

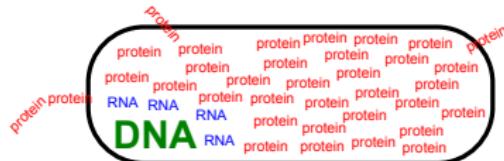
The Origin of the Central Dogma through Conflicting Multilevel Evolution

Nobuto Takeuchi
University of Tokyo

EVOLUTION meeting
Salzburg, Austria
July 7, 2018

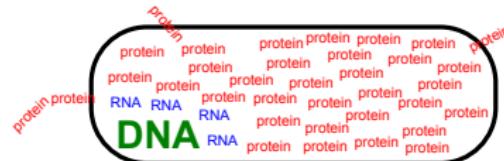
A unique feature of life

Distinction between genomes & enzymes



A unique feature of life

Distinction between genomes & enzymes

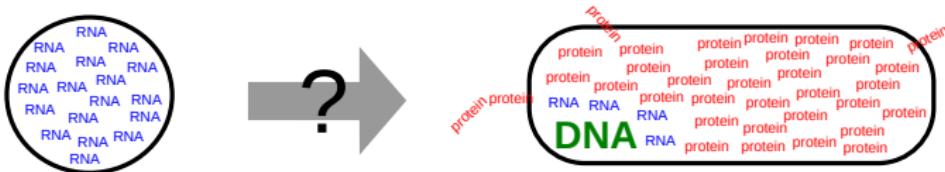


Three asymmetries that mark genome-enzyme distinction

- Functional: template vs. catalyst
 - Informatic: template → catalyst (central dogma)
 - Numerical: little templates vs. many catalyststs

A unique feature of life

Distinction between genomes & enzymes



Three asymmetries that mark genome-enzyme distinction

- Functional: template vs. catalyst
 - Informatic: template → catalyst (central dogma)
 - Numerical: little templates vs. many catalyststs

Outline of this talk

Purpose

We propose that genome-enzyme distinction spontaneously arises from conflicting multilevel evolution

Contents

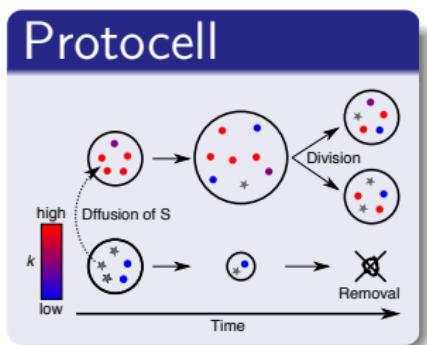
1. Basic facts about conflicting multilevel evolution
2. Emergence of genome-enzyme distinction

Quotes from this conference

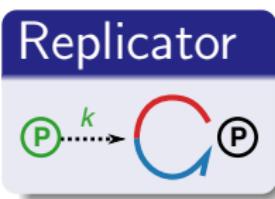
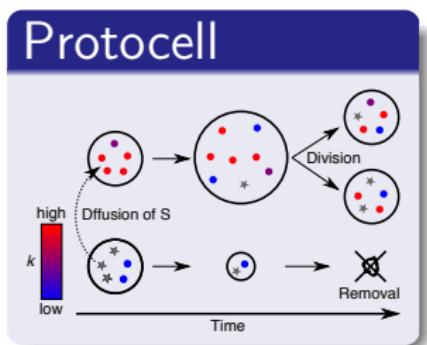
“Host-parasite conflicts drive evolution of complexity including major evolutionary transitions”

(Eugene Koonin)

