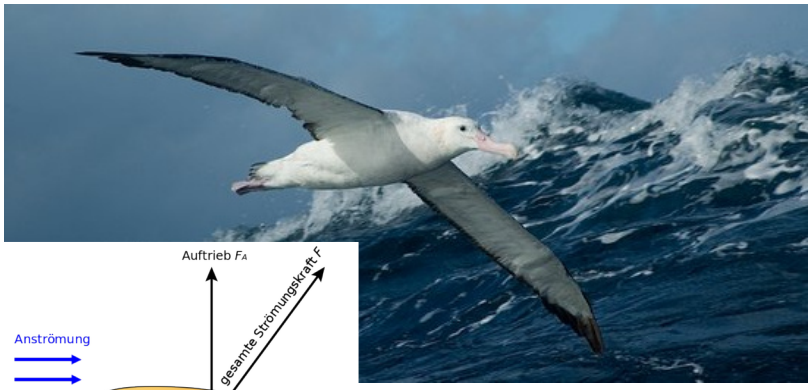
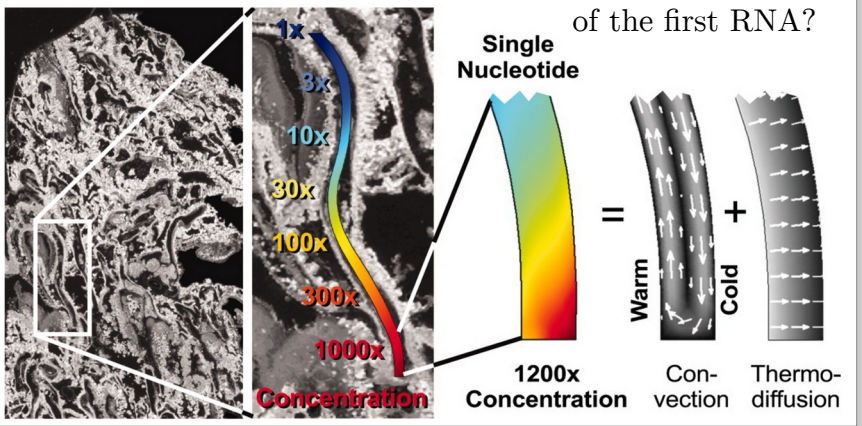
Ausbildungsseminar
Sommersemester 2023

Physik der lebendigen Welt / Physics of Life*



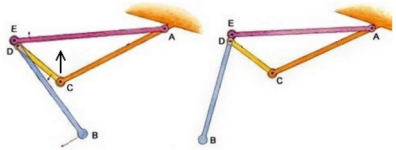
Aerodynamics: wing profiles, flight stability

Thermodynamics: thermal cycles in rock pores, increasing the concentration of nucleotides → origin of the first RNA?

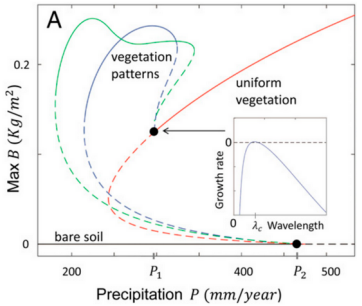


Eckdaten: 4 ECTS für regelmäßige Teilnahme und eigenen Vortrag (35-45 min), weitere 2 ECTS wenn Sie zusätzlich eine schriftliche Ausarbeitung anfertigen.
Veranstaltungsnummer: 52312S
Ab 4. Semester, jüngere Semester nach Rücksprache

joerg.mertins@ur.de,
magdalena.marganska@ur.de



Optics and mechanics: the mantis shrimp has eyes which detect even the polarization of light, and its claws are built so that the little animal can punch through glass.



Population dynamics: fairy circle patterns in arid grass countries

1. Choose the date for your presentation

2. Choose your topic

3. A week or two before the presentation: arrange a time for discussing your presentation with us. We'll give you feedback on the structure and scientific content of the presentation, but also about its reception by the audience.

4. Finalize your presentation

5. Give the talk

6. Write up your talk in the form of a report/essay/popular science article.

Guidelines: at least 4 pages of text alone, 1200 characters per page.
Bibliography and images are necessary, but don't enter the page count.

Topics in the Physics of Life

Structure

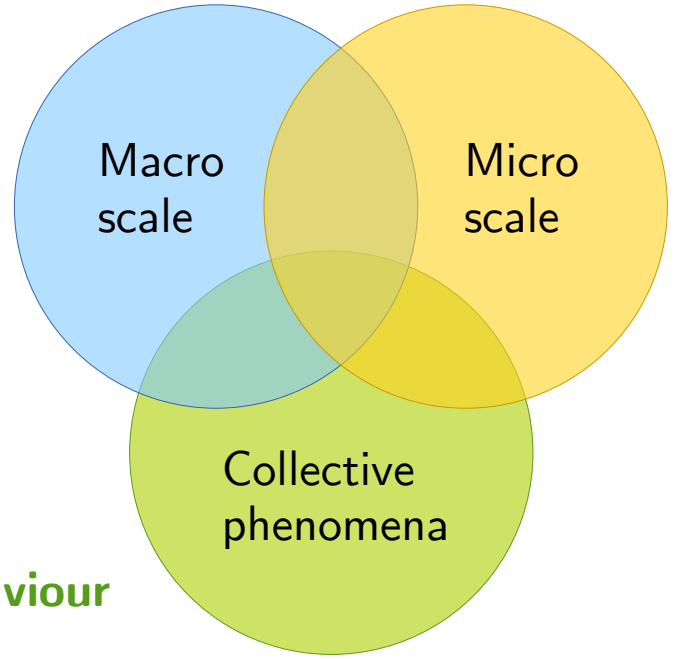
Locomotion

Sensing

Powering up

Intracellular transport

Membranes



Collective behaviour

Communication

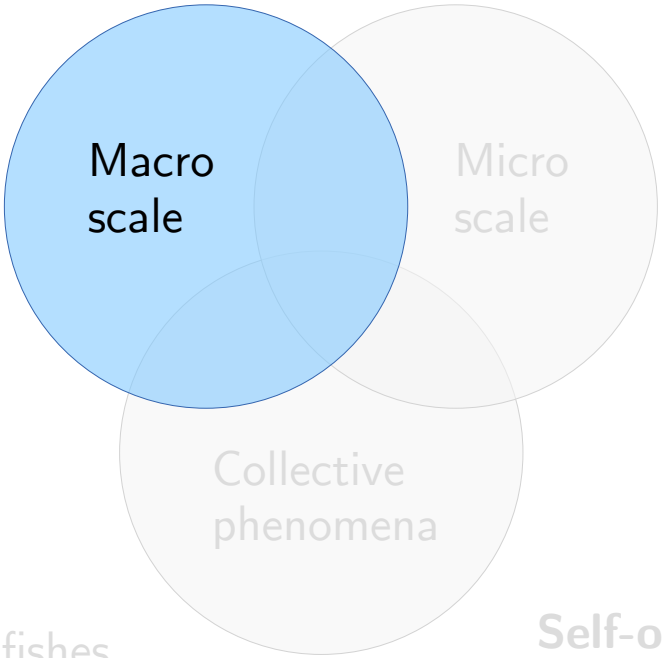
Self-organization

Topics in the Physics of Life

Structure
- mechanics of the skeleton
- mechanics of the muscles
- structure of the bone/shell material

Locomotion
- aerodynamics of flight
- swimming: macro and microscale
- adhesive motion (snails, cells)

Sensing
- vision (ultraviolet, polarized)
- mechanoreception (hearing, touch)
- gravity sensing
- chemical sensing (smell, taste)



Powering up
- different metabolic pathways
- fermentation vs respiration
- proton gradients

Intracellular transport
- molecular motors
- Brownian ratchets

Membranes
- organization and properties

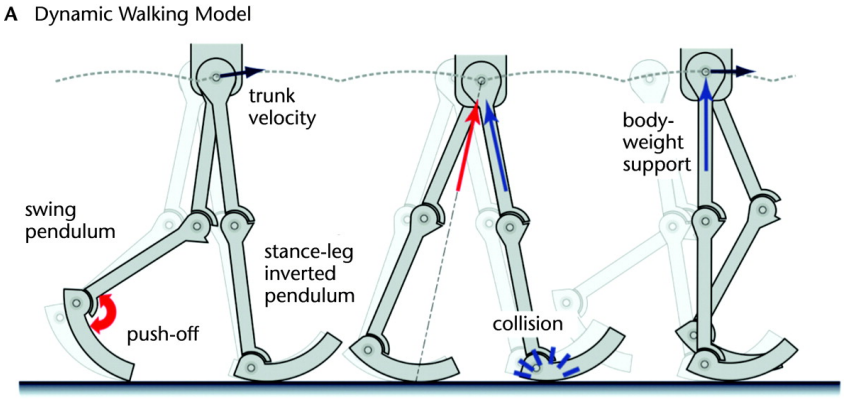
Collective behaviour
- flocks of birds, shoals of fishes
- growth of bacterial colonies

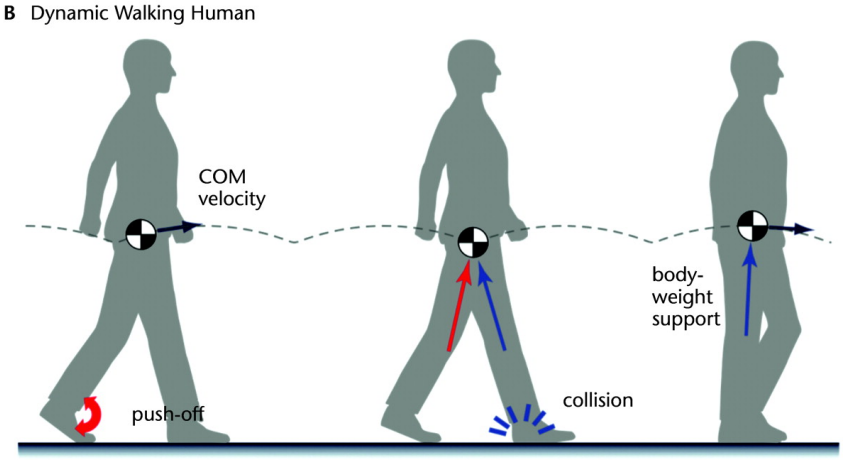
Communication
- quorum sensing
- internal communication: neural networks

