Event-based Life in a Nutshell

How Evaluation of Individual Life Cycles Can Reveal Statistical Inferences using Action-accumulating P Systems

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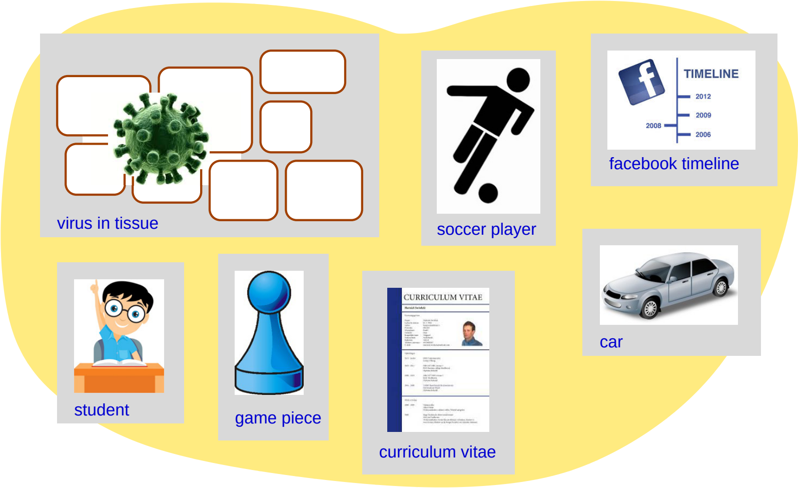
What Do These Individuals Have in Common?



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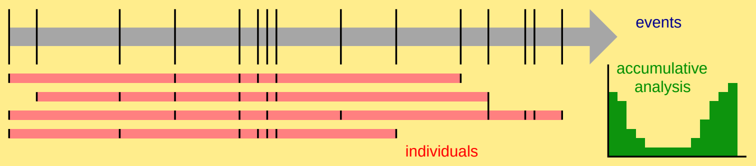
Idea: Exploiting the Potential of Life Cycles

using Membrane Computing

- A *life cycle* of an *individual* consists of a sequence of time-stamped *events*.



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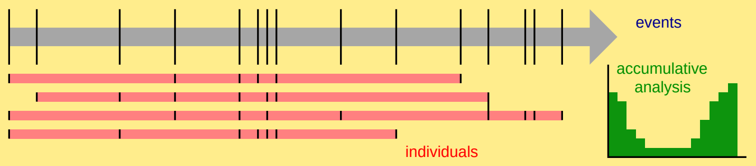

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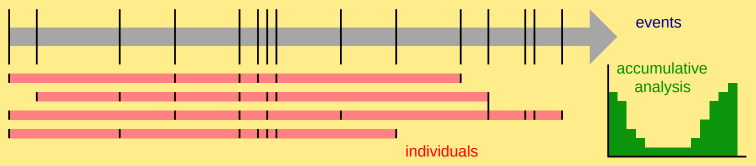

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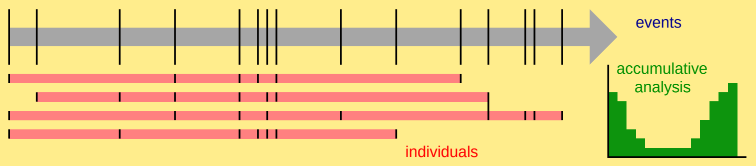

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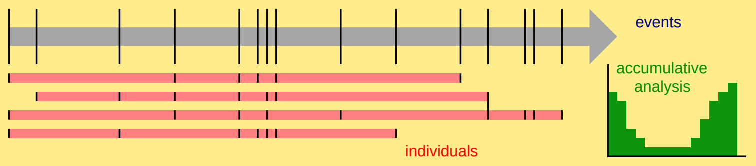
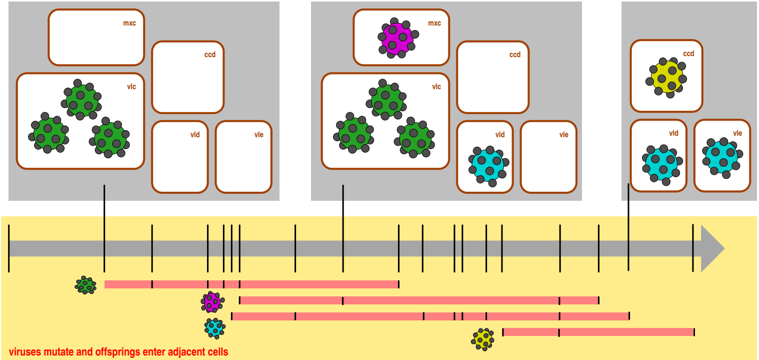
- Alternative events might *create* new individuals but also *kill*, *merge*, or *clone* existing ones.
- We consider a *population* (multiset) of individuals over time.
- Accumulation and statistical *analysis* of events affecting a population of individuals can give new insights.



Example: Progress of Virus Infection



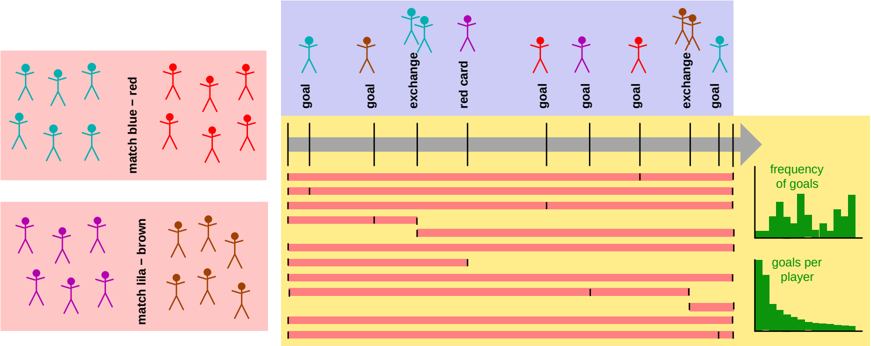
individuals: viruses

attributes: host membrane, genome sequence, mutability, infectivity

events: virus creation, mutation, entering cell membrane, “death”

analysis: variance of virus genome pool, progress of virus infection, . . .

Example: Soccer / Football Game(s)



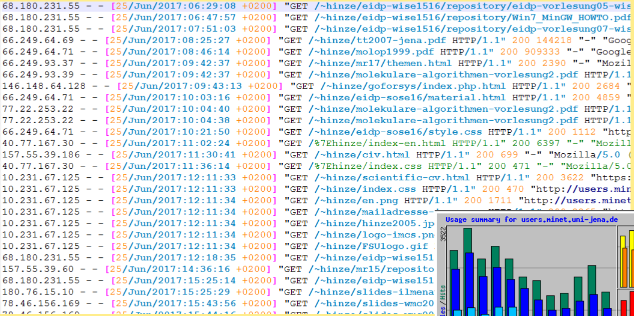
individuals: players

attributes: team membership, number of goals, match identificator

events: player set into match, goal, player exchange, player leaves match

analysis: frequency of goals, goals per player, . . .

