Seven Research Suggestions

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Abstract. Some rather general research suggestions in membrane computing, as well as a couple of more specific ideas are formulated.

1 Introduction

At more than two decades since membrane computing (MC) was initiated, the achievements in this research area, in terms of publications, PhD theses, collective volumes, monographs, applications and software are considerable – see a detailed overview of membrane computing in the CMC20 talk of Gexiang Zhang, "Membrane Computing: Developmental Analysis" (to be published in *Journal of Membrane Computing*).

By the way, a really important issue in this moment for the membrane computing community is to "help growing" our journal. I would formulate it in a short "triadic form": *write, read, cite*! Write and submit papers to JMC, efficiently participate in reviewing papers for JMC, promote the journal, especially (for this period, before getting an impact factor from ISI) citing papers published in JMC. Of a great help in this last direction is *Bulletin of IMCS* (accessible at `http://membranecomputing.net/IMCSBulletin/`), where the contents of JMC is recalled.

Coming back to the goal of the present notes, as said in the Abstract, some suggestions are formulated, some of them rather general and only a few are more specific. As the field is really mature, no prerequisites are provided and almost no references, except those really necessary.

2 Two Very General Ideas

The first suggestion is somewhat classic and trivial: *back to literature!*

(Q1) There are plenty of open problems and research topics formulated in the MC literature. Some of these problems were solved, some of these research vistas were explored, many others might be now obsolete, of no much interest, but many enough still wait for research efforts.

For instance, I would like to recall the attention about the problems collected in [2], also available in a preliminary form in a Brainstorming volume, [1]. I believe that a nice and useful analysis would be to systematically examine the proposals from this paper and see the status of each of them, thus revealing the topics which need/deserve our attention from now on.

(Q2) The previous idea was to look to the past – now I would like to suggest to look to the future... With the mentioning that *the future started yesterday...* It is about *the Fourth Industrial Revolution.* The key-words describing it are of the kind: connectivity, artificial intelligence, machine learning, cyber-systems, robots.

Which of these syntagma are "reachable" by MC, which were already addressed, which suggestions can we get from this direction? Very general questions, but a good answer can have rather positive consequences. What about a "very distributed" P system/colony, about swarms of membranes? Much work is still needed in the learning (deep learning?) direction. Both these issues can have nice practical applications (the same with evolutionary computing, membrane algorithms and connected areas, making use of the "brute force" brought into the stage by the complex systems of weak components cooperating in a cleaver manner).

3 Three "Hybridization" Suggestions

Suggestions of the forms bellow were formulated many times, in more general or more specific terms. I recall them, with some further details.

(Q3) Systematic comparison of "basic" classes of P systems – cell-like, tissue-like, spiking neural, and numerical, with multiset rewriting rules, active membranes, symport/antiport, spiking rules, programs (production-repartition) rules, respectively, with various specific features – catalysts, polarizations, regular expression guarding the (spiking) rules, unique object (the spike), etc.

Many combinations of these ingredients were considered – but not all of them and not in a systematic manner.

We know, for instance, the power (also the efficiency?) of one-object cell-like P system, or of cell-like SN P systems, but I no not remember papers examining numerical P systems using only one variable (in each region), or using the notion of anti-matter.

A biological detail which is not satisfactorily captured in SN P systems is the sigmoidal function involved in the spiking operation. Maybe by borrowing the way of evolving variables in numerical P systems and using "programs" (again: with two parts, producing and then distributing) in SN P systems one can obtain something of interest.

(Q4) Bridging P and R was requested for several times and there are some attempts in this direction, but for sure much more remains to be done. The two areas are rather connected (cell-structure, evolution rules, biochemical metaphor), but they also differ in essential details (multisets, active membranes, symport/antiport and spiking rules, etc. in MC, zero or arbitrarily large multiplicity, no-surviving principle, different goals than computing, etc., in reaction systems). Borrowing notions investigated in R and investigating them for P (which of them make sense? which of them are decidable?) was suggested many times.

Let me formulate one really "hybridization" idea: in R systems, the evolution is influenced by the environment, which provides arbitrary (multi)sets of objects to the system; what about having these objects produced by a P system – or by several P systems. The idea is illustrated in Figure 1. Of course, the P systems work "in the MC style" (multisets, maximal parallelism, objects that do not evolve persist, etc.) while R is a reaction system. Plenty of questions appear: examine the usual R questions for such a hybrid system; what about computability in this framework? (the first question is how to define the result of a computation); what about the case when the P systems not only send objects to the environment, but they can also bring objects back inside? what about using simple P systems (non-universal), or of various types? in the case of SN P systems, we will have two possibilities: to distinguish between the spikes of various SN P systems or not – in the latter case, the R system is supposed to get only one (type of) object from the environment; how R systems with only one object in their alphabet behave?

Find other types of P-R hybrid systems.

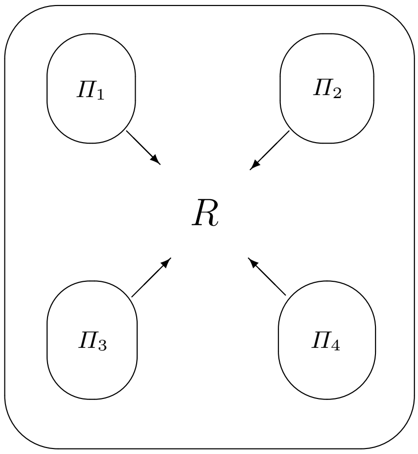

Fig. 1.

