

Physik der lebendigen Welt /
Physics of Life*

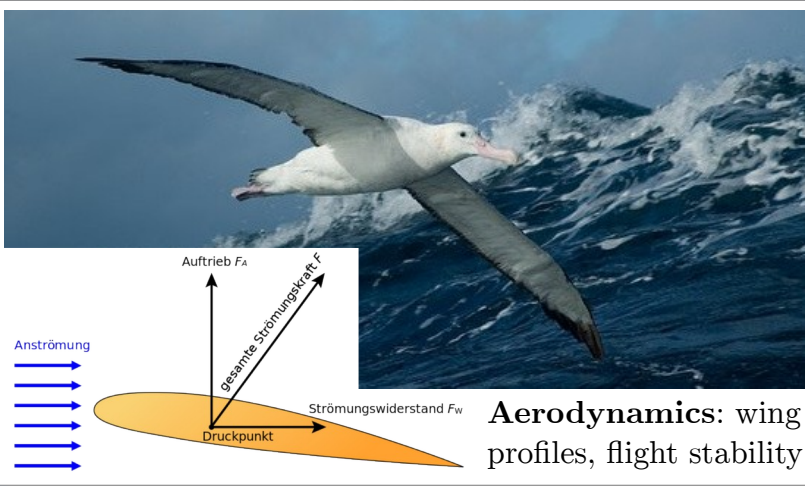
Mi, 12:30-14, PHY 7.1.21

Eckdaten: 4 ECTS für regelmäßige Teilnahme und eigenen Vortrag (35-45 min), weitere 2 ECTS wenn Sie zusätzlich eine schriftliche Ausarbeitung anfertigen.

Veranstaltungsnummer: 52312S

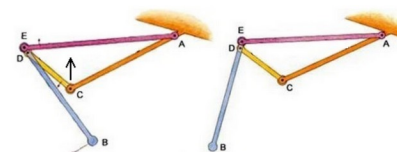
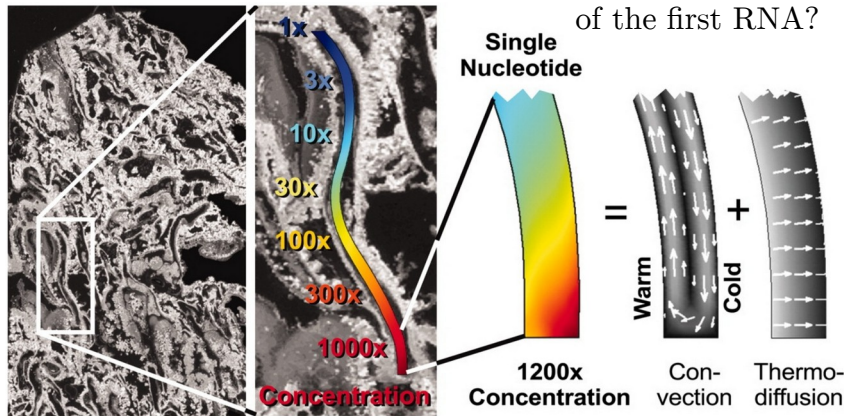
Ab 4. Semester, jüngere Semester nach Rücksprache

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

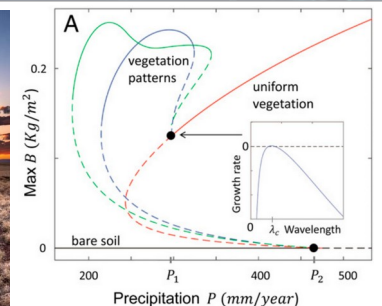


Aerodynamics: wing profiles, flight stability

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



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

Topics in the Physics of Life

Structure

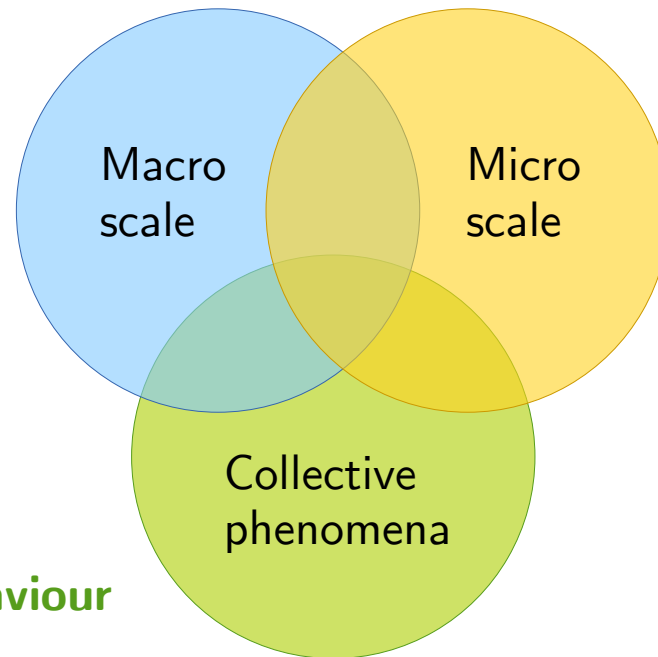
Locomotion

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
- mechanoreception (hearing, touch)
- gravity sensing

Powering up

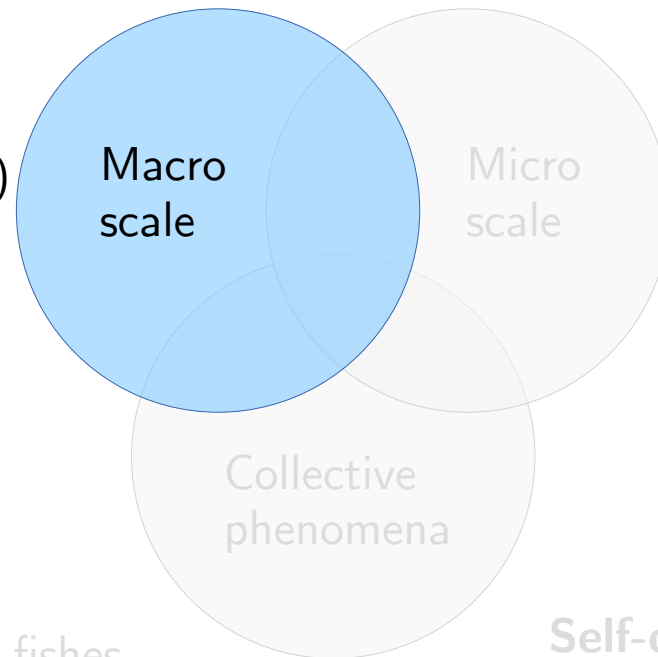
- different metabolic pathways
- fermentation vs respiration
- proton gradients

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

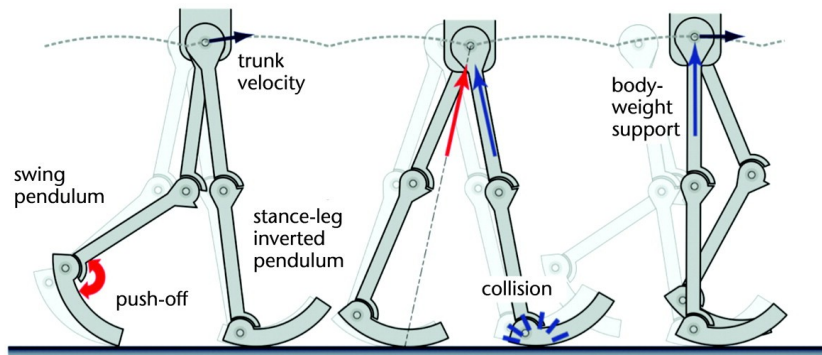
- cell division and embryo growth
- population dynamics
- transport networks
- origins of life

