Functional motifs controlling *drosophila* navigation revealed by connectome-derived computational model

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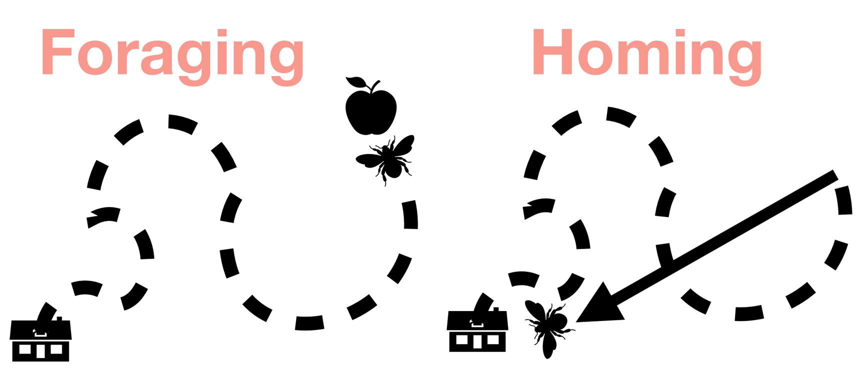
Introduction

Insects have a remarkable ability to navigate complex environments with a proficiency that belies their simple nervous systems.



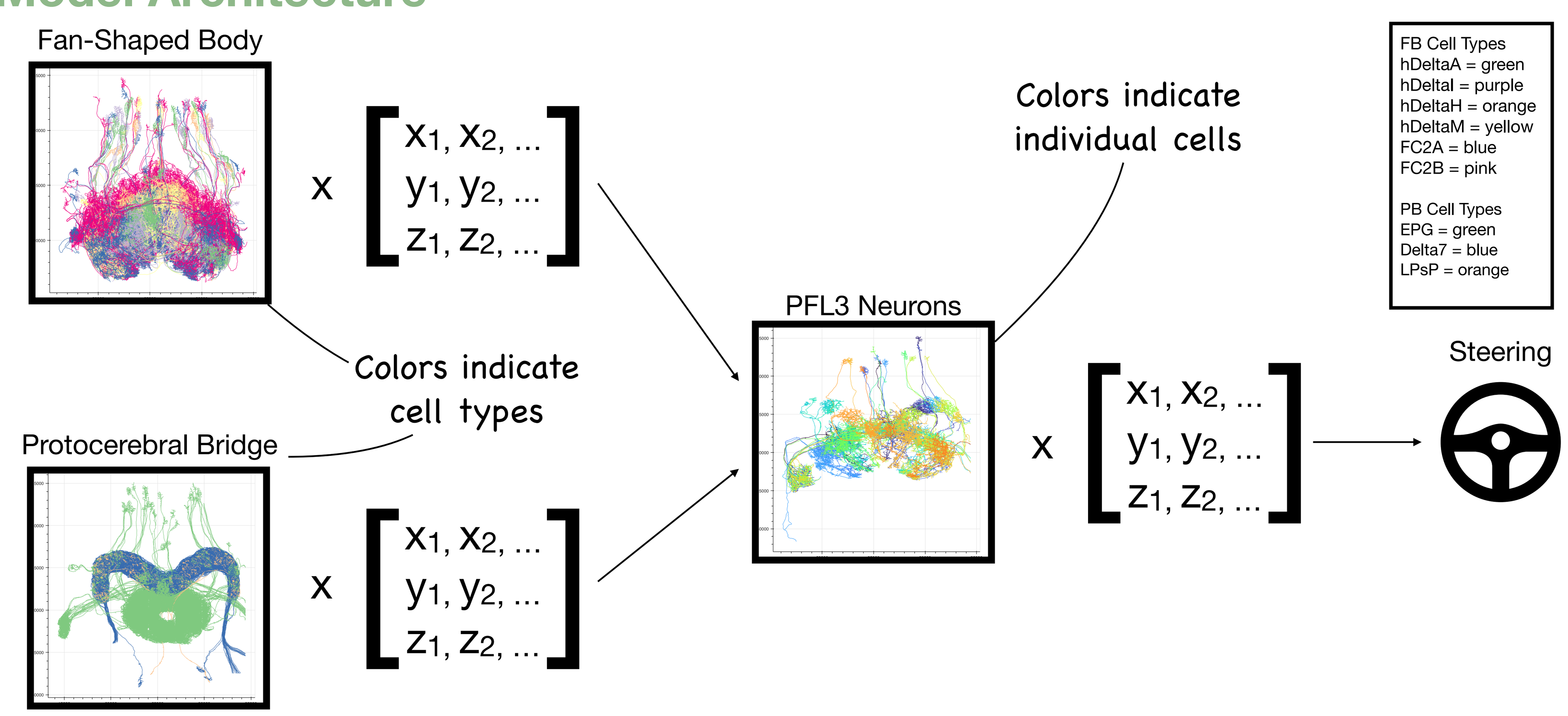
In vivo experiments[1] have demonstrated that regions and cell types in the *drosophila* central complex use *sinusoidal patterns of neuronal activity to represent navigational variables such as head direction and allocentric heading,* providing important insights into the neurobiology of insect navigation. However, much about the mechanistic role of distinct neuron types, regions, and connectivities remains unknown.

