Below is the unedited draft of the article that has been accepted for publication
(© Chaos and Complexity Letters, 2017, V. 11, No 1, P. 81-91.)

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

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: andrew.fingelkurts@bm-science.com ; Url: www.bm-science.com/team/fingelkurts.html

Abstract:

Walter Jackson Freeman III (January 30, 1927 – April 24, 2016) was a true explorer, a Renaissance Man, who transcended the boundaries of disciplines and scientific knowledge. He has revolutionized the field of neuroscience, by bringing into it many pioneering ideas on brain dynamics. The authors of this brief essay address the main legacy of Walter Freeman through their framework of Operational Architectonics of brain-mind functioning that encompasses Freeman's mass action in the nervous system in the form of nested, dynamic neuronal assemblies and his cinematic model of cognitive dynamics, leading to emergence of consciousness. According to Operational Architectonics theory, the hierarchy of phenomenal world (features, patterns, objects, scenes) has its electrophysiological equivalent in an operational hierarchy of neuronal assemblies and nested spatial-temporal conglomerates of them in the form of operational modules (with different size and life-span), which correspond to the phenomenal entities of different complexity.

Keywords:

Walter Freeman, self-organisation, circular causality, metastability, operational architectonics, operational modules, EEG, operational synchrony, rapid transitional periods, consciousness, phenomenology.

ABBREVIATIONS

AM = Amplitude modulation; EEG = Electroencephalogram; EPSP = Excitatory postsynaptic potential; IPSP = inhibitory postsynaptic potential; OA = Operational architectonics; OM = Operational module; RTP = Rapid transitional period; OST = Operational space–time; IPST = Internal physical space–time; PST = Phenomenal (subjective) space-time.

Like other true explorers, we don’t know what we will find, and we don’t yet have the proper framework in which to describe whatever is there. This broad view from an open mind is my legacy.

Walter Jackson Freeman (2007a)

1. Introduction

He was an *Open Mind*. He was a *True Explorer*. He was a *Renaissance Man* (Kozma, 2016). Originated in Italy, the ideal of Renaissance Man, whereas a man’s capacity for personal development in a broad range of abilities and areas of knowledge is without limits (Debus, 1978) was exemplified with acute strength in Walter Jackson Freeman III (January 30, 1927 – April 24, 2016). Being a fourth generation physician, he studied medicine at Yale University, physics and mathematics at M.I.T., electronics and engineering in the Navy during World War II, and philosophy at the University of Chicago. He had also an encyclopedic knowledge in arts and humanities. But above all, Freeman revolutionized the field of neuroscience by bringing into it many pioneering ideas on brain dynamics that have been ahead of time by decades, and which transformed the field (Kozma, 2016).

The authors of this small essay were fortunate and privileged to enjoy the friendship with Walter Freeman and greatly appreciate long and thought-provoking discussions not only about neuroscience, but also politics, arts and universe. His groundbreaking work and ideas constantly inspire us in our own effort to cognize the greatest mystery in the world–the human brain–as the epicenter of cognition, personality, and selfhood, as well as a source of creativity, artistic expression and unconditional love.

In this article we seek briefly to address the main legacy of Walter Freeman through our framework of *Operational Architectonics (OA*) of brain-mind functioning (Fingelkurts & Fingelkurts, 2001, 2005, 2008, 2012, 2015; Fingelkurts et al., 2009, 2010, 2012a,b, 2013) that encompasses Freeman’s mass action in the nervous system in the form of nested, dynamic neuronal assemblies and cinematic model of cognitive dynamics, leading to emergence of consciousness.

2. Mass action in the nervous system

Freeman's Mass Action refers to the collective synaptic actions that neurons in the cortex exert on each other by synchronizing their potentials to create thought that guides intelligent behavior (Freeman, 1975) and eventually consciousness (Fingelkurts et al., 2013). A spatial pattern of coordinated activity among cooperative neurons manifests a ‘*wave packet*’ (Freeman, 2003) that requires synchronization of a shared carrier wave of the outputs of a large number of neurons over the neuronal assembly. Such a wave packet has a spatial amplitude modulation pattern that is expressed in high and low intensities of the dendritic currents, thus establishing *local fields* over the cortex that are reflected in the electroencephalogram (EEG) (Freeman, 2004a).

