

# Spiking Neural P system without delay simulator implementation using GPGPUs

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## ABSTRACT

This paper presents a parallel simulator for a type of P system known as spiking neural P system (SNP system) using general purpose graphics processing units (GPGPUs). GPGPUs, unlike the more conventional multi-core CPUs, are used for parallelizable problems due to their architectural optimization for parallel computing. Membrane computing or P systems, are computational models which compute in a maximally parallel and non-deterministic manner. SNP systems, w/c compute via time separated spikes and whose inspiration was taken from the way neurons operate in living organisms, have been represented as matrices. The algorithms, design considerations, implementation of the simulator, as well as simulation results are discussed.

## Keywords

Membrane computing, Parallel computing, GPGPUs

## 1. INTRODUCTION

The trend for massively parallel computation is moving from the more common multi-core CPUs towards GPGPUs for several significant reasons [7][8]. One important reason for such a trend in recent years include the low consumption in terms of power, of GPGPUs compared to setting up machines and infrastructure which will utilize multiple CPUs in order to obtain the same level of parallelization and performance[9]. Another more important reason is that GPGPUs are architected for massively parallel computations since unlike the architectures of most general purpose CPUs, a large part of GPGPUs are devoted for arithmetic operations and not on control and caching [7][8]. Arithmetic operations are at the heart of many basic operations as well as scientific computations, and these are performed with larger speedups when done in parallel, by GPGPUs over CPUs.

Membrane computing or its more specific counterpart, a P system, are Turing complete computing models that perform computations nondeterministically, exhausting all pos-

sible computations at any given time. This type of unconventional model of computation was introduced by George Paun in 1998 and takes inspiration, similar to other members of natural computing, from nature[4][5]. Specifically, P systems try to mimic the constitution and dynamics of the living cell: the multitude of elements inside it, and their interactions within themselves and their environment, or outside the cell's skin membrane.

SN P systems differ from other types of P systems precisely because they are mono-membranar and only use one type of object in its computation. These characteristics, among others, are meant to capture the workings of a special type of cell known as the neuron. Neurons, such as those in the human brain, communicate or 'compute' by sending indistinct electro-chemical signals more commonly known as spikes. Information is then communicated and encoded not by the spikes themselves, since the spikes are unrecognizable from one another, by means of time duration as well as the number of spikes sent/received from one neuron to another, oftentimes under a certain time interval[1]. The time duration between two spikes, or several successive spikes, transmit information from one cell to another.

It has been shown that SN P systems, given their nature, are representable by matrices[2][3]. This representation allows design and implementation of an SN P system simulator using parallel computing machines such as GPGPUs.

The design of the simulator, including the algorithms devised, architectural considerations, are then implemented using a particular type of GPGPU, namely NVIDIA CUDA (compute unified device architecture). NVIDIA CUDA extends the widely known ANSI C programming language and makes parallel computation via GPGPUs manufactured by NVIDIA more accessible.

## 2. SPIKING NEURAL P SYSTEMS

### 2.1 Computing with SNP systems

The type of SNP systems focused on by this paper are those without delays i.e. those that spike or transmit signals the moment they are able to do so. An SNP system of this type is of the form: An SN P system without delay, of degree  $m \geq 1$ , is a construct of the form

$$\Pi = (O, \sigma_1, \dots, \sigma_m, syn, in, out),$$

where:

1.  $O = \{a\}$  is the singleton alphabet ( $a$  is called spike);
2.  $\sigma_1, \dots, \sigma_m$  are neurons, of the form

$$\sigma_i = (n_i, R_i), 1 \leq i \leq m,$$

where:

- a)  $n_i \geq 0$  is the initial number of spikes contained in  $\sigma_i$ ;
  - b)  $R_i$  is a finite set of rules of the following two forms:
    - (1)  $E/a^c \rightarrow a^p$ , where  $E$  is a regular expression over  $a$ , and  $c \geq 1, p \geq 1$ , with the restriction  $c \geq p$ ;
    - (2)  $a^s \rightarrow \lambda$ , for  $s \geq 1$ , with the restriction that for each rule  $E/a^c \rightarrow a^p$  of type (1) from  $R_i$ ,  $a^s \notin L(E)$ ;
3.  $syn = \{(i, j) \mid 1 \leq i, j \leq m, i \neq j\}$  (synapses between neurons);
  4.  $in, out \in \{1, 2, \dots, m\}$  indicate the input and output neurons, respectively.

(2a) represents an SNP system without delay of degree  $m \geq 1$ , that is, with  $m$  neurons, where

## 2.2 Citations

Citations to articles [?, ?, ?, ?], conference proceedings [?] or books [?, ?] listed in the Bibliography section of your article will occur throughout the text of your article. You should use BibTeX to automatically produce this bibliography; you simply need to insert one of several citation commands with a key of the item cited in the proper location in the .tex file [?]. The key is a short reference you invent to uniquely identify each work; in this sample document, the key is the first author's surname and a word from the title. This identifying key is included with each item in the .bib file for your article.

The details of the construction of the .bib file are beyond the scope of this sample document, but more information can be found in the *Author's Guide*, and exhaustive details in the *LaTeX User's Guide*[?].

This article shows only the plainest form of the citation command, using \cite. This is what is stipulated in the SIGS style specifications. No other citation format is endorsed.

