Statistical simplicity of random chemical reaction networks

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Possibilité de thèse: Oui
Financement: Non

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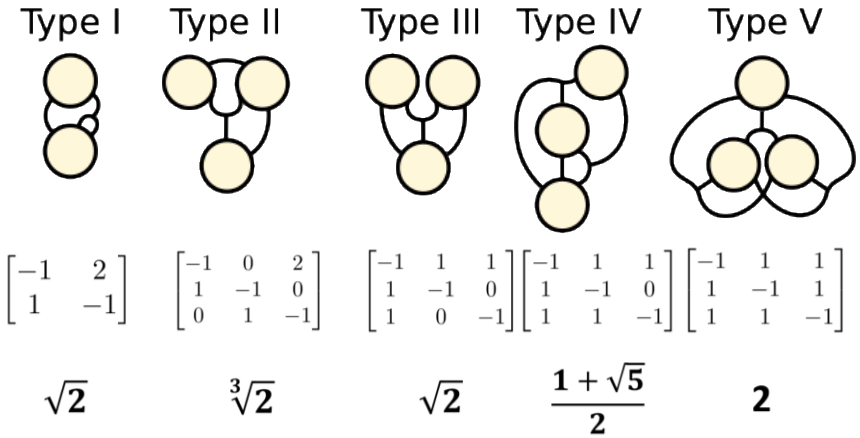

Five minimal autocatalytic motifs (figure taken from [2]). Yellow circles represent species, black lines connecting them represent reactions. Below, their associated stoichiometric matrices are shown together with their stoichiometric growth factor (bottom line).

Summary

Many systems in nature can be described using discrete input-output maps. A priori, there is no reason to expect that randomly chosen inputs are more likely to generate one output instead of another one. In ref. [1] however, using methods of algorithmic information theory, it was shown that the probability to obtain a given output from randomly sampled inputs is biased towards output of low complexity in the sense of Kolmogorov. This simplicity bias was found in various systems ranging from the folding of RNA to financial data and to the parameter-function maps in neural networks.

In this internship, we aim to extend these ideas to random chemical networks and investigate whether a similar bias towards networks of low complexity and high symmetry exists there.

We are particularly interested in a specific class of chemical networks, namely autocatalytic chemical reaction networks, because for these networks, we have previously identified specific minimal and topological motifs (see figure and Ref. [2]). These motifs appear frequently among random chemical networks of this type, suggesting a possible bias towards simplicity. Another question which we would like to investigate concerns the relation between the simplicity bias, the network robustness and thermodynamic constraints following our study in Ref [3]. Note that beyond chemical reaction networks, these methods may be also relevant to understand growth in economic systems [4].

The internship will take place in a mixed environment of theoreticians and experimentalists interested in various applications of Statistical physics to molecular programs, soft matter and living systems.

[1] Input-output maps are strongly biased towards simple outputs. K. Dingle, C. Q. Camargo, and A. Louis, Nature Com., 9, 71, (2018)

[2] Universal motifs and the diversity of autocatalytic systems, A. Blokhuis, D. D. Lacoste, and P. Nghe, PNAS, 117, 25230 (2020).

[3] Structural constraints limit the regime of optimal flux in autocatalytic reaction networks, A. Despons et al., Commun. Phys. (2024)

[4] Universal properties of autocatalysis, D. Lacoste and B. Ledoux, , chapter in book: 'Economic principles in cell biology' (2025), https://zenodo.org/records/15397884

Keywords: algorithmic information theory, chemical networks, statistical physics