Model 1

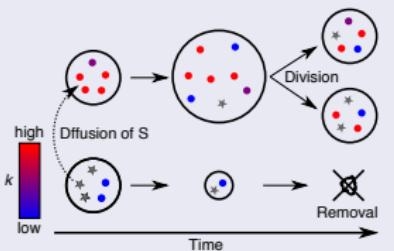


Model 1



Model 1

Protocell



Replicator



Reaction

Complex formation



Replication

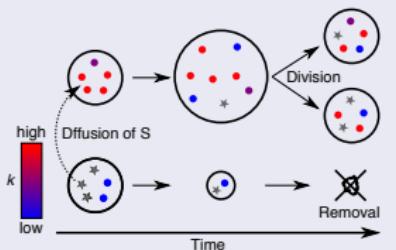


Decay

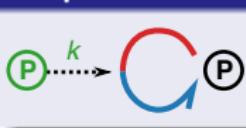


Model 1

Protocell

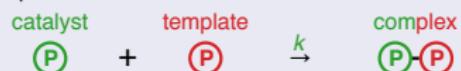


Replicator



Reaction

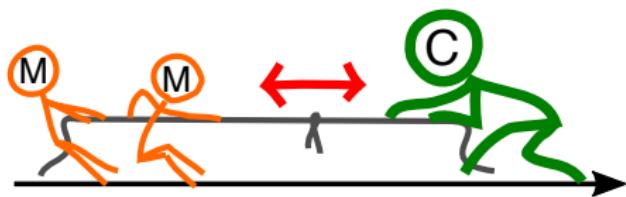
Complex formation



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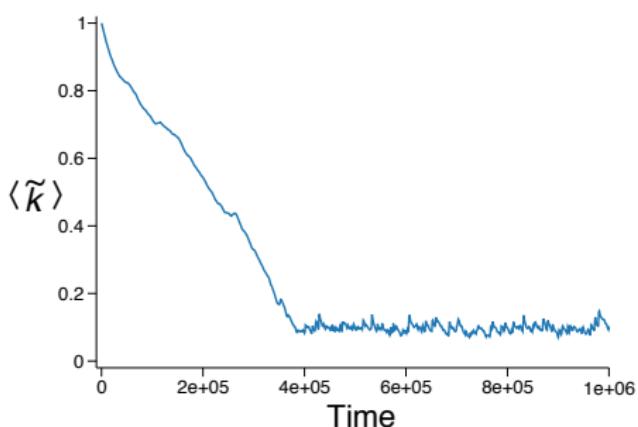


Decay

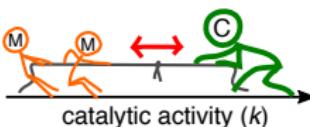


catalytic activity (k)

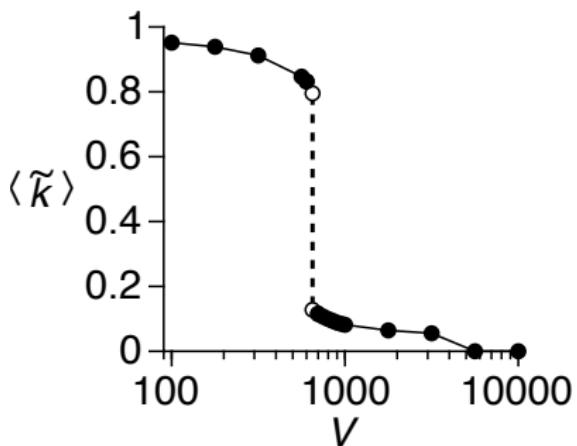
Evolution of catalytic activity



$\langle \tilde{k} \rangle$: average catalytic activity

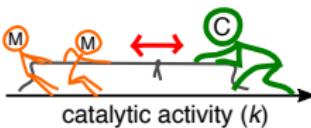


Catalytic activity as function of cell size

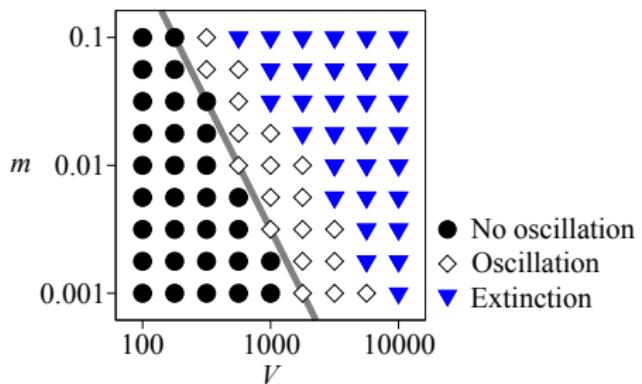


$\langle \tilde{k} \rangle$: average catalytic activity

V : max. no. of molecules per cell

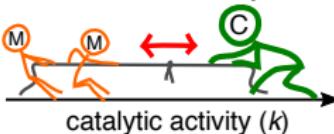


Phase diagram



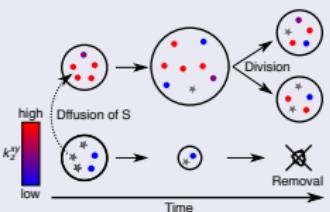
V : max. no. of molecules per cell

m : mutation rate of k per replication



Model 2

Protocell

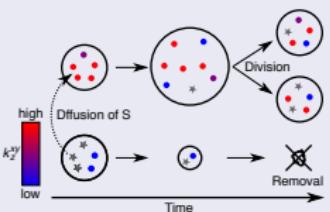


Replicator

(P)

