Modeling Navigation of *Caenorhabditis elegans* on Thermal Gradients

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INTRODUCTION

Due to their simplistic neuronal network, Caenorhabditis elegans sensitivity to temperature provides insight to navigational regulation between tracks and turns of organisms with a central neural network. 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.

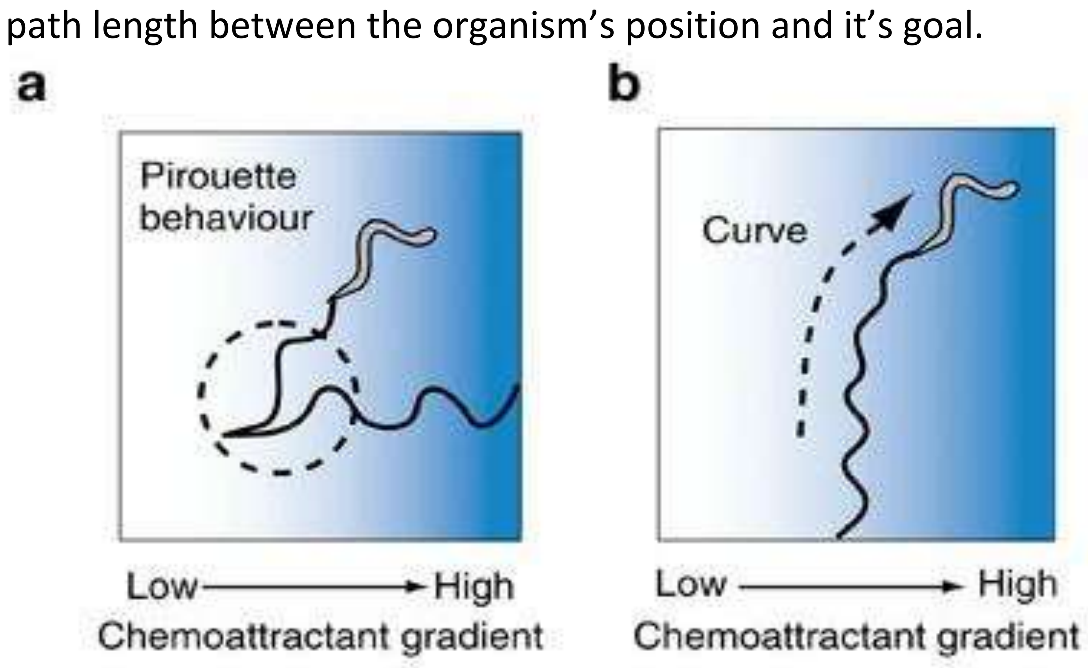

Figure 1: (figure from Yoshida et al 2012)
a) Worm completing a pirouette
6) Worm curving and exhibiting steering

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

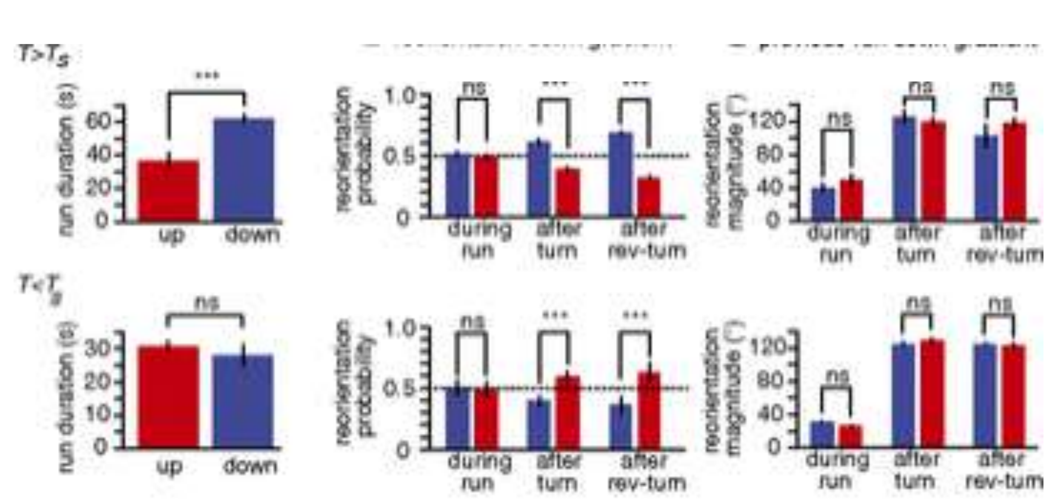

***Figure 2:** Significance of behavioral phenotypes. (figure from Luo et al 2014).*

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 17 degrees. We place them on a thermal gradient, and record them for 30 minutes.
- Gradient: Our gradient is created with an aluminum plate cooled and heated by Peltier plates.