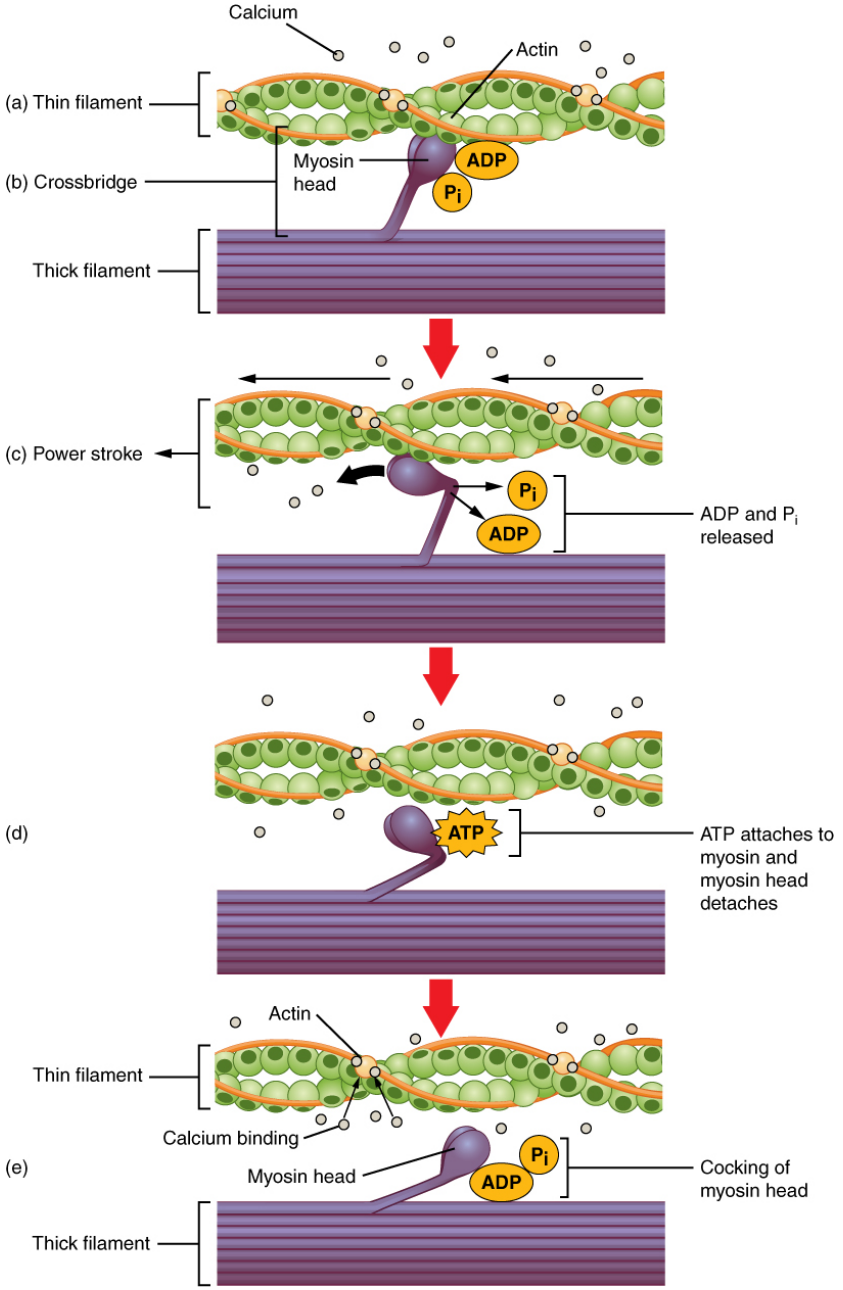
Self-organization
- cell division and embryo growth
- population dynamics
- transport networks
- origins of life

Structure

- **mechanics of the skeleton**
- **mechanics of the muscles**
- structure of the bone/shell material

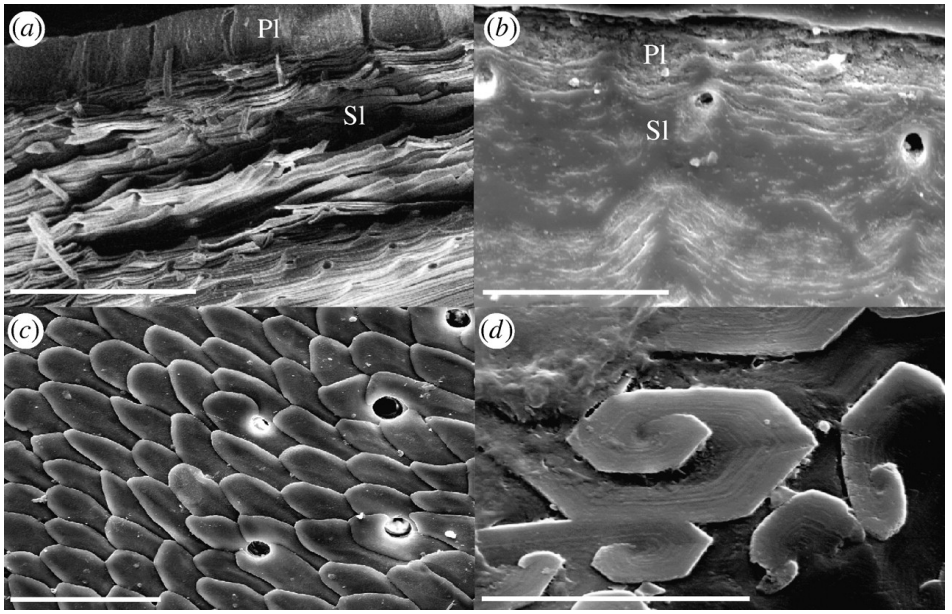


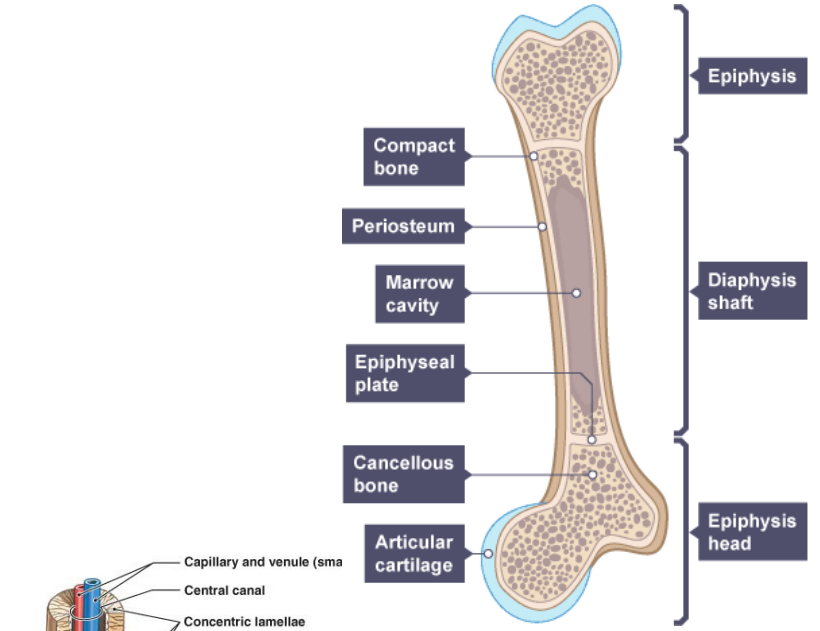


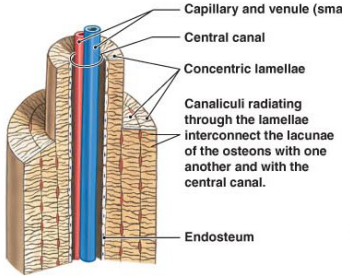


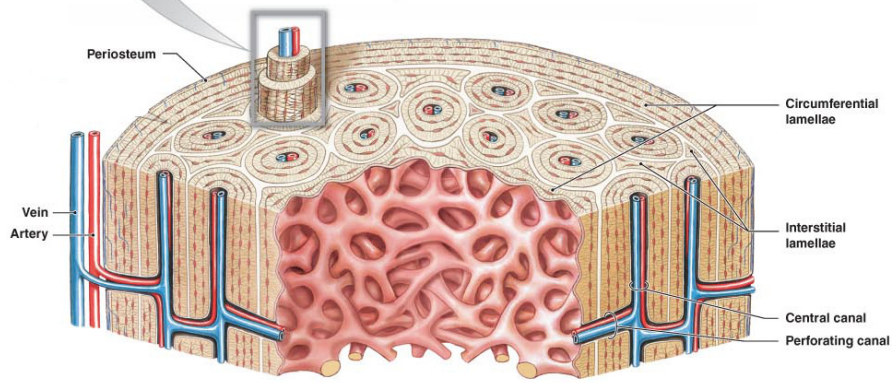
Structure

- mechanics of the skeleton
- mechanics of the muscles
- **structure of the bone/shell material**



