Graphical Modelling of Higher Plants Using P Systems

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Goal

Modelling developmental processes of plants

- Simple developmental algorithms
- Self-similarity
- L-systems with geometric features

Outline

1. Lindenmayer Systems
2. Graphical Representation of Lindenmayer Systems
3. Restricted P Systems with Membrane Creation
4. Graphical Representation of Restricted P Systems with Membrane Creation
5. Final Remarks

String 0L-system

$G = \langle V, \omega, P \rangle$

- V alphabet
- $\omega \in V^+$ axiom
- P production rules

Production rule: $a \rightarrow v$

- $a \in V$ predecessor
- $v \in V^*$ successor
- For any $a \in V$ at least one $a \rightarrow v \in P$

Evolution of L-Systems

Parallel rewriting

$\rho \in V^*$ directly derives from $\mu \in V^+$: $\mu \Rightarrow \rho$

- $\mu = a_1 \dots a_m$, with $a_i \in V$
- $\rho = \phi_1 \dots \phi_m$, with $\phi_i \in V^*$
- $a_i \rightarrow \phi_i \in P$, for all $i = 1, \dots, m$

Sequence of strings $\omega, \mu_1, \mu_2, \dots$ generated recursively

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Turtle graphics

Step size and turn angle fixed

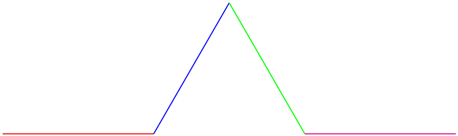
Graphical commands:

- F: move a step forward drawing a line
- f: move a step forward not drawing a line
- $+$: turn left
- $-$: turn right

L-System Representation: Example

Step size: 2 cm   Turn angle: 60 degrees

$$F + F - -F + F$$



L-Systems and Tree Structures

Consider a push-down stack.

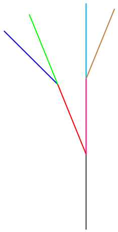
Additional graphical commands:

- [: push current state onto the stack
-]: pop a state from the stack

Tree Structure Representation: Example

Step size: 2 cm   Turn angle: 22.5 degrees

$$F[+F[+F][F]][F[F][-F]]$$



Overall Picture

Strong points:

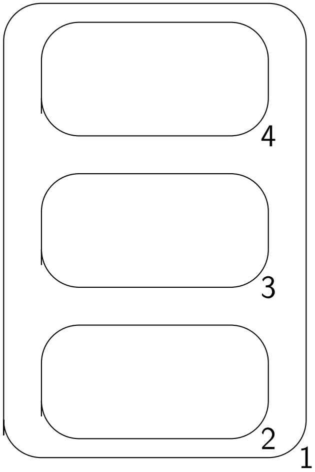
- Simple
- Deeply studied
- Many software available

Drawbacks:

