

# Implementation of a Spiking Neural P System Without Delay Simulator 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 [CITE]. 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 [CITE] in order to obtain the same level of parallelization and performance. 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 [CITE]. 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 possible computations at any given time. This type of unconventional model of computation was introduced by George Paun in 1998 [CITE] and takes inspiration, similar to other members of natural computing, from nature. 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. [CITE]. 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 [?]. 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. THE BODY OF THE PAPER

Typically, the body of a paper is organized into a hierarchical structure, with numbered or unnumbered

Because the entire article is contained in the **document** environment, you can indicate the start of a new paragraph with a blank line in your input file; that is why this sentence forms a separate paragraph.

## 2.1 Type Changes and *Special Characters*

We have already seen several typeface changes in this sample. You can indicate italicized words or phrases in your text with document class file. Take care with the use of<sup>1</sup> the text that is to be in the different typeface.

You can use whatever symbols, accented characters, or User's Guide[?].

## 2.2 Math Equations

You may want to display math equations in three distinct styles: the three are discussed in the next sections.

### 2.2.1 *Inline (In-text) Equations*

A formula that appears in the running text is called an inline or in-text formula. It is produced by the **math** environment, which can be invoked with the usual `\begin. . . \end` construction or with the short form `$. . . $`. You can use any of the symbols and structures, from  $\alpha$  to  $\omega$ , available in L<sup>A</sup>T<sub>E</sub>X[?]; this section will simply show a few examples of in-text equations in context. Notice how this equation:  $\lim_{n \rightarrow \infty} x = 0$ , set here in in-line math style, looks slightly different when set in display style. (See next section).

### 2.2.2 *Display Equations*

A numbered display equation – one set off by vertical space from the text and centered horizontally – is produced by the **equation** environment. An unnumbered display equation is produced by the **displaymath** environment.

Again, in either environment, you can use any of the symbols and structures available in L<sup>A</sup>T<sub>E</sub>X; this section will just give a couple of examples of display equations in context. First, consider the equation, shown as an inline equation above:

$$\lim_{n \rightarrow \infty} x = 0 \quad (1)$$

Notice how it is formatted somewhat differently in the **displaymath** environment. Now, we'll enter an unnumbered equation:

$$\sum_{i=0}^{\infty} x + 1$$

and follow it with another numbered equation:

$$\sum_{i=0}^{\infty} x_i = \int_0^{\pi+2} f \quad (2)$$

just to demonstrate L<sup>A</sup>T<sub>E</sub>X's able handling of numbering.

## 2.3 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

<sup>1</sup>A fourth, and last, footnote.

Table 1: Frequency of Special Characters

Non-English or Math	Frequency	Comments
Ø	1 in 1,000	For Swedish names
π	1 in 5	Common in math
\$	4 in 5	Used in business
Ψ <sub>1</sub> <sup>2</sup>	1 in 40,000	Unexplained usage

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

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 *L<sup>A</sup>T<sub>E</sub>X 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.

## 2.4 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 *L<sup>A</sup>T<sub>E</sub>X 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.

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.

## 2.5 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*.

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

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

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.

## 2.6 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 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 an 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 T<sub>E</sub>X Expert

Because you have just been given permission to use the `\newdef` command to create a new form, you might think you can use T<sub>E</sub>X’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

This section is optional; it is a location for you to acknowledge grants, funding, editing assistance and what have you. In the present case, for example, the authors would like to thank Gerald Murray of ACM for his help in codifying this *Author’s Guide* and the **.cls** and **.tex** files that it describes.

## 5. REFERENCES

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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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