

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

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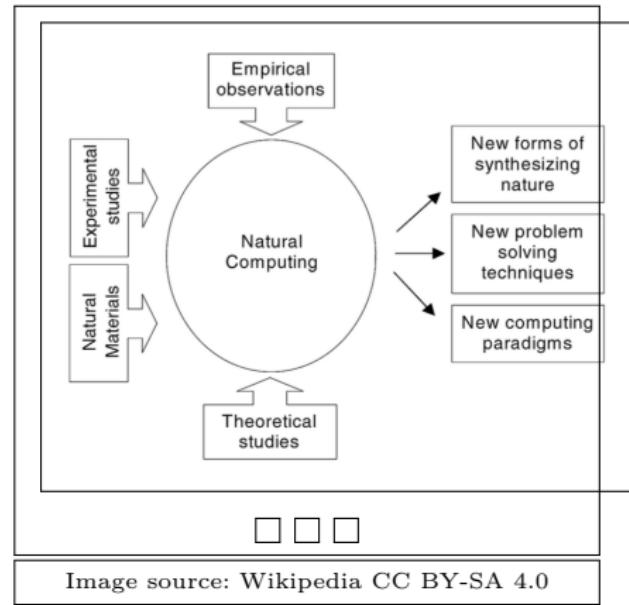
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# Part I: Natural Computing with *P. polycephalum*

# Natural Computing in a Nutshell

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



Natural Computing is a highly interdisciplinary field!

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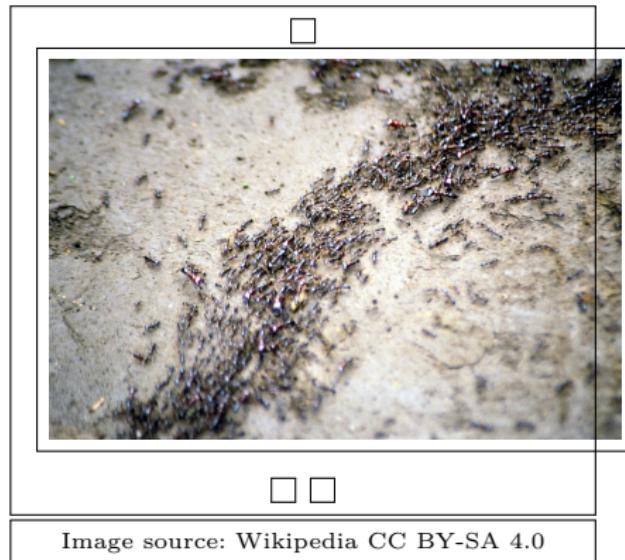
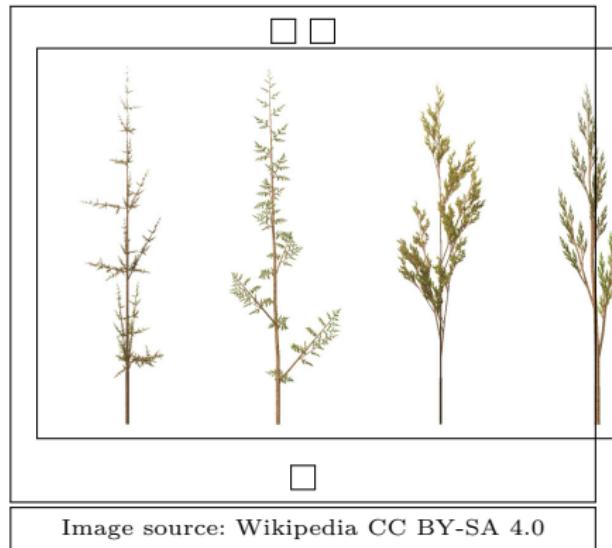


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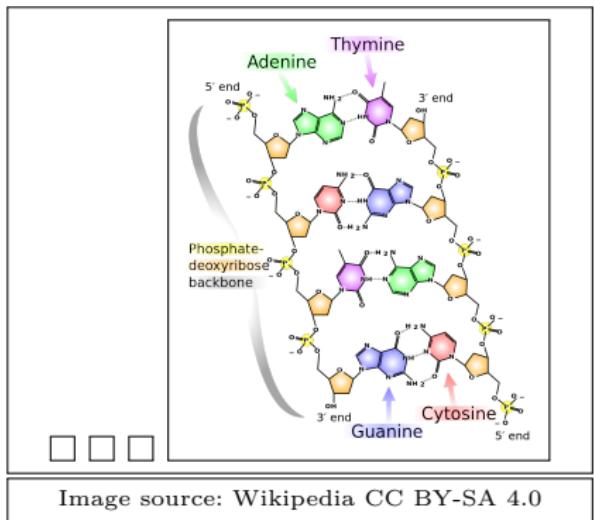


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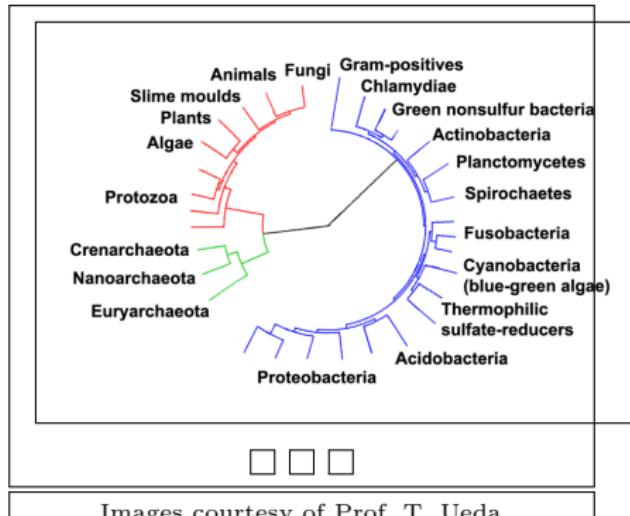
# Meet a Magnificent Mold

## *Physarum Polycephalum*:

- ▶ Unicellular organism with many nuclei.
- ▶ Intricate foraging strategy.
- ▶ Networks distribute protoplasm.

## Key Experiments show:

Distributed operation, Minimisation/Maximitation capabilities



Images courtesy of Prof. T. Ueda.