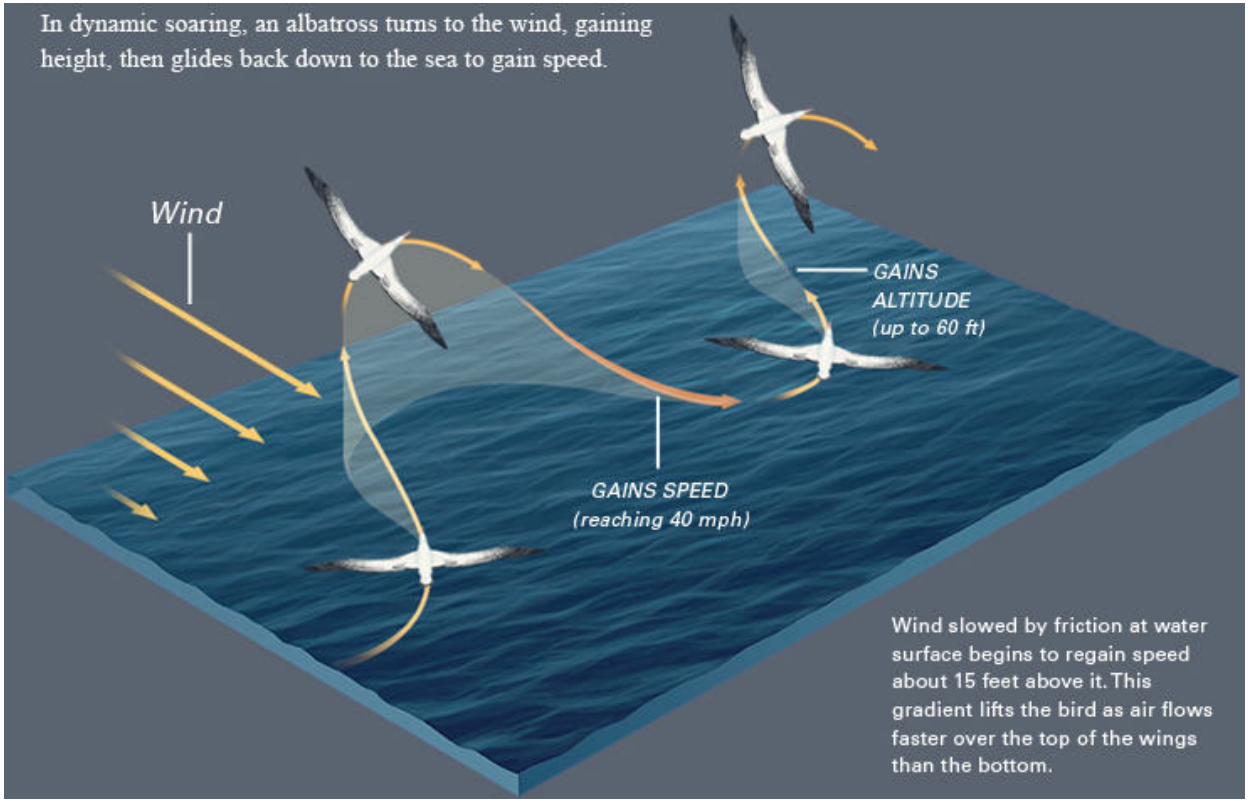


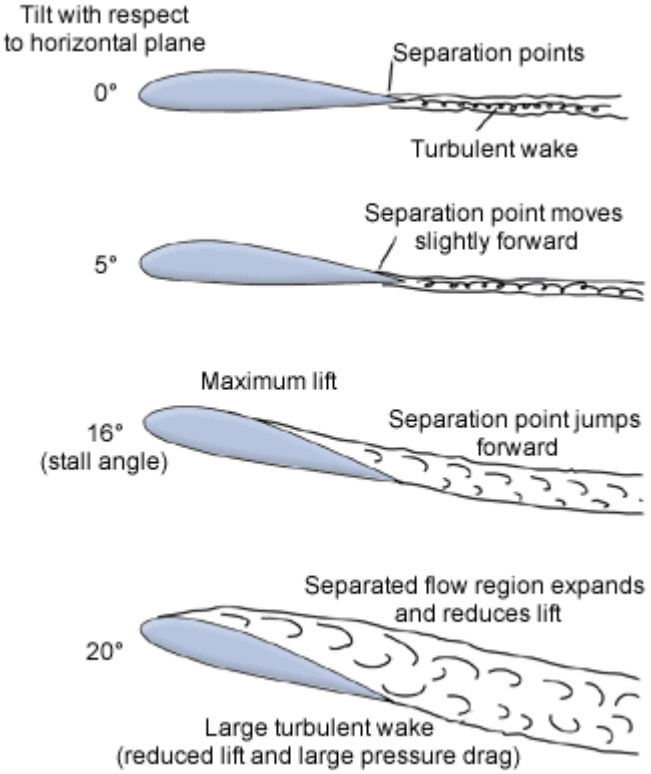


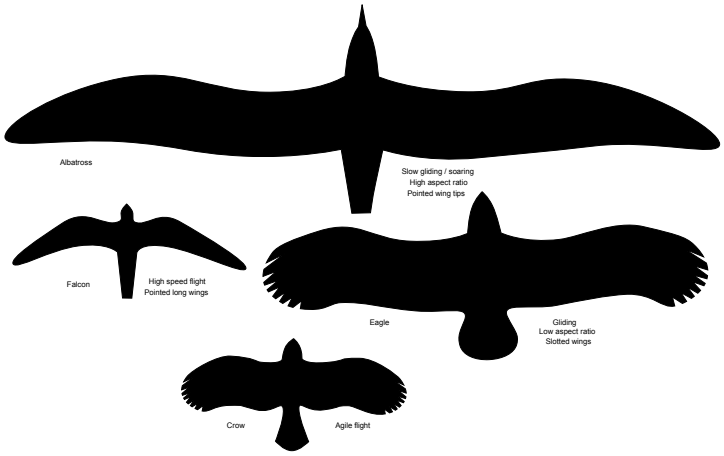


Locomotion

- **aerodynamics of flight**
- swimming: macro and microscale
- adhesive motion (snails, cells)







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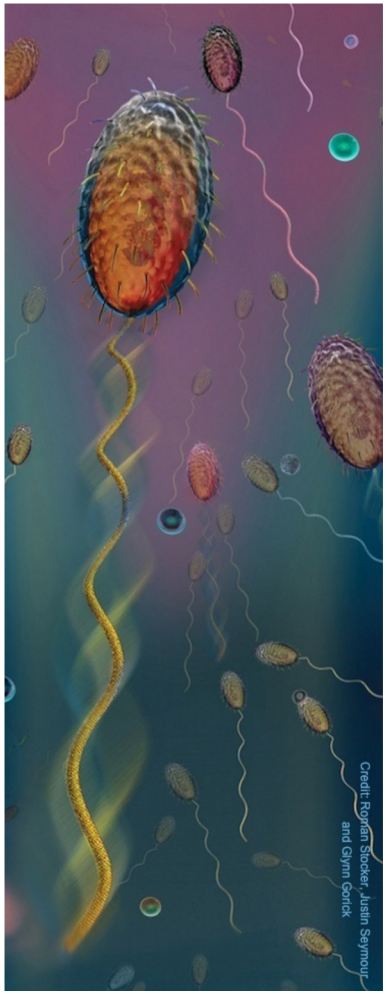
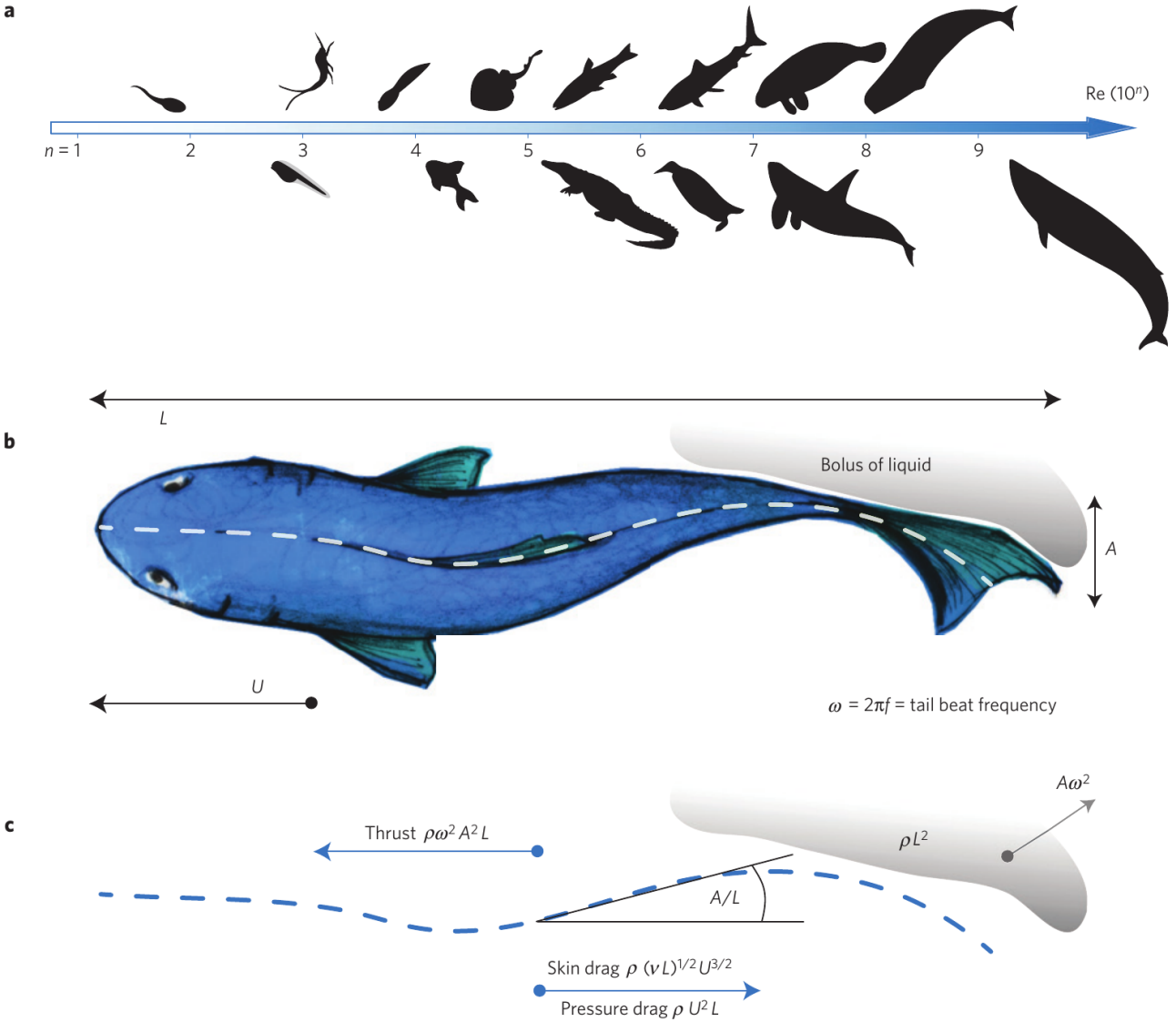
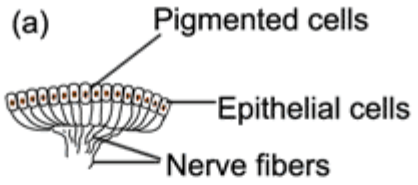
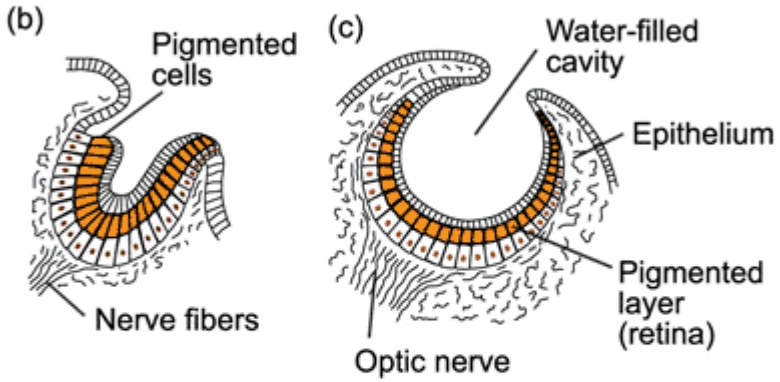