Data Sets Commonly Provided by Logfiles



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68.180.231.55 - - [25/Jun/2017:06:47:57 +0200] "GET /~hinze/eidp-wise1516/repository/Win7_MinGW_HOWTO.pdf
68.180.231.55 - - [25/Jun/2017:07:51:03 +0200] "GET /~hinze/eidp-wise1516/repository/eidp-vorlesung07-wis
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66.249.64.71 - - [25/Jun/2017:08:46:14 +0200] "GET /~hinze/molop1999.pdf HTTP/1.1" 200 909333 "-" "Google
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10.231.67.125 - - [25/Jun/2017:12:11:34 +0200] "GET /~hinze/en.png HTTP/1.1" 200 1711 "http://users.minet
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180.76.15.10 - - [25/Jun/2017:15:25:29 +0200] "GET /~hinze/slides-ilmena
78.46.156.169 - - [25/Jun/2017:15:43:56 +0200] "GET /~hinze/slides-wmc20
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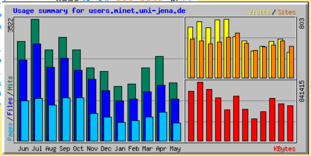
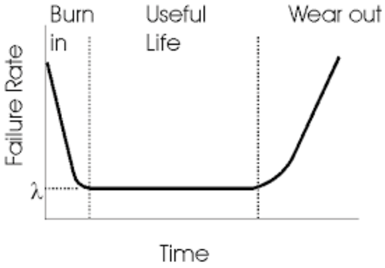
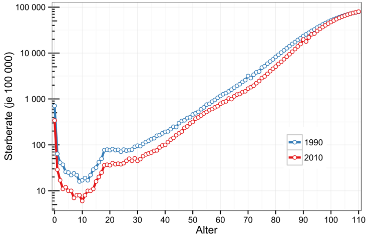


access_log for website file downloads

- In numerous situations, logfiles automatically generated
- Logfile contents might differ from plain text
- Logfile captures all considered events with a time-stamp
- Logfiles can be large-sized data sets

Durability of Technical Products Resembles Mortality





- **Left:** *bathtub-shaped* distribution of failure rate in technical products, particularly those assembled from many components with high inherent complexity
- **Right:** *mortality* of German population (number of persons out of $100,000$ who die in an age of $0 \dots 110$)
- Getting new or more detailed insights from huge data sets

sources: `www.vde.com`, `www.destasis.de`

Membrane Computing

meets

Data Science

linked by

action-accumulating

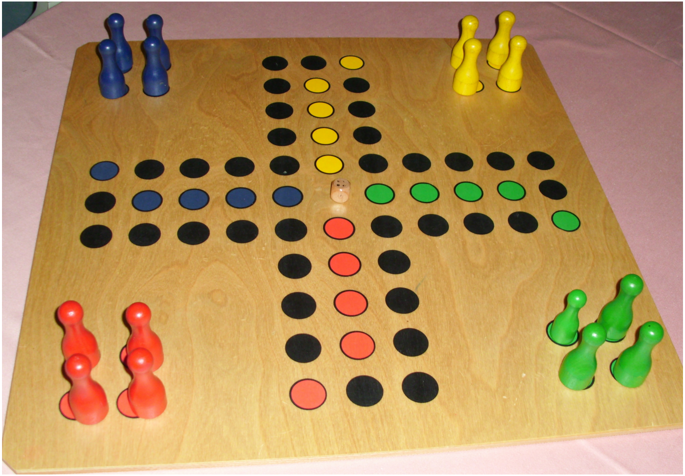
P systems.

Introductory Example

Board Game
"Mensch ärgere Dich nicht"

Board Game “Mensch ärgere Dich nicht”

Man, don’t get annoyed – a German variation of Ludo



Action-accumulating P System for Game Evaluation

$$\Pi_{\square} = (C, 2, D_1, D_2, \mathcal{I}, R, E, 4, S_1, s_1, S_2, s_2, S_3, s_3, S_4, s_4)$$

with its components

$C = \{0, \ldots, 360\} \subset \mathbb{N}$ .... clock with points in time

2 .... number of distinct attributes

Action-accumulating P System for Game Evaluation

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$C = \{0, \ldots, 360\} \subset \mathbb{N}$ .... clock with points in time

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$D_1 = \{b1, b2, b3, b4, y1, y2, y3, y4, g1, g2, g3, g4, r1, r2, r3, r4\}$
.... names of individual pieces (4 black, 4 yellow, 4 green, 4 red)

Action-accumulating P System for Game Evaluation

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$D_2 = \{0, \ldots, 44\}$ .... current place of a piece

0: .... position outside game
1:......................... piece's starting position
$1, \ldots, 40$: .... round course
$41, \ldots, 44$:......... places in piece's safe heaven

Action-accumulating P System for Game Evaluation

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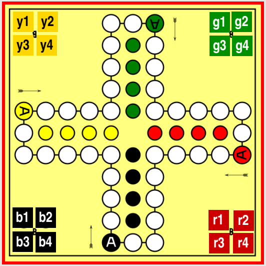
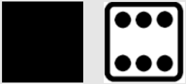
$R = \{\mathtt{create}(\mathrm{p}, 1) \,|\, \mathrm{p} \in D_1\} \cup \{\mathtt{modify}(a_1, a_2 + d) \,|\, d \in \{1, \ldots, 6\}\} \cup \{\mathtt{kill}\}$
... available actions for the events capturing the game course over time

Observing and Processing Events During Game



point in time 0

dice throw



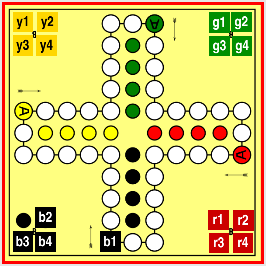
Resulting *events* forming elements from E

$$(0, \emptyset, \texttt{create}(b1, 1))$$

Current systems *configuration* by transition function $\mathcal{O}(t)$ capturing all individuals with their attribute values at time t

$$\mathcal{O}(0) = \mathcal{I} = \emptyset$$

Observing and Processing Events During Game



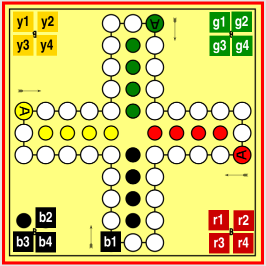
point in time **0**

Resulting *events* forming elements from E

Current systems *configuration* by transition function $\mathcal{O}(t)$ capturing all individuals with their attribute values at time t

