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*(© The International Journal of Neuroscience, 2004, V. 114. No 7. P. 843 - 862)*

# Making Complexity Simpler:
# Multivariability and Metastability in the Brain

Andrew A. Fingelkurts* and Alexander A. Fingelkurts

*BM-Science Brain & Mind Technologies Research Centre, PO Box 77,*
*FI-02601, Espoo, Finland*

**Abstract**
This article provides a retrospective, current and prospective overview on developments in brain research and neuroscience. Both theoretical and empirical studies are considered, with emphasis in the concept of multivariability and metastability in the brain. In this new view on the human brain, the potential multivariability of the neuronal networks appears to be far from continuous in time, but confined by the dynamics of short-term local and global metastable brain states. The article closes by suggesting some of the implications of this view in future multidisciplinary brain research.

**Keywords***:* Neural networks, Multivariability, Metastability, Self-organization, Brain research, Operational architectonics, Isomorphism, Cognition, Consciousness

## 1. Introduction

The human brain is the junction point of the material world and the world of ideas, the body, and the mind, the objective and subjective. The intuition and science say that our brain is complicated[1]. Brain is more than simply a physical system, symbol-processing device, and neural information processing architecture. It is an epistemic system that observes and interacts with its environment (Cariani, 2001). The brain hosts an enormous number of complicated actions of our organism. Humans breathe, cough, sneeze, gulp, and have sex; play football and musical instruments; add and subtract; speak and even reflect – write, sing and compose poems. This is due to the fact that brain is the organ in which "super-" or

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[1] The broad definition of the term "complexity" is used as an attribute of complex system (Bechtel & Richardson, 1993), meaning that the complex system has internal structure where each element in its turn also has its own internal structure and so on.

"virtual-reality" is originated (Revonsuo, 1995). This super-reality turns a mammal into a *human being*. From this point, the faded pieces of the external physical world are transformed as images into nonmaterial clusters of reality, and these clusters form what is called mental reality. Having unlimited degrees of freedom and being momentarily accessed, these mental images become the subjects of the remarkable theater of nature – consciousness and unconsciousness. More precisely, from this process emerges the capacity to engage in something like off-line reasoning (Clark & Grush, 1999) and/or intentional object driven activity (Brentano, 1973) that might not be present-at-hand nor even exist (Clark & Grush, 1999). Thus, in humans nature becomes aware of itself.

These aspects are and have always been behind the continuously growing interest in the topics of brain research and in particular in the search for a general theory of brain and mind functioning that can explain what this brain-mind relation is, and how and why it emerges. A brain research which explains everything about the brain except for how it generates the mind, is a neuroscience that essentially explains nothing, because it is the mind that makes the brain interesting in the first place.

There is also a need for a general theoretical framework that may allow researchers to handle an enormous amount of diverse observations related to the brain and mind phenomena. Generally, the brain is considered as a physiochemical system that operates simultaneously at many hierarchical levels. Prior to recent conceptual and methodological developments, the majority of the neuroscientists believed that the physiological basis of behavior and cognition was to be found at the level of individual neurons (Hubel & Wiesel, 1966; Barlow, 1972) or even at the level of neuronal organelles, such as the synapse or dendritic spine (Hyden, 1967; Lynch, 1986). This approach goes back to Hebb (1949).

The developments in technology, experimental techniques, and theoretical frameworks within specific disciplines have pushed forward our understanding. Thus, different views on brain research have been established by postulating that behavior and cognition is a cooperative process that accomplishes the synthesis of distributed non-randomness in an anatomically extensive mass of neurons (John, 2002) or the large-scale neural networks (Kohonen, 1984). Here the concept of "grandmother" does not seem to be represented by a single "grandmother cell," but is rather distributed across a network of neurons (Churchland & Sejnowski, 1992). Consequently, it has been argued that distributed representations are the natural result of an organization of statistical input and therefore they provide the means to capture semantic information (Smolensky, 1995). It is here that some neuroscientists appeal to dynamical system models (Van Gelder, 1995). Global dynamics (such as large-scale pattern organizations) are now explained in terms of the interaction of local lower-level physical phenomena, but by dynamical, nonlinear and often chaotic sequences and combinations (Freeman & Barrie, 1993; Friston, 1997; Nunez, 2000; Pouget, Dayan, & Zemel, 2000; Triesch & von der Malsburg, 2001; Tsuda, 2001; Varela, Lachaux, Rodriguez, & Martinerie, 2001; Wright et al., 2001; John, 2002; only to mention a few). In this dynamic self-assembling process, parts of the brain engage and disengage in time, allowing a person to perceive objects or scenes, and to separate remembered parts of an experience, and to bind them all together into a coherent whole (Kelso, 2002a).

Recently, this line of conceptualization and the corresponding brain research has lead neuroscientists to discover the *metastability* principle in the *multivariability* of brain functioning (Kelso, 1995; Friston, 1997; Kaplan, 1998). In this new view (Fig. 1), the potential multivariability of the neuronal networks appears to be far from continuous in time, but confined by the dynamics of short-term local and global metastable brain states (Kelso, 1991; Kaplan & Shishkin, 2000; Bressler & Kelso, 2001; Fingelkurts & Fingelkurts, 2001, 2003).