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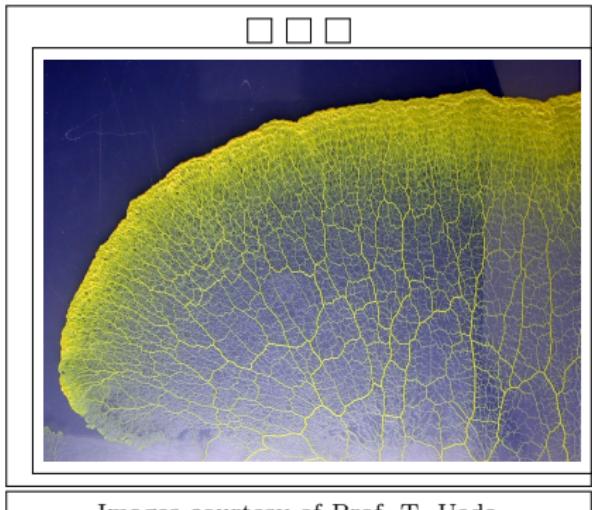
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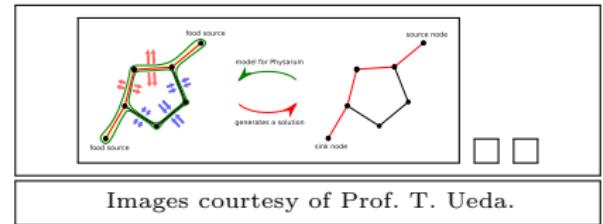


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# Natural Computing with *P. polycephalum*

## Succes stories

- ▶ Positive feedback models
- ▶ Many particle simulations/cellular automata
- ▶ Steering *P. polycephalum* using light



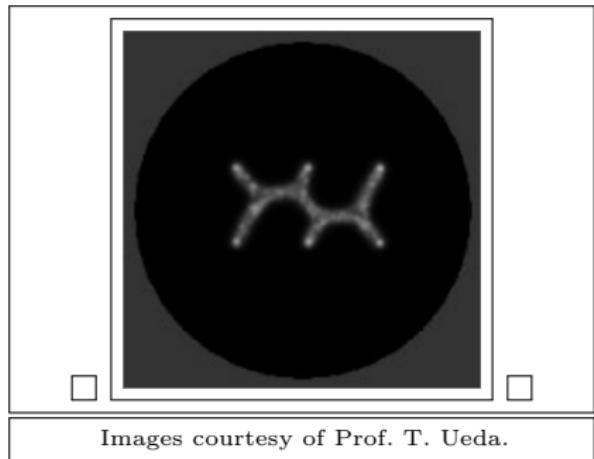
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Distributed nature of *P. polycephalum* has not been investigated in the context of Natural Computing.

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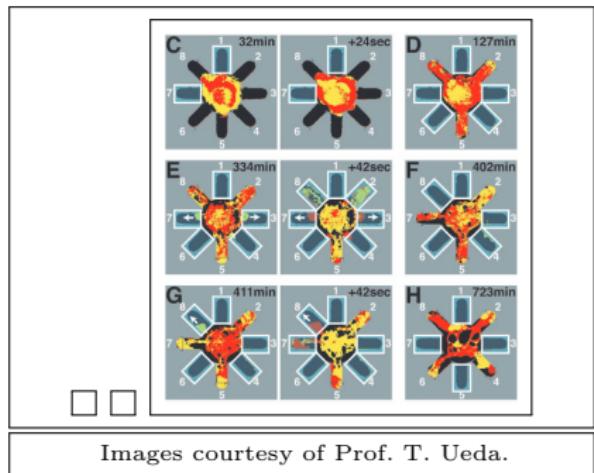
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# Towards distributed Natural Computing with *P. polycephalum*

Our aim:

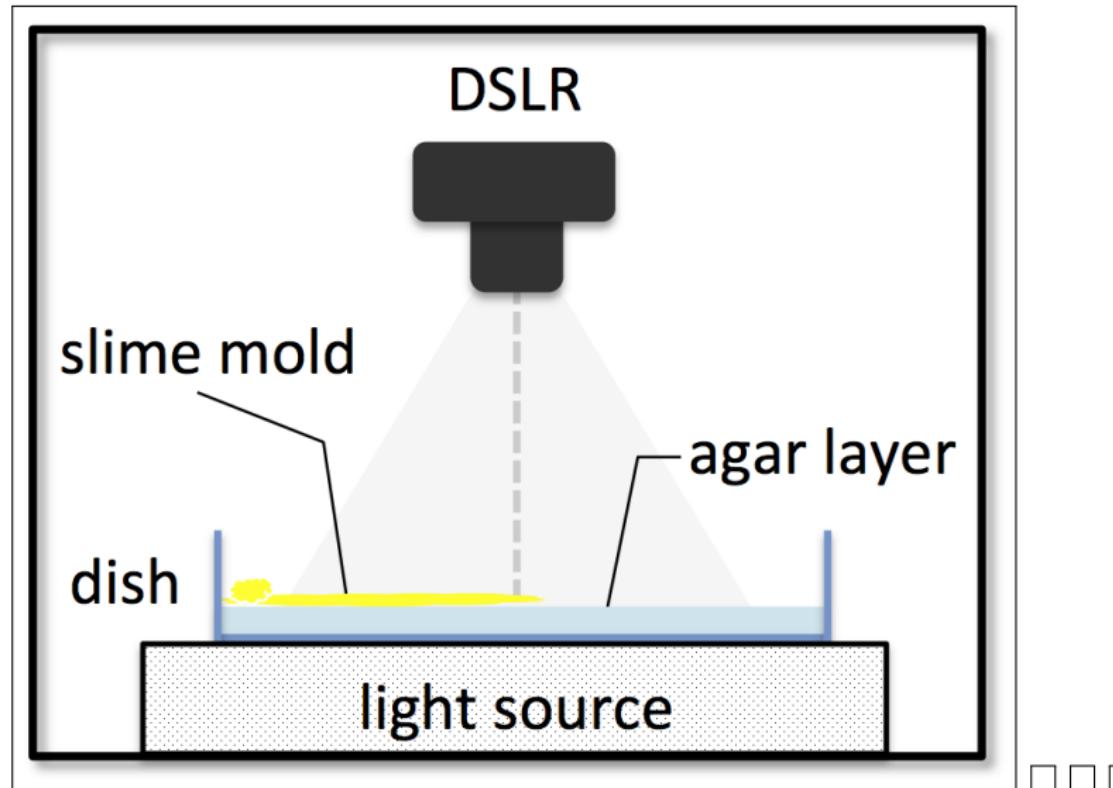
Study the networks formed by *P. polycephalum* in order to drive the development of a distributed model.

