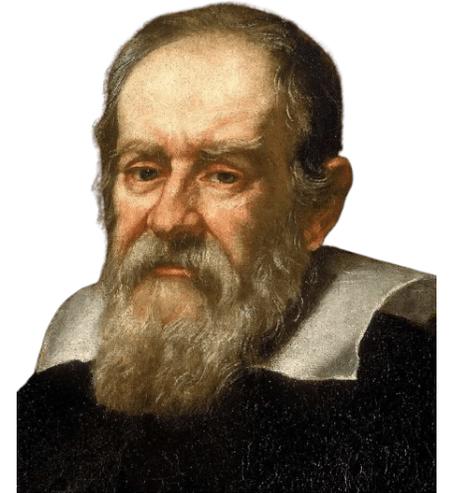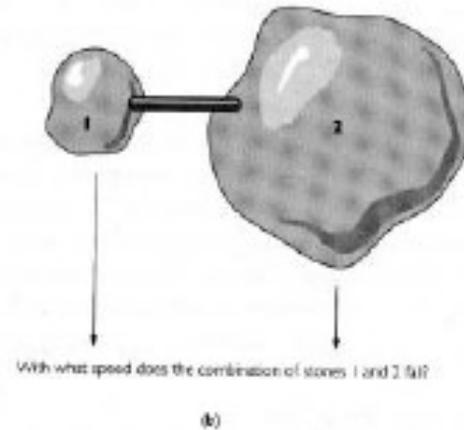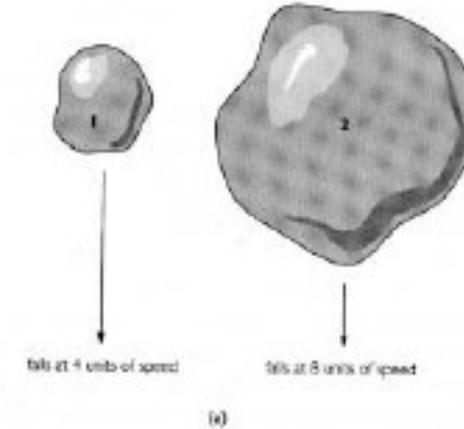# Discussion

- Have you used theory or modelling already? How has it influenced your work?

- What (if any) is the difference between a model, a theory and a simulation?

- Do all models aim to answer the same type of question? If not, what are the different categories?

- What makes a good model versus a bad model?

- What is your aesthetic experience of modelling?

Predictive versus explanatory modelling

Predictive modelling
- Main goal is to provide a prediction of the future state of a system, potentially under different scenarios. Of use to *e.g.* policy makers.
- Methods adopted are of interest only to the extent that they affect model accuracy. A 'black box' that predicts perfectly is better than a comprehensible model that predicts less well.
- Inaccuracies are generally attributed to missing features of the model, not the

Explanatory modelling (or 'theory')
- Main goal is to provide a general explanation of a particular phenomenon. Generally, we want to understand how a particular pattern emerges from underlying processes.
- Model structure matters enormously, with different models leading to contradictory results depending on assumptions
- As much extraneous detail must be stripped out of the system as possible to mathematical analysis

What does theory look like?