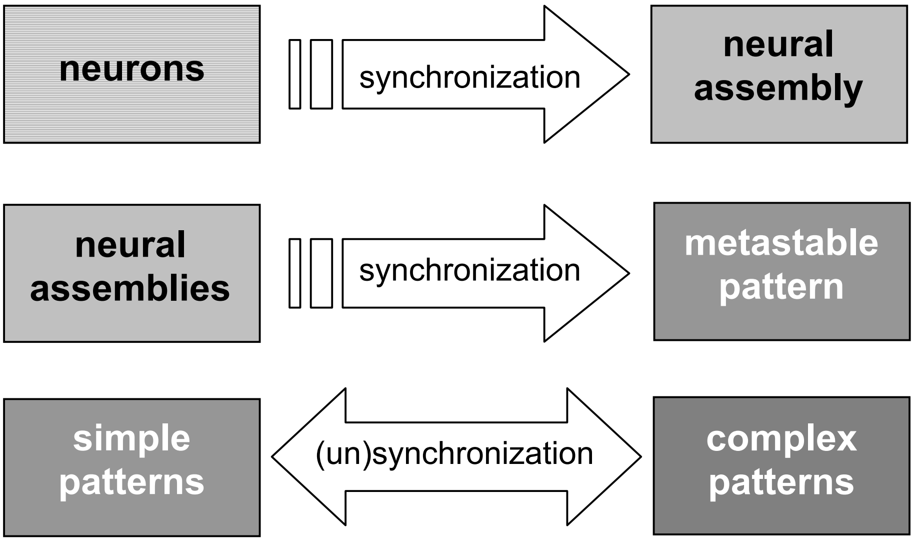

Figure 1. **Schematic illustration of multivariability and metastability concept.**

However, we should not overestimate our current understanding: Both, our theories on large-scale organization of brain functioning, and our capacity to observe and to study its phenomena are still limited. Hopefully, the new fairly wide synthesis of neuroscientific, physical, mathematical, cognitive, and theoretical computer science knowledge will produce a new theoretical framework – a general theory of brain and mind functioning. Only reasonable cooperation and mutual interest between experimental and theoretical approaches will lead to a progress in creation of such a general theory (McIntosh, Fitzpatrick, & Friston, 2001).

We shall now review two of the most prominent principles of brain functioning that have been established throughout the recent decades, and are based on a good deal of empirical evidence and biologically realistic models of brain dynamics: Multivariability and Metastability. These being entangled with each other and seems proceed concurrently at multiple levels: metabolic, single neurons, neuronal nets and between brain areas (for a detailed discussion, see Fingelkurts & Fingelkurts, 2001).

## 2. Multivariability of brain functioning

Brain is an example of a distributed environment without a centralized control within it. It is evident that human brain is an extraordinary integrative and complex organ (Ingber, 1983; Haken, 1999; Tononi, Edelman, & Sporns, 1998; Nunez, 2000; Wright et al., 2001), organized into parallel processing streams with complementary properties thereby providing conditions to generate a multisensory scene (Fingelkurts et al., 2003b), to form a Gestalt (Lehar, 2003). Indeed, more than $10^{15}$ of neurons (Ashmarin & Sukalov, 1996) and about 150 billion of brain cells (Laming et al., 2000) are connected with one another locally (more than 10.000 direct connections of one neuron with others) in the assembly of structures (Jacobs &. Scheibel, 1993). These structures in their turn globally communicate with one another through long-distance projections (Jirsa & Kelso, 2000) in order to act in a concerted fashion in the construction of the behavior of the large-scale networks (Churchland & Sejnowski, 1992; Nunez, 1995) (Fig. 2). Since the number of distinct brain structures scales proportionally with network size, there are potentially an ever-increasing number of structures with which a particular brain structure may need to interact (Changizi, 2003). This means that each structure (or cortical area) receives modulatory input from several other parts of the brain (Fig. 2). The modulation does not provide information-specific input, but it changes and adjusts the cortical state in such ways as “turn on”, “turn off” and so on, by simultaneously operating on assemblies of cortical neurons (Freeman, 1996).

