Bioinspired navigation based on distributed sensing in the leech using dynamic neural fields

Sebastian Nichols[1], Catherine Kehl[1], Brian Taylor[1], Cynthia Harley[2]

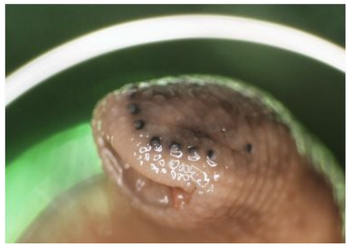
[1]Department of Biology, The University of North Carolina at Chapel Hill
[2]Department of Natural Sciences, Metropolitan State University

Abstract

Leeches use various sensory stimuli to navigate around their environment and perform survival behaviors. Water wave disturbances serve as an important source of environmental information for aquatic animals as they can be the distinguishing factor between a predator or prey. Previous studies show that certain leech species prefer specific frequencies of water waves, suggesting that the leech's sensory receptors have been evolutionarily calibrated to respond to wave frequencies in the safest way. While these animal studies provide important discoveries about the relationship between sensory information and animal behavior, the internal neural mechanisms driving the leech's decision making are still unknown. In this study we present a model that mimics the navigational behavior of the leech using dynamic neural fields and an agent-based simulation. The modeled leech (agent) was placed in virtual environments containing simulated stimuli based on the actual stimuli a leech detects in their natural environment. Sensors placed around the agent detected the stimulus and sent the sensory information to a neural field, which was responsible for calculating navigational behaviors. Data produced by the model matched real-world observed behaviors found in previous leech studies. The development and validation of this model offers a fast and low-cost way to study leech behavior, compliment animal experiments, and provide insights into the mechanics behind distributed sensing in animals. Additionally, the findings may provide insights into novel data-processing methods and architectures for man-made sensory systems that rely on multiple sensors.

What is distributed sensing?

- Refers to a set of sensors around an animal's body allowing it to sense oncoming stimuli
- Leeches are excellent organisms to study distributed sensing due to their thoroughly mapped out nervous systems
- Simulating the leech nervous as well as its distributed sensors can help us learn how animals perceive and navigate around their environment.
- This study uses a dynamic neural field to process sensory information. Neural fields are mathematical models that represent the spike rate patterns of a set of populations of neurons, making it a useful model to process information from distributed sensors.
- *Goal: Present a simulation tool that mimics the sensing, planning, and acting of leeches to compliment animal experiments and improve engineered systems.*



- Leeches use distributed sensors to detect water wave disturbances elicited by nearby prey. Here is a set of visual sensilla located on the head of a leech.

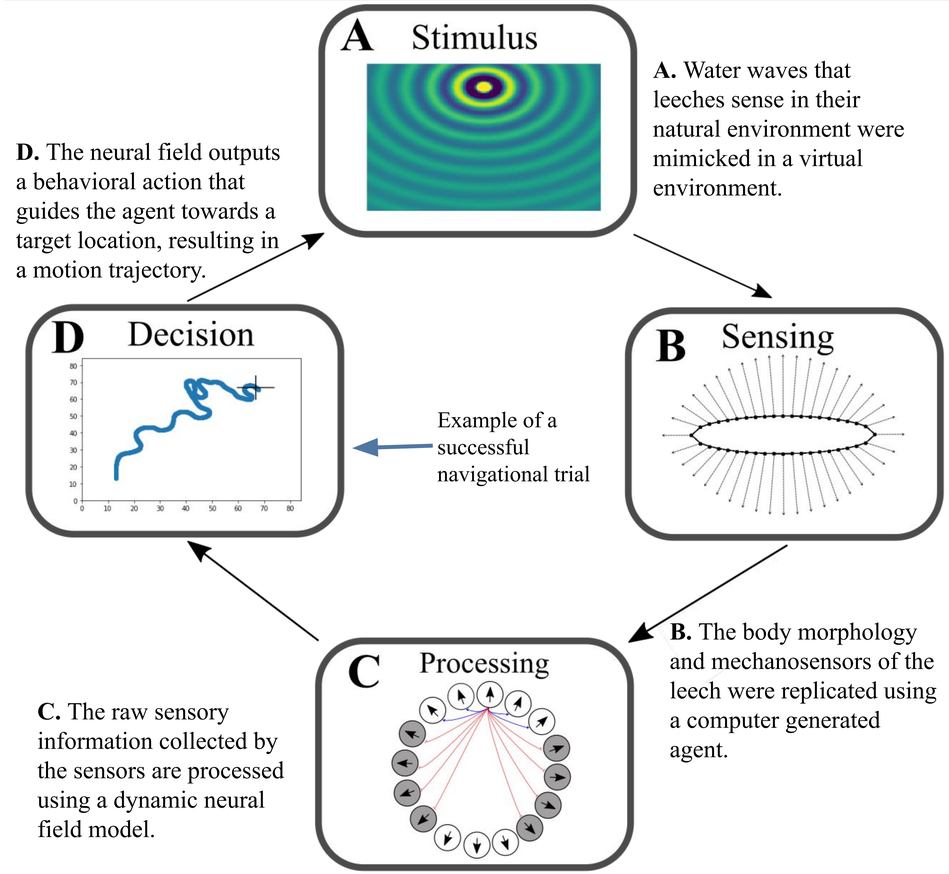
References

- Harley C.M., Cienfuegos J., Wagenaar D.A. (2011) "Developmentally regulated multisensory integration for prey localization in the medicinal leech." J Theor Biol 214: 3801-3807
- Taylor, B.K. (2016) "Validating a model for detecting magnetic field intensity using dynamic neural fields." J Theor Biol 408: 53-65
- Wilson, H. (1999) "Spikes, Decisions, and Actions: The dynamical foundations of neuroscience. New York." Oxford University Press

