Delayed Feedback Control of Oscillations in a Spiking Neural Network Model of Aberrant Brain Dynamics

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Abstract: Open-loop methods for deep-brain stimulation have been effective in controlling aberrant activity associated with various neurological disorders such as Parkinson's disease. Recently, adaptive control strategies have emerged, which promise to increase the efficacy of these existing stimulation methods. Here, we investigate the effects of closed-loop control schemes in networks of spiking neurons that operate in a synchronous irregular regime. In this regime the population activity is highly regular, despite the fact that individual neurons fire stochastically. These oscillations are known to be robust compared to synchronous regular activity and are not easily affected by noise or heterogeneity. We design an appropriate control strategy, based on delayed state-feedback to quench these stochastic oscillations. We also show that our control protocol is able to restore the network transfer function thus overcoming the undesired side-effects of existing methods.

During the last two decades various methods such as high-frequency deep brain stimulation (DBS) have been developed for the treatment of oscillations associated with several pathological conditions, e.g. in Parkinson's disease (Perlmutter, 2006). These methods have been traditionally based on open-loop strategies, that is on fixed, predetermined stimulation parameters. They have been highly effective in quenching the aberrant oscillations and, thus, in alleviating the clinical symptoms. At the same time, however, they introduce undesirable side effects and in most cases they do not restore the network transfer function. Recently, adaptive control strategies have emerged, which promise to increase the efficacy of the existing stimulation methods to control and correct the network activity dynamics (Priori, 2013).

Here, we investigate the effects of closed-loop control schemes in networks of spiking neurons. Previous results have shown that delayed feedback can be used to desynchronizes a network of neurons, in which the population dynamics results from the coupling of single neurons modeled themselves as phase oscillators. In this work, we do not assume individual neurons to behave as oscillators, i.e. to fire synchronously and in a regular manner. We rather fine-tune the network to operate in a synchronous irregular regime, in which neurons fire stochastically with frequencies much lower than the population frequency (Brunel, 1999). These oscillations are known to be robust compared to synchronous regular activity (Brunel, 2008) and are not easily affected by noise or heterogeneity.

We design an appropriate control strategy, based on delayed state-feedback to quench these sparse or stochastic oscillations, which resemble a wide range of pathological conditions. Our control protocol is able to sufficiently suppress the oscillations and to drive the network in an asynchronous irregular regime. Importantly, the network transfer function, defined as the ratio of the population rate response to incoming stimuli, is also recovered. Our results thus suggest that delayed state-feedback control is a promising strategy to design brain stimulation protocols to correct stochastic oscillations without inducing strong side-effects.

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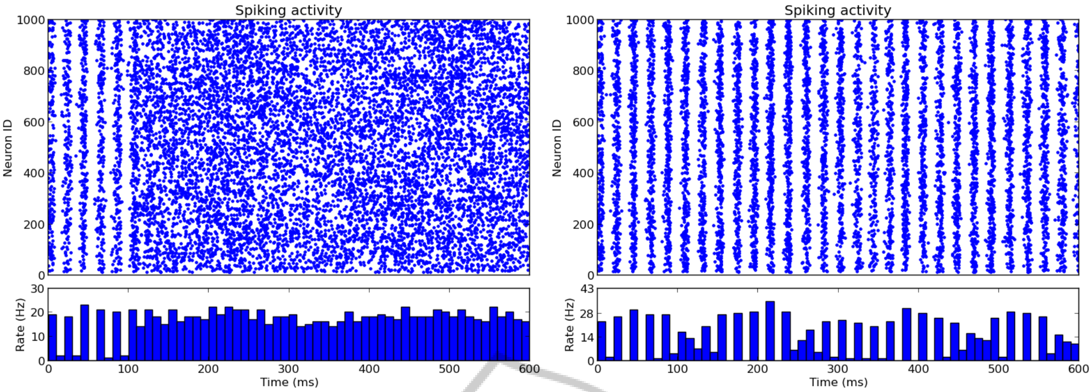

Figure 1: Effects of closed-loop control on stochastic oscillations. Synchronous irregular activity in a network of one thousand leaky-integrate-and-fire neurons (left). Delayed state-feedback control is switched on at 100ms. Oscillations are quenched and the network is driven in an asynchronous irregular regime (right).

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