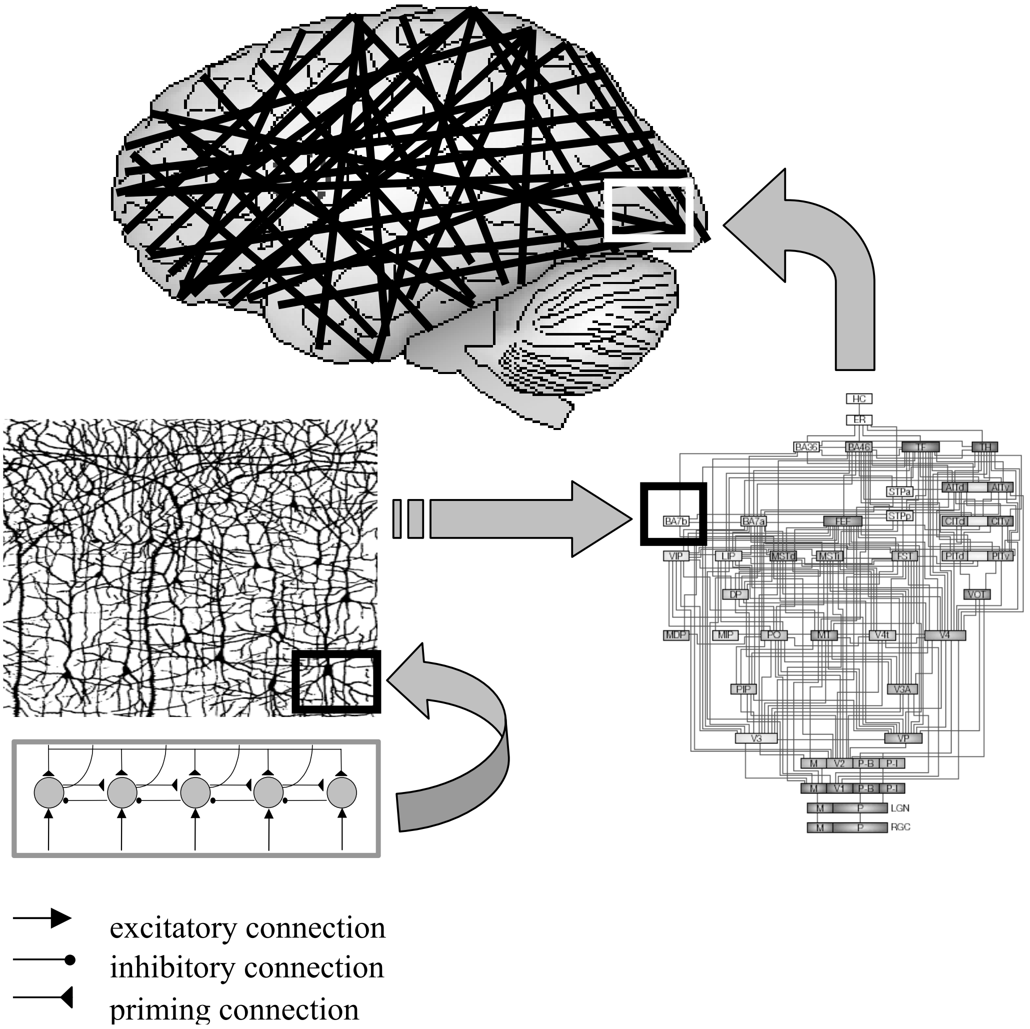

Figure 2. **Schematic illustration of interconnectedness at different levels of brain organization.** The cerebral cortex is highly interconnected. This provides evidence that activity in any cortical area might potentially be coordinated with activity in other connected areas.

However, this “interconnectedness” may be a considerable problem: as calculations show, full neuron-neuron interconnectedness would lead to brains with the size of a bathtub (Cherniak, 1990; Ringo, 1991). The scaling properties of the brain enable the solving of this problem (Jirsa, 2000; Changizi, 2003). Thus, in neocortex, the increase of structure-degree (the number of structures to which a particular structure connects) is achieved by increasing the number of synapses per neuron[2], and neuron density accordingly falls in larger brains

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[2] It is about 5-10 thousand of synapses on each neuron with tens of operational modes in each synapse (Garoutte, 1987). Each operational mode of synapse depends on the amount and number of types of neurotransmitters, where only one “quanta” of neurotransmitter contains ~103 molecules (Ingber, 1983).

(Prothero, 1997); meaning that neuron density scales as the 1/3 power of gray matter volume, or, equivalently, number of neurons scales as the 2/3 power of gray matter volume (Changizi, 2003). Therefore, the gray matter volume scales as the number of neurons to the power of 1.5. The increasing number of synapses per neuron also has the effect of increasing the physical diameters of axons and somas as the 1/9 power of gray matter volume (Shultz & Wang, 2001; Harrison, Hof, & Wang, 2002). Finally, the physical increase in axon caliber, in turn, is critical in understanding why neocortical white matter scales disproportionately quickly as a function of gray matter volume; namely, with exponent approximately 4/3 (Allman, 1999). Thus, the increase of connectivity drives many of the broad micro- and macro-features of neocortical anatomy and function, leading to neocortical parcellation (formation or *segregation* of functional areas) and inter-area functional interactions (*integration*) (Changizi, 2003). The brain exhibits a range of varying connectivity structures (Fig. 2) allowing flexibility for the same functions, generally assumed to be represented by network operations (Jirsa & Kelso, 2000). This is the “elementary basis,” which creates a very high number of combinations of possible brain states[3] – ***multivariability*** of brain functioning (Kaplan, 1998; Fingelkurts & Fingelkurts, 2001).