Objective

Here, we model those processes using the drosophila connectome.[2] We demonstrate how *activity motifs in the FB manipulate target heading, and the causal relationship between activity asymmetries across PFL3 and changes in heading.* As such, we present not only new findings, but a *testbed* for evaluating functional motifs, cell types, connectivity patterns, or any combination therein.

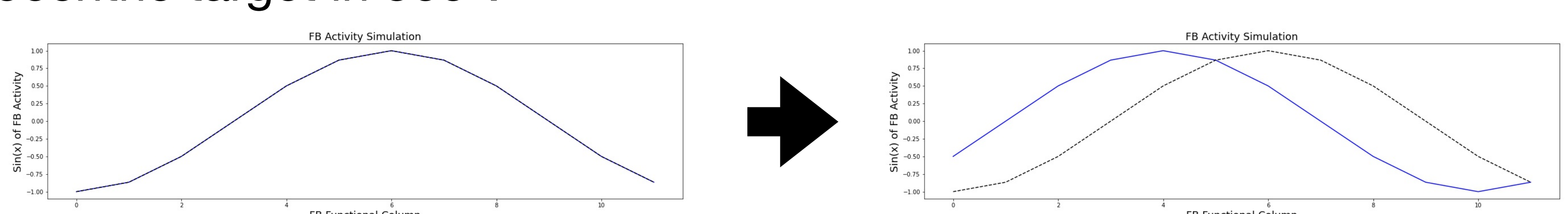
Methods & Model Design

Model Architecture



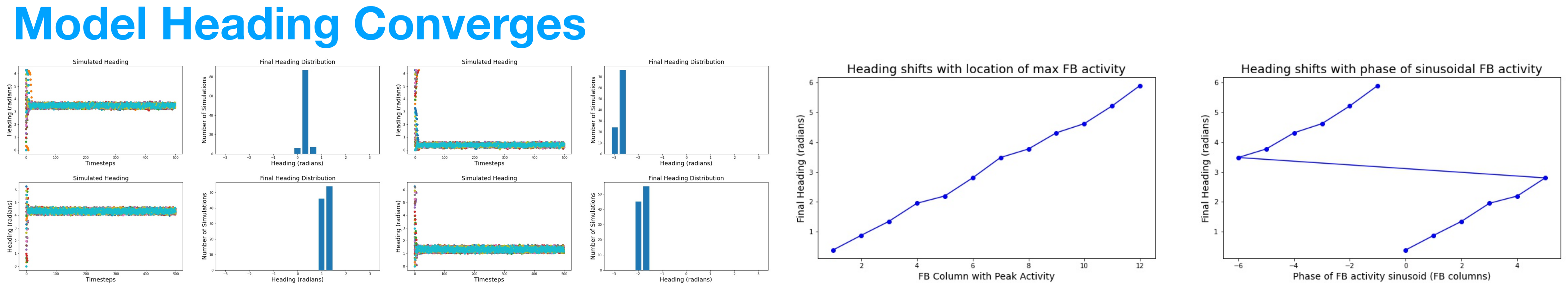
Neural Activity Simulations

Activity in the fan-shaped body (FB) represents target heading, whereas the protocerebral bridge (PB) represents allocentric traveling direction.[1] Here, *FB activity is simulated by a phasor for the target heading* (representative subset shown). PFL3 combines these inputs to steer the fly towards an allocentric target in 360°.



