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Implementation and Application of Automata

12th International Conference, CIAA 2007
Prague, Czech Republic, July 2007
Revised Selected Papers

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Preface

The 12th International Conference on Implementation and Application of Automata CIAA 2007 was held at the Czech Technical University in Prague, Czech Republic on July 16–18, 2007.

These proceedings contain the papers that were presented at CIAA 2007, as well as the abstracts of the poster papers that were displayed during the conference. The proceedings also include the abstracts and extended abstracts of four invited lectures presented by Gheorghe Păun, Michael Riley, Moshe Vardi, and Bruce W. Watson.

The 23 regular papers and 7 poster papers were selected from 79 submitted papers covering various topics in the theory, implementation, and application of automata and related structures. Each submitted paper was reviewed by at least three Program Committee members, with the assistance of referees. The authors of the papers presented here come from the following countries: Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Israel, Italy, Poland, Romania, Russia, South Africa, Spain, Sweden, UK, and USA.

We wish to thank all those who made this meeting possible: the authors for submitting papers, the Program Committee members and external referees (listed on pages VII and VIII) for their excellent work, and last but not least our four invited speakers. Finally, we wish to express our sincere appreciation to the sponsors and local organizers.

July 2007

Jan Holub
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Spiking Neural P Systems Used as Acceptors and Transducers (Extended Abstract of an Invited Talk)

Gheorghe Păun

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Keywords: membrane computing, spiking neural P system, Turing computability, string processing.

The study of spiking neural P systems is a branch of membrane computing (comprehensive information about this area of natural computing can be found in [24], [9], or at the web page [31]) initiated in [18]. The goal is to build a model of the way the neurons cooperate in (large) neural nets, communicating by means of spikes, electrical impulses of identical shapes. "Computing by spiking" is a vivid research area in neural computing, which promises to lead to a neural computing "of the third generation" – see [12], [22], etc.

Very briefly, the resulting models, called *spiking neural P systems* (in short, SN P systems), consists of a set of *neurons* (cells, consisting of only one membrane) placed in the nodes of a directed graph and sending signals (*spikes*, denoted in what follows by the symbol a) along *synapses* (arcs of the graph). Thus, the architecture is that of a tissue-like P system, with only one kind of objects present in the cells. The objects evolve by means of *spiking rules*, which are of the form $E/a^c \rightarrow a; d$, where E is a regular expression over $\{a\}$ and c, d are natural numbers, $c \geq 1, d \geq 0$. The meaning is that a neuron containing k spikes such that $a^k \in L(E), k \geq c$, can consume c spikes and produce one spike, after a delay of d steps. This spike is sent to all neurons to which a synapse exists outgoing from the neuron where the rule was applied. There also are *forgetting rules*, of the form $a^s \rightarrow \lambda$, with the meaning that $s \geq 1$ spikes are removed, provided that the neuron contains exactly s spikes. We say that the rules "cover" the neuron, all spikes are taken into consideration when using a rule.

The system works in a synchronized manner, i.e., in each time unit, each neuron which can use a rule should do it, but the work of the system is sequential in each neuron: only (at most) one rule is used in each neuron. If there are several rules which can be applied in a neuron, then one of them is chosen in a non-deterministic way.

There are various ways of using such a device. For instance, we can consider one of the neurons as the *input neuron* and one of them as the *output neuron*. Spikes can be introduced in the former one, at various steps, while the spikes

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of the output neuron are sent to the environment. The moments of time when a spike is emitted by the output neuron are marked with 1, the other moments are marked with 0. The binary sequence obtained in this way is called the *spike train* of the system – it might be infinite if the computation does not stop. A binary sequence is similarly associated with the spikes entering the system.

If we do not consider an input neuron, then the system is used in the *generative* mode: we start from an initial configuration and all spike trains produced by the system by means of computations constitute the set of binary strings/sequences generated by the system; various sets of numbers can be associated with the spike trains, such as the distance in time between the first two spikes, between all consecutive spikes, the total number of spikes (in the case of halting computations), and so on. If we only consider an input neuron, then an SN P system can be used in the *accepting* mode: we introduce a string of symbols 0 and 1 (as a sequence of steps, with 1 associated with time units when spikes enters the system), or a number represented by such a string (e.g., as the number of steps elapsed between the first two spikes entering the system), and the input is accepted/recognized if and only if the computation stops. When both an input and an output neuron are considered, the system can be used as a *transducer*, both for strings and infinite sequences, as well as for computing numerical functions.

Two main types of results were obtained in the generative and the accepting modes: computational completeness in the case when no bound was imposed on the number of spikes present in the system, and a characterization of semilinear sets of numbers in the case when a bound was imposed (hence for finite SN P systems). In the transducing mode, a large class of (Boolean) functions can be computed, but strong restrictions exist in the case of morphisms – details can be found in [28] and [29].

Also strings/languages on arbitrary alphabets can be handled, for instance, using extended rules, i.e., rules of the form $E/a^c \to a^p; d$: when the rule is used, p spikes are produced and sent (after d steps) to all neighboring neurons. Then, with a step when the system sends out i spikes, we associate a symbol b_i, and thus we get a language over an alphabet with as many symbols as the number of spikes simultaneously produced. This case was investigated in [7].

The proofs of all computational completeness results known up to now in this area are based on simulating register machines. Starting the proofs from small universal register machines, as those produced in [20], one can find small universal SN P systems. This idea was explored in [23].

In the initial definition of SN P systems several ingredients are used (delay, forgetting rules), some of them of a general form (general synapse graph, general regular expressions). As shown in [15], rather restrictive normal forms can be found, in the sense that some ingredients can be removed or simplified without losing the computational completeness. For instance, the forgetting rules or the delay can be removed, both the indegree and the outdegree of the synapse graph can be bounded by 2, while the regular expressions from firing rules can be of very restricted forms.

There were investigated many other types of SN P systems: with several output neurons ([16], [17]), with a non-synchronous use of rules ([2]), with an exhaustive use of rules (whenever enabled, a rule is used as much as possible for the number of spikes present in the neuron, [19]), with packages of spikes sent along specified synapse links ([1]), etc. We refer the reader to the bibliography of this note, with many papers being available at [31].

This area of research is fast developing and there are many research topics and open problems formulated in the literature (see, e.g., [25]). We recall here only some general ideas: bring more ingredients from neural computing, especially related to learning/training/efficiency; incorporate other facts from neurobiology, such as the role played by astrocytes, the way the axon not only transmits impulses, but also amplifies them; consider not only "positive" spikes, but also inhibitory impulses; define a notion of *memory* in this framework, which can be read without being destroyed; provide ways for generating an exponential working space (by splitting neurons? by enlarging the number of synapses?), in such a way to trade space for time and provide polynomial solutions to computationally hard problems; define systems with a dynamical synaptic structure; compare the SN P systems as generator/acceptor/transducers of infinite sequences with other devices handling such sequences; investigate further the systems with exhaustive and other parallel ways of using the rules, as well as systems working in a non-synchronized way; find classes of (accepting) SN P systems for which there is a difference between deterministic and non-deterministic systems; find classes which characterize levels of computability different from those corresponding to finite automata (semilinear sets of numbers or regular languages) or to Turing machines (recursively enumerable sets of numbers or languages).

For the reader convenience, the bibliography provided below mentions many of the papers circulated at this moment in the literature of spiking neural P systems.

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