High multivariability of brain activity is the key characteristic feature of ongoing (a.k.a. spontaneous) brain activity (Fingelkurts et al., 2003a, 2003d). There is emerging evidence for that: It was shown that the alert eyes closed EEG state is very much an active state (Fingelkurts et al., 2003a, 2003d). There is still about 20% glucose metabolism of the whole body occurring in the brain of a subject during eyes closed condition (Herscovitch, 1994). During this condition, there is dynamic circulation of neural activity in connected cortical, reticular and thalamo-cortical loops (Thatcher & John, 1877). Neural activity can be also modulated by purely intrinsic factors what was testified by investigations on normal subjects during mental imagery (Goebel et al., 1998) and on patients with schizophrenia during auditory hallucinations (Dierks et al., 1999). Thus, ongoing brain activity consists from the ordered states of internally generated activity and reflects the functional architecture of the networks: Traces of the past history and the features of planned behavior (Alexandrov, 1999). This process becomes even more complicated when the brain engaged with the active cognitive processing. Now attentional, motivational and emotional modulations, including those related to working memory, perception, novelty-seeking and planning, become

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[3] The "state" of the brain is a description of what it is doing in some specified time period (Freeman, 1999).

increasingly more pronounced, thus, further contributing to the multivariability of cognition (for a discussion, see Mesulam, 1998).

A cognitive act requires a prior state of readiness that expresses the existence of a goal, a preparation for motor action to position the sense organs, and selective sensitization of the sensory cortices (Freeman, 1999). Their excitability has already been shaped by the past experience that is relevant to the goal and the expectancy of stimuli (Alexandrov, 1999; Freeman, 1999; Beer, 2000). In contrast to classical theories which interpret the brain as a passive, stimulus-driven device, this conceptualization (named an "*active paradigm*," Luria, reprint of 1980) emphasizes the constructive nature of brain processing (Alexandrov, 1999; Arbib & Erdi, 2000; Engel, Fries, & Singer, 2001). In the framework of this paradigm it is suggested that the brain is intent or directed toward some future state and goal. Thus, the principle determinant of the brain activity is an event that is not in the past with respect to behavior – a stimulus, but in the future – a result. Therefore, cognitive activity is not the responses to the past, but preparing and shaping the future acts (Alexandrov, 1999). Already in 1914 Dewey phrased the main idea: An organism does not react to a stimulus but acts into it and incorporates it (cited by Freeman, 1999). Now it is obvious that complex material system with distributed nonlinear feedback, such as brain with its neural and behavioral activities, cannot be explained by linear causality (Freeman, 1999).

How does the brain achieve the efficient functioning under such high multivariability of its systems and structures? Indeed, how do brain areas, each with unique individual functional properties cooperate to execute complex functional acts, behavior, cognition and particularly consciousness?

## 3. Metastability of brain functioning

Dynamical ideas[4] are beginning to have a major impact on neuroscience, from foundational debates to daily practice (Beer, 1995, 2000). It has been empirically established that the biological basis of behavior and cognition is not only globally distributed in the brain networks; it is a self-organized process[5] (Schöner & Kelso, 1988) which is reflected in

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[4] The theoretical roots of this so called dynamicism are derived from the mathematical theory known as "dynamical systems theory," which uses sets of differential equations to describe the evolution of a system through time (Eliasmith, 2001).

[5] Theoretical hypotheses about self-organization go back to Haken (1988), Szentagothai (1972) and Katchalsky (1972).

the nonlinear and chaotic dynamics (Skarda & Freeman, 1990). Therefore, the sufficient coordination of the integrative activity of cortical (and subcortical) areas is reached to the extent that these brain areas are able to mutually influence each other in order to reach a common functional state, stabilizing main parameters of its activity (Fingelkurts & Fingelkurts, 2001). However, it is worth to note that each specialized cortical area 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 areas to which it is functionally connected (Bressler, 2003). This regimen of brain functioning was named as ***metastability***[6] (Kelso, 1991; 1995; Kaplan, 1998; Friston, 2000).

Metastability is an entirely new conception of brain functioning, where the individual parts of the brain exhibit tendencies to function autonomously at the same time as they exhibit tendencies for coordinated activity (Kelso, 1991; 1995; Bressler & Kelso, 2001; see also Bressler, 2003). That metastability (when the system's degrees of freedom are restricted) is circumstantial for the interaction among the elementary neuronal systems in order to generate adaptive behavior within changing and not fully predictable environments. By *synchronizing* the stable microstates of the "microscopic variables" during certain period, the neuronal systems have the possibility for *interactive information exchange* of the essential variables, which are important for the acceptance and expression of "consensual decision"[7] that is appropriate for the functional requirements engendered by each successive stage of behavioral performance (Kaplan, 1998; Kaplan & Shishkin, 2000; see also Fingelkurts & Fingelkurts, 2001; Bressler, 2003). Thus, synchronization of brain activities (Fig. 1), going on in different brain areas, is a mechanism for the integration of local circuits within the large-scale anatomical structure and was claimed to be crucial for neural computation (Phillips & Singer, 1997).

