# Spiking Neural P Systems with Astrocytes

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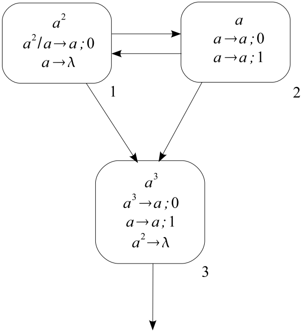
1. Spiking Neural P Systems (Normal Forms)
2. Spiking Neural P Systems with Astrocytes (SNPA)
3. Asynchronous Extended Spiking Neural P Systems with Astrocytes




An *standard* SN P system:

- a set of *neurons*;
- sending signals (*spikes*, symbol *a*);
- the arcs of the graph (*synapses*).

- **Spiking rules** ($E/a^c \to a; d$):
  - neuron contains $k$ spikes
  - $a^k \in L(E), k \geq c$
  - $E$ is a **regular expression** over $\{a\}$
  - consume $c$ spikes
  - produce one spike
  - **delay** $d$ steps.

- **Forgetting rules** ($a^s \to \lambda, s \geq 1$):
  - neuron contains exactly $s$ spikes
  - $s$ spikes are removed.

**Theorem**

$NRE = SNP$.

- Normal forms for spiking neural P systems. (O.H. Ibarra, A. Păun, Gh. Păun, A. Rodriguez-Paton, P. Sosik, S.Woodworth)(2007)
  - removing the delay
  - removing the forgetting rules
  - simplifying the regular expressions ($a^i$, $i \geq 1$, or $a^+$)
- Spiking neural P systems: Stronger normal forms. (M. García-Arnau, D. Pérez, A. Rodríguez-Patón, P. Sosík)(2007)
  - removing delays and forgetting rules simultaneously
  - removing delays and simplifying regular expressions

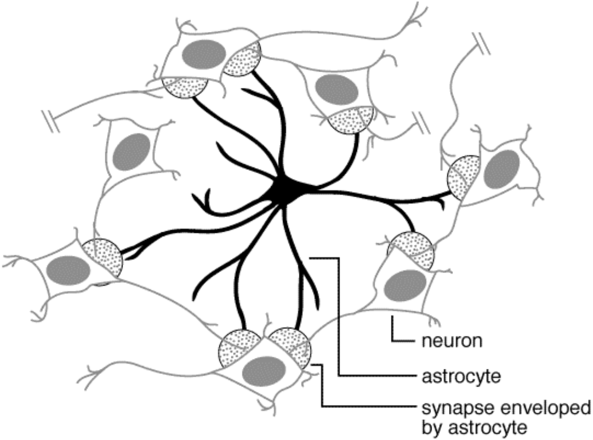
- Homogeneous Spiking Neural P Systems. (X. Zeng, X. Zhang, L. Pan)(2009)
  - each neuron has the same set of rules

$$a \to \lambda$$
$$a^2 \to a$$
$$a^3 \to a$$
$$a^3 \to a; 1$$
$$a^4 \to \lambda$$
$$a^2(a^5)^+/a^7 \to a; 1$$
$$a^4(a^5)^+/a^5 \to a$$

- Spiking neural P systems: An improved normal form. (L. Pan, Gh. Păun)(2010)
  - each neuron contains at most two rules;
  - the firing rules in the neurons have the same regular expression.

Open problem:
Is there a type of spiking neural p systems that could be universal even if:

- the systems have no delay;
- each neuron has only one rule;
- the set of rules in each neuron is the same;
- the regular expressions are simple (a*)?




www.wikipedia.org

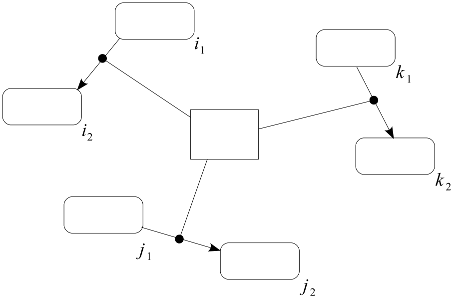
Astrocytes are cells which sense at the same time the spike traffic along several neighboring axons, and feed the respective neurons (e.g., with calcium) depending on the spikes frequency.

Extended spiking neural P systems with excitatory and inhibitory astrocytes. (A. Binder, R. Freund, M. Oswald, L. Vock, ) (2007)

- the excitatory and inhibitory role of astrocyte
- $h \leq h$ are the 2 thresholds of the astrocyte, and $f, f', f''$ are functions, the spikes $w$, sent along the axon from neuron $p$ to $q$, to $w'$ as follows:
  - if $w < h$, then $w' = f(w)$;
  - if $h \leq w \leq h'$, then $w' = f'(w)$
  - if $w > h'$, then $w' = f''(w)$.