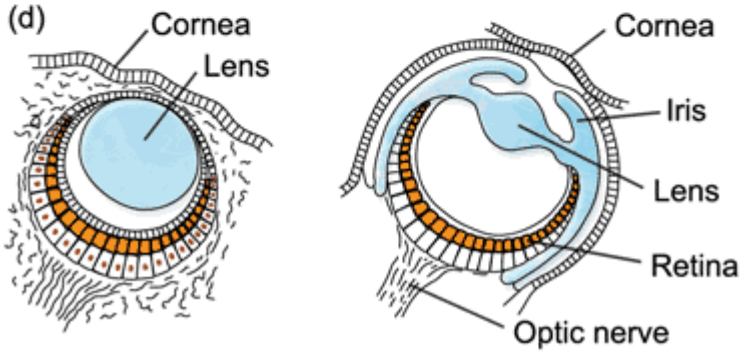


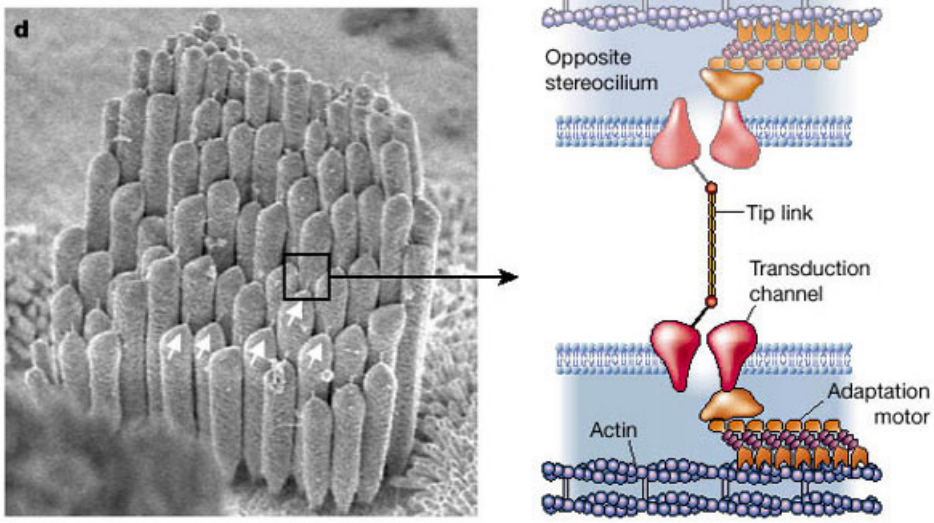
Sensing

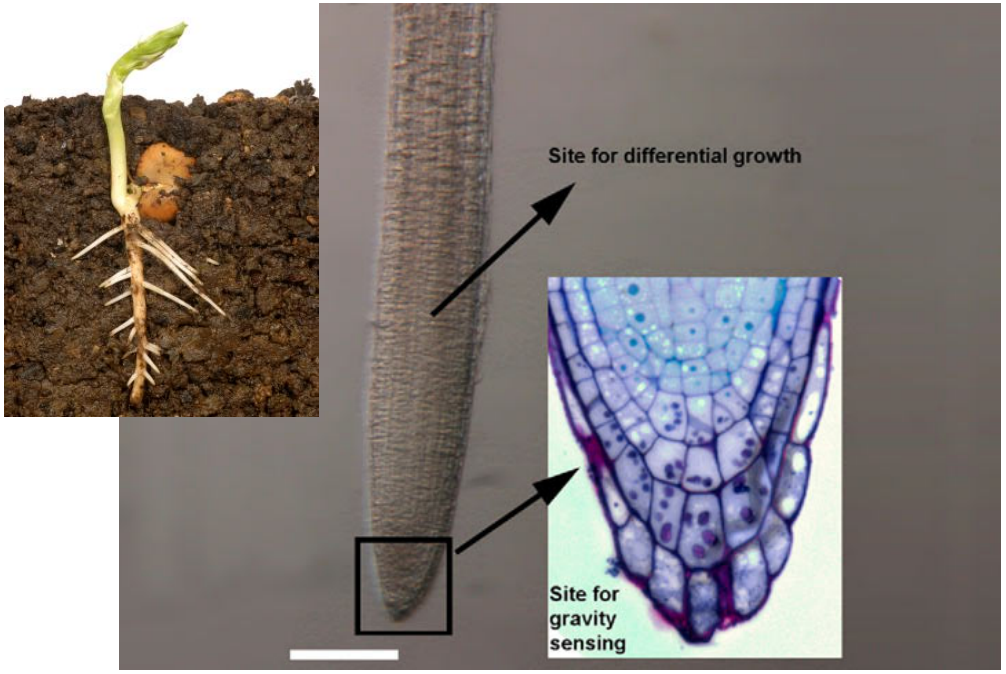
- vision
- mechanoreception (hearing, touch)
- gravity sensing











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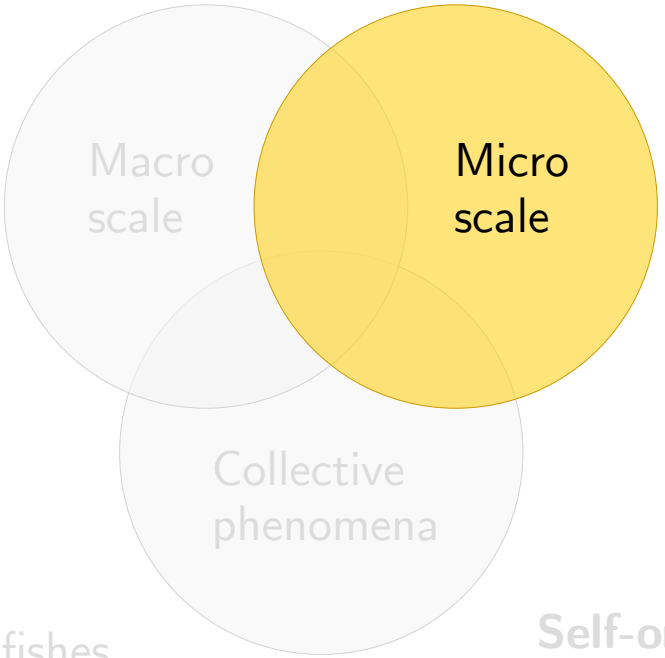
- different metabolic pathways
- fermentation vs respiration
- proton gradients

Intracellular transport
- molecular motors
- Brownian ratchets

Membranes
- organization and properties



Collective behaviour
- flocks of birds, shoals of fishes
- growth of bacterial colonies

Communication
- quorum sensing
- internal communication: neural networks

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- cell division and embryo growth
- population dynamics
- transport networks
- origins of life

