Preliminaries for Distributed Natural Computing Inspired by the Slime Mold Physarum Polycephalum

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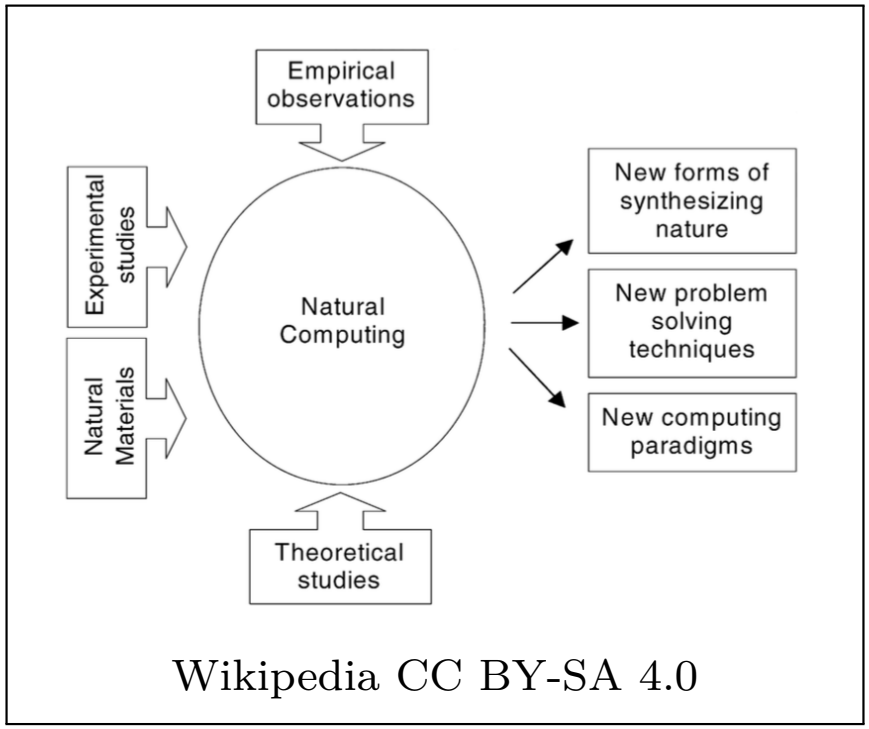
Natural Computing in a Nutshell

- Design novel nature-inspired algorithms.
- Synthesize natural phenomena using computers.
- Use natural materials to do computations.



Natural Computing is a highly interdisciplinary field!

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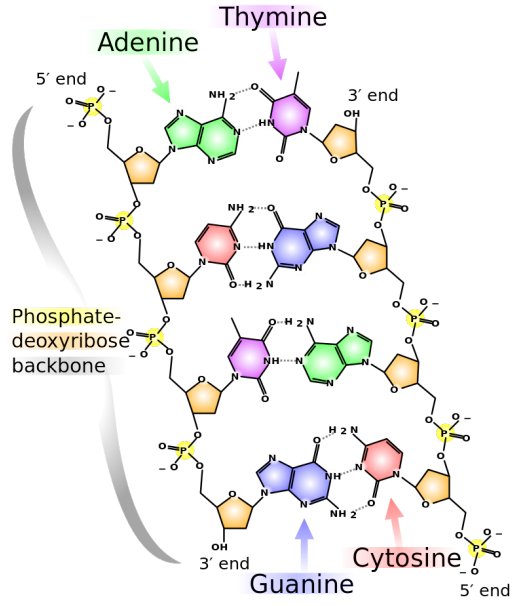

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Part III: A distributed model of P. polycephalum

What we know about *P. polycephalum*

Desirable properties:

- The **organism** operates in a fully distributed manner and requires no central control.
- The **organism** maintains a dynamic circulation of flow.
- The **organism** is robust against changes in topology.
- The **organism** has a degree of efficiency.

What we want from a model of *P. polycephalum*

Desirable properties:

- The **model** operates in a fully distributed manner and requires no central control.
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- The **model** is robust against changes in topology.
- The **model** has a degree of efficiency.

Modelling the dynamics of *P. polycephalum*

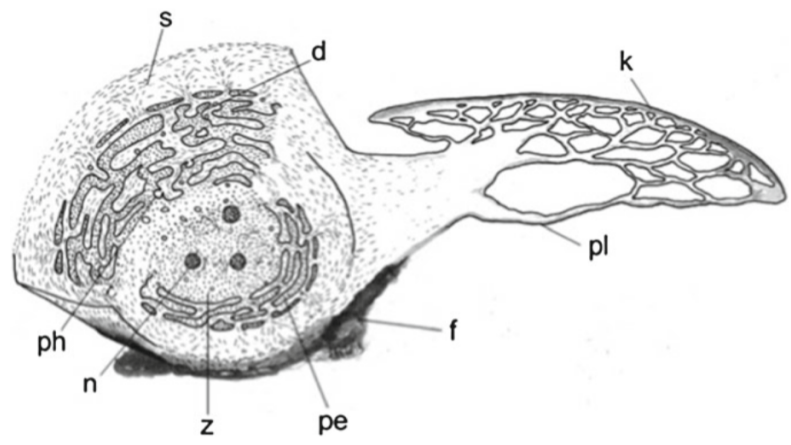
The goal:

Model the peristaltic pumping and derive dynamic fluid flows similar to what is observed in *P. polycephalum*.

The problem: Hydrodynamics is extremely difficult to work with!

Solution: Go electric!

