Membrane Systems with Surface Objects

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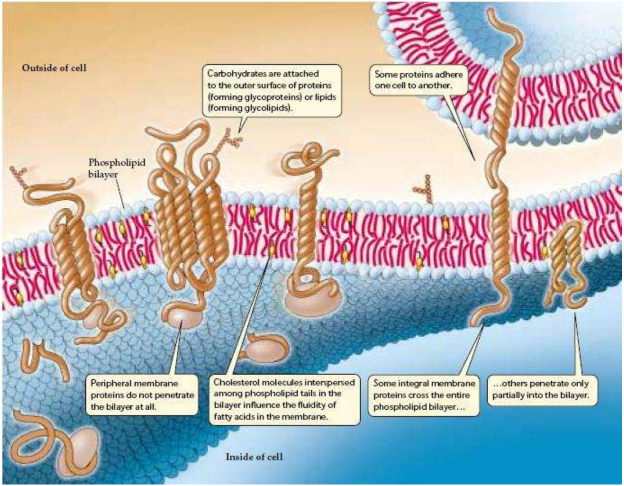
Computing with Biomolecules
August 27th, 2008
Vienna, Austria

Outline

Membrane Systems with Surface Objects

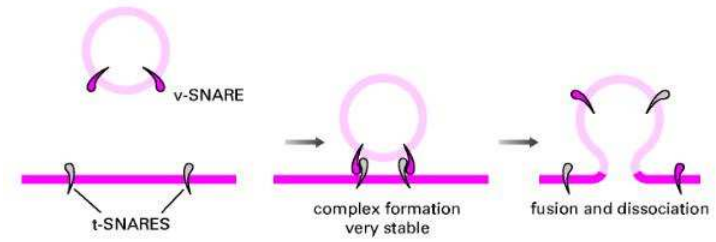
- Some work was done previously trying to relate membrane systems and brane calculus [4, 5, 7, 9].
- Inspired by brane calculus, a model of the membrane system having objects attached to the membranes has been introduced in [8].
- In [3], a class of membrane systems containing both free floating objects and objects attached to membranes have been proposed.
- In this paper we are continuing this research line, and simulate a variant of brane calculus by using membrane systems with surface objects.

Membrane Systems with Surface Objects



The Fluid Mosaic Model: The general molecular structure of biological membranes is a continuous phospholipid bilayer in which proteins are embedded.

Membrane Systems with Surface Objects



Membrane Fusion

- Is the process by which a vesicle membrane incorporates its components into the target membrane;
- First, the vesicle and the target membrane mutually identify each other;
- Then, proteins from both membranes interact with one another to form stable complexes and bring the two membranes into close apposition, resulting in the docking of the vesicle to the target membrane.
- Finally, considerable energy is supplied to force the membranes to fuse.

Membrane Systems with Surface Objects

Definition

A membrane system with surface objects (MSO) and n membranes is a construct

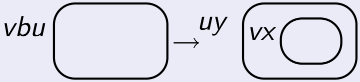
$$\Pi = (A, \mu, u_1, \ldots, u_n, R)$$

where:

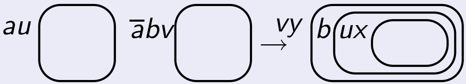
1. A is an alphabet (finite, non-empty) of proteins;
2. μ is a membrane structure with $n \geq 2$ membranes;
3. $u_1, \ldots, u_n$ are multisets of proteins; the skin membrane is labelled with 1 and $u_1 = \lambda$;
4. R is a finite set of rules of the following forms:

Membrane Systems with Surface Objects

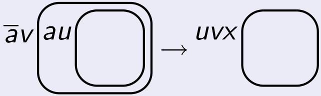
$[\ ]_{vbu} \rightarrow_m [[\ ]_{vx}]_{uy}$, where $b \in A, u, x, y \in A^*, v \in A^+$ **pino**



$[\ ]_{au}[\ ]_{\overline{a}bv} \rightarrow_m [[[\ ]_{ux}]_{b}]_{vy}$, where $a, \overline{a} \in A, u, v, x, y \in A^*$ **phago**



$[[\ ]_{au}]_{\overline{a}v} \rightarrow_m [\ ]_{uvx}$, where $a, \overline{a} \in A, u, v, x \in A^*$ **exo**



- $A(\Pi)$ denotes the finite alphabet of the system Π;
- a marking w represent a distribution of the multiset of objects w over the structure μ of Π;
- if we consider a multiset of objects w containing all the objects present in the system at a certain moment, then the following proposition holds.