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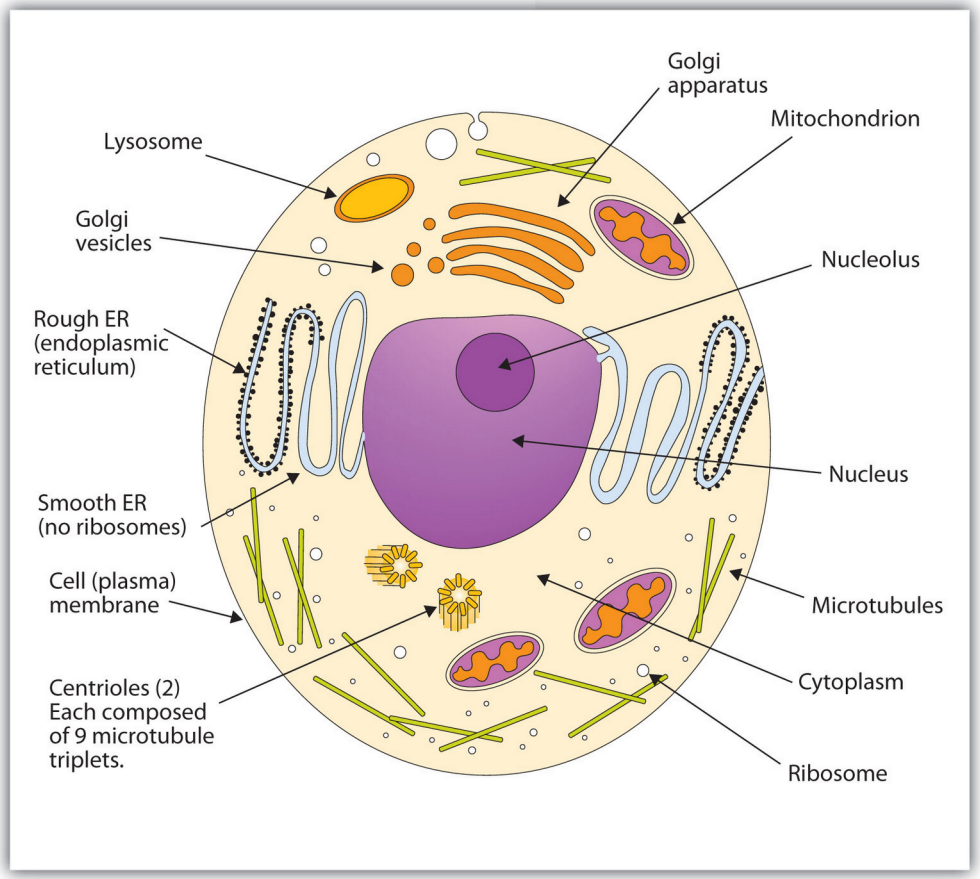

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➢ **Inner life of the cell** vesicle transport (3:43)

➢ **Inner life of the cell – realistic** vesicle transport (1:16)

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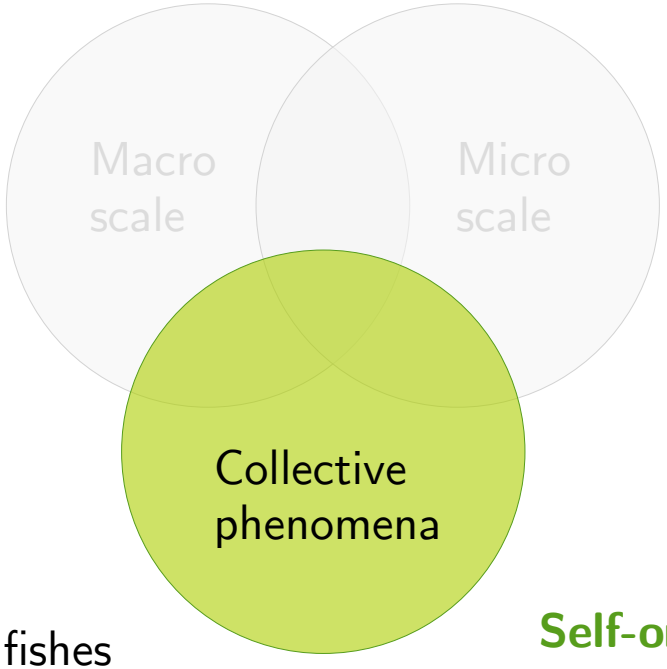

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Communication

- **quorum sensing**
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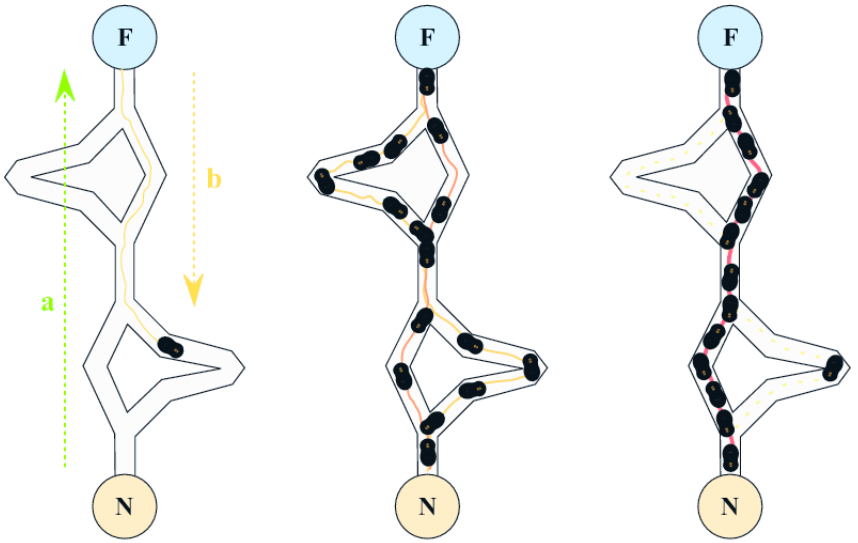

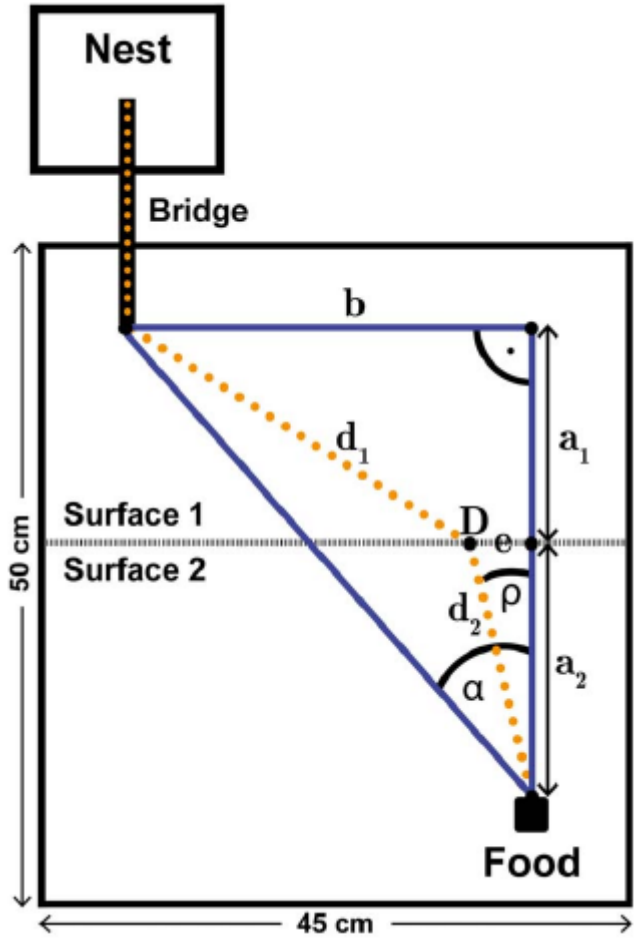

Oettler et al., PloS ONE **8**, e59739 (2013)