## 2.3 Tables

Because tables cannot be split across pages, the best placement for them is typically the top of the page nearest their initial cite. To ensure this proper “floating” placement of tables, use the environment **table** to enclose the table's contents and the table caption. The contents of the table itself must go in the **tabular** environment, to be aligned properly in rows and columns, with the desired horizontal and vertical rules. Again, detailed instructions on **tabular** material is found in the *LaTeX User's Guide*.

Immediately following this sentence is the point at which Table 1 is included in the input file; compare the placement of the table here with the table in the printed dvi output of this document.

**Table 1: Frequency of Special Characters**

| Non-English or Math | Frequency   | Comments          |
|---------------------|-------------|-------------------|
| $\emptyset$         | 1 in 1,000  | For Swedish names |
| $\pi$               | 1 in 5      | Common in math    |
| $\$$                | 4 in 5      | Used in business  |
| $\Psi_1^2$          | 1 in 40,000 | Unexplained usage |

**Figure 1: A sample black and white graphic (.eps format).**

To set a wider table, which takes up the whole width of the page's live area, use the environment **table\*** to enclose the table's contents and the table caption. As with a single-column table, this wide table will “float” to a location deemed more desirable. Immediately following this sentence is the point at which Table 2 is included in the input file; again, it is instructive to compare the placement of the table here with the table in the printed dvi output of this document.

## 2.4 Figures

Like tables, figures cannot be split across pages; the best placement for them is typically the top or the bottom of the page nearest their initial cite. To ensure this proper “floating” placement of figures, use the environment **figure** to enclose the figure and its caption.

This sample document contains examples of .eps and .ps files to be displayable with L<sup>A</sup>T<sub>E</sub>X. More details on each of these is found in the *Author's Guide*.

As was the case with tables, you may want a figure that spans two columns. To do this, and still to ensure proper “floating” placement of tables, use the environment **figure\*** to enclose the figure and its caption.

Note that either .ps or .eps formats are used; use the \epsfig or \psfig commands as appropriate for the different file types.

## 2.5 Theorem-like Constructs

Other common constructs that may occur in your article are the forms for logical constructs like theorems, axioms, corollaries and proofs. There are two forms, one produced by the command \newtheorem and the other by the command \newdef; perhaps the clearest and easiest way to distinguish them is to compare the two in the output of this sample document:

This uses the **theorem** environment, created by the \newtheorem command:

THEOREM 1. *Let  $f$  be continuous on  $[a, b]$ . If  $G$  is an*

**Figure 2: A sample black and white graphic (.eps format) that has been resized with the epsfig command.**

**Table 2: Some Typical Commands**

| Command                       | A Number | Comments           |
|-------------------------------|----------|--------------------|
| <code>\alignauthor</code>     | 100      | Author alignment   |
| <code>\numberofauthors</code> | 200      | Author enumeration |
| <code>\table</code>           | 300      | For tables         |
| <code>\table*</code>          | 400      | For wider tables   |

**Figure 3: A sample black and white graphic (.ps format) that has been resized with the `psfig` command.**

antiderivative for  $f$  on  $[a, b]$ , then

$$\int_a^b f(t)dt = G(b) - G(a).$$

The other uses the **definition** environment, created by the `\newdef` command:

*Definition 1.* If  $z$  is irrational, then by  $e^z$  we mean the unique number which has logarithm  $z$ :

$$\log e^z = z$$

Two lists of constructs that use one of these forms is given in the *Author's Guidelines*.

and don't forget to end the environment with `figure*`, not `figure`!

There is one other similar construct environment, which is already set up for you; i.e. you must *not* use a `\newdef` command to create it: the **proof** environment. Here is a example of its use:

PROOF. Suppose on the contrary there exists a real number  $L$  such that

$$\lim_{x \rightarrow \infty} \frac{f(x)}{g(x)} = L.$$

Then

$$l = \lim_{x \rightarrow c} f(x) = \lim_{x \rightarrow c} \left[ g(x) \cdot \frac{f(x)}{g(x)} \right] = \lim_{x \rightarrow c} g(x) \cdot \lim_{x \rightarrow c} \frac{f(x)}{g(x)} = 0 \cdot L = 0,$$

which contradicts our assumption that  $l \neq 0$ .  $\square$

Complete rules about using these environments and using the two different creation commands are in the *Author's Guide*; please consult it for more detailed instructions. If you need to use another construct, not listed therein, which you want to have the same formatting as the Theorem or the Definition[?] shown above, use the `\newtheorem` or the `\newdef` command, respectively, to create it.

### A Caveat for the TeX Expert

Because you have just been given permission to use the `\newdef` command to create a new form, you might think you can use TeX's `\def` to create a new command: *Please refrain from doing this!* Remember that your L<sup>A</sup>T<sub>E</sub>X source

code is primarily intended to create camera-ready copy, but may be converted to other forms – e.g. HTML. If you inadvertently omit some or all of the `\defs` recompilation will be, to say the least, problematic.

## 3. CONCLUSIONS

This paragraph will end the body of this sample document. Remember that you might still have Acknowledgments or Appendices; brief samples of these follow. There is still the Bibliography to deal with; and we will make a disclaimer about that here: with the exception of the reference to the L<sup>A</sup>T<sub>E</sub>X book, the citations in this paper are to articles which have nothing to do with the present subject and are used as examples only.

## 4. ACKNOWLEDGMENTS

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**Figure 4: A sample black and white graphic (.eps format) that needs to span two columns of text.**

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