

Turing Computation with Neural Networks Composed of Synfire Rings

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Abstract

Synfire rings are fundamental neural circuits capable of conveying self-sustained activities in a robust and temporally precise manner. We propose a Turing-complete paradigm for neural computation based on synfire rings. More specifically, we provide an algorithmic procedure which, for any fixed-space Turing machine, builds a corresponding Boolean neural network composed of synfire rings capable of simulating it. As a consequence, any fixed-space Turing machine with tapes of length N can be simulated in linear time by some Boolean neural network composed of $O(N)$ rings and cells. The construction can naturally be extended to general Turing machines. Therefore, any Turing machine can be simulated in linear time by some Boolean neural network composed of infinitely many synfire rings. The linear time simulation relies on the possibility to mimic the behavior of the machines. In the long term, these results might contribute to the realization of biological neural computers.

Introduction

In theoretical neural computation, the computational capabilities of diverse models of neural networks have been shown to range from the finite state automaton degree, up to the Turing or even to the super-Turing level [2, 5–8]. But the neural networks involved in these results are generally far from the biological reality.

Synfire chains are fundamental neural circuits where every layer is connected to the next by means of convergent/divergent excitatory synapses [1, 4]. *Synfire rings* are looping synfire chains [9]. As an additional dynamical feature, the ring shape enables the emergence of self-sustained activities, which correspond to attractor dynamics.

Based on these considerations, an automaton-complete paradigm for neural computation based on synfire rings has been proposed [3]. Here, we extend these results to Turing computation.

Boolean neural networks and Turing machines

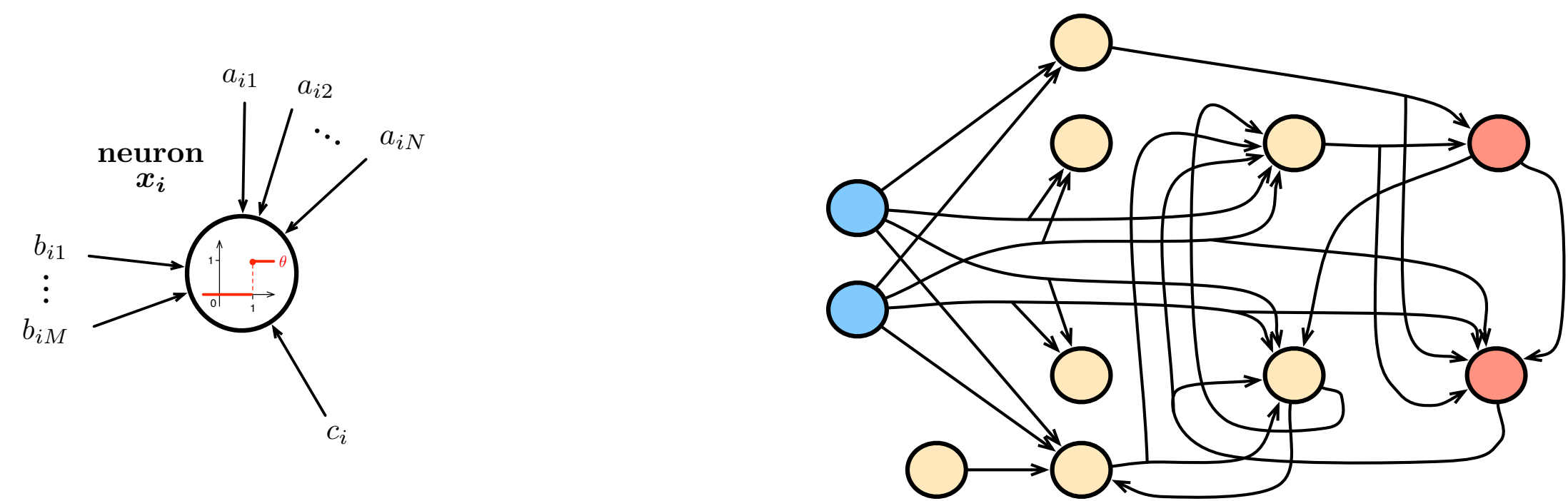


Figure 1. (Left) Example of a Boolean recurrent neural network (BRNN). (Right) Dynamics of a Boolean neuron.