Model 2

Protocell

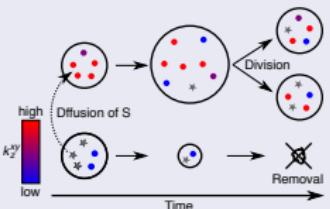


Replicator



Model 2

Protocell

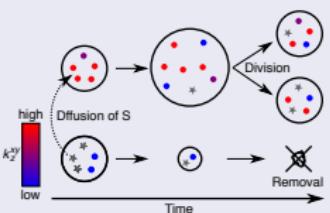


Replicator



Model 2

Protocell

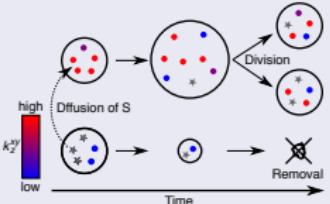


Replicator

(P) (Q)

Model 2

Protocell

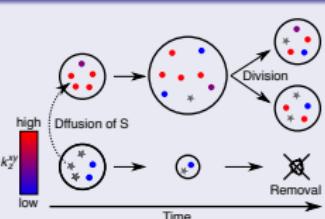


Replicator

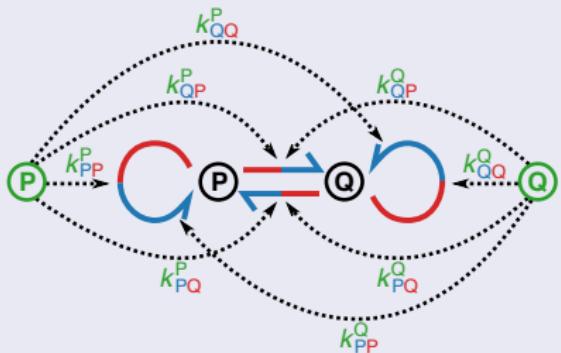


Model 2

Protocell

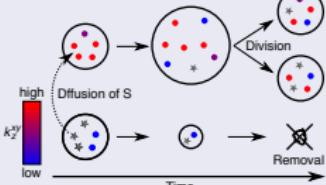


Replicator

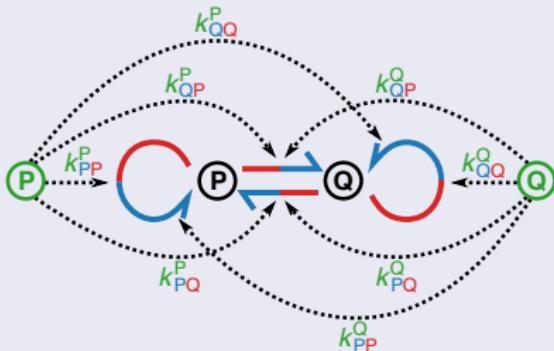


Model 2

Protocell

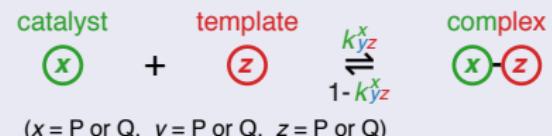


Replicator



Reaction

Complex formation



Production: replication ($y=z$) or transcription ($y \neq z$)

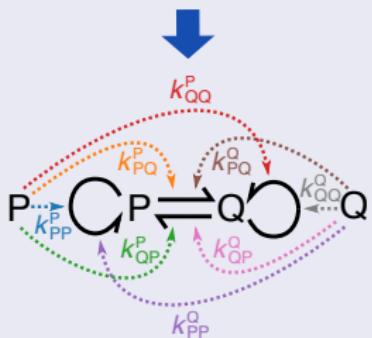
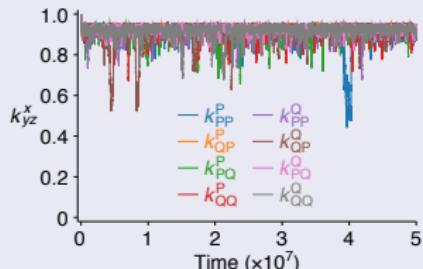


Decay



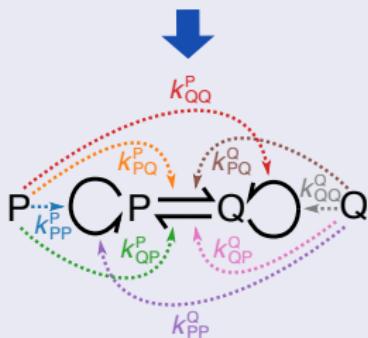
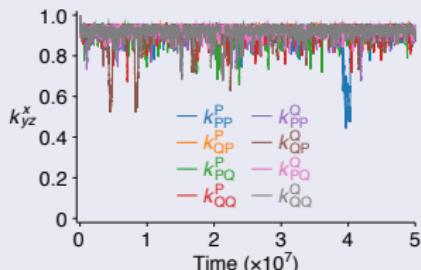
Symmetry breaking

