P Colony - some new ideas

Lucie Ciencialová, Luděk Ciencial[1] and Erzsébet Csuhaj-Varjú [2]

18th Brainstorming Week on Membrane Computing

February 3 - 6, 2020, Sevilla, Spain

[1]Institute of Computer Science
and Research Institute of the IT4Innovations Centre of Excellence,
Silesian University in Opava, Czech Republic
{lucie.ciencialova, ludek.cienciala}@fpf.slu.cz

[2]Department of Algorithms and Their Applications, Faculty of Informatics
Eötvös Loránd University
Pázmány Péter sétány 1/c, 1117 Budapest, Hungary
csuhaj@inf.elte.hu

Outline

P Colonies

P Colonies

- A kind of membrane systems with structure of elemetary membranes
- The membranes are usually called cells or agents
- P Colonies were introduced in 2004 by Jozef Kelemen, Alica Kelemenová and Gheorghe Păun[1]

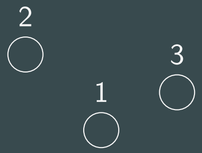
[1] J. Kelemen, A. Kelemenová, and Gh. Păun. "Preview of P colonies: A biochemically inspired computing model". In: *Workshop and Tutorial Proceedings. Ninth International Conference on the Simulation and Synthesis of Living Systems (Alife IX)*. Boston, Mass, 2004, pp. 82–86.

P Colonies

A P colony consists of

- a finite number of components called agents - finite collections of objects embedded in a membrane

P Colony

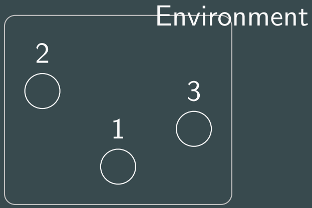


P Colonies

A P colony consists of

- a finite number of components called agents - finite collections of objects embedded in a membrane
- a shared environment

P Colony



P Colonies

Agents

- equipped with programs which are composed from rules that allow them to interact with their environment.
- Capacity - the number of objects inside each agent is constant and it is usually a very small number: 1, **2** or 3.

P Colonies

The activity of the agents is based on rules[2].

Rules

[2] J. Kelemen, A. Kelemenová, and Gh. Păun. "Preview of P colonies: A biochemically inspired computing model". In: *Workshop and Tutorial Proceedings. Ninth International Conference on the Simulation and Synthesis of Living Systems (Alife IX)*. Boston, Mass, 2004, pp. 82–86.

P Colonies

The activity of the agents is based on rules.

Rules

- Rewriting rule $a \to b$ - rewrite (evolve) one object a to object b. Both objects are placed inside the agent.

Rewriting rule $a \to b$

$wdab\ldots$

P Colonies

The activity of the agents is based on rules.

Rules

- Rewriting rule $a \to b$ - rewrite (evolve) one object a to object b. Both objects are placed inside the agent.

Rewriting rule $a \to b$

$wdab\ldots$

P Colonies

The activity of the agents is based on rules.

Rules

- Rewriting rule $a \rightarrow b$ - rewrite (evolve) one object a to object b. Both objects are placed inside the agent.
- Communication rule $c \leftrightarrow d$ - exchange object c placed inside the agent with object d in the string.

Communication rule $c \leftrightarrow d$

$wdab\ldots$

P Colonies

The activity of the agents is based on rules.

Rules

- Rewriting rule $a \to b$ - rewrite (evolve) one object a to object b. Both objects are placed inside the agent.
- Communication rule $c \leftrightarrow d$ - exchange object c placed inside the agent with object d in the string.

Communication rule $c \leftrightarrow d$

d $\qquad$ $wcab\ldots$

P Colonies

The activity of the agents is based on rules.

Rules

- Rewriting rule $a \to b$ - rewrite (evolve) one object a to object b. Both objects are placed inside the agent.
- Communication rule $c \leftrightarrow d$ - exchange object c placed inside the agent with object d in the string.
- Checking rule is formed from two rules r_1, r_2 of type rewriting or communication. It sets a kind of priority between the two rules r_1 and r_2.

Checking rule $a \leftrightarrow e \ / \ a \to f$

a $\qquad$ $weab \ldots$

P Colonies

The activity of the agents is based on rules.