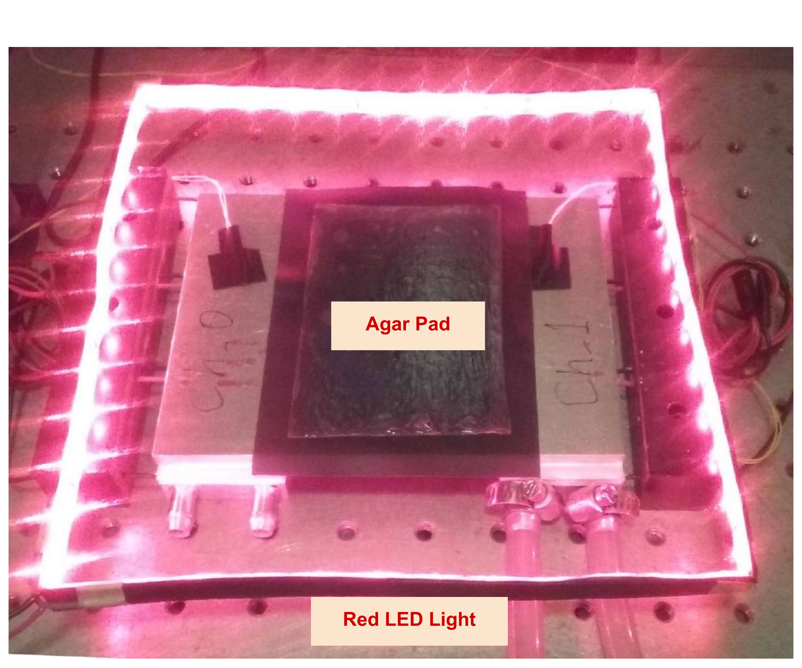

Figure 3: Setup for thermotaxis experiments on a linear gradient.

- Data Analysis: With custom MATLAB software track their trajectories and 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.

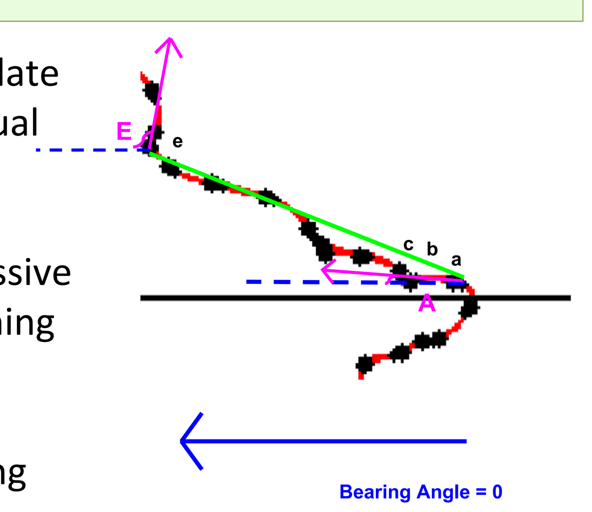

Figure 4: Diagram of basic calculations.

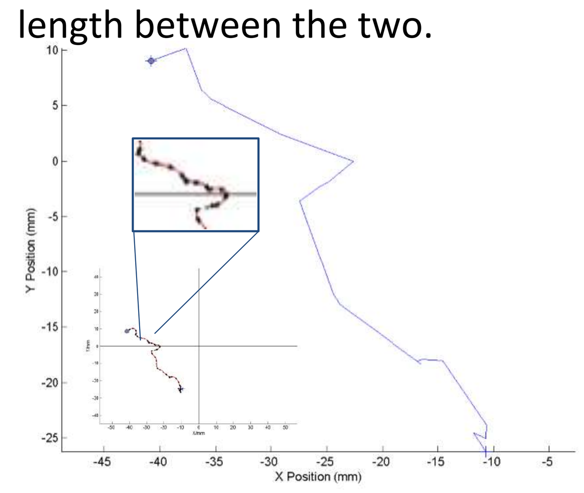

Figure 5: Example of edited track.