Small cell size ($V = 178$)

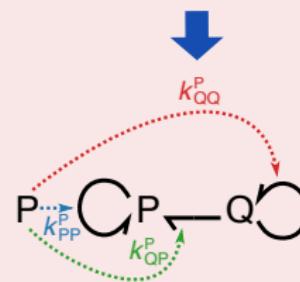
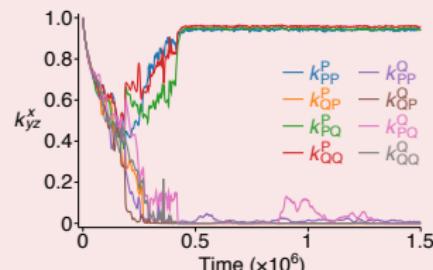


Symmetry breaking

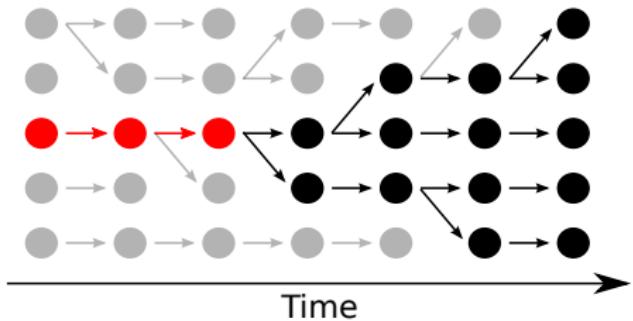
Small cell size ($V = 178$)



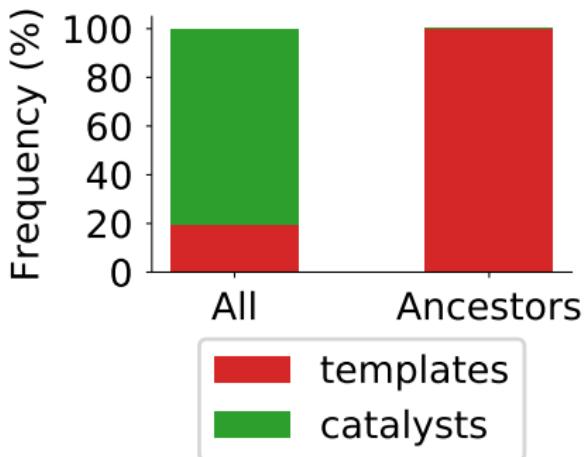
Large cell size ($V = 10000$)



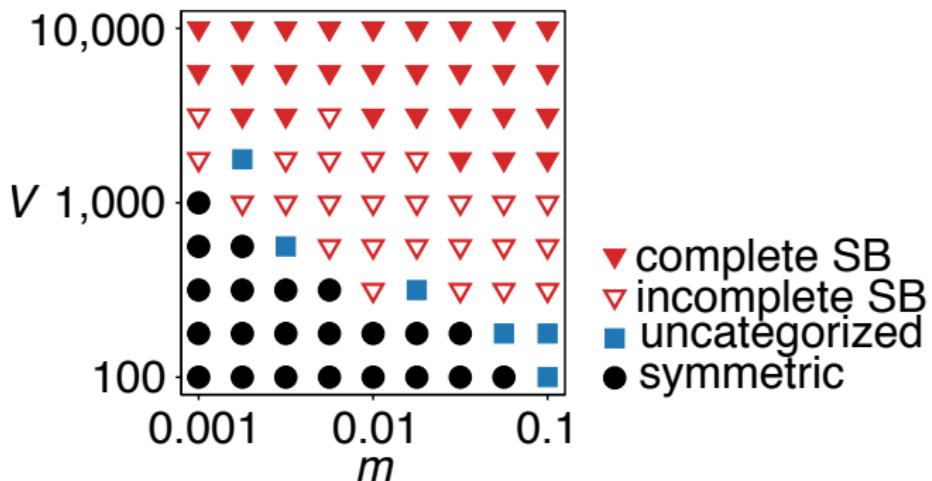
Ancestor tracking



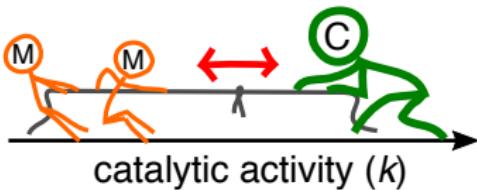
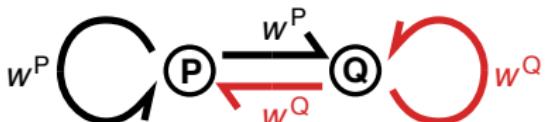
Symmetry breaking



