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## **PHENOMENOLOGICAL ARCHITECTURE OF A MIND AND OPERATIONAL ARCHITECTONICS OF THE BRAIN: THE UNIFIED METASTABLE CONTINUUM**

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In our contribution we will observe phenomenal architecture of a mind and operational architectonics of the brain and will show their intimate connectedness within a single integrated metastable continuum. The notion of operation of different complexity is the fundamental and central one in bridging the gap between brain and mind: it is precisely by means of this notion that it is possible to identify what at the same time belongs to the phenomenal conscious level and to the neurophysiological level of brain activity organization, and what mediates between them. Implications for linguistic semantics, self-organized distributed computing algorithms, artificial machine consciousness, and diagnosis of dynamic brain diseases will be discussed briefly.

*Keywords:* EEG, brain operation; functional isomorphism; dynamical neuroscience; consciousness

### **1. Introduction**

Modern neuroscience, which is based on the conceptual resources of dynamical system theory and the methodological principles of complex system science, began about three decades ago, when Walter Freeman, the giant of 20th century neuroscience and one of the architects of the dynamical system framework in neuroscience, has produced a steady flow of studies of the dynamic principles of wave patterns, attractors, bifurcations, and critical phase transitions in brains.<sup>1-10</sup> These and some other studies (for the review see Ref. 11) have yielded numerous relevant findings, which help to establish a basis for formulating the relation between neural and mental events on a common basis.

Freeman's classic experiments<sup>12,13</sup> measuring electroencephalographic (EEG) activity within the olfactory bulb of rabbits and cats demonstrated that information concerning the identity of a particular odour was not carried by the temporal shape of any particular EEG wave, but by the spatial pattern of EEG amplitude across the entire surface of the olfactory bulb. These data lead to building a model of a hierarchy of 'neural masses',<sup>14</sup> which describes increasing complexity of

structure and dynamical behavior of brain process.<sup>15,16</sup> The basic building blocks of this model are K-sets – topological specifications of the hierarchy of connectivity in neuron populations in the 6-layer cortex. The K0 set describes the dynamics of a cortical micro-column (~10 thousand neurons). A KI set includes K0 sets from a given cortical layer with specific properties. Similarly, KII includes KI sets from different populations (i.e., excitatory and inhibitory ones). KIII subsumes several KII sets modeling various cortical areas and KIV already covers many cortical areas across the hemisphere. The highest level of neocortex hierarchy is described by KV.

Neurophysiological observations made by Freeman over several decades contribute to the idea that brains are essentially non-equilibrium systems which do not come to a steady state even for a fraction of second. Brains constantly change, using dynamical patterns of activation in their operation to present memories, concepts, and actions.<sup>17</sup>

Indeed, as it is shown in the recent review by Bressler (see Ref. 18), cortex dynamically generates global neuro-cognitive states from interactions among its areas using local and remote patterning within the cortex, whereas each cortical area is a relatively autonomous entity and has a unique pattern of interconnectivity with other cortical areas. These considerations suggest that brain integrative functions are the result of competition of complementary tendencies of cooperative integration and autonomous fragmentation among many distributed areas.<sup>19,20</sup> The interplay of these two tendencies (autonomy and integration) constitutes the metastable regime of brain functioning,<sup>21</sup> whereas local (autonomous) and global (integrated) processes coexist as a complementary pair, not as conflicting principles.<sup>22</sup>

Following Freeman's model of hierarchy of 'neural masses' and Kelso's metastable principle of brain functioning, we would like to propose in this article that mind phenomenological architecture and brain operational architectonics represent the complementary aspects of the same unified metastable continuum. We will show that metastability introduces the hierarchical coupling between the brain and mind while simultaneously allowing them to retain their individuality.

## **2. Mind Phenomenological Architecture**

There have been numerous attempts to describe the phenomenological properties of mind (for the review, see Ref. 23). Literally, phenomenology refers to "phenomena": appearances of things, or things as they appear in our experience, or the ways we experience things.<sup>24</sup> William James was the first scientist, who did the most fecund and deep (even though metaphorical at

places) phenomenological description of the structure of human consciousness in his ‘Stream of Thought’ essay.<sup>25</sup> His main observation that consciousness is dynamic where it continually moves from one relatively stable thought to another relatively stable thought is currently being developed by various authors.<sup>26-29</sup>

The most recent and the most detailed analysis of phenomenological architecture of consciousness has been done by neuroscientist Antti Revonsuo in his book ‘Inner Presence’.<sup>30</sup> In the present contribution we will use his description of phenomenal world. Although a full account of the phenomenal (virtual) world is beyond the scope of this article, we will illustrate this world by describing the most important features of it (those which are required for instantiation of phenomenal consciousness). However, before we will go on to elaborate this subject, it might be useful to clarify the definition of phenomenal consciousness.

It is a common place that the term “consciousness” has a number of different connotations. We take a stand that phenomenal consciousness refers to the level of organization in the brain<sup>30</sup> that captures all immediate and undeniable facts (phenomena) of subjective experiences (concerning hearing, seeing, touching, feeling, embodiment, moving, and thinking) that present to any person right now and right here. This subjective phenomenal (virtual) world consists of the fine hierarchical architecture (as it described in Ref. 30), which we will describe below.