Galileo's gedankenexperiment

$$\frac{dx_i}{dt} = x_i \left(+ \sum^{n} \propto_{ij} x_j \right)$$

'...hat's all Greek to me...'
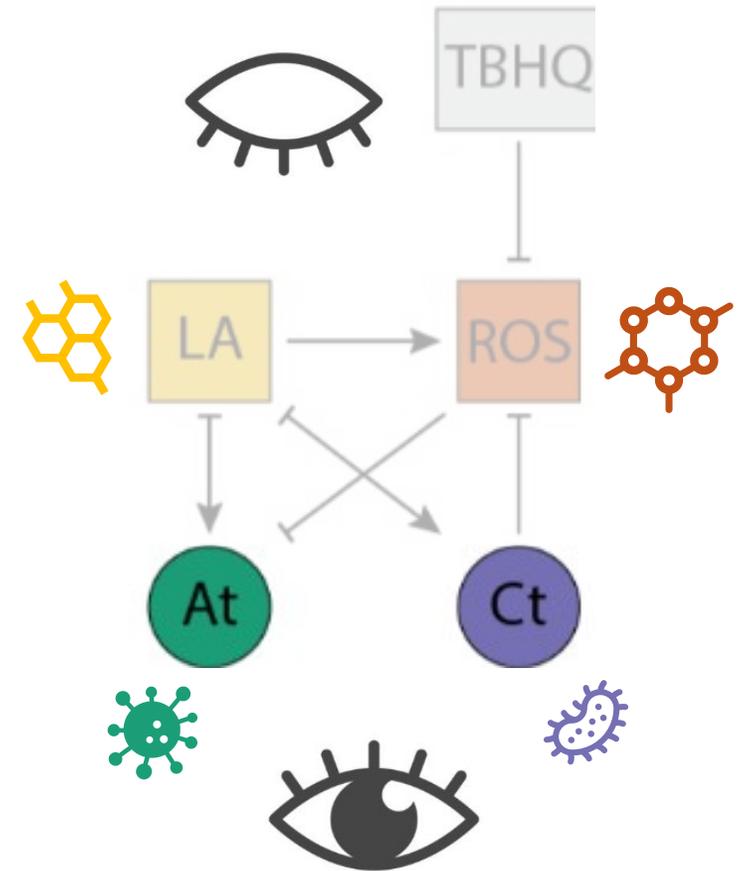
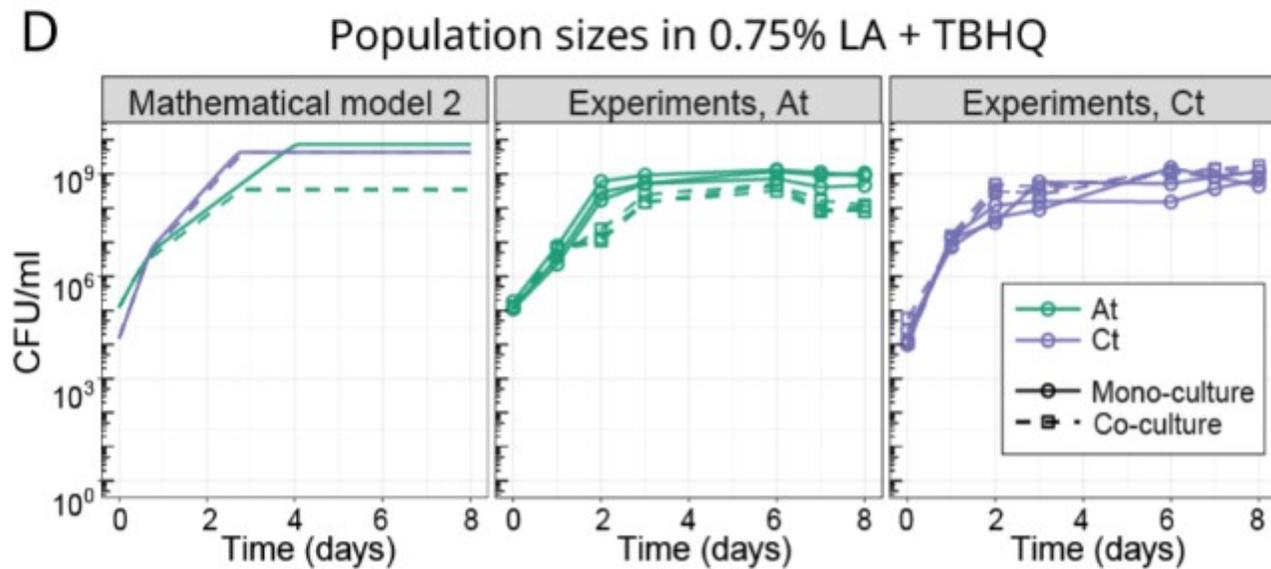# The 'emergence paradigm' for systemising theoretical approaches
