Below is the unedited draft of the article that has been accepted for publication
(© Physics of Life Reviews, 2020, V. 33, P. 61-63; https://doi.org/10.1016/j.plrev.2019.09.008)

From spatio-temporal brain-mind dynamics to Spatiotemporal Neuroscience

Comment on "Is temporo-spatial dynamics the "common currency" of brain and mind? In Quest of "Spatiotemporal Neuroscience" by Georg Northoff, Soren Wainio-Theberge, Kathinka Evers

Andrew A. Fingelkurts [a], Alexander A. Fingelkurts [a,*], Carlos F.H. Neves [a]

[a] *BM-Science – Brain and Mind Technologies Research Centre, Espoo, Finland*

E-mail: alexander.fingelkurts@bm-science.com Url: www.bm-science.com/team/fingelkurts.html

Keywords:

spatio-temporal brain dynamics; Spatiotemporal Neuroscience; common currency; cinematic cognitive dynamics; EEG; metastability; synergetics; thermodynamics; Operational Architectonics; brain-mind relation; nested architecture; operation; one-to-one correspondence; brain fields.

The target paper of Northoff, Wainio-Theberge, and Evers [1] is an excellent and comprehensive review of diverse evidences on spatio-temporal brain dynamics that urges to bridge the "epistemic gap" between brain and mental realities through so called "common currency" which is the dynamics of the brain's time and space. Analyzing the dynamics of time and space, as they understood in contemporary physics (in contrast to a classical physics) and observing the recent empirical evidence from different experimental models of consciousness, self, and psychiatric disorders, the authors of the target paper presented a convincing argument that the dynamics of the brain's own "inner time and space" is the "common currency" of neuronal and mental features. They further proposed to establish a new brunch of Neuroscience – "Spatiotemporal Neuroscience" that conceives the brain and mind in terms of their spatio-temporal dynamics rather than in terms of specific functions like cognitive, affective, social, cultural, etc. [1]. Importantly, the 'function-based view' is here replaced by what can be described as 'dynamic-based view' of the brain [2-4]. And in its own turn, the dynamic-based view of the brain shifts the focus away from the stimulus-induced or task-evoked activity to its own spontaneous activity, the so-called resting state activity [5,6].

The main strength of the target article is that it provides an upper- (meta-) level conceptualization of the work that has been in focus of a number of researchers (including the authors of the target article [1]) for many years. In this respect it is important to mention the lifetime work of Walter Freeman, which was focused on mass action in the brain in the form of nested, dynamic neuronal

assemblies [7-9] (for a review see [10,11]). Based on his work, Freeman has proposed a cinematographic (or cinematic) model of cognitive dynamics [12]. This model states that the brain cortical code that supports cognition and mind, in general, consists of repetitive spatial frames of metastable amplitude modulation (AM) patterns in brain's electromagnetic filed [2,8,12-16] that are analogous to the movie frames. In a set of experiments Freeman proved that AM patterns (frames) embody the meaning of the stimuli rather than be their representations [17]. The major significance of this cinematic model is that it leaded to a new understanding that all brain-mind processes share the same coding in the form of cinematic sampling [11]. The cinematic synchronization of activity observed in multiple experiments in diverse cortex locations allows Freeman to propose that the rapid transition that initiates every AM *spatio-temporal* pattern does so by creating a field of nonsynaptic communication in the neuropil shared by all synchronized neuronal assemblies in a simultaneous coordination rather than by serial synaptic transmission [18]. Such emergent neural fields of self-organized activity framed within the AM patterns, incorporated Haken's synergetics [19] and Prigogine's 'dissipative structures' [20] that feed on energy, and leaded to self-organizing, far-from-equilibrium brain thermodynamics [2]. While Freeman never spoke about the "common currency" of brain and mind, he nevertheless systematically stressed that it is the spatio-temporal brain dynamics that is the best available candidate that neuroscientists have for connecting neural (physical) activity to mental (subjective) activity [21].