Collective behaviour

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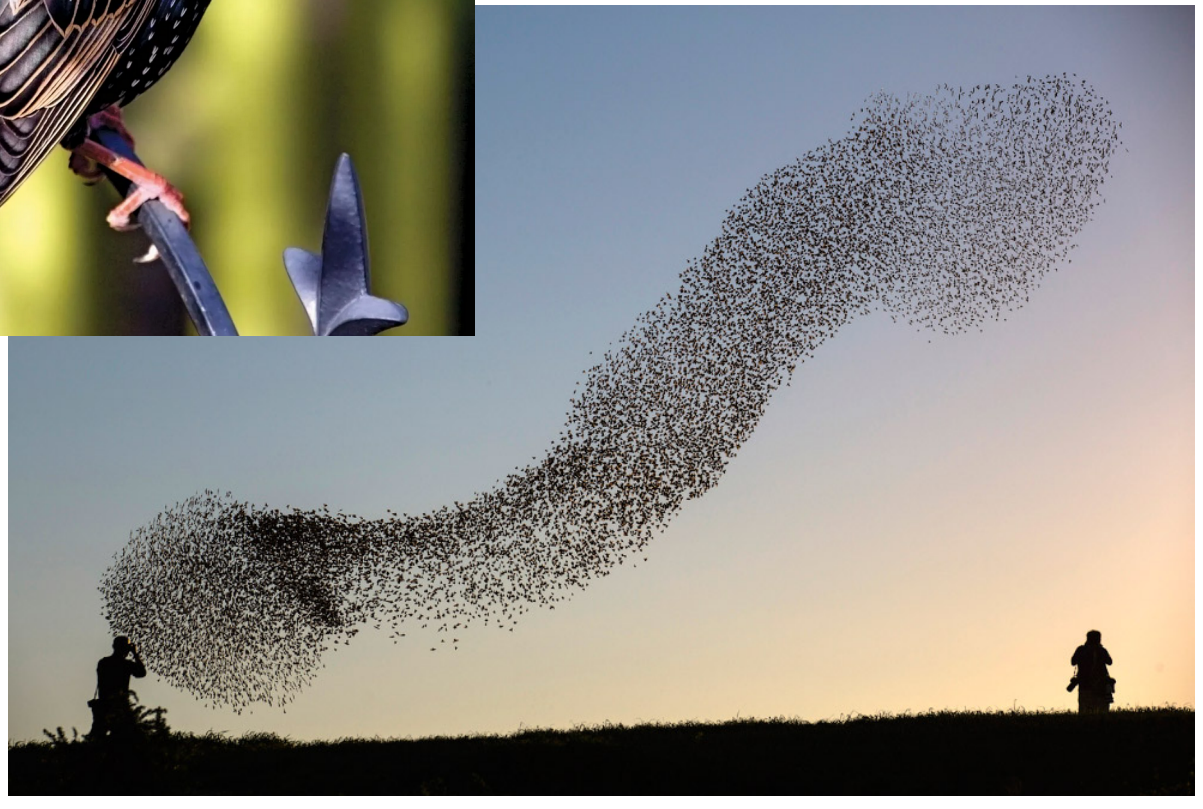
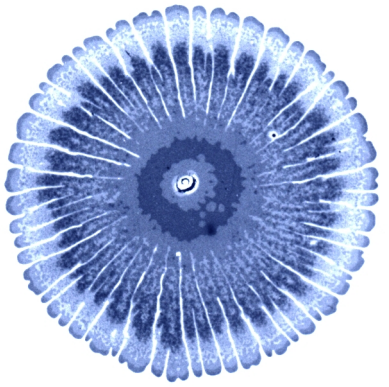
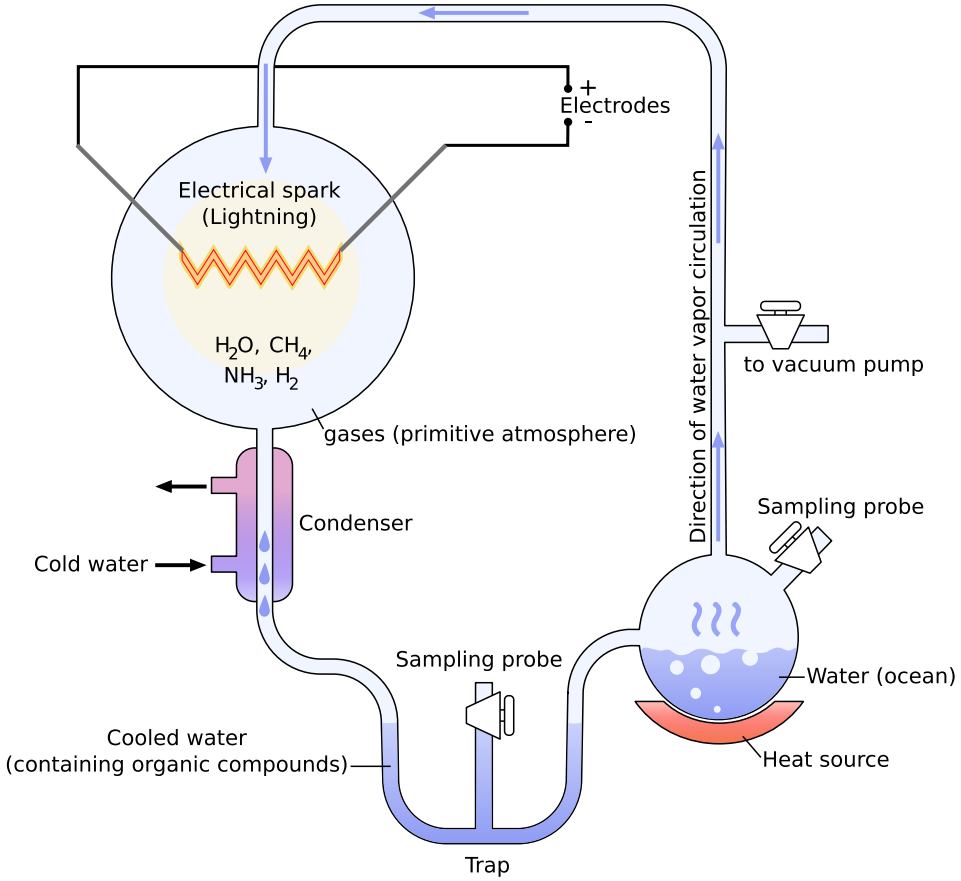
➢ Starling murmuration





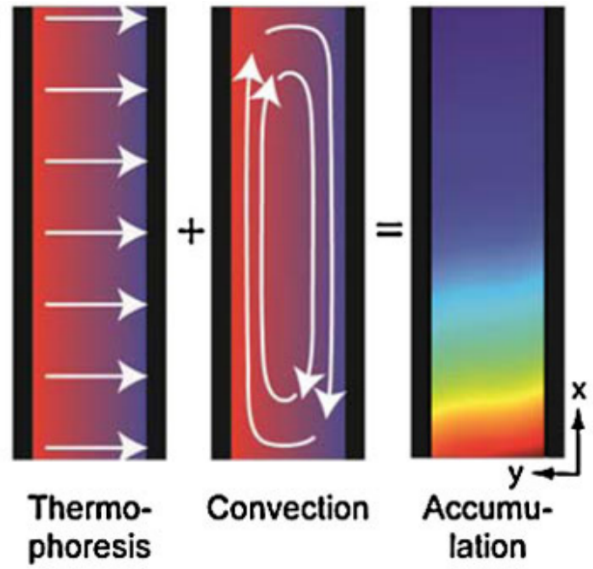
Self-organization

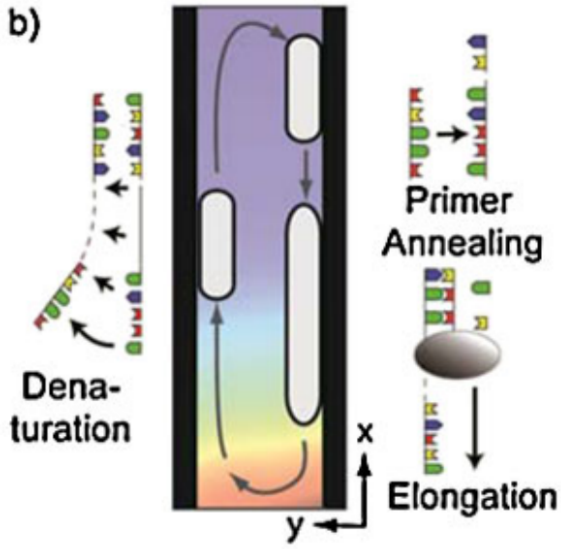
- cell division and embryo growth
- population dynamics
- transport networks
- **origins of life**



Urey-Miller experiment ("primordial soup")
problem: not enough complexity,
whatever is synthesized, diffuses away

DNA replication in thermal traps (rock pores)





Mast & Braun, Phys. Rev. Lett. **104**, 188102 (2010)

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- swimming: macro and microscale
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- proton gradients

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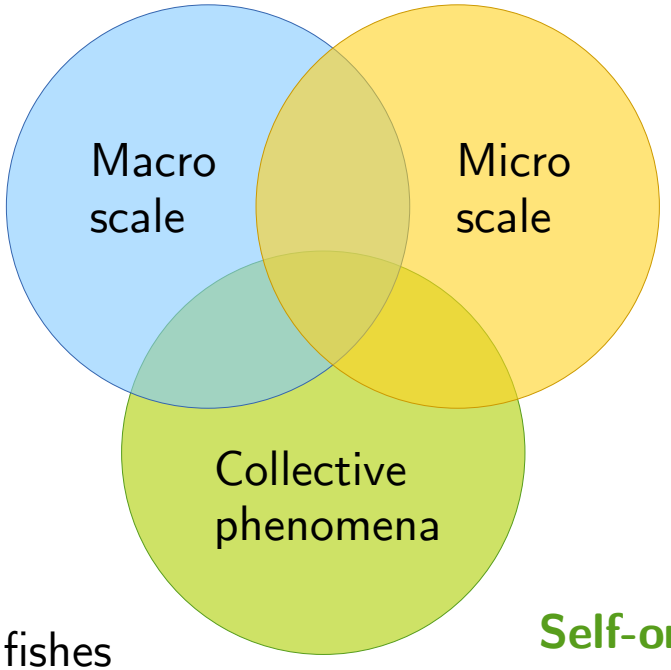
- molecular motors
- Brownian ratchets

Membranes
- organization and properties



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- transport networks
- origins of life

Topics from previous editions of the seminar

2015

- "Der Vogelflug"
- "Mechanics of muscles"
- "Sound navigation and ranging"
- "Nanobots"
- "Control of motion – manoeuvrability vs stability"
- "Syntrophie"
- "Membrane physics"
- "Thermodynamics of life"