### ***2.1. Properties of phenomenal consciousness (subjective virtual experience)***

The following is a brief description of the properties of phenomenal consciousness, which we borrow from Antti Revonsuo (detailed description and discussion see in Ref. 30):

- The phenomenal patterns, objects, and persons are never experienced as representations, – they are *transparent phenomenal states*, – we just ‘look’ through them as if they are the entities of the real world itself and they are immediately present and directly perceived by us. Thus, the phenomenal patterns, objects, and persons are transparent surrogates (or realistic mental, virtual simulations) of physical patterns, objects, and persons that they are representative of.
- The phenomenal features of any complexity (either patterns or even objects) involve *temporal* aspect: they are what is happening right now. They are present during some subjective temporal window; they are constituents of the *states of affairs* in which they occur. This state did not exist before; it endures across time and then disappears. In this sense they are both the *act (process)* and the *object (thing)* at the same time.

- The phenomenal level is capable of realizing an astronomical number of different phenomenal qualities, patterns, and objects. It is thus characterized by enormous *multivariability* and *combinatorial* capacity.
- Neither the phenomenal level as a whole nor any of its parts are somehow “perceived” by themselves. That is, they do not serve as objects of perception, instead they are intrinsically *self-presenting* (meaning that they do not need to be present to anyone).
- Phenomenal experiences constructed and updated extremely rapidly. For example, we are able of recognizing and understanding complex images of scenery flashed briefly around only 100 ms. In everyday life if we turn our eyes or head very rapidly, our phenomenal experience is instantly updated to accommodate the new perspective. Thus, the *temporal resolution* of phenomenal consciousness should be very high (it can completely reorganize itself 3 to 10 times per second).
- The phenomenal field tends to retain a coherent *multisensory* coordination and organization. Shape, color, location, sound, touch, and other sensory features defining a phenomenal object are perfectly coordinated in time and unified in space (so-called *phenomenal space-time*, PST).
- Subject that experiences phenomenal consciousness always feels directly present in the center of an externalized multimodal perceptual reality, the virtual world. However, this phenomenal world is in online resonance with external physical world (*external physical space-time*, EPST), which can causally modulate the structure of phenomenal experience through multiple sensory systems.
- The phenomenal world has immensely complex structure and fine hierarchical organization:
  - *Phenomenal space* – can be described as a 3D, centered, bounded volume (coordinate system) in which each location has the capability to realize a characteristic variety of self-presenting, qualitative features and thereby to construct transparent surrogates or virtual objects. Importantly, the phenomenal fields of different modalities (for example, visual and auditory) are spatially and temporally integrated, so that the different features belonging to the same object are realized in the same location and time (PTS).
  - *Phenomenal features (qualities)* – can be described as simple phenomenal contents (sounds, colors, touches, emotions, tastes, smells, and so on). They are the identity, the “stuff” that experiences per se are made of.

- *Patterns of qualities* – can be described as carefully organized qualities to make up the patterns of experiences.
- *Phenomenal objects* (with their Gestalt and semantic windows) – can be described as complex patterns of qualities which are spatially extended and bounded with each other to form a unified item (Gestalt window) with a particular meaningful categorization (semantic window) immediately present for the subject. Any such object can be further organized hierarchically into parts (or features) of a more complex object, or on the contrary be decomposed to its parts, all of each can be realized as separate simpler virtual objects independent of each other and with their own Gestalt and semantic windows.
- *Phenomenal map* – can be described as a geographical orientation which gives understanding where is the currently present place located in relation to other places not currently present.
- Phenomenal qualities, their patterns, and full-fledged objects should be *simultaneously present* within the phenomenal space in order to establish relations (spatial and meaningful) between each other. The phenomenal objects that are not actualized at the moment (being preattentive or not in the focus of awareness) can be described as raw (or candidate) objects that possess no Gestalt and semantic windows, but rather some phenomenal undefined “stuff”.
- Attention guides the actualization of full-fledged virtual, phenomenal objects on a one at a time basis, moving serially from one phenomenal pattern to another. This process gives rise to *stream of consciousness*.

Currently in neuroscience it is agreed that the further understanding of phenomenal consciousness will obviously rely upon the view according to which phenomenal consciousness is grounded to material carrier processes that take place in the brain.<sup>17,31-36</sup> It is even suggested that phenomenal consciousness is a higher level of biological organization in the brain.<sup>30</sup>

There are several theoretical frameworks that try to integrate brain and mind.<sup>17,31,32,34,37-46</sup> However, practically all of them do not take phenomenal consciousness of mind seriously and in the best case they try to explain consciousness through its neural correlates,<sup>47-49</sup> despite the fact that ‘correlation’ is too weak relation to be definitive in any explanation.<sup>30</sup> Another drawback of such theories is the fact that they postulate many entities which could not be measured in practice easily, and their experimental exploration stands as an important challenge.<sup>50</sup> Furthermore, they

usually do not consider dynamical and compositional nature of phenomenal world and disagree about relevant for the consciousness level of brain organization.