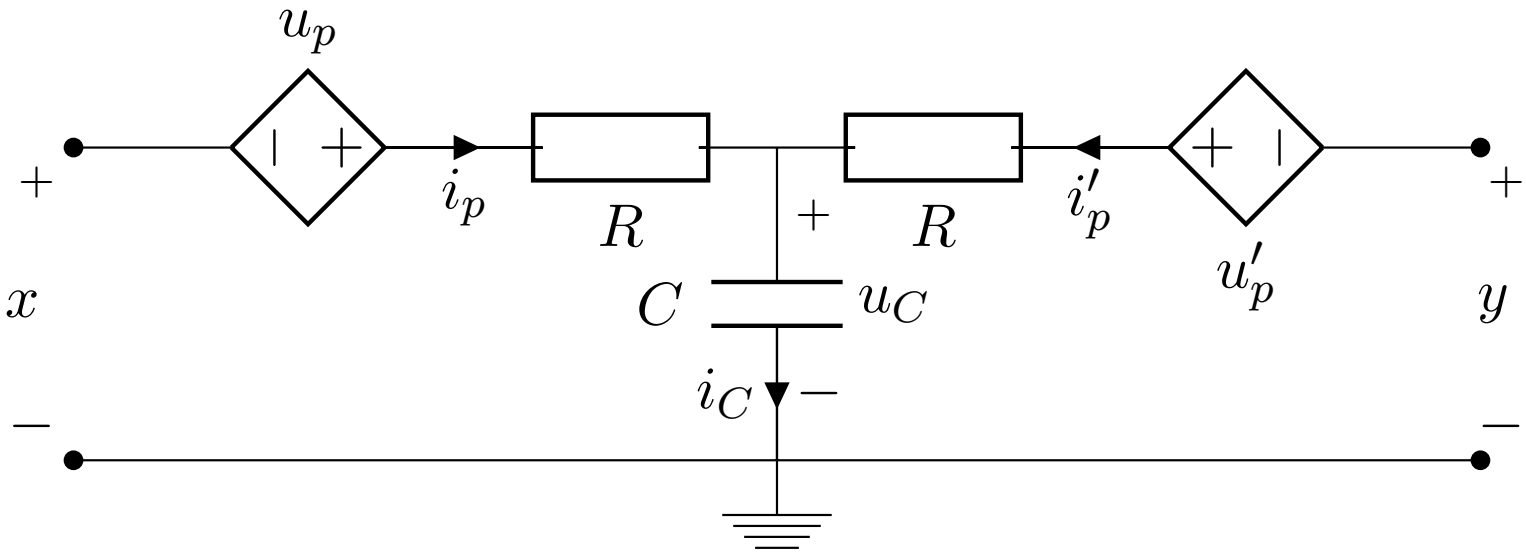
- Windkessel model.
- Peristaltic pumps replaced by current controlled voltage sources.
- Emergent oscillatory dynamics mimics real flow patterns.



Courtesy of Prof. M. Grube.

Modelling vein segments - *Physarum* elements

Hydrodynamic System	Electrical analogue
Fluid	Charge
Fluid flow	Current
Pressure	Potential
Pressure difference	Voltage
Viscosity	Resistance
Distensibility	Capacitance
Pump	Voltage souce



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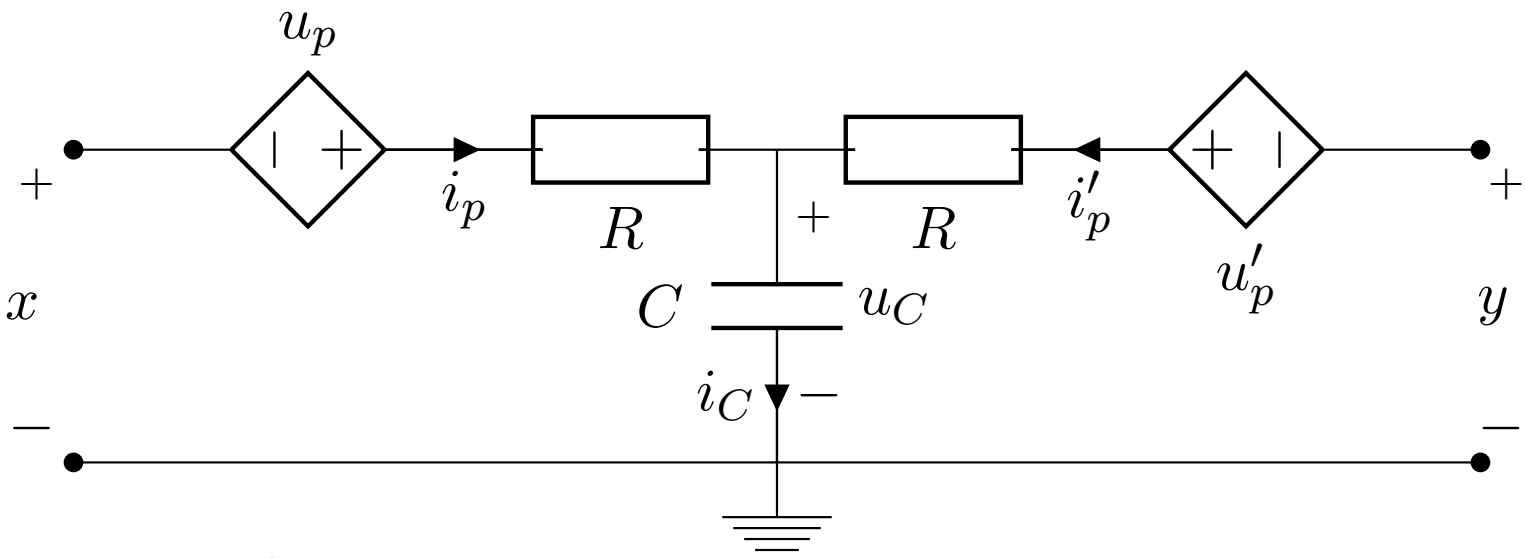

