P vs. B

P systems vs. Boolean networks in biological modelling and analysis

Artiom Alhazov, Rudi Freund, Sergiu Ivanov

The E-Moldovan Team

Taming complexity

Biological systems are complex.

Abstract discrete models are

- understandable,
- analysable.

Goal: Tame the complexity by modelling.

Natural computing

Invent models of computing to do better computing.

Modelling and analysis

Formal structures to tame real-world complexity.

I am interested in both.

Formal models and frameworks

reaction systems

Petri nets

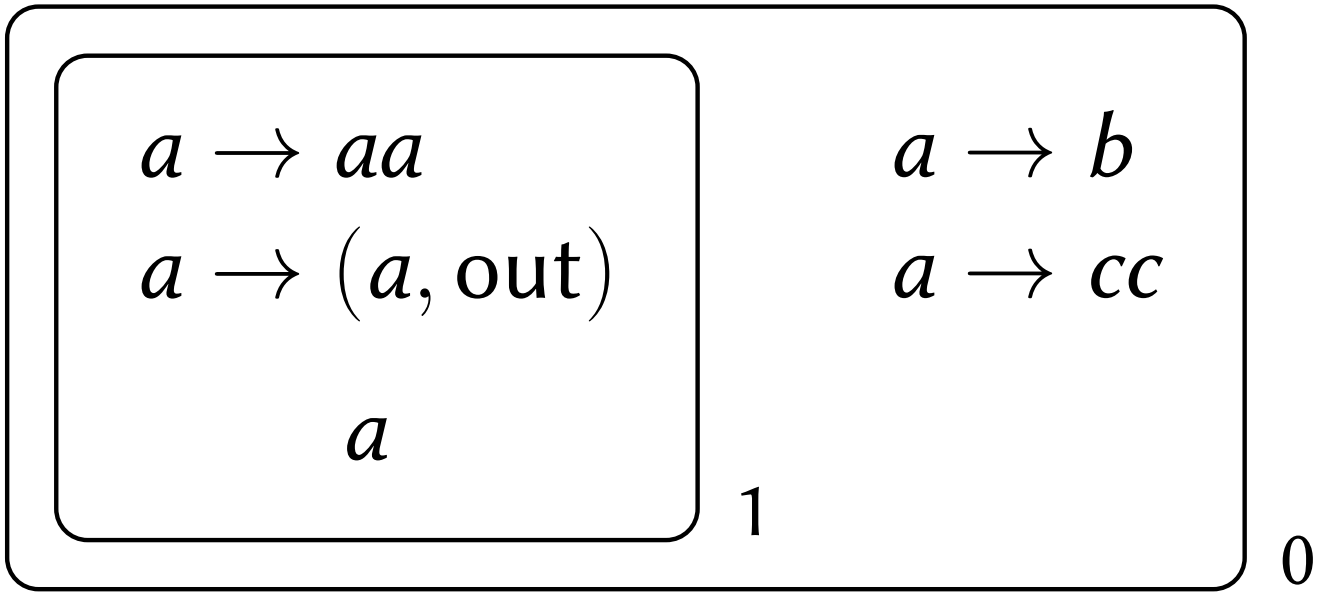
cellular automata

P systems vs. Boolean networks

linear networks

chemical reaction networks

P systems



- hierarchy
- parallelism
- communication
- non-determinism
- counting
- competition

Boolean networks

$$\begin{cases} x \leftarrow f_x(x,y,z) \\ y \leftarrow f_y(x,y,z) \\ z \leftarrow f_z(x,y,z) \end{cases} \qquad \begin{array}{l} x,y,z \in \{0,1\} \\ f_x, f_y, f_z : \{0,1\}^3 \to \{0,1\} \end{array}$$

- no competition
- various update modes
- simple
- finite states

P systems vs. Boolean networks

in modelling and analysis

Not a reduction of P systems to a single problem.

Personal interest in biological complexity.

Why?

P systems are inspired by biology.

P systems are more "natural" than Boolean networks.

??

State of the art: methodology

Publications from 2010 to 2021.