Among the different methodological strategies adopted to study and describe the brain-mind complexity and its expression in the complexity of brain activity, the so-called “*Operational Architectonics*” (OA) framework<sup>35,51-55</sup> has received attention, especially due to its good compromise between simplicity, neurophysiologic accuracy, and cognitive plausibility. Even though OA framework has many similarities with other theoretical conceptualizations, it is quite distant from them in the core principles (for the detailed analysis, see Ref. 54). Additionally, in the context of OA framework, there is a range of methodological tools which enable in practice to measure the postulated entities of the theory.<sup>55</sup>

### 3. Brain Operational Architectonics

Previously (see Ref. 35, 54), we have already discussed that phenomenological constructs of mind should be related to the dynamic operations of large-scale brain networks. It seems that this view is supported by most researchers working in the field.<sup>17,20,31-34,56-58</sup> Indeed, brain generates a highly structured and dynamic extracellular electric field in spatial and temporal domains<sup>34</sup> and over a range of frequencies.<sup>59</sup> This field exists within brain *internal physical space-time* (IPST) and is best captured by the electroencephalogram (EEG) measurement.<sup>60</sup> Studies indicate that EEG is a highly organized macro-level electrophysiological phenomenon in the brain, which captures the operations of large-scale cortical networks and which is remarkably correlated with both behavior and cognition.<sup>3,35,60,61,63</sup>

OA theory explores the temporal structure of information flow and the inter-area interactions within a network of dynamical, transient, and functional neuronal assemblies (which activity is “hidden” in the complex nonstationary structure of EEG signal; see Ref. 62) by examining topographic sharp transition processes (on the millisecond scale) in the EEG.<sup>35,51-55</sup> The detailed analysis of the complex structure of hierarchical architecture of EEG reveals the particular *operational space-time* (OST) which literally resides within the IPST and is isomorphic to the PST (phenomenal space-time, see above) and, as we propose, constitutes the neurophysiological basis of mind phenomenal architecture.<sup>35,54</sup> Below we will illustrate this functional isomorphism by relating the EEG structure with the structure of phenomenal consciousness as it is described in the previous section. By definition, two systems that are functionally isomorphic are, in virtue of this fact, different realizations of the same kind (for detailed discussion see Ref. 64). In other words, two functionally isomorphic different systems bring about the same function that defines

the kind. Functional isomorphism is ‘visible’ only at the level in which similarities between otherwise disparate realizations can be seen, and so it is at this level that we must look for laws ranging over them.

According to the OA theory, whenever any pattern of phenomenality (including reflective thought) is instantiated, there is neurophysiological pattern of appropriate kind that corresponds to it.<sup>65</sup> These patterns (expressed as the virtual *operational modules*) are brought to existence by joint operations of many functional and transient neuronal assemblies in the brain. The notion of “*operation*”, then, is the fundamental and central one in bridging the gap between brain and mind: it is precisely by means of this notion that it is possible to identify what at the same time belongs to the phenomenal conscious level and to the neurophysiological level of brain activity organization, and what mediates between them.<sup>35,52</sup> Both, the material neurophysiological organization that characterizes brain and the informational order that characterizes mind necessarily involve such events as operations at their cores.

“*Operation*” stands for the *process* or series of *acts/functions* that applied to an operand, yield a transform, and are limited in time;<sup>66</sup> and can be broadly defined as the state of being in effect.<sup>67</sup> This is so regardless of whether this process is conceptual/phenomenal or physical/biological. In fact, everything what can be represented by a process is an operation. This provides a basis for discussion of the relative *complexity* of operations, where there is a more complex operation/operational act that subsumes the simpler ones.<sup>35,52</sup> Understanding of the operation as a process and considering its combinatorial nature, seems especially well suited for describing and studying the mechanisms of how information about the objective physical entities of the external world can be integrated, and how unified/coherent phenomenal objects or thoughts can be presented in the internal subjective world by means of entities of distributed neuronal brain assemblies.

Below we will analyse the main properties of brain operational architectonics, describe their relation/isomorphism with the phenomenal properties of mind, and indicate how they can be practically measured.

### ***3.1. Properties of brain operational architectonics***

- Brain operational architectonics has inherently complex and fine hierarchical organization which is isomorphic to mind phenomenal architecture<sup>35,52</sup>:
  - The starting point is to specify the functionality of the system at most basic, low level. The electrical field at any point in the brain supposed to be a superposition

of the induced fields from all of the neurons in the vicinity which is superimposed on the fields generated by ion movement; and it depends on the firing frequency, geometry, and the dielectric properties of neurons and the connections among them.<sup>34</sup> For neurons that would be arranged randomly, their induced fields will tend to sum to zero; however, the laminar organization of the brain neocortex (and other) structures with parallel and re-entrant loops is responsible for the 3D, bounded and structured volume (coordinate system) in which each location (neuron) has the potential capacity to realize and process some attribute of the physical object or scene. The fact that neurons are able to synchronize their subthreshold oscillations (*elemental operations*), leading to fixed states of an overall neuronal assembly and to a rapid transition between such states, has been shown experimentally and in computational models.<sup>68,69</sup>

Considering that functional isomorphism requires the functional coupling (connectivity) between component entities of the system, their functional organizations and their behaviors (for further detail, see Ref. 53 and 54), one may see that the neuropil of spatially and temporally organized neurons (IPST), which produce highly structured electrical field in the brain, is isomorphic with the phenomenal space-time (PST; see Section 2.1.).