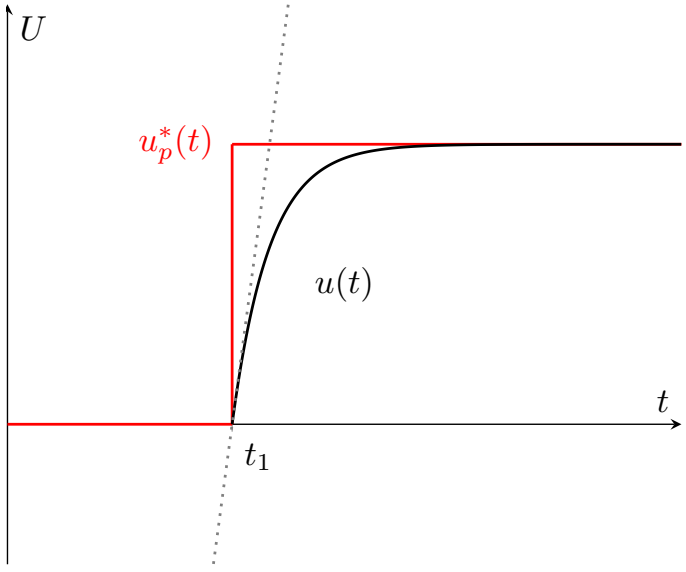

Speed of response:

$$\dot{u}_p(t) = \alpha(u_p^*(t) - u_p(t))$$

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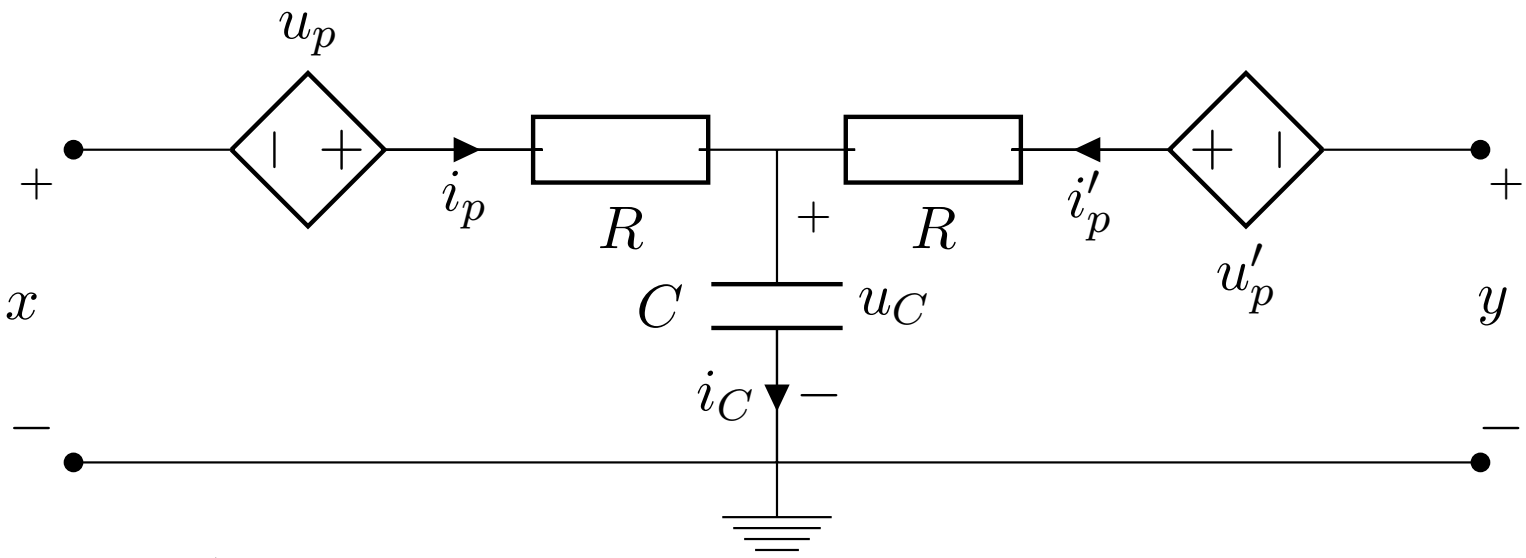
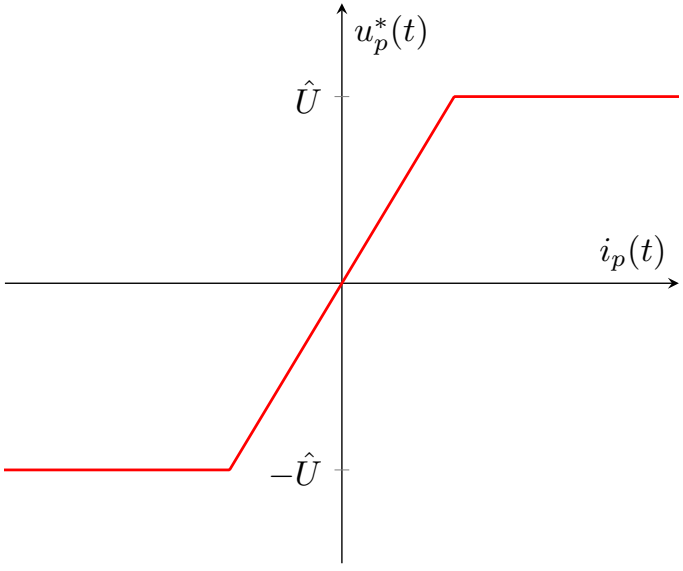




