SPIKE – CLUSTERING IN NEURONAL CULTURES: SIMULATIONS VS. EXPERIMENTAL DATA

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Abstract

Computational models of cultured cortical networks require either synaptic noise or pacemaker neurons to trigger activity. We aimed to investigate the behavior of noise-driven neuronal networks (NN). We show that NN with synaptic differentiation reproduces experimental activity better than network with uniformly distributed synaptic weights.

1 Introduction

Biologically inspired neuronal networks (NN) have major applications in the field of Artificial Intelligence. Yet none of them can achieve the processing power of their biological original. In order to bring NN models closer to their original, it is necessary to learn more about biological NN. Neuronal cultures (NC) provide a good basis to study and analysis of biological neuronal networks. Combined with simulation models it can reveal mechanisms of typical characteristics of spontaneous spiking behavior.

Cortical NC typically show bursting behavior, which is basically represented as spike-clusters throughout all recorded neurons. This behavior is usually characterized by intra- and inter- burst parameters. Several experimental studies showed a big variety of those parameters. In this paper we analyzed recorded data and then simulated spike clusters as acquired from several cortical NC of different age. We show that in fact network bursts and the interval in between may vary widely, indicating a weakly synchronous operational regime. In this paper we put forward a hypothesis to explain the observed bursting patterns in cultures. Inspired by several experimental observations about the set of triggering neurons, we propose that the typical feature of this set of neurons is their strong outward synapses. This allows them to keep leadership in network activity and build heterogeneous distribution in synaptic weights.

We show that noise-driven models require such heterogeneity of synaptic weights to fit the range of experimentally observed bursting patterns.

2 Methods

In total 7 cultures were recorded for several weeks in vitro. We quantified the variability of temporal firing rate using a dispersion index for spike counts in 5ms time window referred to as the Fano factor: FF = σ^2/μ, where σ^2 is the variance and μ is the mean of spike counts. FF=1 indicates random firing whereas high FF values indicate bursting. This quantification facilitates identification of spike clusters, which indicate bursting behavior in the NN activity.

Then, we simulated these cultures with a NN model based on recurrent NNs with random sparse connectivity maps. To mimic synaptic or membrane noise each neuron received a Poissonian spike train with mean firing rate (F_n). We used the Izhikevich neuronal model to reproduce the whole range of physiological variability of basic cortical neuronal spiking forms as our cultures contained a random mixture of cortical cells.

We studied firing behavior in two types of NN models: one with homogeneous distribution of synaptic weights (all neurons had synapses with normally distributed weights (W_e) between 0.01 and 1 mV), and the other had a subset of (P) neurons whose synaptic weights (W_p) were A=10 times higher ($W_p = W_e*A$). Other parameters remained the same.

3 Results and discussion

In all recordings FF ranged from 5 to about 70, indicating bursting.

At low F_n both models generated random Poissonian spikes with FF ≈ 1. Then with higher F_n, the first NN model abruptly switched to completely synchronous and regular bursting (FF = 130), whereas the second model could reproduce experimental data much better, showing a smooth change to a bursting regime with gradual increase of FF from 1 to 100. Similar change was observed while playing with other parameters such as network connectivity, transmission delays, etc.

Our results support earlier experimental observations that suggested the existence of a set of triggering neurons. Such a set may be characterized by stronger outward synapses.