Phase diagram



Approximate Price's equation



$$\Delta \langle \kappa_{ij}^P \rangle \approx \frac{\langle w_{ij}^P \rangle}{\langle \lambda_{ij}^P \rangle} \left(\frac{\partial \ln \langle w_{ij}^P \rangle}{\partial \langle \kappa_{ij}^P \rangle} \sigma_b^2 + \frac{\partial \ln w_{ij}^P}{\partial \kappa_{ij}^P} \sigma_w^2 \right) + \frac{\langle w_{ij}^Q \rangle}{\langle \lambda_{ij}^Q \rangle} \frac{\partial \ln w_{ij}^Q}{\partial \kappa_{ij}^P} \sigma_w^2$$

$$\Delta \langle \kappa_{ij}^Q \rangle \approx \frac{\langle w_{ij}^P \rangle}{\langle \lambda_{ij}^P \rangle} \frac{\partial \ln w_{ij}^P}{\partial \kappa_{ij}^Q} \sigma_w^2 + \frac{\langle w_{ij}^Q \rangle}{\langle \lambda_{ij}^Q \rangle} \left(\frac{\partial \ln \langle w_{ij}^Q \rangle}{\partial \langle \kappa_{ij}^Q \rangle} \sigma_b^2 + \frac{\partial \ln w_{ij}^Q}{\partial \kappa_{ij}^Q} \sigma_w^2 \right)$$

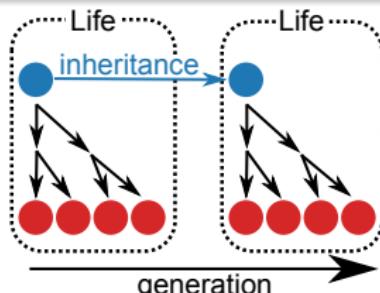
Summary

- Conflicting multilevel evolution induces functional, informatic, and numerical symmetry breaking, establishing central dogma.
- This is due to positive feedback between conflicting multilevel evolution and asymmetric flow of information between molecules. (\leftarrow omitted)

Information versus operation

Universal feature of life

Hierarchy		Differentiation	
whole	parts	informatic	operational
cell	molecule	genome	enzyme
ciliate	nucleus	micro nuc.	macro nuc.
individual	cell	germ	soma
society	individual	queen	worker



Acknowledgements

Collaborator

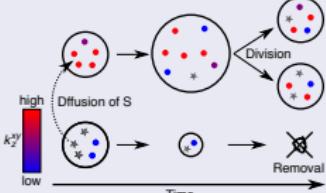
- Kunihiko Kaneko (University of Tokyo)

Funding

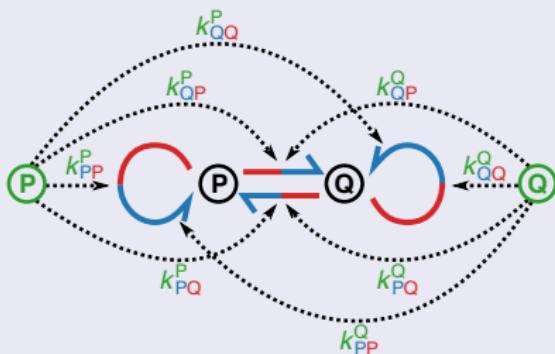
- Japan Society for Promotion of Science
- University of Tokyo

Model (original)

Protocell



Replicator



Reaction

Complex formation



($x = P$ or Q , $y = P$ or Q , $z = P$ or Q)

Production: replication ($y=z$) or transcription ($y \neq z$)

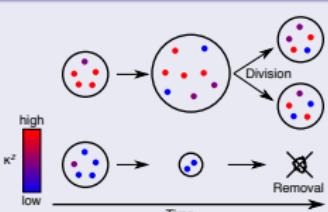


Decay



Model (simplified)