Magnitude of response:

$$u_p^*(t) = \max(\min(\beta \cdot i_p(t), \hat{U}), -\hat{U})$$

Physarum networks

A *Physarum* network is specified by a directed graph $G(V, E)$ where each edge $e = (i, j) \in E$ represents a *Physarum* element with $i, j \in V$. All *Physarum* elements are identical.

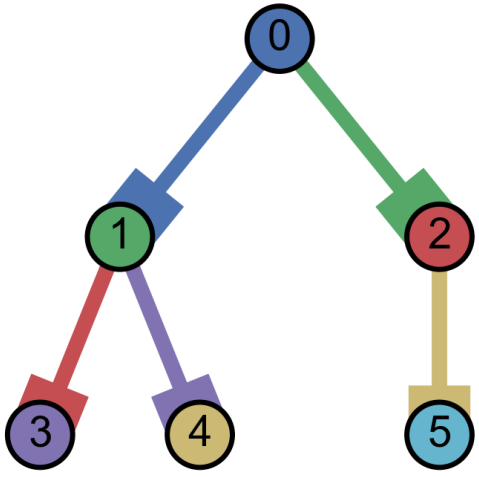
Exploration of *Physarum* networks:

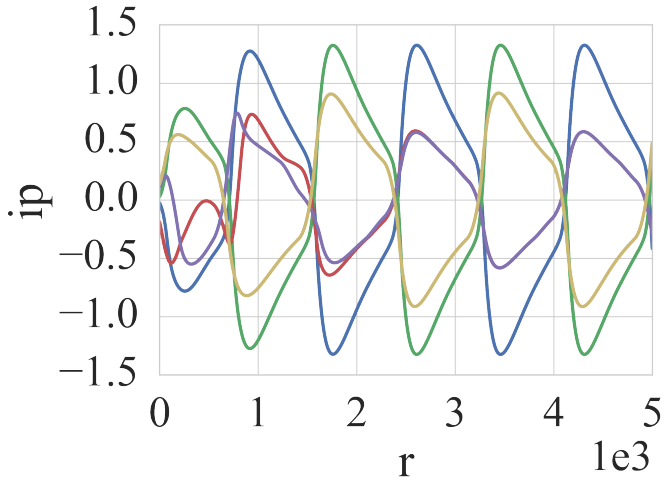
- Continuous version
- Discrete version (Forward-Euler)

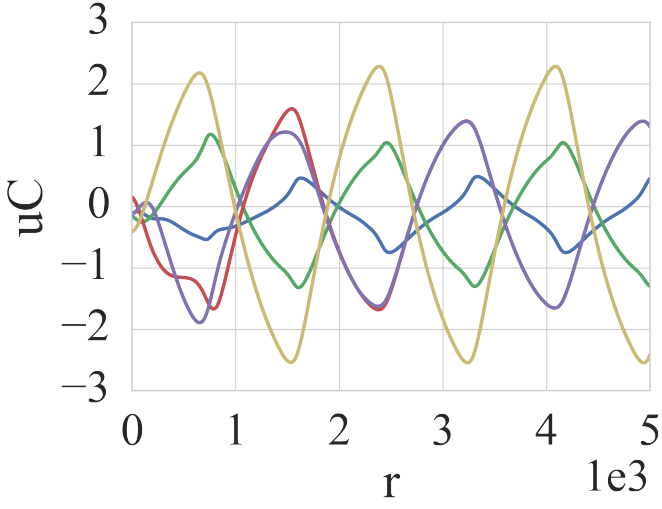
An *execution* of a *Physarum* network is a function that maps each edge in G to a signal $t \mapsto u_C(t)$.

A *Physarum* network G *converges* if for its execution we have that $u_{C,e}$ converges for all $e \in G$. It *dies* if it converges, and for all its edges $e \in G$, $i_{p,e} = 0$.

