“In the wild”, free movement

Single colony, one cycle of movement

The Psychophysics of Non-neuronal Cognition

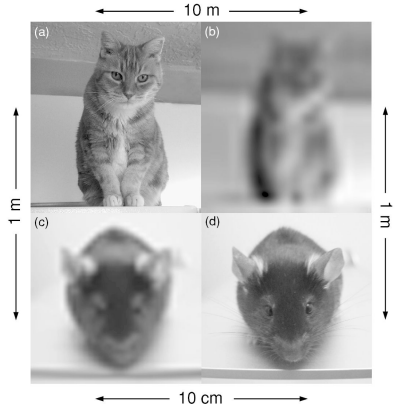
Bradly Alicea, Akshara Gopi, Richard Gordon, Thomas Harbich, Jesse Parent, Asmit Singh, and Ujjwal Singh

Psychophysics in Animal Models

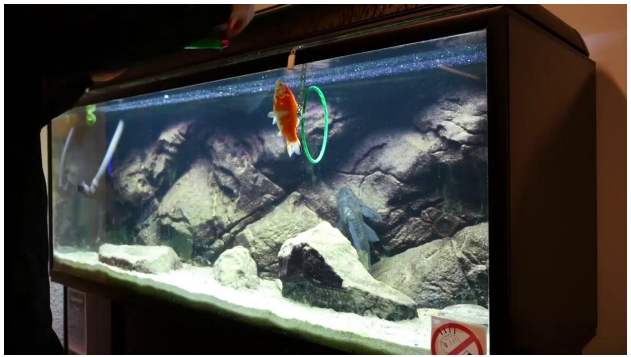
Stebbins, W.C. (1970). Animal Psychophysics: the design and conduct of sensory experiments.

Humans

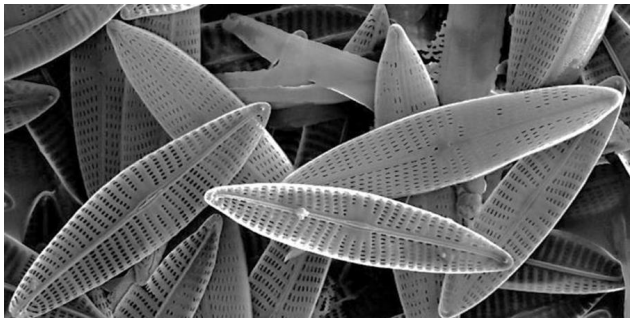
Mouse



Goldfish



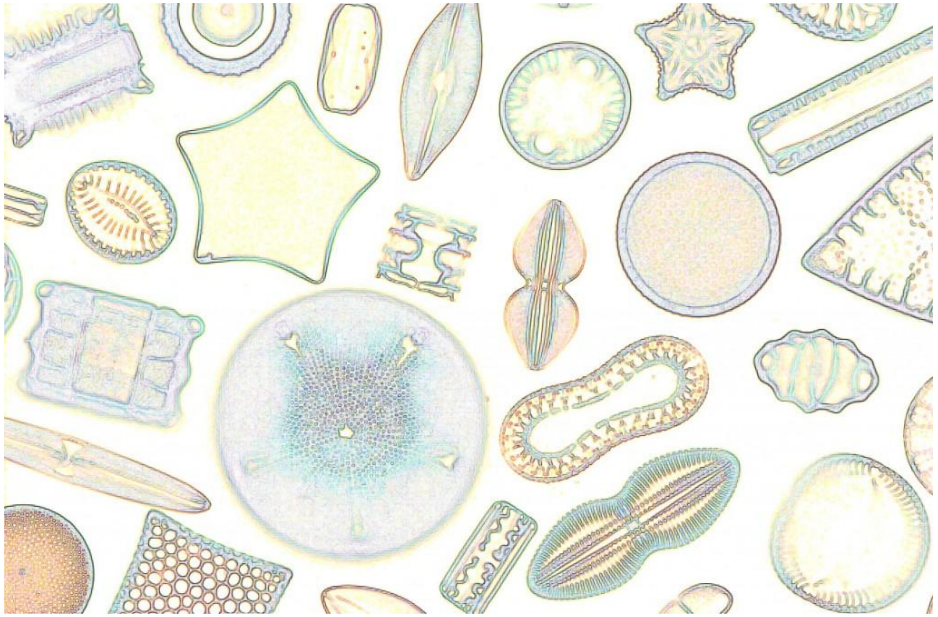
Diatoms??