Rules

- Rewriting rule $a \to b$ - rewrite (evolve) one object a to object b. Both objects are placed inside the agent.
- Communication rule $c \leftrightarrow d$ - exchange object c placed inside the agent with object d in the string.
- Checking rule is formed from two rules r_1, r_2 of type rewriting or communication. It sets a kind of priority between the two rules r_1 and r_2.

Checking rule $a \leftrightarrow e \;/\; a \to f$

e $\quad$ $waab\ldots$

P Colonies

The activity of the agents is based on rules.

Rules

- Rewriting rule $a \to b$ - rewrite (evolve) one object a to object b. Both objects are placed inside the agent.
- Communication rule $c \leftrightarrow d$ - exchange object c placed inside the agent with object d in the string.
- Checking rule is formed from two rules r_1, r_2 of type rewriting or communication. It sets a kind of priority between the two rules r_1 and r_2.

Checking rule $a \leftrightarrow e \;/\; a \to f$

e $\quad waab\ldots \qquad a \quad wcab\ldots$

P Colonies

The activity of the agents is based on rules.

Rules

- Rewriting rule $a \to b$ - rewrite (evolve) one object a to object b. Both objects are placed inside the agent.
- Communication rule $c \leftrightarrow d$ - exchange object c placed inside the agent with object d in the string.
- Checking rule is formed from two rules r_1, r_2 of type rewriting or communication. It sets a kind of priority between the two rules r_1 and r_2.

Checking rule $a \leftrightarrow e \;/\; a \to f$

e $waab\ldots$ f $wcab\ldots$

Programs

The rules are combined into programs in such a way that all objects inside the agent are affected by execution of the rules. Consequently, the number of rules in the program is the same as the number of objects inside the agent.

Computation

- starts in initial configuration - given by definition
- is maximally parallel - a set of agents executing programs is maximal
- is halting when no agent has applicable program

P Colonies

Result of computation

- is associated with a halting computation
- the number of final objects placed in the environment after the computation halts
- P colony can generate a set of natural numbers

Because the use of synchronization P colonies with low capacity and without checking rules are computationally complete.

Dynamic Behaviour

- we can record the contents of the environment after every step of computation or
- we can filter them - we can monitor only such state of the environment that content some ”special” symbol - in connection with final object ?

P Colonies and R Systems

R systems

- A reaction is a triple $a = (R, I, P)$ such that R, I, P are finite non-empty sets with $R \cap I = \emptyset$.
- $rac(S)$ - the set of all reactions in S.
- A reaction system is an ordered pair $\mathcal{A} = (S, A)$, where S is a background set and A is a nonempty finite subset of $rac(S)$.

R systems

Let S be a background set, let $X \subseteq S$, and let $a = (R_a, I_a, P_a) \in rac(S)$.

Reaction enabled by a set

a is enabled by X, denoted by $en_a(X)$, if

- $R_a \subseteq X$ and
- $I_a \cap X = \emptyset$.

Result . . .

. . . of a reaction on a set

The result of a on X, denoted by $res_a(X)$, is defined by

$$res_a(X) = P_a \text{ if } en_a(X)$$

and

$$res_a(X) = \emptyset \text{ otherwise}$$

. . . of a set of reactions on a set

$en(A, X) = \{a \in A \mid en_a(X)\}$

The result of A on X ($res(A, X)$), is defined by

$$res(A, X) = \{res_a(X) \mid a \in A\}$$

Interactive process

- In every step there is input - subset of background set
- at the beginning input_0 is processed.
- a set to be processed in the second step is formed from new input and result from previous step
- unprocessed symbols from previous step are erased
- when there is no enabled reactions interactive process terminates

Simulation of Interactive process by P Colonies

For given R system $\mathcal{A} = (S, A)$ and sequence of inputs $i_0, i_1, \ldots, i_n$

1 Generate Input

i-agents generate input symbols in one step - the number of agents $= |S|$ - and go to waiting phase

input 0

a_1, a_3

background set

$S = \{a_1, a_2, a_3\}$

i-agent 1 | i-agent 2 | i-agent 3 | i-agent f

a_1 0 | e 0 | a_3 0 | f 0

Simulation of Interactive process by P Colonies

For given R system $\mathcal{A} = (S, A)$ and sequence of inputs $i_0, i_1, \ldots, i_n$