For this reason, temporal coding was proposed, based on the selective synchronization of neuronal responses (Abeles, 1982; Engel et al., 1992; von der Malsburg, 1995). Several singular neurons-recording-studies from the cortex have demonstrated the role of synchronization in visual grouping and segregation (Gray, Konig, Engel, & Singer, 1989;

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[6] One may note that the metastability principle extends the Haken synergetics rules (Haken, 1983), which aim to compress the effective number of degrees of freedom in complex systems to a few "order parameters" or variables that adequately approximate system dynamics at large scales (Haken, 1999). Metastability extends them to situations where there are neither stable nor unstable states, only coexisting tendencies (see Kelso, 2002b). Metastability explicitly refers to transient, nonstationary processes and differs from synergetics in this respect (thanks to reviewer for this comment).

[7] The idea that satisfaction of multiple constraints may produce a unified consensual state is also found in the theory of cognitive coherence (Thagard, 2000).

Sheinberg & Logothetis, 1997; Castelo-Branco, Goebel, Neuenschwander, & Singer, 2000), as well as in binding sensory and motor responses (Murthy & Fetz, 1992; Roelfsema, Engel, Konig, & Singer, 1997). However, the brain function cannot be explained in terms of features of neurons taken individually or as part of a local network (Freeman, 1981; John, 2002). Even in the case of neural net models that recognize the role of self-organized dynamics, focus is exclusively on the properties of the system's parts, whether these be connection strengths among units in the network, individual neurons, or at the level of the genome (Skarda & Freeman, 1990). The physiologically plausible mechanism of synchronization should coordinate the activity of multiple neuronal ensembles rather than just single neurons (John, 2001). These ensembles should be coordinated both locally within individual cortical areas and on a *large-scale* across distributed areas (Tononi, Sporns, & Edelman, 1994; Tononi, Edelman, & Sporns, 1998). And finally, this synchronizing mechanism should allow for spontaneous variation in the degree of coordination as the cortical system dynamics evolve over time (Bressler, 2003).

From a dynamical systems viewpoint, the best way to assess this large-scale level of synchronization is through EEG and/or MEG measure (Nunez, 2000; John, 2002; Freeman, 2003). Such synchronization was defined (Friston, 1994, but see Horwitz, 2003 for a critical discussion) and illustrated with numerical examples (Kelso et al., 1992; Achermann & Borbely, 1998; Rodriguez et al., 1999; Frank et al., 2000; Freeman, 2000; Friston, 2000; Varela, Lachaux, Rodriguez, & Martinerie, 2001; Breakspear & Terry, 2001; Koenig et al., 2001; Nunez, Wingeler, & Silberstein, 2001; Breakspear, 2002; only to mention a few). The natural development and extension of this line of research was the establishing of *Operational Architectonics* (OA) concept[8] of brain functioning (Fingelkurts & Fingelkurts, 2001, 2003). In the framework of this concept it is possible to extract from EEG/MEG recordings information about the discrete brain operations and estimate the level of inherent synchrony of these operations appearing simultaneously in different cortical areas and on different time scales (Kaplan, 1998). This type of synchronization has been named "Operational Synchrony" (Kaplan, Fingelkurts, Fingelkurts, & Darkhovsky, 1997). At the EEG/MEG level operations are reflected in the form of quasi-stationary segments in corresponding locations/sites (Fig. 3; for the review see Kaplan & Shishkin, 2000; Fingelkurts & Fingelkurts, 2003). It was shown that the segment sequences in different

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[8] This concept takes its direct origin and is rooted in the work of Kaplan et al. (Kaplan, 1995, 1998; Kaplan, Fingelkurts, Fingelkurts, & Darkhovsky, 1997; Kaplan & Shishkin, 2000, Kaplan, Röschke, Darkhovsky, & Fell, 2001).

cortical locations are synchronized, forming short-term *metastable* topological combinations (Fig. 4) underling multisensory integration (Fingelkurts et al., 2003b), and memory encoding and retrieval (Kaplan, Fingelkurts, Fingelkurts, & Darkhovsky, 1997; Fingelkurts et al., 2003c). These metastable topological combinations appeared to be correlated with and dependent on the subjects' individual level of anxiety (Shishkin et al., 1998) and on the pharmacological influence (Fingelkurts et al., 2004a,b), large ontogeny shifts (differences between children and adults) (Borisov, 2002) and changes in the functional state of brain during schizoid diseases (Kaplan & Borisov, 2002). This methodological approach is also consistent with the concept of brain microstates: momentary cortical electric field distributions which are constantly upgraded and replaced (Lehmann, Ozaki, & Pal, 1987), and which are associated with "atoms of thought" (Lehmann & Koenig, 1997; Lehmann et al., 1998).