Our approach:

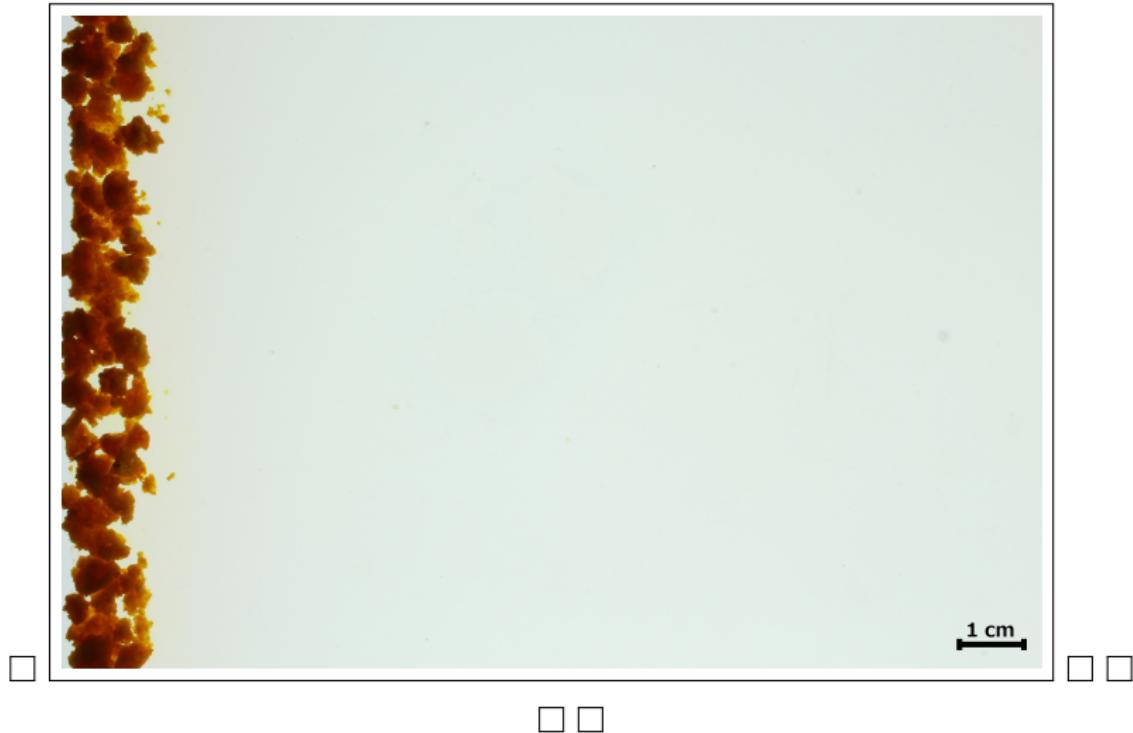
- ▶ Obtain a large body of experimental data
- ▶ Process raw experimental data
- ▶ Analyze network properties
- ▶ Model the dynamics exhibited by *P. polycephalum*