To relate the dynamic of neuronal masses at microscopic level through mesoscopic level to macroscopic functional structures Freeman introduced a *nested hierarchy* of so-called *K*-sets or models (for an overview, see Freeman, 2000a; Freeman & Erwin, 2008), which describes increasing complexity of structure and dynamical behavior of brain processes (Kozma & Freeman, 2001, 2003; Kozma et al., 2003, 2007). The letter 'K' stands for the name of biophysicist Aharon Katzir Katchalsky (1913-1972) who was one of the pioneers of emergent collective behaviors and dynamic patterns in chemical and biological systems (Katchalsky et al., 1974). In this hierarchy, the K0-set describes the dynamics of a cortical micro-column (~10 thousand neurons) that is governed by a point attractor with zero output and stays at equilibrium except when perturbed (Kozma et al., 2007). A KI-set subsumes K0-sets from a given cortical layer and maintains a state of non-zero background activity (Kozma, 2016). Similarly, a KII-set incorporates KI-sets from different populations (i.e. excitatory and inhibitory ones) allowing exhibition of limit cycle periodic oscillations at a narrow band frequency (Freeman & Erwin, 2008). A KIII-set made up of multiple interacting KII-sets modeling various cortical areas and capable of learning representations as well as do match-mismatch processing (Erwin, 1994). A KIV-set already covers many cortical areas (KIII-sets) across the hemisphere and could support simple forms of intentional behaviors with intermittent synchronization–desynchronization (Kozma & Freeman, 2003; Kozma et al., 2007). The highest level of the neocortical hierarchy is described by the KV-set that models the scale-free dynamics of neocortex operating on KIV-sets to support cognition (Freeman & Erwin, 2008).

2.1. OA perspective on mass action in the brain

It is an empirical fact that brain generates a highly structured dynamic in spatial and temporal domains (Fingelkurts et al., 2010) involving a range of frequencies (Basar et al., 2001) within an extracellular electric field. This field exists within brain internal physical space-time (IPST) (Fingelkurts et al., 2010) and is best captured by using EEG (Nunez, 2000). Indeed, multiple studies indicate that EEG is a highly organized macro-level electrophysiological phenomenon in the brain, which captures the operations of medium and large-scale cortical networks and which is remarkably correlated with behavior, cognition and consciousness (Nunez, 2000; John, 2001; Freeman, 2003; Fingelkurts et al., 2010, 2013; Yoo et al., 2014).

OA theory explores the *temporal* structure of information flow and the *spatial* inter-area interactions within a network of dynamical, transient, and functional neuronal assemblies (which activity is "hidden" in the complex non-stationary structure of EEG signal, Fingelkurts & Fingelkurts, 2015) by examining topographic couplings among *rapid transition processes (RTPs)* in the amplitude of the local EEG signals on the millisecond scale (Fingelkurts & Fingelkurts, 2001, 2008, 2015). In other words, at the EEG level the activity of neuronal assemblies is reflected in defined periods (segments) of quasi-stationarity within different frequency ranges framed by the RTPs (for review, see Fingelkurts & Fingelkurts, 2015). 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 (John, 2002), 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'; Freeman 2003) in the neuronal masses near to the recording electrode. Plikynas, based on Pribram and Bohm's holonomic brain theory (Pribram, 1991, 1999) and Vitello's dissipative quantum model of the brain (Pessa & Vitello, 2004; Vitello, 2001), as well as the orchestrated objective reduction theory proposed by Hameroff and Penrose (2013), has suggested (Plikynas, 2015) that such a non-random wave mode can be best described using the wave mechanics approach (Conte et al., 2009), such as wave/state function (Born, 1927) or linear operators (Haven & Khrennikov, 2013). Haken described such waves using the term "order parameter" (Haken, 1983) that is the result generated by the large numbers of neurons and synapses, and which creates and sustains a field that "enslaves" the neurons that actually generate it. These concepts resonate with that of "control parameter" portrayed by Abraham & Shaw (2005) and Cucker & Smale (2007) and others.

As we have discussed elsewhere operations of transient neuronal assemblies instantiated by emergent neural fields of self-organized activity are functionally isomorphic with simple phenomenal features (qualities) (Fingelkurts et al., 2010, 2013). It has been demonstrated that a set of 'feature extracting neural assemblies' decompose in parallel the complex stimulus into so-called *fragments of sensation* (Yufik, 1998; John, 2002; Orpwood, 2013). The detailed analysis of the complex structure of hierarchical architecture of EEG reveals the particular operational space-time (OST) which literally resides within the internal physical space-time (IPST) and is isomorphic to the PST (phenomenal space-time) level that constitutes the neurophysiological basis of mind phenomenal architecture (Fingelkurts et al., 2009, 2010, 2012a,b, 2013).

