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Pattern learning using spike-timing-dependent plasticity: a theoretical approach

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Introduction

Recognition tasks performed by humans and animals require the learning and storage of representations by neuronal networks of external sensory stimuli. Recent studies have established the importance of timing within spike trains for synaptic plasticity, which is hypothesised to lead to learning at the behavioral level [1,2]. This spike-timing-dependent plasticity (STDP) was shown to both stabilize the weights of the synapses on a neuron and induce competition between them in order to generate network structure [3]. For example, STDP can capture temporal correlation or interaural time differences at the scale of milliseconds within spike trains [1,3].

Methods

Spike patterns are a specific representation of neuronal information, where the spike times of given input neurons satisfy a given ordering. Previous work based on numerical simulation showed that the presentation of such patterns to a neuron with plastic input connections subject to STDP can result in the potentiation of synapses involved in the pattern [4]. In the present study we address this problem from an analytical point of view using a framework developed previously based on the Poisson neuron model [3,5]. We focus on the situation where a neuron learns a single spike pattern whose repeated presentation over time does not affect the global structure of the input firing-rates, which means that rate-based learning rules cannot detect the stimulus pattern.

Results

We first show that the pattern presentation amongst noisy input spike trains affects their probabilistic properties, namely the spike-time correlation at a small time scale. Then, under the assumption of slow learning, we show that the change in the input weights induced by STDP can be evaluated using a dynamical system, which is analyzed in terms of fixed points and their stability to predict the asymptotic distribution of the input weights. We found that STDP modifies the response of the neuron to fire at the beginning of the stimulus pattern. This general rule confirms previous results obtained numerically [4], although exceptions may occur for certain patterns with specific distributions of spikes.

Discussion

Our results support the idea that STDP is an adequate learning rule to enable neurons to detect spike patterns, such as those observed in auditory or olfactory sensory areas. This is a promising first step in providing an understanding of pattern learning in neuronal networks with richer input structure and arbitrary connectivity topology. We aim in future studies to use these methods to gain insight into the encoding of neuronal information in sensory pathways.

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