## Part II: Studying the networks formed by *P. polycephalum*

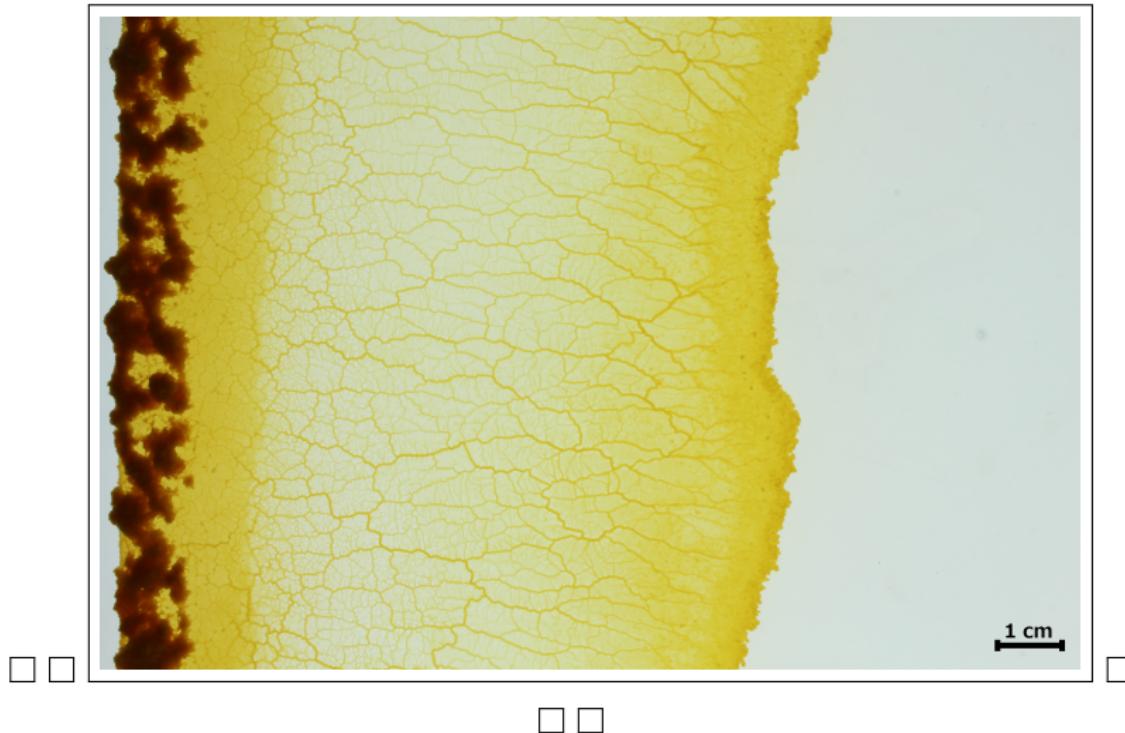
# Experiments



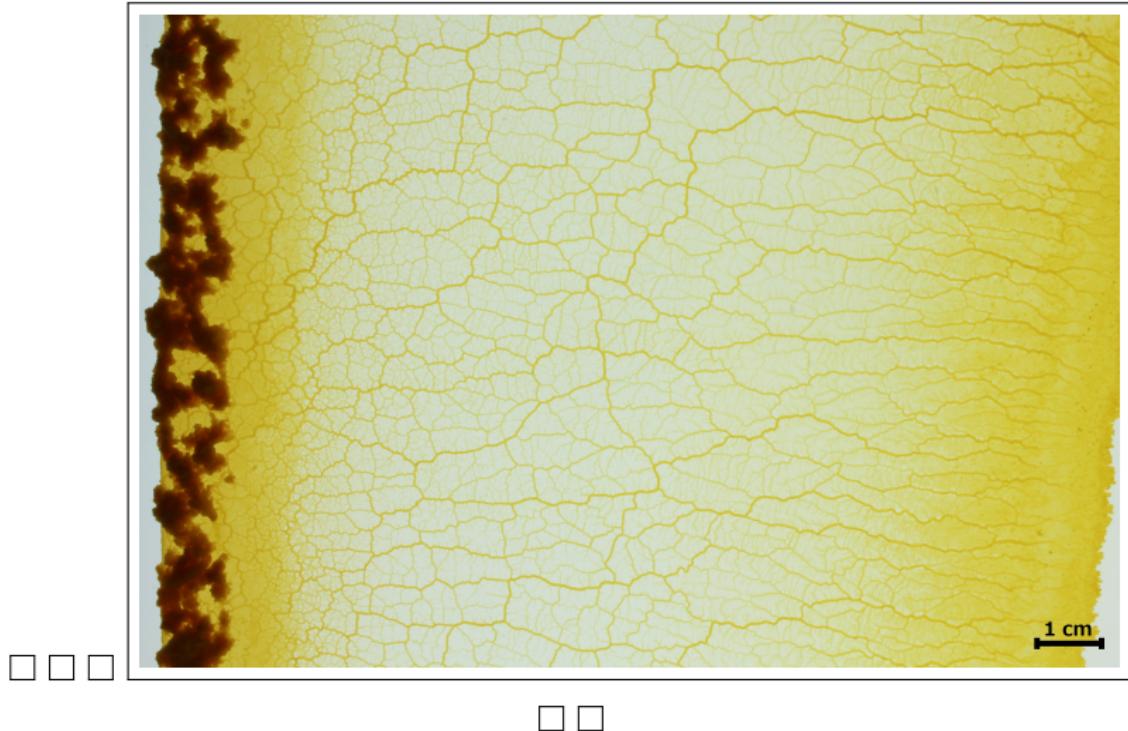
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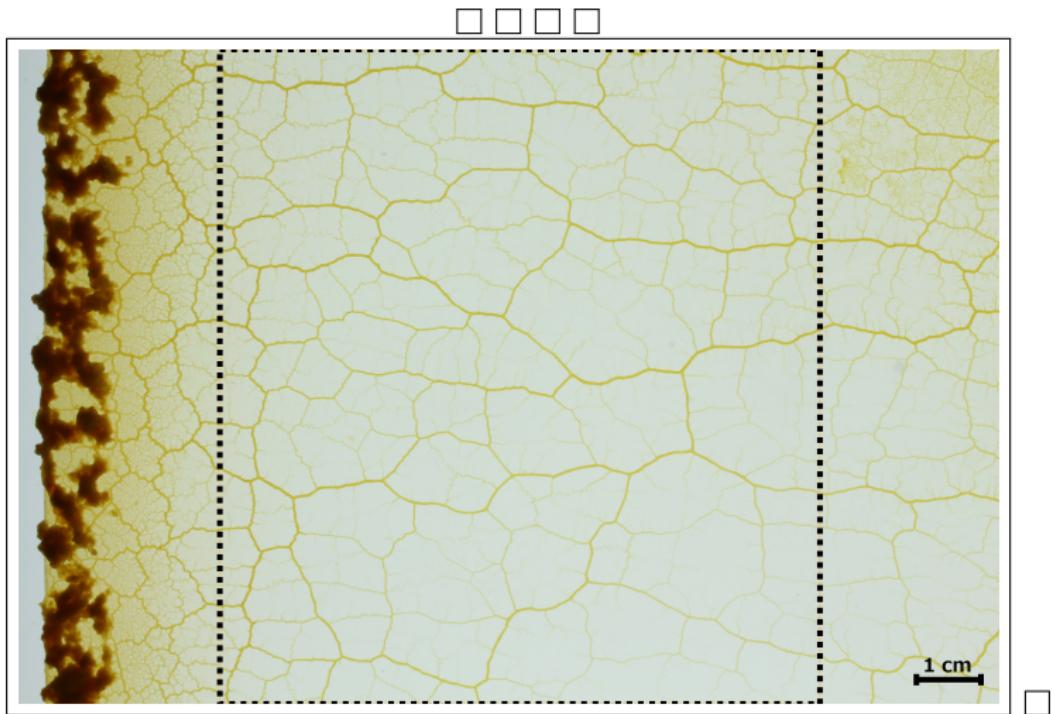
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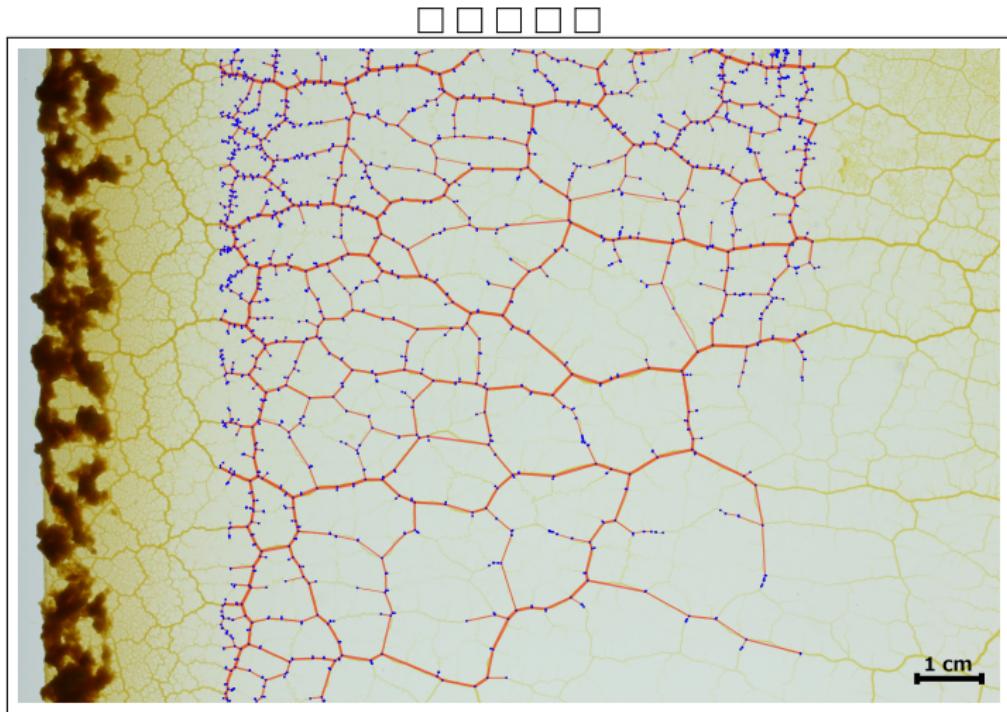
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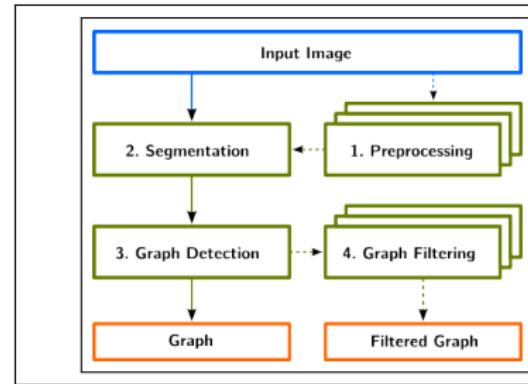
# Experiments