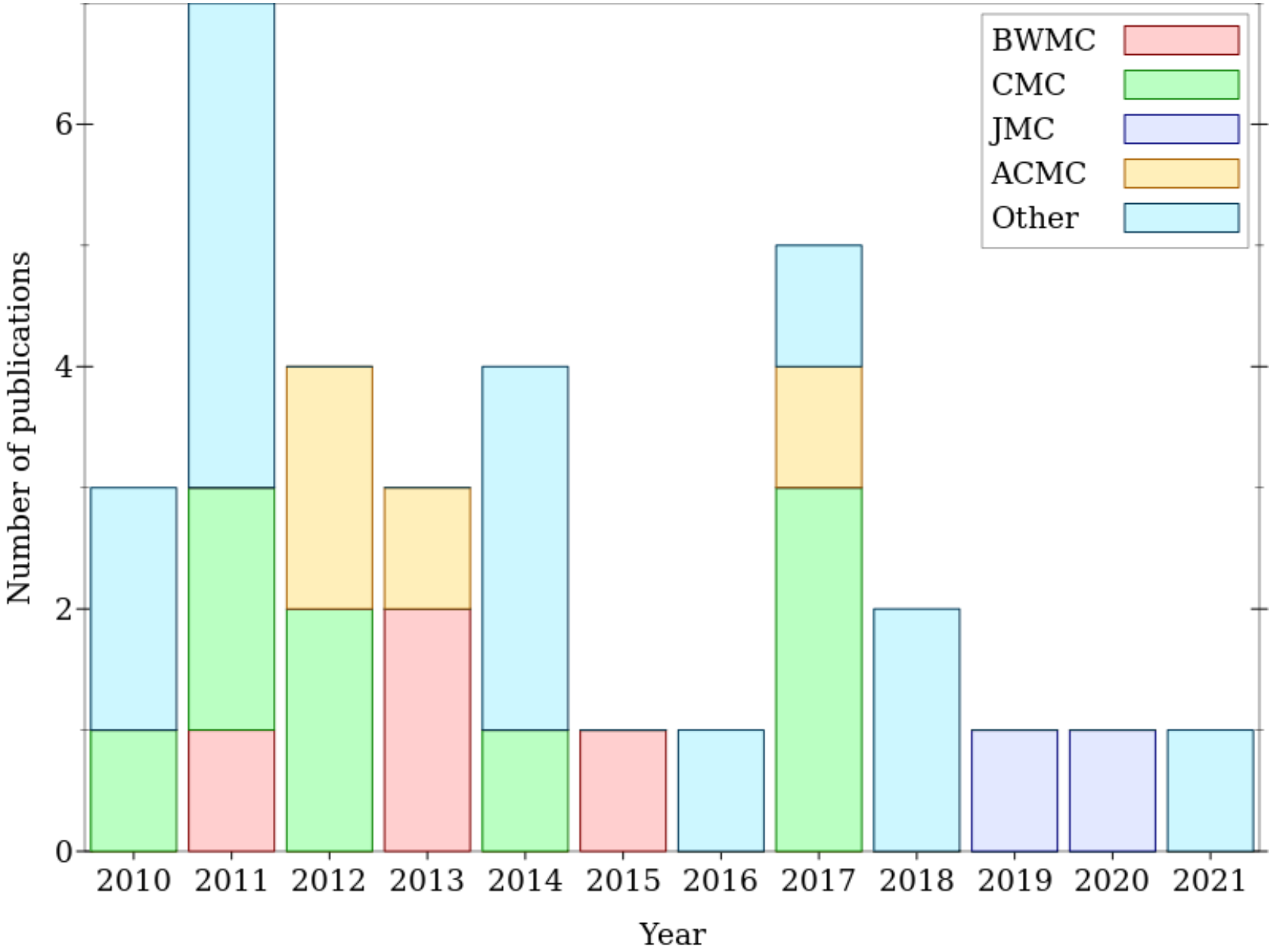
Papers, informal papers, invited talks, abstracts.

- Bibliography of RGNC (Seville),
- Proceedings of BWMC,
- Proceedings of CMC,
- JMC,
- Proceedings of ACMC,
- Other papers I bumped into.

Suggestions, corrections, completions welcome!