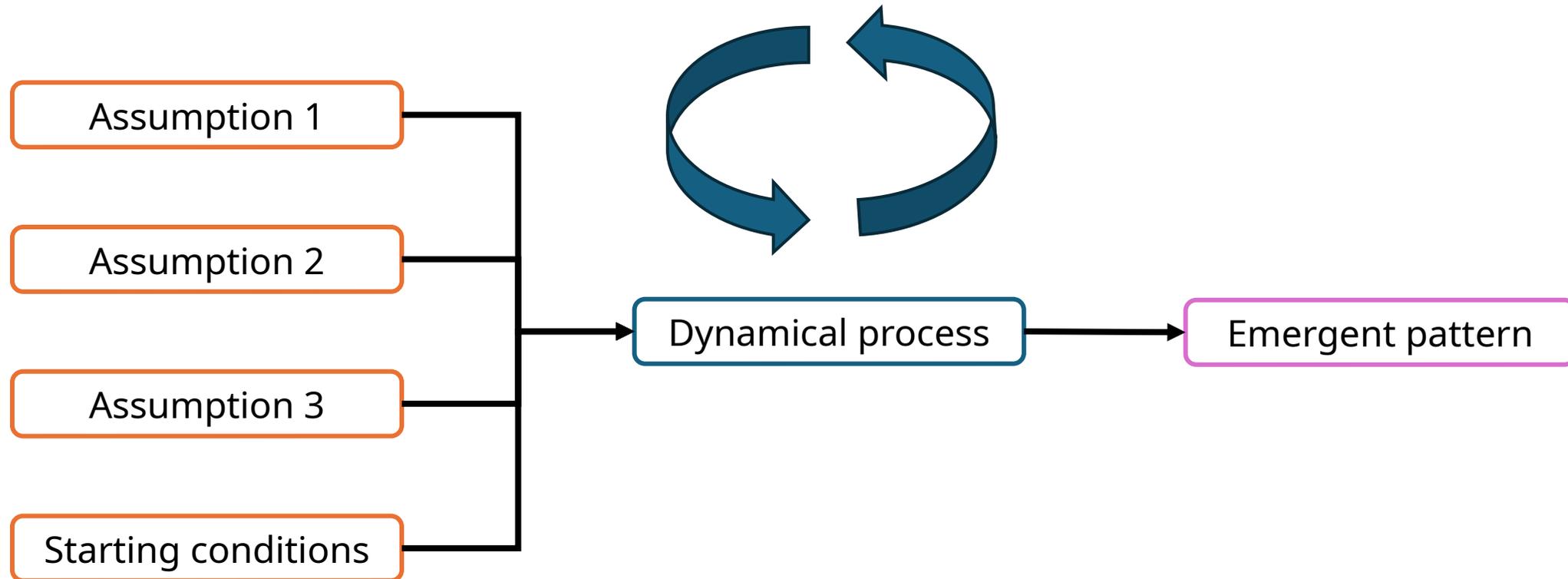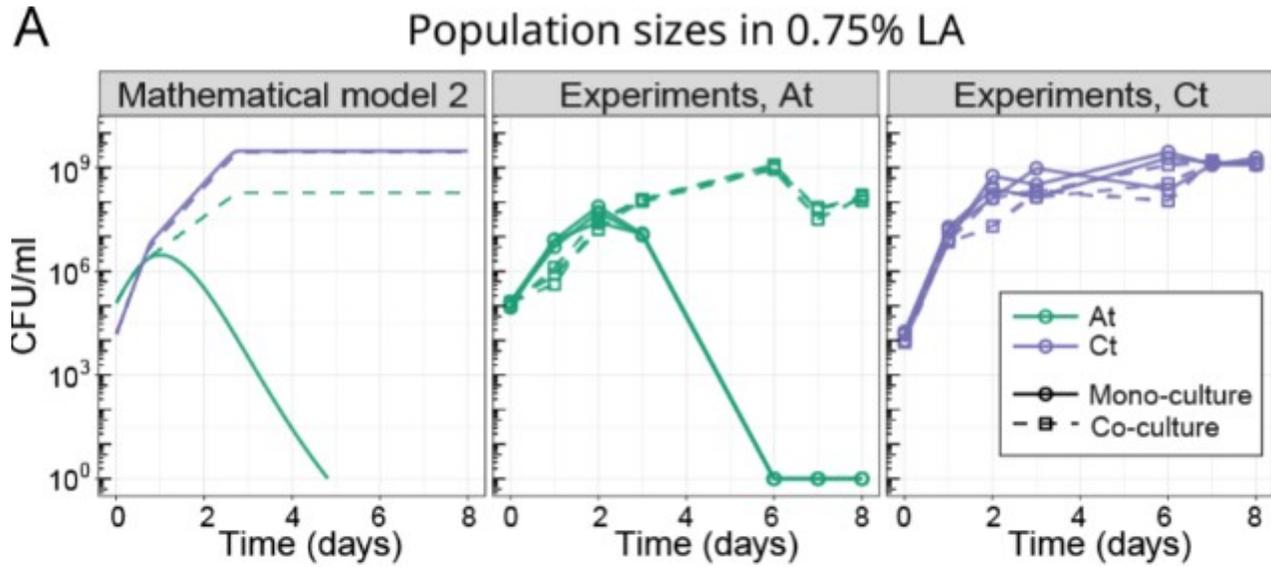
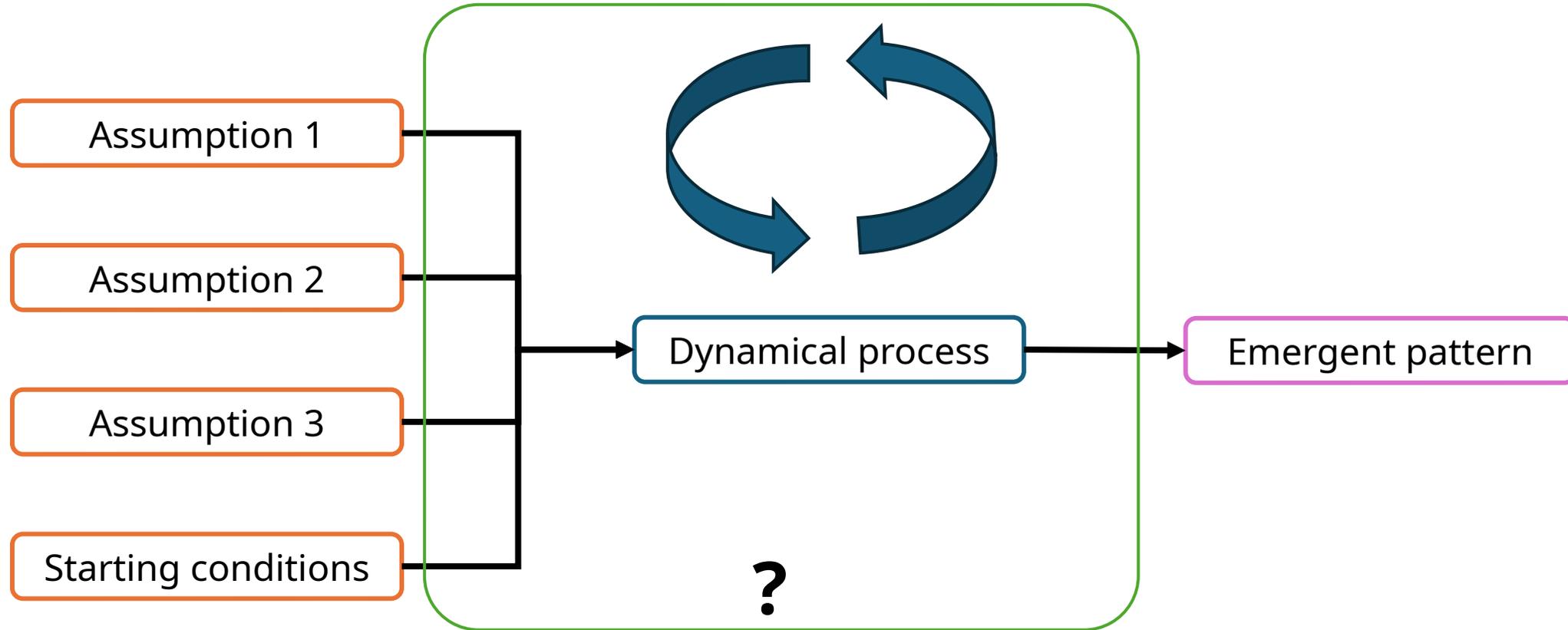# Identifying underlying mechanisms based on emergent patterns
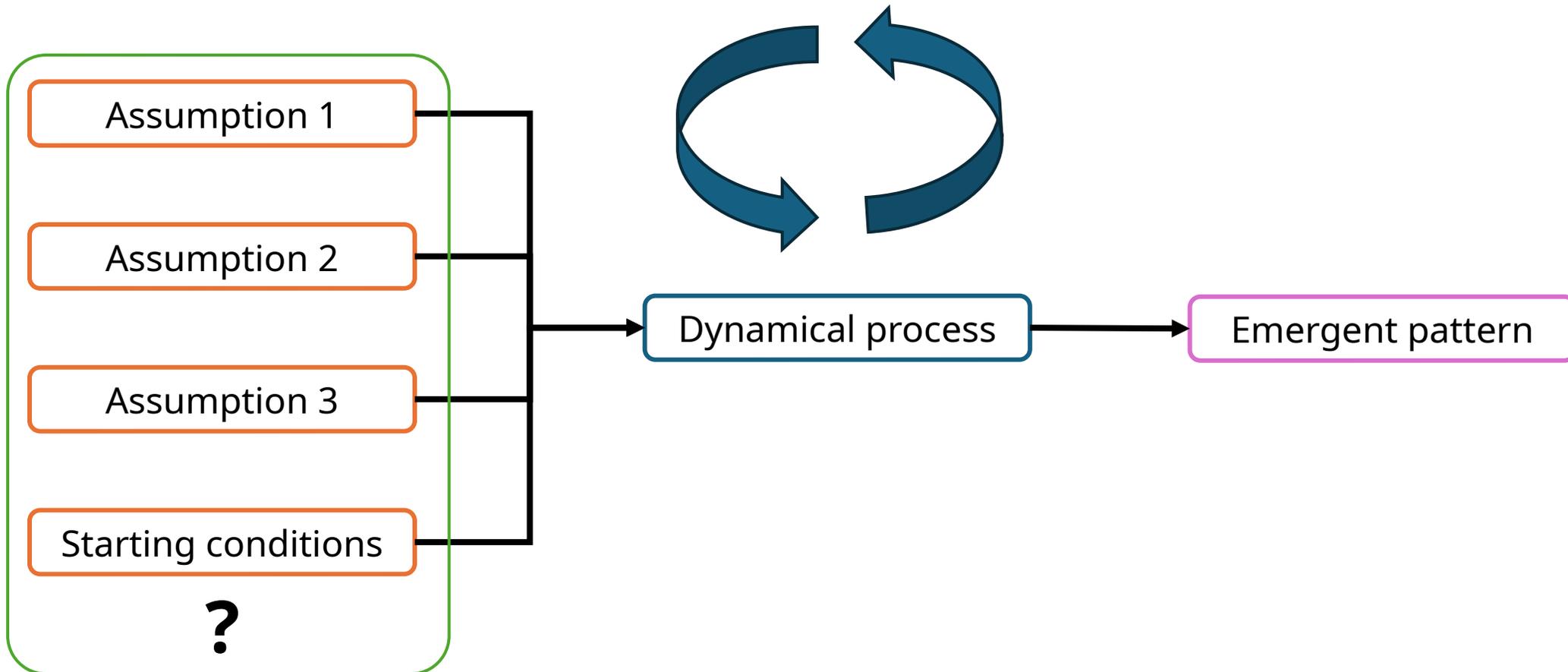
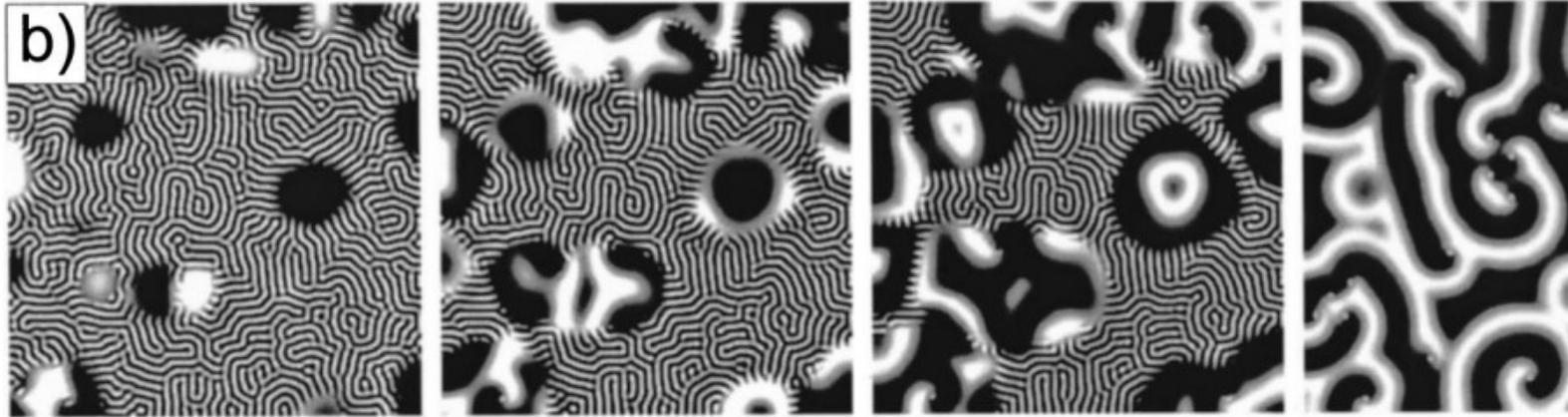# Identifying hidden mechanisms