Topics in the Physics of Life

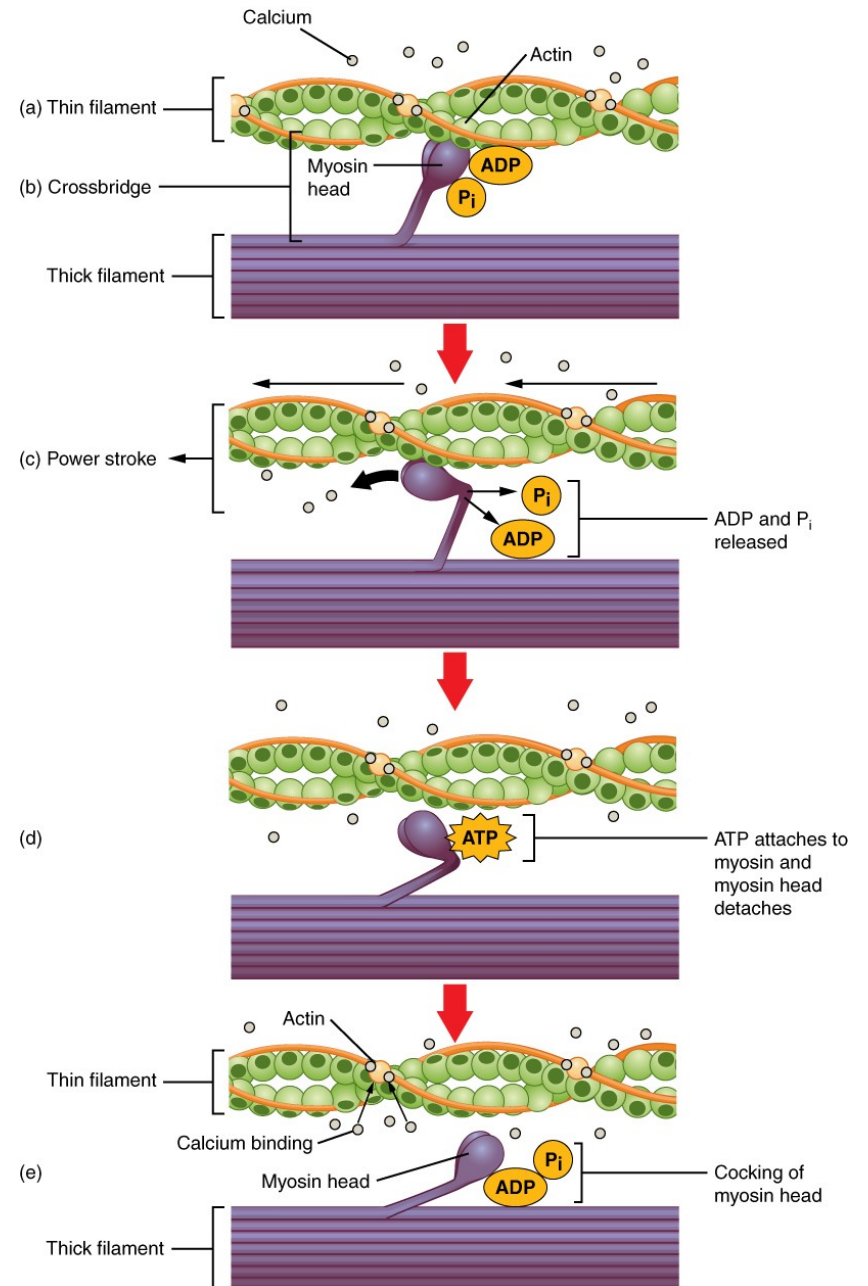
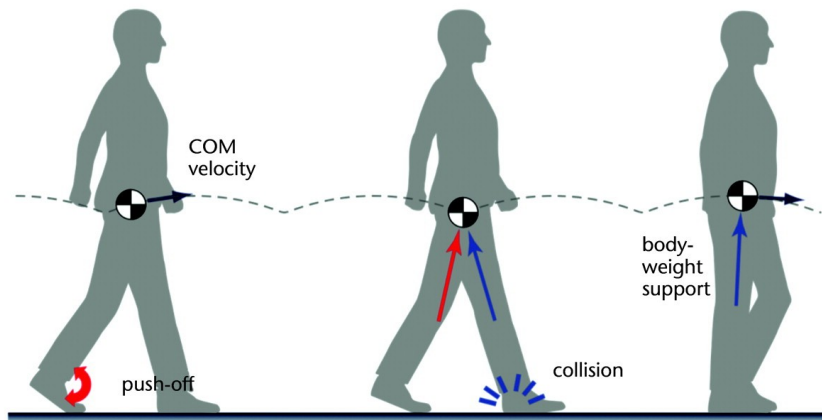
Structure

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A Dynamic Walking Model



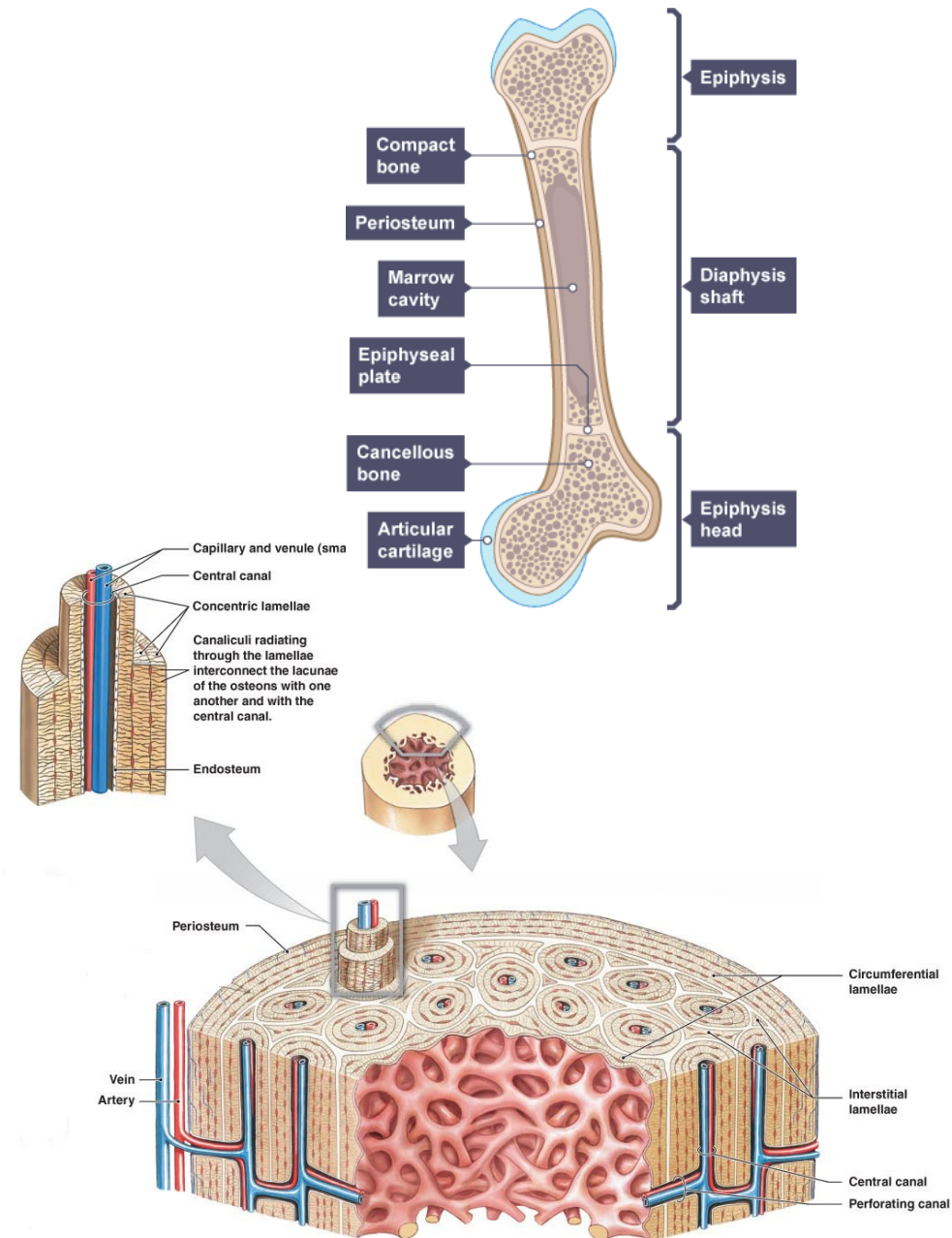
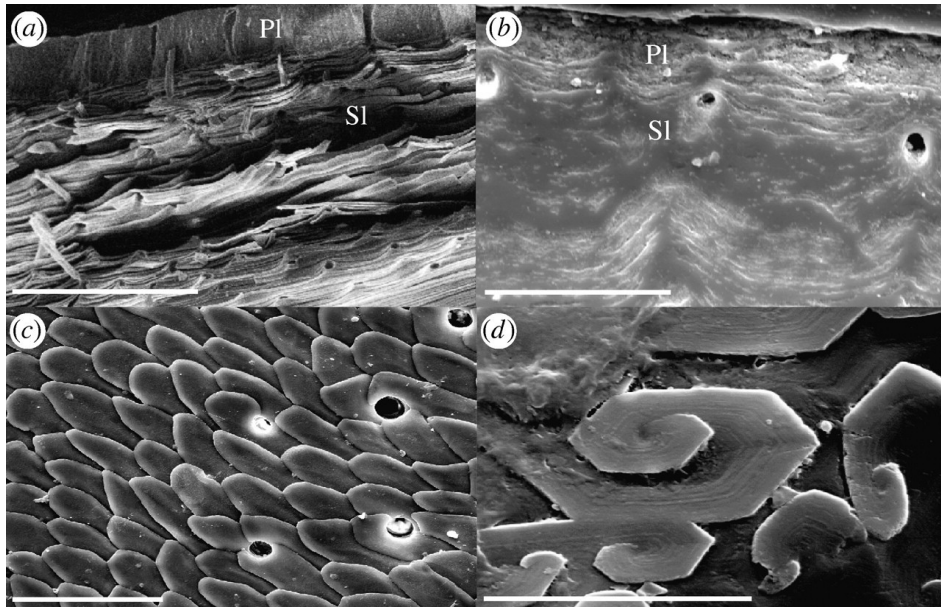
B Dynamic Walking Human