1 Generate Input

i-agents generate input symbols in one step - the number of agents $= |S|$ - and go to waiting phase

input 0

a_1, a_3

background set

$S = \{a_1, a_2, a_3\}$

$a_1 \; a_3 \; f$

i-agent 1: $e \; 0'$

i-agent 2: $e \; 0'$

i-agent 3: $e \; 0'$

i-agent f: $e \; 0'$

Simulation of Interactive process by P Colonies

For given R system $\mathcal{A} = (S, A)$ and sequence of inputs $i_0, i_1, \ldots, i_n$

2. Multiply Input

to be "accessible" for every reaction

a-agents generate $|A|$ symbols that appear in the environment in second step ($a \to \bar{a}$) - the number of agents $= |A|$ - and go to waiting phase

input 0

a_1, a_3

background set

$S = \{a_1, a_2, a_3\}$

$a_1 \; a_3 \; f$

a-agent 1	a-agent 2	a-agent 3	a-agent f
$e \; 0$	$e \; 0$	$e \; 0$	$e \; 0$

Simulation of Interactive process by P Colonies

For given R system $\mathcal{A} = (S, A)$ and sequence of inputs $i_0, i_1, \ldots, i_n$

2. Multiply Input

to be "accessible" for every reaction

a-agents generate $|A|$ symbols that appear in the environment in second step ($a \to \bar{a}$) - the number of agents $= |A|$ - and go to waiting phase

input 0

a_1, a_3

background set

$S = \{a_1, a_2, a_3\}$

a-agent 1: a_1 $0'$

a-agent 2: W $0'$

a-agent 3: a_3 $0'$

a-agent f: f $0'$

Simulation of Interactive process by P Colonies

For given R system $\mathcal{A} = (S, A)$ and sequence of inputs $i_0, i_1, \ldots, i_n$

2. Multiply Input

to be "accessible" for every reaction

a-agents generate $|A|$ symbols that appear in the environment in second step ($a \to \overline{a}$) - the number of agents $= |A|$ - and go to waiting phase

input 0

a_1, a_3

background set

$S = \{a_1, a_2, a_3\}$

a-agent 1	a-agent 2	a-agent 3	a-agent f
$\overline{a_1}$ $0''$	e W	$\overline{a_3}$ $0''$	e W

For given R system $\mathcal{A} = (S, A)$ and sequence of inputs $i_0, i_1, \ldots, i_n$

2. Multiply Input

to be "accessible" for every reaction

a-agents generate $|A|$ symbols that appear in the environment in second step ($a \to \bar{a}$) - the number of agents $= |A|$ - and go to waiting phase

input 0

a_1, a_3

$\overline{a_1}\ \overline{a_3}$

background set

$S = \{a_1, a_2, a_3\}$

a-agent 1	a-agent 2	a-agent 3	a-agent f
$e\ 0'''$	$e\ W$	$e\ 0'''$	$e\ W$

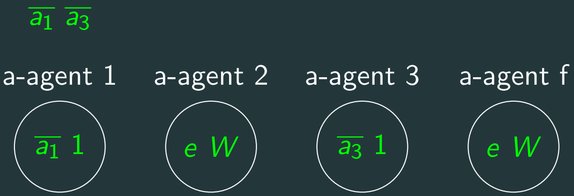
Simulation of Interactive process by P Colonies

For given R system $\mathcal{A} = (S, A)$ and sequence of inputs $i_0, i_1, \ldots, i_n$

2. Multiply Input

to be "accessible" for every reaction

a-agents generate $|A|$ symbols that appear in the environment in second step ($a \to \overline{a}$) - the number of agents $= |A|$ - and go to waiting phase

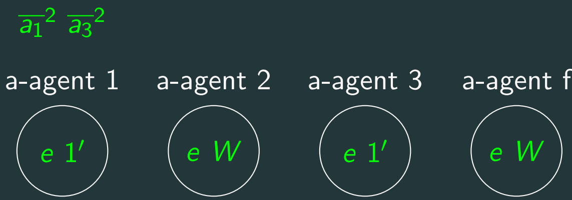


For given R system $\mathcal{A} = (S, A)$ and sequence of inputs $i_0, i_1, \ldots, i_n$