$$\mathcal{O}(1) = \{((b1, 1), 1)\}$$

Observing and Processing Events During Game



point in time **1**

dice throw

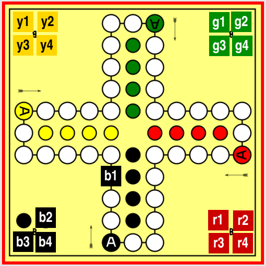
Resulting *events* forming elements from E

$$(1, \{((b1, 1), 1)\}, \texttt{modify}(a_1, a_2 + 3))$$

Current systems *configuration* by transition function $\mathcal{O}(t)$ capturing all individuals with their attribute values at time t

$$\mathcal{O}(1) = \{((b1, 1), 1)\}$$

Observing and Processing Events During Game



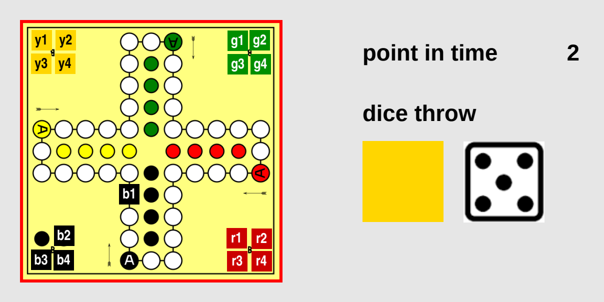
point in time **1**

Resulting *events* forming elements from E

Current systems *configuration* by transition function $\mathcal{O}(t)$ capturing all individuals with their attribute values at time t

$$\mathcal{O}(2) = \{((b1, 4), 1)\}$$

Observing and Processing Events During Game

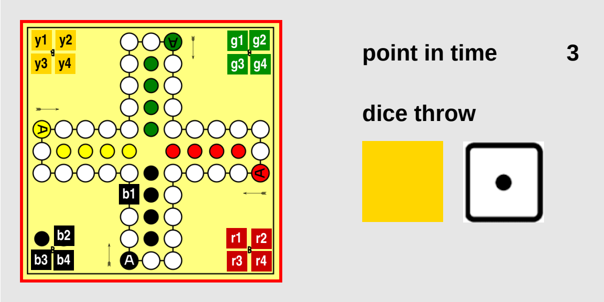


Resulting *events* forming elements from *E*

Current systems *configuration* by transition function $\mathcal{O}(t)$ capturing all individuals with their attribute values at time t

$$\mathcal{O}(3) = \{(b1, 4), 1)\}$$

Observing and Processing Events During Game

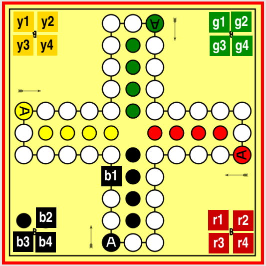


Resulting *events* forming elements from E

Current systems *configuration* by transition function $\mathcal{O}(t)$ capturing all individuals with their attribute values at time t

$$\mathcal{O}(4) = \{((b1, 4), 1)\}$$

Observing and Processing Events During Game



point in time **4**

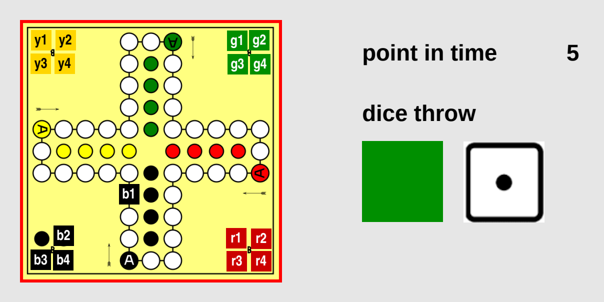
dice throw

Resulting *events* forming elements from E

Current systems *configuration* by transition function $\mathcal{O}(t)$ capturing all individuals with their attribute values at time t

$$\mathcal{O}(5) = \{((b1, 4), 1)\}$$

Observing and Processing Events During Game

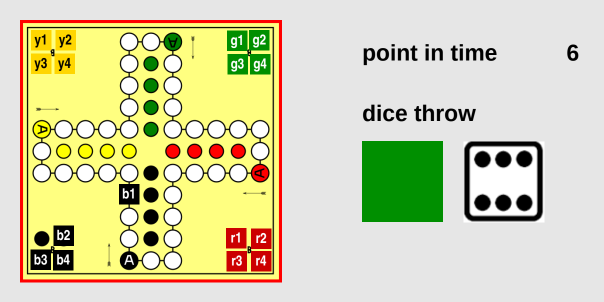


Resulting *events* forming elements from *E*

Current systems *configuration* by transition function $\mathcal{O}(t)$ capturing all individuals with their attribute values at time t

$$\mathcal{O}(6) = \{((b1, 4), 1)\}$$

Observing and Processing Events During Game



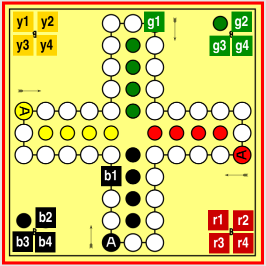
Resulting *events* forming elements from E

$$(6, \emptyset, \texttt{create}(g1, 1))$$

Current systems *configuration* by transition function $\mathcal{O}(t)$ capturing all individuals with their attribute values at time t

$$\mathcal{O}(6) = \{((b1, 4), 1)\}$$

Observing and Processing Events During Game



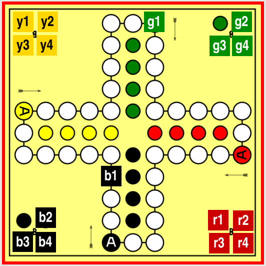
point in time 6

Resulting *events* forming elements from *E*

Current systems *configuration* by transition function $\mathcal{O}(t)$ capturing all individuals with their attribute values at time t

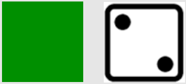
$$\mathcal{O}(7) = \{((b1, 4), 1), ((g1, 1), 1)\}$$

Observing and Processing Events During Game



point in time **7**

dice throw



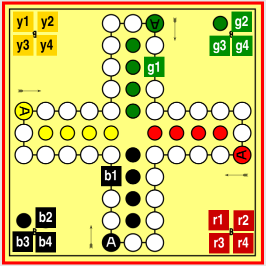
Resulting *events* forming elements from *E*

$$(7, \{((g1, 1), 1)\}, \texttt{modify}(a_1, a_2 + 2))$$

Current systems *configuration* by transition function $\mathcal{O}(t)$ capturing all individuals with their attribute values at time t

$$\mathcal{O}(7) = \{((b1, 4), 1), ((g1, 1), 1)\}$$

Observing and Processing Events During Game



point in time **7**

Resulting *events* forming elements from E

Current systems *configuration* by transition function $\mathcal{O}(t)$ capturing all individuals with their attribute values at time t