Topics in the Physics of Life

Structure

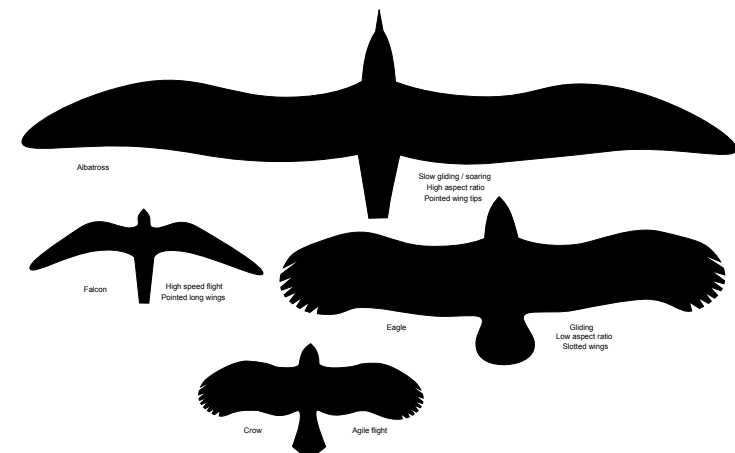
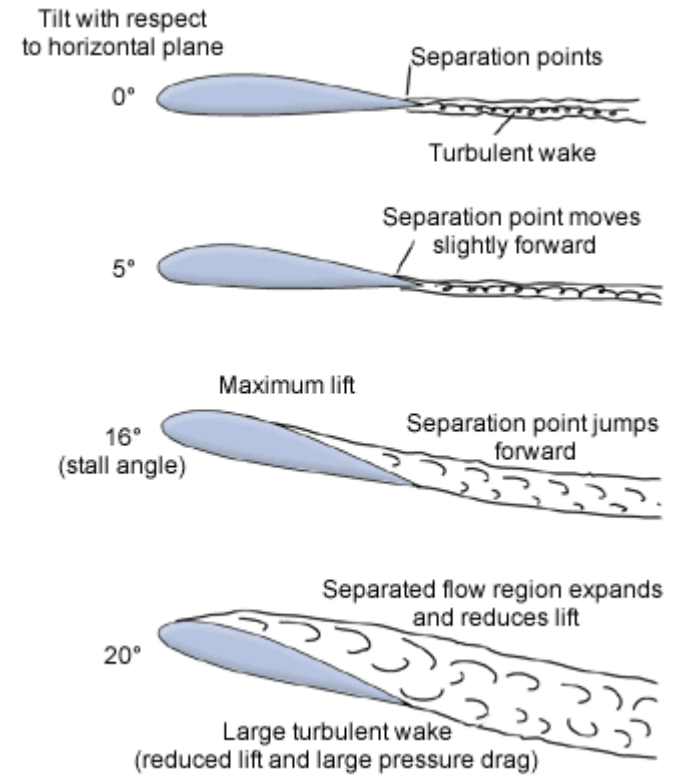
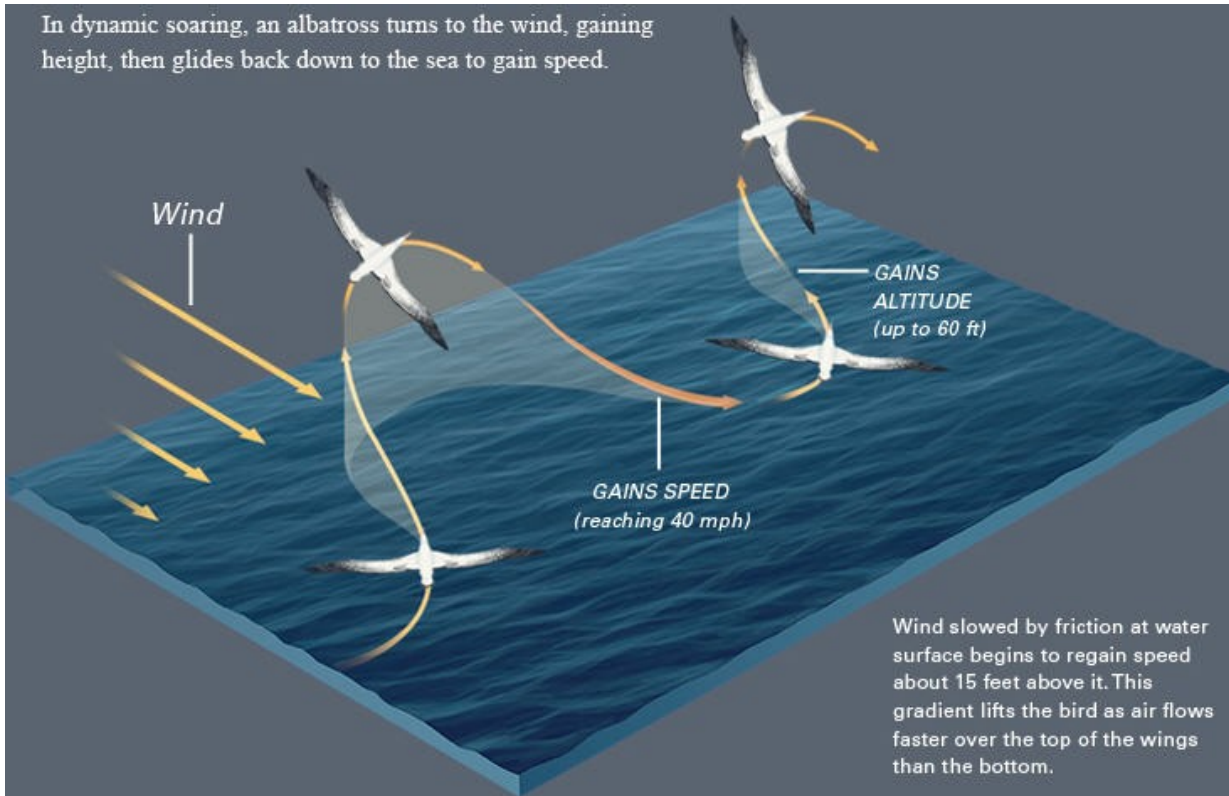
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Topics in the Physics of Life

