NITMB Workshop Report

Curiosity-Driven Dialogue and Collaboration Between Experiment and Theory

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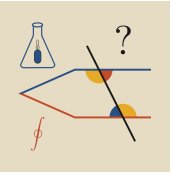

Workshop Philosophy and Overview

Collaborating across disciplines and uniting theoretical and experimental approaches is often necessary to advance our understanding of natural phenomena and unlock progress on open problems. This workshop explored how curiosity is more than a virtuous mental stance, but in fact a practical activity to navigate these interdisciplinary challenges while in pursuit of understanding biological systems. Often, generative collaborations between theorists and experimentalists do not start from pre-planned philosophical foresight. Instead, they frequently start from humble coincidences that sharpen into questions nurtured by dialog. This power of unexpectedly learning something new and asking, “Huh, that’s interesting; I wonder…” argues for the value of juxtaposing perspectives of careful thinkers willing to teach, and allowing unexpected (and intrinsically unpredictable) connections to emerge naturally from inspiration. Crucially, such generous and reciprocal exchanges of these intuitions lead to new collaborations, formalisms, and research directions.

This spirit motivated the experiment of our workshop, which was composed of roughly 50 participants of varying career stages (in an even split of graduate students, postdocs, and faculty) with expertise ranging across mathematics, biology, physics, computation, and engineering. Some participants employed purely empirical or theoretical research approaches, while others employed both theory and experiment in their work. We as organizers deliberately refrained from asking prematurely in advance how each talk philosophically or scientifically might fit together, instead allowing the rhymes across talks and participants to develop more spontaneously. In this vein, invited talks were organized to alternate between disciplines and approaches, and short lightning talk vignettes were scattered throughout where speakers were asked to be speculative and make the audience curious, rather than “pitch” their research. Rewardingly, a nearly even balance of both established and early career researchers gave excellent and provocative talks. Many participants chose clear chalk talks or accessible tutorials. These features helped all of us come away inspired by fresh

problems, emerging collaborations (whose blooming will necessarily occur on multiple longer timescales), and unexpected approaches to living systems.

Emerging Themes and Research Questions

Below we loosely paraphrase a subset of themes and questions invited by the participants' talks during the workshop. This highly-stylized summary is necessarily incomplete (and filtered by our own subjective impressions), but we feel reflects the exciting diversity of conversations that were catalyzed by this workshop.

Lightning talks

- **Alasdair Hastewell** beckoned the audience to question how biological systems adapt in regions of the world where lightning, in fact, strikes often.
- **Nour Khoudari** explored how robustness in fern morphogenesis can be demonstrated through reaction-diffusion mathematical models.
- **Mariana De Niz** asked: how can clinical diagnostics be improved by integrating together diverse biomedical imaging and data from wearable devices?
- **Megan Morrison** suggested an underlying low-dimensional structure in the apparently high-dimensional responses of neurons in *C. elegans*.
- **Prathyusha K.R.** demonstrated how polymer physics may help us understand how entangled worm groups associate with aquatic plant structures.
- **Milena Chakraverti-Wuerthwein** wondered how we can discover the covariation of species abundances and environmental variations from soil microbe data in rapidly-changing environments.
- **Yicong Fu** showed how computational fluid dynamics reveals the consequences of perforation in structures important for swimming.
- **Raine Detmer** showed how dynamical systems modeling can reveal how coral populations respond to changes in environmental conditions through their symbiotic relationship with algae.
- **Yufei Xiao** asked: explored through theories of collective behavior and data, how might flocks of herd animals naturally revitalize the use of agricultural land?
- **Kristina Braverman** explored how machine learning approaches can help us process images and understand behavioral signatures displayed in morphologically plastic organisms.