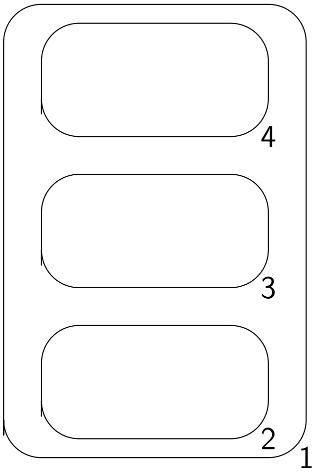
- Artificial
- Unrealistic

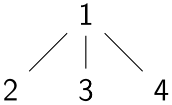
Outline

Membrane Structures Are Trees

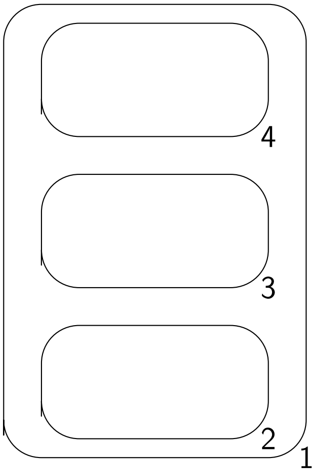


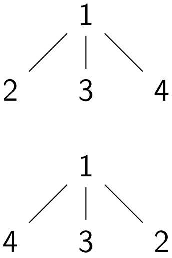
Membrane Structures Are Trees



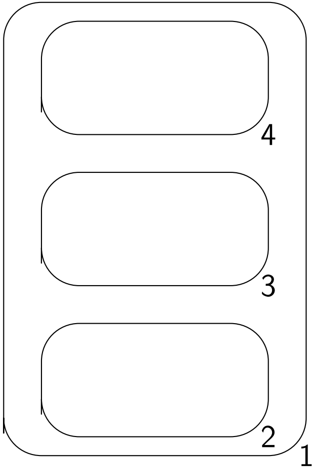


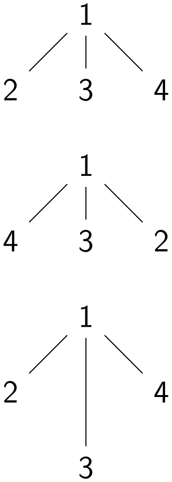
Membrane Structures Are Trees





Membrane Structures Are Trees





Basic Requirements

Looking for a model:

- As simple as possible
- With membrane creation

Drop from P systems with membrane creation everything not needed

Restricted P Systems with Membrane Creation

$\Pi = (O, \mu, w_1, \ldots, w_m, R)$

- O alphabet of objects
- μ initial membrane structure
- w_i multiset initially placed in region i
- R finite set of evolution rules:
  - $a \to v$, with $a \in O$, v multiset over O
  - $a \to [v]$, with $a \in O$, v multiset over O

A unique label for the membranes, so R global set of rules

Outline

Graphical Model for P Systems

Branch length and rotation angle fixed

Depth-first search of the membrane structure

Graphical objects:

- F: draw the branch
- $+$: rotate the branch to the left
- $-$: rotate the branch to the right

P System Representation: Example 1

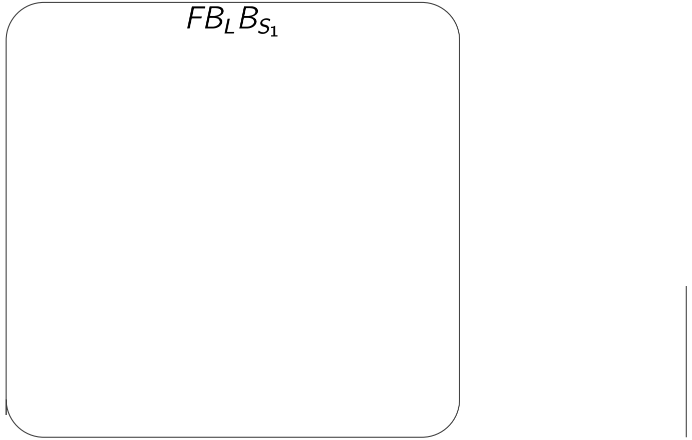
Π_1 components:

- Alphabet: $\{F, +, -, B_L, B_R, B_{S_1}, B_{S_2}\}$
- Initial membrane structure and multiset: $[FB_L B_{S_1}]$
- Rules:

$$B_{S_1} \rightarrow [FB_{S_2} B_R] \qquad B_L \rightarrow [+FB_L B_{S_1}]$$
$$B_{S_2} \rightarrow [FB_L B_{S_1}] \qquad B_R \rightarrow [-FB_L B_{S_1}]$$

P System Representation: Example 1

Branch length: 2 cm Rotation angle: 22.5 degrees



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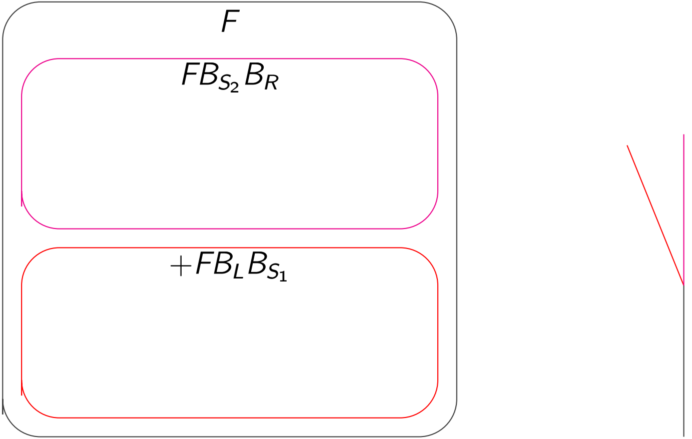
Branch length: 2 cm   Rotation angle: 22.5 degrees