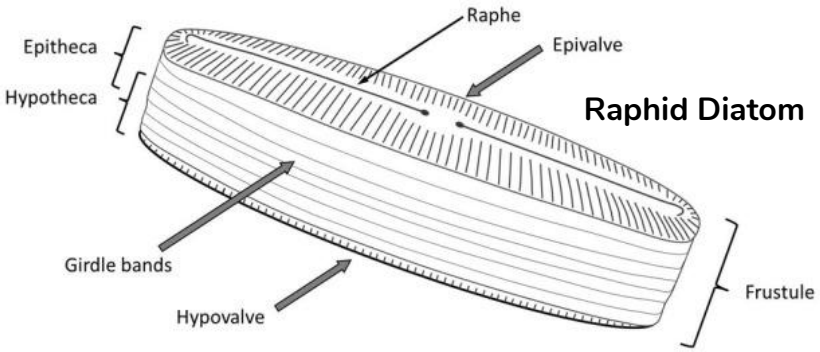
Sarris, V. (2006). Relational Psychophysics in Humans and Animals.

Short Introduction to Diatoms

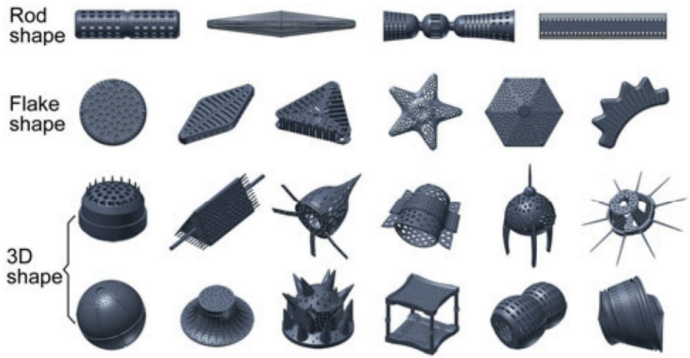
Algae, single-celled Eukaryotes with plant-like characteristics (chlorophyll) and a silica cell wall.



Frazer, Diatoms, or The Trouble with Life in Glass Houses. *Scientific American*, October 16, 2012.



Size: 10-80µm



Analysis of Bacillaria Movement in Culture

Accordian-like movement (series of oscillators).

Phases of movement (free-sliding, changes in momentum during the oscillation).

Model this as a series of coupled oscillators, but movement can vary due to stimuli.

Lyon (2015). The cognitive cell: bacterial behavior reconsidered. *Frontiers in Microbiology*, 6, 264.

> Non-neuronal cognition "*total set of mechanisms and processes that underlie information, acquisition, storage, processing, and utilization*"

Baluska and Levin (2016). On Having No Head: Cognition throughout Biological Systems. *Frontiers in Psychology*, 6, 264.

> Extracellular matrix ideal as a memory medium. Internal (model) stigmergy: "*physical traces that can be referenced and read in the future*"

Baluska and Levin (2016). On Having No Head: Cognition throughout Biological Systems. *Frontiers in Psychology*, 6, 264.

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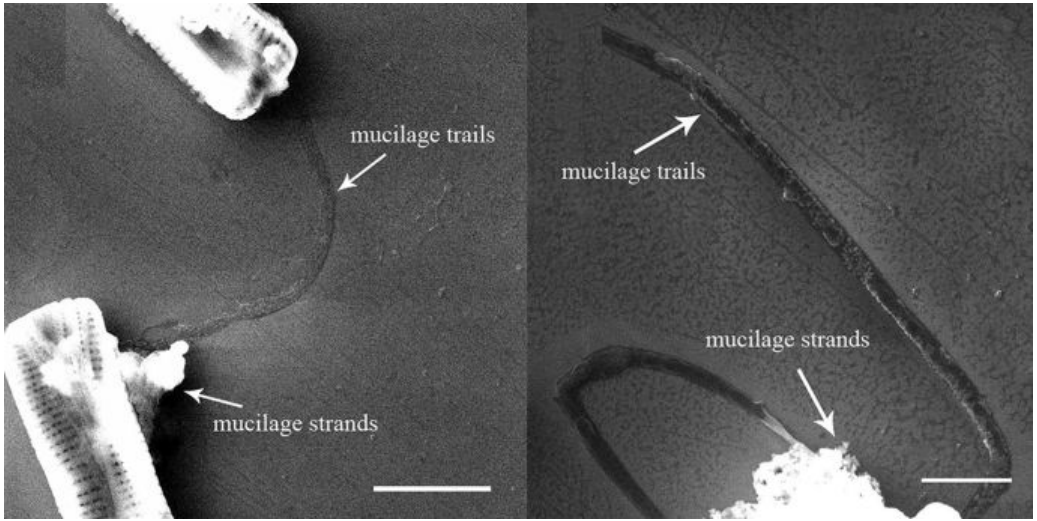


Secreted polymers that completely encase the cell and are responsible for adhesion and interactions with the external environment.

