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Dissipative many-body model and a nested operational architectonics of the brain

Comment on "Dissipation of dark energy by cortex in knowledge retrieval" by Antonio Capolupo, Walter J. Freeman and Giuseppe Vitiello

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The target review of Capolupo, Freeman and Vitiello [1] is an extremely important contribution to a current trend in neuroscience aiming to combine neurophysiological and physical concepts in order to understand the emergence of spatio-temporal patterns within brain activity by which brain constructs knowledge from multiple streams of information. Extending on previous studies of Prigogine [2] (patterns of dissipative structures and negentropy), Haken [3] (order parameters and circular causality), Kelso [4] (metastability), Freeman [5] (neurodynamics and phase transitions in brains), and Vitiello [6] (many-body field model), the authors of the target review proposed to treat brain cortices as dissipative thermodynamic systems that by homeostasis hold themselves near a critical level of activity that is far from equilibrium and which is characterized by the expenditure of energy (reduction of entropy) to facilitate the emergence of patterns responsible for knowledge creation [1]. The authors further suggested that the meanings, which subjectively are experienced as thoughts or perceptions can best be described objectively as created and carried by large fields of neural activity: "The contents of such fields are constructed from the fragments of information that are imported by sensory neurons and stored by changes in the synaptic linkages among the cortical neurons. It is the dynamics of the populations in each sensory cortex that subsequently organizes the microscopic fragments into meaningful knowledge by creating macroscopic vector fields of activity that organize hundreds of millions of neurons and trillions of synapses" [1].

Such theoretical conceptualization is compatible with and could be enriched by the adoption of the brain Operational Architectonics (OA) framework centered around the notion of operation [7-9]. Understanding of the operation as a finite process lasting in time and considering its combinatorial nature (increasing complexity) seems especially well suited for understanding and studying the neurodynamic mechanisms of how subjective thoughts emerge from the brain [9]. In short, the OA theory claims [9] that *local fields* of transient functional neuronal assemblies are equivalent to elemental operations which can be conscious (phenomenal). Such simple operations are reflected in the local electrical brain fields (EEG) in the form of *quasi-stationary segments*, which can be conceptualized as standing waves within a 3D volume [9]. These segments are temporally limited in time, in the sense that they have a finite lifetime which is marked by so-called *rapid transitive periods* (RTPs). In terms of many-body field model, local fields (indexed by segments) condense and evaporate continually, with power-law distributions of duration and diameter. According to authors of the target review [1] such segments could be treated as the result of a space-time non-homogeneous boson condensation process [6,10] and as neural avalanches by which criticality is maintained [11]. During each RTP, the peak in entropy is followed by reversal (a so-called biphasic transient), leading the local system (neuronal assembly) to a state that differs from the previous one [9]. As observed and predicted by the many-body model, the RTP could be the effect of localized (non-homogeneous) boson condensation [1]. The abrupt change require an increase in dissipation of free energy as heat and therefore in temperature (entropy increase); but the phase transition itself begins with cooling as predicted by the dissipative model (negentropy). Our data have shown that RTPs in local EEGs are reliably and consistently associated with changes in the phenomenal (subjective) content during both spontaneous (stimulus independent) and induced (stimulus dependent) experimental conditions (for the review see [12]).

As a matter of fact, the functioning of brain undergoes a continuous sequence of transitions in infinitely many local neuronal assemblies' states whose existence is allowed by OA [9]. Again, the dissipative many-body model turns out to be very helpful in depicting such brain multivariability – the feature that a traditional non-equilibrium thermodynamic approach cannot explain. As we have observed in our experiments the same neural mechanism which we have discussed above repeats at this macroscopic level, when the percepts from all of the sensory cortices are combined into concepts, gestalts, and intentional actions. According to the OA theory, this process requires temporally coordinated operations (equivalent of local bioelectrical fields) of many neural assemblies, which selectively emerge from the entire brain [9]. Indeed, to have an experience of any phenomenal object, several features/elements of that object (shape, color, smell, texture, etc.) should be spatially and temporally integrated. In agreement with the OA theory, different (simple) phenomenal features are presented in the brain by local fields/operations generated by different transient neuronal assemblies and temporal synchronization of these local fields/operations produces complex brain operations [7]. As a result, metastable brain states – *operational modules* (OMs) – emerge that accompany the realization of complex brain operations, whereas each of them is instantiated by the particular volumetric spatial-temporal pattern in the electromagnetic field [7-9,12]. Thus, within the OA, any complex operation or operational act has internal structure where each element in its turn also has its own internal structure and so on, all the way down to the simplest elemental operations. Such architecture has a clear *nested hierarchy* and thus could serve as the needed ingredient of brain organization that allows conscious thoughts/images of different complexity to be expressed in the brain, in agreement with the macroscopic manifestation of the underlying coherent many-body dynamics, namely in terms of the scale-free property of coherent states discussed in the target review [1].

OMs, similarly to the quasi-stationary segments, change abruptly though a RTP, which, in a similar way to mesoscopic processes, could be characterized by the boson transformations (boson transformations are the ones by which coherent states are constructed [13]). During the RTP, a *set* of local bioelectrical fields (which constitute an OM) produced by transient neuronal assemblies that are located in several brain areas, rapidly loses functional couplings with one another and establishes new couplings within another set of local bioelectric fields; thus demarcating a new OM in the volumetric operational space-time continuum of the brain [9]. In other words and compatibly to dissipative many-body model [1], during a critical transition point the macroscopic manifestation (OM) is essentially based on a kind of abstraction from the original low-level (neuronal assemblies with their local electromagnetic fields), with all but those low-level features preserved (operations of neuronal assemblies) that now determine the novel macroscopic observable (OM) and presenting in fact a different biophysical state [9].

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