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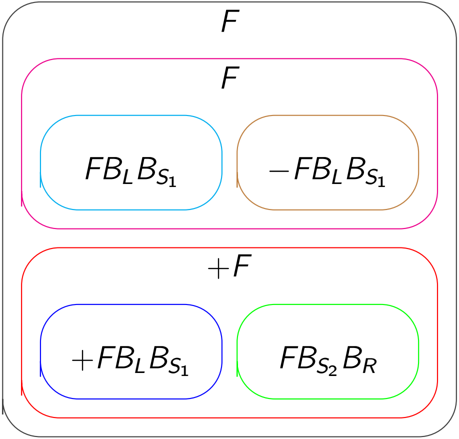
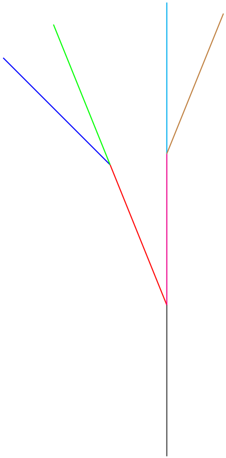




Extended Graphical Model for P Systems

Fix lengths l and w and angle δ

Graphical objects: F, W, $+$ and $-$

For each membrane draw a branch with:

- Length: (multiplicity of F) $\times$ l
- Width: (multiplicity of W) $\times$ w
- Rotation angle:
  (multiplicity of $+$ minus multiplicity of $-$) $\times$ δ

P System Representation: Example 2

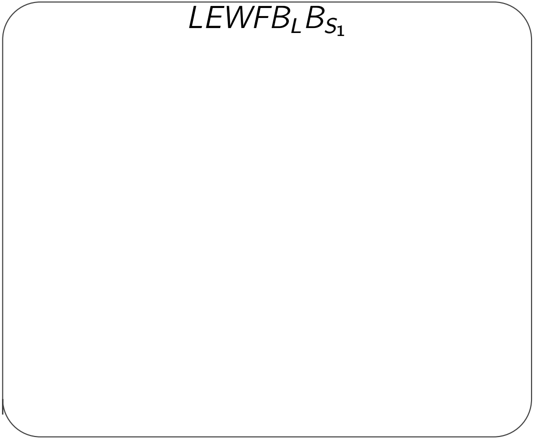
Π_2 components:

- Alphabet: $\{F, W, +, -, L, E, B_L, B_R, B_{S_1}, B_{S_2}\}$
- Initial membrane structure and multiset: $[LEWFB_L B_{S_1}]$
- Rules:

$$B_{S_1} \rightarrow [LEWFB_{S_2} B_R] \quad B_L \rightarrow [+LEWFB_L B_{S_1}]$$
$$B_{S_2} \rightarrow [LEWFB_L B_{S_1}] \quad B_R \rightarrow [-LEWFB_L B_{S_1}]$$
$$L \rightarrow LF \quad E \rightarrow EW$$