Spiking neural P systems with astrocyte-like control. (Gh. Păun) (2007)

- Consider astrocytes with only inhibitory astrocytes, working in a rather restricted manner: an astrocyte checking several axons leaves to pass only one spike along them, suppressing all others.

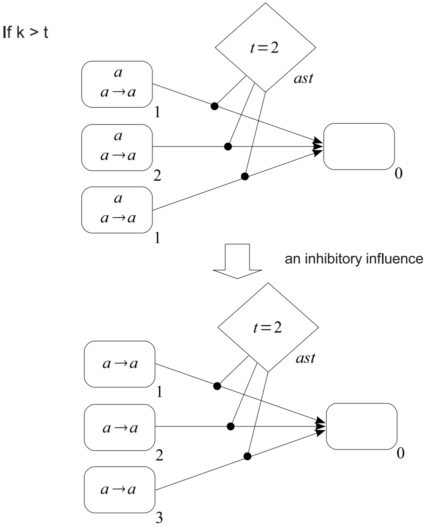


A more realistic computing model in the sense that it is closer to the neuro-biological reality.

**Spiking Neural P Systems with Astrocytes (SNPA systems)** (submitted)

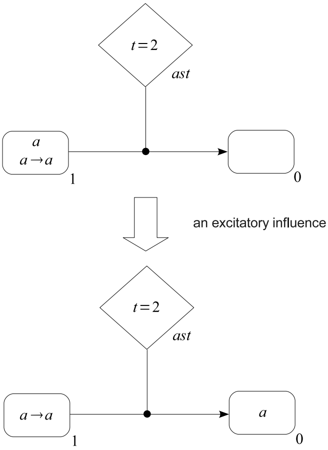
In an SN P system with astrocytes:

- an astrocyte can **sense and control** the spike traffic along the neighboring synapses;
- each astrocyte *ast* has a given **threshold** $t$;
- for an astrocyte *ast*, suppose that there are $k$ **spikes** passing along the neighboring synapses.

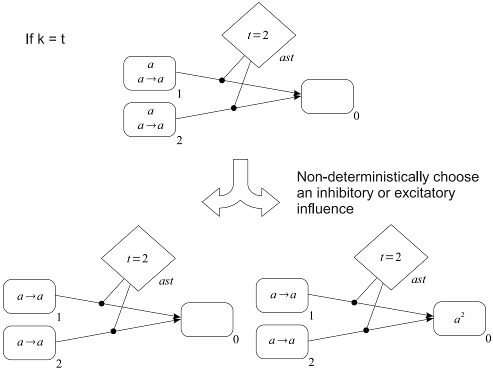



If $k > t$, then the astrocyte *ast* has an inhibitory influence on the neighboring synapses, the $k$ spikes are suppressed (that is, the $k$ spikes are removed from the system).

If k < t



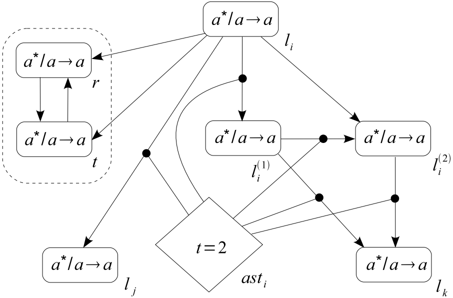

If $k < t$, then the astrocyte *ast* has an excitatory influence on the neighboring synapses, the $k$ spikes survive and pass to the destination neurons.




If $k = t$, then the astrocyte *ast* non-deterministically chooses an inhibitory or excitatory influence on the neighboring synapses.

## Theorem

$NRE = N_2SNPA.$




Model ADD (simulating $l_i : (\mathtt{ADD}(r), l_j, l_k)$)

- Each neuron has only one spiking rule $a^*/a \to a$, so the spiking rule is omitted in the graphical representation.
- Neuron $r$ with neuron $t$ together is a counter.

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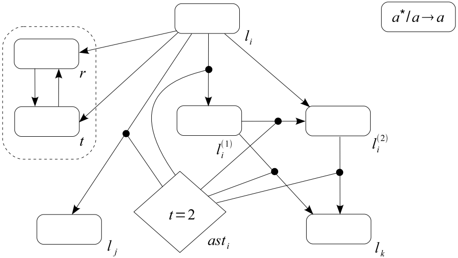