- The synchronization of operations executed by each neuron forms *transient functional neuronal assemblies*.<sup>70-72</sup> Neuronal assembly has defined as distributed group of neurons or neural masses for which correlated activity persists over substantial time interval.<sup>60</sup> It is suggested that these time intervals are required to accomplish *basic operations*<sup>57,73-75</sup> on presenting simple phenomenal contents, such as sounds, colors, smells, and so on.<sup>35</sup> Here we should stress that in the activity of neuronal assemblies, additionally to phenomenal, also the physical (non-mental) operations are reflected.

The activity of these neuronal assemblies is ‘hidden’ in the complex *nonstationary structure* of EEG signal.<sup>35,53,62</sup> Precisely, at the EEG level the activity of neuronal assemblies is reflected in defined periods (segments) of quasi-stationarity within different frequency ranges (for reviews, see Ref. 35, 51, 52, 76). Indeed, EEG waves recorded from the scalp are integrated excitatory and inhibitory post-synaptic potentials of neuronal membranes. Since they reflect extracellular currents caused by synchronized neural activity within the local brain volume,<sup>58</sup> the EEG signal within quasi-stationary segments is the envelope



of the probability of non-random coherence (so-called a ‘common mode’ or a ‘wave packet’,<sup>77</sup> in the neuronal masses near to the recording electrode. The segments of quasi-stationarity in EEG can be obtained using an adaptive segmentation approach.<sup>35,51,55,61,76</sup>

One may see that operations of transient neuronal assemblies are functionally isomorphic with phenomenal features (qualities) (see Section 2.1.). It has been shown that a set of ‘feature extracting neural assemblies’ decompose in parallel the complex stimulus into so-called fragments of sensation.<sup>58</sup>

- Different brain operations presenting different qualities and executed by different neuronal assemblies tend to be synchronized if they happened to be at the same time and related to the same perceptual/cognitive object or act.<sup>35,51,54</sup> As a result, the metastable brain states are emerged which accompany the realization of brain *complex operations*. These metastable brain states, which we call *Operational Modules* (OM), constitute the new (higher) level of abstractness (OST,<sup>35,52,54</sup>). OMs (being by themselves the result of synchronized operations going on in distributed brain structures) could be operationally synchronized between each other on new time scale, and thus forming more abstract and more complex OM, which constitute new integrated experience.<sup>35,52,54</sup> We have proposed that each of the new OMs is not just a sum of simpler OMs, but rather is most naturally a union of abstractions about simpler OMs.<sup>35,52,54</sup> At the same time, the complex OMs could be decomposed to simpler ones and all the way down until the basic operations.

At the EEG level, the constancy and continuous existence of OMs persist across a sequence of discrete and concatenated segments of stabilized local EEG activities that underlie them. In this sense the OMs are *metastable*: intrinsic differences in the activity between neuronal assemblies which constitute OM are sufficiently large and each neuronal assembly does its own job, while still retaining a tendency to be coordinated together. Simultaneous existence of autonomous and integrated tendencies signifies the metastable principle of brain functioning.<sup>20,21,51,53,78</sup> In practice, the structural (or operational) synchrony measure enables researchers to detect periods (OMs) with a more or less generalized stabilization of quasi-stationary segments registered in the local EEGs.<sup>35,51,55,61,76</sup> For experimental support see Ref. 80-83.

One may see that the level of OMs is functionally isomorphic with the organized patterns of qualities and with the full-fledged phenomenal objects (see Section 2.1.). Operational synchrony processes among different neuronal assemblies, located in different brain regions, serve to bind spatially dispersed phenomenal features (bases of sensations) of a multimodal stimulus or objects into the integrated and unified patterns of qualities and further into the phenomenal objects<sup>35,52</sup> with unique Gestalt and semantic windows.<sup>30</sup> For the experimental support see Ref. 82.

- The metastable regime of brain functioning allows simultaneous presence of transient neuronal assemblies as autonomous entities and OMs of different complexity (synchronized neuronal assemblies) within the same IPST of the brain. Because of the composite polyphonic character of the electrical (EEG) brain field, this field may be presented as a mixture of many time-scale processes (individual frequency components).<sup>59,60,79</sup> Consequently, a large number of functionally distinct OMs can *co-exist simultaneously* on different frequencies and even between them (for experimental support, see Ref. 61, 80, and 81).

One may see that these peculiarities of OST are functionally isomorphic with analogous features of PST (see Section 2.1.) where phenomenal features, their patterns and full-fledged objects are simultaneously present within the phenomenal space.

- Attention guides the construction or decomposition of complex OMs on a one at a time basis *moving serially* from one OM to another.<sup>35,52</sup> Attention could impose an operational synchrony threshold modulation on neural assemblies that need to participate in the execution of a particular mental, cognitive, or behavioral act and thereby permits rapid synchronization of selected operations within the same OM. In this way, attention could act like a dynamic filter that accomplishes the rapid required (un)grouping and temporal (un)binding of neural assemblies operations.<sup>84</sup>

One may see that proposed role of attention is functionally isomorphic with the analogous role of attention in the construction of virtual, phenomenal objects in a serial way. This process gives rise to *stream of consciousness* (see Section 2.1.). As it was discussed in our previous work,<sup>51</sup> the succession of discrete and relatively stable OMs which present cognitive acts, phenomenal objects, or

thoughts separated by rapid transitive processes (abrupt changes of OMs, cognitive acts, or thoughts). For the similar view see Ref. 17, 85.

