Models of coupled oscillators to study the parcellation of the brain pial arterial network

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At the surface of the brain lies a two-dimensional network of arteries known as the pial network, that provides blood to the whole cortex. Because of the spatial and temporal variability of neuronal activity, the diameter of pial arteries is constantly tuned in order to locally adjust the blood influx, through a process called neurovascular coupling. Oscillations in the diameter of blood vessels, a phenomenon known as vasomotion, is observed in pial arteries. It is an intrinsic phenomenon, happening even in the absence of neuronal activity; however, vasomotion is also locally phase-locked to oscillations in the underlying neuronal activity. The spatial inhomogeneity of this neuronal driving leads to patterns of coherent oscillations that effectively parcellates the pial network in regions of different vasomotor frequencies. In an effort to understand the parcellation of the pial network, we modeled a one-dimensional continuous oscillatory medium with a spatially varying natural frequency and diffusive coupling, using the Ginzburg-Landau equation. Exploring parameters and boundary conditions, we reproduced the observed phenomenology and found the system to display very interesting dynamics. In particular, it can divide in regions of different average frequencies, and exhibits space-time defects at the transition between two regions. Using simulations and analytical calculations, we were able to gain understanding on the stability of oscillations, on how the number of regions of different average frequency varies, on when synchronisation is achieved, and on the appearance of space-time defects — thus fully characterizing the phase diagram of a Ginzburg-Landau model with a gradient of frequencies. Gaining understanding of this type of system could contribute to the improvement of neuronal activity imaging techniques, such as BOLD fMRI. Additionally, this work could be of interest for extended oscillatory systems displaying a spatially inhomogeneous natural frequency or driving, such as the mammalian intestine (peristalsis).