Outline
Overview of formal models
Sequential active set membrane systems

Sequential P Systems with Active Membranes Working on Sets

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P systems
Using sets instead of multisets

Membrane structure

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Membrane structure

- Multisets

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Membrane structure

- Multisets
- Rewriting rules

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P systems
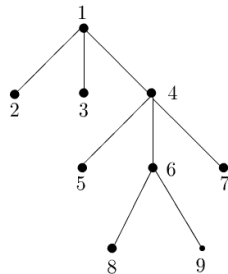Using sets instead of multisets
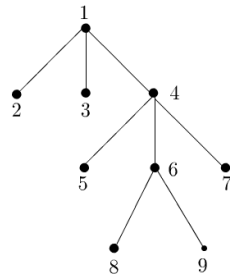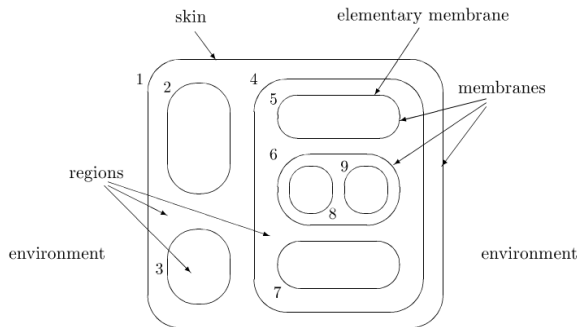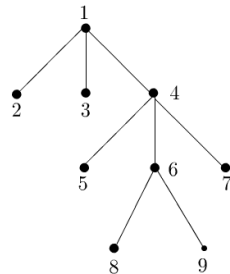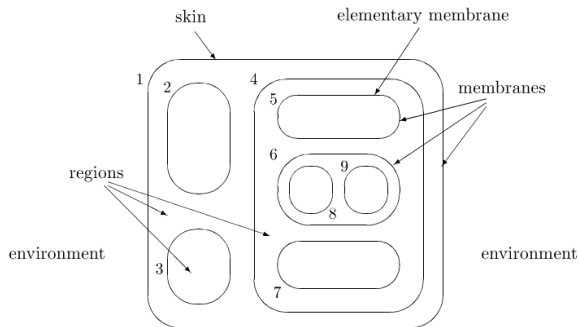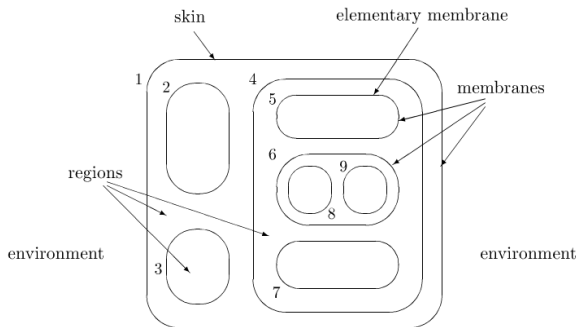
Membrane structure
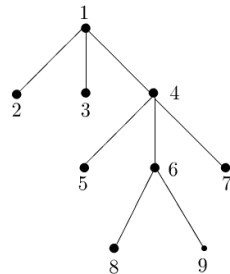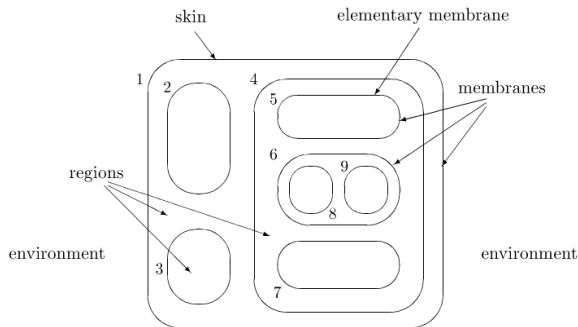
- Multisets
- Rewriting rules
- Passive vs. Active

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Computation

- Maximal parallel vs. sequential

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Computation

- Maximal parallel vs. sequential
- Language
  - Generating mode: language of sequences of objects sent out from the skin membrane
  - Accepting mode: accept the given configuration if the system can halt

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- How realistic is the counting?
- Effectiveness of verification techniques

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Set membane systems

- Alhazov [Alhazov, 2006]: multiplicities of objects are ignored

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    - maximal parallel $\Rightarrow$ deterministic
    - equivalent to finite state machines

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    - maximal parallel $\Rightarrow$ deterministic
    - equivalent to finite state machines
    - with active membranes universal
- Kleijn, Koutny [Kleijn and Koutny, 2011]: "min-enabled" computational step $=$ sequential
    - equivalent to finite state machines
- Properties:
    - No conflict (objects can participate as reactants in as many rules as they want).
    - If an object is used as a reactant for at least one rule, it is consumed.