Di Martino et al. 2024, *PLOS Bio.*
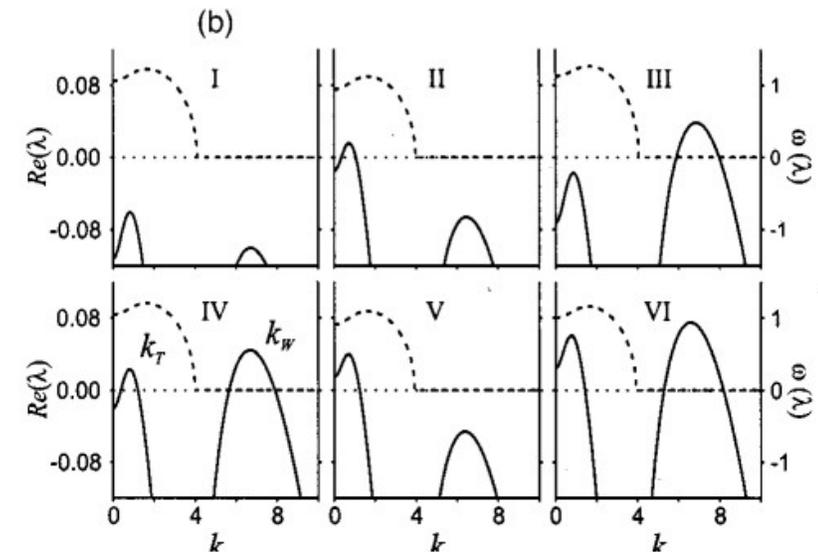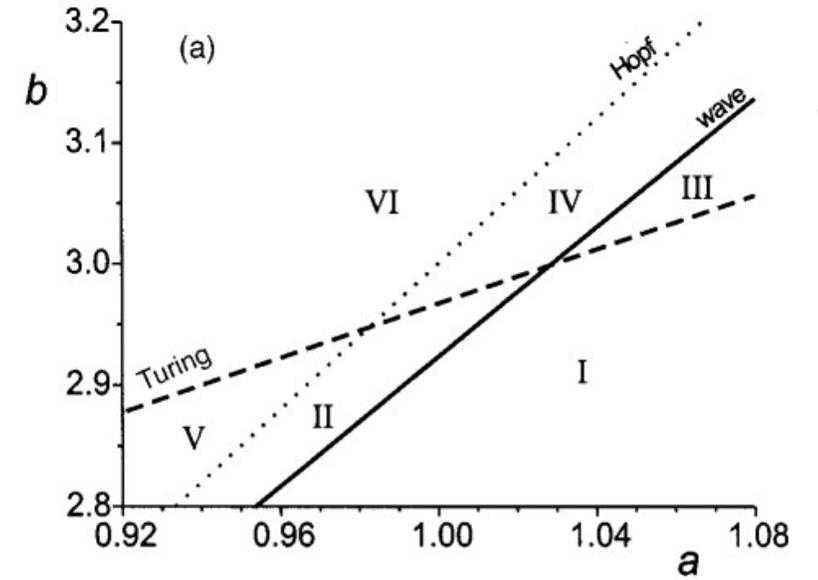
Understanding emergence