Locomotion

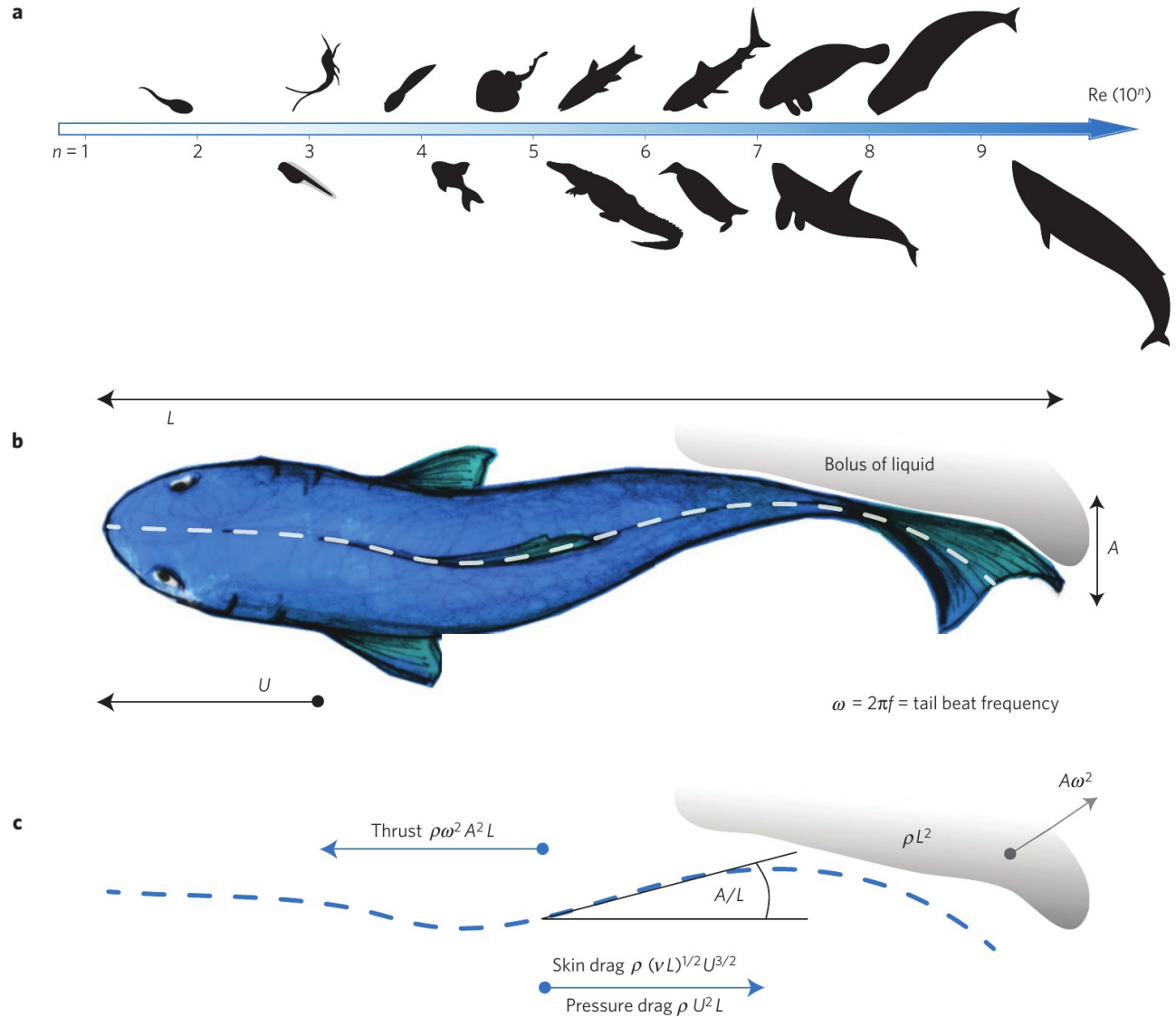
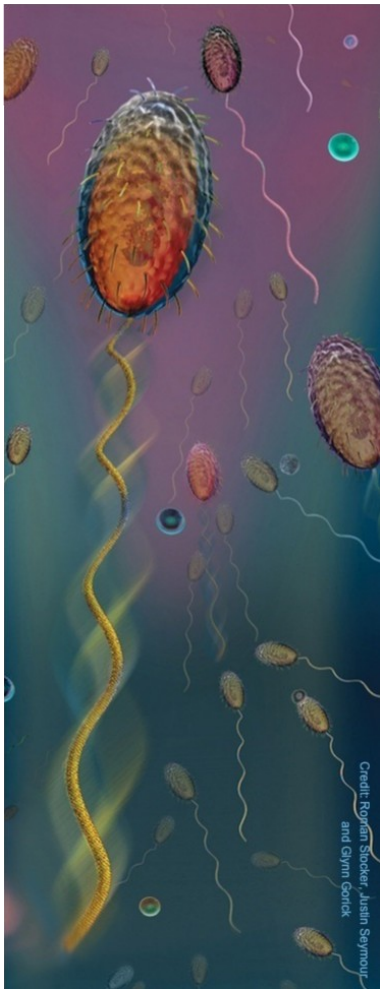
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Locomotion

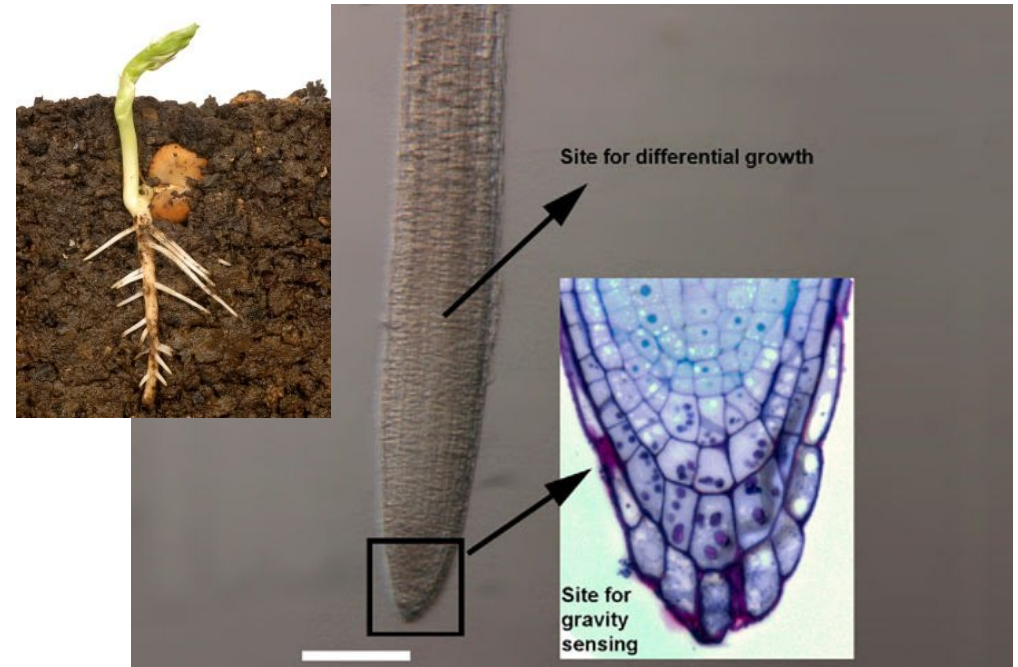
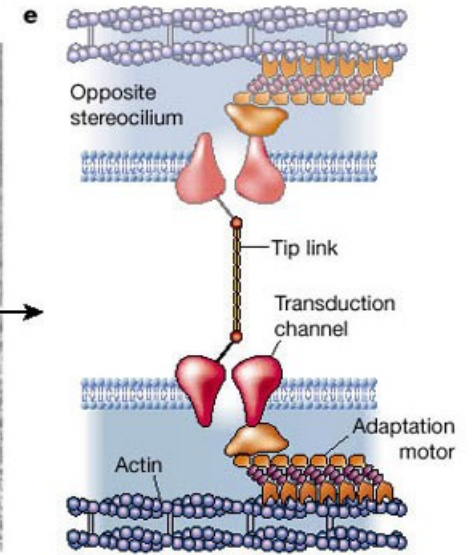
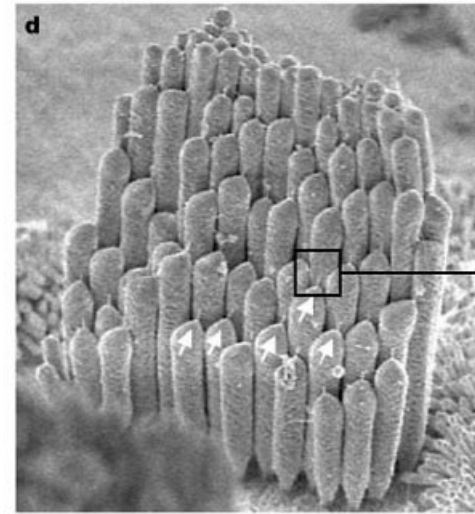
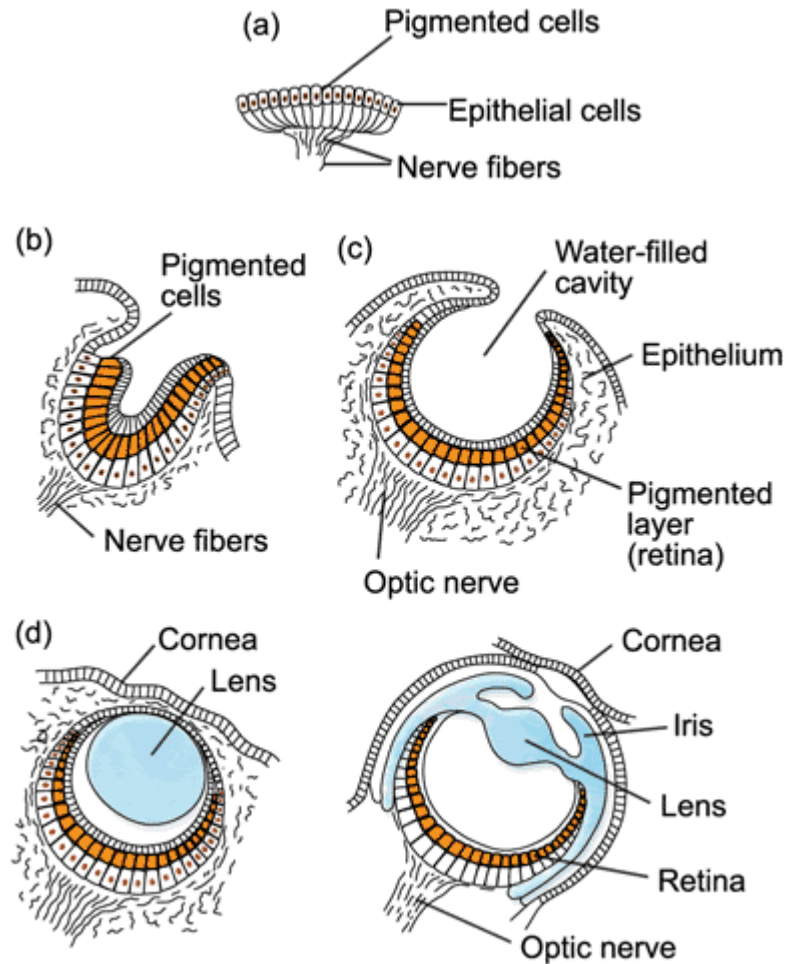
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Topics in the Physics of Life