Example: Synchronisation on a tree

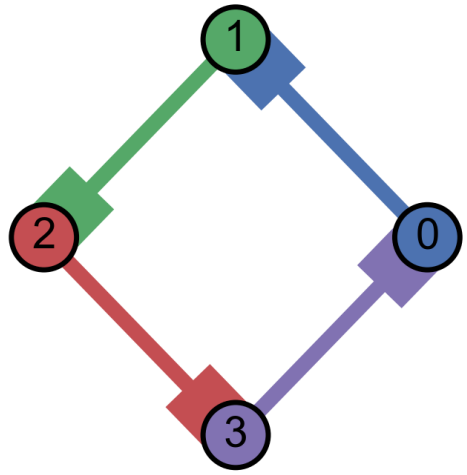


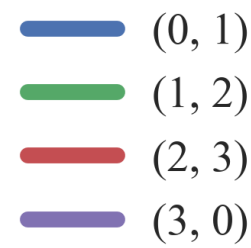


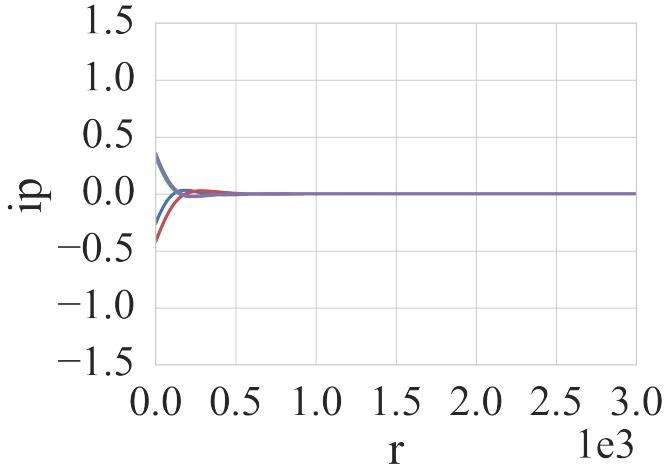


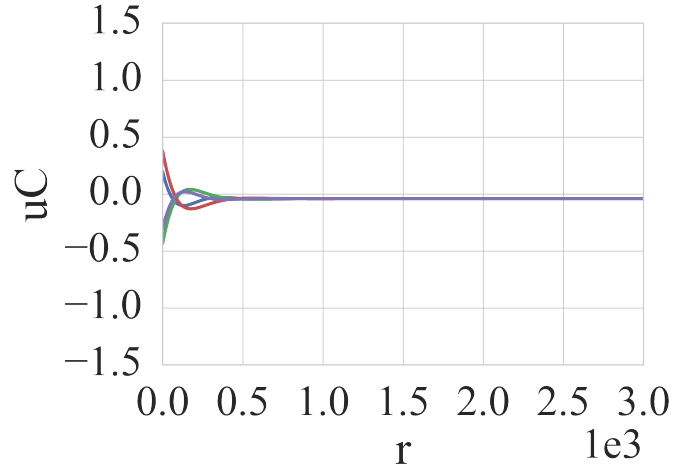
Lemma: If a tree converges it dies.

