PHYSICS OF BEHAVIOR

⊷ Tom Shimizu

Research in the Physics of Behavior group aims to achieve a physical understanding of biological behavior by connecting dynamics across scales. Our experiments quantify dynamics at multiple levels of organization, from molecules to whole organisms. We develop theoretical and computational frameworks to link phenomena at different scales. Understanding is achieved when we succeed in reducing higher dimensional data to interpretable lower-dimensional descriptions. When those descriptions have predictive value over higher-dimensional dynamics, we call the understanding mechanistic. Ultimately, we seek design principles that explain nature and inspire applications by studying those mechanisms in terms of functional causes and consequences.

Highlights

- A random-walk model of nematode motility [1]: By imaging and analyzing C. elegans motility at high throughput, we extracted a statistical model of whole-animal behavior with just seven parameters.

- Motility and spatial competition as a mechanism for coexistence [2]: Combining experiments with theory, we revealed the fundamental role of physical space in competitive outcomes in microbial ecology.

- Near-critical tuning of a protein signaling array [3]: Using single-cell FRET technology developed in our group, we revealed how bacteria tune the strength of signaling protein interactions close to a critical point.

Plans

In recent years, we have begun extending our multiscale approach beyond whole organisms, to the level of collective population-scale behavior [3] and even ecological / community-level dynamics such as symbiosis [5]. In the coming years, our ambition is to establish the biophysics of soil – a functional complex matter of fundamental importance – as a new interface between physics, mechanistic biology and ecology. It is an exciting frontier that brings together all three experimental model systems (bacteria [2,3], nematodes [1,5], and fungi [4]) we have established in our group over the years, with substantial real-world implications for biodiversity and sustainability.

Key research items

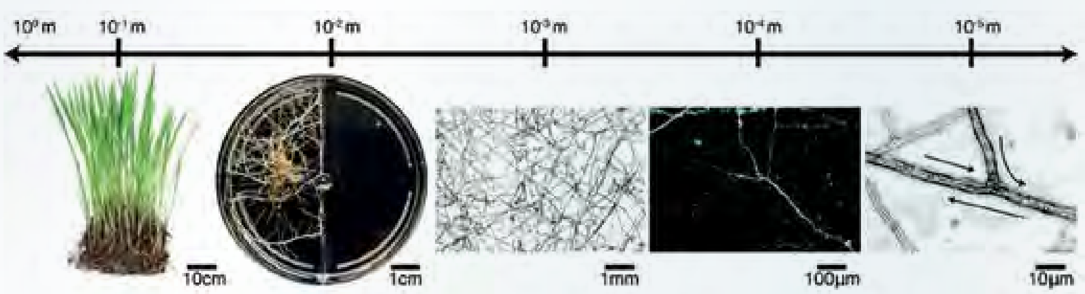
1. S.J. Helms, M.W. Rozemuller, A.C. Costa, L. Avery, G.J. Stephens and T.S. Shimizu, *Modelling the ballistic-to-diffusive transition in nematode motility reveals variation in exploratory behaviour across species*, J. R. Soc. Interface 16, (157) (2019)

2. S. Gude, E. Pince, K.M. Taute, A.B. Seinen, T.S. Shimizu and S.J. Tans, *Bacterial coexistence driven by motility and spatial competition*, Nature 578, 588-592 (2020)

3. J.M. Keegstra, F. Avgidis, Y. Mullah, J.S. Parkinson, T.S. Shimizu, *Near-critical tuning of cooperativity revealed by spontaneous switching in a protein signalling array,* bioRxiv doi:10.1101/2022.12.04.518992 (2022)

4. M.D. Whiteside, G.D.A. Werner, V.E.A. Caldas, A. van't Padje, S.E. Dupin, B. Elbers, M. Bakker, M. Klein, G.A.K. Wyatt, M.A. Hink, M. Postma, B. Vaitla, R. Noë, T.S. Shimizu, S.A. West and E.T. Kiers, *Mycorrhizal Fungi Respond to Resource Inequalityby Moving Phosphorus from Rich to PoorPatches across Networks*, Current Biol. 29, (12), 1-8 (2019)

5. W.M. Rozemuller, *C. elegans behaviour and brain dynamics; a physical exploration*, PhD Thesis, VU University Amsterdam, 2023-04-26



Multiscale investigations of arbuscular mycorrhizal fungi (AMF) [5] (pictured), as well as bacteria [2,3] and nematodes [1,5] will form a foundation for our future work on the biophysics of soil – a functional complex matter of fundamental importance for biodiversity and sustainability.