Protocell



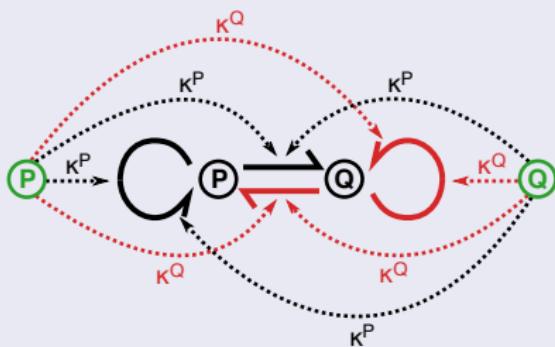
Reaction

Replication ($y=z$) or transcription ($y \neq z$)
template product



$$(y = P \text{ or } Q, z = P \text{ or } Q)$$

Replicator



Definition of w^z

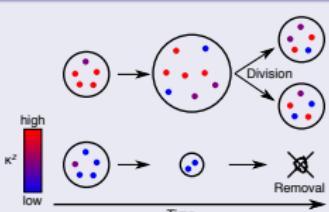
$$w_{ij}^z = e^{\langle \kappa_{ij}^z \rangle} \frac{e^{-c(\kappa_{ij}^P + \kappa_{ij}^Q)}}{\langle e^{-c(\kappa_{ij}^P + \kappa_{ij}^Q)} \rangle}$$

i : protocell

j : replicator

Model (simplified)

Protocell



Reaction

Replication ($y=z$) or transcription ($y \neq z$)

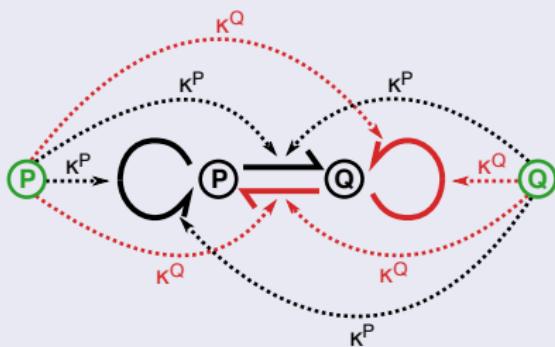
template

product



($y \equiv P$ or Q , $z \equiv P$ or Q)

Replicator



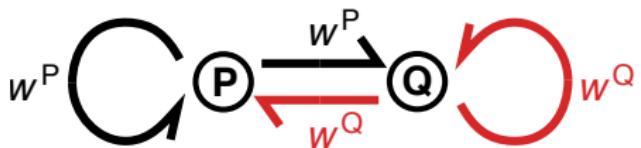
Definition of w^z

$$W_{ij}^z = e^{\langle \kappa_{ij}^z \rangle} \frac{e^{-c(\kappa_{ij}^P + \kappa_{ij}^Q)}}{\langle e^{-c(\kappa_{ij}^P + \kappa_{ij}^Q)} \rangle}$$

i: protocell

j: replicator

Model (simplified)



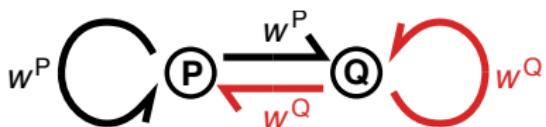
$$\begin{bmatrix} n_{ij}^P(t+1) \\ n_{ij}^P(t+1) \end{bmatrix} = \begin{bmatrix} w_{ij}^P & w_{ij}^Q \\ w_{ij}^P & w_{ij}^Q \end{bmatrix} \begin{bmatrix} n_{ij}^P(t) \\ n_{ij}^P(t) \end{bmatrix}$$

Fitness: $\lambda_{ij} = w_{ij}^P + w_{ij}^Q$

Price's equation

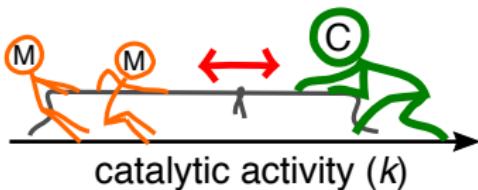
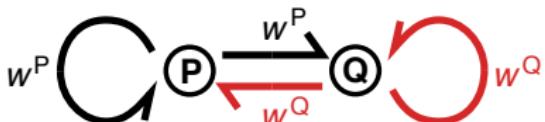
$$\langle \lambda_{\tilde{i}\tilde{j}} \rangle \Delta \langle \kappa_{\tilde{i}\tilde{j}}^P \rangle = \sigma_{\tilde{i}}^2 [\langle \lambda_{i\tilde{j}} \rangle, \langle \kappa_{i\tilde{j}}^P \rangle] + \mathbb{E}_{\tilde{i}} [\sigma_{i\tilde{j}}^2 [\lambda_{ij}, \kappa_{ij}^P]]$$
$$\langle \lambda_{\tilde{i}\tilde{j}} \rangle \Delta \langle \kappa_{\tilde{i}\tilde{j}}^Q \rangle = \sigma_{\tilde{i}}^2 [\langle \lambda_{i\tilde{j}} \rangle, \langle \kappa_{i\tilde{j}}^Q \rangle] + \mathbb{E}_{\tilde{i}} [\sigma_{i\tilde{j}}^2 [\lambda_{ij}, \kappa_{ij}^Q]]$$