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Original semantics
Modified membrane creation semantics

Sequential active set membrane systems

- $\Pi = (\Sigma, C_0, R_0, \ldots R_{m-1})$

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- $\Pi = (\Sigma, C_0, R_0, \ldots R_{m-1})$
- $C = (T, l, c)$
    - $l : V(T) \to \{0, \ldots, m-1\}$
    - $c : V(T) \to 2^{\Sigma}$

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- $C = (T, l, c)$
  - $l : V(T) \rightarrow \{0, \ldots, m-1\}$
  - $c : V(T) \rightarrow 2^{\Sigma}$
- Rewriting rules
  - $u \rightarrow w$
  - $u \rightarrow w\delta$
  - $u \rightarrow [_j v_1]_j v_2,$
    where $u \subseteq \Sigma, |u| \geq 1, \ v_1, v_2 \subseteq \Sigma$ and $w \subseteq (\Sigma \times \{\cdot, \uparrow, \downarrow_j\})$

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Register machine

- Registers with non-negative values $r_1, r_2, \ldots$
- Labeled instructions $i : op$, where op is:
    - $add(j, k)$
    - $sub(j, k, l)$
    - $halt$
- State $=$ (instruction pointer, values of registers)
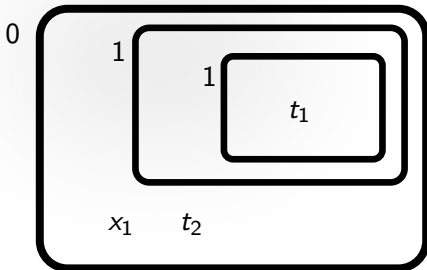- Step: modify the register value, move the instruction pointer

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Simulation of a register machine

Simulation of a register machine (2 registers, 3 instructions):

- $1 : sub(1, 2, 3)$
- $2 : add(2, 1)$
- $3 : halt$

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Example simulation

Skin membrane (6 rules):

- $x_1 \rightarrow x_1 \downarrow_1$, $x_2 \rightarrow x_2 \downarrow_2$
- $x_2 t_2 \rightarrow [_2 y_1 t_2]_2$
- $x_1 t_1 \rightarrow x_3$
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Membrane 1 (4 rules):

- $x_1 \rightarrow x_1 \downarrow_1$
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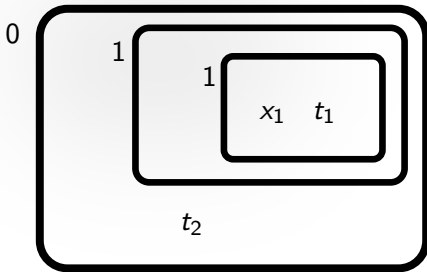

Membrane 2 (4 rules):