Proposition

It is decidable whether w is a reachable marking of Π, for any MSO system Π and any multiset w of objects over $A(\Pi)$.

Membrane Systems with Surface Objects

Operational Semantics

Syntax of MSO

Systems	$M, N ::= M\ N \mid [M]_u$	membranes with surface objects
Multisets	$u, v\ ::= \lambda \mid a \mid \overline{a} \mid uv$	multisets of objects where $a, \overline{a} \in A$

Structural Congruence of MSO

$M\ N \equiv_m N\ M$

$M\ (N\ P) \equiv_m (M\ N)\ P$

$uv \equiv_m vu$

$u(vw) \equiv_m (uv)w$

$\lambda u \equiv_m u$

$M \equiv_m N$ implies $M\ P \equiv_m N\ P$

$M \equiv_m N$ and $u \equiv_m v$ implies $[M]_u \equiv_m [N]_v$

$u \equiv_m v$ implies $uw \equiv_m vw$

Reductions of MSO

$P \rightarrow_m Q$ implies $P\ R \rightarrow_m Q\ R$	Par
$P \rightarrow_m Q$ implies $[P]_u \rightarrow_m [Q]_u$	Mem
$P \equiv_m P'$ and $P' \rightarrow_m Q'$ and $Q' \equiv_m Q$ implies $P \rightarrow_m Q$	Struct

PEP Calculus Without Replication

Syntax of PEP

Systems	$P, Q ::= \diamond \mid P \circ Q \mid \sigma(P)$	nests of membranes
Branes	$\sigma, \tau ::= O \mid \sigma \vert \tau \mid a.\sigma$	combinations of actions
Actions	$a, b ::= n^{\searrow} \mid \overline{n}^{\searrow}(\sigma) \mid n^{\nwarrow} \mid \overline{n}^{\nwarrow} \mid pino(\sigma)$	phago $\searrow$, exo $\nwarrow$

Structural Congruence of PEP

$P \circ Q \equiv_b Q \circ P$	$\sigma \mid \tau \equiv_b \tau \mid \sigma$
$P \circ (Q \circ R) \equiv_b (P \circ Q) \circ R$	$\sigma \mid (\tau \mid \rho) \equiv_b (\sigma \mid \tau) \mid \rho$
$P \circ \diamond \equiv_b P \quad 0(\diamond) \equiv_b \diamond$	$\sigma \mid o \equiv_b \sigma$
$P \equiv_b Q$ implies $P \circ R \equiv_b Q \circ R$	$\sigma \equiv_b \tau$ implies $\sigma \mid \rho \equiv_b \tau \mid \rho$
$P \equiv_b Q$ and $\sigma \equiv_b \tau$ implies $\sigma(P) \equiv_b \tau(Q)$	$\sigma \equiv_b \tau$ implies $a.\sigma \equiv_b a.\tau$

Reductions of PEP

$pino(\rho).\sigma \vert \sigma_0(P) \rightarrow_b \sigma \vert \sigma_0(\rho(\diamond) \circ P)$	Pino
$\overline{n}^{\nwarrow}.\tau \vert \tau_0(n^{\nwarrow}.\sigma \vert \sigma_0(P) \circ Q) \rightarrow_b P \circ \sigma \vert \sigma_0 \vert \tau \vert \tau_0(Q)$	Exo
$n^{\searrow}.\sigma \vert \sigma_0(P) \circ \overline{n}^{\searrow}(\rho).\tau \vert \tau_0(Q) \rightarrow_b \tau \vert \tau_0(\rho(\sigma \vert \sigma_0(P)) \circ Q)$	Phago
$P \rightarrow_b Q$ implies $P \circ R \rightarrow_b Q \circ R$	Par
$P \rightarrow_b Q$ implies $\sigma(P) \rightarrow_b \sigma(Q)$	Mem
$P \equiv_b P'$ and $P' \rightarrow_b Q'$ and $Q' \equiv_b Q$ implies $P \rightarrow_b Q$	Struct

Encoding PEP into Membranes with Surface Objects

Definition

A translation $\mathcal{T} : \mathcal{P} \to \mathcal{M}$ is given by

$$\mathcal{T}(P) = \begin{cases} [\mathcal{T}(P)]_{\mathcal{S}(\sigma)} & \text{if } \sigma(P) \\ \mathcal{T}(Q)\ \mathcal{T}(R) & \text{if } P = Q \mid R \end{cases}$$

where $\mathcal{S} : \mathcal{P} \to A$ is defined as:

$$\mathcal{S}(\sigma) = \begin{cases} \sigma & \text{if } \sigma = n^{\searrow} \text{ or } \sigma = n^{\nwarrow} \text{ or } \sigma = \overline{n}^{\nwarrow} \\ \overline{n}^{\searrow}\ S(\rho) & \text{if } \sigma = \overline{n}^{\searrow}(\rho) \\ pino\ S(\rho) & \text{if } \sigma = pino(\rho) \\ \mathcal{S}(a)\ \mathcal{S}(\rho) & \text{if } \sigma = a.\rho \\ \mathcal{S}(\tau)\ \mathcal{S}(\rho) & \text{if } \sigma = \tau \mid \rho \end{cases}$$