Thus, from the OA perspective, the focus is not so much on the anatomically formed neuronal assemblies but rather on the nested and dynamic hierarchy of fields produced by such neuronal assemblies in the course of supporting the complex dynamics of cognition and consciousness (Fingelkurts & Fingelkurts, 2009, 2012).

3. Cinematic model of cognitive dynamics

Freeman has proposed a *cinematographic* or *cinematic model* of cognitive dynamics (Freeman, 2006). According to this model the cortical code that supports cognition consists of repetitive spatial frames of metastable amplitude modulation (AM) patterns (Freeman 2000a,b, 2003, 2004a,b, 2005a, 2006) that are analogous to the movie *frame*s, while the rapid transition from one AM pattern to the other acts as the shutter (Freeman & Quian-Quiroga, 2013; Kozma & Freeman, 2014). Freeman proved experimentally that AM patterns (frames) embody the meaning of the stimuli rather than be their representations (Freeman, 1992; Barrie et al., 1996). In other words, the neocortical AM patterns showed a lack of invariance in respect to stimuli, but dependence on context and learning (meaning).

The major significance of this cinematic model of cognition was that it leads to the hypothesis that all sensory modalities share the same coding of their cognitive outputs in the form of cinematic sampling of the environment (Kozma, 2016). The cinematic synchronization of activity observed in multiple experiments in diverse cortex locations allows Freeman to propose that the rapid transition that initiates the AM 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. Freeman saw it as an important advantage allowing the extremely rapid updating of the local sensations/memories to incorporate contributions from all modalities within the time window defined by the duration of a global AM pattern (Freeman, 2015). Such emergent neural fields of self-organized activity framed within the AM patterns, following Haken's synergetics (Haken, 1983) and Prigogine's 'dissipative structures' (Prigogine, 1961) that feed on energy, extend attractor theory to the filed of self-organizing, far-from-equilibrium thermodynamics (Freeman, 2007a, 2008). In this context, Freeman suggested that the square of analytic amplitude (A^2) is an index of the dissipation rate of free energy (E) in the cortex (Freeman, 2004a). Here E signifies the metabolically derived energy that does work by driving ionic current and then is lost as heat. Freeman further proposed (Freeman, 2004a) that the spatiotemporal pattern of $A^2(t)$ when integrated over appropriate time and space windows may be used to estimate spatial patterns of the energy dissipated by excitatory and inhibitory populations to sustain the excitatory and inhibitory postsynaptic potentials (EPSPs/IPSPs).

3.1. OA perspective on the cinematic model of cognitive dynamics

OA model extends the cinematic model of Freeman from the homogeneous AM patterns to the hierarchically structured AM patterns. In agreement with the above OA analysis, we already know that local fields/operations generated by different transient neuronal assemblies are reflected in the local EEG signals in more or less stable (quasi-stationary) episodes framed by sudden changes in amplitude of the signal – RTPs (Fingelkurts & Fingelkurts, 2001, 2008, 2015). These quasi-stationary EEG segments (local fields of transient neuronal assemblies) present simple phenomenal features/operations, while the temporal synchronization of these EEG segments (local fields/operations) obtained from distributed neuronal assemblies produces complex phenomenal objects or operations (Fingelkurts et al., 2010, 2013). As a result of such synchronization the *metastable* brain states emerge that we have named *Operational Modules (OMs)* (Fingelkurts & Fingelkurts, 2001, 2008, 2015). Metastability means simultaneous co-existence of the seemingly opposing tendencies: autonomy and cooperation functioning (Kelso, 1995; Bressler & Kelso, 2001; Fingelkurts & Fingelkurts, 2004; Kelso & Tognoli, 2007). The OMs are metastable because they accommodate such tendencies in a natural way without involving any additional mechanism: there is intrinsic differences in the activity among neuronal assemblies that constitute every OM, whereas each neuronal assembly performs its own operation, while at the same time still retain a tendency to be coordinated together within the same OM to instantiate a more complex and holistic operation (Fingelkurts et al., 2010, 2013; Fingelkurts & Fingelkurts, 2015). We have argued elsewhere that at the phenomenological level the lasting OM is experienced as a "phenomenal present" of consciousness (Fingelkurts & Fingelkurts, 2014). In this sense, every OM is both the act (process) and the object (thing) at the same time.

