Modeling Navigation of Caenorhabditis Elegans on Thermal Gradients

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INTRODUCTION

Due to their simplistic neuronal network, Caenorhabditis elegans is often used as a model organism for understanding migrational patterns of attractant-seeking organisms. More specifically, their sensitivity to temperature provides insight to navigational regulation between tracks and turns of organisms with a central neural network.

C. elegans have been used to model navigation. Their navigation has been broken down in simplistic behavioral phenotypes.

- **Biased Random Walk-** Regulation of track length based on external conditions
- **Biased Reorientaition**-Improvement of trajectory to decrease the path length between the organism's position and it's goal.

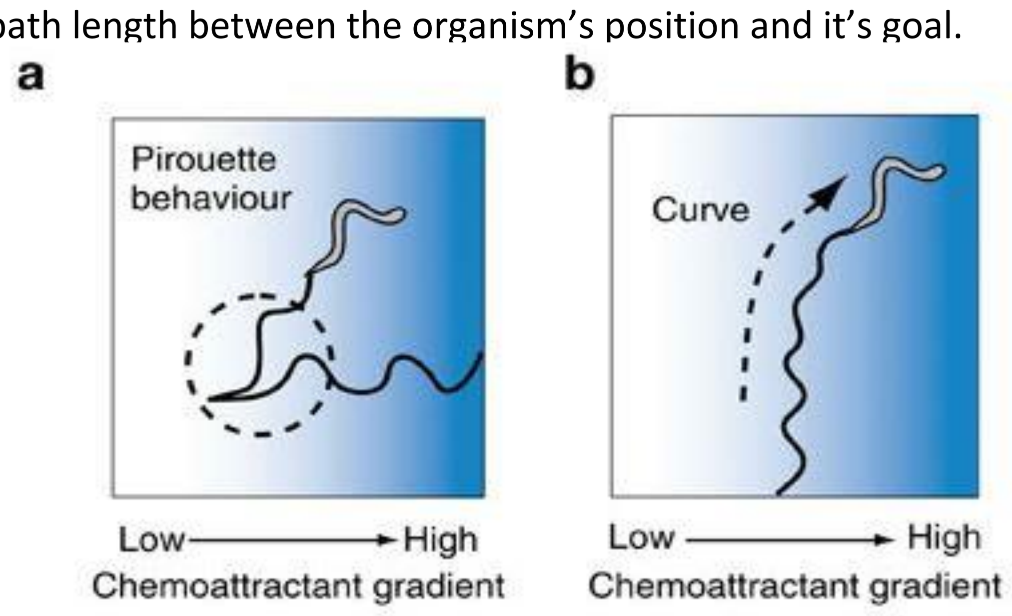

Figure 1: (figure from Yoshida et al 2012)
a) Worm completing a pirouette
6) Worm curving and exhibiting steering

Their type of turns can be further broken down.

- Steering-Slight alterations in the worm's tracks
- Pirouettes-Sharp turns which terminates runs.