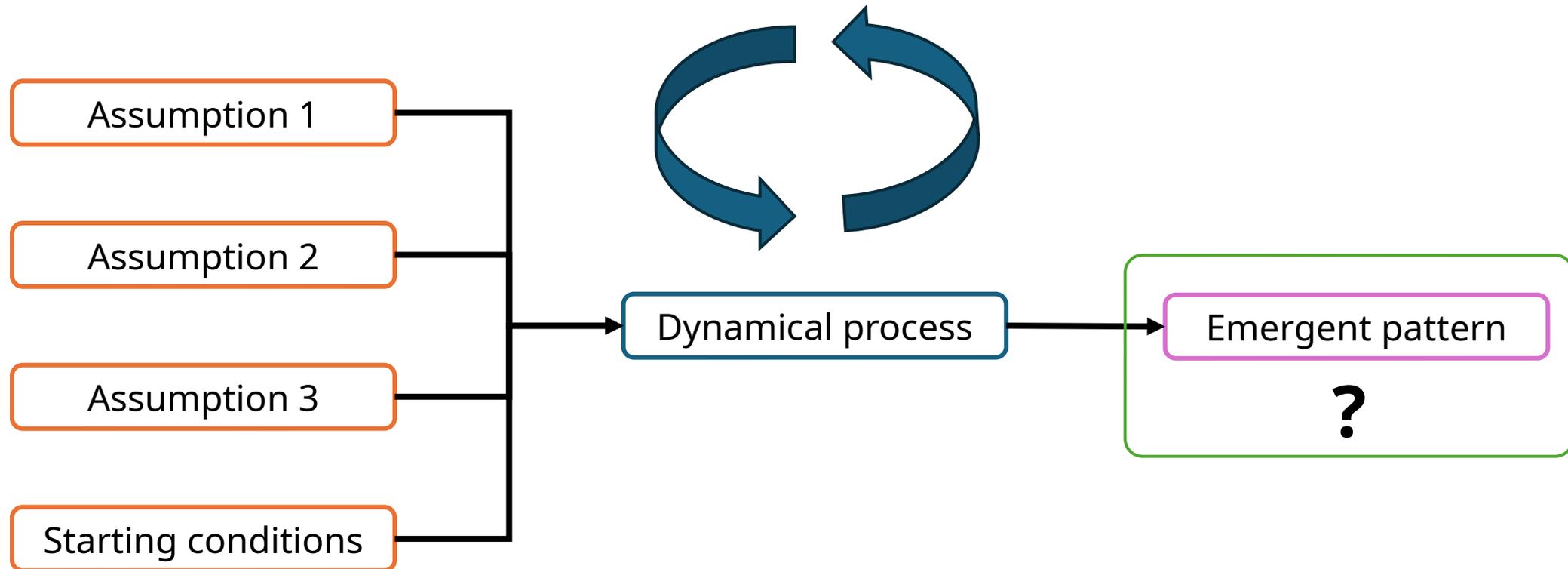# Understanding emergence: Turing patterns