- Transient neuronal assemblies and OMs (of any complexity) are not experienced from the first-point of view as representations, – they are *transparent brain local and global operational states* that directly present phenomenal patterns, objects, and persons (see Section 2.1.), which in their own turn are *transparent virtual surrogates* of physical patterns, objects, and persons that they are representative of.<sup>30</sup> For a similar view see Ref. 17.
- Each transient neuronal assembly and OM (of any complexity) exists in their own OST (*operational space-time*).<sup>35,54</sup> OST is the abstract space and time ‘constructed’ by the brain each time a particular OM emerges. The continuity of OMs exists as long as the set of spatially distributed neuronal assemblies keeps synchronicity between their discrete operations.<sup>54</sup> We argue that at the phenomenological level, a continuity of consciousness would be experienced. In this context, transient neuronal assemblies and OMs are both the acts (*processes*) and the objects (*things*) at the same time. These features of the brain operational architectonics are functionally isomorphic with the mind phenomenal architecture’s features, whereas phenomenal patterns and full-fledged objects are also both the processes and things<sup>30</sup> (see Section 2.1.).
- Operational architectonics of the brain is characterized by enormous *multivariability* and *combinatorial* capacity.<sup>53</sup> It is capable of realizing practically infinite hierarchy of OMs. On the top of such infinite hierarchy there should be the maximal OM presenting and abstracting all the ‘underneath’ OMs for a given moment of time. These features of brain operational architectonics are functionally isomorphic with analogous features of phenomenal subjective experience (see Section 2.1.). Here it is worth to note that if simple OMs presenting component elements of complex object or scene get operationally synchronized into a new complex OM, then the complex object or scene is experienced subjectively, but there are no experiences about component elements, since component simple OMs are not presented anymore.<sup>35,52</sup>
- It was demonstrated experimentally that the construction of OM and their updates/transitions appear extremely *abruptly*, when the set of brain areas which constitute an OM rapidly loses functional couplings with each other and establishes new couplings within another set of brain areas, thus demarcating a new OM in the IPST continuum of the brain.<sup>80,83</sup> Hence, *temporal resolution* of operational architecture is very

high. The same is true for the temporal resolution of phenomenal architecture of mind<sup>30</sup> (see Section 2.1.).

- Operational synchrony process going on among different neuronal assemblies (located in distant brain regions) serves to *bind* spatially dispersed presentations of a multimodal stimulus and/or objects into an integrated and *unified percept* or OM.<sup>52</sup> Indeed, using a robust illusion known as the ‘McGurk effect’,<sup>86</sup> it has been shown that the crossmodal binding in the human brain is achieved through the process of operational synchrony between modality-specific and non-specific cortical areas, rather than in so-called convergence regions of the cortex.<sup>82</sup> It is interesting that the subjects who did not experience subjectively the McGurk illusion (meaning that they were lack of conscious multisensory integration) in contrast demonstrated significant uncoupling (negative values of the operational synchrony) of particular brain areas (for a discussion see Ref. 82). These processes are functionally isomorphic with the multisensory coordination and integration taking place in the phenomenal architecture of a mind (see Section 2.1.).

The description of both architectures of the phenomenal consciousness (previous Section) and operational brain functioning (current Section) clearly shows that they are isomorphic to each other through the shared very notion of operation. Summarizing, we can conclude that PST literally resides within the confines of the brain, meaning that it is realized in the IPST inside the brain. However, to understand how the PST is actually realized in the brain, we need to introduce the intermediate level of description which would bridge the biological (physical) and phenomenal (mental) levels of brain organization and tie these two levels ontologically together. The electrophysiological and bioelectrical activity of the brain uses the IPST to form the new level of abstractness – OST, which serves as a transparent surrogate of even higher level of abstractness – PST (which is described in the previous Section). PST, in its own turn, also serves as a transparent surrogate of the EPST of the world. If this happens to be correct, then the phenomenal architecture of mind can, in fact, be measured by the brain operational space-time (OST) architectonics. In this context brain operational architectonics and mind phenomenal architecture are the complementary aspects of the same metastable continuum.

Metastability introduces four important characteristics that are described in recent article by Kelso and Tognoli<sup>19</sup> and should be considered by any theoretical framework, which uses principle of metastability. First, metastability accommodates heterogeneous elements: in the context of the present contribution, it is brain operational architectonics and mind phenomenal architecture with their intrinsic dynamics. Second, metastability does not require a

disengagement mechanism when the system has to switch to another state: indeed, when there is any change in the phenomenology we observe changes in the electrophysiology.<sup>35,52-54</sup> Third, metastability allows the system to flexibly browse through a set of possibilities (tendencies of the system) rather than adopting a single ‘point of view’: this is the case for both physiological and phenomenological levels of brain organization.<sup>30</sup> Fourth, the metastable system favors no extremes; in other words, metastability of a system is an expression of the full complexity of this system: indeed, mind-brain continuum is expressed through the entangled complementary structures of electrophysiological and phenomenological phenomena in the brain.<sup>35,53</sup>

The approach formulated in this paper relates to *Biological Realism* (a variety of scientific realism) that directly study the interface between neural and mental phenomena.<sup>30</sup> According to this philosophical view (a) consciousness exists in its own right, (b) it is natural phenomenon, (c) it has some causal powers distinct from purely neurophysiological (non-phenomenal) realm, and (d) it ontologically depends on brain – the spatial location of the mental phenomenon in the natural world. If phenomenal mind is a biological level of brain organization,<sup>30</sup> then it follows that the *structure* of neurobiological phenomena (at some higher level of its organization, such as EEG) corresponds to (or is functionally isomorphic with) the *structure* of the phenomenal level itself.<sup>51,65</sup> Hence, the presented approach is physiologically and theoretically plausible and leads to several interesting implications for linguistic semantics, self-organized distributed computing algorithms, artificial machine consciousness, and diagnosis of dynamic brain diseases.