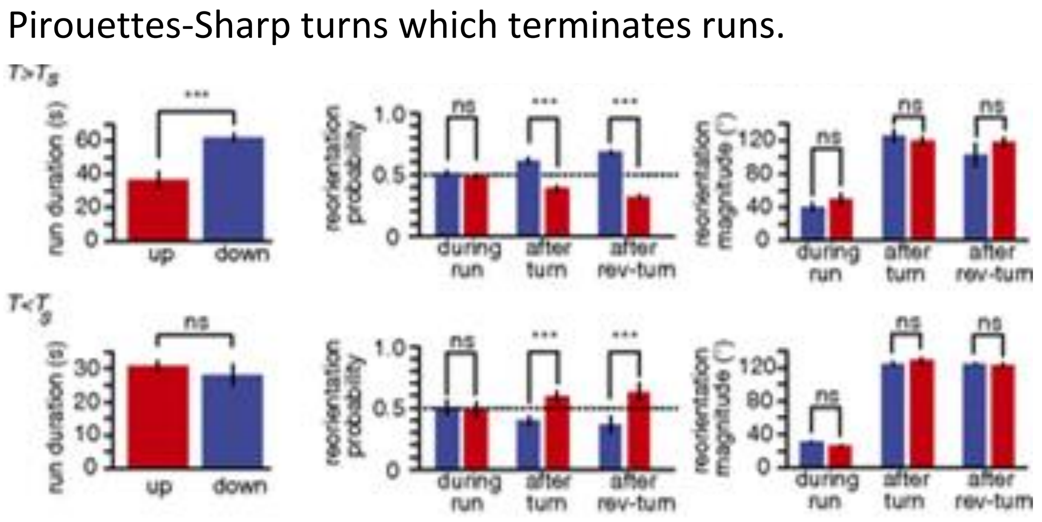

***Figure 2:** Significance of behavioral phenotypes. (figure from Luo et al 2014).*

Previous studies have claimed C. elegans exhibit biased random walk and biased reorientation during negative thermotaxis, but not biased reorientation during positive thermotaxis. We had expected to see the same, but instead found the positive phenotypes were switched.

MATERIALS AND METHODS

- We use N2 worms cultivated at 20 degrees Celsius. For negative thermotaxis, we feed the worms for 2 hours with OP50 at 18 degrees Celsius before the experiment. We wash the worms, place them on an agar plate with a thermal gradient, and record them for 30 minutes.
- Gradient: Our gradient is created with an aluminum plate by cooling one side with a chiller, and heating the other side up with a power source. We use a thermistor and a thermocouple input device(Omega 7500) to detect the temperature of the plate and control the gradient.

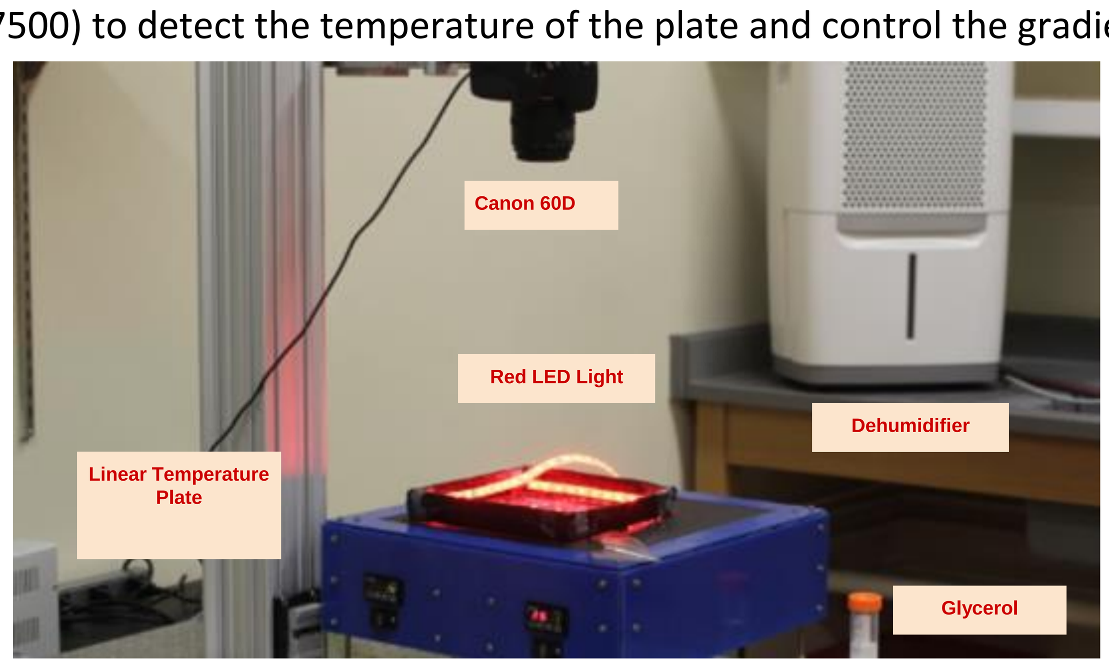

Figure 3: Setup for thermotaxis experiments on a linear gradient.

- Data Analysis: With custom MATLAB software, we calculate the center of mass of the worms and track their trajectories. With another custom MATLAB software, we calculate other parameters, such as track length and track angle, and plot the information.

CALCULATIONS

-Use Pythagorean's Theorem to calculate the angle between successive individual points and gradient.

-Take difference between each successive angle, and if different, consider a turning point.

-Find angle between successive turning points and the gradient. Calculate the length between the two.