$$\frac{\partial z}{\partial \tau} = D_z \nabla^2 z + x - z, \qquad (14)$$

$$\frac{\partial r}{\partial \tau} = D_r \nabla^2 r + \frac{1}{\epsilon_1}(cx - dr), \qquad (15)$$
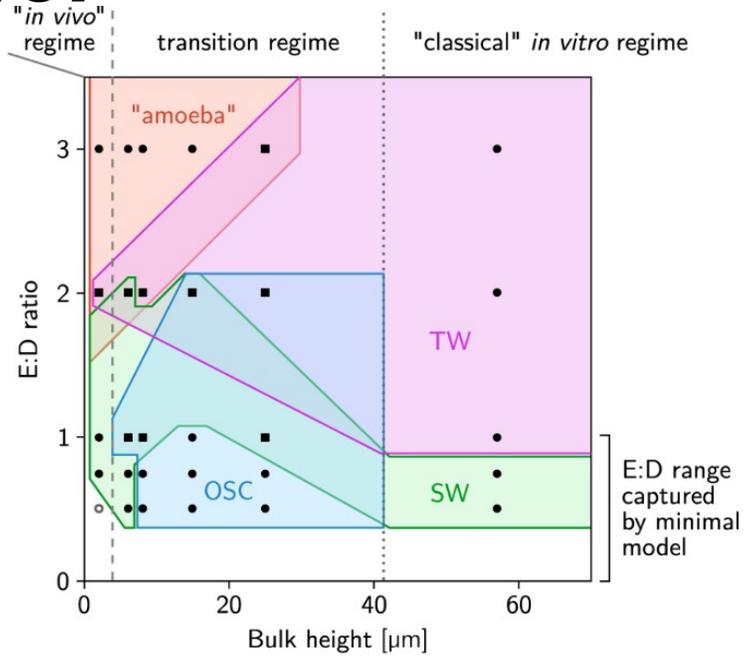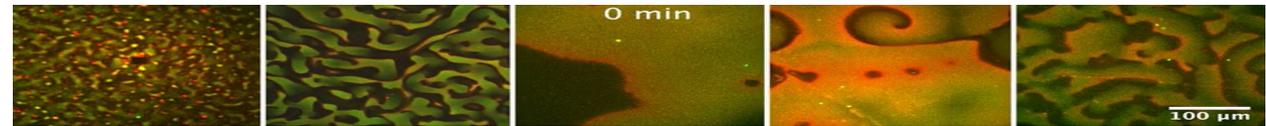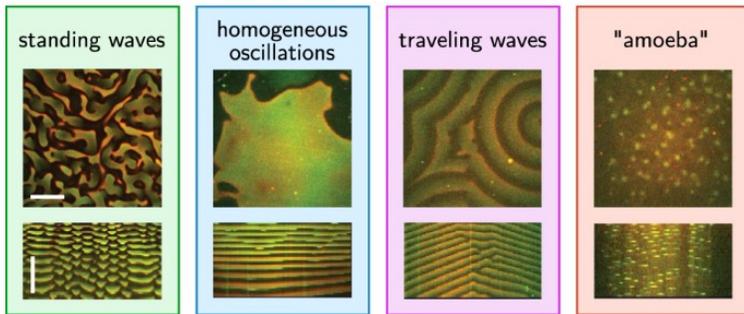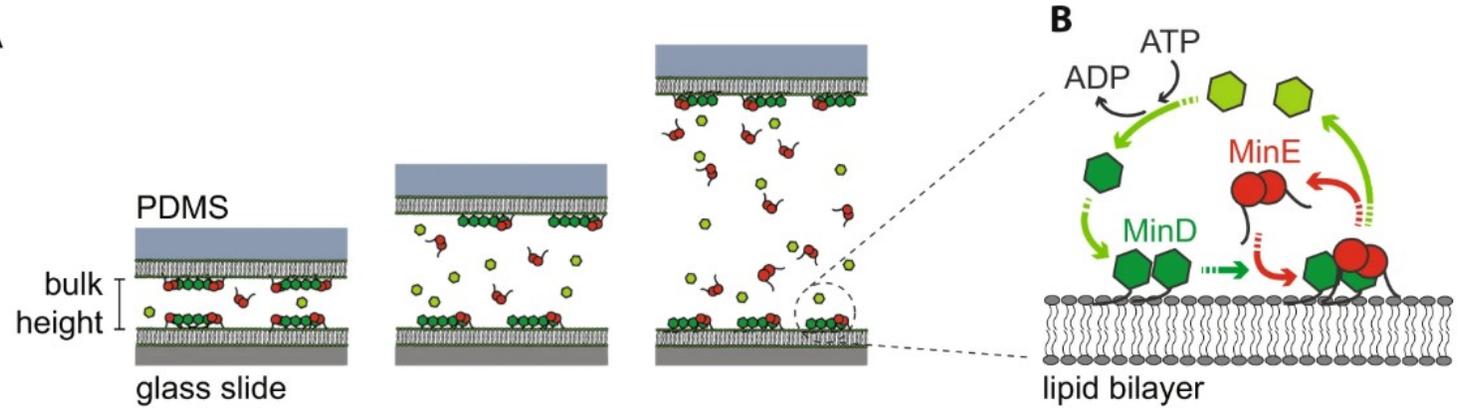
Yang et al. 2002, *J. Chem. Phys*

Identifying new patterns to search for

Identifying new patterns to search for

Brauns et al. 2021, *Nat. Comms.*

The sins of theory: Faulty assumptions

A Logistic & sublinear growth

Per capita growth — Population density

Exponential

Steady-state

A Stability vs. diversity

Probability of stable system — Species diversity S

— Logistic
— Sublinear
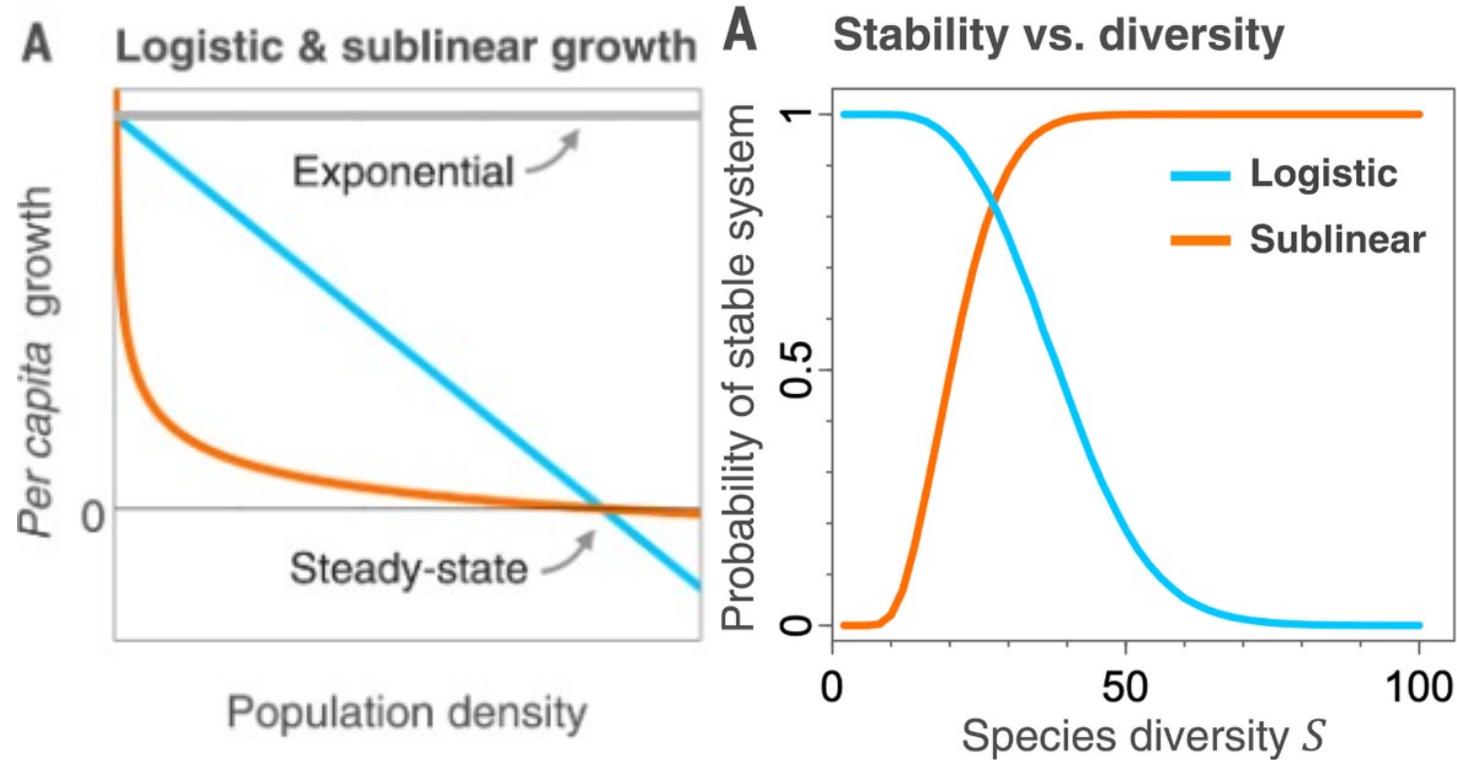
$$P_i(B_i) = \begin{cases} (r_i - z_i)B_i(1 - B_i/K) & \text{(logistic)} \\ r_i B_0^{1-k} B_i^k - z_i B_i & \text{(sublinear)} \end{cases}$$