#### **4. Implications of Brain-Mind Metastable Continuum Framework**

Presented in this contribution theory enables researchers to identify and eventually to start experimentally to study the parallels between phenomenal and brain levels within the same theoretical and methodological framework. To do so, the explanation should be made within the terms of a phenomenon that is shared by both organizational levels of the brain (phenomenological/mental and neurophysiological/biological). As we postulated above, it is the concept of ‘operation’ that is the needed shared fundamental reference and which provides us with a starting point for the conceptual integration and unified research program.

##### ***4.1. Implications for the linguistic semantics***

Operational semantics (OS) theory describes and studies the nature and structure of linguistic thought, that is, the kind of reflective thought that lies at the basis of human language, and of

which such language is the expression.<sup>87,88</sup> This is the only linguistic framework that explicitly aims to describe, measure, and model the linguistic operations involved in the complex human higher-order reflective consciousness (thoughts) which is governed by the brain.

According to OS theory, reflective/linguistic thought is always operational (made up of operations) and OS defines explicitly the structure of linguistic thought. This structure is characterized by correlators, correlata, and by a hierarchy of operations of increasing complexity.<sup>87,88</sup> One may see that OA theory of brain functioning (as it is described in Section 3) uses the same theoretical constructs: the brain functioning is also characterized by a hierarchy of operations of increasing complexity and functional connections between these different operations. The basic idea is that the synchronized brain activity produced by local neuronal assemblies is linked to the required operation (of any complexity) and only those local activities evoked by common objects, scenes, or tasks are bound together in dynamically formed metastable OMs.<sup>35,51-54</sup>

Thus, the operational level of linguistic thought can be studied simultaneously with the correspondent level of brain operational architectonics and, in such a way, bridge the gap between linguistic thought and the brain.<sup>89</sup>

#### ***4.2. Implications for self-organized distributed computing algorithms***

Principles of the OA framework can be used to build the scalable applications (computing systems) operating in dynamic context. Such system would be a set of components. There is no need to have a dedicated decision making unit for the purpose of defining the best configuration of the system. This is because the intelligence required for optimal adaptation should be distributed around the system. Each component shall have some parts of the overall intelligence and the system as a whole shall have an ability to organize its components into a working framework without the need of external help or control.<sup>90</sup>

For example, input to the system is presented as a multimodal signal. Each modal represents one required function. The multimodal signal (with several frequencies inbuilt in it) is distributed among all the system components. These signals are used for setting up coalitions for tackling external requirements, resource management, and unexpected disturbances. The signal is activating only those components that can ‘understand’ and process a particular modal of the broadcasted signal. Ignited/activated components also generate their own frequency signals and might activate other components that would react to the messages.

This is exactly the scenario by which the brain operates: the sufficient coordination of the integrative activity of brain neuronal assemblies (located in different brain areas) is reached to the extent that these assemblies are able to mutually influence each other in order to reach a common functional state, stabilizing main parameters of its activity.<sup>35,51,53</sup> However, each specialized neuronal assembly performs a unique role by expressing its own form of information, and at the same time its performance is largely constrained by interactions with other neuronal assemblies to which it is functionally connected – metastability principle of brain-mind functioning.<sup>53</sup>

By activating each other and being activated by external (or internal) requests, the components form the system in which they collectively solve the required tasks and heading toward the goal.

It is obvious that scalability of the above approach is limited by the size of the functional module, the communication, and processing capacity in it. The OA framework offers a following hierarchical approach to extend the scalability. Basically, the modules of the system at level  $n$  are treated as members of a module of the higher level of abstractness  $n+1$ . At this level only those functions (services) are presented, which could not be installed in the lower level modules. Such architecture suggests a layered algorithm, where lower layers provide self-organizing properties used by higher, more complex layers.

### ***4.3. Implications for the artificial machine consciousness***

The OA theory offers the plausible framework which states that whenever any pattern of phenomenality (including reflective thought) is instantiated, there is neuro-physiological pattern (revealed directly by EEG) of appropriate kind that corresponds to it.<sup>35,51</sup> These neuron-physiological patterns (expressed as the virtual operational modules) are brought to existence by joint operations of many functional and transient neuronal assemblies in the brain.<sup>35,54</sup> The activity of neuronal assemblies is ‘hidden’ in the complex nonstationary structure of EEG.<sup>35,51</sup> However, proper EEG analysis<sup>55</sup> reveals the EEG architecture which is strikingly similar to the architecture of a phenomenal world (see above).