2. Multiply Input

to be "accessible" for every reaction

a-agents generate $|A|$ symbols that appear in the environment in second step ($a \rightarrow \overline{a}$) - the number of agents $= |A|$ - and go to waiting phase



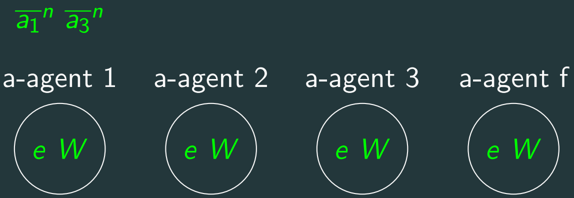
Simulation of Interactive process by P Colonies

For given R system $\mathcal{A} = (S, A)$ and sequence of inputs $i_0, i_1, \ldots, i_n$

2. Multiply Input

to be "accessible" for every reaction

a-agents generate $|A|$ symbols that appear in the environment in second step ($a \rightarrow \overline{a}$) - the number of agents $= |A|$ - and go to waiting phase



Simulation of Interactive process by P Colonies

For given R system $\mathcal{A} = (S, A)$ and sequence of inputs $i_0, i_1, \ldots, i_n$

3. Reaction-simulation phase

r-agents looking for inhibitors, reactants, generating semi-products (a') - the number of agents $= |A|$ - and go to waiting phase

input 0

a_1, a_3

$\overline{a_1}^3 \ \overline{a_3}^3$

background set

$S = \{a_1, a_2, a_3\}$

$$r_1 = (\{a_2\}, \{f\}, \{a_2\})$$
$$r_2 = (\{a_1, a_3\}, \{f\}, \{a_1, a_2\})$$
$$r_3 = (\{a_3\}, \{a_1\}, \{a_1, a_2\})$$

r-agent 1: $e \ T_0$

r-agent 2: $e \ T_0$

r-agent 3: $e \ T_0$

For given R system $\mathcal{A} = (S, A)$ and sequence of inputs $i_0, i_1, \ldots, i_n$

3. Reaction-simulation phase

r-agents looking for inhibitors, reactants, generating semi-products (a') - the number of agents $= |A|$ - and go to waiting phase

input 0

a_1, a_3

$\overline{a_1}^2 \ \overline{a_3}^3$

background set

$S = \{a_1, a_2, a_3\}$

$$r_1 = (\{a_2\}, \{f\}, \{a_2\})$$
$$r_2 = (\{a_1, a_3\}, \{f\}, \{a_1, a_2\})$$
$$r_3 = (\{a_3\}, \{a_1\}, \{a_1, a_2\})$$

r-agent 1	r-agent 2	r-agent 3
$T_1 \ x_1$	$T_1 \ x_1$	$T_1 \ \overline{a_1}$

Simulation of Interactive process by P Colonies

For given R system $\mathcal{A} = (S, A)$ and sequence of inputs $i_0, i_1, \ldots, i_n$

3. Reaction-simulation phase

r-agents looking for inhibitors, reactants, generating semi-products (a') - the number of agents $= |A|$ - and go to waiting phase

input 0

a_1, a_3

$\overline{a_1}^2\ \overline{a_3}^3$

background set

$S = \{a_1, a_2, a_3\}$

$$r_1 = (\{a_2\}, \{f\}, \{a_2\})$$
$$r_2 = (\{a_1, a_3\}, \{f\}, \{a_1, a_2\})$$
$$r_3 = (\{a_3\}, \{a_1\}, \{a_1, a_2\})$$

r-agent 1: $x_1\ e$

r-agent 2: $x_1\ e$

r-agent 3: $F\ e$

For given R system $\mathcal{A} = (S, A)$ and sequence of inputs $i_0, i_1, \ldots, i_n$

3. Reaction-simulation phase

r-agents looking for inhibitors, reactants, generating semi-products (a') - the number of agents $= |A|$ - and go to waiting phase

input 0

a_1, a_3

$\overline{a_1}^2 \; \overline{a_3}^3$

background set

$S = \{a_1, a_2, a_3\}$

$$r_1 = (\{a_2\}, \{f\}, \{a_2\})$$
$$r_2 = (\{a_1, a_3\}, \{f\}, \{a_1, a_2\})$$
$$r_3 = (\{a_3\}, \{a_1\}, \{a_1, a_2\})$$

r-agent 1 — $T_2 \; x_2$

r-agent 2 — $T_2 \; x_2$

r-agent 3 — $F \; e$

For given R system $\mathcal{A} = (S, A)$ and sequence of inputs $i_0, i_1, \ldots, i_n$