Hatton et al. 2024, *Science*
(current references: 121)

"Here we clarify why SG [Sublinear-Growth] models do not solve the paradox of species coexistence. This is because, in the SG model, coexistence emerges from an unrealistic property, in which population per capita growth rates tend to infinity at low abundance, preventing species from ever going extinct due to competitive exclusion."
Aguadé-Gorgorió et al. 2024, *Oikos*
(current references: 7)

The sins of theory: Indistinguishable explanations

Niche theory

Neutral theory

Simulations

Data
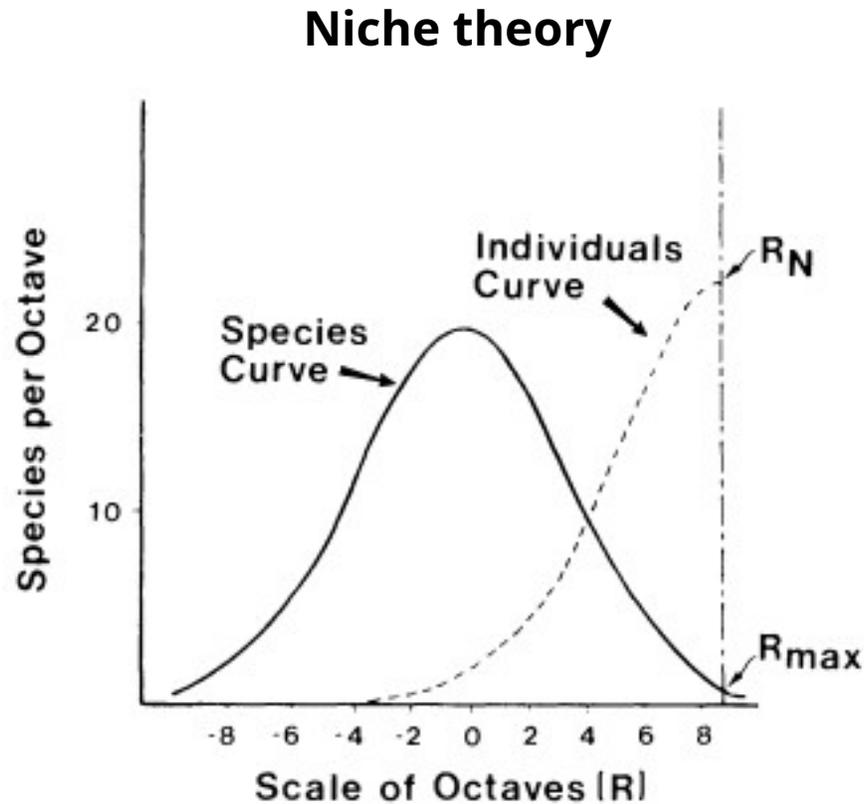
Bell 2000, *Am. Nat.*

Sugihara 1980, *Am. Nat.*

The sins of theory: Obfuscation by mathematics

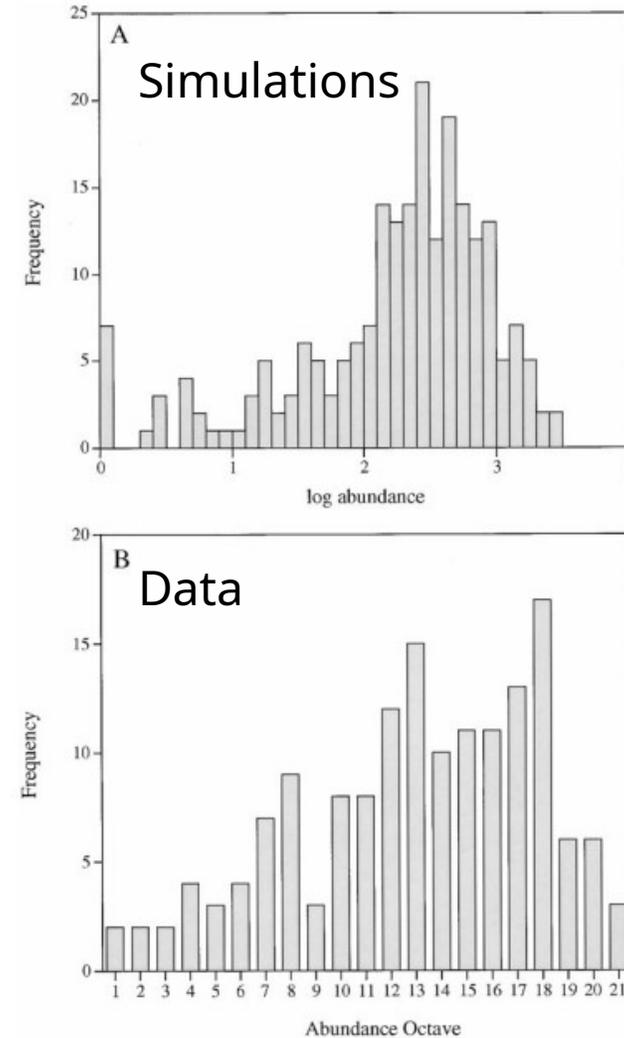$$\kappa_i > \rho_i \left(\mathbf{P}^{\{-i\}} \right)^{-1} \boldsymbol{\kappa}^{\{-i\}}, \tag{44}$$