Example: The death of a cycle



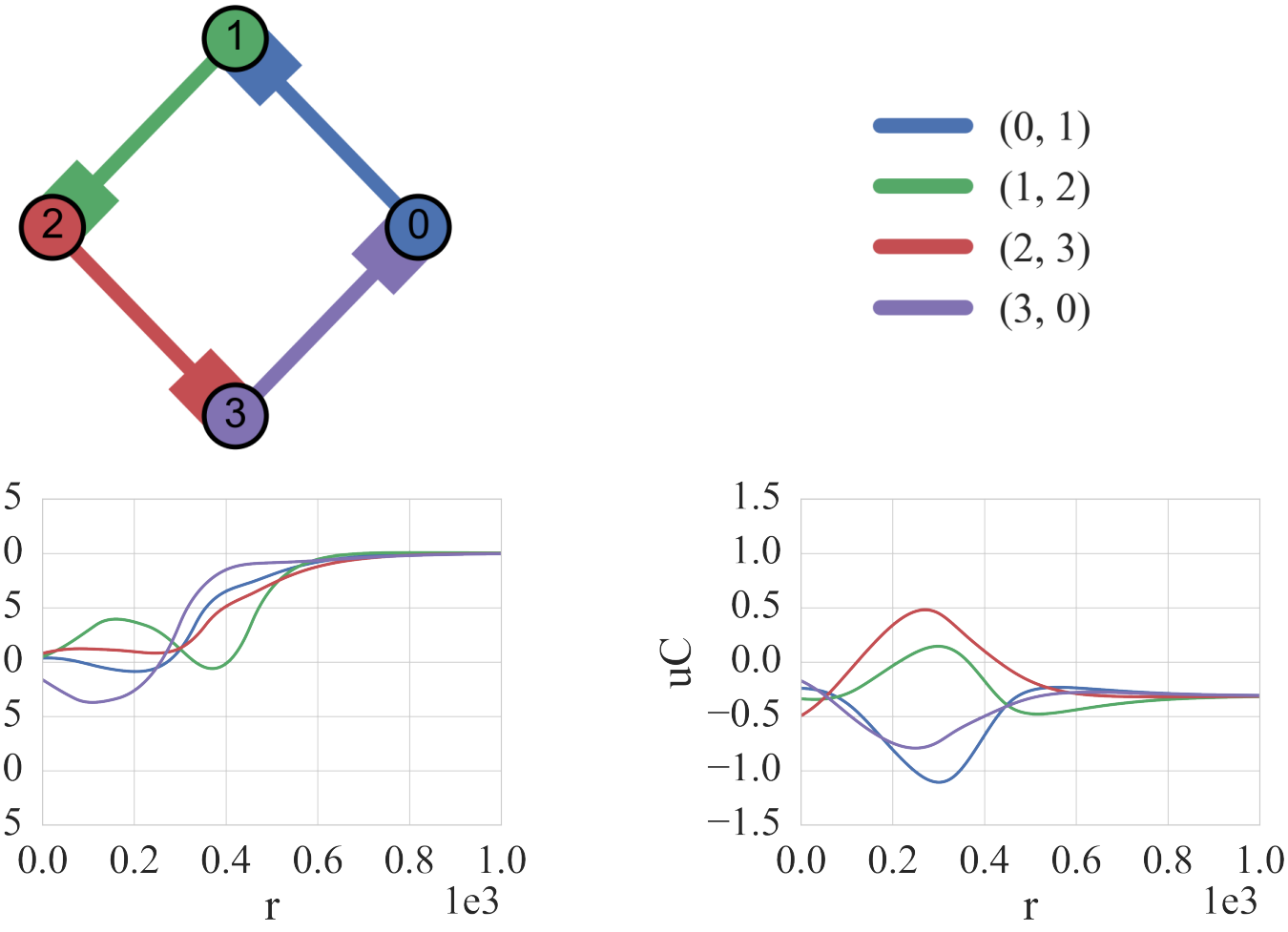






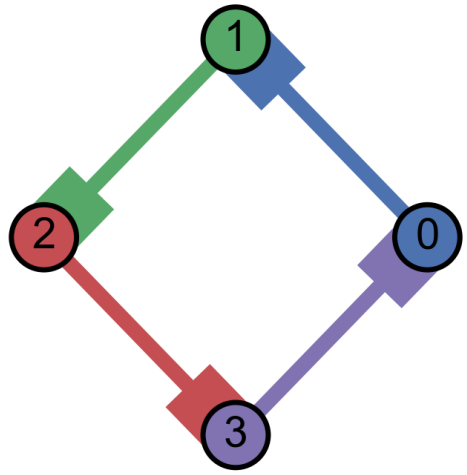
Lemma: If a cycle converges it either a) dies . . .

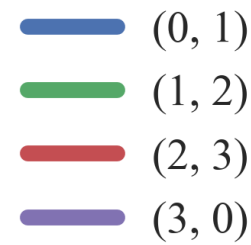
Example: Counter-clockwise flow

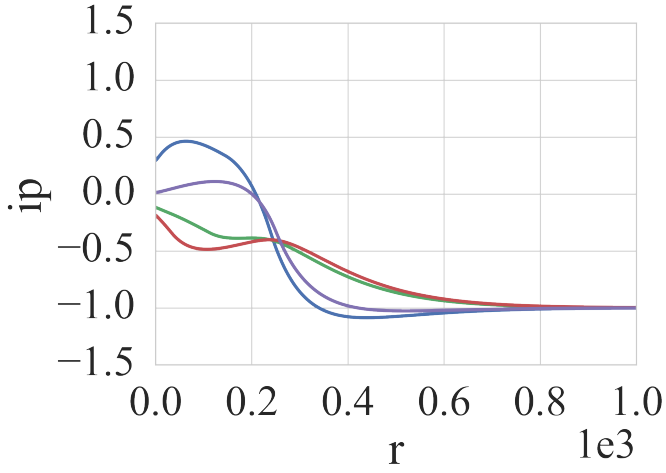


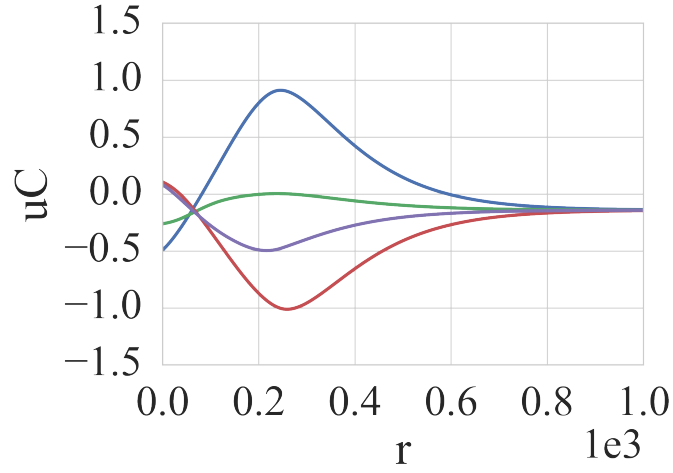
. . . it b) shows constant counter-clockwise flow or . . .