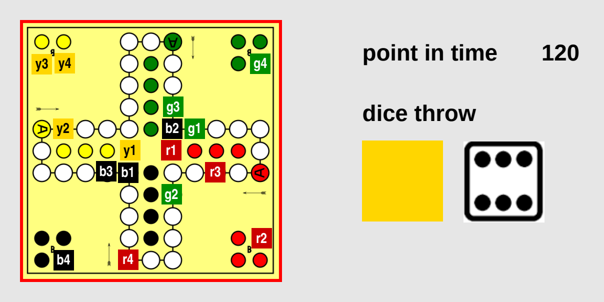
$$\mathcal{O}(8) = \{((b1, 4), 1), ((g1, 3), 1)\}$$

Observing and Processing Events During Game

Resulting *events* forming elements from E

Current systems *configuration* by transition function $\mathcal{O}(t)$ capturing all individuals with their attribute values at time t

Observing and Processing Events During Game



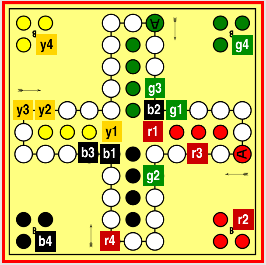
Resulting *events* forming elements from E

$$(120, \emptyset, \texttt{create}(y3, 1))$$

Current systems *configuration* by transition function $\mathcal{O}(t)$ capturing all individuals with their attribute values at time t

$$\mathcal{O}(120) = \{((b1,5),1),((b2,25),1),((b3,6),1),((y1,44),1),((y2,2),1), ((g1,6),1),((g2,16),1),((g3,4),1),((r1,44),1), ((r3,3),1),((r4,11),1)\}$$

Observing and Processing Events During Game



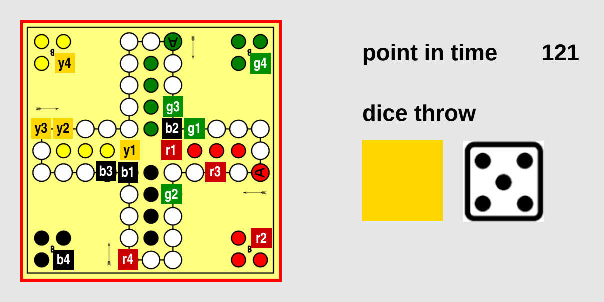
point in time 120

Resulting *events* forming elements from E

Current systems *configuration* by transition function $\mathcal{O}(t)$ capturing all individuals with their attribute values at time t

$$\mathcal{O}(121) = \{((b1,5),1),((b2,25),1),((b3,6),1),((y1,44),1),((y2,2),1),((y3,1),1),((g1,6),1),((g2,16),1),((g3,4),1),((r1,44),1),((r3,3),1),((r4,11),1)\}$$

Observing and Processing Events During Game



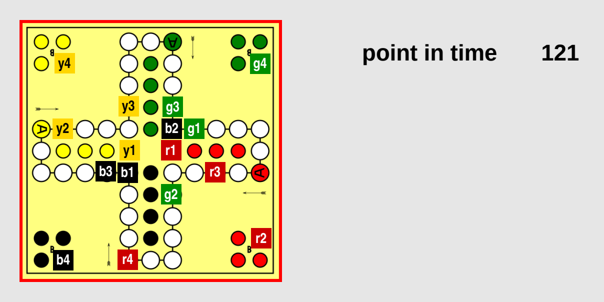
Resulting *events* forming elements from E

$$(121, \{((y3, 1), 1)\}, \texttt{modify}(a_1, a_2 + 5))$$

Current systems *configuration* by transition function $\mathcal{O}(t)$ capturing all individuals with their attribute values at time t

$$\mathcal{O}(121) = \{((b1, 5), 1), ((b2, 25), 1), ((b3, 6), 1), ((y1, 44), 1), ((y2, 2), 1), ((y3, 1), 1), ((g1, 6), 1), ((g2, 16), 1), ((g3, 4), 1), ((r1, 44), 1), ((r3, 3), 1), ((r4, 11), 1)\}$$

Observing and Processing Events During Game

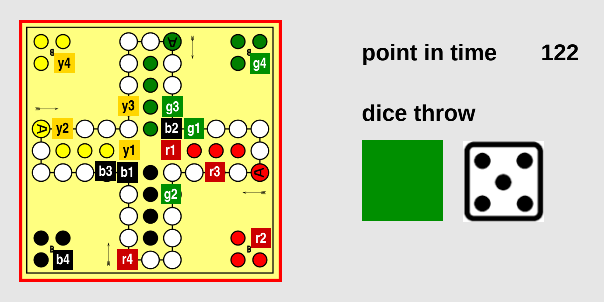


Resulting *events* forming elements from E

Current systems *configuration* by transition function $\mathcal{O}(t)$ capturing all individuals with their attribute values at time t

$$\mathcal{O}(122) = \{((b1, 5), 1), ((b2, 25), 1), ((b3, 6), 1), ((y1, 44), 1), ((y2, 2), 1), ((y3, 6), 1), ((g1, 6), 1), ((g2, 16), 1), ((g3, 4), 1), ((r1, 44), 1), ((r3, 3), 1), ((r4, 11), 1)\}$$

Observing and Processing Events During Game



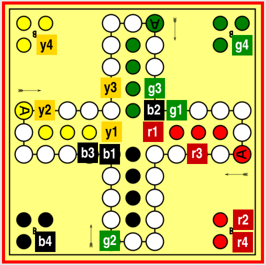
Resulting *events* forming elements from E

$$(122, \{((g2, 16), 1)\}, \texttt{modify}(a_1, a_2 + 5)), (122, \{((r4, 11), 1)\}, \texttt{kill})$$

Current systems *configuration* by transition function $\mathcal{O}(t)$ capturing all individuals with their attribute values at time t

$$\mathcal{O}(122) = \{((b1, 5), 1), ((b2, 25), 1), ((b3, 6), 1), ((y1, 44), 1), ((y2, 2), 1), ((y3, 6), 1), ((g1, 6), 1), ((g2, 16), 1), ((g3, 4), 1), ((r1, 44), 1), ((r3, 3), 1), ((r4, 11), 1)\}$$

Observing and Processing Events During Game



point in time 122

Resulting *events* forming elements from E

Current systems *configuration* by transition function $\mathcal{O}(t)$ capturing all individuals with their attribute values at time t