3. Reaction-simulation phase

r-agents looking for inhibitors, reactants, generating semi-products (a') - the number of agents $= |A|$ - and go to waiting phase

input 0

a_1, a_3

$\overline{a_1}^1\ \overline{a_3}^3$

background set

$S = \{a_1, a_2, a_3\}$

$$r_1 = (\{a_2\}, \{f\}, \{a_2\})$$
$$r_2 = (\{a_1, a_3\}, \{f\}, \{a_1, a_2\})$$
$$r_3 = (\{a_3\}, \{a_1\}, \{a_1, a_2\})$$

r-agent 1: $y_1\ F_1$

r-agent 2: $y_1\ \overline{a_1}$

r-agent 3: $F\ e$

For given R system $\mathcal{A} = (S, A)$ and sequence of inputs $i_0, i_1, \ldots, i_n$

3. Reaction-simulation phase

r-agents looking for inhibitors, reactants, generating semi-products (a') - the number of agents $= |A|$ - and go to waiting phase

input 0

a_1, a_3

$\overline{a_1}^1$ $\overline{a_3}^3$

background set

$S = \{a_1, a_2, a_3\}$

$$
\begin{aligned}
r_1 &= (\{a_2\}, \{f\}, \{a_2\}) \\
r_2 &= (\{a_1, a_3\}, \{f\}, \{a_1, a_2\}) \\
r_3 &= (\{a_3\}, \{a_1\}, \{a_1, a_2\})
\end{aligned}
$$

r-agent 1: F e

r-agent 2: y_1 e

r-agent 3: F e

Simulation of Interactive process by P Colonies

For given R system $\mathcal{A} = (S, A)$ and sequence of inputs $i_0, i_1, \ldots, i_n$

3. Reaction-simulation phase

r-agents looking for inhibitors, reactants, generating semi-products (a') - the number of agents $= |A|$ - and go to waiting phase

input 0

a_1, a_3

$\overline{a_1}^1 \; \overline{a_3}^2$

background set

$S = \{a_1, a_2, a_3\}$

$$r_1 = (\{a_2\}, \{f\}, \{a_2\})$$
$$r_2 = (\{a_1, a_3\}, \{f\}, \{a_1, a_2\})$$
$$r_3 = (\{a_3\}, \{a_1\}, \{a_1, a_2\})$$

r-agent 1	r-agent 2	r-agent 3
$F \; e$	$y_2 \; \overline{a_3}$	$F \; e$

For given R system $\mathcal{A} = (S, A)$ and sequence of inputs $i_0, i_1, \ldots, i_n$

3. Reaction-simulation phase

r-agents looking for inhibitors, reactants, generating semi-products (a') - the number of agents $= |A|$ - and go to waiting phase

input 0

a_1, a_3

$\overline{a_1}^1 \; \overline{a_3}^2$

background set

$S = \{a_1, a_2, a_3\}$

$$r_1 = (\{a_2\}, \{f\}, \{a_2\})$$
$$r_2 = (\{a_1, a_3\}, \{f\}, \{a_1, a_2\})$$
$$r_3 = (\{a_3\}, \{a_1\}, \{a_1, a_2\})$$

r-agent 1: $F \; e$

r-agent 2: $Z \; a_1'$

r-agent 3: $F \; e$

For given R system $\mathcal{A} = (S, A)$ and sequence of inputs $i_0, i_1, \ldots, i_n$

3. Reaction-simulation phase

r-agents looking for inhibitors, reactants, generating semi-products (a') - the number of agents $= |A|$ - and go to waiting phase

input 0

a_1, a_3

background set

$S = \{a_1, a_2, a_3\}$

a_1' $\overline{a_1}^1$ $\overline{a_3}^2$

$$r_1 = (\{a_2\}, \{f\}, \{a_2\})$$
$$r_2 = (\{a_1, a_3\}, \{f\}, \{a_1, a_2\})$$
$$r_3 = (\{a_3\}, \{a_1\}, \{a_1, a_2\})$$

r-agent 1: F e

r-agent 2: Z_1 e

r-agent 3: F e

For given R system $\mathcal{A} = (S, A)$ and sequence of inputs $i_0, i_1, \ldots, i_n$