Example: Clockwise flow



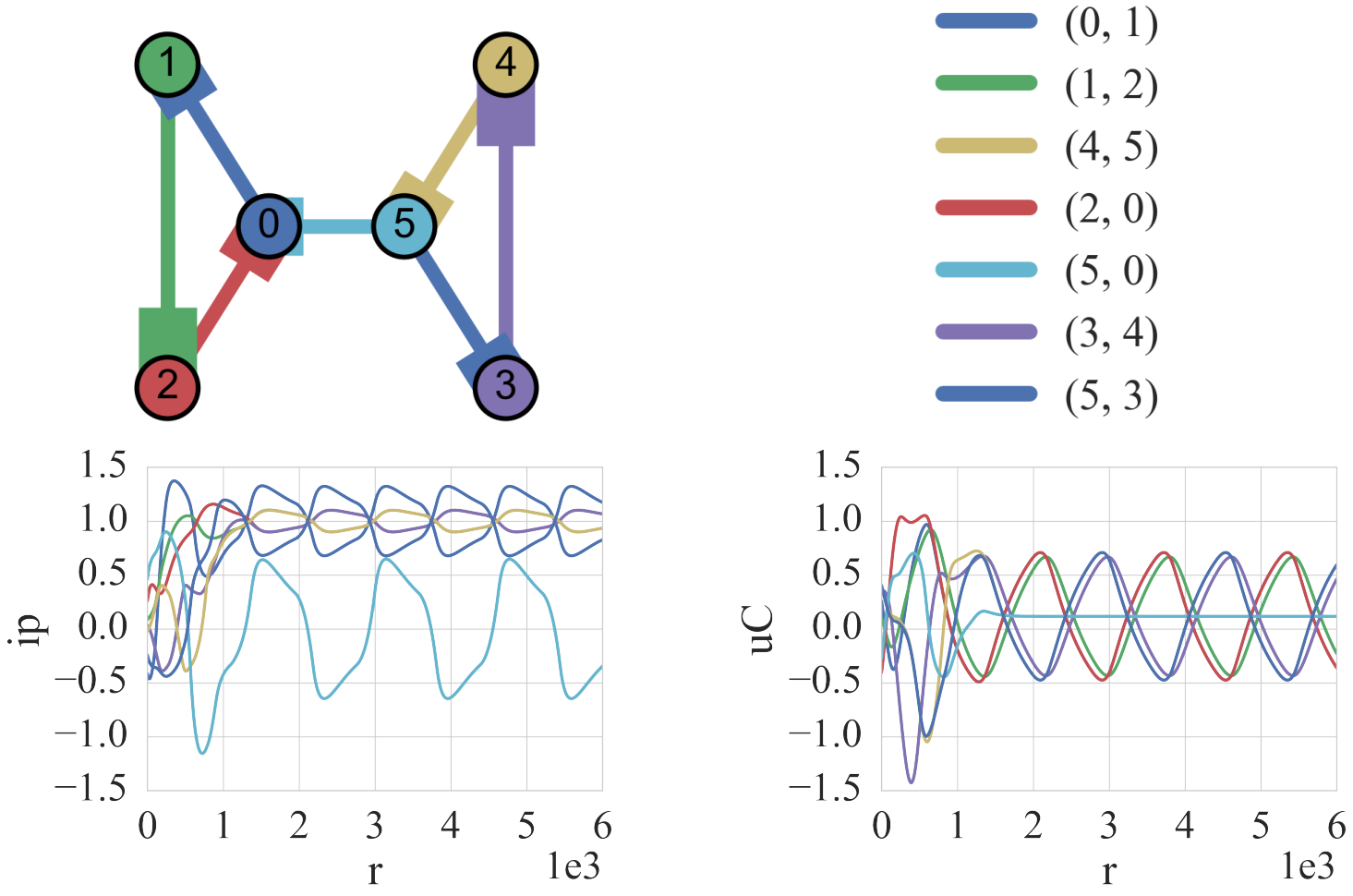






. . . it c) shows constant clockwise flow.

Example: Two coupled cycles



Model behaviour mimics experimental observations of A. Takamatsu et al., 2000.

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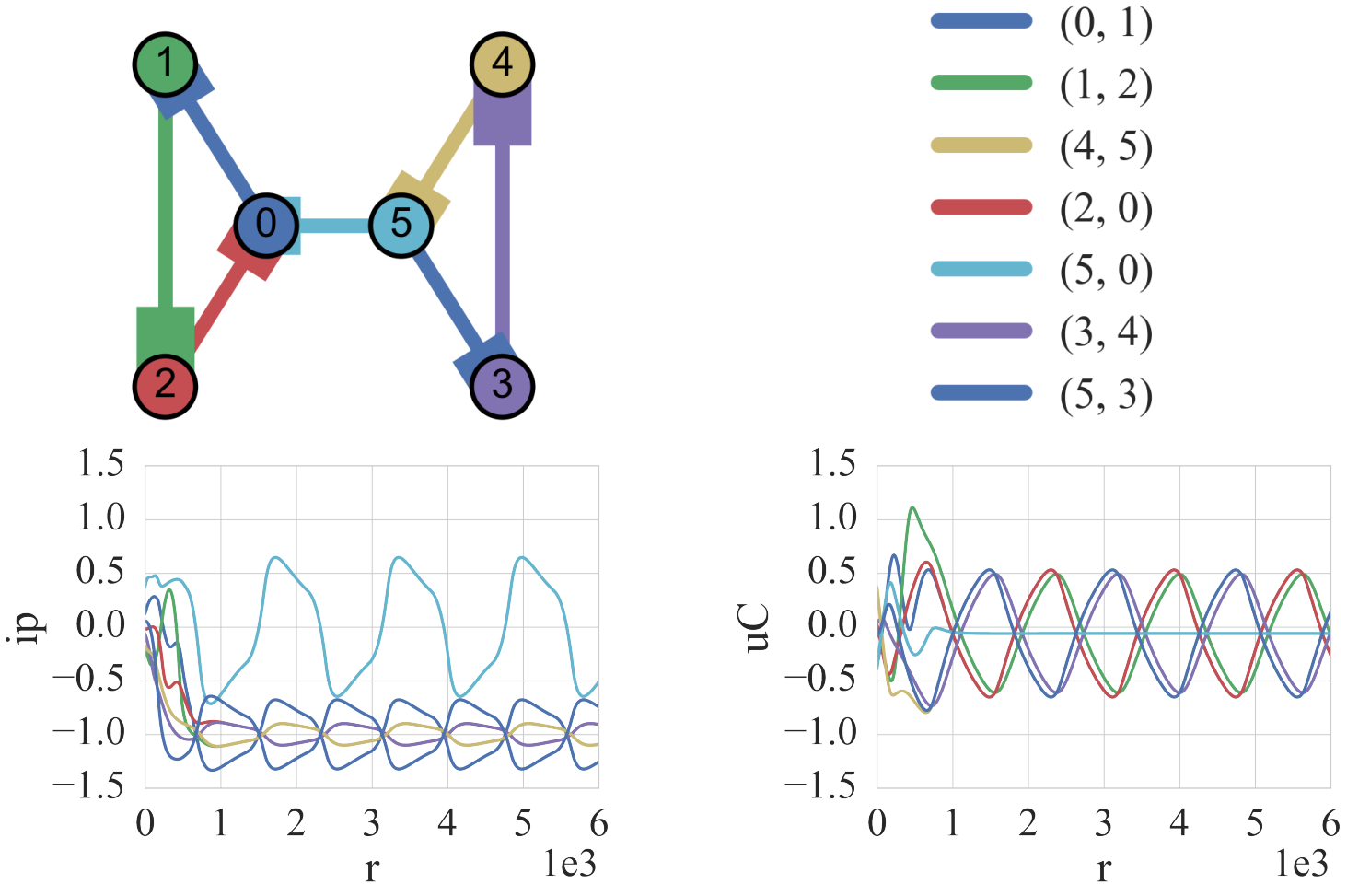