(Q5) A similarly promising topic, partially, but not enough explored, is that of bringing to MC further notions from the quantum area.

Two immediate ideas are the following.

1. To consider P systems with *qobjects*, objects having a *name* and a *probability* associated, a number between 0 and 1: $(a, \alpha), a \in A, 0 \leq \alpha \leq 1$. Taking α as a "standard" probability does not seem to be very productive (there are some

attempts of this kind). Maybe processing the objects with rules of the form

$$a \to (b, \beta)(c, \gamma), \ \beta, \gamma \in [-1, 1],$$

with the effect

$$(a, \alpha) \to (b, \alpha \oplus \beta)(c, \alpha \oplus \gamma), \text{ where}$$
$$\alpha \oplus \delta = \begin{cases} 0, & \text{if } \alpha + \delta < 0, \\ \alpha + \delta, & \text{if } 0 \leq \alpha + \delta \leq 1, \\ 1, & \text{if } \alpha + \delta > 1, \end{cases}$$

might be more interesting. Maybe also a multiplicative operation can be considered. How to define a successful computation? By halting? And which could be the result of a computation? (Maybe the distance between two prescribed events, without halting, maybe the string of objcts which reach probability 1.) Should the objects of the form $(a, 0)$ be preserved in the system or they should be eliminated?

2. The second idea refers to objects as well, but also to their evolution: entanglement. Define objects which have identical evolution, irrespective where they are placed. There is no obvious definition – e.g., in the case of cooperative rules. Should entanglement be hereditary? (Copies of the same object, having a common ancestor, should be necessarily entangled?)

A good definition is the first step – after that, questions about computing power and efficiency are to be formulated.

Is entanglement a further door towards efficiency? (Entanglement means, in some sense, sending signals at an arbitrary distance in no time, which looks to be a powerful operation.) Maybe entanglement combined with the idea of qobjects? Maybe also imitating efficiency ideas from quantum computing?

4 Two More Precise Proposals

(Q6) There is a fundamental feature of P systems which, in some sense, is departing from the (bio)chemistry: the localization of evolution rules. In theoretical-abstract terms, *the (bio)chemistry is the same everywhere*, the "dictionary" of reactions is unique. What is applicable-active in a given "reactor" (compartment of a cell) is selected according to the local reactants, enzymes, catalysts, promoters and inhibitors, as well as according to the reaction conditions (e.g., temperature). This directly leads to the idea of *homogeneity*, of considering P systems, of any kind, with the same set of rules in each compartment.

The idea was investigated for many classes of P systems, but not for numerical P systems. I am also not aware of efficiency results for homogeneous P systems. The same for the various ways of using the rules (semantics): maximally parallel, sequential, minimally parallel – whatever definition for these notions is chosen.

What about a sort of an additional "uniform" restriction of the following form: if P is the homogeneous set of rules present in all compartments (instead of using different rules in different compartments, depending on the local reactants and "reaction conditions"), choose a subset $P' \subseteq P$ (maximal?) and use it (in the maximally parallel way, etc.) in all compartments.

Power and efficiency results should be looked for.

(Q7) Still more specific is the last question: consider SN P systems with astrocytes producing calcium, with calcium directly involved in the spiking activity.

Formally, the system will contain two types of cells,

$$\begin{array}{rl} \textit{astrocytes} & \alpha_1, \ldots, \alpha_m, \text{ of the form } (c^{p_{i,0}}, A_i), p_{i,0} \geq 0, \\ & \text{with the rules in } A_i \text{ of the form } E_c/c^s \to c^t, s \geq 1, t \geq 0, \text{ and} \\ \textit{neurons} & \sigma_1, \ldots, \sigma_n, \text{ of the form } (a^{r_{i,0}}, R_i), r_{i,0} \geq 0, \\ & \text{with the rules in } R_i \text{ of the form } E_a/a^s c^{s'} \to a^t, s, s' \geq 1, t \geq 0, \end{array}$$

where E_c, E_a are regular expressions over the one-letter alphabets consisting of c and a, respectively.

The idea is clear: producing t spikes in a neuron means consuming both s spikes and s' calcium units.

The synapses should link either astrocytes or neurons, as well astrocytes to neurons (but not conversely: links (σ_i, α_j) are not permitted).

Of course, versions are possible: with the regular expressions in neurons also depending on the calcium units (hence over the alphabet $\{a, c\}$), with delay, with or without the possibility of replicating calcium, when an astrocyte sends objects c to several neurons. Now, the whole investigation program usual in the SN P systems area should be explored: normal forms, universality, small universal systems, plasticity, homogeneity, etc. Are astrocytes of this form improving the results known for usual SN P systems?

5 Final Remarks

This note had two main goals: to show that still there is much work to do in membrane computing, even at this basic level (not to speak about applications, which is by far the most promising and most important direction of research at this stage), and to recall again and again that a very important task of all of us at this moment is to... *write-read-cite*, supporting our journal JMC!...

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