Self-synchronization Patterns of Spiking Neuronal Network

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***Abstract*—Spiking neurons based on integrate and fire circuits have recently been optimized for silicon hardware implementations. There is interest in understanding the synchrony and asynchrony of a population of such spiking neurons as a form of neuronal computational patterns, memory, and information processing. Most recent approaches use supervised mechanism in achieving synchrony. In this paper, we show that self-synchrony or asynchrony can be triggered by network connectivity (structure) and local learning based on Hebbian-like mechanism. The network connects neurons and achieves collective energy properties that achieves desired dynamic patterns of synchrony, phase-locking, etc. that are critical for information processing. Finally, we describe how dynamical properties can be interpreted in terms of memory, patterns, and information processing of an interconnected network with local synaptic learning.**

I. INTRODUCTION

Integrated electronic circuit models of biological spiking neurons have been proposed by Mead (see [1] and the references therein). Their emulation of biological neurons have been improved over the years. Their implementations have been expanded to closely mimic the behavior of numerous types of biological neurons and have been also been demonstrated for small scale biological networks [1]. Interest has also focused on the role of the dendritic tree of a neuron in processing temporal impinging signals from other neurons [1, 2]. It is also suspected to play a role in synchronization of inter population neuronal networks, and the relative timing of impinging signaling from various neurons [1]. The dendritic tree of a neuron is sensitive to the timing of the impinging signals' arrival from its connected neurons. The Hebbian mechanism postulates that learning in synapses is correlated to the timing synchrony of pre- and post- synaptic potentials [1]. The capturing of the Hebbian hypothesis into a mathematical (tractable) expression has taken many forms in simulating or emulating one aspect of the synaptic learning process. One popular form of the Hebbian learning mechanism is inversely proportional to the timing difference between pre- and post-synaptic signals as a rule for gradually strengthening or weakening the local synaptic connection [1]. It postulated that the mechanism of Spike-Timing Dependent Plasticity (STDP) can enable synchronization or various populations of neurons. However, this has not been demonstrated in electronic circuit spiking neuron implementations. On the other hand, electronic implementations using Voltage-controlled oscillators as mimicking neurons has shown electronic circuit connectivity that enforces synchronizations assuming they all share a common center frequency [2].

II. THE GENERAL FORMULATION

It is noted that synthesizable and simple circuits elements and blocks to construct a variety of integrated electronic neuronal network structures are feasible for hundreds of neurons [1,2]. The challenge still remains for scaling up the network sizes to the real biological scale. Moreover, an important enabler is to understand (local) learning mechanisms that can achieve robust synchrony or asynchrony of populations of neurons in response to different external stimuli. With such driven synchrony, various synchronized patterns of populations of neurons would emerge with distinct frequency and/or excess phase to map to unique impinging stimuli that generate patterns of memory, processing, or actuation activities.

The formulation and approach is to provide local architecture governed by the overall energy to synchronize a network of electronic Spiking neurons. Such an approach is motivated from neuronal networks but also supported by mathematical rigor. The key concept is to focus on the spiking signals along the axons (which is digital in nature and varies only in phase) as opposed to the existing common trend of focusing on the synchrony of the signals along the dendritic trees (which is complex analog in nature and varies in shape, amplitude and phase). It is observed that the digital signals along the axons are a mapping equivalence of the complex signals along the dendritic trees in a network.

REFERENCES

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