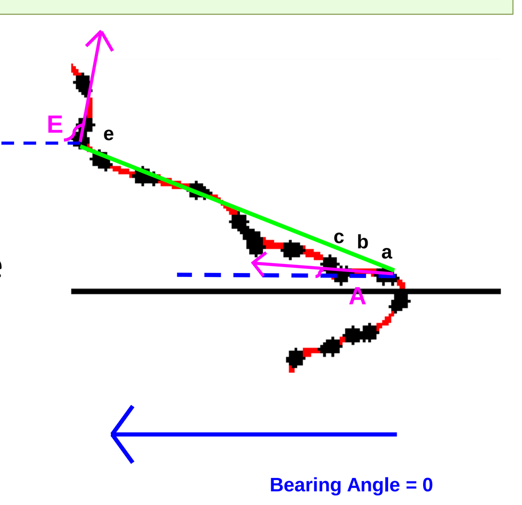

Figure 4: Diagram of basic calculations.

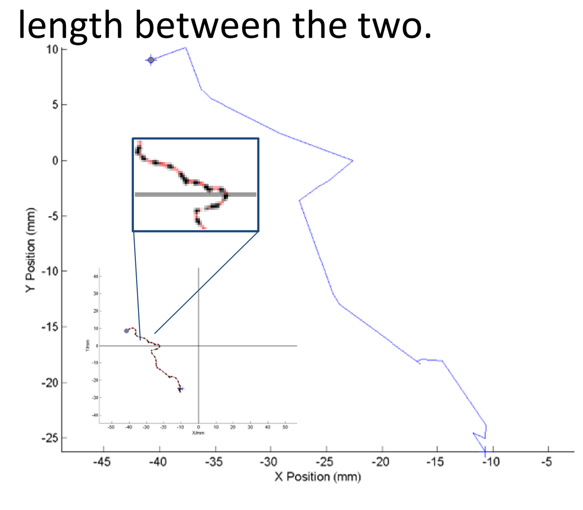

Figure 5: Example of edited track.

Pirouette Angle: >75
Minimum Track Length: 3mm

Effects:
-Cut out noise from path variation
-Remove human bias and keep calculations consistent
-Differentiate between steering and pirouettes.
-Analyze multiple tracks quickly.

RESULTS

Negative Thermotaxis:

- Worms fed at 18C
- Worms travel down gradient to cold temperature
- Significant improvements in bearing angle after pirouettes
- Normal distribution of increasing track length when oriented towards a preferred direction.

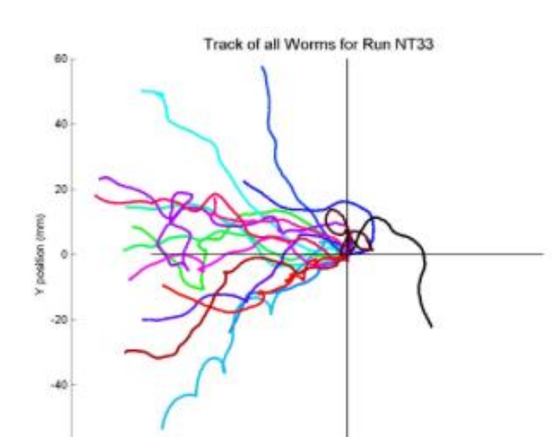

***Figure 6:** Tracks of worms moving towards 18C.*

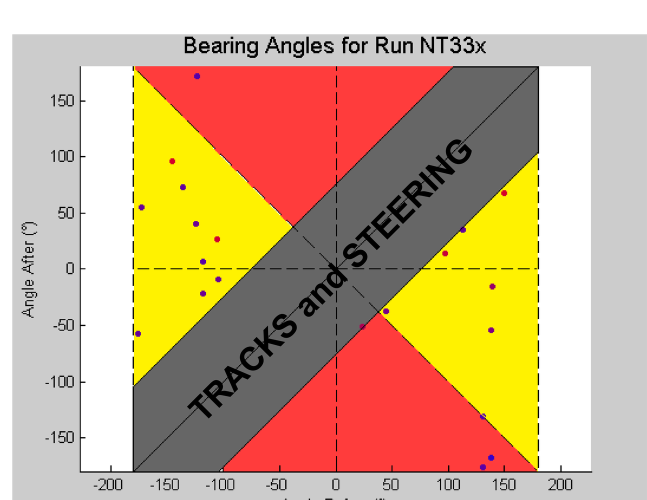

Figure 7: Bearing angle before a turn versus after a turn.