If consciousness is a biological phenomenon in the brain<sup>30</sup> realized by the highly organized macro-level electrophysiological (EEG) phenomena (metastable OMs),<sup>35,51-54</sup> the problem of producing man-made ‘machine’ consciousness is the problem of duplicating the whole level of architecture (with its inherent rules and mechanisms) found in EEG, which can constitute this phenomenal level.<sup>91</sup>

#### ***4.4. Implications for diagnosis of dynamic brain diseases***

Recent research emphasizes the fact that majority of brain disorders and mental/psychiatric problems are accompanied by disruption in the temporal structure of brain activity.<sup>92</sup> From this perspective, such disruption is viewed as a disorder of the metastable balance between large-scale integration and independent processing in the brain, in favor of either independent or hyper-ordered processing. In this context, it is important to study how different brain and mind pathologies alter the temporal structure and metastable regimen of brain activity and how different psychotropic drugs can modify temporal structure of brain activity in healthy subjects and patients.

##### *4.4.1. Depressive disorder*

Depressed individuals tend to see even positive information as negative because it becomes associated with personally relevant negative information.<sup>93</sup> Additionally, an automatic, unintentional use of negative social constructs in self-perception was reported in depressed individuals.<sup>94</sup>

Analysis of EEG of depressed individuals showed that the particular spatial distribution of functional connections and the sets of OMs reflect the metastable dysregulation between cortical and subcortical systems, and the disordered representation of semantics that depressed individuals tend to hold.<sup>95</sup> It was found that the number and strength of short cortex functional connections were significantly larger for the left than for the right hemisphere, while the number and strength of long functional connections were significantly larger for the right than for the left hemisphere. These findings were interpreted within the semantic framework, where an observed increase in respected functional connections is adaptive, compensated, and is due to different specializations of the left (monosemantic context) and right (polysemantic context) hemispheres, both of which are functionally insufficient in patients with major depression.<sup>95</sup> The ability to form an adequate semantic context means the ability to integrate both mono- and polysemantic contexts into a cohesive experience, thus helping subjects to experience themselves as ‘unity’ integrated into interrelations with other humans and the world. This integration is the most important feature of the subject’s mental life and emotional balance.<sup>96</sup> Distortion of such integration results in changes in adaptive compensative mechanisms, with an increase in functional connectivity being a particularly important one.



#### 4.4.2. Opioid dependence

Given that repeated exposure to opiates initiates a significant reorganization of mental functions, including those associated with drug-seeking and drug-taking behavior that characterize addiction,<sup>97</sup> we predict that systematic opioid exposure in abuse patients would result in a significant reorganization of local and remote functional connectivity in the neocortex.<sup>98</sup>

It was found that acute use of opioids, together with the longitudinal opioid usage history, results in the increase of local functional connectivity; and this was reflected in the formation of large and stable neuronal assemblies.<sup>98</sup> Therefore, the brain of opioid dependent patients cannot reach a proper (for the healthy brain) resting state where individual brain areas, besides expressing their own functioning, are also heavily involved in a collective activity (metastable principle). Thus, such ‘normal’ resting brain state is alien to the neuron-cognitive profile of ‘addicted’ resting brain.

At the same time there was significant disruption in the remote functional synchrony among neuronal assemblies in the brain of opioid addicts.<sup>98</sup> Most likely, this disrupted brain remote functional connectivity may constitute the candidate mechanism for a well-documented pattern of phenomenal impairment in addicts that expressed as the lack of integration of different cognitive functions for effective problem solving, deficits in abstract concept formation, set-maintenance, set-shifting, behavioral control, and problems in the regulation of affect and behavior.<sup>99-101</sup>

Altogether, these findings suggest that opioid dependence may be conceptualized as a new metastable state around altered homeostatic levels in the brain.<sup>98</sup>

#### 4.4.3. Opioid withdrawal

When addicts crave for drug, the anxiety, nervousness, lack of inhibitory control, positive drug related expectancies, and intrusive thoughts related to drugs are simultaneously active in the phenomenal mental world of addicts.<sup>102,103</sup> Consistent with the OA framework, these complex phenomenal states are critically based on the dynamical interactions between and within many cortical neuronal assemblies responsible for such mental states.

It was predicted that such mental states would result in a significant increase of local and remote functional cortical connectivity, where the dynamics of local brain operations (functions) would be restrained by the large-scale context (removal of the aversive state) of mutually

connected cortical areas.<sup>104</sup> Then it would explain the opioid withdrawal mental state: a strong motivation for the excessive drug craving and drug related intrusive thoughts.

Experimental results (for detail, see Ref. 104) demonstrated significant increase in local and remote cortical functional connectivity in the opioid-dependent patients during short-term withdrawal period, thus suggesting that increased inter-area communication among cortical areas may be one of the neurobiological underpinnings of the biased motivational and cognitive processes such as attention, emotions, and memories during withdrawal<sup>103,105</sup> supporting the removal of the aversive state behavior. The restructuring of the operational synchrony process in the brain of withdrawn addicts originates as a new altered metastable state around possible homeostatic brain levels and is defined as adaptive process of achieving stability through change, a metastability that is not within the normal homeostatic range.<sup>104</sup>