Approximate Price's equation



$$\Delta \langle \kappa_{ij}^P \rangle \approx \frac{\langle w_{ij}^P \rangle}{\langle \lambda_{ij} \rangle} \left(\frac{\partial \ln \langle w_{ij}^P \rangle}{\partial \langle \kappa_{ij}^P \rangle} \sigma_b^2 + \frac{\partial \ln w_{ij}^P}{\partial \kappa_{ij}^P} \sigma_w^2 \right) + \frac{\langle w_{ij}^Q \rangle}{\langle \lambda_{ij} \rangle} \frac{\partial \ln w_{ij}^Q}{\partial \kappa_{ij}^P} \sigma_w^2$$
$$\Delta \langle \kappa_{ij}^Q \rangle \approx \frac{\langle w_{ij}^P \rangle}{\langle \lambda_{ij} \rangle} \frac{\partial \ln w_{ij}^P}{\partial \kappa_{ij}^Q} \sigma_w^2 + \frac{\langle w_{ij}^Q \rangle}{\langle \lambda_{ij} \rangle} \left(\frac{\partial \ln \langle w_{ij}^Q \rangle}{\partial \langle \kappa_{ij}^Q \rangle} \sigma_b^2 + \frac{\partial \ln w_{ij}^Q}{\partial \kappa_{ij}^Q} \sigma_w^2 \right)$$

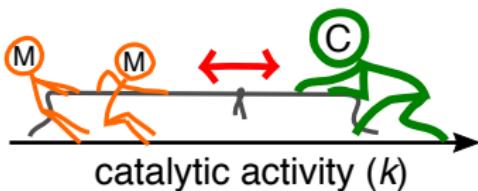
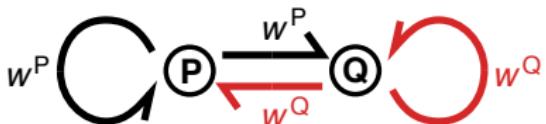
Approximate Price's equation



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$$\Delta \langle \kappa_{ij}^Q \rangle \approx \frac{\langle w_{ij}^P \rangle}{\langle \lambda_{ij}^Q \rangle} \frac{\partial \ln w_{ij}^P}{\partial \kappa_{ij}^Q} \sigma_w^2 + \frac{\langle w_{ij}^Q \rangle}{\langle \lambda_{ij}^Q \rangle} \left(\frac{\partial \ln \langle w_{ij}^Q \rangle}{\partial \langle \kappa_{ij}^Q \rangle} \sigma_b^2 + \frac{\partial \ln w_{ij}^Q}{\partial \kappa_{ij}^Q} \sigma_w^2 \right)$$

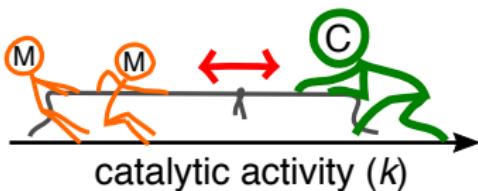
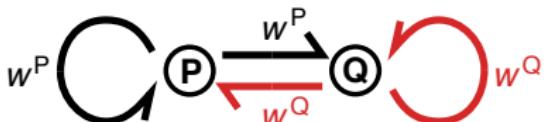
Approximate Price's equation



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$$\Delta \langle \kappa_{ij}^Q \rangle \approx \frac{\langle w_{ij}^P \rangle}{\langle \lambda_{ij}^Q \rangle} \frac{\partial \ln w_{ij}^P}{\partial \kappa_{ij}^Q} \sigma_w^2 + \frac{\langle w_{ij}^Q \rangle}{\langle \lambda_{ij}^Q \rangle} \left(\frac{\partial \ln \langle w_{ij}^Q \rangle}{\partial \langle \kappa_{ij}^Q \rangle} \sigma_b^2 + \frac{\partial \ln w_{ij}^Q}{\partial \kappa_{ij}^Q} \sigma_w^2 \right)$$

