



Comment

The key role of coexisting opposite dynamic behaviors in brains and in cognition.

Comment on “Chimera states in neuronal networks: A review”

by M. Perc et al.

Robert Kozma^{a,b,*}

^a Department of Computer Science, University of Massachusetts Amherst, MA 01003, USA

^b Department of Mathematical Sciences, The University of Memphis, TN 38152, USA

Received 13 March 2019; accepted 14 March 2019

Available online 19 March 2019

Communicated by J. Fontanari

The coexistence of opposing dynamical states in a single system is an important and often baffling behavior observed in many fields of science and engineering. An example of such behavior is the coexistence of macroscopic order and microscopic disorder in hierarchical systems, like lasers and semiconductors, illustrating Haken’s principle of synergetics, when the collection of particles creates an order parameter, which enslaves the movement of the individuals in circular causality [1]. Coordination dynamics is a closely related area, when complementary aspects of human manual coordination reveal multistability and intermittent phase transitions, which are interpreted according to the Haken-Bunz-Kelso model through coupled nonlinear dynamics [2]. Kelso’s principle of complementarity provides a powerful, unifying framework for chimera dynamics by describing the coexistence of opposing aspects due to spontaneous symmetry breaking [3].

The target article [4] provides a concise review on chimera dynamics in neural networks. This is a very timely undertaking to bridge the gap between mathematical perfection and biological reality. The authors cover the rapid development of the field of chimera dynamics, following the groundbreaking works in the early 2000’s. They summarize the mathematical and statistical tools to rigorously model and analyze chimera effects in neural systems. The terminology “chimera” is very useful in helping to identify the research and to focus the attention and efforts on this field. It is worth mentioning that the coexistence of coherent and incoherent states in a system, in particular in neural systems and brains, has been observed and described well before the start of this century. Researchers at that time, more than 20 years ago, did not use the terminology “chimera,” still described related behaviors. I believe it is useful for the development of the field to look at those early roots, particularly in the context of neural networks. By doing so, we could build bridges between scientific disciplines which address similar phenomena, just use different languages.

Without claiming completeness, here are a few works from the significant literature on transient dynamics in brains and neural systems, related to chimeras, such as Friston’s brain transients [5], Tsuda’s chaotic itinerancy [6], and Rabinovich heteroclinic chimera effects [7]. Predating the introduction of rigorous chimera concepts, the work [8]

DOI of original article: <https://doi.org/10.1016/j.plrev.2018.09.003>.

* Correspondence to: Department of Mathematical Sciences, The University of Memphis, TN 38152, USA.

E-mail address: rkozma@memphis.edu.

describes intermediate-range coupling in coupled-map lattices modeling long-axons in neural tissues, having phase diagrams with regions of high synchrony and low synchrony producing chimera effects deeply in the chaotic region of these lattices. It is important to mention Freeman's lifetime work on studying spatial and temporal synchronization and desynchronization of electrocorticogram (ECoG) recordings with arrays of electrodes placed over the sensory cortices of animals trained according to classical conditioning paradigm [9–11]. These electrode arrays measured the coexistence of limit cycle and chaotic dynamics, manifesting chimera dynamics. ECoG measurements with intermittent transitions between synchronized and desynchronized brain states are interpreted in the framework of the cinematic theory of cognition. In the cinematic theory [4,12], neocortex processes information in metastable frames at a rate of 5-6 frames per second, while various dynamical regimes coexist over the metastable activity frames, in line with chimera dynamics.

Chimera effects may have further applications in intelligent systems. Recent advances in brain imaging document the emergence of intelligent behavior as the result of the delicate balance between fragmentation of incoherent localized components (granules, microcolumns) and global dominance of coherent states across the hemisphere [13]. In the field of artificial intelligence (AI), there is a contentious debate between proponents of top-down (formal) and bottom-up (emergent) approaches to AI. Cutting edge brain monitoring experiments indicate that these complementary approaches must coexist in successful and sustainable AI designs [14]. Although the aforementioned problems may not satisfy the strict definition of chimeras, and brains as dynamical system are certainly messy and imperfect, still they represent the real world. It would be very beneficial to be able to link the abstract concept of chimera to these practically important problems of science, technology, and the society.

Acknowledgements

Research reported in this work has been supported in part by DARPA/MTO research grant HR0011-16-1-0006 on Superior Artificial intelligence.

References

- [1] Haken H. *Synergetics: introduction and advanced topics*. Berlin: Springer; 2004.
- [2] Kelso JS. *Dynamic patterns: the self-organization of brain and behavior*. Cambridge, MA: MIT Press; 1997.
- [3] Kelso JS, Engstrom DA. *The complementary nature*. Cambridge, MA: MIT Press; 2006.
- [4] Majhi S, Bera BK, Ghosh D, Perc M. Chimera states in neuronal networks: a review. *Phys Life Rev* 2019;28:100–21. <https://doi.org/10.1016/j.plrev.2018.09.003> [in this issue].
- [5] Friston KJ. The labile brain. I. Neuronal transients and nonlinear coupling. *Philos Trans R Soc Lond B, Biol Sci* 2000;355(1394):215–36.
- [6] Tsuda I. Toward an interpretation of dynamic neural activity in terms of chaotic dynamical systems. *Behav Brain Sci* 2001;24(5):793–810.
- [7] Rabinovich MI, Sokolov Y, Kozma R. Robust sequential working memory recall in heterogeneous cognitive networks. *Front Syst Neurosci* 2014;8:220.
- [8] Kozma R. Intermediate-range coupling generates low-dimensional attractors deeply in the chaotic region of one-dimensional lattices. *Phys Lett A* 1998;244(1–3):85–91.
- [9] Freeman WJ, Baird B. Relation of olfactory EEG to behavior: spatial analysis. *Behav Neurosci* 1987;101(3):393.
- [10] Freeman WJ. The physiology of perception. *Sci Am* 1991;264(2):78–87.
- [11] Freeman WJ, Kozma R. Local-global interactions and the role of mesoscopic (intermediate-range) elements in brain dynamics. *Behav Brain Sci* 2000;23(3):401–2.
- [12] Kozma R, Freeman WJ. Intermittent spatio-temporal de-synchronization and sequenced synchrony in ECoG signals. *Chaos* 2008;18:037131.
- [13] Kozma R, Freeman WJ. *Cognitive phase transitions in the cerebral cortex: enhancing the neuron doctrine by modeling neural fields*. New York: Springer; 2016.
- [14] Kozma R. Computers versus brains: game is over or more to come?. In: Kozma R, Alippi C, Choe Y, Morabito C, editors. *Artificial intelligence in the age of neural networks and brain computing*. Elsevier Imprint, Academic Press. ISBN 9780128154809, 2018. p. 205–18.