Research talks

- **Vicky Hoznek**, a developmental biologist, highlighted the role of mechanics in development, and how this mechanics arises from the underlying molecular structure of the structurally supportive basement membrane in fruit fly embryos.
- **Anne Pringle**, an experimental mycologist, revealed the rich spectrum of urgent biophysics puzzles arising in mushroom spore dispersal.
- **Saad Bhamla** and **Vishal Patil** shared informative vignettes from their vigorous and established collaboration between theory and experiment. They gave a behind-the-scenes, metacognitive reflection about practices and heuristics that helped navigate the natural divides between theoretical values and experimental tests, as they explored the rapid tangling and untangling of worm collectives through experiments and topology.
- **Riccardo Ravasio** discussed how error-correction mechanisms in living systems (e.g. in DNA replication) evolve to be fast “for free”, without explicit selection, through a mathematical analysis of the role of stalling.
- **Sunny Jung** showed how fluid dynamics models combined with experiments reveal the mechanisms underlying drinking and diving in animals – importantly, how these animals adapt, exploit, or respond to fluid dynamic instabilities.
- **Amanda Johnson** demonstrated how incisive and controlled experiments with geometrically patterned stem cell colonies can reveal how human mesoderm cells use signaling and mechanical cues to learn during gastrulation.
- **Matthew Nelsen**, joining from the Field Museum in Chicago, asked how analysis of patterns in evolutionary history (phylogeny) can reveal features of lichen symbiosis with fungus, cyanobacteria, and/or algae.
- **Ben Larson** examined how we can understand complex cell behaviors through exploration of the diversity of function, form, and motility in single-cell protists.
- **Holly Moeller** discussed an example of how mathematical modeling revealed the problem underlying seemingly “broken” experiments examining the metabolic activity of chloroplast stealing marine ciliates. Moeller used a careful chalk talk to walk the audience through how one builds a ‘minimal’ dynamical model of the system.
- **Leanna Owen** shared experiments revealing the key molecular drivers of endocytosis in budding yeast, and discussed the importance of how scientists schematically represent their models as well as the power of animated visuals.
- **Jasmine Nirody** highlighted examples of adaptivity across length and timescales, combining experiments and theory to examine bacterial motility both in terms of locomotive strategies and the underlying biomechanical motors.

- **Andrea Herman** asked enticing questions regarding the three-dimensional complexity of DNA and gene localization: how do thus neighboring genes talk to each other? What influence does spatial colocalization have in gene expression? How can new measurements with unprecedented spatial and temporal resolution help inform these large questions?

Panel

This session, featuring **Anne Pringle**, **Al Volkening**, and **Holly Moeller**, was structured to serve as an open discussion regarding collaborative and curiosity-driven science. They were asked questions such as how one encourages reciprocity in theory-experiment relationships and what heuristics they employ to branch away into new fields and learn. The panel participants noted the role of students in exploring new biological systems as well as the importance of respect and dedicated time in collaborations.

Tutorials

This workshop featured two tutorials. In the first, **Madhav Mani** prompted the audience to question how we think about development, and instead suggested a new perspective from the lens of dynamical systems and topology, using a data-driven approach to understand the evolution of embryonic shape in fly gastrulation. In the second tutorial, **Al Volkening** demonstrated how we can robustly analyze and compare features of data using topological data analysis, a toolkit largely unfamiliar to the workshop audience. Volkening provided a highly practical and conceptual tutorial analyzing data in real time with the workshop participants.

Workshop Feedback and Future Directions

The value of this workshop to the participants was affirmed by enthusiastic personal and official survey feedback, perhaps most gladly in the form, “Please let this workshop be a recurring event!”. Several participants noted that the workshop felt balanced across experiment and theory, and junior participants expressed an appreciation for how invited talks were not strictly given by faculty, highlighting also the work of graduate students and postdocs. Participants noted that this workshop led them to pursue new collaborations and expand their research networks, as well as think about how to improve their science communication. The main constructive criticisms were a desire for more discussion time and structured mixers or brainstorming sessions later in the workshop to foster the chance of developing connections and ideas on particular open questions raised.

This workshop highlighted fantastic interdisciplinary research across scales and systems in biology, as well as exposed participants to new ideas outside their respective fields in accessible, humble ways. Most importantly, this workshop raised important discussions of how we pursue collaborative research, and the challenges of connecting, communicating, and developing scientific relationships across disciplines toward the unified goal of exploring biological systems. The consensus, from our perspective as organizers, is that approaching interdisciplinary research with curiosity and generosity serves to inspire and drive impactful new research forward.