Experimental studies have demonstrated that OMs (which are the result of synchronized local fields/operations produced by distributed transitive neuronal assemblies) could be further operationally synchronized between each other but now at different time scales, and thus forming a more abstract and more complex OM, which now constitutes the integrated experience (Fingelkurts et al., 2009, 2010, 2013). In such a way, every complex, nested OM is not just a superset of the simpler OMs, but rather is a natural union of abstractions about simpler OMs (Fingelkurts et al., 2010). Therefore, every OM has a rich combinatorial/nested complexity and the ability to rapidly reconfigure itself into a different OM or a set of OMs–the feature that is crucially important for the presentation of highly dynamic and structured phenomenal (subjective) experience (Fingelkurts et al., 2009, 2013). Such synchrony of local fields/operations among different neuronal assemblies serves to bind spatially dispersed phenomenal features (bases of sensations) of a multimodal stimulus or objects into integrated and unified patterns of qualities and further into the phenomenal objects or scenes with unique Gestalt and semantic windows (Fingelkurts et al., 2009).

According to OA, the succession of discrete and relatively stable OMs, which are separated by rapid transitive processes (i.e. abrupt changes of OMs), instantiates the succession of phenomenal images or thoughts, thus presenting a *stream of consciousness* (James, 1890). In this context, the metastable OMs at an OST level somehow isolate and "freeze" or "classify" at a PST level the ever changing and multiform cinematographic stream of conscious experiences. At the critical point of transition (RTP) in mental state, the OM undergoes a profound and rapid reconfiguration which is expressed through the following process: A set of coupled local bioelectrical fields produced by transient neuronal assemblies located in several brain areas (an OM), rapidly loses functional couplings with one another and establishes new couplings within another set of local bioelectrical fields (produced by transient neuronal assemblies), thus demarcating a new OM in the volumetric OST continuum of the brain (Fingelkurts et al., 2010).

According to Freeman and Vitiello (2006, 2008) the change of scales in a nested OA hierarchy of brain functional activity is dynamically achieved through the spontaneous breakdown of symmetry, which can be usefully modelled by the dissipative quantum model (Vitiello, 1995) or neuropercolation (Kozma et al., 2005). Both these approaches model collective and nested behavior of interacting neural populations in brain networks near critical states though from different perspectives (Kozma, 2016). Freeman stressed that the nested global patterns of brain electromagnetic field reflected in the form of nested OMs are the best available candidates that neuroscientists have for connecting neural (physical) activity to mental (subjective) activity (Freeman, 2010).

4. Conclusion

Neurophysiological observations and visionary conceptualizations made by Freeman over several decades pioneered and developed the view that brains are essentially non-equilibrium systems which do not come to a steady state even for a fraction of second (Freeman, 2005b; Freeman & Vitiello, 2006). Exactly this property of brains allows them, using dynamical patterns of activation in their operation to present dynamic and finely structured memories, concepts, actions and thoughts (Freeman, 2007b). Such brain's property motivated us in developing the theory of Operational Architectonics (OA) of the brain-mind functioning which was and continue to be constantly inspired by the Freeman's lifelong groundbreaking ideas.

According to OA, brain operational architectonics and mind phenomenological architecture are the *complementary aspects of the same unified metastable continuum*, whereas the metastability introduces the hierarchical coupling between the brain and mind while simultaneously allowing them to retain their individuality (Fingelkurts et al., 2009). Here the "phenomenal consciousness refers to the level of organization in the brain 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" (Fingelkurts et al., 2009; p. 223). Our analysis of the brain-mind OA revealed that the phenomenal level may be presented as the space where phenomenal experiences 'springs to life' through organized spatial–temporal patterns (operational modules, OMs) of lower (operational) level of brain organization (Fingelkurts & Fingelkurts, 2001, 2005; Fingelkurts et al., 2010, 2013). Importantly neither separate phenomenal objects, scenes or even self (Fingelkurts et al., 2012b, 2016a,b), nor the whole phenomenal level are somehow perceived by some other mental entities or brain systems. It is precisely for this reason that the nature of phenomenal objects or images is regarded as *self-presenting* (Fingelkurts et al., 2009, 2010, 2013). In this context, the hierarchy of phenomenal world (features, patterns, objects, scenes) has its electrophysiological equivalent in an operational hierarchy of neuronal assemblies and nested OMs, which correspond to the phenomenal entities of different complexity (Fingelkurts et al., 2009, 2010, 2013).

