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First-to-fire neurons induced by clustering in sparse networks

Olav Stetter*[1], Anna Levina[1,2] and Theo Geisel[1,2]

Address: [1]Department of Nonlinear Dynamics, Max-Planck-Institute for Dynamics and Self-Organization, D37073 Göttingen, Germany and [2]Bernstein Center for Computational Neuroscience, D37073 Göttingen, Germany

Email: Olav Stetter* - olav.stetter@nld.ds.mpg.de

* Corresponding author

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Recent studies demonstrated the dependence of the temporal evolution of avalanches in neural networks on the specific parameters of the network like connection strength and network size [1]. The dependence of the averaged network activity on the strength of an external stimulus has also been shown experimentally [2]. Additionally, in these experiments, the temporal order of activation has been shown to be non-random. There exists a topological hierarchy [3] with a number of neurons that are more likely to take part in an early phase of synchronized network activity ("burst"). Their activity can in fact be used to predict the "following" network behavior [4]. An exact characterization of these "burst initiation zones," however, is missing.

Here we ask under which topological conditions neural networks display such non-random behavior. As a model system we use a directed sparsely connected random graph with integrate-and-fire neurons. We observe that neurons with a high in-degree tend to be active slightly earlier during an avalanche. In fact, we show analytically that the mean first firing time of a neuron can be approximated by being proportional to $C_1 \log(C_2/k + 1)$ with the in-degree of a node k and constants C_1 and C_2 depending on the parameters of the network. Since the degree distribution $P_k(k)$ is known, we can calculate the variance in the time of the first spike.

We then show how the introduction of clustering leads to a large increase in this variance. To do this we extend our model by giving each node a 2D position and using a distance-dependent connection probability (proportional to r^{-4}). The mean first firing time, however, will then not only depend on the in-degree k of a node, but also on its neighborhood. To take this into account we characterize the different topologies using the Katz status index. We demonstrate that, using an appropriate coefficient, this index is much more efficient in predicting first-to-fire neurons than the degree alone.

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