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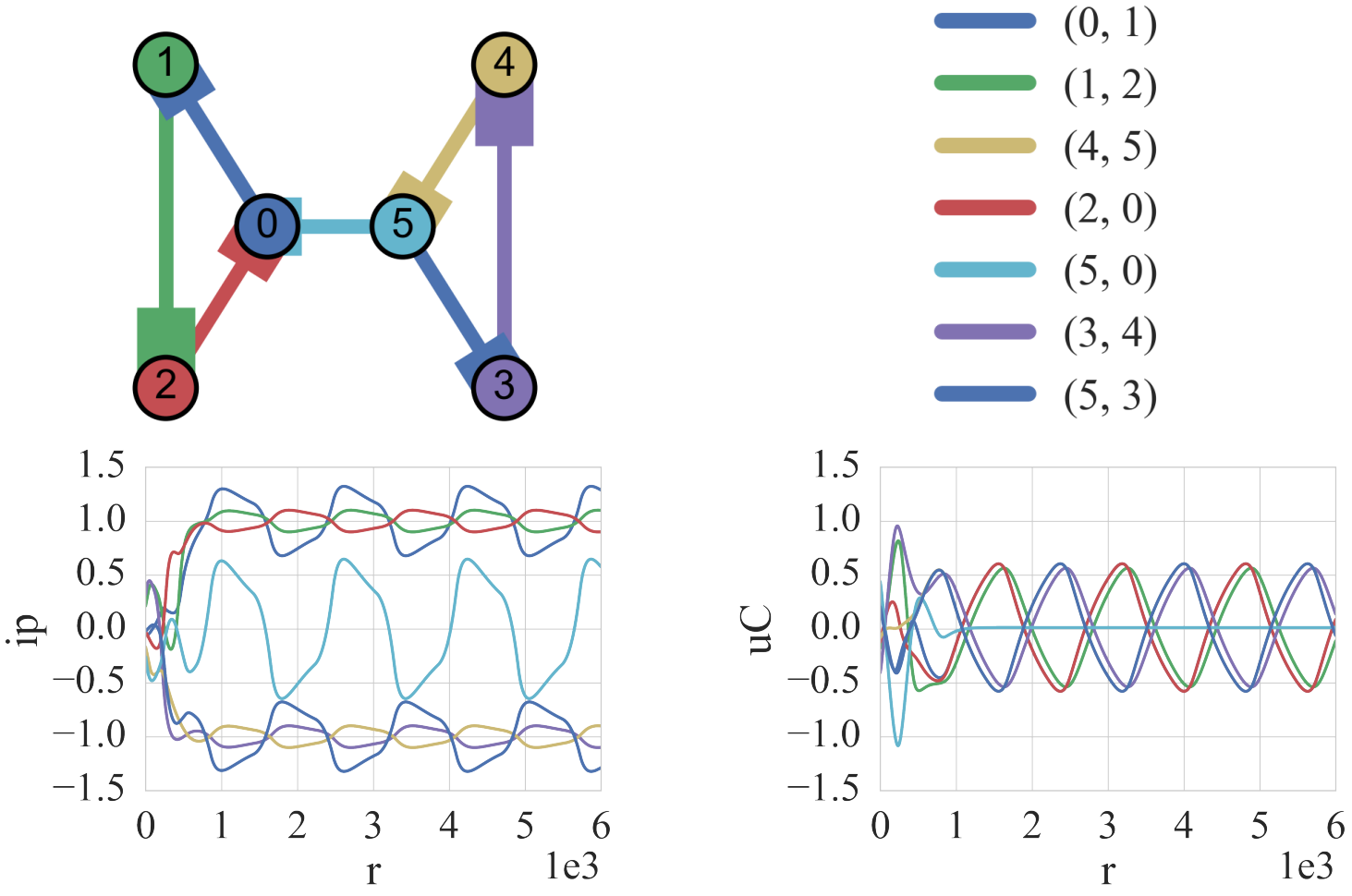

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A model at the cross-roads

Status Quo:

We have obtained a novel distributed, robust model that mimics the flow dynamics of *P. polycephalum*!

How to proceed?

- Try to use the flow reversals exhibited in the model in the context of link reversal algorithms (M. Függer, M. Grube).
- Try to improve the realism of the model to obtain a more physical description.

Both approaches are worthwhile and require specialist input.

Summary

- Illustrated how the distributed nature of *Physarum polycephalum* renders it a promising candidate for Natural Computing.
- Presented our efforts to better understand the networks formed by the organism.
- Sketched our modelling attempts and demonstrated the validity of the approach.
- Briefly discussed possible avenues for future developments.