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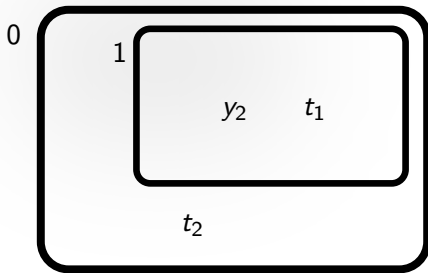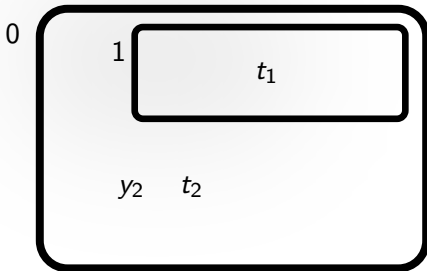
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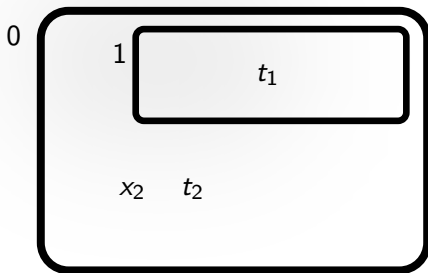
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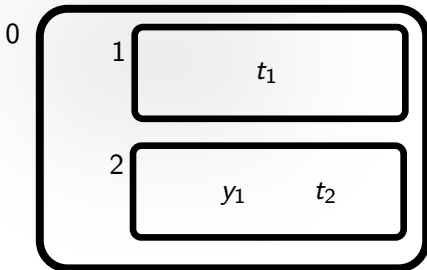- $y_1 \rightarrow y_1 \uparrow$, $y_2 \rightarrow y_2 \uparrow$

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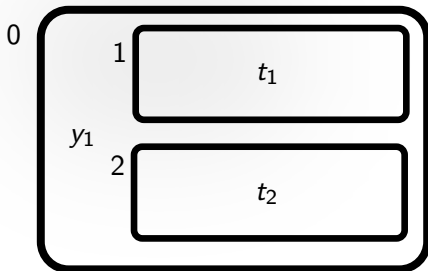- $y_1 \rightarrow y_1 \uparrow$, $y_2 \rightarrow y_2 \uparrow$

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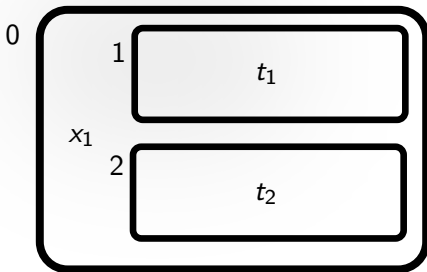
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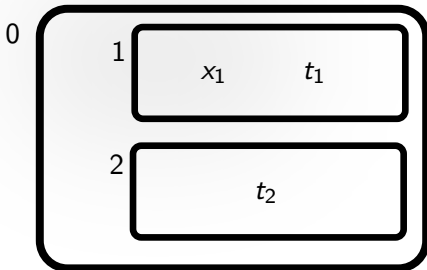

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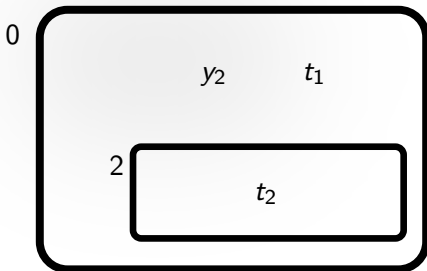- $y_1 \rightarrow y_1 \uparrow$, $y_2 \rightarrow y_2 \uparrow$

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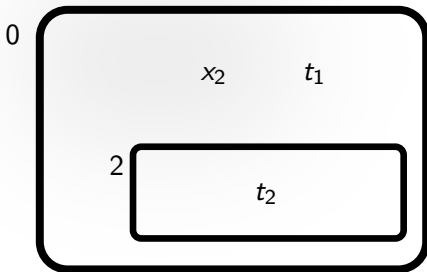
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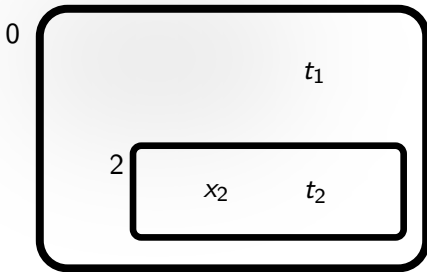
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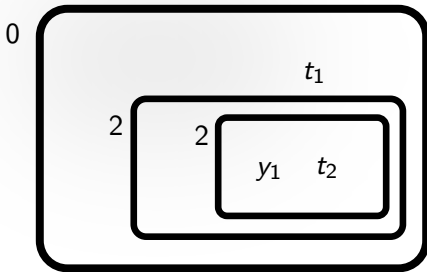- $y_1 \rightarrow y_1 \uparrow$, $y_2 \rightarrow y_2 \uparrow$

