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as of 10-Jul-2018

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Major Goals: Predicting the large-scale and long-term collective behavior of a population of swimming organisms in terms of their small-scale intermittent movement is a major challenge in biomathematics. This project took a mechanistic approach toward understanding the unsteady dynamics of zooplankton known as copepods. Major goals of the project were to (i) develop a mathematical model that accounts for sudden changes in velocity as commonly observed in the behavior of zooplankton; (ii) perform laboratory experiments to assess the validity of the model assumptions and predictions; (iii) to gain a general understanding of the dynamics across different length and time scales.

The initial plan was to represent each swimming organism as an individual agent alternating randomly between two arbitrary speeds in the model. The objective was to obtain analytical expressions for important statistical quantities such as the effective diffusivity. A careful analysis of the model led to an exciting discovery that the results could be obtained in a more general setting, where individuals switch stochastically not only between two but any number of distinct speeds. However, preliminary experiments showed that the changes in speed are not entirely random as initially assumed. Instead they are governed importantly by sensory cues from the external environment. Thus the focus of the project shifted toward identifying the key sensory cues that trigger behavioral responses and how such responses in turn modify the external environment.

Accomplishments: A new mathematical model was developed to obtain analytical formulas for important statistical quantities: the mean-square displacement and effective diffusivity of individuals undergoing unsteady motion, jumping randomly between distinct velocities. The results reveal how the intermediate to long-term behavior depends importantly on the detailed assumptions about short-term fluctuations, such as the transition rates between distinct speeds and whether the fluctuations are deterministic or stochastic. These findings imply that any accurate model of a living system must adequately account for the transient dynamics of individual components making up the system. A manuscript outlining the theory is on track to be published in the Journal of Statistical Mechanics: Theory and Experiment. Two reviewers recommended publication with minor corrections, which we are currently addressing.

Experimental observations of copepods in the laboratory revealed that, contrary to the model assumptions, the swimming behavior depends importantly on what they sense. A striking manifestation of this is when a predatory fish approaches slowly. The fish creates a hydrodynamic disturbance which triggers a rapid escape response in copepods. Based on preliminary observations, a mathematical model was formulated to quantify what information becomes available to a copepod while a predator approaches slowly. The model shows that copepods perceive an intriguingly uncertain world yet they can still make informed decisions about which direction to escape. The theory was presented at the 2017 Society for Mathematical Biology Annual Meeting in Salt Lake City, Utah, and published in the Bulletin of Mathematical Biology.

The effect of unsteady motion on the external fluid environment was investigated in a model system consisting of a pair of oscillating rods. A theoretical model predicted that synchronous oscillations produce no net motion in the surrounding fluid, but a simple phase delay leads to complex flow patterns at a much larger scale. Scaled-up experiments performed in a bath of silicone oil validated the theory. The findings demonstrate the intriguing link between the rapid fluctuations at the microscopic scale and the slow resultant dynamics at the macroscopic level. The results were published in the Physical Review Fluids.

Training Opportunities: This project offered training for two graduate students and three undergraduate students who all assisted in the performed research. In addition, the research provided a basis for a new graduate course on stochastic processes, which the PI taught in Fall 2016. The course was completed by 8 students from mathematics and engineering departments.

Results Dissemination: The laboratory participates regularly in outreach events to promote mathematics and science in general to the broader community in Hawaii. In January 2017, a Robotics Winter Camp was held on campus to promote hands-on learning in robotics, programming and mathematics. In April 2017 Molokai Math Day was held to reach out to students from the Molokai High School, the only high school on the neighbor island of Molokai. A poster summarizing activities in our laboratory was presented to promote the joys of mathematics and science in general.

Honors and Awards: One of the undergraduate students who assisted in the performed research was awarded the Kern-Clark Award for excellence in undergraduate mathematics in 2017.

The PI was awarded the Departmental Teaching Award in 2017 for offering interdisciplinary research opportunities to students across different departments on campus.

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PARTICIPANTS:

Participant Type: PD/PI
Participant: Daisuke Takagi
Person Months Worked: 1.00 **Funding Support:**
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

Participant Type: Graduate Student (research assistant)
Participant: Don Krasky
Person Months Worked: 9.00 **Funding Support:**
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

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Participant: Rintaro Hayashi
Person Months Worked: 2.00 **Funding Support:**
Project Contribution:

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International Travel:
National Academy Member: N
Other Collaborators:

Participant Type: Undergraduate Student
Participant: Soyoun Joo
Person Months Worked: 2.00 **Funding Support:**
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International Travel:
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Person Months Worked: 1.00 **Funding Support:**
Project Contribution:
International Collaboration:
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National Academy Member: N
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Nothing to report in the uploaded pdf (see accomplishments)