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In Partial Fulfillment of the Requirements for the Degree of
Doctor of Philosophy in Computer Science

FRANCIS GEORGE CARREON-CABARLE

will defend his dissertation

COMPUTATIONS IN SPIKING NEURAL P SYSTEMS: SIMULATIONS AND STRUCTURAL PLASTICITY

Abstract

Spiking neural P systems (in short, *SNP systems*) are a class of parallel, distributed, synchronous, and nondeterministic models of computation. SNP systems are membrane models within the *membrane computing* area (a branch of the larger *natural computing* area) initiated by *Gheorghe Paun* in 1999. SNP systems are inspired by the structure and function of spiking neurons, which compute using indistinct signals called *spikes*. *Neurons* are spike processors which are placed on the nodes of a directed graph, where the directed edges between neurons are called *synapses*.

In this work, the neuroscience feature of *structural plasticity* is introduced into the SNP systems framework. The computing power of *SNP systems with structural plasticity* (in short, *SNPSP systems*) are investigated by simulating other models of computation, e.g. linear grammars, register machines. SNPSP systems are a class of SNP systems that can create or delete synapses: they have a dynamical structure applied only to the synapses. We prove the computational (non)universality of SNPSP systems in four semantics, i.e. depending on how the system applies rules. Two of the four semantics include the usual parallel and synchronous semantic, and a modification of this semantic called *spike saving mode*. The remaining semantics include two restrictions: removing either synchronization (i.e. *asynchronous operation*) or parallelism (i.e. *sequential operation*). We prove that such restricted SNPSP systems can still achieve universality. All universality results in this work apply to SNPSP systems as number generators or acceptors. In SNPSP systems, the *plasticity rules* used provide a new source of nondeterminism when selecting which synapses to create or delete. Plasticity rules also provide a ``programming capacity" that could, at certain cases, replace *forgetting rules* (rules that remove but do not produce spikes) and *rules with delays* (a time delay takes effect prior to spike production). This nondeterminism source and capacity allow SNPSP systems to have *normal forms*, which are a set of simplifying restrictions on system parameters, e.g. number or types of rules inside a neuron. We provide *uniform* modules of sequential SNPSP systems, i.e. the system construction is independent from the simulated register machine, providing some hint to an open problem on uniform modules of sequential SNP systems. The asynchronous SNPSP systems in this work provide support to the conjecture that asynchronous SNP systems with *standard rules* (each step, each neuron produces at most one spike) are not universal. Lastly, *semi-uniform* (i.e. system construction is based on the problem instance) and uniform solutions, both nondeterministic and under a normal form, to the **NP**-complete problem *Subset Sum* are provided. The uniform solution reduces the number of neurons by a linear amount (with respect to the input size) as compared to a previous uniform solution using SNP systems.

Keywords: *Natural Computing, Membrane Computing, Spiking Neural P systems, Models of computation, Turing universality, Asynchronous systems, Sequential systems*

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Date: 20 May 2015
Time: 3PM – 5PM
Venue: ERDT room, Department of Computer Science,
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Faculty, students, and the general public are invited.