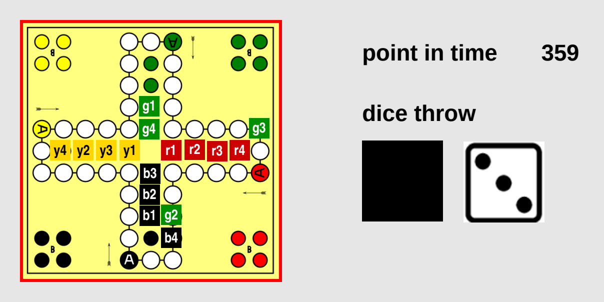
$$\mathcal{O}(123) = \{((b1,5),1),((b2,25),1),((b3,6),1),((y1,44),1),((y2,2),1), ((y3,6),1),((g1,6),1),((g2,21),1),((g3,4),1),((r1,44),1), ((r3,3),1)\}$$

Observing and Processing Events During Game

Resulting *events* forming elements from E

Current systems *configuration* by transition function $\mathcal{O}(t)$ capturing all individuals with their attribute values at time t

Observing and Processing Events During Game



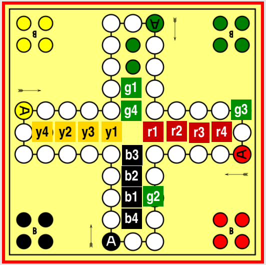
Resulting *events* forming elements from E

$$(359, \{((b4, 38), 1)\}, \texttt{modify}(a_1, a_2 + 3))$$

Current systems *configuration* by transition function $\mathcal{O}(t)$ capturing all individuals with their attribute values at time t

$$\mathcal{O}(359) = \{((b1, 42), 1), ((b2, 43), 1), ((b3, 44), 1), ((b4, 38), 1), ((y1, 44), 1), ((y2, 42), 1), (y3, 43), 1), ((y4, 41), 1), ((g1, 43), 1), ((g2, 17), 1), ((g3, 9), 1), ((g4, 44), 1), ((r1, 44), 1), ((r2, 43), 1), ((r3, 42), 1), ((r4, 41), 1)\}$$

Observing and Processing Events During Game



point in time 359

Resulting *events* forming elements from E

Current systems *configuration* by transition function $\mathcal{O}(t)$ capturing all individuals with their attribute values at time t

$$\mathcal{O}(360) = \{((b1, 42), 1), ((b2, 43), 1), ((b3, 44), 1), ((b4, 41), 1), ((y1, 44), 1), ((y2, 42), 1), (y3, 43), 1), ((y4, 41), 1), ((g1, 43), 1), ((g2, 17), 1), ((g3, 9), 1), ((g4, 44), 1), ((r1, 44), 1), ((r2, 43), 1), ((r3, 42), 1), ((r4, 41), 1)\}$$

Ranking Among All Players

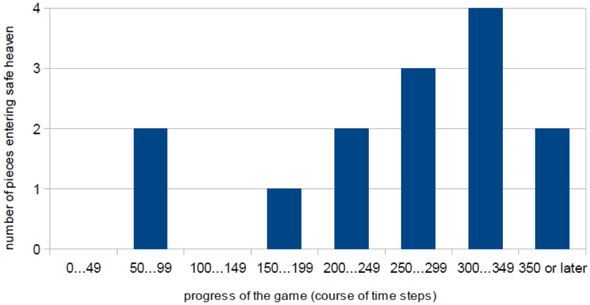
Winner: red, Second: yellow, Third: black, Last: green

$$
\begin{aligned}
S_1 &= C \\
s_1 &: \{b, y, g, r\} \longrightarrow S_1 \\
s_1 &= \{(b, t_b), (y, t_y), (g, t_g), (r, t_r) \mid \\
&\exists t_b \in C.\forall p \in \{b1, b2, b3, b4\}.[((p, z), 1) \in \mathcal{O}(t_b) \wedge (z > 40) \wedge ((p, z), 1) \notin \mathcal{O}(t_b - 1)] \vee \\
&\exists t_y \in C.\forall p \in \{y1, y2, y3, y4\}.[((p, z), 1) \in \mathcal{O}(t_y) \wedge (z > 40) \wedge ((p, z), 1) \notin \mathcal{O}(t_y - 1)] \vee \\
&\exists t_g \in C.\forall p \in \{g1, g2, g3, g4\}.[((p, z), 1) \in \mathcal{O}(t_g) \wedge (z > 40) \wedge ((p, z), 1) \notin \mathcal{O}(t_g - 1)] \vee \\
&\exists t_r \in C.\forall p \in \{r1, r2, r3, r4\}.[((p, z), 1) \in \mathcal{O}(t_r) \wedge (z > 40) \wedge ((p, z), 1) \notin \mathcal{O}(t_r - 1)]\}
\end{aligned}
$$

"For each player b, y, g, r the earliest point in time in which all of its pieces reached its safe heaven."

$$s_1 = \{(b, 360), (y, 355), (r, 291)\}$$

Frequency of Entering Safe Heavens during Game

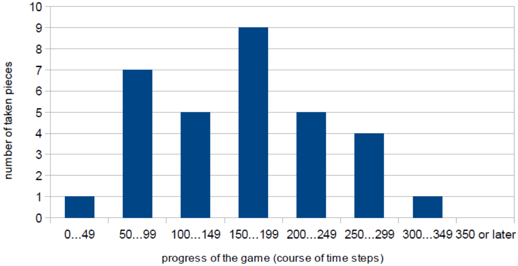


$$S_2 = \mathbb{N}$$
$$s_2 : \{p_0, \ldots, p_{360}\} \longrightarrow S_2$$
$$s_2 = \{p_{enter} \mid \exists enter \in C \;.\; \exists y, z \in D_2 \;.\; \exists x \in D_1 \;.[((x, y), 1) \in \mathcal{O}(enter) \wedge (y > 40) \wedge ((x, z), 1) \in \mathcal{O}(enter - 1) \wedge (z \leq 40) \wedge \forall t \in C \text{ with } (t > enter) \;.\; [((x, \alpha), 1) \in \mathcal{O}(t)]]$$

"For each relevant piece the earliest point in time in which its position is greater than 40."

$$s_2 = \{p_{96}, p_{99}, p_{199}, p_{220}, p_{244}, p_{253}, p_{259}, p_{291}, p_{309}, p_{316}, p_{347}, p_{349}, p_{355}, p_{360}\}$$

