\mathcal{N}_{A_k}\}$ running over the space of the representations $\{|0(t)\rangle_{\mathcal{N}}\}$ can be shown to be classical chaotic trajectories [30]. Minimization of free energy at each time t plays a crucial role in the system dynamics. The free energy functional is given by

$$\mathcal{F}_A \equiv {}_{\mathcal{N}}\langle 0(t)|\Big(H_A - \frac{1}{\beta}S_A\Big)|0(t)\rangle_{\mathcal{N}}.$$

β is the (time-dependent) inverse temperature $T(t)$: $\beta(t) = 1/(k_B T(t))$; $H_A = \sum_k \hbar\Omega_k A_k^{\dagger} A_k$. The stationarity condition $d\mathcal{F} = 0$ leads to the Bose distribution for A_k at time t

$$\mathcal{N}_{A_k}(\theta, t) = \sinh^2\big(\Gamma_k t - \theta_k\big) = \frac{1}{\mathrm{e}^{\beta(t)E_k} - 1},$$

where $E_k \equiv \hbar\Omega_k$. The entropy for the complete system is given by $(S_A - S_{\tilde{A}})$ and is constant in time. The change in the energy $E_A \equiv \sum_k E_k \mathcal{N}_{A_k}$ and in the entropy is given by

$$dE_A = \sum_k E_k \dot{\mathcal{N}}_{A_k} dt = \frac{1}{\beta} d\mathcal{S}_A,$$

i.e. $d\mathcal{F}_A = dE_A - (1/\beta)d\mathcal{S}_A = 0$ (assuming quasi-equilibrium or stationary approximation, i.e. slow changes in inverse temperature, $\partial\beta/\partial t = -(1/k_B T^2)\partial T/\partial t \approx 0$). As usual heat is $dQ = (1/\beta)dS$. Thus the change in time of condensate, $\dot{\mathcal{N}}_{A_k}$, turns out into heat dissipation dQ.

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