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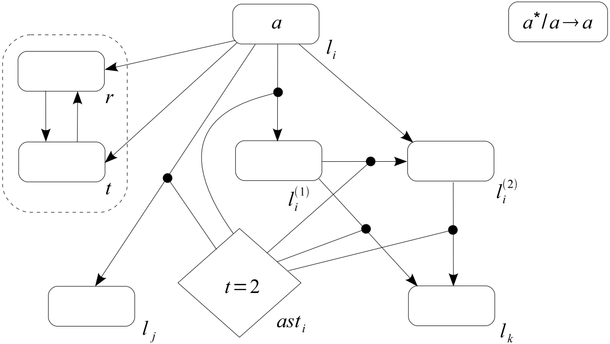
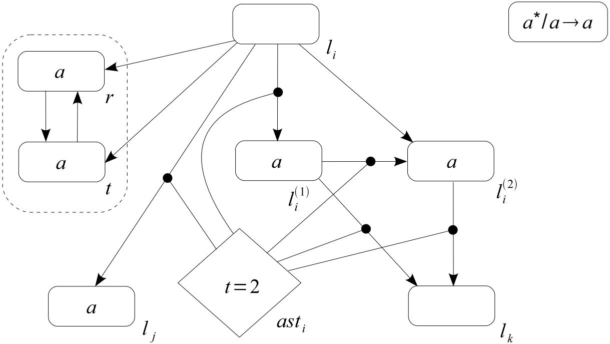



Model ADD (simulating $l_i$ : (ADD($r$), $l_j$, $l_k$))

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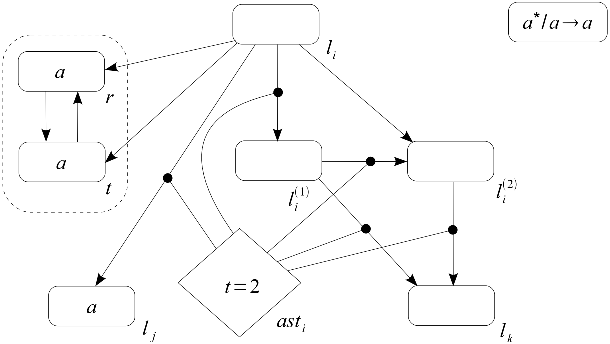


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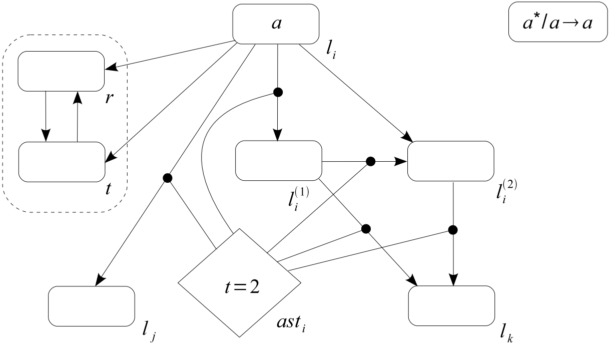


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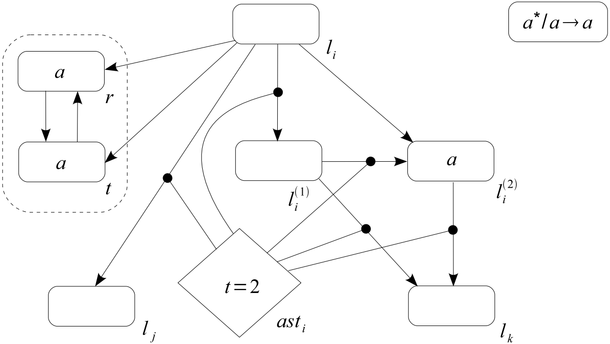


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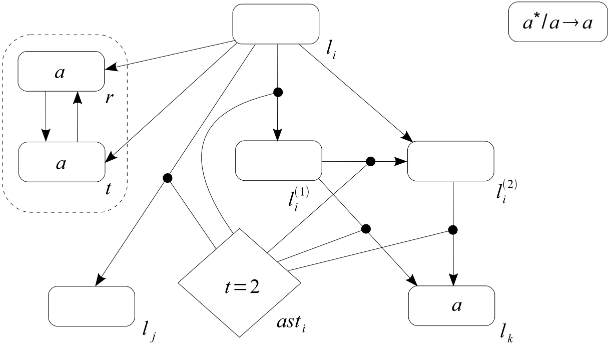


