BMC Neuroscience

BioMed Central

Poster presentation

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Bifurcation analysis of synchronization dynamics in cortical feed-forward networks in novel coordinates

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from Eighteenth Annual Computational Neuroscience Meeting: CNS*2009
Berlin, Germany. 18–23 July 2009

Published: 13 July 2009

BMC Neuroscience 2009, **10**(Suppl 1):P256 doi:10.1186/1471-2202-10-S1-P256

This abstract is available from: http://www.biomedcentral.com/1471-2202/10/S1/P256

In a synfire chain [1], synchronous activity in one group of neurons can excite neurons of the next group to fire synchronously themselves. If this mechanism repeats itself from group to group, a "pulse packet" of spiking activity can travel down the chain. For a homogeneous chain, the spike packet profile of one group is uniquely mapped to the packet profile of the successive group, thereby establishing a map for the packet dynamics in the space of pulse-shaped functions. A stable packet corresponds to a stable fixed point of this infinite-dimensional map.

In a previous contribution [2], we derived an explicit, analytical expression for this map, which permits a quick generation of the pulse evolution. However, for the analysis of the dynamical system, it is necessary to reduce the dimensions of the map by determining a small number of relevant variables. A reduced two-dimensional map for the variables "pulse width" and "pulse area" has been proposed [3]. In that paper, extensive numerical simulations have revealed the phase plane structure of the 2D map. In accordance, our theoretical map quantitatively reproduces the same phase portrait for the full dynamical range, including sub- and superthreshold depolarizations. The intricate functional form of the expression, however, does not allow for an analytical calculation of width and area of the pulses, so that one again has to resort to numerical evaluations.

Based on our recent theoretical work [2,4], we find here that natural variables of the synchronization dynamics are the amplitude and the rise time of the membrane potential excursion caused by an incoming pulse packet. The amplitude of the membrane depolarization of neurons in one group is dominated by the amplitude in the previous group. The relationship has a sigmoidal shape and permits a bifurcation analysis. This enables us to study the conditions under which the reduced one-dimensional map exhibits stable and unstable fixed points. The latter corresponds to the separatrix between unstable and stable pulse propagation in the original analysis. We emphasize that the reduction to a 1D map promises much simpler analytical treatments of theoretical problems of synfire dynamics.

Acknowledgements

TS thanks Benjamin Lindner for helpful discussions. Partially funded by EU Grant 15879 (FACETS), BMBF Grant 01GQ0420 to BCCN Freiburg, Next-Generation Supercomputer Project of MEXT, Japan, and the Helmholtz Alliance on Systems Biology.

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