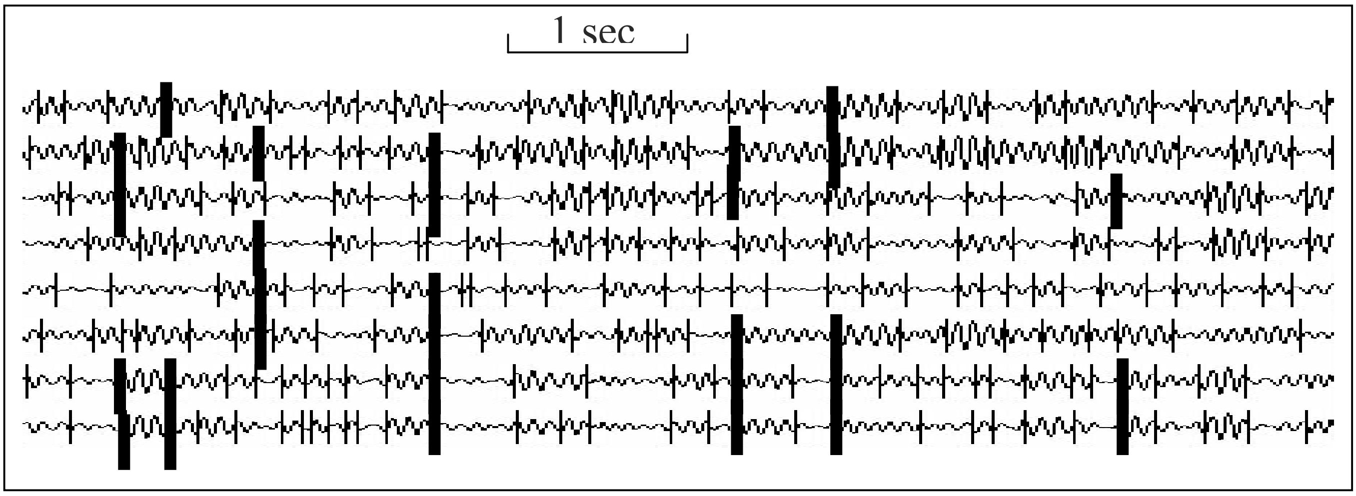

Figure 3. **Structural or operational synchrony.** Qualitatively synchronization of operations refer to the Operational Synchrony (OS) whereas quantitatively such a phenomenon is assessed through the measure of synchronization of EEG/MEG segments (Structural Synchrony – SS) obtained from different brain areas. As a typical example, 8 EEG channels filtered in alpha frequency band with automatically detected boundaries (shown as vertical lines) between quasi-stationary segments are presented. It can be seen that some segments' boundaries in different EEG channels appeared temporally close (shown as thick vertical lines).

It is tempting to believe that electromagnetic brain field complexity is mirrored in phenomenological (functional) complexity and vice versa. Assuming this and as a step further in development of the Operational Architectonics Concept, we suggested the *functional isomorphism*[9] between the structure (not just features) of phenomenal consciousness and the structure of operational architectonics of brain electromagnetic field (Fingelkurts & Fingelkurts, 2001). It was emphasized, based on this principle of functional isomorphism, that the metastable (large-scale) spatial EEG/MEG mosaics or *operational modules* (OM) may underlie mental states and conscious states in particular (Fig. 5; see also Fingelkurts & Fingelkurts, 2001; 2003 for a detail discussion).