#### *4.4.4. Schizophrenia*

Schizophrenia is associated with impairments in pre-attentive sensory gating, perceptual grouping, selective attention, working memory, and long-term memory (LTM), as well as with phenomenal impairments usually interpreted in terms of context (hallucinations, delusions, and appearance of incongruent associations).<sup>106-108</sup> Such a broad range of contextual impairments is exactly the type of general consequence to be expected from the failure of a common brain inter-area coordination mechanism.<sup>109</sup> It was suggested that such altered phenomenal world of schizophrenics would be reflected in the disruption of the metastable balance between large-scale integration and independent processing in the cortex, in favor of independent processing. Such disruption is suggested as a contributing factor to the disorganization syndrome in schizophrenia.<sup>109</sup>

OA studies provided evidence that in the brain of schizophrenic patients, there is shortening of the life-span of transient neuronal assemblies, the size of neuronal assemblies decreased, and their stability diminished.<sup>110</sup> Simultaneously, there is reorganization of functional connectivity among neuronal assemblies located in different cortical areas: such synchrony was reduced for the long-distance brain areas and became stronger for the short-distance brain areas in schizophrenic patients.<sup>111</sup> These findings suggest a loss of dynamical balance between local, specialized network functions and global integrative processes during schizophrenia. This proposal offers the following interpretation: high ratings of cognitive disorganization symptomatology in schizophrenics may be associated with a decrease in the long-distance functional connectivity, while an increase in dynamical functional connections for the short-

distance unstable neuronal assemblies may underlie the inappropriate associations and reality distortion.

#### 4.4.5. Epilepsy

Considering that during chronic epilepsy patients experience altered mentality (so-called ‘epileptic personality’<sup>112,113</sup>), characterized by affective viscosity, egocentricity, obsessiveness, and circumstantial thought, we hypothesize that the brain of such patients should produce metastable OMs of larger size and longer life-span when compared with healthy subjects.

Study of epileptic patients confirms this supposition: OMs indeed tend to longer periods of temporal stabilization and they involve more cortex areas than OMs in the brain of healthy subjects.<sup>114</sup> These findings suggest less dynamic performance of cooperative brain operations – dynamic rigidity. As a result, such patients are less able to cope with the demands of a constantly changing environment. Considering that interictal (in between the epileptic attacks) EEG in the present study had not any signs of epileptiform abnormalities, observed mutual stabilization between the types of spectral patterns in EEG channels independently on their correlation and coherence is an inherent part of the mechanisms of ictogenesis which take place long before the actual onset of a seizure (for detailed discussion, see Ref. 114).

#### 4.4.6. Hypnosis

According to the mind-brain metastable continuum thesis (see Section 3), every event or change at the mental (or cognitive) level must be accompanied by a corresponding change at the neural level. Then it follows that if hypnosis involves a change in mental and cognitive mechanisms, there must be a corresponding alteration taking place at the neural level. Furthermore, if change on the neural level involves changes in the communication between different functional operational modules in the brain, then they should be associated with changes in the underlying EEG activity (synchrony between different brain areas). Thus, changes in the brain operational architectonics during hypnosis may be regarded as a putative neuronal correlate of hypnosis.

Experimental research showed that during pure hypnosis<sup>115</sup> as compared to the baseline condition of consciousness, all studied parameters of functional connectivity were significantly changed<sup>116</sup>: a) Delta-, beta-, and gamma-generated neuronal assemblies were characterized by decreased size and decreased stability, being indicative of an increased independence of brain processes (effort to maintain a state of alertness) in the hypnotic condition. Large and stable

alpha- and theta-generated neuronal assemblies, which appeared during hypnosis, indicate that the subject was more facilitated to process information than in the baseline condition; b) Practically all cortical locations demonstrated decrease in functional connections and decrease in their strength, signifying the enhancement of independent processes in the brain and disruption of the integrated brain functioning.

#### *4.4.7. Psychotropic drugs*

Elsewhere we propose that the future of psychopharmacology lies in its ability to design the psychotropic drugs which can restore the normal temporal and metastable structure of brain activity.<sup>92</sup> Research studies conform the idea that psychotropic drugs can alter or restore the natural metastable organization of brain activity.

In the lorazepam (benzodiazepine) study it has been shown that in healthy subjects under the lorazepam administration the number of functional connections in the cortex and the strength of these connections increased significantly; and that these changes in the brain operational architecture were paralleled by such mental changes as slowing of thinking and cognition.<sup>81</sup>

In the methadone (used as a maintenance treatment for opioid dependent patients) study it was found that methadone could actually restore the normal cortical metastable balance in opioid addicts after at least six-month methadone treatment; and this was paralleled by a decrease of aggressive, dependent, and depressive mind states (for a detailed discussion, see Ref. 117).

The data reviewed above illustrate that psychotropic drugs can modify the metastable organization of brain functioning.

## **5. Conclusion**

The intuitive understanding that what happens in the mind depends upon what happens in the brain and vice-versa goes back for at least two millennia. Already ancient doctors or healers had observed that injuries to the brain at times resulted in profound changes in the personality and mental life of a person.

Many years of careful research in neuroscience prepared the basis for a conclusion which we stressed in the current contribution, – that brain and mental processes are best seen as two aspects of one unified, but metastable continuum. Based on the evidence presented here we may regard brain and mental architectures as complementary physiological (inner) and phenomenological (outer) aspects of one complex set of events that together constitute

metastable brain-mind agency. In this context, the hierarchy of phenomenal structures (features, patterns, objects, scenes) has its electrophysiological equivalent in an operational hierarchy of neuronal assemblies and OMs, which correspond to the phenomenal entities.

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