IMAGE: Chen et.al (2019). *Scientific Reports*, 9, 7342.

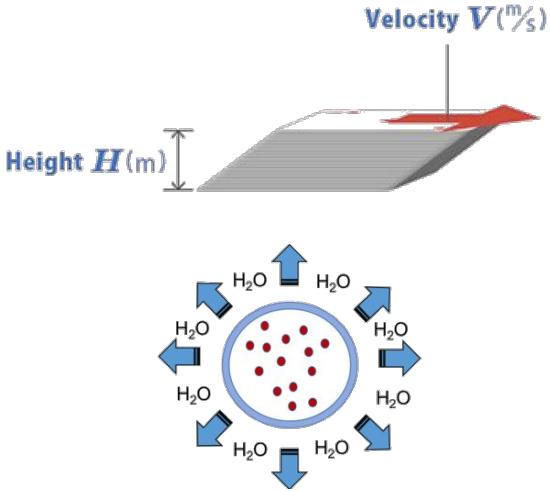
The sensory world (habitats) experienced by Diatoms

Bach et.al (2019). Effects of elevated CO2 on a Natural Diatom Community in the Subtropical Northeast Atlantic. *Frontiers in Marine Science*, 6, 75. doi:10.3389/fmars.2019.00075.

CO2 sensation and concentration, affects growth. High CO2, reduced grazing pressure, effect on photosynthesis.

Bondoc et.al (2018). Decision-making Physiology of the Benthic Diatom *Seminavis robusta*: Searching for Inorganic Nutrients and Pheromones. *ISME Journal*, 13(2), doi:10.1038/s41396-018-0299-2.

Falciatore et.al (2000). Perception of Environmental Signals by a Marine Diatom. *Science*, 288(5478), 2363-2366.

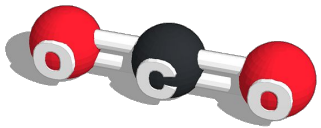


Diatoms have sensory systems for detecting/responding to fluid motion (shear), osmotic stress, and iron abundance.

Heiden et.al (2016). Light Intensity Modulates the Response of Two Antarctic Diatom Species to Ocean Acidification. *Frontiers in Marine Science*, 3, 260.

CO2 and light availability affect diatom physiology: three light intensities. Low light affects physiology, distinct physiology traits.

Localize sources of chemokinetic and chemotactic mobility. Attraction pheromone-guided search to find mates (restore cell size).



Collective Pattern Generators (CoPG)

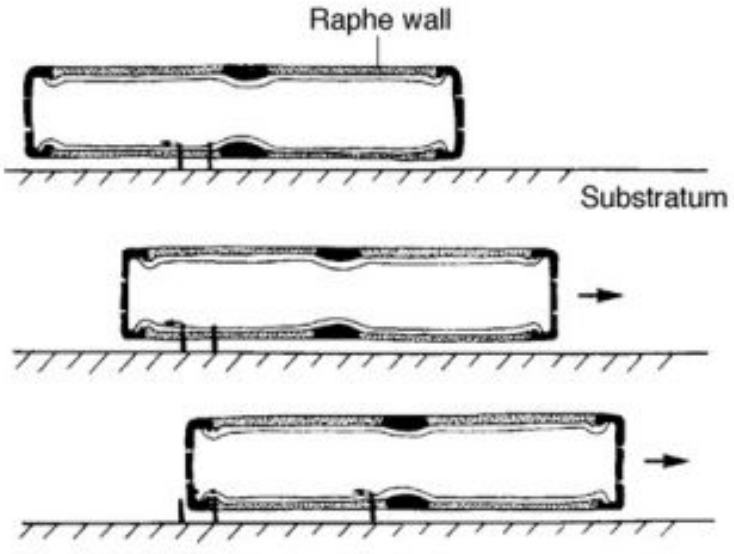
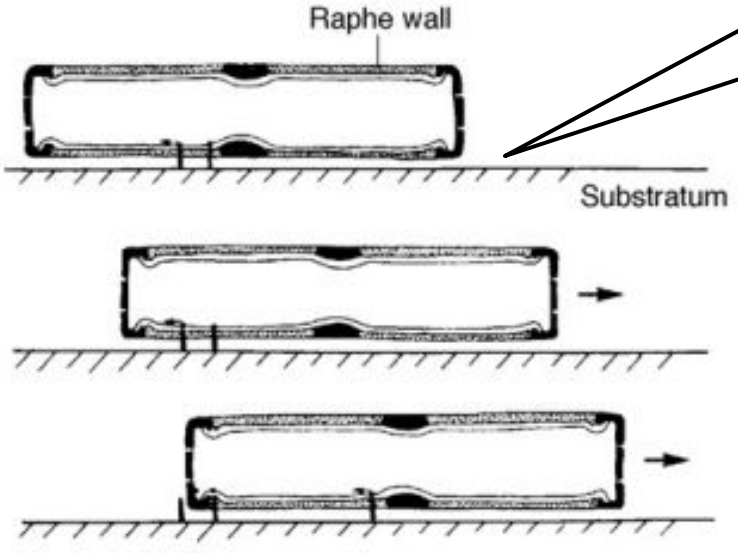