3. Reaction-simulation phase

r-agents looking for inhibitors, reactants, generating semi-products (a') - the number of agents $= |A|$ - and go to waiting phase

input 0

a_1, a_3

background set

$S = \{a_1, a_2, a_3\}$

$a'_1 \; \overline{a_1}^1 \; \overline{a_3}^2$

$$
\begin{aligned}
r_1 &= (\{a_2\}, \{f\}, \{a_2\}) \\
r_2 &= (\{a_1, a_3\}, \{f\}, \{a_1, a_2\}) \\
r_3 &= (\{a_3\}, \{a_1\}, \{a_1, a_2\})
\end{aligned}
$$

r-agent 1: $F \; e$

r-agent 2: $Z_1 \; a'_2$

r-agent 3: $F \; e$

Simulation of Interactive process by P Colonies

For given R system $\mathcal{A} = (S, A)$ and sequence of inputs $i_0, i_1, \ldots, i_n$

3. Reaction-simulation phase

r-agents looking for inhibitors, reactants, generating semi-products (a') - the number of agents $= |A|$ - and go to waiting phase

input 0

a_1, a_3

background set

$S = \{a_1, a_2, a_3\}$

$a'_1 \; a'_2 \; \overline{a_1}^1 \; \overline{a_3}^2$

$$r_1 = (\{a_2\}, \{f\}, \{a_2\})$$
$$r_2 = (\{a_1, a_3\}, \{f\}, \{a_1, a_2\})$$
$$r_3 = (\{a_3\}, \{a_1\}, \{a_1, a_2\})$$

r-agent 1	r-agent 2	r-agent 3
$F \; e$	$D \; e$	$F \; e$

Simulation of Interactive process by P Colonies

For given R system $\mathcal{A} = (S, A)$ and sequence of inputs $i_0, i_1, \ldots, i_n$

4. Consuming phase

The first i-agents consumes symbol that is generated by special agent - it was active from the beginning of the third phase.
i-agents after consuming this object generate the next input.

a-agents consuming duplicate symbols ($a' \rightarrow a$) and erasing unused symbols ($\overline{a} \rightarrow e$).

For given R system $\mathcal{A} = (S, A)$ and sequence of inputs $i_0, i_1, \ldots, i_n$

5. Checking-Restarting phase

c-agents check if all a-agents stop working. Then they send symbols for i-agent to generate symbol f and symbols to "restart" a-agents. After a short waiting phase c-agents also generate symbols to allow r-agents to work.

Simulation of Interactive process by P Colonies

For given R system $\mathcal{A} = (S, A)$ and sequence of inputs $i_0, i_1, \ldots, i_n$

f- **symbol**

to ensure that only configurations with input and result of previous step will take part at "report about behaviour" of P Colony, in this step, symbol f is emitted to be consumed in the next step.

P Colony with Environment in a Form of Set

Idea

The idea comes from R systems

- R systems were introduced in 2004[2] as a computational device, which components are a simile for basic chemical reactions (reactants, inhibitors, products).
- The environment is in a form of a set (a content is a subset of background set)

[2] A. Ehrenfeucht and G. Rozenberg. "Basic Notions of Reaction Systems". In: *Developments in Language Theory*. Ed. by Cristian S. Calude, Elena Calude, and Michael J. Dinneen. Berlin, Heidelberg: Springer Berlin Heidelberg, 2005, pp. 27–29. ISBN: 978-3-540-30550-7.

P Colony with environment in a form of a set

Environment

- The environment is set of objects
- If an agent has applicable programs it must use one of them – the maximal number of active agents.
- if agents have deterministic set of programs a computation is deterministic too.

P Colonies with e-set

Simulation of interactive process o R system is shorter because we do not need multiplication phase.

Conclusion

Conclusion

P Colonies with capacity two can simulate interactive process of reaction systems.

We have introduced the new type of P Colonies with environment in a form of a set.

What kind of restriction we have to set to construct reaction system that simulate such restricted P Colony?

Thanks!

I would like to thank :

- my colleagues for their work and patience,
- You, the audience, for your attention.