Rules of MSO

$[\ ]_{S(n^{\searrow}\sigma|\sigma_0)}[\ ]_{S(\overline{n}^{\searrow}(\rho).\tau|\tau_0)} \to_m [[[\ ]_{S(\sigma|\sigma_0)}]_{S(\rho)}]_{S(\tau|\tau_0)}$

$[[\ ]_{S(n^{\nwarrow}.\sigma|\sigma_0)}]_{S(\overline{n}^{\nwarrow}.\tau|\tau_0)} \to_m [\ ]_{S(\sigma|\sigma_0|\tau|\tau_0)}$

$[\ ]_{S(pino(\rho).\sigma|\sigma_0)} \to_m [[\ ]_{S(\rho)}]_{S(\sigma|\sigma_0)}$

Encoding PEP into Membranes with Surface Objects

Proposition

If P is a PEP system and $M = \mathcal{T}(P)$ is a membrane system with surface objects, then there exists N such that $M \equiv_m N$ and $N = \mathcal{T}(Q)$, whenever $P \equiv_b Q$.

Proposition

If P is a PEP system and $M = \mathcal{T}(P)$ is a membrane system with surface objects, then there exists Q such that $N = \mathcal{T}(Q)$ whenever $M \equiv_m N$.

Proposition

If P is a PEP system and $M = \mathcal{T}(P)$ is a membrane system with surface objects, then there exists N such that $M \rightarrow_m N$ and $N = \mathcal{T}(Q)$, whenever $P \rightarrow_b Q$.

Proposition

If P is a PEP system and $M = \mathcal{T}(P)$ is a membrane system with surface objects, then there exists Q such that $N = \mathcal{T}(Q)$ whenever $M \rightarrow_m N$.