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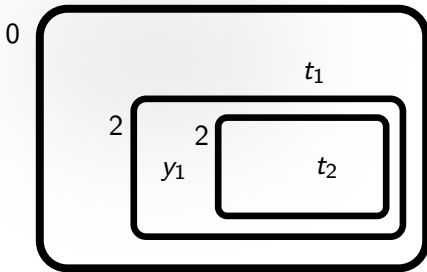

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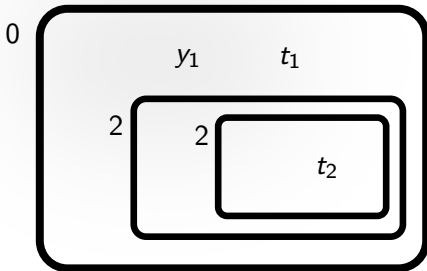- $y_1 \rightarrow y_1 \uparrow$, $y_2 \rightarrow y_2 \uparrow$

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- $y_1 \to y_1 \uparrow$, $y_2 \to y_2 \uparrow$

Outline
Overview of formal models
Sequential active set membrane systems

Original semantics
Modified membrane creation semantics
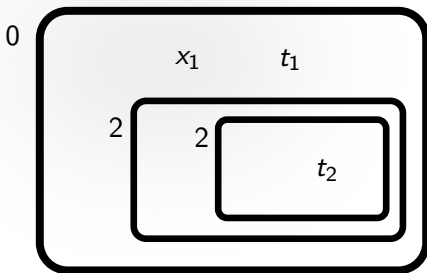
Example simulation

Skin membrane (6 rules):

- $x_1 \rightarrow x_1 \downarrow_1$, $x_2 \rightarrow x_2 \downarrow_2$
- $x_2 t_2 \rightarrow [_2 y_1 t_2]_2$
- $x_1 t_1 \rightarrow x_3$
- $y_1 \rightarrow x_1$, $y_2 \rightarrow x_2$

Membrane 1 (4 rules):

- $x_1 \rightarrow x_1 \downarrow_1$
- $x_1 t_1 \rightarrow y_2 t_1 \delta$
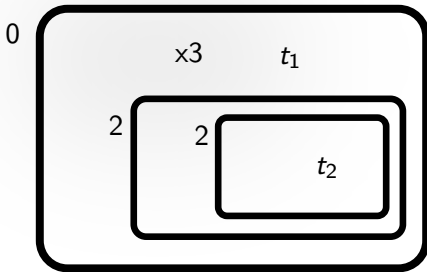- $y_1 \rightarrow y_1 \uparrow$, $y_2 \rightarrow y_2 \uparrow$

Membrane 2 (4 rules):

- $x_2 \rightarrow x_2 \downarrow_2$
- $x_2 t_2 \rightarrow [_2 y_1 t_2]_2$
- $y_1 \rightarrow y_1 \uparrow$, $y_2 \rightarrow y_2 \uparrow$

Outline
Overview of formal models
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Example simulation

Skin membrane (6 rules):

- $x_1 \rightarrow x_1 \downarrow_1$, $x_2 \rightarrow x_2 \downarrow_2$
- $x_2 t_2 \rightarrow [_2 y_1 t_2]_2$
- $x_1 t_1 \rightarrow x_3$
- $y_1 \rightarrow x_1$, $y_2 \rightarrow x_2$

Membrane 1 (4 rules):

- $x_1 \rightarrow x_1 \downarrow_1$
- $x_1 t_1 \rightarrow y_2 t_1 \delta$
- $y_1 \rightarrow y_1 \uparrow$, $y_2 \rightarrow y_2 \uparrow$

Membrane 2 (4 rules):

- $x_2 \rightarrow x_2 \downarrow_2$
- $x_2 t_2 \rightarrow [_2 y_1 t_2]_2$
- $y_1 \rightarrow y_1 \uparrow$, $y_2 \rightarrow y_2 \uparrow$

Outline
Overview of formal models
Sequential active set membrane systems

Original semantics
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Issues with original semantics

- Two issues:
  1. Explicit membrane creation rule

Outline
Overview of formal models
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Modified membrane creation semantics