# Network Extraction From Images

## NEFI:

- ▶ Input: High quality image of a network
- ▶ Output: Graph representation of depicted structure



## Design goals:

- ▶ Combine well-known algorithms from Computer Vision, Image Processing and Graph Theory to obtain a new modular tool.
- ▶ Make it such that non-experts can use it.

# Analysis of *P. polycephalum* networks

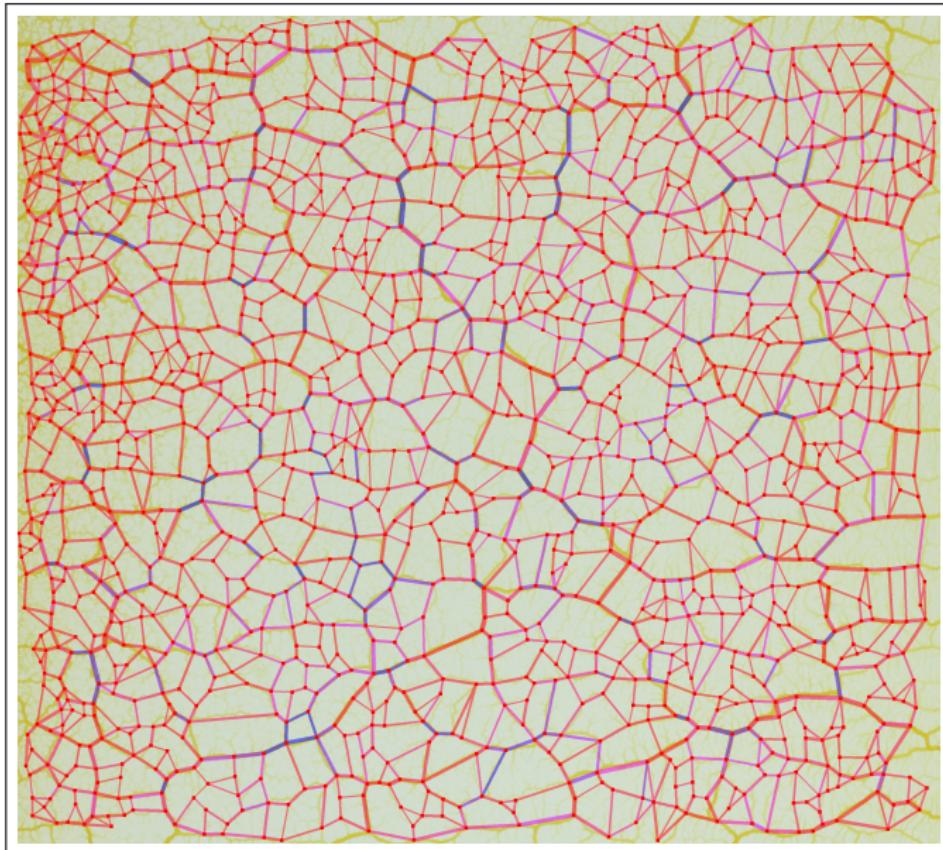
Dataset: Ca. 38 time series of graphs. A total of 1998 weighted cubic planar graphs.

Goal: Obtain a catalogue of Observables that describes various aspects of *P. polycephalum* networks.

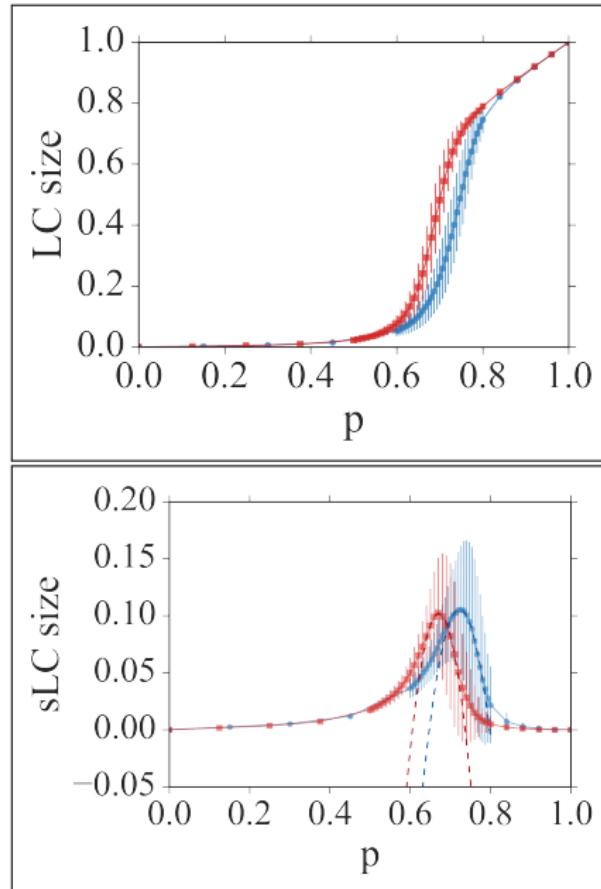
## Key components:

- ▶ Distributions of observables and their time development.
- ▶ Examples: Edge lengths/widths, Face area/circumference and various other properties

# Robustness of *P. polycephalum* networks



# Robustness of *P. polycephalum* networks



# SMGR: Sharing is caring

## Slime Mold Graph Repository:

Collects raw experimental data, graphs, results and useful tools

## Motivation:

- ▶ Facilitates exchange and reuse of data
- ▶ Makes data available to everyone

Important Use Case: Guiding and evaluating various modelling attempts.