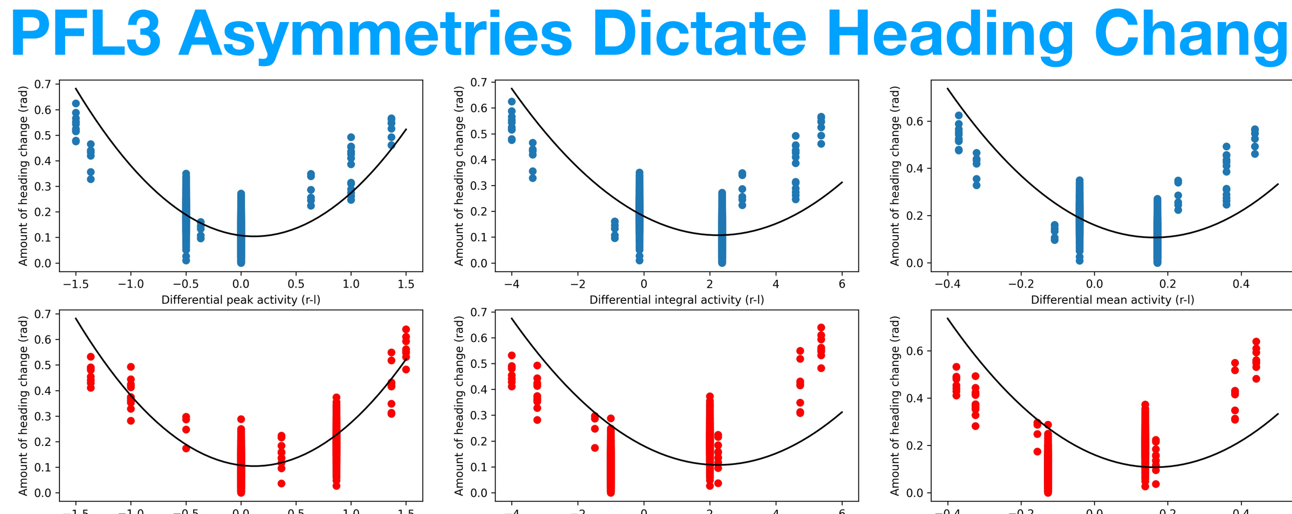
Model Results

Model Heading Converges



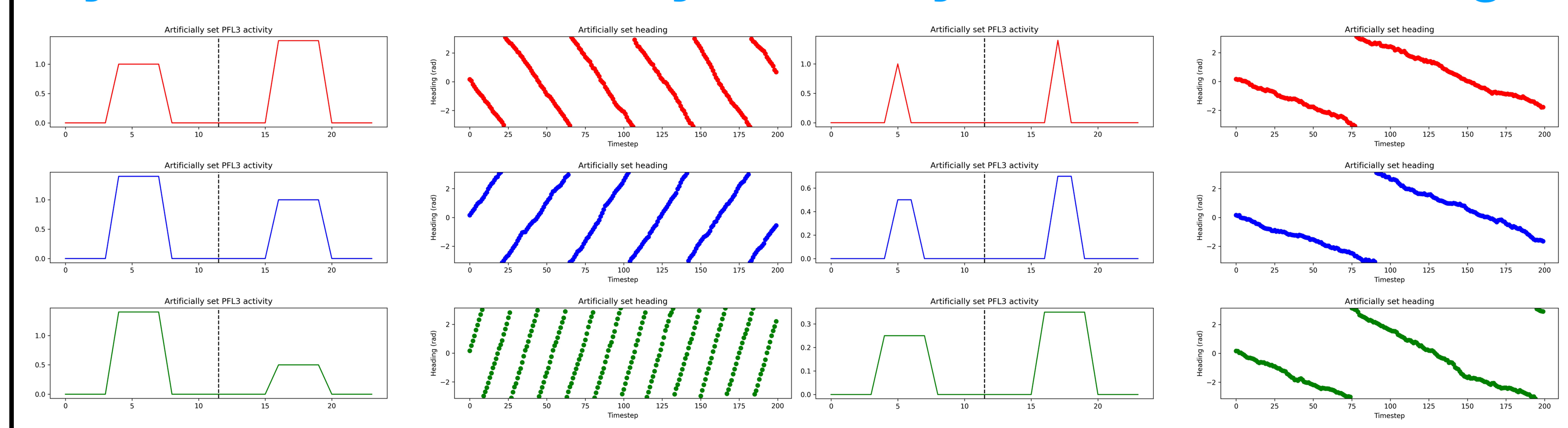
The model *converges upon the target heading,* represented by the FB sinusoid (subset shown). *Shifting the phase of the FB sinusoid shifts the location of the target heading.* The target heading corresponds linearly with the FB column with peak activity. Note that the *FB sinusoid is static for each target heading* whereas PB activity updates at each tilmestep.

PFL3 Asymmetries Dictate Heading Change

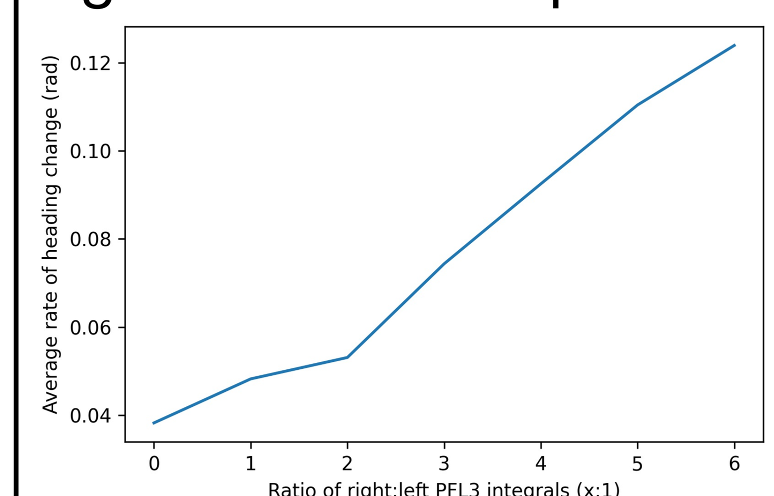


Parabolic relationship between asymmetries across left/right PFL3 shown by quadratic fit to a given target heading (blue). Generalizes to other target heading (red).

Synthetic PFL3 Activity Causally Linked to Steering



Synthetic PFL3 activity designed to have asymmetrical levels of activity across the right and left PFL3 *evidence control of not only the direction of heading updates, but also their magnitude.* Further tests with synthetic PFL3 activity show that it's the cumulative activity across left/right PFL3 that impacts steering, not peak activity.



The relationship between the ratio of cumulative activity between the two sides of PFL3 and change in heading show a linear relationship.

Conclusions

Statement

The proposed model confirms in vivo findings on the sinusoidal nature of central complex activity and *constitutes a robust, high-throughput testbed for evaluating the effects of functional motifs, cell types, and connectivity patterns, or any combination therein.* We apply the model to establish that *changes in heading are driven by activity asymmetries across PFL3,* and that *target heading is set by the phase of the FB activity sinusoid.*

Summary

- Model proves capable of evaluating drosophila navigation circuits.
- FB sinusoid phase sets target heading.
- PFL3 activity asymmetries set change in heading.

References & Acknowledgements

1. Lyu, Abbott, and Maimon, *bioRxiv,* 2020.
2. Scheffer et al., *eLife,* 2020.

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