We hope that by our work we honor Walter Freeman's legacy and continue the direction in neurophysiology that Walter has started.

Conflict of interest

The authors confirm that this article content has no conflict of interest.

Acknowledgements

We would like also to thank D. Skarin for English editing.

Funding

The authors received no financial support or funding for the research, authorship, and/or publication of this article.

References

Abraham RH, Shaw CD (2005). *Dynamics: The Geometry of Behavior, Fourth Edition*. Aerial, Four part eBook. Library of Congress Control Number 00-135270, ISBN 0-942344-24-3.

Barrie JM, Freeman WJ, Lenhart MD. (1996). Spatiotemporal analysis of prepyriform, visual, auditory, and somesthetic surface EEGs in trained rabbits. *Journal of neurophysiology*, 76(1): 520–539.

Basar E, Basar-Eroglu C, Karakas S, Schurmann M. (2001). Gamma, alpha, delta, and theta oscillations govern cognitive processes, *International Journal of Psychophysiology*, 39: 241–248.

Born M. (1927). Physical aspects of quantum mechanics. *Nature*, 119: 354–357.

Bressler SL, Kelso JAS. (2001). Cortical coordination dynamics and cognition. *Trends in Cognitive Sciences*, 5: 26–36.

Conte E, Khrennikov AY, Todarello O, Federici A. Mendolicchio L, Zbilut JP. (2009). Mental states follow quantum mechanics during perception and cognition of ambiguous figures. *Open Systems & Information Dynamics*, 16(1): 1-17.

Cucker F, Smale S. (2007). Emergent behavior in flocks. *IEEE Transactions on Automatic Control*, 52: 852-862.

Debus A. (1978). *Man and Nature in the Renaissance*. Cambridge: Cambridge University Press.

Erwin H. (1994). The application of 'Katchalsky Networks' to radar pattern recognition. In: Pribram K (ed), *Origins: Brain and Self-Organization*. INNS Press and Lawrence Erlbaum Associates, Inc.; pp. 546-555.

Fingelkurts AA, Fingelkurts AA. (2001). Operational architectonics of the human brain biopotential field: towards solving the mind-brain problem. *Brain and Mind*, 2: 261–296.

Fingelkurts AA, Fingelkurts AA. (2004). Making complexity simpler: Multivariability and metastability in the brain. *The International Journal of Neuroscience*, 114: 843–862.

Fingelkurts AA, Fingelkurts AA. (2005). Mapping of the brain operational architectonics. In: Chen FJ (ed), *Focus on Brain Mapping Research*. Nova Science Publishers, Inc.; pp. 59–98.

Fingelkurts AA, Fingelkurts AA. (2008). Brain-mind operational architectonics imaging: Technical and methodological aspects. *The Open Neuroimaging Journal*, 2: 73–93.

Fingelkurts AA, Fingelkurts AA. (2012). Mind as a nested operational architectonics of the brain. Comment on “Neuroontology, neurobiological naturalism, and consciousness: a challenge to scientific reduction and a solution” by Todd E. Feinberg. *Physics of Life Reviews*, 9: 49–50.

Fingelkurts AA, Fingelkurts AA. (2014). Present moment, past, and future: mental kaleidoscope. *Frontiers in Psychology*, 5: 395. doi: 10.3389/fpsyg.2014.00395.

Fingelkurts AA, Fingelkurts AA. (20015). Operational architectonics methodology for EEG analysis: Theory and results. *Neuromethods*, 91: 1–59, DOI 10.1007/7657_2013_60.

Fingelkurts AA, Fingelkurts AA, Neves CFH. (2009). Phenomenological architecture of a mind and operational architectonics of the brain: The unified metastable continuum. *New Mathematics and Natural Computation*, 5(1): 221–244.

Fingelkurts AA, Fingelkurts AA, Neves CFH. (2010). Natural world physical, brain operational, and mind phenomenal space-time. *Physics of Life Reviews*, 7: 195–249.