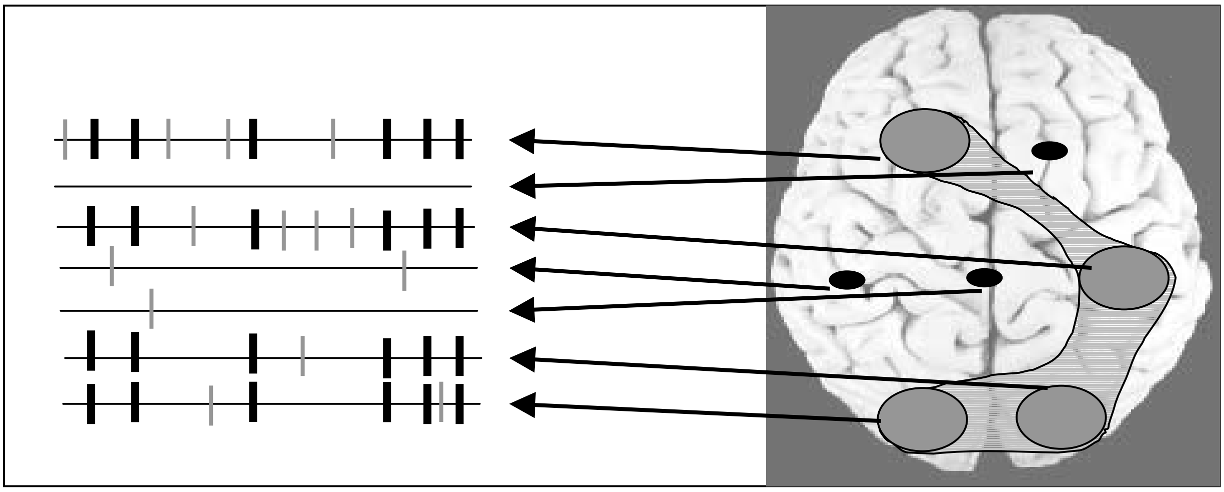

Figure 4. **Metastable spatial-temporal pattern – operational module (scheme).**

In the result of operational synchrony process, the metastable brain states are emerged which accompany the realization of brain complex macrooperations. These metastable brain states (when the number of degrees of freedom of the neural networks are maximally decreased) constitute the operational modules (OM), which we supposed to accompany mental states. Seven schematic EEG/MEG channels (horizontal lines) with automatically detected boundaries (shown as vertical lines) between quasi-stationary segments are presented. Temporally synchronous boundaries between different EEG/MEG channels are shown as thick vertical lines. Exactly these EEG locations form the OM (grey shape on the cortex background).

One can see that the structure of electrical brain field, the structure of cognition and the phenomenal structure of consciousness have the same organization: the succession of discrete and relatively stable periods (metastable OMs, cognitive acts or thoughts,

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[9] Isomorphism is generally defined as a mapping of one entity into another having the same elemental structure, whereby the behaviors of the two entities are identically describable (Warfield, 1977). A functional isomorphism on the other hand requires the functional connectivity between its component entities (Lehar, 2003). It is an extension to Müller's psychophysical postulate (Müller, 1896), and Chalmers' principle of structural coherence (Chalmers, 1995).

correspondently) separated by rapid transitive processes (abrupt changes between OMs, cognitive acts or thoughts, correspondently) (Fingelkurts & Fingelkurts, 2001).