Figure 9, Heintzelman, M.B. (2006). Cellular and Molecular Mechanics of Gliding Locomotion in Eukaryotes. *International Review of Cytology*, 251, 79-129.

Collective Pattern Generators (CoPG)



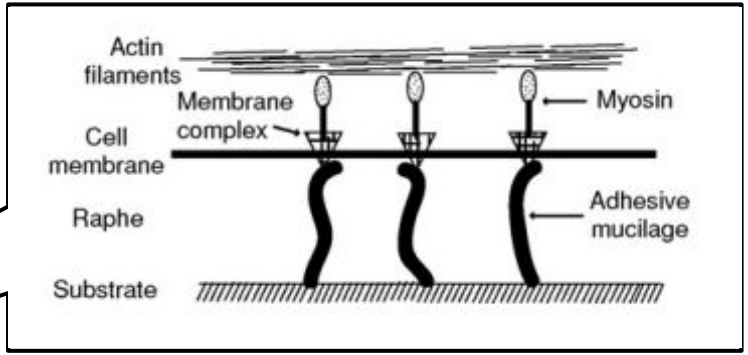


Figure 9, Heintzelman, M.B. (2006). Cellular and Molecular Mechanics of Gliding Locomotion in Eukaryotes. *International Review of Cytology*, 251, 79-129.

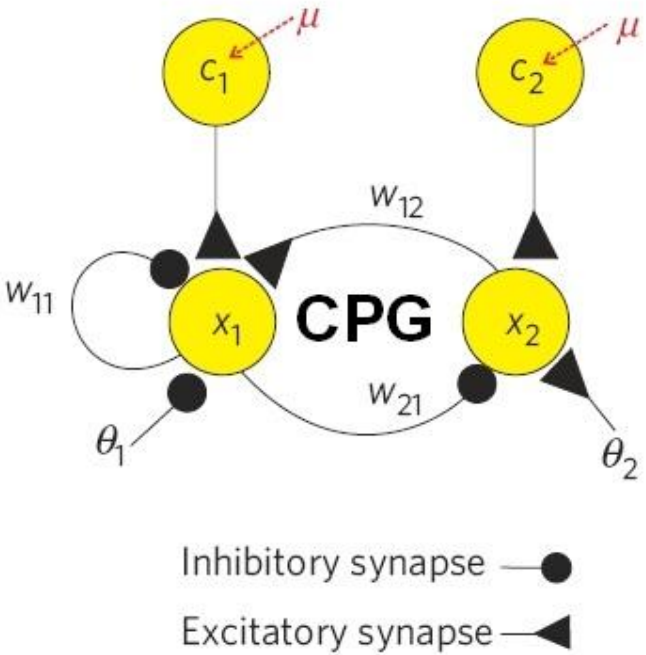
Actin and myosin system that interact between cell bodies, produce collective movements.

We will build our model around propulsion as the mode of movement:

- Psychophysics model (environmental inputs, actin filament outputs).
- oscillatory movements are a small subset of behavior, but allows us to view the CoPG circuit.
- Psychophysics model accounts for a wide range of behaviors outside of oscillatory movements.