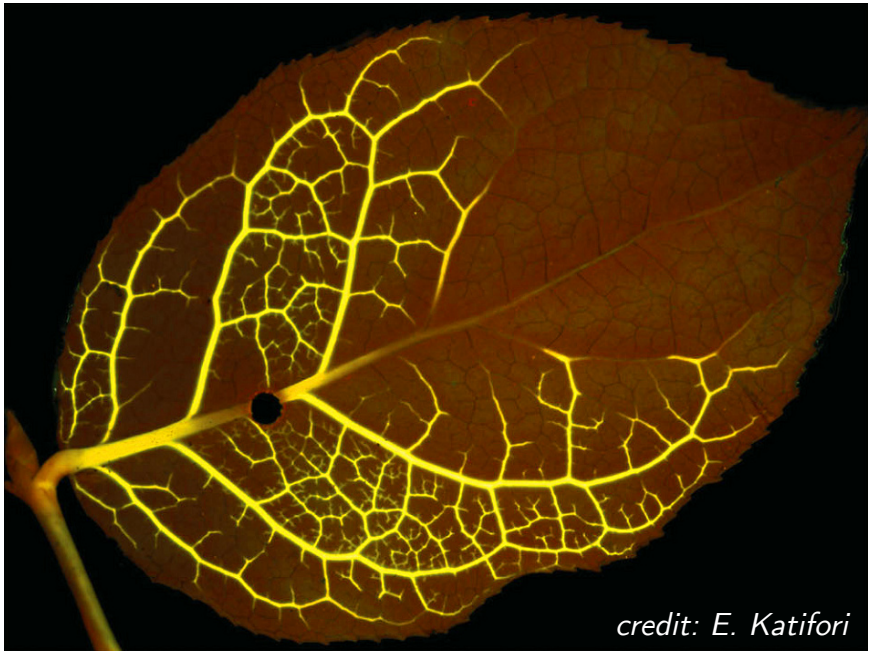
2019

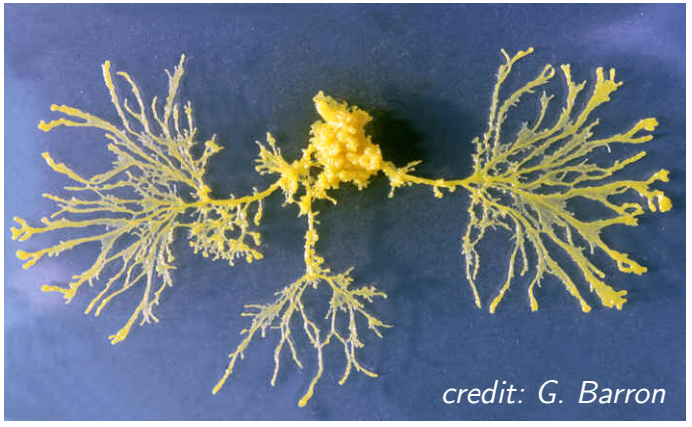
- "Electric fish"
- "The nervous system"
- "The art of flying"
- "Optical sensing"
- "Using atmospheric electricity for flight"

2022

- "Eye development"
- "Haftung an Oberflächen – der Gecko"
- "Der Narwhal"
- "Struktur von Exo- und Endoskeletten"
- "Physics of life in deep ocean"
- "The life of networks"

Example: Network organization



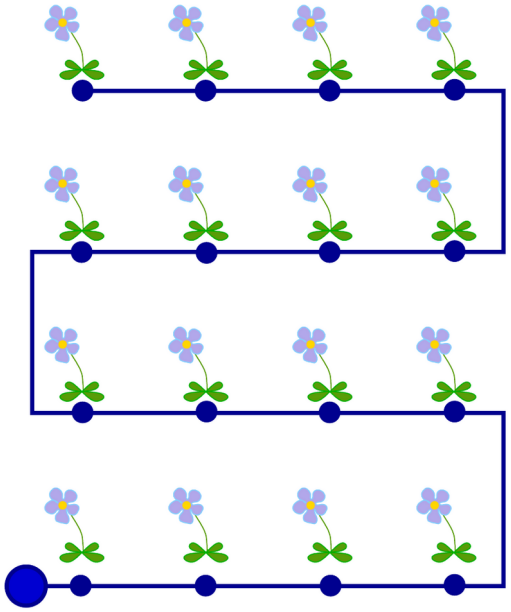


Network organization

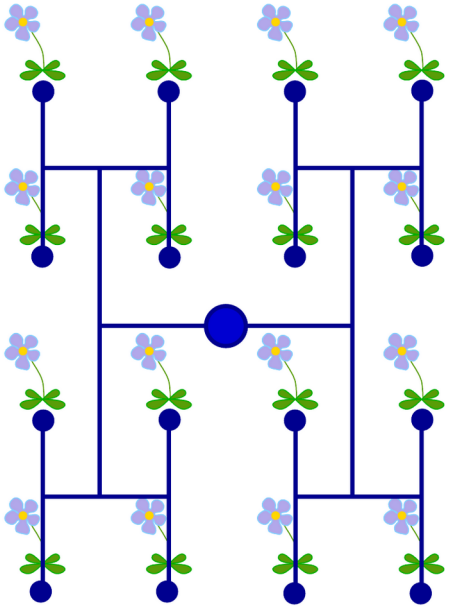
Starting principle: maximum efficiency

M. Denny, A. McFadzean

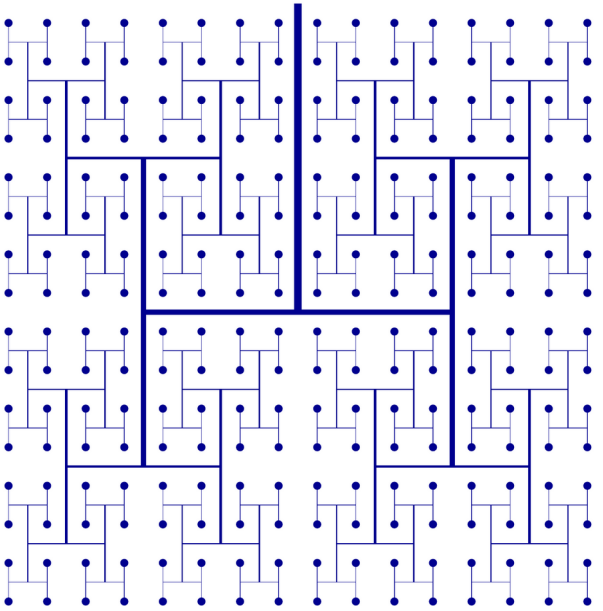
"*Engineering Animals: How life works*"



Linear network: each outlet has a different pressure



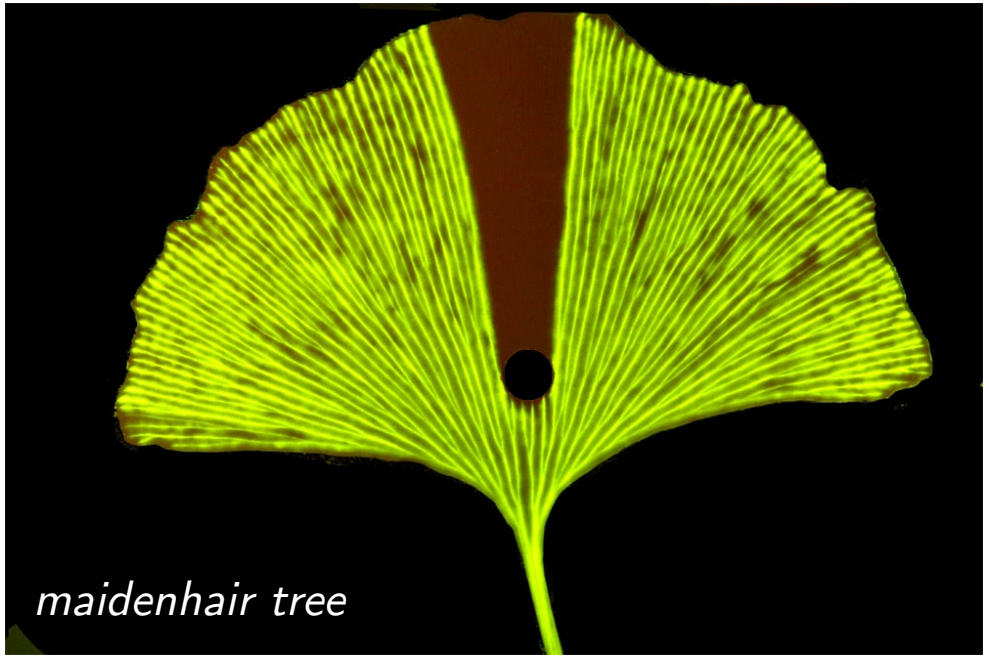
Hierarchical network: equal pressure at each outlet

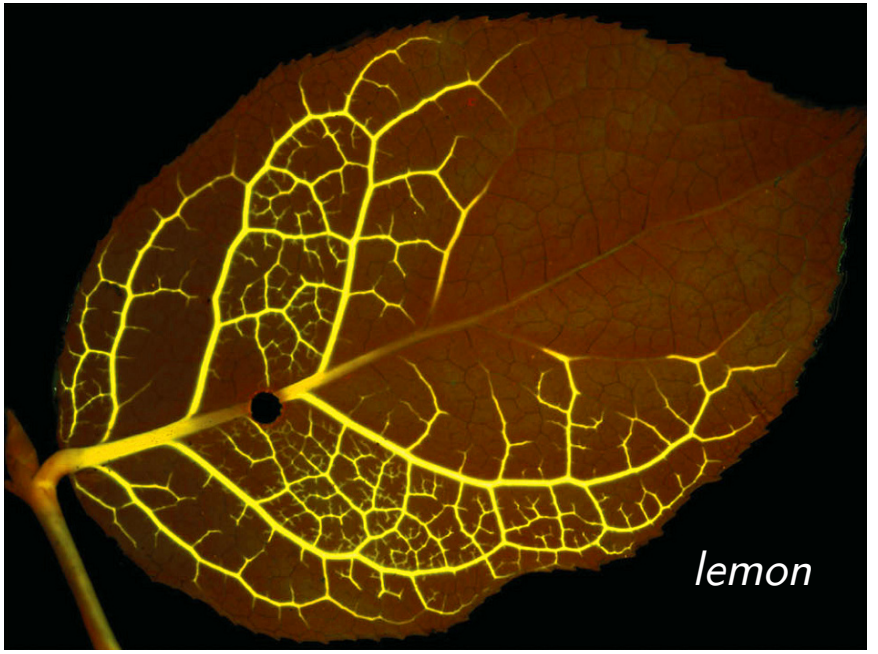


Fractal network:
- equal pressure at each outlet,
- maximizes the covered area

But: how to deal with a damage in the network?

Networks resistant to damage





Katifori et al., Phys. Rev. Lett. **104**, 048704 (2010)

Model:

Network consisting of nodes k, joined by conductances C_{jk}.