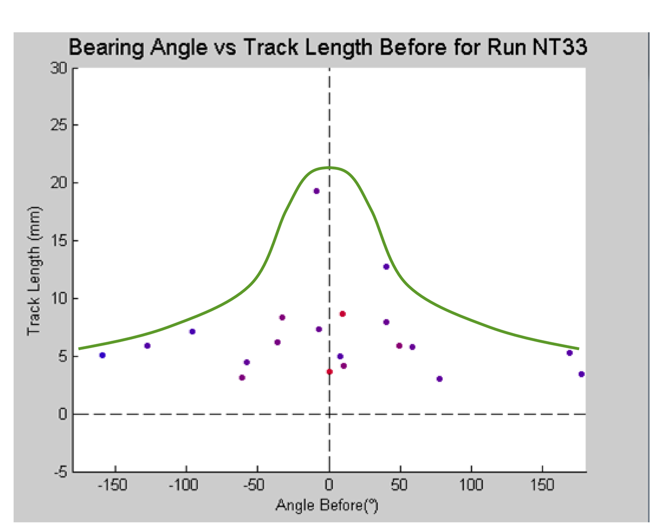

Figure 8: Bearing Angle versus Track Length.

Positive Thermotaxis:

- Worms fed at 20C
- Worms travel up gradient to hot temperature
- No significant improvements in bearing angle after pirouettes
- Normal distribution of increasing track length when oriented towards a preferred direction.

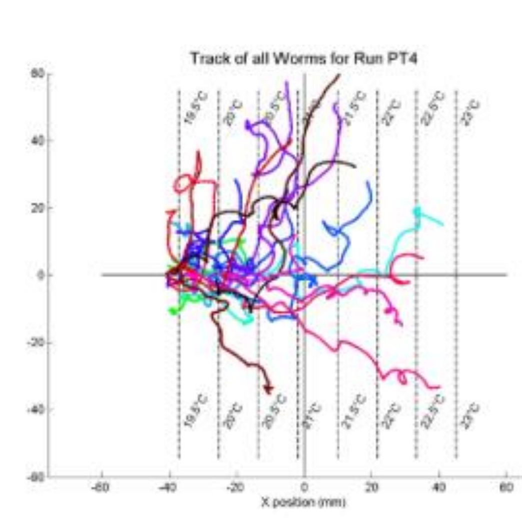

Figure 9: Tracks of worms moving towards 20C.

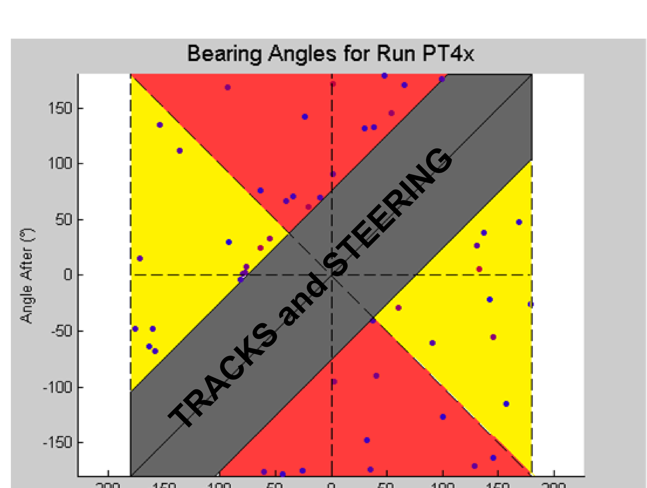

Figure 10: Bearing angle before a turn versus after a turn.

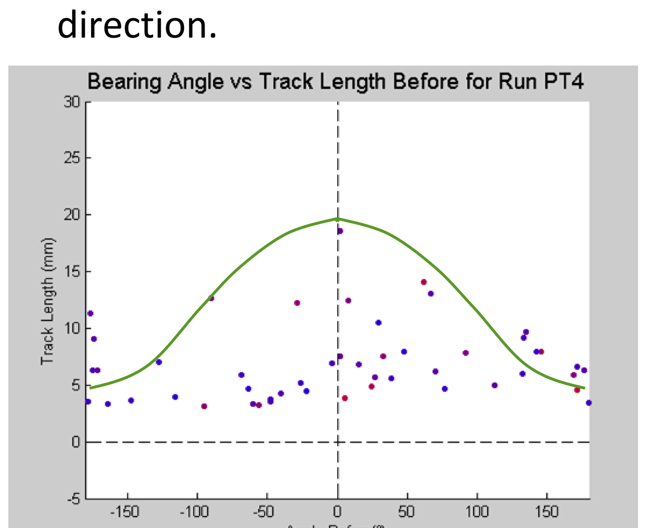

Figure 11: Bearing Angle versus Track Length.