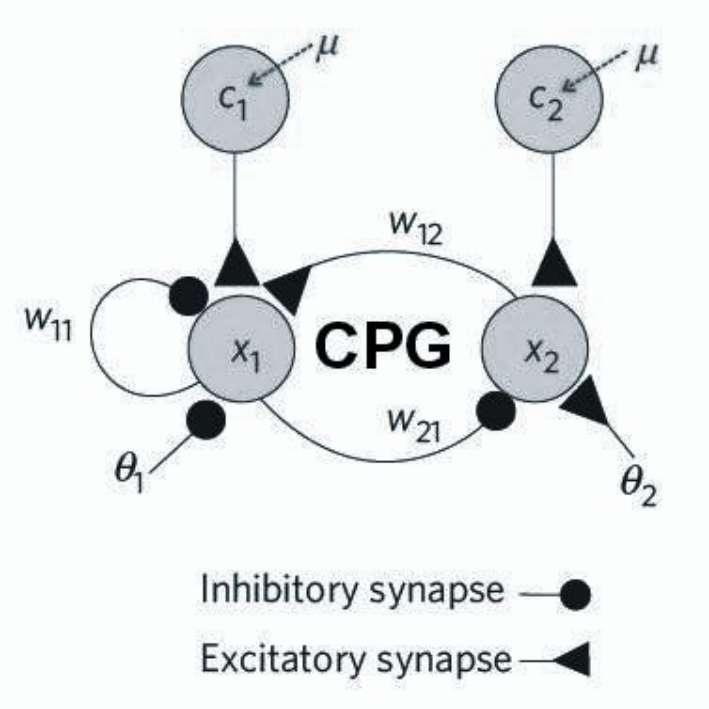
CPG vs. CoPG

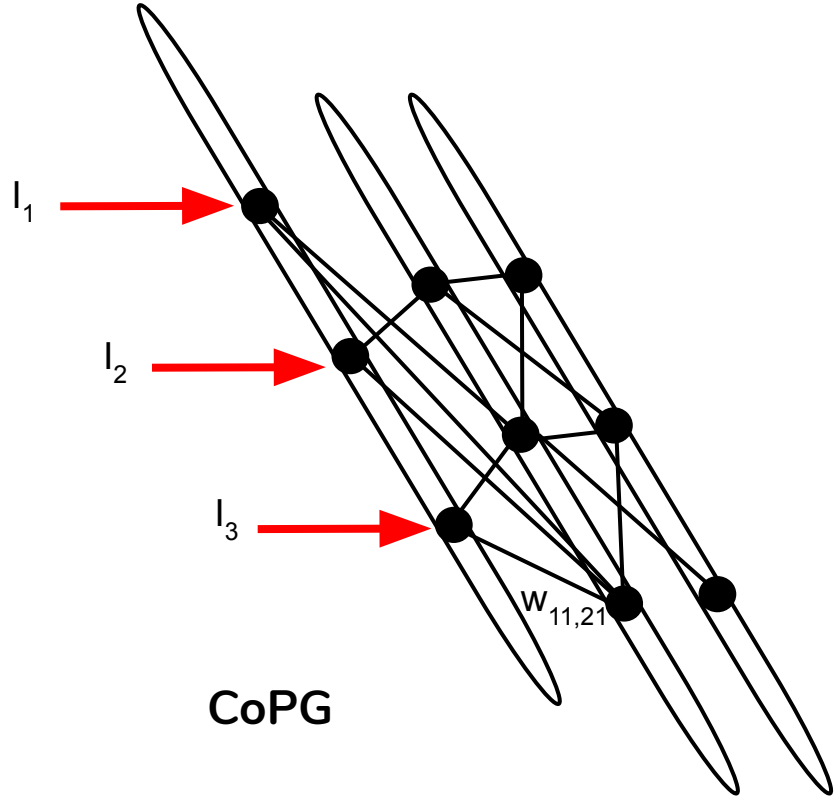
CPG



CPG vs. CoPG

CPG





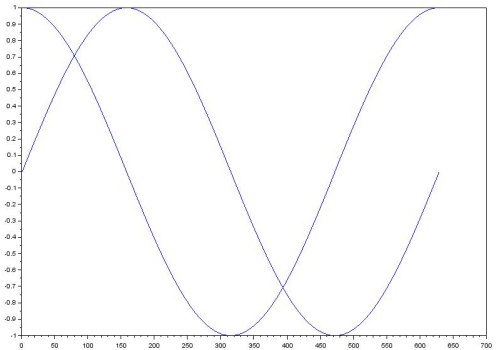
CoPG

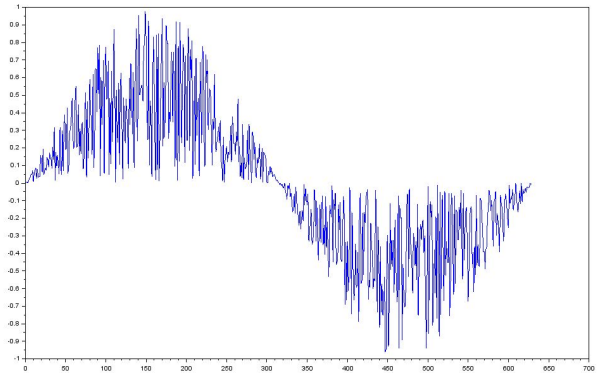
We can use a series of coupled sinusoids to model an ideal CoPG:

- Half-phase (90 degrees out of phase), Quarter-phase (45 degree out of phase) can be used to simulate discoordination.

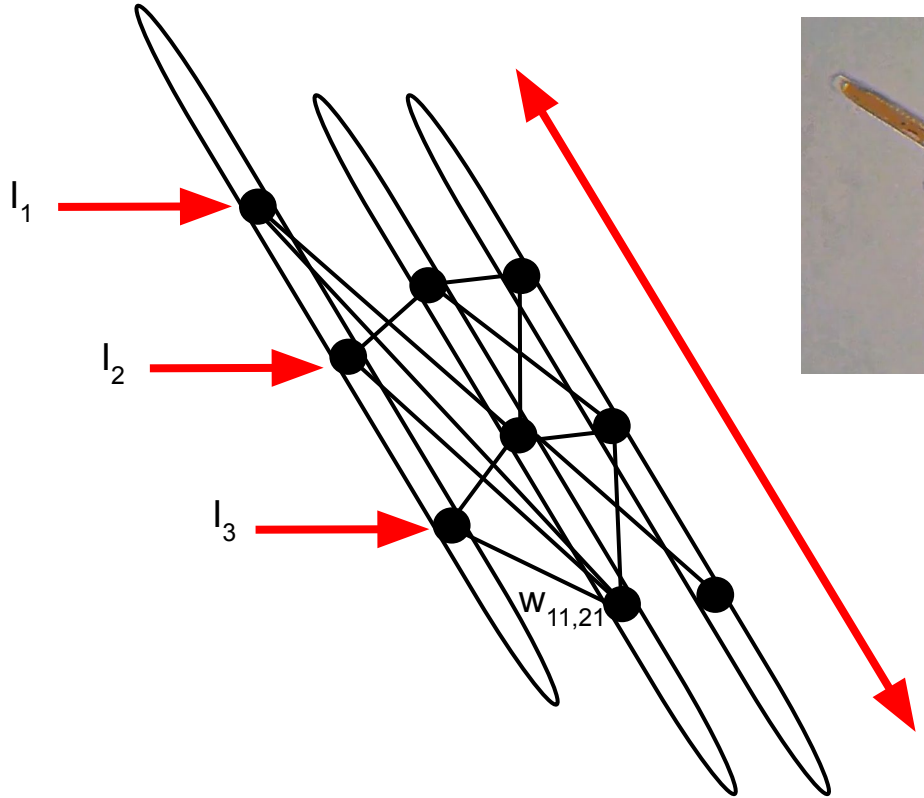
- Additive noise can also be used to simulate discoordination.

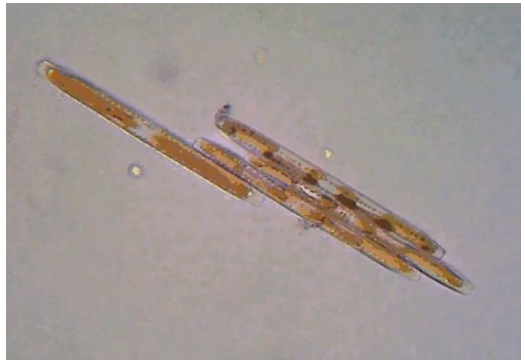
- Speed of movement (derivatives of position) can also be varied according to effects of stimulus.