Sensing

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



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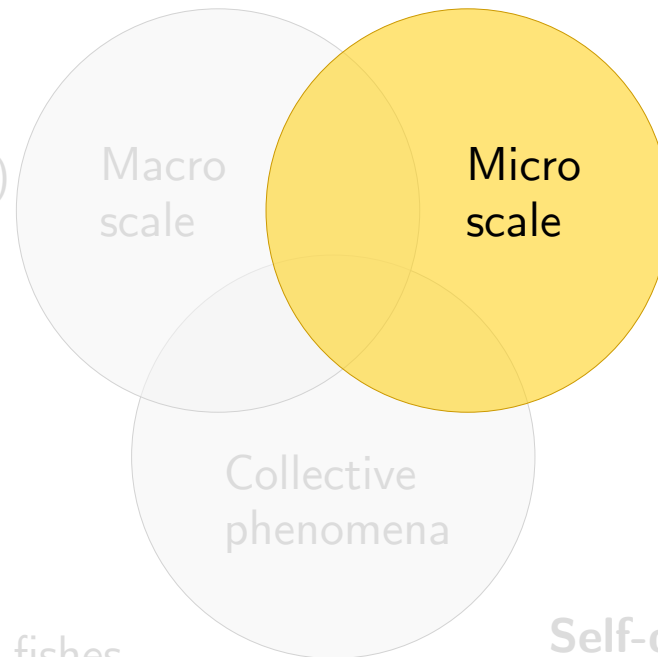
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Communication

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Powering up

- different metabolic pathways
- fermentation vs respiration
- proton gradients

Intracellular transport

- molecular motors
- Brownian ratchets

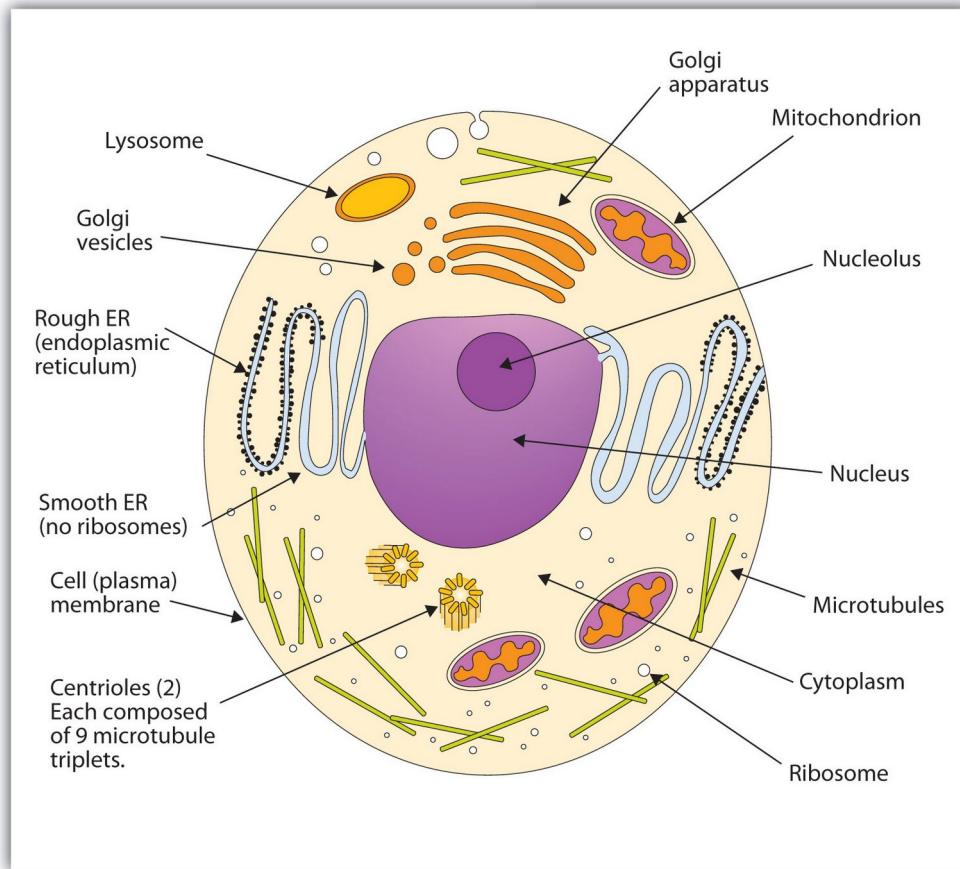
Membranes

- organization and properties

Self-organization

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

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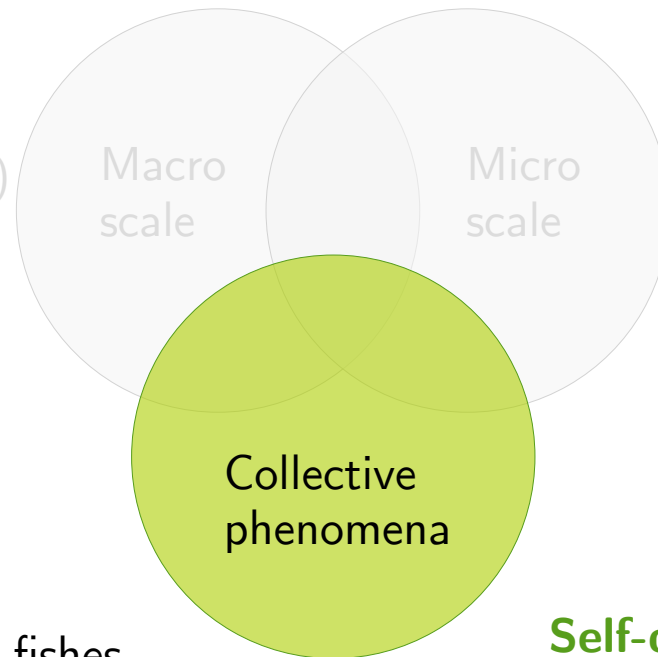
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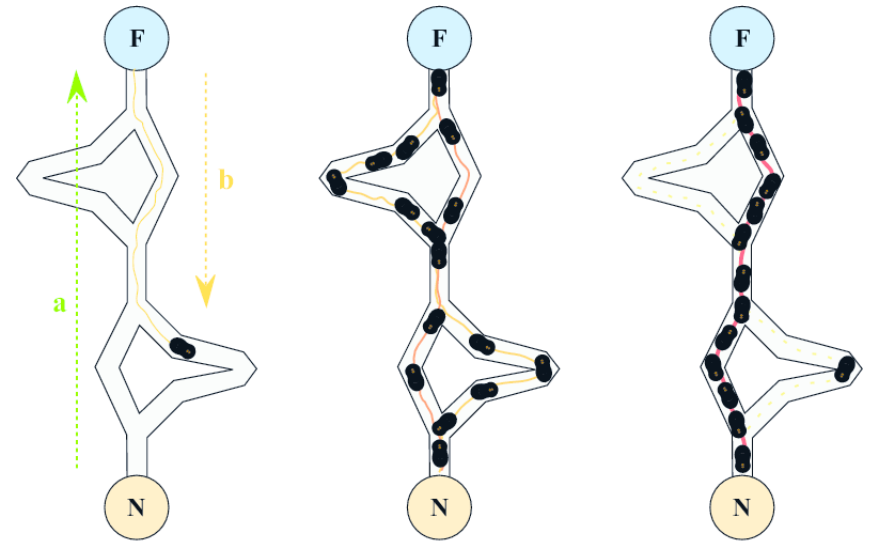
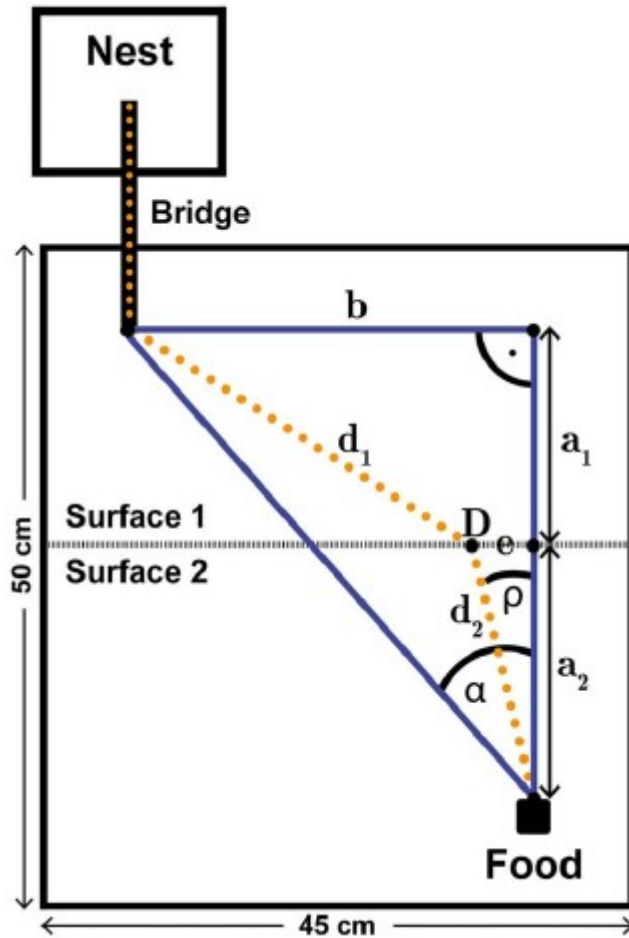
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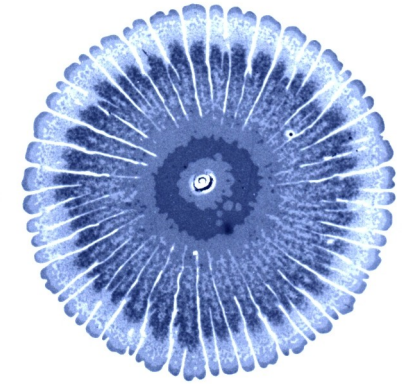
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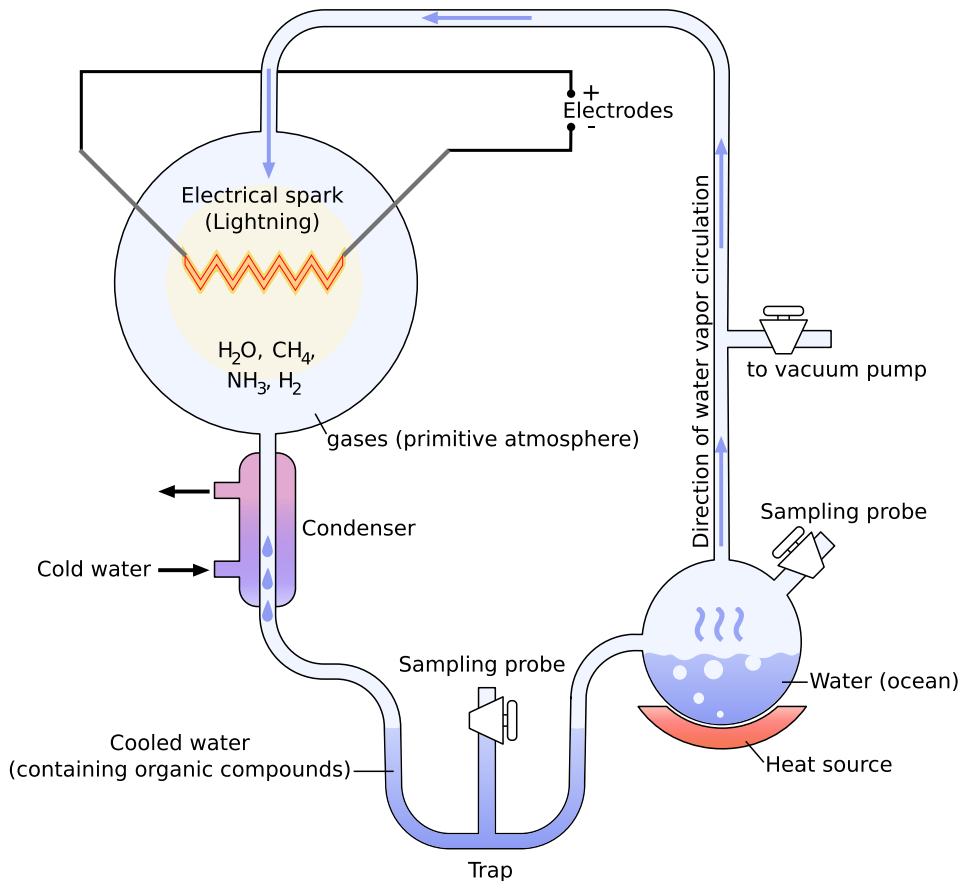