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 travel to cold temperature
- Significant improvements in bearing angle after pirouettes
- Normal distribution of increasing track length when oriented towards a preferred direction.

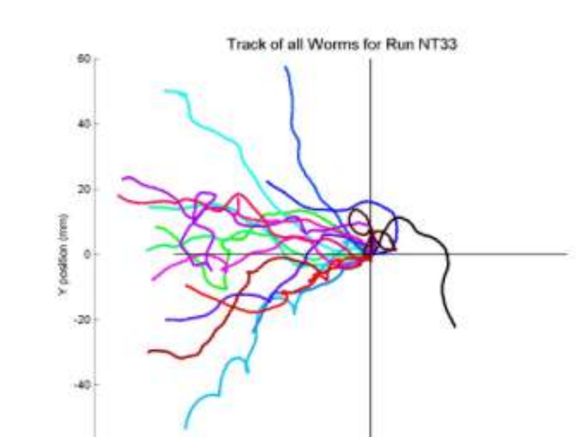

***Figure 6:** Tracks of worms moving towards 18C.*

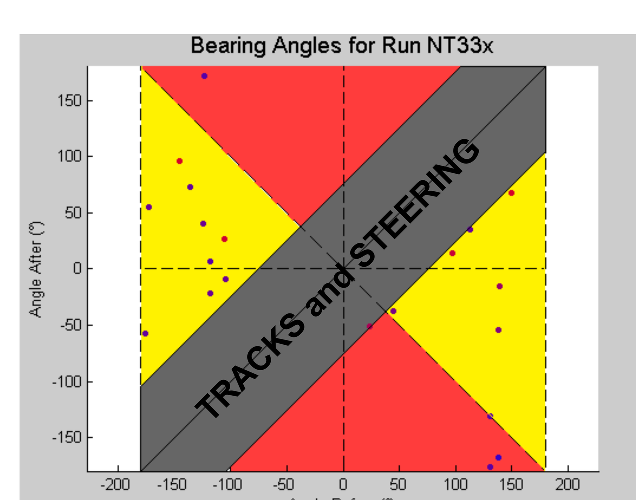

Figure 7: Bearing angle before a turn versus after a turn.

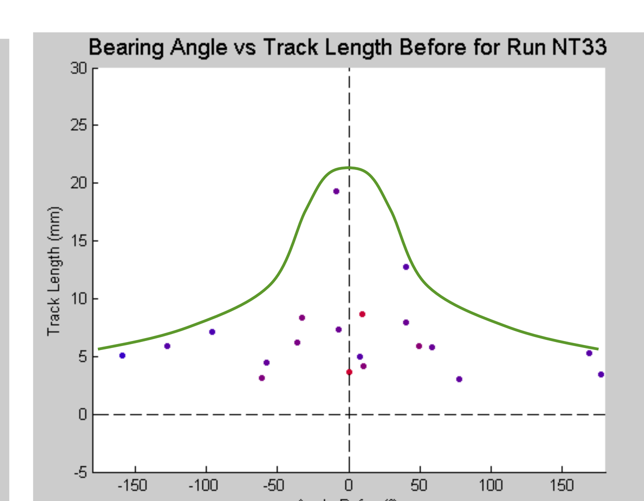

Figure 8: Bearing Angle versus Track Length.

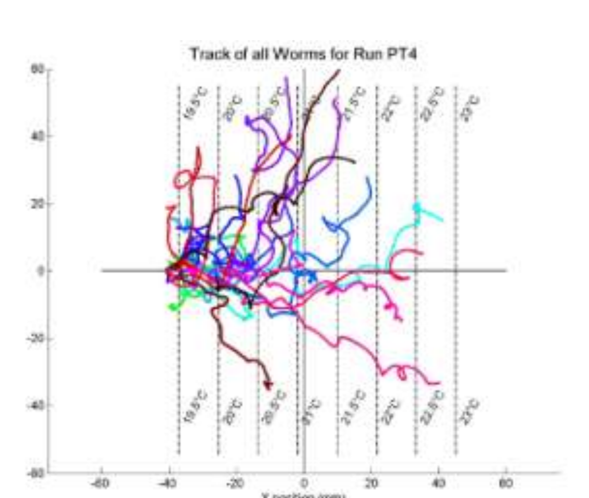

Figure 9: Tracks of worms moving towards 20C.