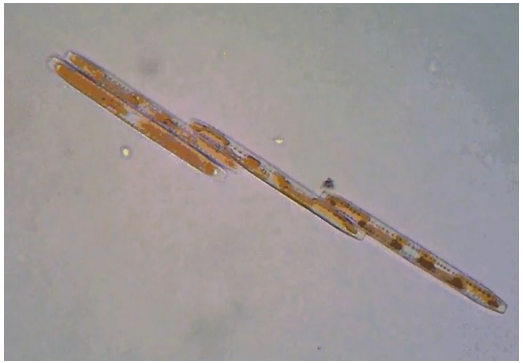




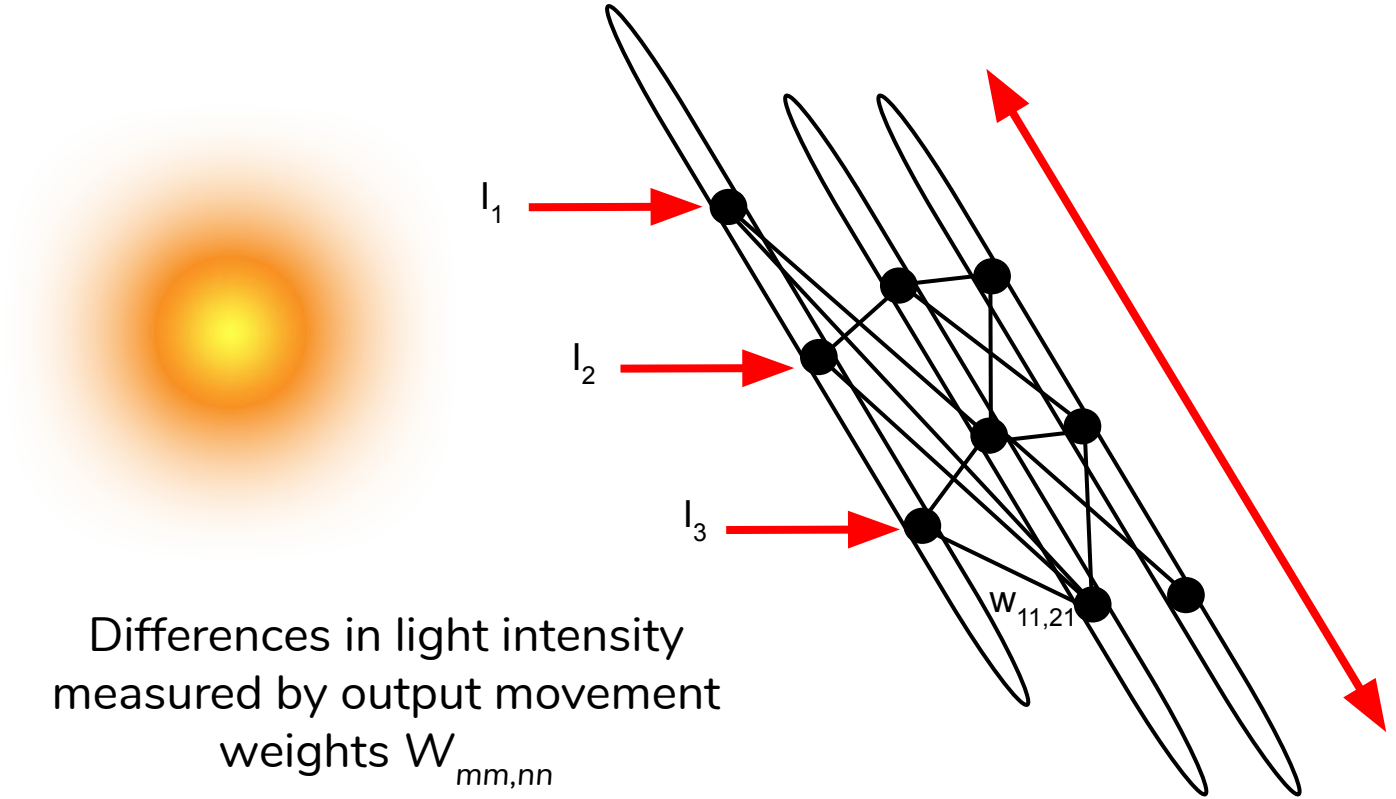
Differences in stretch phase in coupled cells





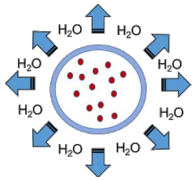


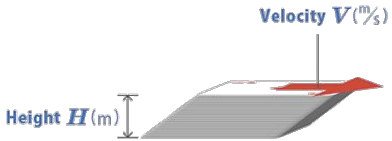
Sensory Thresholds (just noticeable difference)