Topics in the Physics of Life

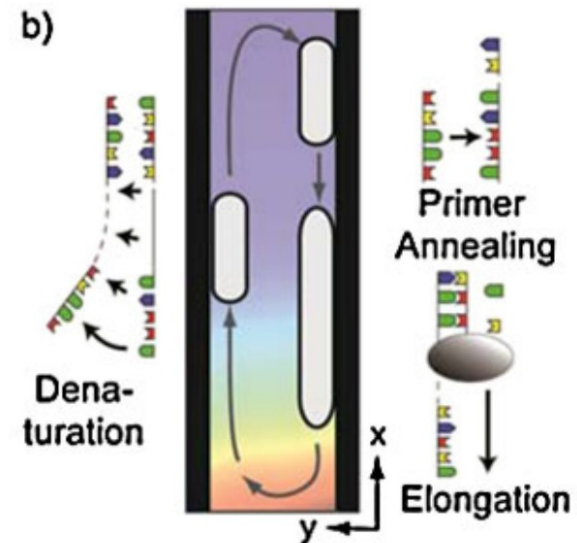
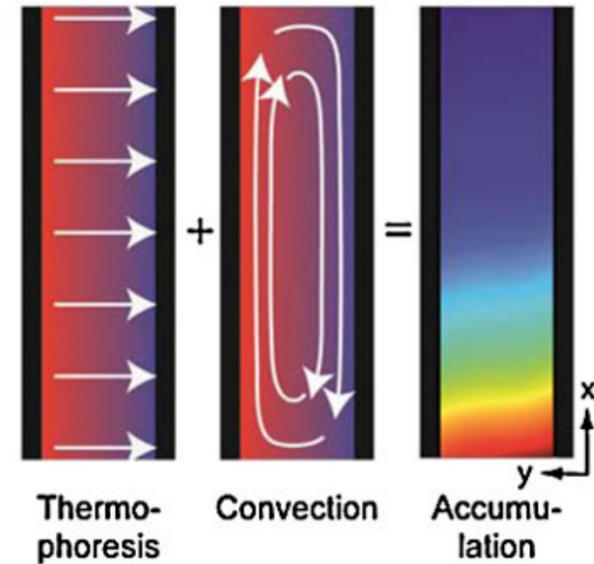
Self-organization

- cell division and embryo growth
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- **origins of life**

DNA replication in thermal traps (rock pores)



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



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

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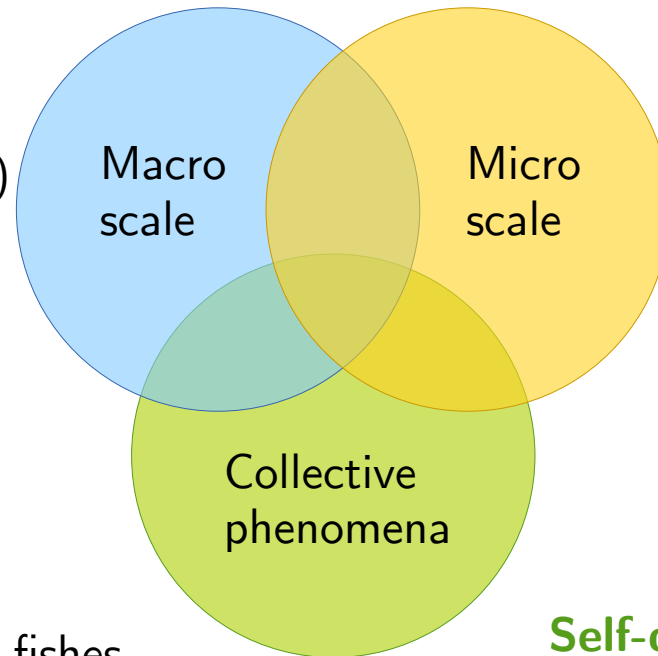
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Topics from previous editions of the seminar