Issues with original semantics

- Two issues:
    1. Explicit membrane creation rule
    2. Sending an object to a child membrane

Outline
Overview of formal models
Sequential active set membrane systems

Original semantics
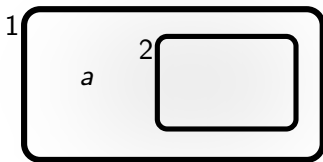Modified membrane creation semantics
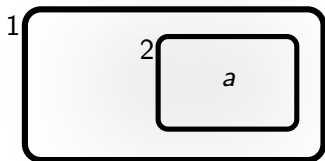
Issues with original semantics

- Two issues:
    1. Explicit membrane creation rule
    2. Sending an object to a child membrane
- Alternatives:
    1. Inject-or-create (no explicit membrane creation rule)

Outline
Overview of formal models
Sequential active set membrane systems

Original semantics
Modified membrane creation semantics

Issues with original semantics

- Two issues:
    1. Explicit membrane creation rule
    2. Sending an object to a child membrane
- Alternatives:
    1. Inject-or-create (no explicit membrane creation rule)
    2. Wrap-or-create

Outline
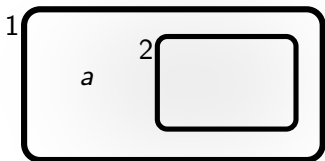Overview of formal models
Sequential active set membrane systems

Original semantics
Modified membrane creation semantics

Inject-or-create semantics

Outline
Overview of formal models
Sequential active set membrane systems

Original semantics
Modified membrane creation semantics

Inject-or-create semantics

$$a \rightarrow a \downarrow_2$$

Outline
Overview of formal models
Sequential active set membrane systems

Original semantics
Modified membrane creation semantics

Inject-or-create semantics

$a \rightarrow a \downarrow_3$

Outline
Overview of formal models
Sequential active set membrane systems

Original semantics
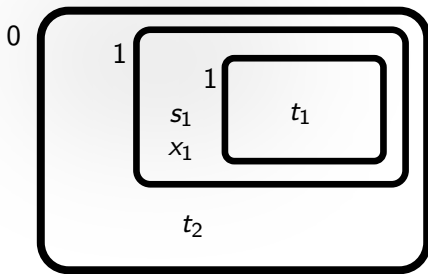Modified membrane creation semantics

Wrap-or-create semantics

Skin membrane:

- $x_1 t_1 \rightarrow x_3 t_1$
- $x_1 s_1 \rightarrow x_1 \downarrow_1$
- $x_2 s_2 \rightarrow [_2 s_2]_2 s_2 x_1$
- $x_2 t_2 \rightarrow [_2 t_2]_2 s_2 x_1$

Membrane 1:

- $x_1 \rightarrow x_2 \delta$

Outline
Overview of formal models
Sequential active set membrane systems

Original semantics
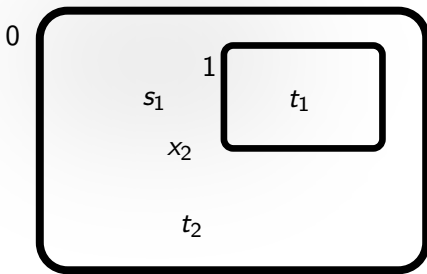Modified membrane creation semantics

Wrap-or-create semantics

Skin membrane:

- $x_1 t_1 \rightarrow x_3 t_1$
- $x_1 s_1 \rightarrow x_1 \downarrow_1$
- $x_2 s_2 \rightarrow [_2 s_2]_2 s_2 x_1$
- $x_2 t_2 \rightarrow [_2 t_2]_2 s_2 x_1$

Membrane 1:

- $x_1 \rightarrow x_2 \delta$

Outline
Overview of formal models
Sequential active set membrane systems

Original semantics
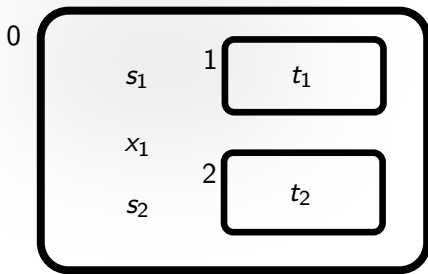Modified membrane creation semantics