Frequency of Killing during the Game

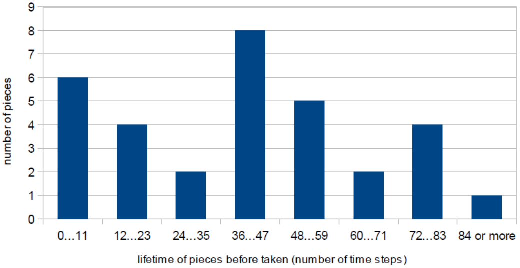


$$
\begin{aligned}
S_3 &= \mathbb{N} \\
s_3 &: \{p_0, \ldots, p_{360}\} \longrightarrow S_3 \\
s_3 &= \{p_{end} \mid \exists begin \in C\ .\ \exists end \in C\ .\ \exists y \in D_2\ .\ \exists z \in D_2\ .\ \exists x \in D_1\ . \\
&\quad [((x,y),1) \in \mathcal{O}(begin) \wedge ((x,y),1) \notin \mathcal{O}(begin-1) \wedge ((x,z),1) \in \mathcal{O}(end) \wedge \\
&\quad ((x,z),1) \notin \mathcal{O}(end+1) \wedge (y > 0) \wedge (y \leq 40) \wedge (z > 0) \wedge (z \leq 40) \wedge (z \geq y) \wedge \\
&\quad (\forall w \in \{begin, \ldots, end\}\ .\ [((x,\alpha),1) \in \mathcal{O}(w) \wedge (\alpha > 0) \wedge (\alpha \leq 40)])]\}
\end{aligned}
$$

"For each relevant piece the point in time in which it leaves the game from a position less than 41."

$$
\begin{aligned}
s_3 = \{&p_{36}, p_{56}, p_{58}, p_{59}, p_{73}, p_{81}, p_{93}, p_{99}, p_{121}, p_{127}, p_{128}, p_{135}, p_{137}, p_{157}, p_{158}, p_{165}, p_{166}, \\
&p_{171}, p_{180}, p_{181}, p_{189}, p_{192}, p_{210}, p_{219}, p_{223}, p_{224}, p_{248}, p_{264}, p_{277}, p_{280}, p_{295}, p_{304}\}
\end{aligned}
$$

Lifetime Distribution of Killed Pieces



$$S_4 = \mathbb{N}$$

$$s_4 : \{p_0, \ldots, p_{360}\} \longrightarrow S_4$$

$$s_4 = \{p_{end-begin} \mid \exists begin \in C \ . \ \exists end \in C \ . \ \exists y \in D_2 \ . \ \exists z \in D_2 \ . \ \exists x \in D_1 \ . \ [((x,y),1) \in \mathcal{O}(begin) \wedge ((x,y),1) \notin \mathcal{O}(begin-1) \wedge ((x,z),1) \in \mathcal{O}(end) \wedge ((x,z),1) \notin \mathcal{O}(end+1) \wedge (y > 0) \wedge (y \leq 40) \wedge (z > 0) \wedge (z \leq 40) \wedge (z \geq y) \wedge (\forall w \in \{begin, \ldots, end\} \ . \ [((x,\alpha),1) \in \mathcal{O}(w) \wedge (\alpha > 0) \wedge (\alpha \leq 40)])]\}$$

"For each relevant piece the time span from setting into game until it leaves the game from a position less than 41."

$$s_4 = \{p_4, p_5, p_6, p_8, p_9, p_{11}, p_{14}, p_{15}, p_{16}, p_{17}, p_{33}, p_{34}, p_{37}, p_{37}, p_{38}, p_{38}, p_{39}, p_{40}, p_{41}, p_{44}, p_{52}, p_{54}, p_{55}, p_{56}, p_{57}, p_{61}, p_{69}, p_{72}, p_{74}, p_{79}, p_{80}, p_{94}\}$$

Case Study

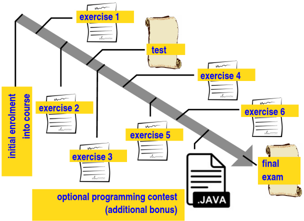
University Course
Introduction to Programming

University Course "Introduction to Programming"

Overview

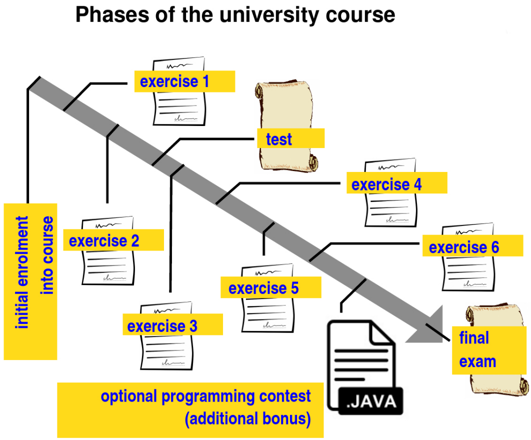
- teaching concepts of popular programming languages
- 1108 attenders between 2012 and 2016
- each attendee represents an individual with an own life cycle
- a life cycle consists of 10 consecutive phases in 18 weeks

Phases of the university course



University Course "Introduction to Programming"

Overview



Action-accumulating P System for Course Evaluation

$$\Pi_{\square} = (C, 11, D_1, \ldots, D_{11}, \mathcal{I}, R, E, 3, S_1, s_1, S_2, s_2, S_3, s_3)$$

- $C = \{0, \ldots, 9\}$ .... course phases

Action-accumulating P System for Course Evaluation

$$\Pi_{\square} = (C, 11, D_1, \ldots, D_{11}, \mathcal{I}, R, E, 3, S_1, s_1, S_2, s_2, S_3, s_3)$$

- C .... course phases
- **11** .... number of attribute values
- D_i .... attributes of each student

Action-accumulating P System for Course Evaluation

$$\Pi_{\Box} = (C, 11, D_1, \ldots, D_{11}, \mathcal{I}, R, E, 3, S_1, s_1, S_2, s_2, S_3, s_3)$$

- C .... course phases
- 11 .... number of attribute values
- D_i .... attributes of each student
  - $D_1 = (\{\mathrm{A}, \ldots, \mathrm{Z}\} \cup \{0, \ldots, 9\})^*$ .... unique identifier
  - $D_2 = D_3 = D_4 = D_5 = D_6 = D_7 = \{0, 1\}$ .... exercise result
  - $D_8 = \{0, \ldots, 30\}$ .... midterm test result
  - $D_9 = \{0, \ldots, 5\}$ ...... bonus points in programming contest
  - $D_{10} = \{0, \ldots, 70\}$ .... result in the final exam
  - $D_{11} = \{1.0, 1.3, 1.7, 2.0, 2.3, 2.7, 3.0, 3.3, 3.7, 4.0, 5.0\}$ $\cup\{\infty\}$ .... final grade

Action-accumulating P System for Course Evaluation

$$\Pi_{\Box} = (C, 11, D_1, \ldots, D_{11}, \mathcal{I}, R, E, 3, S_1, s_1, S_2, s_2, S_3, s_3)$$

- C .... course phases
- 11 .... number of attribute values
- D_i .... attributes of each student
- $\mathcal{I}$ .... multiset of initially enrolled students

Action-accumulating P System for Course Evaluation

$$\Pi_{\square} = (C, 11, D_1, \ldots, D_{11}, \mathcal{I}, R, E, 3, S_1, s_1, S_2, s_2, S_3, s_3)$$

