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Mind the Physics: Physics of Mind

Comment on "Physics of mind: experimental confirmations of theoretical predictions" by Felix Schoeller, Leonid Perlovsky, and Dmitry Arseniev

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The target paper of Schoeller, Perlovsky, and Arseniev [1] is an essential and timely contribution to a current shift of focus in neuroscience aiming to merge neurophysiological, psychological and physical principles in order to build the foundation for the physics of mind. Extending on previous work of Perlovsky et al [2-4] and Badre [5], the authors of the target paper present interesting mathematical models of several basic principles of the physics of mind, such as perception and cognition, concepts and emotions, instincts and learning [1]. Their conceptualization helps to clarify the distinction between conscious and unconscious aspects of mind that is often neglected and further provide a clear description of the mental hierarchy, which extends from physical objects in the physical world to abstract ideas in the mental/subjective realm [1].

While we agree that identification of a few fundamental principles is a first step toward developing the physics of the mind, and we concur with the selection of those principles in the target review paper, we think that the theory of the physics of mind would much benefit from considering also the most basic principles that are *common* for the physics/matter/brain and the mind/subjectivity/cognition. In this respect, such basic principles as time and space [6], as well as criticality, self-organization, and emergence [7] seem to be the most interesting. Indeed, as we have observed in detail somewhere [6], neurons in multiple brain parts oscillate at various frequencies (temporal scales) forming very dynamic and transient neuronal assemblies. Every time a person attends, perceives, learns, memorizes, thinks, imagines, plans, and acts, the operations produced by these neuronal assemblies are selectively coupled or 'bound' together into a *spatio-temporal* operational structures [8]. "During this dynamic self-assembling process different neuronal assemblies *spatially* located in distant parts of the brain engage and disengage in *time*, much like different musical pieces in a symphony, paralleling the emergence and vanishing of different perceptual features, objects, full scenes, and even abstract ideas in a conscious mind" (page 196 in [6]).

In physics, the principles of '*phase space transitions*', '*spatial–temporal separability principle*', '*criticality*', '*self-organization*', and '*emergence*' are very powerful tools for interpreting complex systems phenomena involving multiple spatial and temporal scales [7]. They help to describe in detail the emergence of many levels of new collective behaviors within complex systems (including brain-mind), where every level is presented with its distinct macroscopic (in relation to immediately lower level) physics, organization, and laws within a new spatio-temporal pattern of reality [6,7]. We have shown that all these principles are functioning in both realms – physical (brain) and subjective (mind) [6-8], and concluded that both, the phenomenal/subjective world and material/neurophysiological world have indeed a complementary functional structures and dynamics that are compatible with physical understanding of any complex system [7].

Such theoretical conceptualizations were formulated within the brain Operational Architectonics (OA) framework that is centered around the notion of operation [6-8]. The notion of operation, that is a finite process lasting in time and having the combinatorial nature (increasing complexity), is especially well suited for understanding and studying the neurodynamic mechanisms behind subjectivity [9]. Briefly, the OA theory states [6-8] that *elemental operations* responsible for simple qualia or features are equivalent to *local fields* of transient functional neuronal assemblies. The best way to measure such local fields is using electroencephalogram (EEG) [10], where they are presented in the form of so-called *quasi-stationary segments*, that can be usefully conceptualized as standing waves within a 3D volume [6]. These segments are temporally framed by rapid transitive periods (RTPs) and thus have a finite lifetime. But to have a complete experience of *complex* concepts, gestalts, and intentional actions, several simple operations (responsible for qualia/features/elements) should be spatially and temporally integrated within more *complex operations*. The OA theory proposes [6-8] that such spatio-temporal coupling of simple operations into a complex ones is achieved by means of temporal synchronization of the local fields (EEG quasi-stationary segments) produced by spatially distributed neuronal assemblies. As a result, metastable[1] brain states – *operational modules* (OMs) – emerge that accompany the realization of *complex brain operations* such as images, concepts, gestalts, and intentional actions [6-9]. Thus, according to the OA theory, any complex operation or operational act has internal functional structure where every element of that structure in its turn also has its own internal functional structure, and so on, all the way down to the

[1] Metastability in the brain refers to coexistence of complementary tendencies of cooperative integration and autonomous fragmentation among multiple distributed neuronal assemblies [6,7,12].

simplest elemental operations. OMs, similarly to the simple operations, change abruptly though a RTP. Such operational architecture of the brain electromagnetic field has a clear nested hierarchy[2] that is compatible (*isomorphic*) with the structure of the mind in a sense that it allows conscious percepts/images/thoughts/concepts of different complexity to be expressed [9].

We have shown empirically that RTPs at all levels of brain operational architectonics (from local fields expressed as EEG quasi-stationary segments to OMs expressed as coupled EEG quasi-stationary segments) reliably and consistently marked the changes in the phenomenal (subjective) content during both spontaneous (stimulus independent) and induced (stimulus dependent) experimental conditions (see for the review [11]). Furthermore, our research has shown, that lower-level OMs (the ones that by themselves are the result of synchronized operations produced by distributed transitive neuronal assemblies) can further combine diversely with one another, both, within the same, and across different temporal scales, to form a more abstract higher-level OMs in a nested hierarchy, thus constituting more integrated experiences or abstract concepts [6-11].

Analysis of the topology of functional and dynamic brain field modules (OMs) has shown that it is associated with rich nonlinear dynamical behavior: temporal scale separation due to fast intra-modular processes and slow inter-modular processes, as well as high dynamical complexity due to the coexistence of both segregated and integrated activities in the form of metastability [12]. Practically, this topology can be assessed in terms of projections and mappings that take place on abstract structures, equipped with different dimensions, curvatures and energetic constraints, and computationally and mathematically modeled using topodynamic descriptions (for example the Borsuk–Ulam theorem) [13].

Summarizing, briefly described principles of OA framework such as ‘phase space transitions’, ‘spatial–temporal separability principle’, ‘criticality’, ‘self-organization’, and ‘emergence’ that are common in physics, brain and mind [7] could considerably enrich the Physics of Mind theory proposed by the authors of target paper [1].

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[2] A nested hierarchy is a well defined (super) set which contains and consists of other specified (sub)sets at the lower levels [6,7]. The concept of nesting is well exemplified visually in Russian matryoshka nested dolls. While Matryoshka represents a nested hierarchy where each level contains only one object – there is only one doll of each size, all the way down – a generalized nested hierarchy (as in the brain) allows for multiple objects within levels but with each object having only one parent at each level.

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