Eigenworms Project Proposal

Background Information

The data source for this project comes from the paper entitled "Resolving Coiled Shapes Reveals New Reorientation Behaviors in C. Elegans" by Broekmans et al. There are two types of turns observed in *Caenorhabditis* elegan behavior, an omega turn and a delta turn. An omega turn is a 180 degree turn performed by the worm to escape from a stimulus or during foraging. A delta turn is a 90 degree turn the worm uses to reorient itself dorsally during foraging (1). Broekmans et al. studied these two behaviors, foraging and escape, to track the movements of the worms and photograph their shapes. During the foraging experiments, 12 worms were studied for 35 minutes and during the escape experiments, 91 worms were studied for 30 seconds. To simulate an adverse environment (such as the presence of a predator), worms were given a heat shock on their heads after 10 seconds and then observed performing the escape behavior for 20 additional seconds. The results show that only omega turns occur during the escape behavior, while both omega and delta turns occur at equal rates during foraging (1).

An "eigenworm," a play on the mathematical term eigenvector, is formed by dividing the body of a worm into 100 segments, each with 100 interior angles. Then, a 100 by 100 correlation matrix can be created showing to what degree the angles relate to one another during worm movement. This matrix, let it be called C, can be decomposed (using linear algebra) according to the formula $C = QAQ'$ where Q is a matrix of the eigenvectors, A is a matrix of the eigenvalues, and Q' is the matrix transpose of Q (2, 3). Thus, the term "eigenworms" was coined in reference to the eigenvectors (matrix Q) of a worm. The first four eigenworms account for over 90% of the variance of all possible worm shapes (4).

Previous Work (Fall 2019)

A linear combination of the first four eigenworms can be used to reproduce almost all worm shapes and a fifth measurement can determine the angle of the worm in relation to the positive x axis. Thus, an image of the shape of each worm at every point in time can be replicated on a graph. Using the S-Map feature in the Empirical Dynamic Modeling (EDM) package in R looped five times, one for each measurement, predictions can be made for how a worm will move based on the attractors created by the foraging and escape behavior data sets. The predictions are relatively accurate with a small average error value based on the difference between the predicted shape and the actual (computer-generated) shape. The two behaviors are claimed to be separate, because the foraging and escape data sets can't cross-predict each other with any statistical significance. The success and accuracy of this project has the potential to lead to predicting the movements of more complex organisms.

Future Directions (Spring 2020)

The current version of the code doesn't include all the data, so the first step to improving/completing this project would be to use the supercomputer at Scripps to generate more accurate attractors utilizing the entire dataset. (My laptop would crash if I tried to run the program like that.) Then, it would make sense to adjust several components of the program, such as how far ahead predictions are being made, to search for the most optimal conditions. Additionally, it seems prudent to make predictions based on all data of the same type but excluding the worm in question. A potential easier way of doing this would be to keep track of the worm data in a multidimensional array such that the worms are counted on one axis, coefficients of the eigenworms are on a second axis, and time points are on a third axis. This would be a less cumbersome method of distinguishing worms. Lastly, a more thorough statistical analysis based on all worms and trials would be necessary to determine the accuracy of the predictions. Hopefully a published paper can come out of this work in the end!

Unanswered Questions

1. How does the transition between worms look in the attractor(s)?
2. Are there various clusters making up a single attractor? Can worms be grouped into subsets of behavior type?
3. How does the data before the heat shock compare to after the shock in the escape response scenario?

Reference Papers

1. Broekmans, Onno D, et al. "Resolving Coiled Shapes Reveals New Reorientation Behaviors in C. Elegans." *ELife*, vol. 5, 2016, doi:10.7554/elife.17227. Link
2. Nunez-Iglesias, Juan. "Eigenworms." *I Love Symposia!*, 2 Oct. 2008, ilovesymposia.com/2008/10/02/eigenworms/. Link
3. Stephens, Greg J., et al. "Dimensionality and Dynamics in the Behavior of C. Elegans." *PLoS Computational Biology*, vol. 4, no. 4, 2008, doi:10.1371/journal.pcbi.1000028. Link
4. Szigeti B, Deogade A, Webb B. 2015 *Searching for motifs in the behaviour of larval Drosophila melanogaster and Caenorhabditis elegans reveals continuity between behavioural states*. J. R. Soc. Interface 12: 20150899. Link