State of the art

33 publications



Compare with Boolean networks

Consider CMSB 2010 to 2021

- Computational Methods for Systems Biology

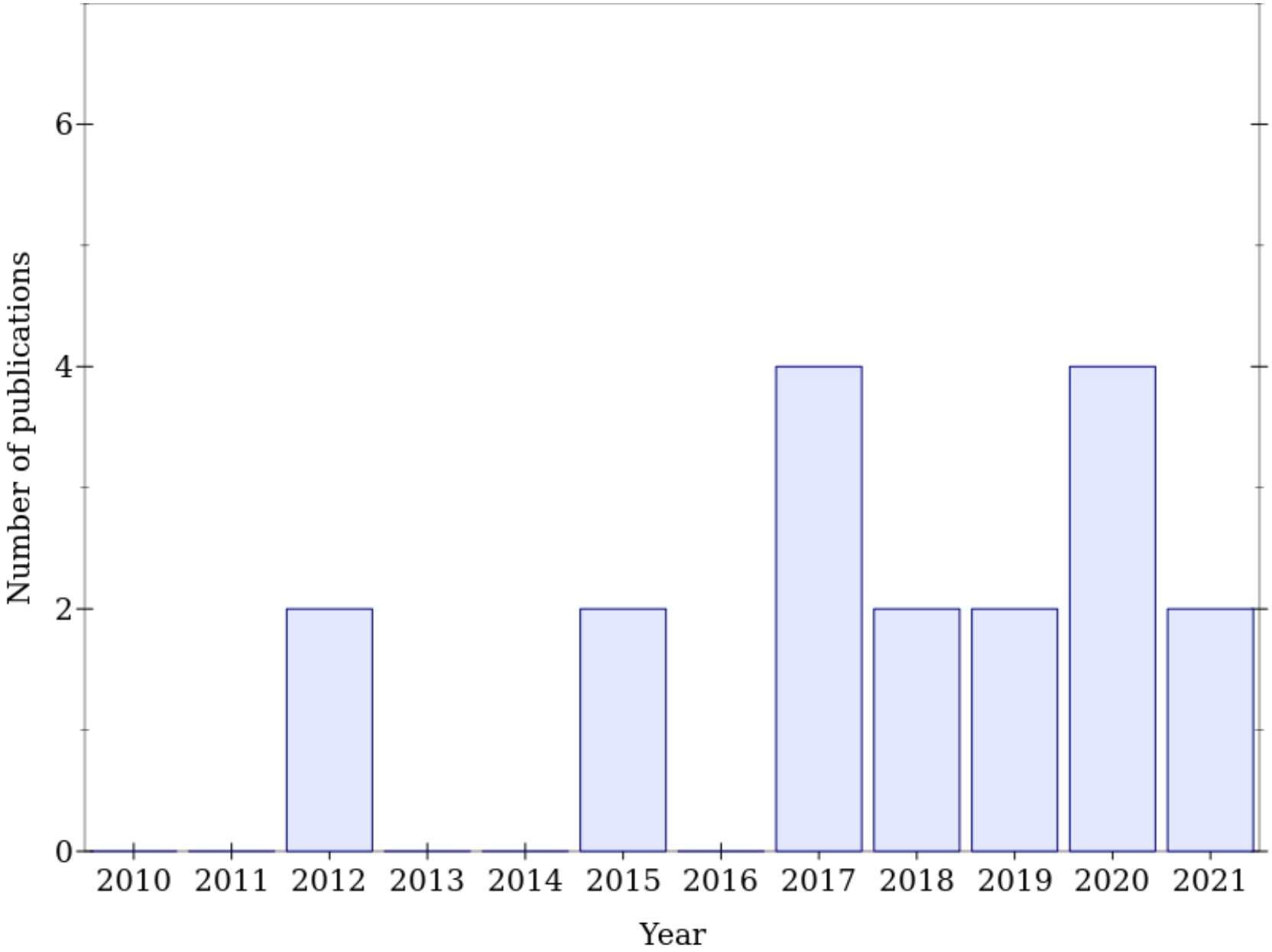
Papers, invited talks, extended abstracts.

Only one of the conferences.

Many many journal publications.

CMSB 2010–2021

18 publications



$$18 > 33$$

Why?

P systems are inspired by biology.

P systems are more "natural" than Boolean networks.

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Opinion

Boolean networks are simpler.

Boolean networks are finite.

Boolean networks are not concurrent.