As a result of our own research work that has lasted already about 30 years and has been constantly inspired by Freeman studies, we have proposed a theoretical conceptualization formulated within the brain-mind ***Operational Architectonics* (*OA*)** framework as an attempt to reduce the "epistemic gap" between a subjective experience (mind) and its neurophysiologic counterpart (brain). This OA theory is centered around the *common* feature ("currency" in terms of authors of the target article [1]) for both the physics/matter/brain and the mind/subjectivity/cognition – *operation* [22-27]. Approaching the notion of operation as a *process* lasting in time, present in both brain and mind, and considering its combinatorial nature (increasing nested complexity) it is evident that operation is especially well suited for understanding and studying the mechanisms of how a conscious mind emerges from the physical brain [25,26]. Furthermore, such definition provides a basis for analyzing the relative complexity and compositionality of operations, where there is a more complex operation/operational act that subsumes the simpler ones [25,26]. In other words, every operation of this nested hierarchy of operations is not monolithic, it has its own inherent structure, whereas every simpler operation exists within every other more complex one.

According to the OA framework, the simplest mental operations (presenting qualia or simple computations) are expressed in the brain in the form of local 3D fields generated by transient

functional neuronal assemblies, while complex operations (presenting complex objects, images or thoughts) are brought into existence by joint simple operations (temporal coupling of local 3D fields by means of operational synchrony, OS) in the form of so-called operational modules (OM) of varied complexity [25,26]. In this context, brain OA is presented as a highly structured and dynamic extracellular electric field nested in *spatial* and *temporal* domains and over a range of frequencies, thus forming a particular *operational space–time* (OST) [25,26]. This OST exists within brain *internal physical space–time* (IPST) and is best captured by the electroencephalogram (EEG) measurement [28]. The advantage of the OST level is that it intervenes between IPST level (where it literally resides) and the *phenomenal (experiential/subjective) space-time* (PST) level to which it is isomorphic. Therefore, phenomenal (PST) level supervenes on the operational (OST) level with one-to-one correspondence and is ontologically inseparable from it (though it is separable from the brain neuroanatomical processes) [25,26,27]. Such description of the brain-mind OA has a number of striking resemblances with quantum processes as we have recently discussed in [27].

The briefly outlined in the present comment research, together with the research of the authors of the target article [1], mark the beginning of developing a comprehensive theory of spatio-temporal dynamics of brain-mind. It is hoped that in the future, with increased experimental research programs more knowledge of the spatio-temporal brain-mind dynamics will be accumulated and this would lead to establishment of a complete brunch of Spatiotemporal Neuroscience.

References

[1] Northoff G, Wainio-Theberge S, Evers K. Is temporo-spatial dynamics the “common currency” of brain and mind? In Quest of “Spatiotemporal Neuroscience”. Physics of Life Reviews 2019; https://doi.org/10.1016/j.plrev.2019.05.002 [this issue].

[2] Freeman W. Neurodynamics: An Exploration in Mesoscopic Brain Dynamics. London: Springer-Verlag, 2000.

[3] Chialvo DR. Emergent complex neural dynamics. Nature Physics 2010;6:744–50. https://doi.org/10.1038/nphys1803

[4] Tozzi A, Peters JF, Fingelkurts AA, Fingelkurts AA, Marijuán PC. Topodynamics of metastable brains. Physics of Life Reviews 2017;21:1–20. https://doi.org/10.1016/j.plrev.2017.03.001

[5] Haimovici A, Tagliazucci E, Balenzuela P, Chialvo DR. Brain organization into resting state networks emerges at criticality on a model of the human connectome. Physical Review Letters 2013;110:178101. https://doi.org/10.1103/PhysRevLett.110.178101.

[6] Tozzi A, Zare M, Benasich AA. New perspectives on spontaneous brain activity: Dynamic networks and energy matter. Frontiers in Human Neuroscience 2016;10:247. doi: 10.3389/fnhum.2016.00247

[7] Freeman WJ. Mass Action in the Nervous System: Examination of the Neurophysiological Basis of Adaptive Behaviour Through the EEG. New York: Academic Press, 1975.

[8] Freeman WJ. How Brains Make Up Their Minds. Columbia University Press, New York, 2000.