- C .... course phases
- 11 .... number of attribute values
- D_i .... attributes of each student
- $\mathcal{I}$ .... multiset of initially enrolled students
  - $\mathcal{O}(t)$ .... example for initial system configuration
    $\mathcal{O}(0) = \mathcal{I} = \{((326C638, 0, 0, 0, 0, 0, 0, 0, 0, 0, \infty), 1), \ldots,$
    $((2F56771, 0, 0, 0, 0, 0, 0, 0, 0, 0, \infty), 1)\}$

Action-accumulating P System for Course Evaluation

$$\Pi_{\square} = (C, 11, D_1, \ldots, D_{11}, \mathcal{I}, R, E, 3, S_1, s_1, S_2, s_2, S_3, s_3)$$

- C .... course phases
- 11 .... number of attribute values
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- $\mathcal{I}$ .... multiset of initially enrolled students
- R .... all possible actions during course phases

Action-accumulating P System for Course Evaluation

$$\Pi_{\square} = (C, 11, D_1, \ldots, D_{11}, \mathcal{I}, R, E, 3, S_1, s_1, S_2, s_2, S_3, s_3)$$

- C .... course phases
- 11 .... number of attribute values
- D_i .... attributes of each student
- $\mathcal{I}$ .... multiset of initially enrolled students
- R .... all possible actions during course phases
  - **create** .... joining the course late
  - **kill** .... leaving the course prematurely
  - **clone** .... attend the course again after interruption
  - **modify** .... update after each course phase
  - **merge** .... unificate individuals of the same student

Action-accumulating P System for Course Evaluation

$$\Pi_{\square} = (C, 11, D_1, \ldots, D_{11}, \mathcal{I}, R, E, 3, S_1, s_1, S_2, s_2, S_3, s_3)$$

- C .... course phases
- 11 .... number of attribute values
- D_i .... attributes of each student
- $\mathcal{I}$ .... multiset of initially enrolled students
- R .... all possible actions during course phases

$$\begin{aligned} = \; & \{\texttt{create}(d_1, \ldots, d_{11}) \mid d_1 \in D_1 \wedge \ldots \wedge d_{11} \in D_{11}\} \cup \\ & \{\texttt{kill}\} \cup \\ & \{\texttt{clone}\} \cup \\ & \{\texttt{modify}(d_1, d_2 + e_1, \ldots, d_7 + e_6, z, d_9 + b, p, g) \mid \\ & \quad e_1 \in D_2 \wedge \ldots \wedge e_6 \in D_7 \wedge z \in D_8 \wedge b \in D_9 \wedge s \in D_{10} \wedge g \in D_{11})\} \cup \\ & \{\texttt{merge}(\bigotimes_{\substack{d_1 \text{ with} \\ (d_1, \ldots, d_{11}) \in \mathcal{P}}} d_1, \sum_{\substack{d_2 \text{ with} \\ (d_1, \ldots, d_{11}) \in \mathcal{P}}} d_2, \ldots, \sum_{\substack{d_7 \text{ with} \\ (d_1, \ldots, d_{11}) \in \mathcal{P}}} d_7, 0, 0, 0, \infty)\} \end{aligned}$$

Action-accumulating P System for Course Evaluation

$$\Pi_{\Box} = (C, 11, D_1, \ldots, D_{11}, \mathcal{I}, R, E, 3, S_1, s_1, S_2, s_2, S_3, s_3)$$

- C .... course phases
- 11 .... number of attribute values
- D_i .... attributes of each student
- $\mathcal{I}$ .... multiset of initially enrolled students
- R .... all possible actions during course phases
- E .... all possible events

Action-accumulating P System for Course Evaluation

$$\Pi_{\square} = (C, 11, D_1, \ldots, D_{11}, \mathcal{I}, R, E, 3, S_1, s_1, S_2, s_2, S_3, s_3)$$

- C .... course phases
- 11 .... number of attribute values
- D_i .... attributes of each student
- $\mathcal{I}$ .... multiset of initially enrolled students
- R .... all possible actions during course phases
- E .... all possible events

$$= \{(1, \{((\text{342D5B8}, 0, 0, 0, 0, 0, 0, 0, 0, 0, \infty), 1)\}, \texttt{modify}(d_1, d_2 + 1, d_3, \ldots, d_{11})),$$

$$\vdots$$

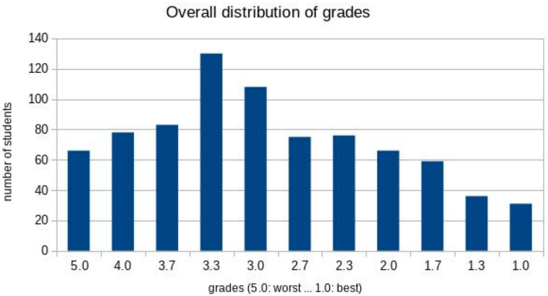
$$(9, \{((\text{3356B8}, d_2, \ldots, d_{10}, \infty), 1) \mid d_i \in D_i \land i = 2, \ldots, 10\}, \texttt{modify}(d_1, \ldots, d_{10}, 1.7))\}$$

Evaluations

- S_1, s_1 .... overall distribution of grades
- S_2, s_2 .... impact of extensive training
- S_3, s_3 .... phase in which course was left prematurely

Evaluations

- S_1, s_1 .... overall distribution of grades



$$S_1 = \mathbb{N}$$

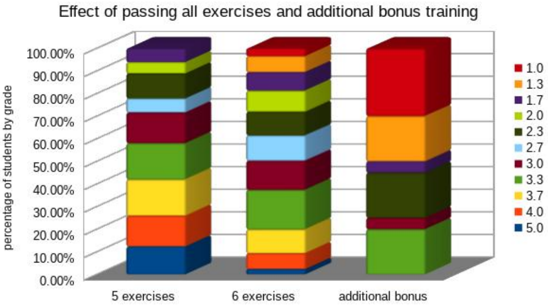
$$s_1 \; : \; D_{11} \setminus \{\infty\} \longrightarrow S_1$$

$$s_1 = \{\mathrm{g}(i) \mid \exists x \in D_1 \; . \; \exists d_2 \in D_2 \ldots \exists d_{10} \in D_{10} \; . \; \exists grade \in D_{11} \setminus \{\infty\} \; . \; \exists i \in \{1, \ldots, 11\} \; . \; [(((x, d_2, \ldots, d_{10}, grade), 1) \in \mathcal{O}(9)) \wedge (grade = \mathrm{g}(i)) \wedge \left(\sum_{k=2}^{7} d_k \geq 5\right)]\}$$

- S_2, s_2 .... impact of extensive training
- S_3, s_3 .... phase in which course was left prematurely

