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Comment

Different properties of neuronal networks matter for the emergence of chimera states

Comment on "Chimera states in neuronal networks: A review" by Majhi et al.

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In last decades, the study of neuronal dynamics has witnessed considerable attention from the perspective of complex systems. In fact, neuronal networks are self-organized systems, representing emergent collective behaviors such as synchronization and chimera patterns. Majhi et al. [1] presented an excellent and comprehensive review of chimera states in neuronal networks. They investigated related researches in the literature to discuss the role of different synaptic connections, neural models, coupling schemes and network structures, on the emergence of chimera patterns. Chimera state was first started from the observation of coexistent synchronized oscillators with unique frequency and desynchronized oscillators with distributed frequencies, in non-locally coupled phase oscillators [2]. It has been in focus of many researches in different fields. In addition to phase oscillators, some studies have revealed the existence of chimera patterns in chaotic and periodic maps [3], pendulum-like oscillators [4] and neuronal networks [1]. According to the observed spatiotemporal patterns, different types of chimeras, including imperfect chimera [5], chimera death [6], alternating chimera [7], traveling chimera [8], etc. have been introduced. It seems that the different mechanism of these chimera types can lead them to be relevant to distinct phenomena. As completely stated in the review [1], chimera states have strong associations with neural functions such as uni-hemispheric sleep in animals, as well as many malfunctions including Epileptic seizure and Parkinson disease [9,10]. Therefore, the survey of chimera states in neuronal network is of crucial importance. Although there are some developments in this area, many attempts and opportunities are remained to concentrate on all aspects.

The collective behaviors in complex networks with single layer, is different from those with multilayer structure. In their review, Majhi et al. [1] have competently described the advantage of using multilayer networks in different systems and reviewed the previous works on chimera states in multilayer networks. The multilayer network is a novel tool for modeling biological systems which include complex interactions [11]. The concept of multilayer and multiplex systems provides comprising several categories of connectivity [12]. The information transmissions between the nerve cells occur through synaptic and non-synaptic communications. In synaptic communications, the information

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flows from one neuron to another, by chemical or electrical neurotransmission, that were well explained in the review [1]. The non-synaptic communications, which are also called ephaptic couplings, take place via the electrical current flow through the extracellular space and are associated with the electric field effects. The ephaptic interactions have considerable significance in restoring significant brain functions, by release of transmitters in the extra synaptic space [13]. Actually, the neural functions are the result of all of these communication paths, which must be considered. The multilayer framework for neuronal networks can overcome limitations of considering only a single type of synaptic interactions. An example of studying a multilayer structure with two coupling types, has been done by Xu et al. [14]. They have studied a two-layer network of Hindmarsh-Rose neurons with intra-layer electrical synapses and inter-layer ephaptic couplings. The chimera states and synchronization were investigated in the network and the effects of electromagnetic induction on neural dynamics were discussed. Therefore, the multilayer structure yields the applicability of multiple neural communications. So, more challenges and efforts are needed for studying chimera states in hypernetworks.

The brain functions are not static in time, temporally and spatially. Therefore, the brain activities are naturally non-stationary. Kaplan et al. [15] have stated that according to their research, the non-stationarity in the brain is the result of alternations of intrinsic metastable states of a population of neurons, when performing specific functions. So, it is expected that the spatiotemporal patterns obtained from neuronal networks, be non-stationary. Non-stationary Chimeras are defined as the chimera states, in which the position of coherent and incoherent oscillators vary in time. The non-stationary chimera state in neuronal networks, has been studied by Wei et al. [16]. They considered a ring network of coupled Hindmarsh-Rose neurons with injected external alternating current, which is characterized by bi-stability. In this network, the neurons were coupled simply through diffusive electrical synapses. Investigating this network demonstrated that non-stationary chimeras were emerged in different cases of local, non-local and global couplings. Recently, chimera states were also observed in locally coupled neuronal networks under two- [17] and three-dimensional [18] grid of network configurations.

As nicely mentioned in the review [1], investigating chimera states in neuronal networks with time-variant connections has achieved negligible attention. However, there are some studies on chimera states in temporal coupled phase oscillators [19], but the chimera states on neuronal networks have been investigated in static network structures. Definitely the biological systems are time-varying networks. In the nervous system, the rate of using dendrites or release of neurotransmitters determines the strength of the connections of neighboring neurons, which vary in time [20]. Changes in the synaptic strength or synaptic connections are known as neural plasticity [21,22]. The plasticity can change the excitability of the neurons and control their behaviors [21]. It has been proved that plasticity has strong associations with memory processes, as well as adjusting the states, such as sleep wake transitions [21]. Due to these biological facts, considering temporal neuronal networks can be more realistic. Recently a few studies have focused on the synchronization of temporal neuronal networks [23–25]. For example, Rakshit et al. [24] have studied a two-layer neuronal network, with chemical and electrical intralayer connections and electrical interlayer couplings. The intralayer connections were supposed to be variable in time with a definite rewiring frequency. They analyzed the network analytically and obtained the inter and intra layer synchrony by calculating the master stability function.

Overall, the review proposed by Majhi et al. [1] gives an insight into perceiving the current advances in the investigation of chimera states in neuronal networks. Analyzing the chimera states and recognizing their mechanisms can help in better identifying specific brain disorders and even controlling them. In order to increase the robustness of the interpretation of results and make the findings more realistic, various aspects and properties of neural connections must be incorporated.

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