Global vs. Local Rules

Example

Global Rules

Consider the membrane system

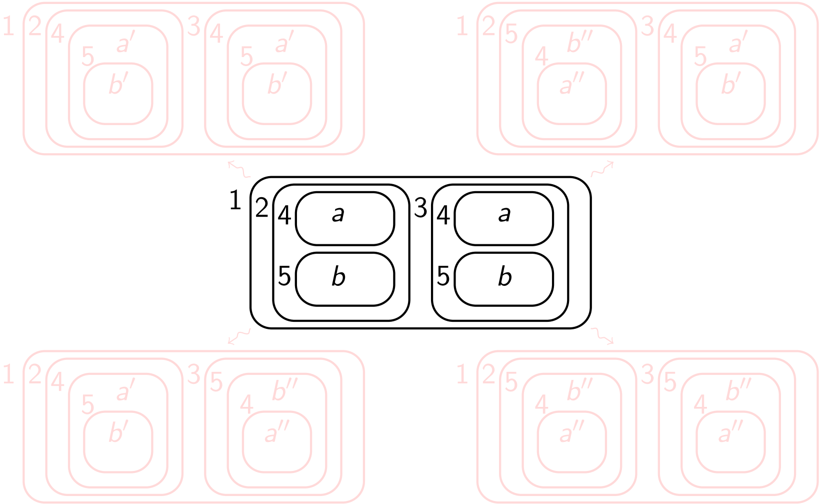
$$[[[a]_4[b]_5]_2[[a]_4[b]_5]_3]_1$$

with the set of rules

$$R = \{[a]_4[b]_5 \to [a'[b']_5]_4, [a]_4[b]_5 \to [b''[a'']_4]_5\}$$

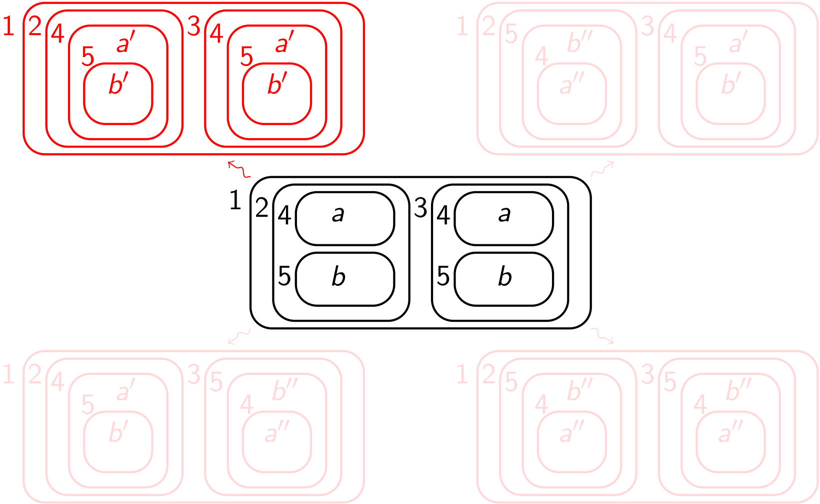
If we let this system evolve then we have the following possible configurations:

Example



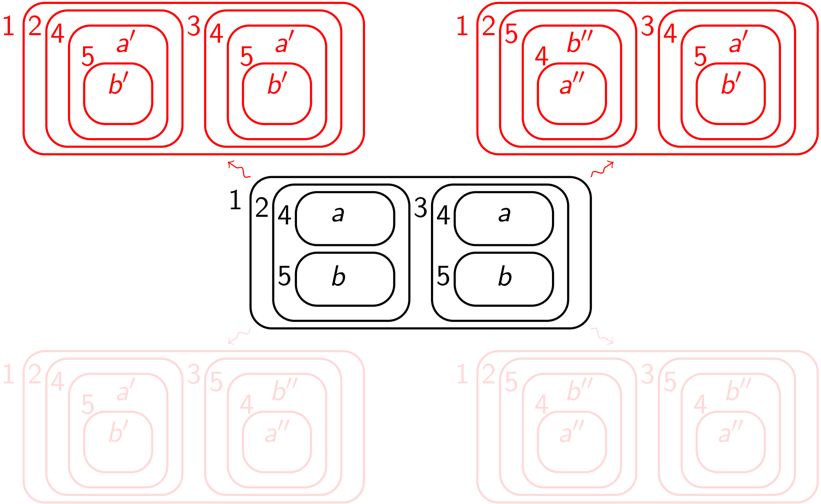
1 2 4 5 a' b' 3 4 5 a' b'
1 2 5 4 b'' a'' 3 4 5 a' b'
1 2 4 a 5 b 3 4 a 5 b
1 2 4 5 a' b' 3 5 4 b'' a''
1 2 5 4 b'' a'' 3 5 4 b'' a''

Example



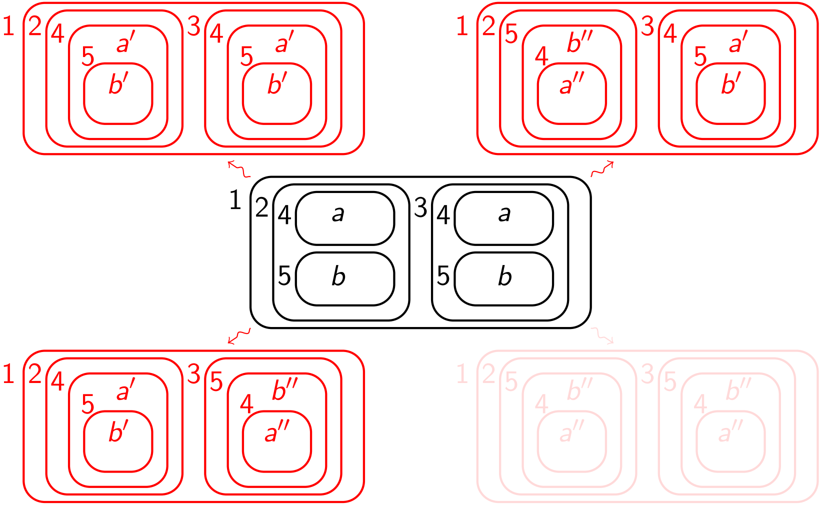
1 2 4 5 a' b' 3 4 5 a' b'
1 2 5 4 b'' a'' 3 4 5 a' b'
1 2 4 a 5 b 3 4 a 5 b
1 2 4 5 a' b' 3 5 4 b'' a''
1 2 5 4 b'' a'' 3 5 4 b'' a''