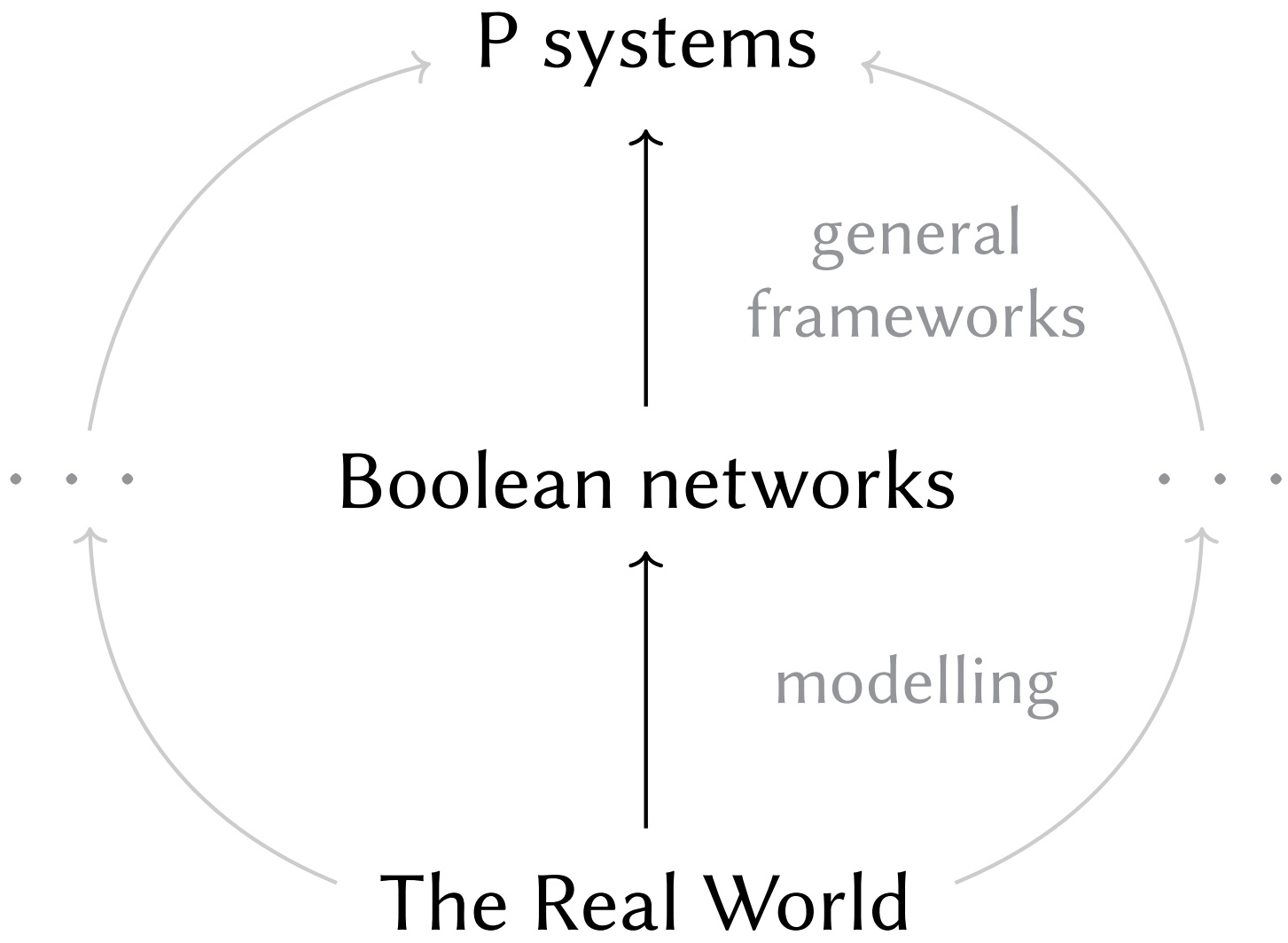
Boolean networks have less parameters.

Massive advantage of P systems

Flexibility

... and the rich methodology

P systems as general frameworks



Boolean P systems

Boolean P systems $\Pi = (V, R)$

States: $s : V \to \{0, 1\}$ and the corresponding subset

Rules: $r : A \to B \mid \varphi$

- $A, B \subseteq V$
- φ a propositional formula over V, the guard

---

r is applicable to $W \subseteq V$ if $A \subseteq W$ and $\varphi(W)$

$$\text{Apply } r \text{ to } W \mapsto W \setminus A \cup B$$

$$\text{Apply } \{r_i : A_i \to B_i \mid \varphi_i\} \text{ to } W \mapsto \left(W \setminus \bigcup_i A_i \right) \cup \bigcup_i B_i$$

- set rewriting
- no competition

Boolean P systems $\supseteq$ Boolean networks

Let $f_y : \{0,1\}^X \to \{0,1\}$. Simulation:

$$R_y = \{\ \emptyset \to \{y\} \mid f_y,\ \{y\} \to \emptyset \mid \neg f_y\ \}$$

produce y if $f_y(W)$ remove y if not $f_y(W)$

Natural extension to whole networks. Theorem

Trivial by design

Evolution, modes, and quasimodes

P systems:

- A mode tells which rules to apply.