## Part III: A distributed model of *P. polycephalum*

# What we know about *P. polycephalum*

## Desireable 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*

## Desireable properties:

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

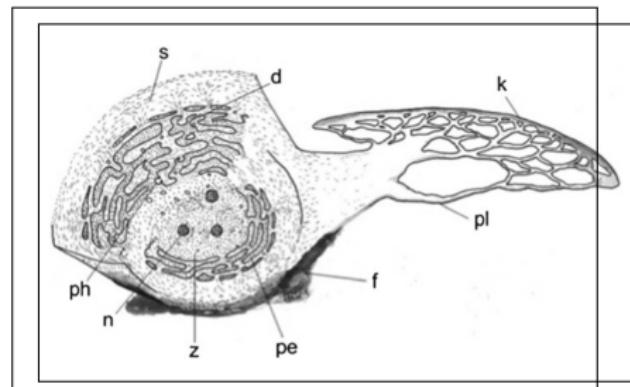
# Modelling the dynamics of *P. polycephalum*

The goal: Model the peristalsis that is central to all flow dynamics of *P. polycephalum*.

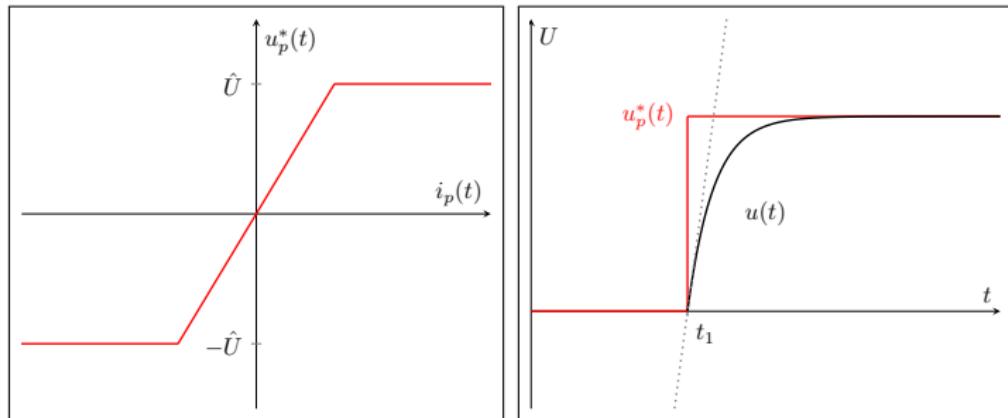
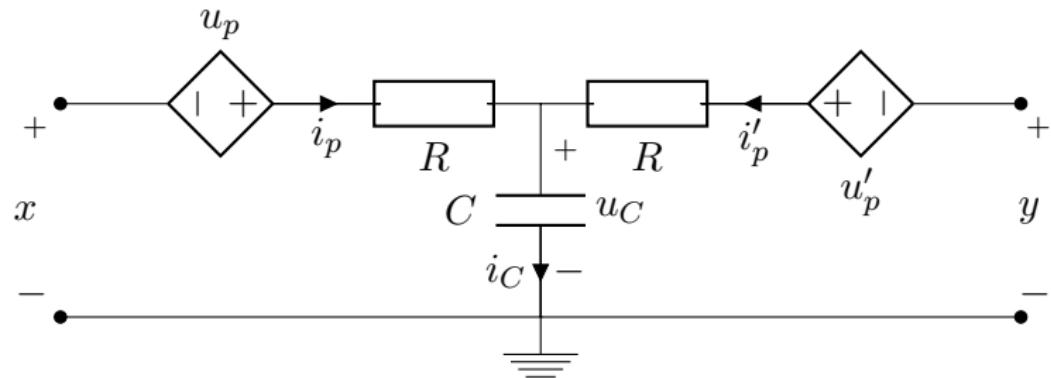
The problem: Hydrodynamics is extremely hard!

*Solution: Go electric!*

- ▶ Augmented 3-element Windkessel model
- ▶ Peristaltic pumping is mapped to current controlled voltage sources
- ▶ Oscillatory dynamics mimics real flow patterns



# Modelling vein segments - *Physarum* elements



## *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.

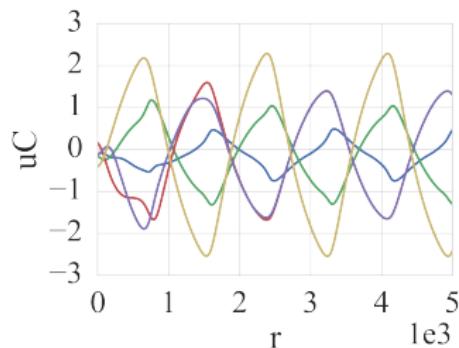
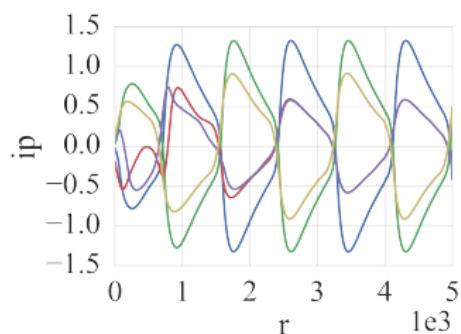
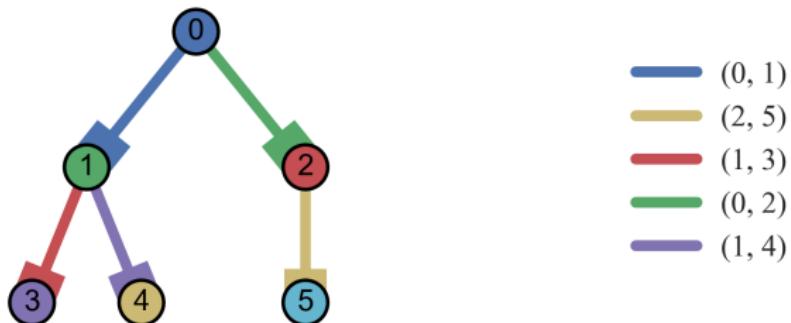
Exploration of *Physarum* networks:

- ▶ Continuous version
- ▶ Discrete version (Forward-Euler)

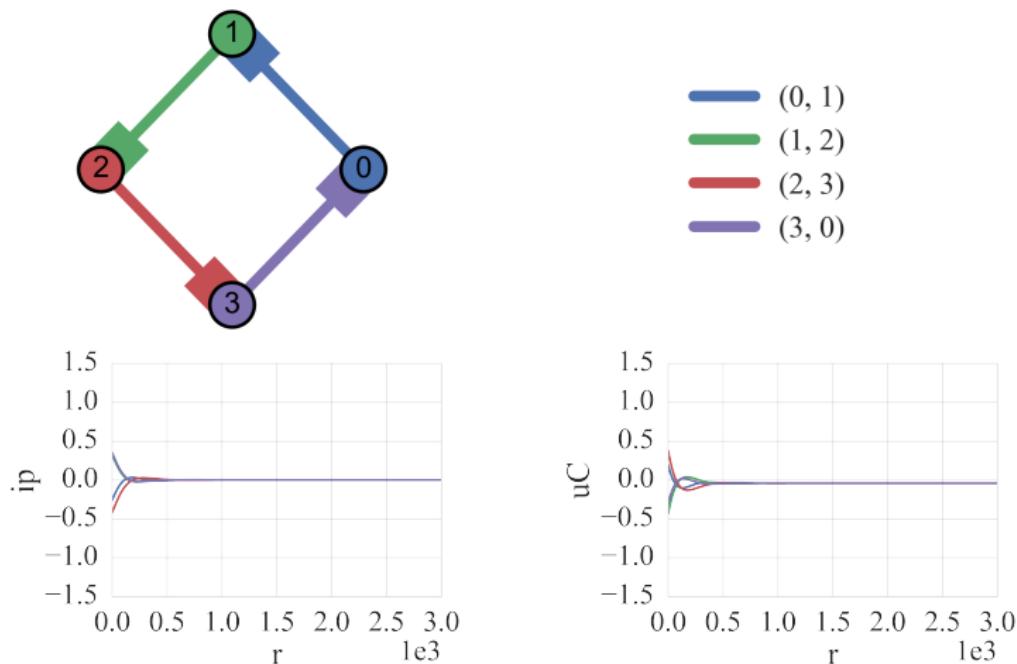
An *execution* of a *Physarum* network is a function that maps each edge in  $G$  to a signal  $t \mapsto u_C(t)$ .

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  $e \in G$ ,  $i_{p,e} = 0$ .

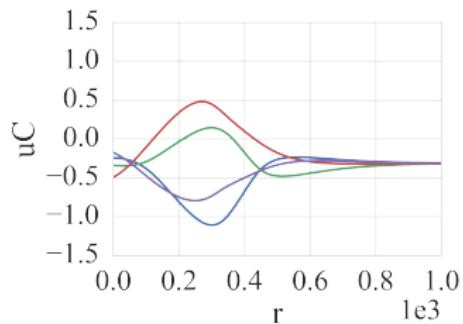
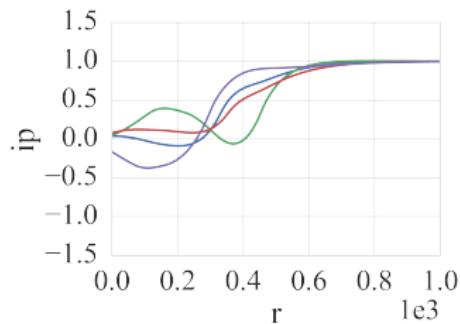
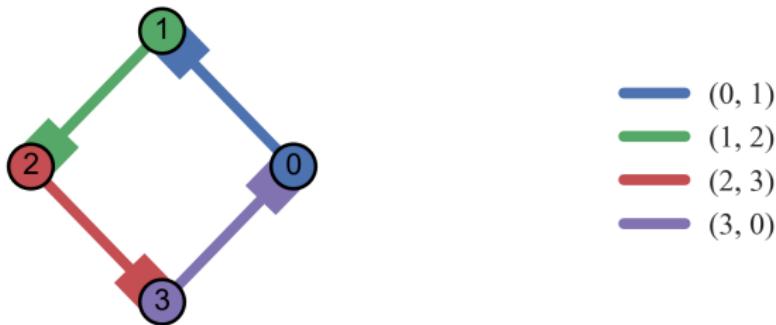
# Example network: A small oscillating tree



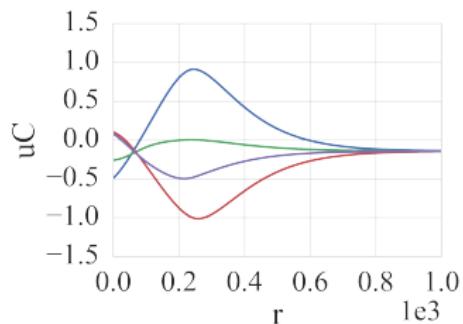
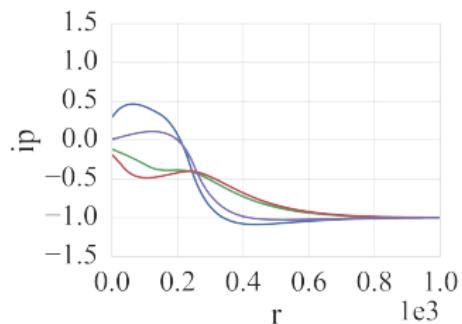
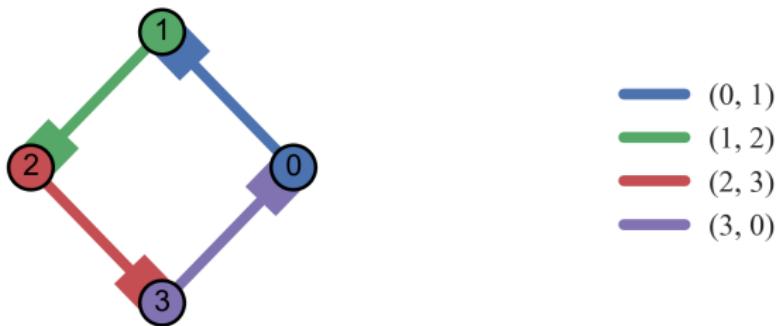
# Example network: The death of a cycle