Fingelkurts AA, Fingelkurts AA, Neves CFH. (2013). Consciousness as a phenomenon in the operational architectonics of brain organization: Criticality and self-organization considerations. *Chaos, Solitons, and Fractals*, 55: 13–31.

Fingelkurts AA, Fingelkurts AA, Bagnato S, Boccagni C, Galardi G. (2012a). Toward operational architectonics of consciousness: basic evidence from patients with severe cerebral injuries. *Cognitive Processing*, 13: 111–131.

Fingelkurts AA, Fingelkurts AA, Bagnato S, Boccagni C, Galardi G. (2012b). DMN operational synchrony relates to self-consciousness: Evidence from patients in vegetative and minimally conscious states. *The Open Neuroimaging Journal*, 6: 55-68.

Fingelkurts AA, Fingelkurts AA, Kallio-Tamminen T. (2016a). Long-term meditation training induced changes in the operational synchrony of default mode network modules during a resting state. *Cognitive Processing*, 17: 27–37.

Fingelkurts AA, Fingelkurts AA, Kallio-Tamminen T. (2016b). Trait lasting alteration of the brain default mode network in experienced meditators and the experiential selfhood. *Self and Identity*, 15(4): 381–393.

Freeman WJ. (1975). *Mass Action in the Nervous System: Examination of the Neurophysiological Basis of Adaptive Behaviour Through the EEG*. New York: Academic Press.

Freeman WJ. (1992). Tutorial on neurobiology: from single neurons to brain chaos. *International Journal of Bifurcation and Chaos*, 2(03): 451–482.

Freeman WJ. (2000a). *Neurodynamics. An Exploration of Mesoscopic Brain Dynamics*. London UK: Springer.

Freeman WJ. (2000b). *How Brains Make Up Their Minds*. Columbia University Press, New York.

Freeman WJ. (2003). The wave packet: an action potential for the 21st century. *Journal of Integrative Neuroscience*, 2: 3–30.

Freeman WJ. (2004a). Origin, structure, and role of background EEG activity. Part 1. Analytic amplitude. *Clinical Neurophysiology*, 115: 2077–2088.

Freeman WJ. (2004b). Origin, structure, and role of background EEG activity. Part 2. Analytic phase. *Clinical Neurophysiology*, 115: 2089–2107.

Freeman WJ. (2005a). Origin, structure, and role of background EEG activity. Part 3. Neural frame classification. *Clinical Neurophysiology*, 116: 1118–1129.

Freeman WJ. (2005b). Neural dynamics, volume transmission, and self-organization in brain dynamics. *Journal of Integrative Neuroscience*, 4: 407–421.

Freeman WJ. (2006). A cinematographic hypothesis of cortical dynamics in perception. *International Journal of Psychophysiology*, 60(2): 149–161.

Freeman WJ. (2007a). My legacy: a launch pad for exploring neocortex. In: *Keynote talk at the 2007 NSF Conference on Brain Network Dynamics*, University of California at Berkeley, January 26-27, 2007; Berkeley. https://archive.org/details/Brain_Network_Dynamics_2007-03_Walter_freeman.

Freeman WJ. (2007b). Indirect biological measures of consciousness from field studies of brains as dynamical systems. *Neural Networks*, 20: 1021–1031.

Freeman WJ. (2008). A pseudo-equilibrium thermodynamic model of information processing in nonlinear brain dynamics. *Neural Networks*, 21: 257–265.

Freeman WJ. (2010). The use of codes to connect mental and material aspects of brain function. *Physics of Life Reviews*, 7(2): 260–261.

Freeman WJ. (2015). Mechanism and significance of global coherence in scalp EEG. *Current Opinion in Neurobiology*, 31: 199–205.

Freeman WJ, Vitiello G. (2006). Nonlinear brain dynamics as macroscopic manifestation of underlying many-body field dynamics. *Physics of Life Reviews*, 3: 93–118.

Freeman WJ, Vitiello G. (2008). Dissipation and spontaneous symmetry breaking in brain dynamics. *Journal of Physics, A: Mathematical and Theoretical*, 41: 304042.

Freeman WJ, Erwin H, Freeman WJ. (2008). K-set. *Scholarpedia*, 3(2): 3238. doi:10.4249/scholarpedia.3238

Freeman WJ, Quian-Quiroga R. (2013). *Imaging Brain Function with EEG*. Springer, New York.

Haken H. (1983). *Synergetics: An Introduction*. Springer, Berlin.