Positive Thermotaxis:

- Worms to hot temperature
- No significant improvements in bearing angle after pirouettes
- Normal distribution of increasing track length when oriented towards a preferred direction.

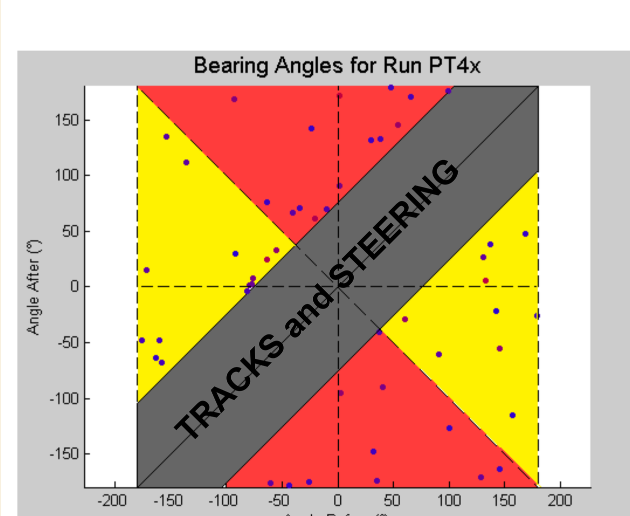

Figure 10: Bearing angle before a turn versus after a turn.

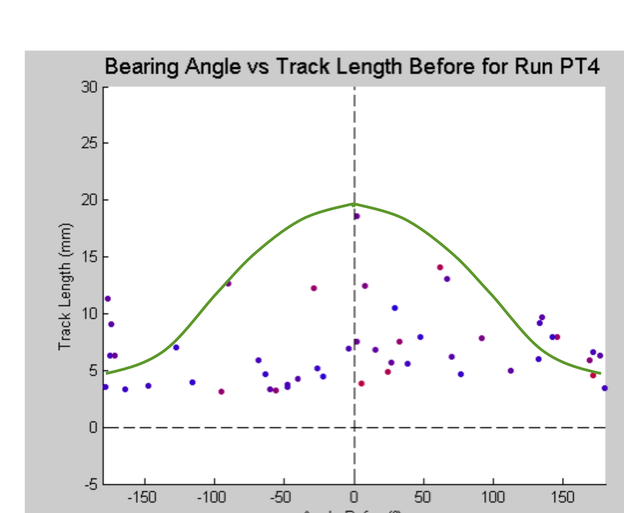

Figure 11: Bearing Angle versus Track Length.

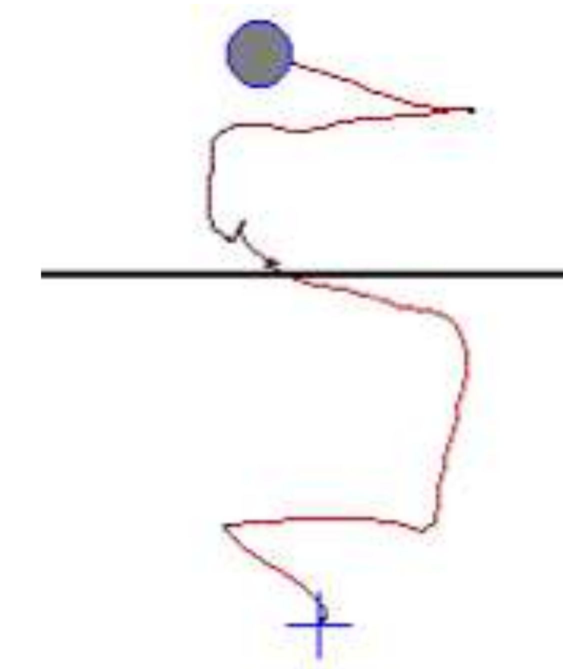

Figure 12: Worm completing 90 degree turns

90 Degree Turn:

- Worm fed at 18C
- Worm find a preferred temp
- Worm turns on isotherm
- Worm finds new preferred temp
- Worm turns on isotherm again

CONCLUSIONS

Here we find worms exhibit negative thermotaxis in a more deterministic manner than positive thermotaxis. This is in accordance with the elegans' AFD which only activates above the worms set temperature. 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.

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