[9] Freeman WJ, Vitiello G. Nonlinear brain dynamics as macroscopic manifestation of underlying many-body field dynamics. Physics of Life Reviews 2006;3:93–118. http://dx.doi.org/10.1016/j.plrev.2006.02.001

[10] Fingelkurts AA, Fingelkurts AA, Neves CFH. The legacy of a Renaissance man: From mass action in the nervous system and cinematic theory of cognitive dynamics to operational architectonics of brain-mind functioning. Chaos and Complexity Letters 2017;11(1):81-91.
[11] Kozma R. Reflections on a giant of brain science: How lucky we are having Walter J. Freeman as our beacon in cognitive neurodynamics research. Cognitive Neurodynamics 2016;10:457-69. https://doi.org/10.1007/s11571-016-9403-3
[12] Freeman WJ. A cinematographic hypothesis of cortical dynamics in perception. International Journal of Psychophysiology 2006;60:149–61. DOI: 10.1016/j.ijpsycho.2005.12.009
[13] Freeman WJ. The wave packet: an action potential for the 21st century. Journal of Integrative Neuroscience 2003;2:3–30. https://doi.org/10.1142/S0219635203000214
[14] Freeman WJ. Origin, structure, and role of background EEG activity. Part 1. Analytic amplitude. Clinical Neurophysiology 2004;115:2077–88. DOI: 10.1016/j.clinph.2004.02.029
[15] Freeman WJ. Origin, structure, and role of background EEG activity. Part 2. Analytic phase. Clinical Neurophysiology 2004;115:2089–107. DOI: 10.1016/j.clinph.2004.02.028
[16] Freeman WJ. Origin, structure, and role of background EEG activity. Part 3. Neural frame classification. Clinical Neurophysiology 2005;116:1118–29. DOI: 10.1016/j.clinph.2004.12.023
[17] Freeman WJ. Tutorial on neurobiology: from single neurons to brain chaos. International Journal of Bifurcation and Chaos 1992;2:451–82. https://doi.org/10.1142/S0218127492000653
[18] Freeman WJ. Mechanism and significance of global coherence in scalp EEG. Current Opinion in Neurobiology 2015;31:199–205. DOI: 10.1016/j.conb.2014.11.008
[19] Haken H. Synergetics: An Introduction. Springer, Berlin, 1983.
[20] Prigogine I. Introduction to the Thermodynamics of Irreversible Processes. Interscience, New York, 1961.
[21] Freeman WJ. The use of codes to connect mental and material aspects of brain function. Physics of Life Reviews 2010;7: 260–1. DOI: 10.1016/j.plrev.2010.04.010
[22] Fingelkurts AA, Fingelkurts AA. Operational architectonics of the human brain biopotential field: Towards solving the mind-brain problem. Brain and Mind 2001;2:261–96. https://doi.org/10.1023/A:1014427822738
[23] Fingelkurts AA, Fingelkurts AA. Timing in cognition and EEG brain dynamics: discreteness versus continuity. Cognitive Processing 2006;7:135–62. DOI 10.1007/s10339-006-0035-0
[24] Fingelkurts AA, Fingelkurts AA, Neves CFH. Phenomenological architecture of a mind and Operational Architectonics of the brain: the unified metastable continuum. Journal of New Mathematics and Natural Computation 2009;5:221–44. https://doi.org/10.1142/S1793005709001258
[25] Fingelkurts AA, Fingelkurts AA, Neves CFH. Natural world physical, brain operational, and mind phenomenal space–time. Physics of Life Reviews 2010;7:195–249. https://doi.org/10.1016/j.plrev.2010.04.001
[26] Fingelkurts AA, Fingelkurts AA, Neves CFH. Consciousness as a phenomenon in the operational architectonics of brain organization: Criticality and self-organization considerations. Chaos, Solitons & Fractals 2013;55:13–31. https://doi.org/10.1016/j.chaos.2013.02.007
[27] Fingelkurts AA, Fingelkurts AA, Neves CFH. Kallio-Tamminen T. Brain-mind operational architectonics: At the boundary between quantum physics and Eastern metaphysics. Physics of Life Reviews 2019; ahead of print, https://doi.org/10.1016/j.plrev.2018.11.001
[28] Fingelkurts AA, Fingelkurts AA. Operational architectonics methodology for EEG analysis: Theory and results. Neuromethods 2015;91:1–59. DOI 10.1007/7657_2013_60