Acknowledgements

I would like to thank Brian Taylor, Catherine Kehl, and Cynthia Harley for their mentorship and the UNC Summer School and the Office for Undergraduate Research for their funding..

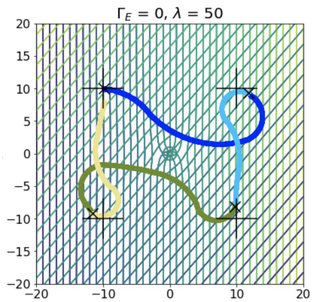
Simulation Components



Conclusions

- The proposed model acts as a framework to simulate animal sensing, processing, and acting
- It can mimic the navigational behavior of a leech without needing any optimization
- It can easily be extended to experiment with different sensory detection methods or entirely different sensory modalities

Future Work

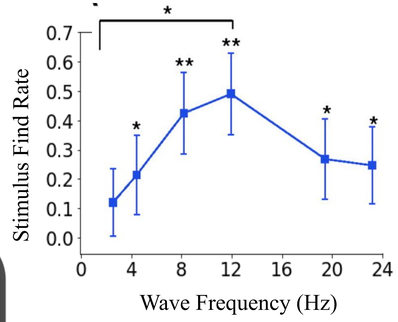


Successful migratory trajectory of an agent using distributed sensors and dynamic neural fields to detect the magnetic field

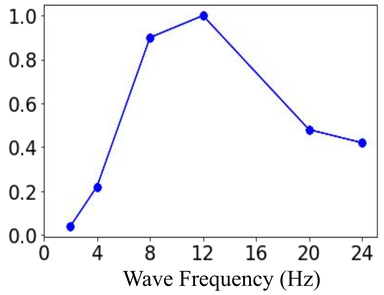
- The model is currently being implemented to sense and process magnetic field stimuli
- We are testing various sensor configurations to study exactly how leeches convert water wave information into neural signals

Results

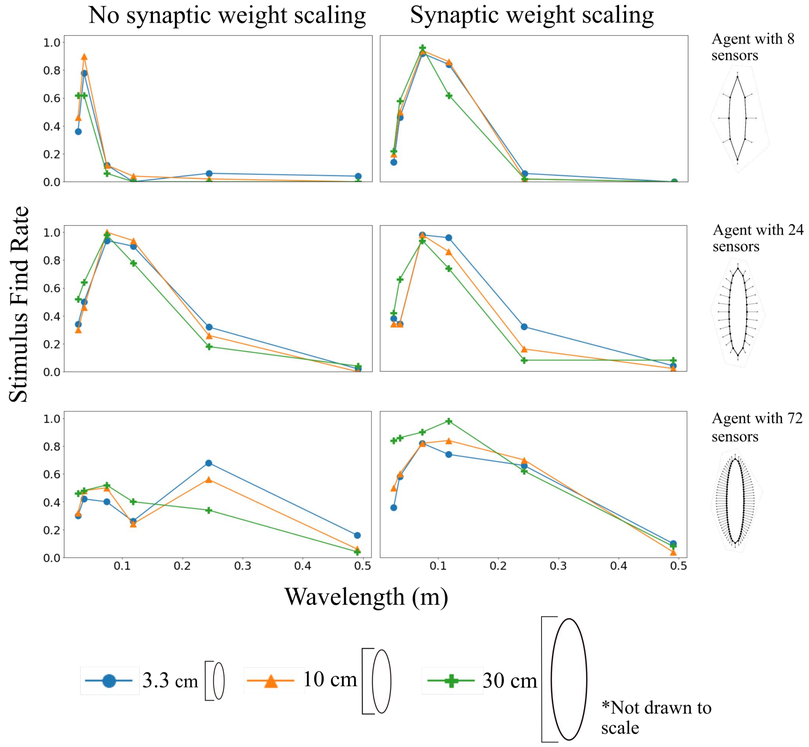
Find rate data collected from animal experiments (Harley, 2011)



Find rate data collected from the neural field model



- Find rate is a measurement of navigat onal success
- The modeled results accurately matcl the animal results trends
- Actual leeches and modeled leeches 1 spond best to waves with frequencies between 8 Hz and 12 Hz



- Further experiments were performed varying the agent's size, sensor quantity, and neural field synaptic weighting (number of connections between neural nodes)
- As sensor quantity increased, the range of preferable wavelengths increased
- Adding in synaptic weight scaling improved over all navigational success