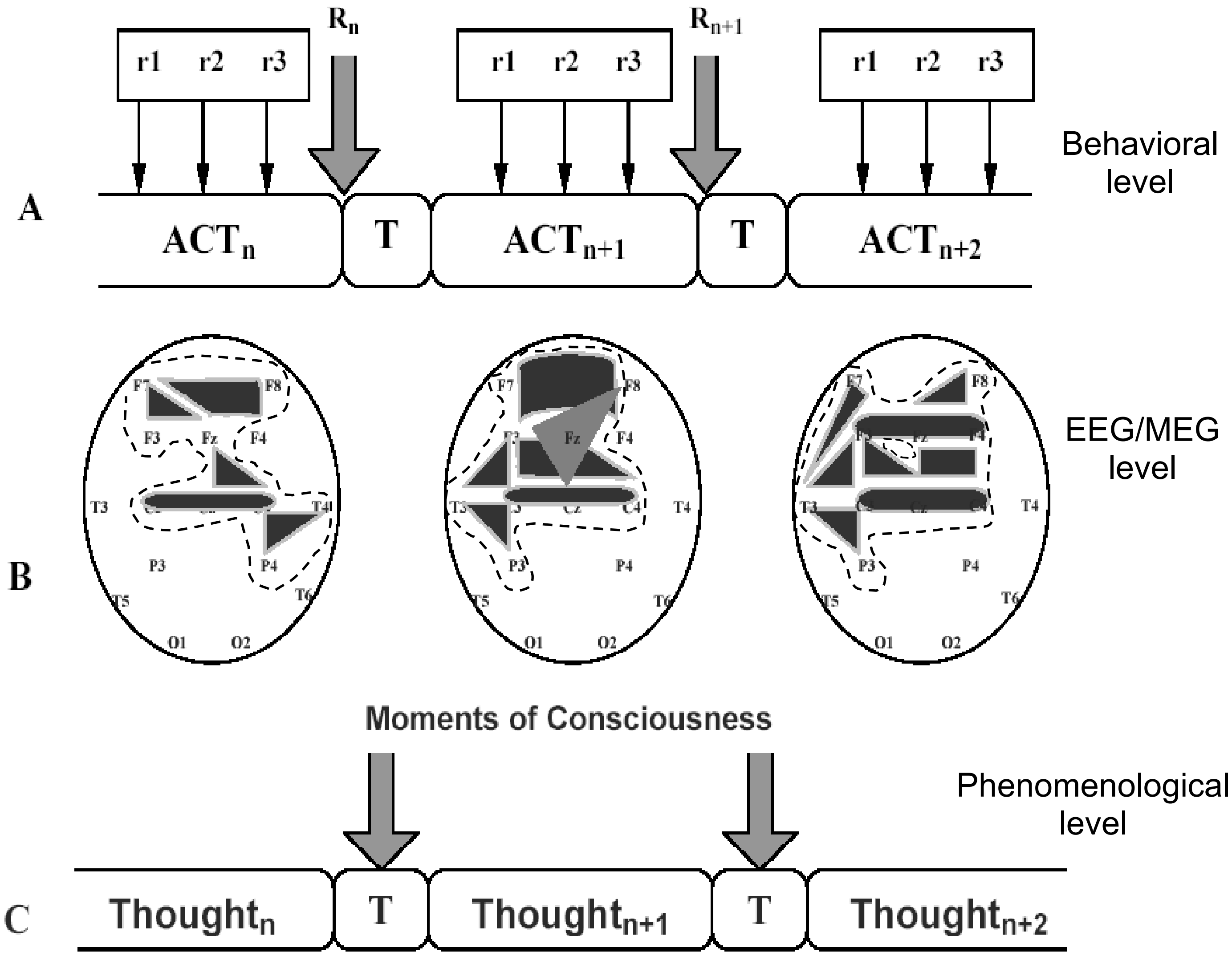

Figure 5. **Isomorphism between functional structures of behavior/cognition, phenomenological experience, and electromagnetic brain field (scheme).** A – the behavioral or cognitive continuum is the succession of discrete behavioral/cognitive acts (ACT) performed by an individual during his/her life. Each separate act is the integration of a certain number of operations, which are important and appropriate for realization of this act. During this operation's binding, the redundant degrees of freedom are eliminated, thus the "decision" of what should be done and how to achieve the adaptive result (R – final result; r – intermediate results) is made. Changes from one act to another are achieved through rapid transitional periods (T). B – at the EEG/MEG level these processes are

reflected in the chain of periods of short-term metastable states (or operational modules – OM) of the whole brain and its individual subsystems (grey shapes), when the numbers of degrees of freedom of the neuronal networks are maximally decreased. Dashed shapes illustrate complex OMs.
C – phenomenological level illustrates the ever-changing stream of thoughts (images) where each momentarily stable pattern is a thought/image. Thus, stream of thoughts has a composite structure: it contains stable nuclei (or thoughts/images) and transitive fringes (or periods).

Indeed, experimental evidence suggests that the behavioral or cognitive continuum is a succession of discrete behavioral/cognitive acts performed by an individual (Alexandrov, 1999; Helekar, 1999). Each separate act is the integration of a certain number of operations, which are important and appropriate for the realization of this act. The change from one behavioral/cognitive act to another is embedded in a rapid "transitional process". The same is true for the phenomenological structure of human consciousness which consists of stable nuclei (or thoughts) and transitive fringes (or periods) – as it is described by James' metaphor of "Stream of Thoughts" (James, 1890). It seems that metastability provides a mechanism of the functional isomorphism realization. This understanding is directly connected to the coordination dynamics phenomena in informationally coupled dynamical systems discussed in Kelso (1995).

Functional isomorphism between the dynamics of operational structure of the electromagnetic brain field and the phenomenological structure of cognition and consciousness definitely deserve wider coverage, and a more integrative review and study than current research can provide. It is probably one of the most plausible and productive lines for forthcoming brain investigations (Thompson & Varela, 2001); however, its tenets require further systematic experimental investigations and mathematical modeling. Even though, at present this issue has not been adequately dealt with in the neuroscience literature, there are several studies that go towards this line of research. Thus, several properties of spatiotemporal cortical activity, as measured by EEG and MEG, have been shown to accompany in a precise manner behavioral transitions in coordinative states (Kelso et al., 1992; Mayville, Bresssler, Fuchs, & Kelso, 1999; Fuchs et al., 2000a, 2000b). It is supposed that isomorphism may be here the causal chain starting from local neural assemble dynamics through electromagnetic data to behavior (Jirsa, Jantzen, Fuchs, & Kelso, 2001) that includes conception, perception, and action reactivated as an ensemble (Clancey, 1996). The next step should be in the establishing an accurate and precise functional link between the dynamic structure of the electromagnetic brain field and the concrete phenomenal experiences; the first attempt has already been done (Fingelkurts & Fingelkurts, 2001). Thus, we have good theoretical reasons to believe that the electromagnetic brain field may be that level of organization in the brain that shows isomorphism with the phenomenological structure of experience (Fingelkurts & Fingelkurts, 2003). Using the phenomenon of functional isomorphism as a base, we believe, it will be possible to study and systematically describe the phenomenal level of brain organization (Revonsuo, 2000) which constitutes the mental phenomena,[10] and eventually discover consciousness in the brain (Revonsuo, 2001).

## Acknowledgements

The authors are grateful for stimulating discussions and useful conversations on related questions to Prof. Alexander Kaplan, Prof. Ernst Pöpple, Prof. Giorgio Innocenti, Prof. Wolf Singer, Prof. Godehardt Link, Dr. Antti Revonsuo, Dr. Chris Langton, Dr. Sergei Shishkin, and Dr. Sergei Borisov. These inspired discussions and constructive criticism profoundly shaped the ideas of authors. The writing of this paper was supported by the BM-Science Centre research funds.

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[10] The crucial point here is that the constitutive mechanisms of mental states (and consciousness too) in the brain form a much more restricted class of phenomena than the class of the neural correlates of mentality. Almost any phenomenon could conceivably correlate with mental states and consciousness, but only very particular phenomena could ever constitute it, i.e. be the underlying mechanism that realizes them (see Revonsuo, 2001 for discussion).

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