Evaluations

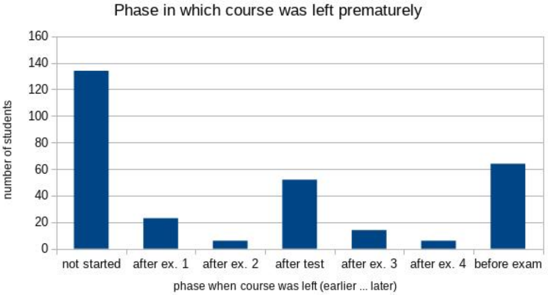
- S_1, s_1 .... overall distribution of grades
- S_2, s_2 .... impact of extensive training



- S_3, s_3 .... phase in which course was left prematurely

Evaluations

- S_1, s_1 .... overall distribution of grades
- S_2, s_2 .... impact of extensive training
- S_3, s_3 .... phase in which course was left prematurely



General Framework

Action–accumulating P Systems

General Definition of Action-accumulating P Systems

Let a *domain* be an arbitrary non-empty set. We define

$$\Pi_\square = (C, n, D_1, \ldots, D_n, \mathcal{I}, R, E, m, S_1, \ldots, S_m, s_1, \ldots, s_m)$$

with its components

$C \subseteq \mathbb{N}$ .... domain of points in time (global clock)

$n \in \mathbb{N} \setminus \{0\}$ .... number of distinct attributes

D_i with $i = 1, \ldots, n$ .... domain of attribute i

$\mathcal{I} =: \bigtimes_{i=1}^{n} D_i \longrightarrow \mathbb{N} \cup \{+\infty\}$ .... final multiset of initial individuals, each of which represented by its initial attribute values

R .... set of actions available for events

action types `modify`, `merge`, `create`, `kill`, `clone`

General Definition of Action-accumulating P Systems

Let a *domain* be an arbitrary non-empty set. We define

$$\Pi_{\square} = (C, n, D_1, \ldots, D_n, \mathcal{I}, R, E, m, S_1, \ldots, S_m, s_1, \ldots, s_m)$$

with its components

$$E \subseteq C \times \wp\left(\left(\bigtimes_{i=1}^{n} D_i\right) \times (\mathbb{N} \cup \{+\infty\})\right) \times R \ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

final set of events.
Each event is described by its point in time followed by the multiset of affected individuals and a rule from R for the action initiated by the event.

General Definition of Action-accumulating P Systems

Let a *domain* be an arbitrary non-empty set. We define

$$\Pi_\square = (C, n, D_1, \ldots, D_n, \mathcal{I}, R, E, m, S_1, \ldots, S_m, s_1, \ldots, s_m)$$

with its components

$m \in \mathbb{N} \setminus \{0\}$ .... number of response functions

S_i with $i = 1, \ldots, m$ .... domain of response i

$s_i : \left(\bigtimes_{i=1}^{n} D_i \longrightarrow \mathbb{N} \cup \{+\infty\} \right) \times C \longrightarrow S_i$ with $i = 1, \ldots, m$ ....

response function provides a system's output taking into account the whole cumulative record tracing the evolution of individuals over time from $\mathcal{I}$ until all events from E have been processed.

System Configurations by Transition Function $\mathcal{O}$

We define the *transition function* $\mathcal{O}$ for tracing the present individuals with their *attribute values* by configuration record over all points in time until all events from E have been completely processed.

$$\mathcal{O} : \left(\bigtimes_{i=1}^{n} D_i \right) \times (\mathbb{N} \cup \{+\infty\}) \times \mathbb{N} \longrightarrow \left(\bigtimes_{i=1}^{n} D_i \right) \times (\mathbb{N} \cup \{+\infty\})$$

- initial configuration $\mathcal{O}(0) = \mathcal{I}$
- $\mathcal{O}(t+1)$ obtained from $\mathcal{O}(t)$ by processing all events from E occurring at time t
- In case there is no event in E at time t: $\mathcal{O}(t+1) = \mathcal{O}(t)$

Event Handling: Progression of Transition Function

Let $(t, \mathcal{P}, \texttt{modify}(\mathrm{f}_1, \ldots, \mathrm{f}_n)) \in E$ be an event at time t affecting a multiset of individuals captured by $\mathcal{P} \subseteq \left(\bigtimes_{i=1}^{n} D_i \right) \times (\mathbb{N} \cup \{+\infty\})$.

It *modifies (updates)* the *attribute values* of all individuals from $\mathcal{P}$ using the update functions $\mathrm{f}_i : D_1 \times \ldots \times D_n \longrightarrow D_i$ whereas $i = 1, \ldots, n$.

$$\begin{aligned} \mathcal{O}(t+1) &= \mathcal{O}(t) \ominus \mathcal{V} \uplus \mathcal{W} \text{ with} \\ \mathcal{V} &= \{v \in \mathcal{P} \mid (t, \mathcal{P}, \texttt{modify}(\mathrm{f}_1, \ldots, \mathrm{f}_n))\} \in E\} \\ \mathcal{W} &= \{((\mathrm{f}_1(a_1, ..., a_n), ..., \mathrm{f}_n(a_1, ..., a_n)), \mu) \mid ((a_1, ..., a_n), \mu) \in \mathcal{V}\} \end{aligned}$$

Simultaneous `modify` actions must be either independent from each other by affecting disjoint individuals or exhibit a confluent behaviour. `merge` actions analogously handled.

Event Handling: Progression of Transition Function

Let $(t, \mathcal{P}, r) \in E$ be an event at time t affecting individuals in $\mathcal{P}$.

- $r = \texttt{create}(a_1, \ldots, a_n)$
  new individual with *initial attribute values* added to population:

$$\mathcal{O}(t+1) \quad = \quad \mathcal{O}(t) \uplus \{((a_1, \ldots, a_n), 1)\}$$

- $r = \texttt{kill}$
  removes all individuals in $\mathcal{P}$ from the population.

$$\mathcal{O}(t+1) \quad = \quad \mathcal{O}(t) \ominus \mathcal{P}$$

- $r = \texttt{clone}$
  duplicates each individual from $\mathcal{P}$ with its *attribute values*.

$$\mathcal{O}(t+1) \quad = \quad \mathcal{O}(t) \uplus \mathcal{P}$$

  `clone` actions technically executed after simultaneous `modify` and `merge` actions in order to keep determinism.

Prospectives

Outlook

Take Home Message

Membrane systems can act as beneficial tools for widespread applications in Data Science and Data Analytics able to evaluate large pools of time-stamped event-based data to gain new or more detailed insights.

Conclusions

- Individual life cycles present in many contexts
- Accumulative analysis and clustering closely related with multiset-based algebraic approach, membranes as attributes
- Further research dedicated to parameterisation of resulting distributions and dynamical handling of attributes following the idea of generic data types in modern programming languages.

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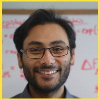

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