which is a direct generalization of the two-species condition **41** taking account of the indirect effects through the inverse matrix $\left(\mathbf{P}^{\{-i\}} \right)^{-1}$. Defining $\bar{\boldsymbol{\rho}}^{\{-i\}}$ to be the average of the rows of $\mathbf{P}^{\{-i\}}$ and $\bar{\kappa}^{\{-i\}}$ to be the average the resident κ's (i.e. the average of the elements of $\boldsymbol{\kappa}^{\{-i\}}$), the invader growth rate can now be written in terms of average fitness differences and stabilizing terms as follows

$$\frac{r_i}{b_i} = \kappa_i - \bar{\kappa}^{\{-i\}} + \left(\bar{\boldsymbol{\rho}}^{\{-i\}} - \rho_i \right) \left(\mathbf{P}^{\{-i\}} \right)^{-1} \boldsymbol{\kappa}^{\{-i\}}. \tag{45}$$

In Chesson (**2000b**), a general approximate invasion formula for diffuse competition is given as

$$\frac{r_i}{b_i} \approx \kappa_i - \bar{\kappa}^{\{-i\}} + \frac{D(1-\rho)}{n-1}, \tag{46}$$

where ρ is a common overlap measure for all pairs of species, and D is a constant depending on the circumstances, as derived in Chesson (**1994**). Expression **45** now allows the exact result for diffuse competition to be stated as

$$\frac{r_i}{b_i} = \kappa_i - \bar{\kappa}^{\{-i\}} + \frac{\bar{k}^{\{-i\}}(1-\rho)}{1+(n-2)\rho}. \tag{47}$$

Chesson 2018, J. Eco.

The aesthetics of theory
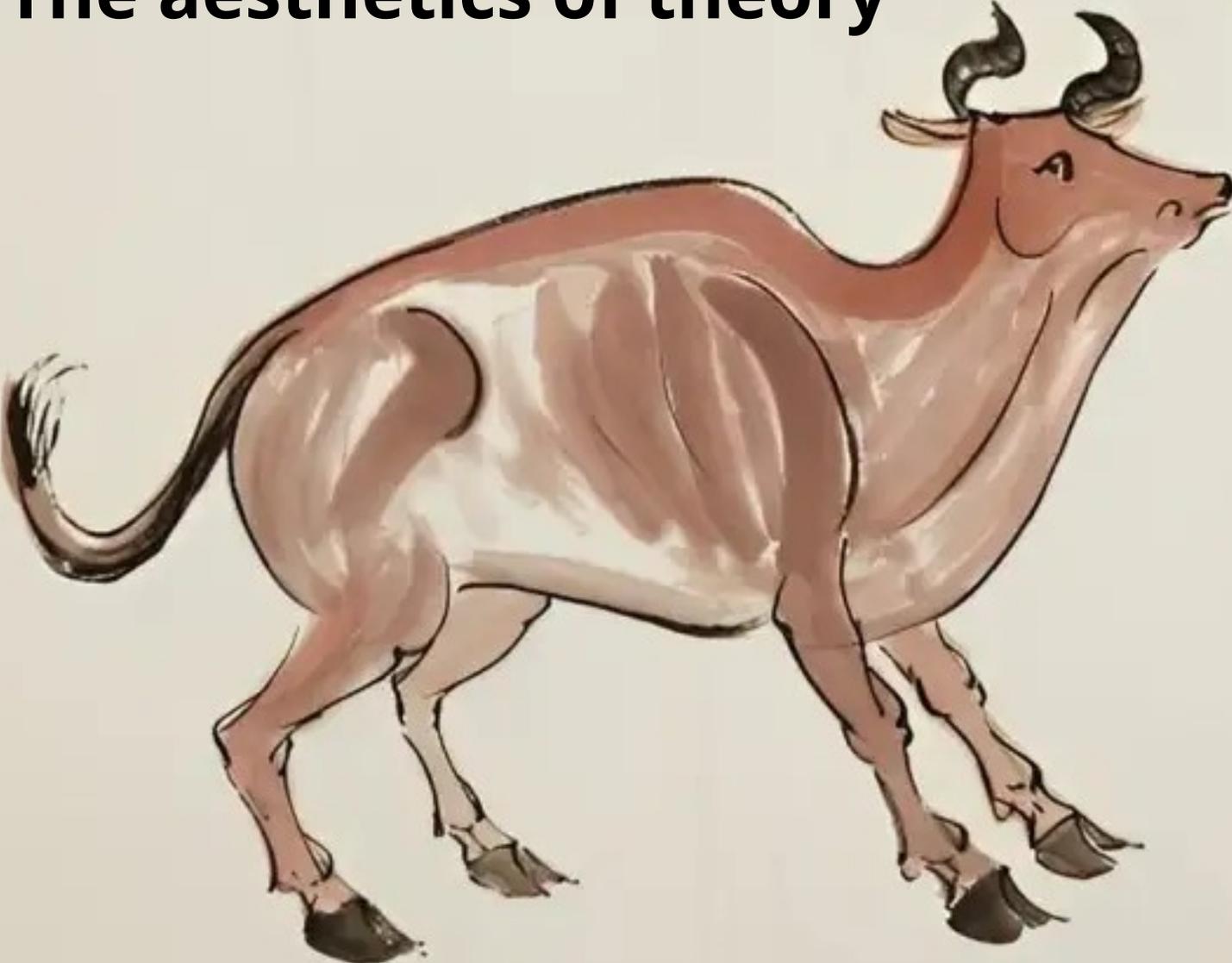
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- Brauns et al., "Bulk-surface coupling identifies the mechanistic connection between Min-protein patterns in vivo and in vitro." *Nature Communications* **12** 3312 (20210)