Each link „costs" C^{γ}

Total „cost" of conductance is constant:

$$\frac{1}{2}\sum_{k}\sum_{\langle j,k\rangle} C_{kj}^{\gamma} = 1$$

The current through the link jk, I_{jk}, is driven by the „voltage" difference between the nodes j and k:

$$\sum_{\langle j,k\rangle} C_{kj}(V_k - V_j) = I_k$$

The functional to minimize: total power dissipation, $P = \frac{1}{2}\sum_{k}\sum_{\langle j,k\rangle} C_{kj}(V_k - V_j)^2$

Network damage models

a) Broken bonds

$$C_{kj}^{ab} = C_{kj}(1 - \delta_{ak}\delta_{bj} - \delta_{aj}\delta_{bk})$$

minimizing: $$R = \sum_{(ab)} P^{ab}$$

b) Moving sink

$$I_k^a = \delta_{0k} - \delta_{ak}$$

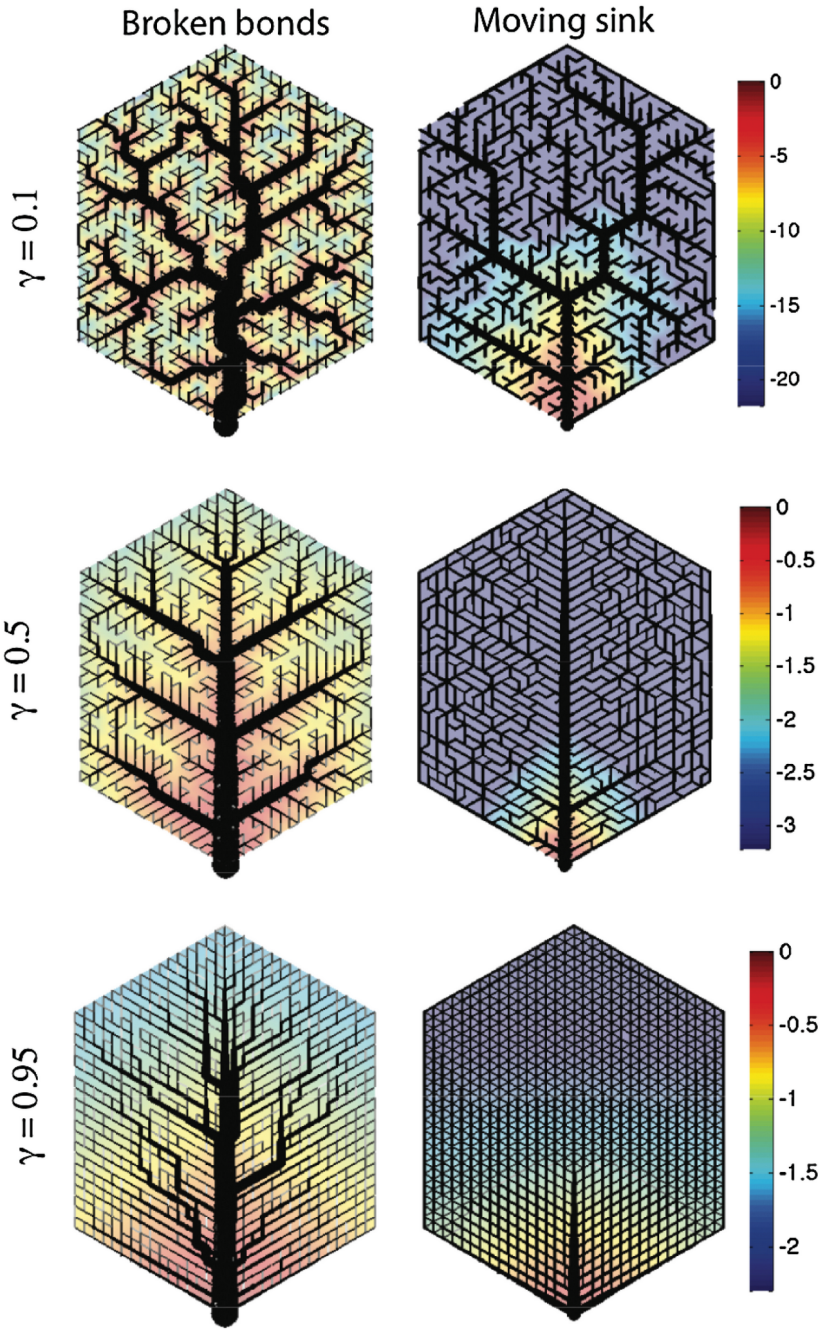
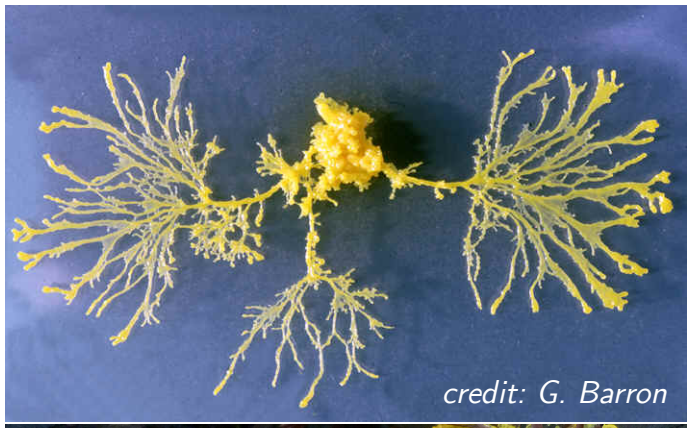


FIG. 2 (color). Loops as a result of optimizing under damage to links (left column) and under a fluctuating load (right column). In all plots the vein thickness (shown in black) is proportional to $C^{(\gamma+1/2)/3}$. The background color of each network represents the pressure drop relative to the network source, normalized by the mean pressure drop of a network optimized for the tree model with the same γ.

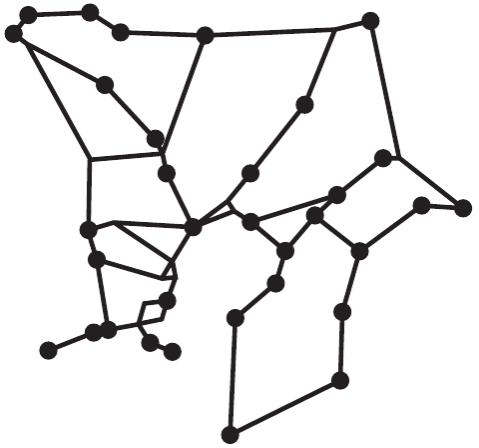
Letting nature do the job: networks created by the slime mould



Tero et al., Science **327**, 439 (2010)

Slime mould

Tokyo railway



➢ **Slime mould BBC**

Question to explore:
How do the different parts of the slime mould organism communicate?

Topics in the Physics of Life

Structure
- mechanics of the skeleton
- mechanics of the muscles
- structure of the bone/shell material

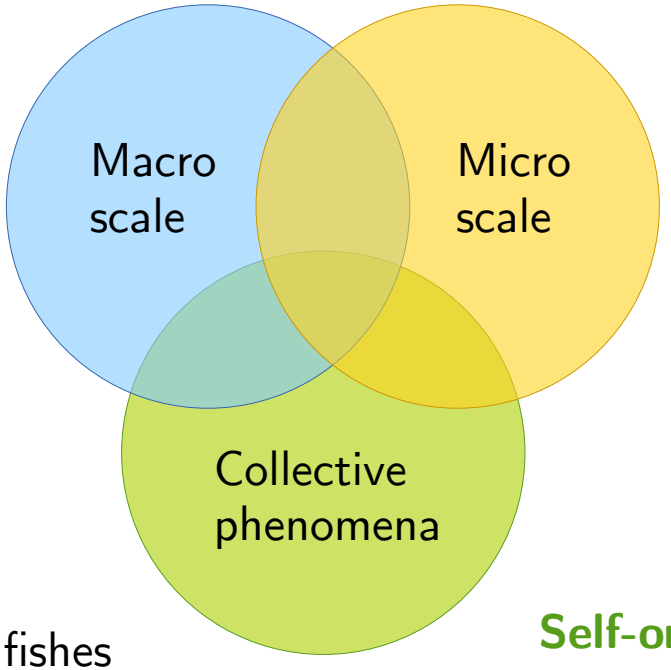
Locomotion
- aerodynamics of flight
- swimming: macro and microscale
- adhesive motion (snails, cells)

Sensing
- vision (ultraviolet, polarized)
- mechanoreception (hearing, touch)
- gravity sensing
- chemical sensing (smell, taste)

Powering up
- different metabolic pathways
- fermentation vs respiration
- proton gradients

Intracellular transport
- molecular motors
- Brownian ratchets

Membranes
- organization and properties



Collective behaviour
- flocks of birds, shoals of fishes
- growth of bacterial colonies

Communication
- quorum sensing
- internal communication: neural networks

Self-organization
- cell division and embryo growth
- population dynamics
- transport networks
- origins of life

Some literature

M. Denny, A. McFadzean "*Engineering Animals: How life works*"

M. Denny "*Air and water*"

M. Lisa "*The physics of sports*"

R.P. McCall "*Physics of the human body*"

I. Stewart "*The mathematics of life*"

Ed Yong "*Not exactly rocket science*"
"*I Contain Multitudes: The Microbes Within Us and a Grander View of Life*"
"*An Immense World: How Animal Senses Reveal the Hidden Realms Around Us*"

2006-2008	https://notexactlyrocketscience.wordpress.com/
2008-2012	http://blogs.discovermagazine.com/notrocketscience/ (defunct)
2015-present	https://www.theatlantic.com/author/ed-yong/

R. Phillips et al. "*Physical biology of the cell*"

D. Dusenbery "*Living at Micro Scale: The Unexpected Physics of Being Small*"

C.Zimmer "*Microcosm: E. coli and the new science of life*"

H. Berg "*Random walks in biology*"

P.M. Hoffmann "*Life's ratchet: how molecular machines extract order from chaos*"