Boolean networks:

- A mode tells which variables to update.
  - all variables can be updated at any step
  - no competition

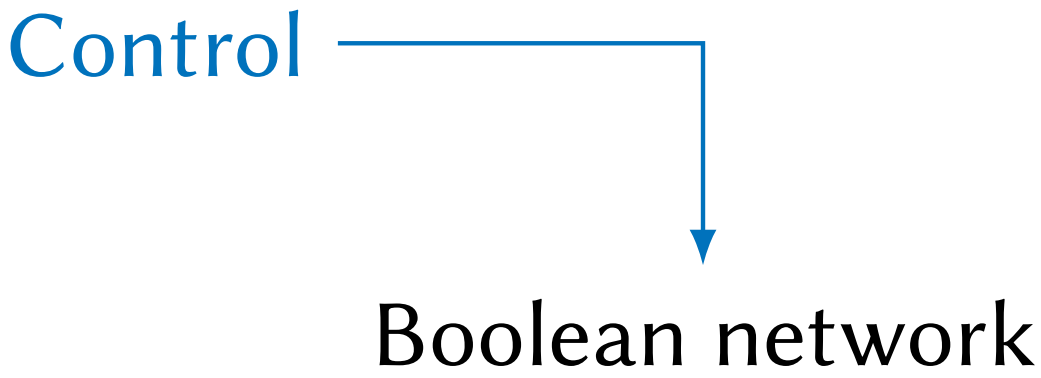
Boolean P systems:

- A quasimode $\widetilde{M} \subseteq 2^R$ suggests the rules to apply.

The corresponding mode M:

$$M(W) = \{\{r \in m \mid r \text{ applicable to } W\} \mid m \in \widetilde{M}\}$$

Controllability of Boolean networks

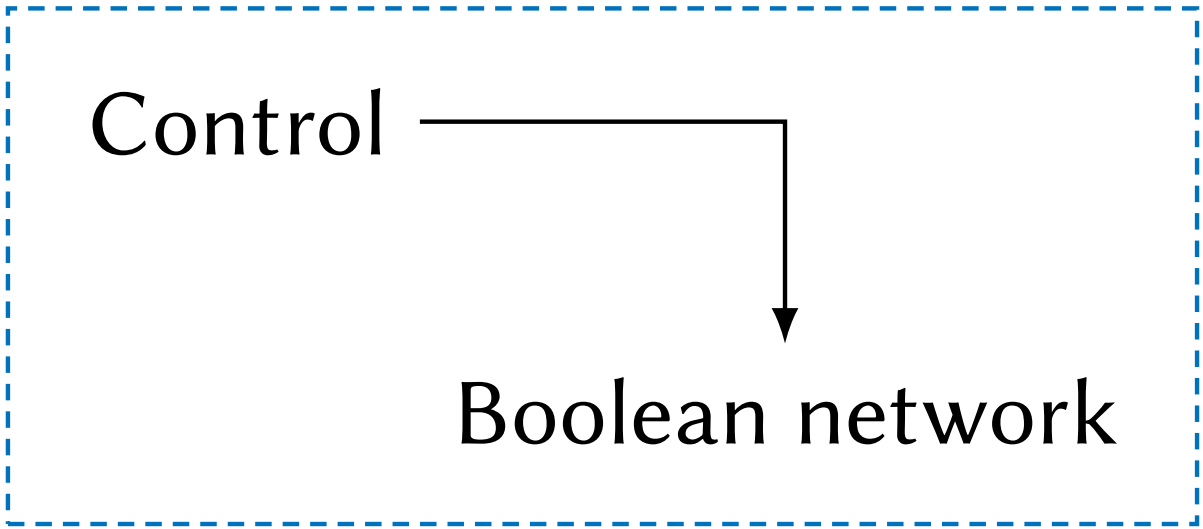


Model diseases, therapies, environment, ...

Boolean P systems for controllability

The control is an implicit dynamical system.

Heterogeneous structure.



Boolean P systems

Capture both in one homogeneous system.

Solve problems :-)

Conclusion and outlook

P systems $\sim$ category theory of computing

- general
- unifying
- multi-paradigm

- sometimes hard to grasp
- sometimes unclear connections
- lots of variants

... but better: more flexibility!

Many possible applications across domains.