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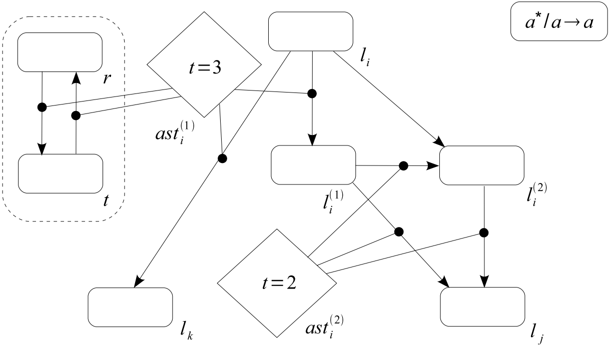
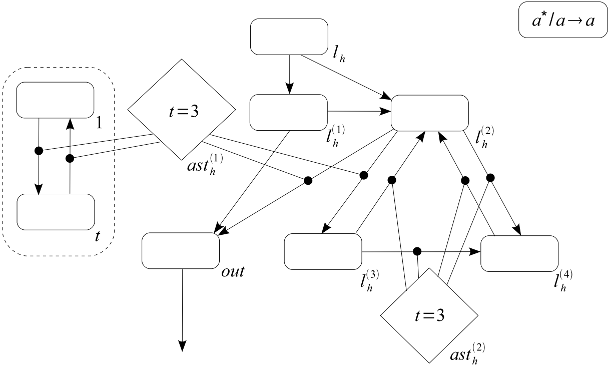



Model SUB (simulating $l_i : (\mathtt{SUB}(r), l_j, l_k)$)




Model FIN (outputting the result of a computation)

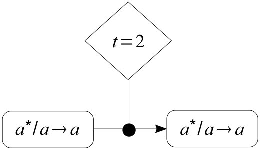
**Theorem**

$NRE = N_{acc}SNPA.$

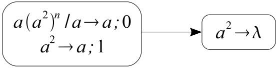
If a bound is given to the number of spikes in each neuron, then SNPA systems can generate semilinear sets of natural number.

**Theorem**

$N_2SNPA(bound_*) = SLIN.$




SNPA systems




SN P systems

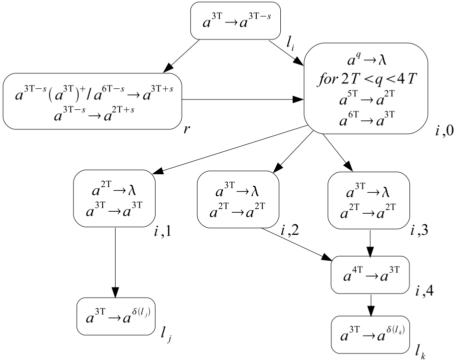
Conclusions:

- Simple: each neuron has only one spiking rule with simple regular expression and without delay.
- Homogenous: each neuron has the same set of rules.
- Neurons do not test how many spikes it received. The rules in them are not complicated.
- Neurons works like a “transmitter” of information.
- Build a biological computer based on the working principles of human brain in future.

## Asynchronous Extended Spiking Neural P Systems with Astrocytes

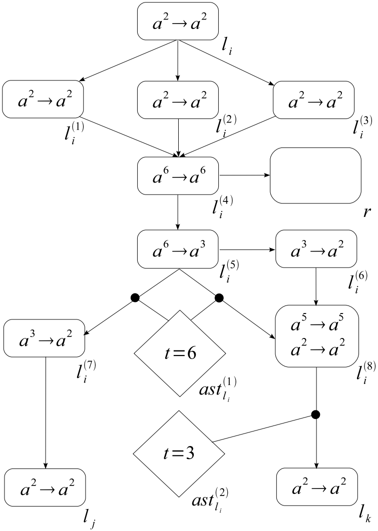
We consider SNPA system in the non-synchronized mode: in any step, when a neuron is enabled, it is not need to be fired, making a global clock dispensable.
It is proved that asynchronous SNPA systems are universal when using extended rules.

Asynchronous spiking neural P systems: decidability and undecidability. (M. Cavaliere, O. Egecioglu, O. H. Ibarra, , S. Woodworth, M. Ionescu, Gh. Păun) (2008)




Model SUB (simulating $l_i : (\mathtt{SUB}(r), l_j, l_k)$)

A parameter $T$ depends on the maximum number of SUB instructions that act on a same counter in the simulated register machine.
However, all modules of systems are constructed in a uniform way in the sense that all modules are independent of the particular register machine that is simulated.




Model ADD (simulating $l_i : (\mathtt{ADD}(r), l_j, l_k)$)

Future researches:

- NP-complete problems;
- Matrix representation;
- small universal machine;
- Petri net;
- P-Lingua;
- CUDA.

# Thank you!

- it is possible that two or more astrocytes control a synapse. In this case, if all these astrocytes have excitatory influence on the synapse, then the spikes along this synapse can survive and pass to the destination neurons;
- if one of these astrocytes has inhibitory influence on the synapse, then the spikes along this synapse are suppressed and removed from the system.

http://www.princeton.edu/main/news/archive/S31/07/36I49/index.xml?section=featured

19-07-2011

"Photonic neuron" may compute a billion times faster than brain circuits

Produce fiber-optic-based computational devices that work similarly to neurons, but are a billion times faster