Wrap-or-create semantics

Skin membrane:

- $x_1 t_1 \rightarrow x_3 t_1$
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Outline
Overview of formal models
Sequential active set membrane systems

Original semantics
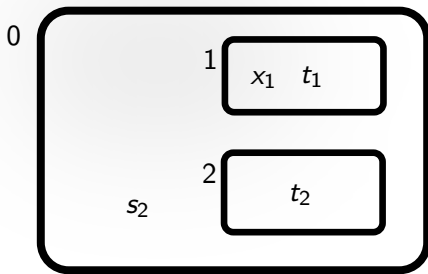Modified membrane creation semantics

Wrap-or-create semantics

Skin membrane:

- $x_1 t_1 \rightarrow x_3 t_1$
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Outline
Overview of formal models
Sequential active set membrane systems

Original semantics
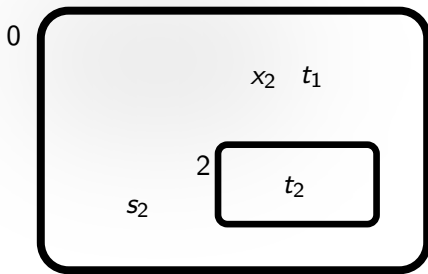Modified membrane creation semantics

Wrap-or-create semantics

Skin membrane:

- $x_1 t_1 \rightarrow x_3 t_1$
- $x_1 s_1 \rightarrow x_1 \downarrow_1$
- $x_2 s_2 \rightarrow [_2 s_2]_2 s_2 x_1$
- $x_2 t_2 \rightarrow [_2 t_2]_2 s_2 x_1$

Membrane 1:

- $x_1 \rightarrow x_2 \delta$

Outline
Overview of formal models
Sequential active set membrane systems

Original semantics
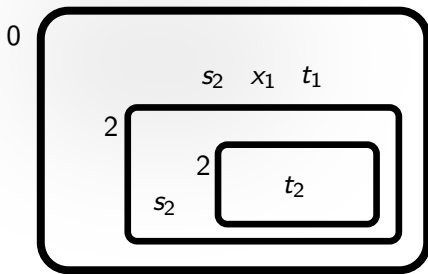Modified membrane creation semantics

Wrap-or-create semantics

Skin membrane:

- $x_1 t_1 \rightarrow x_3 t_1$
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Overview of formal models
Sequential active set membrane systems

Original semantics
Modified membrane creation semantics

Wrap-or-create semantics

Skin membrane:

- $x_1 t_1 \rightarrow x_3 t_1$
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Membrane 1:

- $x_1 \rightarrow x_2 \delta$

Outline
Overview of formal models
Sequential active set membrane systems

Original semantics
Modified membrane creation semantics
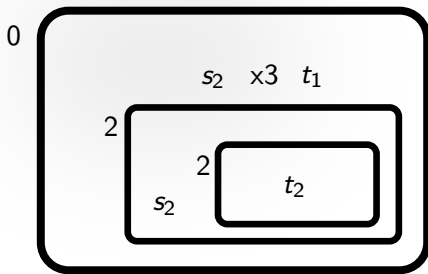
Wrap-or-create semantics

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- $x_1 t_1 \rightarrow x_3 t_1$
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Membrane 1:

- $x_1 \rightarrow x_2 \delta$

Outline
Overview of formal models
Sequential active set membrane systems

Original semantics
Modified membrane creation semantics

Comparison of membrane creation semantics

semantics	membranes	time	alphabet
original	$O(n)$	$O(n)$	$2 * \#instr. + \#reg.$
original	$O(log(n))$	$O(log(n))$	$3 * \#instr. + 5$
inject-or-create	$O(log(n))$	$O(log(n))$	$3 * \#instr. + 5$
wrap-or-create	$O(n)$	$O(1)$	$\#instr. + 2 * \#reg.$

📄 Alhazov, A. (2006).
P systems without multiplicities of symbol-objects.
Information Processing Letters, 100(3):124–129.

📄 Kleijn, J. and Koutny, M. (2011).
Membrane systems with qualitative evolution rules.
Fundam. Inf., 110(1-4):217–230.

Thanks for your attention!