Hameroff S, Penrose R. (2014). Consciousness in the universe: A review of the ‘Orch OR’ theory. *Physics of Life Reviews*, 11: 39–78.

Haven E, Khrennikov A. (2013). *Quantum Social Science*. Cambridge university press, UK.

John ER. (2001). A field theory of consciousness. *Consciousness and Cognition*, 9–10: 184–213.

John ER. (2002). The neurophysics of consciousness. *Brain Research Reviews*, 39: 1–28.

Katchalsky A, Rowland V, Blumenthal R. (1974). *Dynamic Patterns of Brain Cell Assemblies*. MIT Press, Cambridge.

Kelso JAS. (1995). *Dynamic Patterns: The Self-Organization of Brain and Behavior*. MIT Press, Cambridge, MA.

Kelso JAS, Tognoli E. (2007). Toward a complementary neuroscience: Metastable coordination dynamics of the brain. In: Kozma R, Perlovsky L (eds). *Neurodynamics of Higher-Level Cognition and Consciousness*. Springer, Heidelberg, pp. 39–59.

Kozma R. (2016). Reflections on a giant of brain science: How lucky we are having Walter J. Freeman as our beacon in cognitive neurodynamics research. *Cognitive Neurodynamics*, 10(6): 457-469.

Kozma R, Freeman WJ. (2001). Chaotic resonance—methods and applications for robust classification of noisy and variable patterns. *International Journal of Bifurcation and Chaos*, 11(06): 1607–1629.

Kozma R, Freeman WJ. (2003). Basic principles of the KIV model and its application to the navigation problem. *Journal of Integrative Neuroscience*, 2(1): 125–146.

Kozma R, Freeman WJ. (2014) On neural substrates of cognition: theory, experiments and application in brain computer interfaces. In: *Proceedings of the 2014 annals oak ridge national laboratory biomedical science and engineering center conference (BSEC2014)*. IEEE Press, pp. 1–4.

Kozma R, Freeman WJ, Erdi P. (2003). The KIV model: nonlinear spatio-temporal dynamics of the primordial vertebrate forebrain. *Neurocomputing*, 52: 819–826.

Kozma R, Puljic M, Balister P, Bollobas B, Freeman WJ. (2005). Phase transitions in the neuropercolation model of neural populations with mixed local and non-local interactions. *Biological Cybernetics*, 92(6): 367–379.

Kozma R, Aghazarian H, Huntsberger T, Tunstel E, Freeman WJ. (2007). Computational aspects of cognition and consciousness in intelligent devices. *IEEE Computational Intelligence Magazine*, 2(3): 53–64.

Nunez PL. (2000). Toward a quantitative description of large-scale neocortical dynamic function and EEG. *The Behavioral and Brain Sciences*, 23: 371–398.

Orpwood R. (2013). Qualia could arise from information processing in local cortical networks. *Frontiers in Psychology*, 4: 121. doi:10.3389/fpsyg.2013.00121.

Pessa E, Vitello G. (2004). Quantum noise induced entanglement and chaos in the dissipative quantum model of brain. *International Journal of Modern Physics B*, 18(6): 841-858.

Plikynas D. (2015). Oscillating agent model: Quantum approach. *NeuroQuantology*, 13(1): 20-34.

Pribram KH. (1991). *Brain and Perception: Holonomy and Structure in Figural Processing*. Lawrence Erlbaum Associates, Hillsdale.

Pribram KH. (1999). Quantum holography: Is it relevant to brain function? *Information Sciences*, 115(1–4): 97–102.

Prigogine I. (1961). *Introduction to the Thermodynamics of Irreversible Processes*. Interscience, New York.

Vitiello G. (1995). Dissipation and memory capacity in the quantum brain model. *International Journal of Modern Physics B*, 9: 973.

Vitiello G. (2001). *My Double Unveiled: The Dissipative Quantum Model of Brain (Advances in Consciousness Research)*. John Benjamins Pub Co, Amsterdam.

Yoo J, Kwon J, Choe Y, (2014), Predictable internal brain dynamics in EEG and its relation to conscious states. *Frontiers in Neurorobotics*, 8: 18. doi: 10.3389/fnbot.2014.00018

Yufik YM. (1998). Virtual associative networks: a framework for cognitive modelling. In: Pribram KH (ed). *Brain and Values*. Lawence Erlbaum Associates, New York, NY; pp. 109–177.