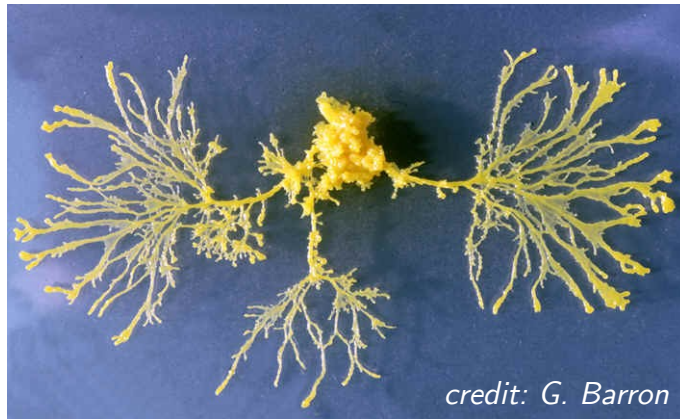
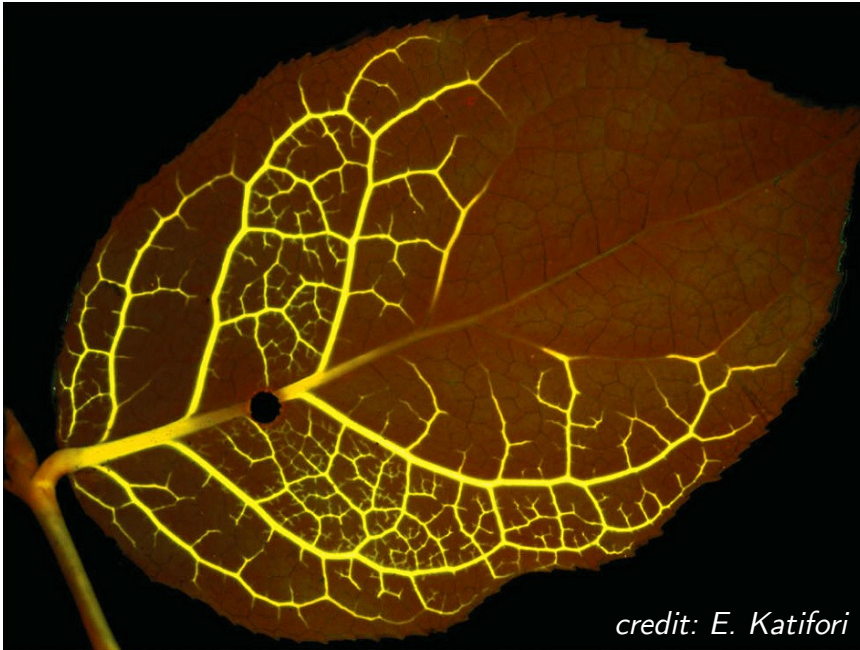
2015

- “Der Vogelflug”
- “Mechanics of muscles”
- “Sound navigation and ranging”
(bats)
- “Nanobots”
(moving in fluids at microscale)
- “Control of motion – manoeuvrability vs stability”
(fish and birds)
- “Syntrophie”
(cell metabolism mediated by a symbiont)
- “Membrane physics”
(cellular)
- “Thermodynamics of life”

2019

- “Electric fish”
- “The nervous system”
(electrical impulse conduction)
- “The art of flying”
- “Optical sensing”
(different eye constructions)
- “Using atmospheric electricity for flight”
(spider flight)

Example: Network organization

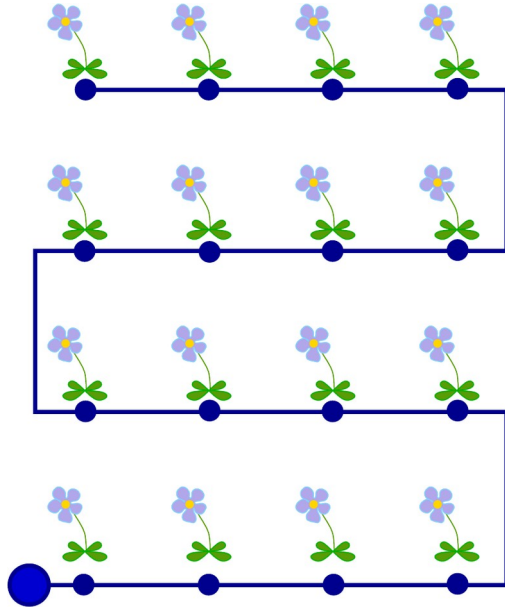


Network organization

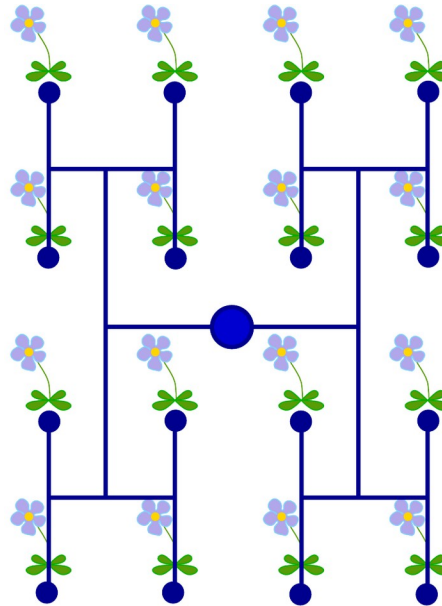
Starting principle: maximum efficiency

M. Denny, A. McFadzean

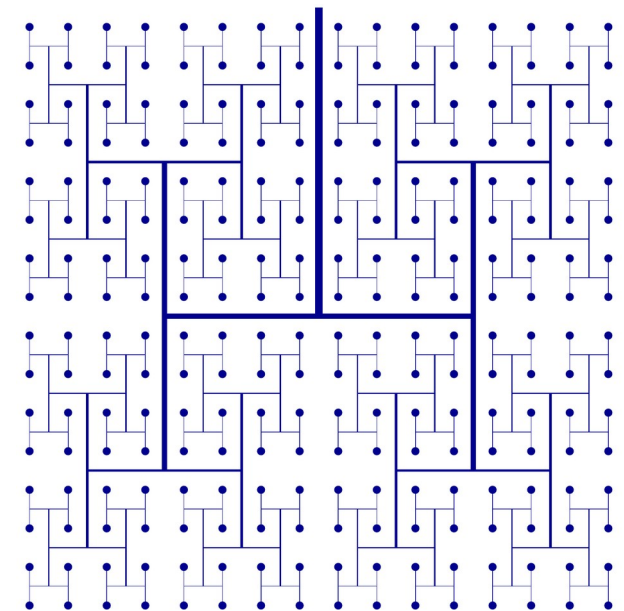
"Engineering Animals: How life works"



Linear network: each outlet has a different pressure



Hierarchical network: equal pressure at each outlet

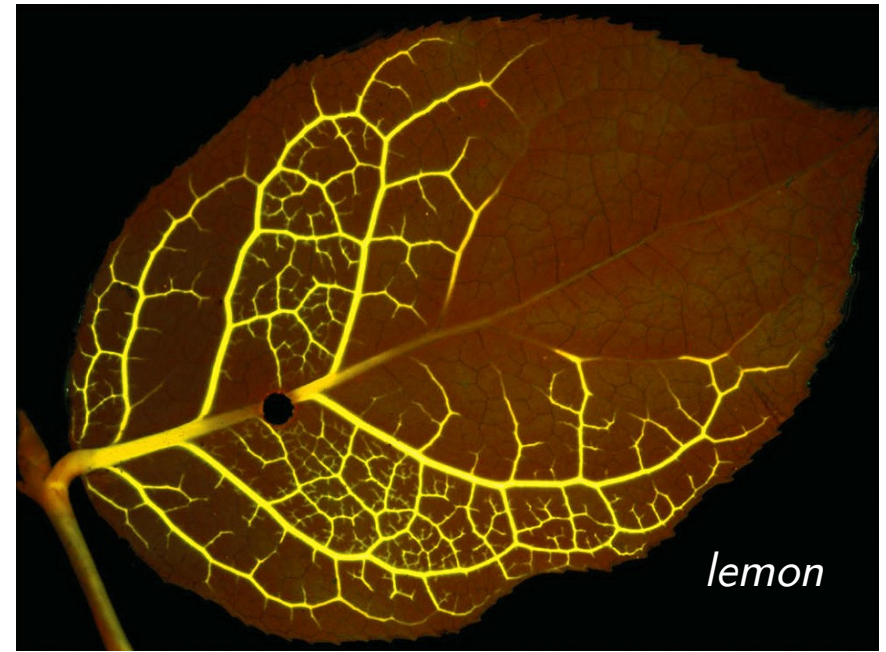
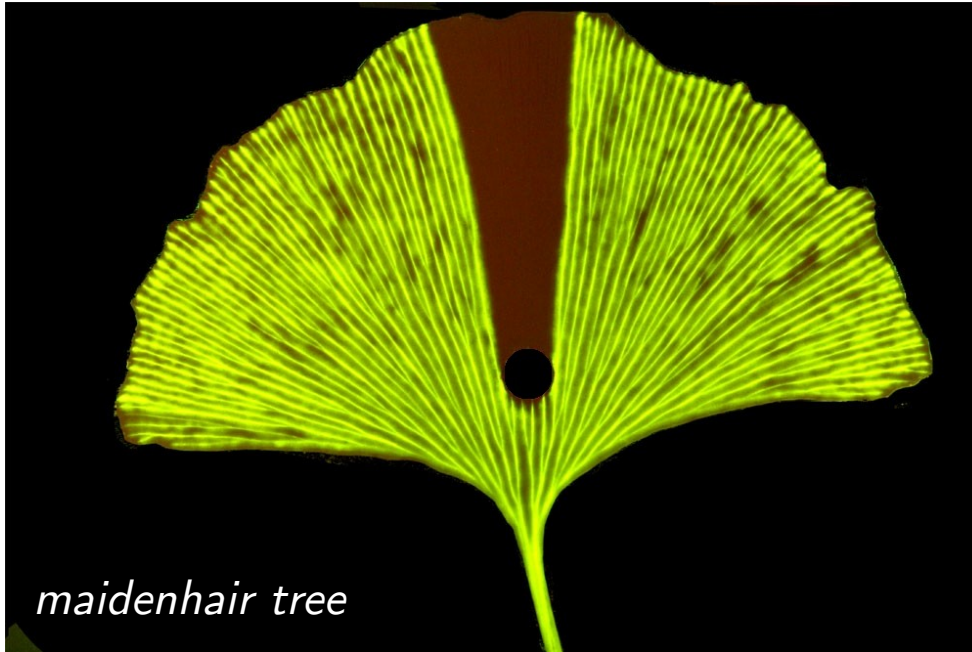


Fractal network:

- 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} .