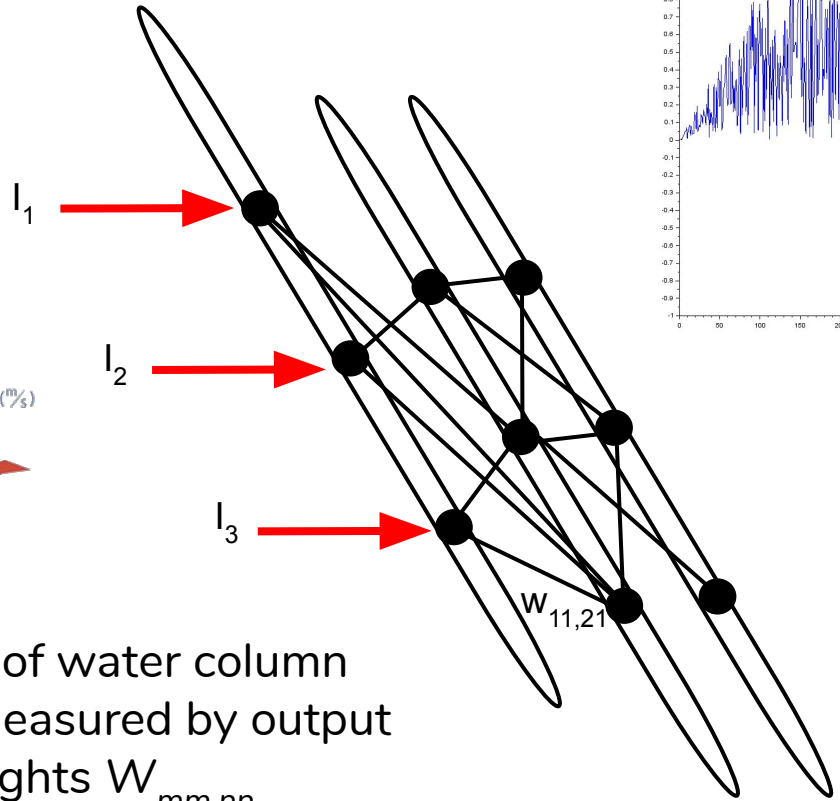


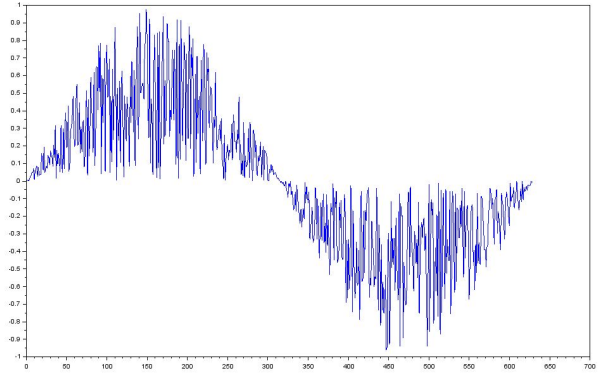
Differences in light intensity measured by output movement weights $W_{mm,nn}$

Signal-to-Noise Ratio





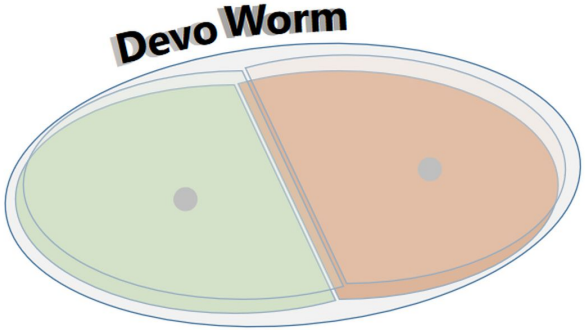




Dynamical sensing of water column physical properties measured by output movement weights $W_{mm,nn}$

Thanks for Your Attention!

Acknowledgements



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https://github.com/devoworm

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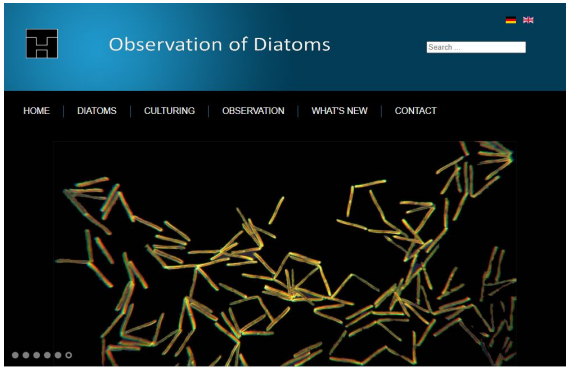

Dr. Thomas Harbich's Observation of Diatoms

https://diatoms.de/en/

Check out the weekly DevoWorm group meetings on YouTube! https://tinyurl.com/y4c254fu