Chimera patterns as complex systems: Examples from two-dimensional networks of coupled neurons

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Chimeras are hybrid states that emerge spontaneously, combining both coherent and incoherent parts [1]. First found in identical and symmetrically coupled phase oscillators [2], chimera states have been the focus of extensive research for over a decade now. Both theoretical and experimental works have shown that this counter-intuitive collective phenomenon may arise in numerous systems including mechanical, chemical, electro-chemical, electro-optical, electronic, and superconducting coupled oscillators. The phenomenon of chimera states has also been addressed in networks of biological neural oscillators. In this context, theoretical studies have considered Hindmarsh-Rose, leaky-integrate-and-fire, SNIPER/SNIC, and FitzHugh-Nagumo models in one-dimensional ring configurations and recently also in more complex network topologies.

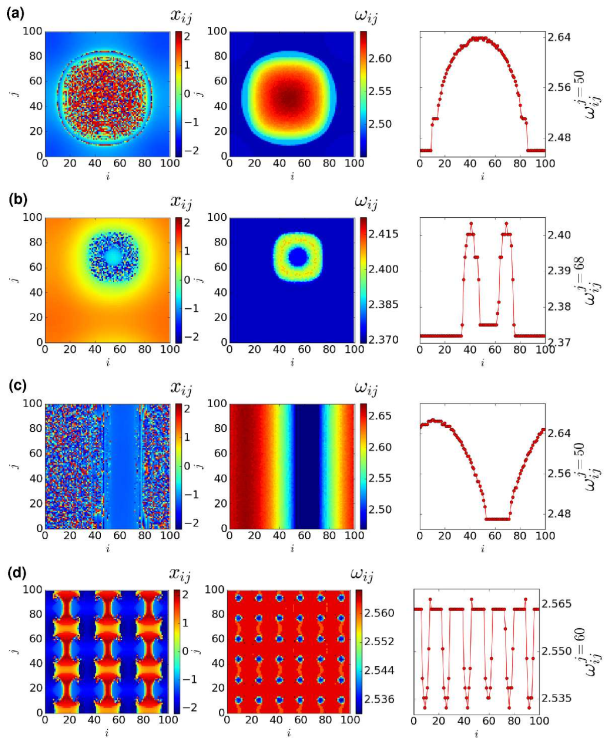

Figure 1: Examples of chimera states for the FitzHugh-Nagumo model: (a) spot, (b) ring, (c) stripe, and (d) grid. The left, center, and right panels show snapshots of the activator variable x_{ij}, the mean phase velocity ω_{ij}, and a section of ω_{ij}, respectively. The index $i, j = 1, \ldots, N$ refers to the position on the two-dimensional lattice.

In our contribution, we consider a two-dimensional network configuration using two different models of neuronal oscillators with nonlocal coupling [3]. This can be seen as an intermediate step extending the intensively studied one-dimensional ring geometries towards a three-dimensional arrangement of the brain. FitzHugh-Nagumo and leaky-integrate-and-fire models are chosen as widely used description for neuronal activity. Finding common synchronization patterns in the two dynamical networks could point the way toward identification of universal dynamical features present in brain activity. The oscillators are arranged on a two-dimensional lattice and couple isotropically to all other oscillators within a finite range.

The aim of the current study is to discuss the occurrence of stable chimera patterns induced by the nonlocal connectivity and to identify patterns that are common in both models. For the FitzHugh-Nagumo model a phase connectivity parameter and the coupling range are varied, while the coupling strength is kept fixed. For the leaky-integrate-and-fire model the coupling strength, coupling range, and refractory period are varied.

Our comparative study demonstrates that, although the dynamics of the single neurons in the two models are described by different equations, both systems support hybrid states composed of coherent and incoherent regions when the elements are coupled. We identify a number of common chimera patterns (cf. Fig. 1): spots, grids, rings, and stripes. Our simulations suggest that the coherent/incoherent pattern characteristics follow similar growth rules. For example, the diameter of the ring patterns grows linearly with the coupling range in both models. Other phenomena typical in nonlinear systems such as multistability and transitions between different patterns are observed as well. The common behavior of the two models supports the universal occurrence of these peculiar dynamics: Chimera patterns are persistent and independent of the specificity of the model, provided that the models retain the characteristics of spiky limit cycles.

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