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

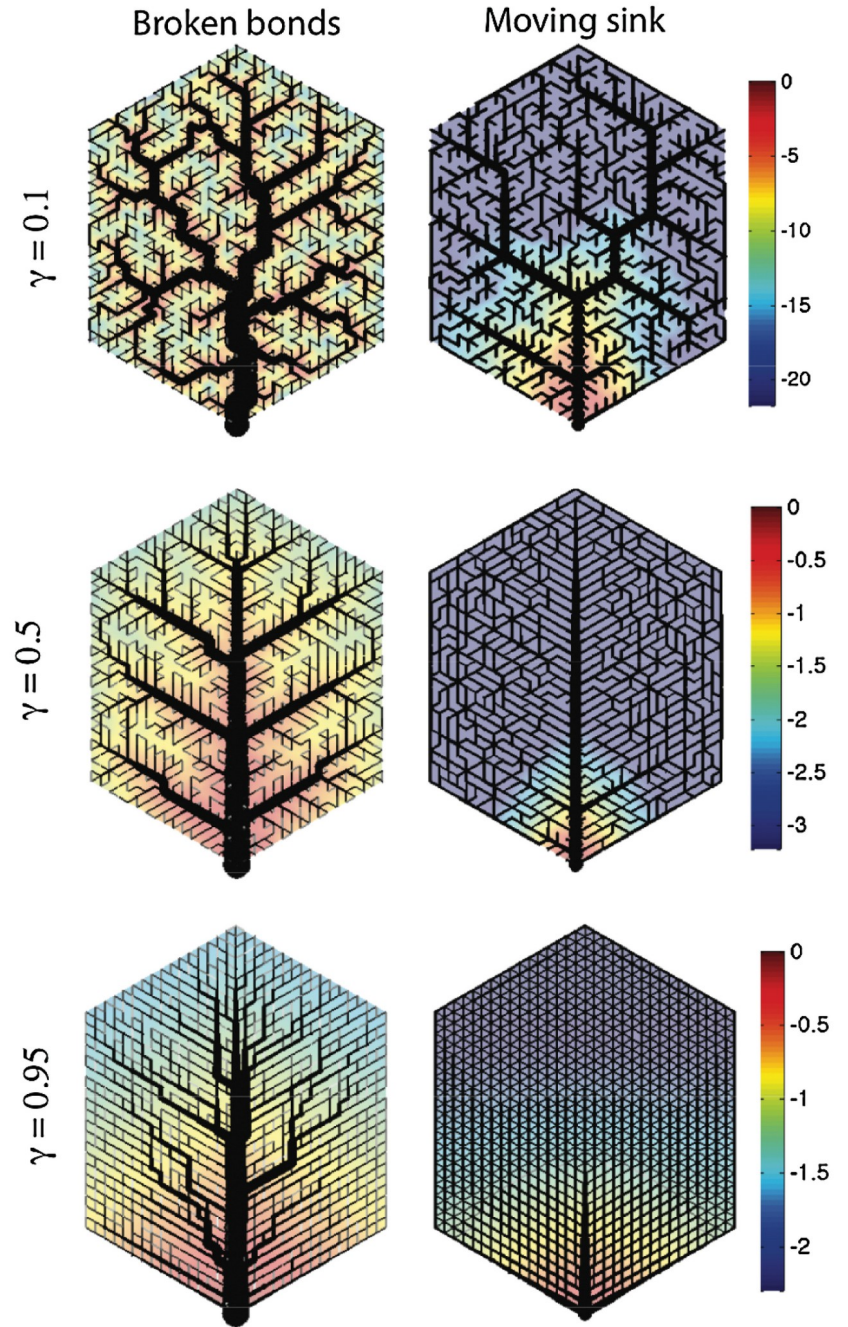
$$C_{kj}^{ab} = C_{kj}(1 - \delta_{ak}\delta_{bj} - \delta_{aj}\delta_{bk})$$

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

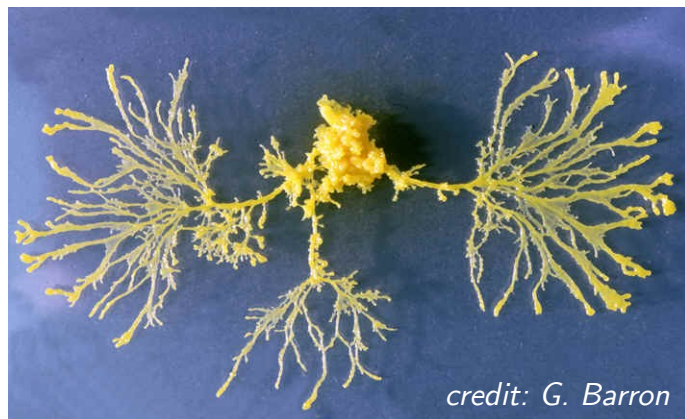
b) Moving sink

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

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 .

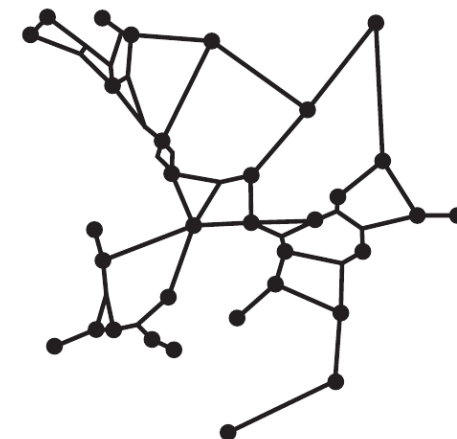


Letting nature do the job: networks created by the slime mould

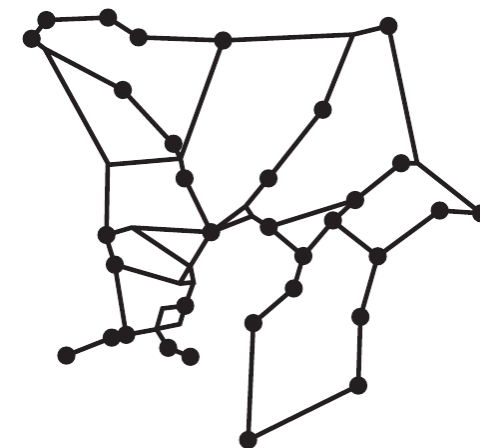


Tero et al., Science **327**, 439 (2010)

Slime mould



Tokyo railway



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

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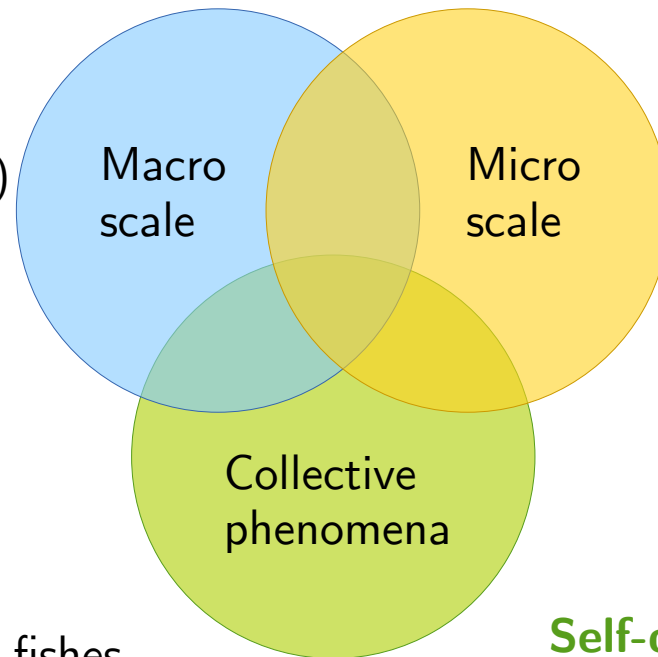
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Some literature

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

M. Lisa “*The physics of sports*”

R.P. McCall “*Physics of the human body*”

I. Stewart “*The mathematics of life*”

R. Phillips et al. “*Physical biology of the cell*”

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*”

Ed Yong “Not exactly rocket science”

2006-2008 <https://notexactlyrocketscience.wordpress.com/>

2008-2012 <http://blogs.discovermagazine.com/notrocketscience/>

2015-present <https://www.theatlantic.com/author/ed-yong/>