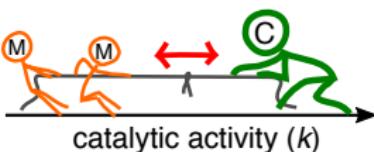
Approximate Price's equation



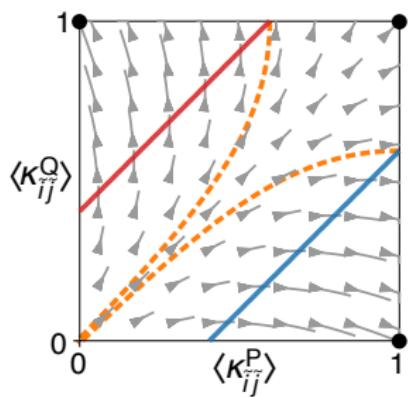
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$$\Delta \langle \kappa_{ij}^Q \rangle \approx \frac{\langle w_{ij}^P \rangle}{\langle \lambda_{ij}^Q \rangle} \frac{\partial \ln w_{ij}^P}{\partial \kappa_{ij}^Q} \sigma_w^2 + \frac{\langle w_{ij}^Q \rangle}{\langle \lambda_{ij}^Q \rangle} \left(\frac{\partial \ln \langle w_{ij}^Q \rangle}{\partial \langle \kappa_{ij}^Q \rangle} \sigma_b^2 + \frac{\partial \ln w_{ij}^Q}{\partial \kappa_{ij}^Q} \sigma_w^2 \right)$$

Phase-space portraits

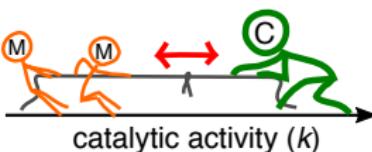


mol. < cell

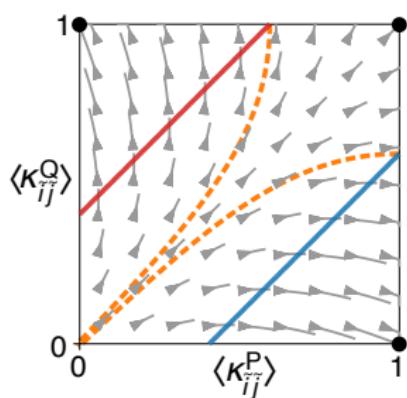


Nullclines: $\Delta \langle \kappa_{ij}^P \rangle = 0$, $\Delta \langle \kappa_{ij}^Q \rangle = 0$

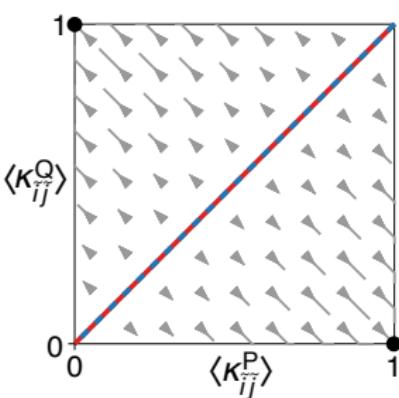
Phase-space portraits



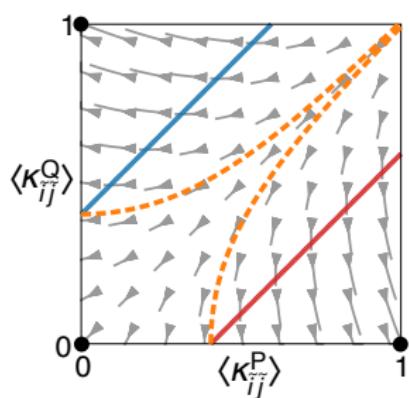
mol. < cell



mol. = cell



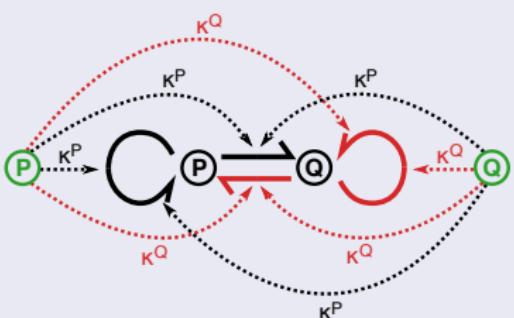
mol. > cell



Nullclines: $\Delta\langle\kappa_{ij}^P\rangle = 0$, $\Delta\langle\kappa_{ij}^Q\rangle = 0$

Functional symmetry breaking

Informatic asymmetry



Functional asymmetry