CONCLUSIONS

We use C. elegans to model navigational behavior and understand migrational decisions in higher order animals. Previous studies have defined navigation in terms of biased random walk, the ability to moderate the length of a run depending on positive or negative conditions, and biased reorientation, the ability to change the worms trajectory to a more direct path to its attractant. In these experiments, we analyze the C. elegans navigational decisions on linear gradients where the worm is dropped both above and below its preferred temperature. Here we only analyze pirouettes, defined as sharp turns, and neglect steering, defined as small turns.

Here we find worms exhibit negative thermotaxis in a more deterministic manner than positive thermotaxis. This is in accordance with the elegans' AFD neuron which is the major contributor of thermotaxis, and only activates above the worms set temperature. When broken down, we see negative thermotaxis is made of both biased random walk and biased reorientation. In contrast, positive thermotaxis is shown to exhibit biased random walk, but not biased reorientation.

	Deterministic Steering	Random Walks		
	C. elegans isothermal tracking	*C. elegans* negative thermotaxis	*Drosophila* larva negative thermotaxis	*E. coli* chemotaxis
Overall trajectory	Long runs steered along isotherms, beginning and ending with abrupt turns	~straight runs punctuated at random by turns	~straight runs punctuated at random by turns	~straight runs punctuated at random by turns
Run speed	Unmodulated	Unbiased	Unbiased	Unbiased
Frequency of abrupt turns	Suppressed	Biased	Biased	Biased
Run orientation	Deterministic steering along isotherms	Unbiased	Biased	Unbiased
Direction of abrupt turns	Unbiased	Unbiased	Biased	Unbiased

Table 12: Comparisons between navigational behavior of C. elegans, Drosophila, and E. coli (figure from Garrity et al 2010).

These conclusions are not consistent with the bidirectional paper published in 2013, and may be due to the difference in testing methodology. We use a computer algorithm to try and mitigate as much human error as possible. However, our data is consistent with the idea behind the paper that compares navigation of Drosophila, E. coli, and C. elegans. This paper shows organisms without a brain such as E.coli can exhibit biased random walk and not biased random reorientation. However more complex organisms like Drosophila can exhibit both. C. elegans, which lays between the two neuronal complexities, should act like Drosophila when it is exhibiting negative thermotaxis due to it's more complex neural pathway. However, it should act like bacteria when echibiting positive thermotaxis and show biased reandom walk but not biased reorientation. This is consistent with our data.

We conclude because of the C.elegans' differentiating neuronal pathway, C. elegans can exhibit both biased random walk and biased reorientation during negative thermotaxis, but only biased random walk during positive thermotaxis.

REFERENCES

- Garrity, P. A., M. B. Goodman, A. D. Samuel, and P. Sengupta. "Running Hot and Cold: Behavioral Strategies, Neural Circuits, and the Molecular Machinery for Thermotaxis in C. Elegans and Drosophila." Genes & Development 24.21 (2010): 2365-382. Web.a
- Luo, L., N. Cook, V. Venkatachalam, L. A. Martinez-Velazquez, X. Zhang, A. C. Calvo, J. Hawk, B. L. Macinnis, M. Frank, J. H. R. Ng, M. Klein, M. Gershow, M. Hammarlund, M. B. Goodman, D. A. Colon-Ramos, Y. Zhang, and A. D. T. Samuel. "Bidirectional Thermotaxis in Caenorhabditis Elegans Is Mediated by Distinct Sensorimotor Strategies Driven by the AFD Thermosensory Neurons." Proceedings of the National Academy of Sciences 111.7 (2014): 2776-781. Web.
- Yoshida, Kazushi, Takaaki Hirotsu, Takanobu Tagawa, Shigekazu Oda, Tokumitsu Wakabayashi, Yuichi Iino, and Takeshi Ishihara. "Odour Concentration-dependent Olfactory Preference Change in C. Elegans." Nature Communications Nat Comms 3 (2012): 739. Web.

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