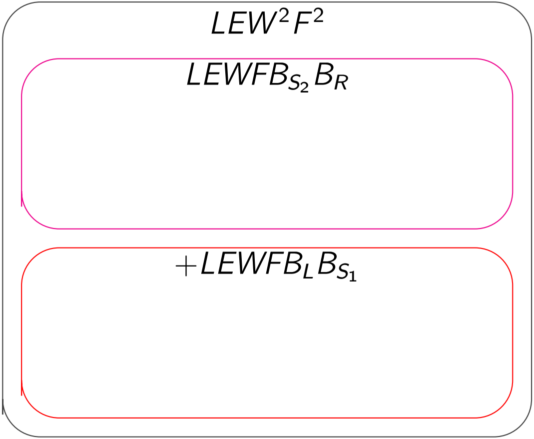
P System Representation: Example 2

l: 1 cm w:1 pt δ: 22.5 degrees



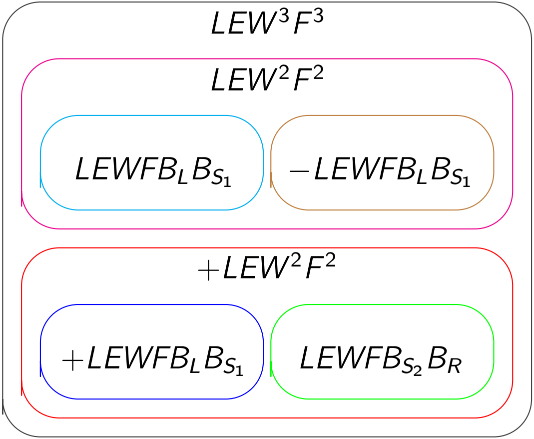
P System Representation: Example 2

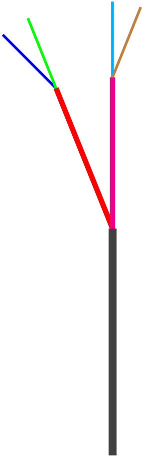
l: 1 cm w:1 pt δ: 22.5 degrees



P System Representation: Example 2

l: 1 cm w:1 pt δ: 22.5 degrees





Specimen-to-Specimen Variation

Stochastic P systems: associate each rule with a probability

Π_3 components:

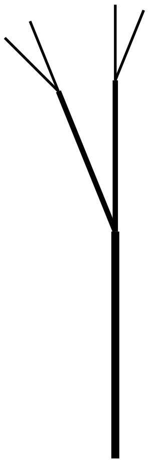
- Alphabet: $\{F, W, +, -, L, E, T, B\}$
- Initial membrane structure and multiset: $[LEWFTB]$
- Rules:

$$T \longrightarrow [LEWFTB] \qquad L \longrightarrow LF \quad E \longrightarrow EW$$

$$B \xrightarrow{2/3} [+LEWFTB] \quad B \xrightarrow{1/3} [-LEWFTB]$$

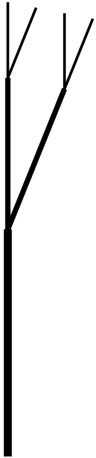
Trees generated by Π_3

l: 1 cm w:1 pt δ: 22.5 degrees



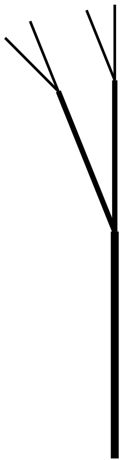
Trees generated by Π_3

l: 1 cm w:1 pt δ: 22.5 degrees



Trees generated by Π_3

l: 1 cm w:1 pt δ: 22.5 degrees



Specimen-to-Specimen Variation

Non-deterministic P systems: consider together all the trees generated by its computations

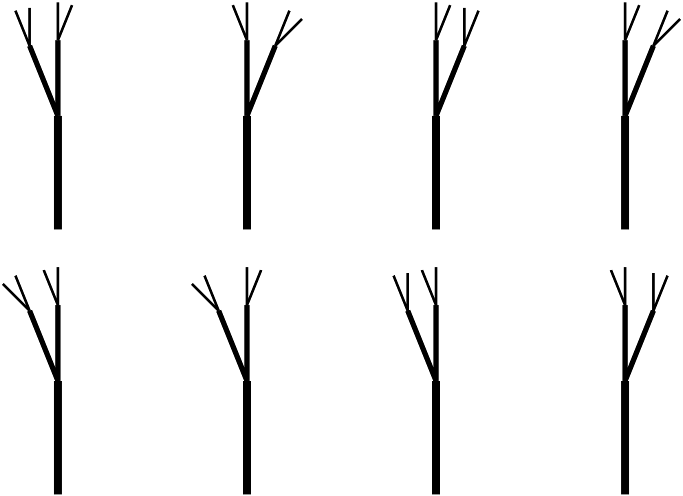
Π_4 components:

- Alphabet: $\{F, W, +, -, L, E, T, B\}$
- Initial membrane structure and multiset: $[LEWFTB]$
- Rules:

$$T \rightarrow [LEWFTB] \qquad L \rightarrow LF \quad E \rightarrow EW$$
$$B \rightarrow [+LEWFTB] \quad B \rightarrow [-LEWFTB]$$

Trees generated by Π_4

l: 1 cm w:1 pt δ: 22.5 degrees



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P Systems versus L-Systems

Two things to investigate:

- Complexity of the representation of the branching structures
- Computational efficiency to generate the graphical representations

Conclusions

Strong points of P systems:

- Closer to reality
- Supports differentiation into small units
- Computational power

Drawbacks:

- No software available (¿Translations to L-systems?)
- Parsing algorithm more complex

Extensions of the model

- Labelling of the membranes
- Communication rules
- Rules of the form $o \to \mu$, with μ a membrane structure

Thanks for your attention