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PAPER

Spiral wave dynamics in a neuronal network model

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Abstract

Spiral waves are spatial-temporal patterns that can emerge in different systems as heart tissues, chemical oscillators, ecological networks and the brain. These waves have been identified in the neocortex of turtles, rats, and humans, particularly during sleep-like states. Although their functions in cognitive activities remain until now poorly understood, these patterns are related to cortical activity modulation and contribute to cortical processing. In this work, ,we construct a neuronal network layer based on the spatial distribution of pyramidal neurons. Our main goal is to investigate how local connectivity and coupling strength are associated with the emergence of spiral waves. Therefore, we propose a trustworthy method capable of detecting different wave patterns, based on local and global phase order parameters. As a result, we find that the range of connection radius (R) plays a crucial role in the appearance of spiral waves. For $R < 20$ μm, only asynchronous activity is observed due to small number of connections. The coupling strength (g_{syn}) greatly influences the pattern transitions for higher R, where spikes and bursts firing patterns can be observed in spiral and non-spiral waves. Finally, we show that for some values of R and g_{syn} bistable states of wave patterns are obtained.

1. Introduction

It has been identified astonishing spatiotemporal patterns which can be seen in 2D and 3D networks with non-local interactions, named spiral wave chimera states. It consists of synchronous oscillators which rotate around a desynchronized core, which is called phase singularity (PS) [1]. This pattern is seen in a variety of fields. In heart tissues [2–4] spiral waves have been extensively studied due their correlation with some heart issues, such as ventricular tachycardia and ventricular fibrillation. Davidenko *et al* [5] demonstrated the emergence of spiral waves in sheep and dog epicardial muscle by means of potentiometric dye with charge-coupled device imaging technology. The authors showed that sometimes the PS drifted away from its original position and dissipated in the tissue border, this drift was associated with a Doppler shift. Supression of spiral waves in the atrial cardiomyocytes can be done by means of optogenetics [6]. Spiral waves are able to emerge in ecological network composed of diffusible prey-predator species locally coupled [7]. Totz *et al* [8] observed the emergence of spiral wave chimeras in large populations of coupled chemical oscillators, they have studied the motion and splitting of the asynchronous core.