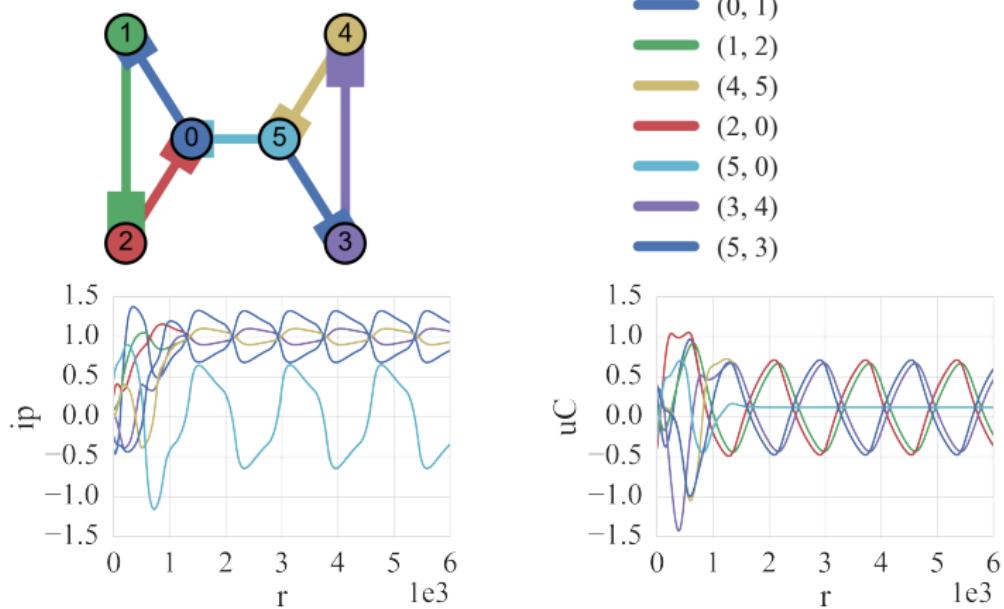
## Example network: Counter-clockwise flow



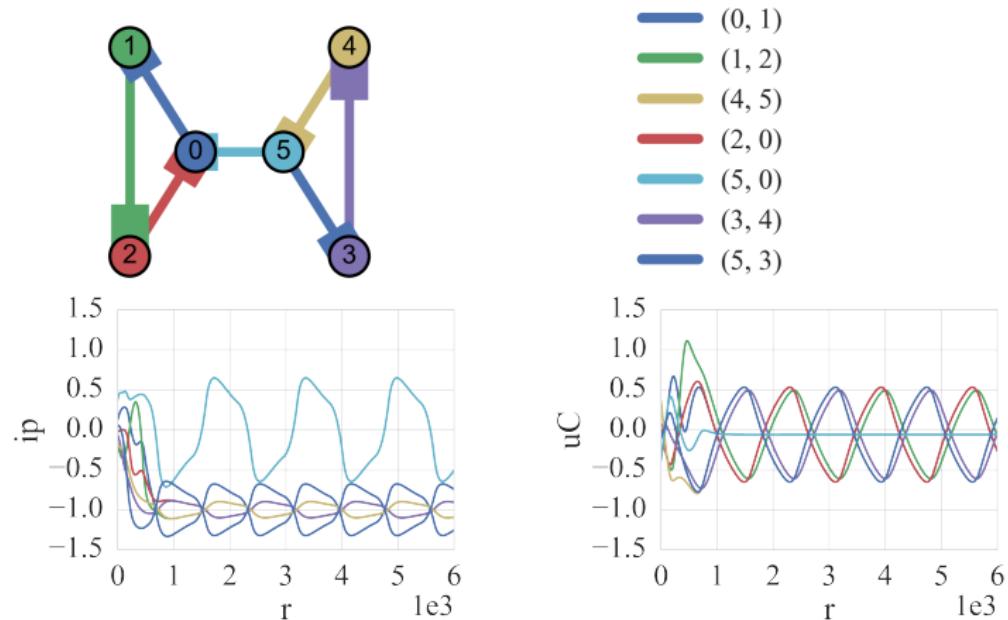
## Example network: Clockwise flow



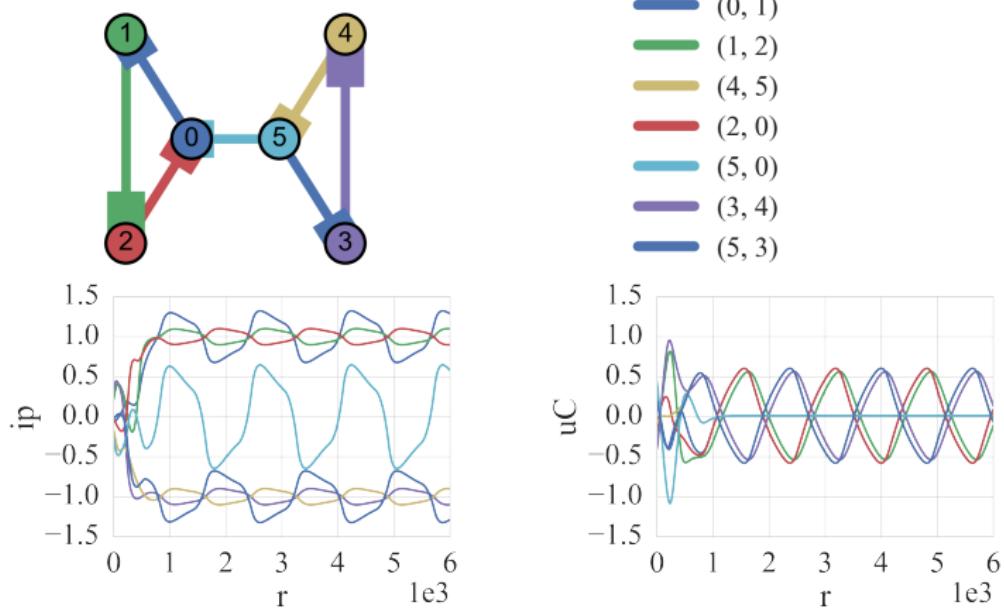
## Example: Two coupled cycles



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# A model at the cross-roads

We have obtained a 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* is a promising candidate for Natural Computing.
- ▶ Presented our approach to better understand the organism.
- ▶ Quick peak of our results regarding network analysis
- ▶ Sketched our modelling attempts and demonstrated the validity of the approach.
- ▶ Showed possible avenues for future developments.