Reverse-engineering natural computation

using reaction-diffusion approaches beyond linear stability

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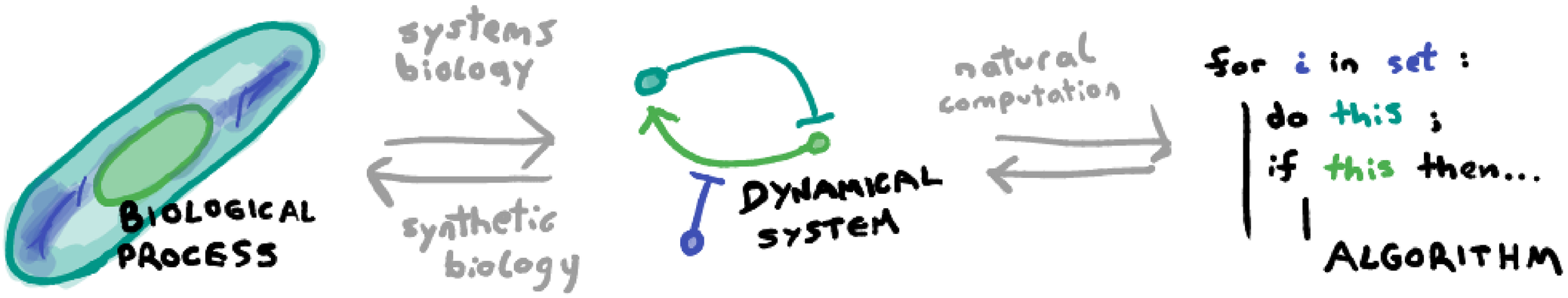

mappings between levels of abstraction from biological process to algorithm

Algorithm → Dynamical System | Given a *response function* what is the *minimal* reaction network?

- Mappings between algorithms and reaction networks pave the path towards programming in cells [1]
- Dynamical structure function and Granger causality methods reconstruct networks from data
- No general mapping exists that takes model complexity into consideration

$$\partial_t \rho = \overbrace{R(\rho)}^{\text{reaction}} + \underbrace{S(t)}_{\text{source}}$$

Biological Process → System | What is the general routine for *reducing complexity* in reaction networks?

- Time-scale separation allows reduction of component number; introducing delays and nonlinearity
- There exist no dimensionality reduction and parameter relevance methods for reaction networks

Biological Process → Dynamical System | How do network motifs such as *switches and clocks* evolve?

- Relationship between robustness and evolvability has been investigated [2]
- Evolutionary relationships between different chemical networks have not been quantified

Dynamical System | Given a *steady state pattern* what is the *minimal* reaction-diffusion network?

- Dynamics of local equilibria show promising analysis beyond linear stability [3]
- Need to design attractors in phase space; no description in phase space exists

Biological Process → Dynamical System | How do patterns form across *growing cell populations*?

- Differential diffusion between cytosolic, membrane and inter-cellular components give rise to patterns
- Finite element reaction-diffusion simulations are computationally expensive

References

[1] Neil Dalchau, Gregory Szép, et al. Computing with biological switches and clocks. *Natural Computing*, 6 2018.
[2] Bryan C Daniels, Yan-Jiun Chen, et al. Sloppiness, robustness and evolvability in systems biology. *Current Opinion in Biotechnology*, 2008.
[3] J. Halatek and E. Frey. Rethinking pattern formation in reactiondiffusion systems. *Nature Physics*, 2 2018.