Example

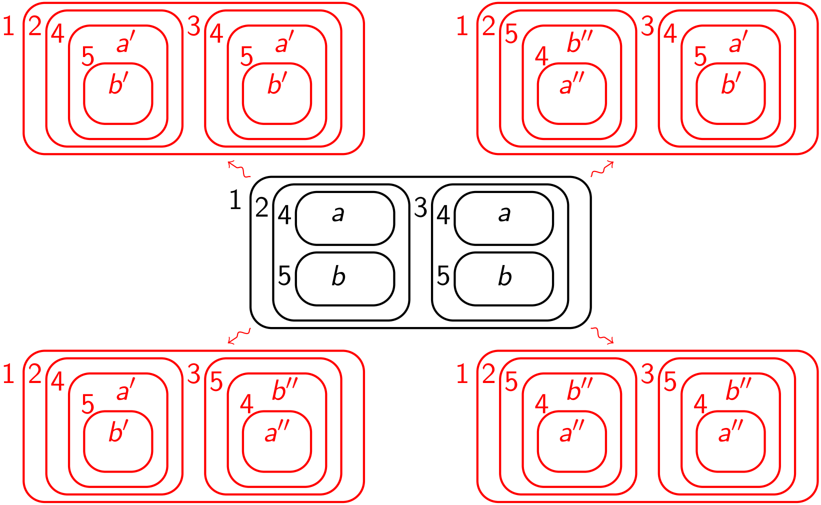


1 2 4 5 a′ b′ 3 4 5 a′ b′
1 2 5 4 b″ a″ 3 4 5 a′ b′
1 2 4 a 5 b 3 4 a 5 b
1 2 4 5 a′ b′ 3 5 4 b″ a″
1 2 5 4 b″ a″ 3 5 4 b″ a″

Example


1 2 4 5 a′ b′ 3 4 5 a′ b′
1 2 5 4 b″ a″ 3 4 5 a′ b′
1 2 4 a 5 b 3 4 a 5 b
1 2 4 5 a′ b′ 3 5 4 b″ a″
1 2 5 4 b″ a″ 3 5 4 b″ a″

Example



1
2
4
5
a'
b'
3
4
5
a'
b'
1
2
5
4
b''
a''
3
4
5
a'
b'
1
2
4
a
5
b
3
4
a
5
b
1
2
4
5
a'
b'
3
5
4
b''
a''
1
2
5
4
b''
a''
3
5
4
b''
a''

Global vs. Local Rules

Example

Local Rules

Consider the membrane system

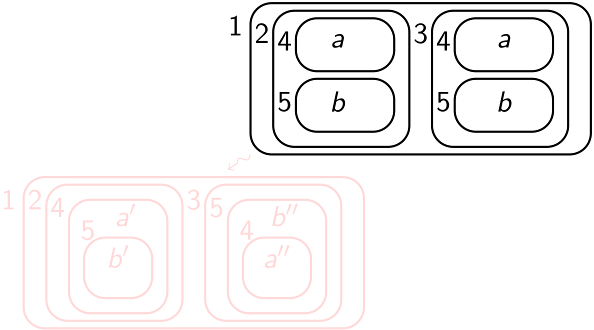
$$[[[a]_4[b]_5]_2[[a]_4[b]_5]_3]_1$$

with the set of rules

$$R_1 = \{[a]_4[b]_5 \rightarrow [a'[b']_5]_4\},\ R_2 = \{[a]_4[b]_5 \rightarrow [b''[a'']_4]_5\}$$

If we let this system evolve we obtain only the solution:

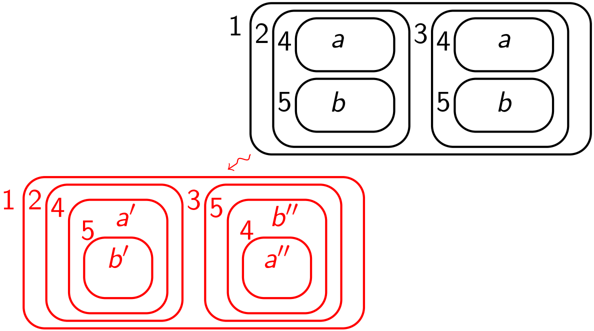
Example



Global vs. Local Rules

By these two examples we want to show that by using local sets of rules we may control better the evolution of a membrane system.

Example



Global vs. Local Rules

By these two examples we want to show that by using local sets of rules we may control better the evolution of a membrane system.

Conclusion

- We introduced in this paper a new set of rules for membrane systems with surface objects in which we use objects and co-object during the evolution. A novel aspect is given by co-objects.
- We show that PEP calculus without replication can be translated into this new class of membrane systems with objects and co-objects. In this way the new class of membranes with surface objects gets the whole computational power of the PEP fragment of the brane calculus.
- We opened the discussion on distributing the global multiset of rules into local sets of rules. The equivalence between the global and the localized system remains an open problem.