The motor programs underlying navigation in *Drosophila* larva

Subhaneil Lahiri

Harvard University

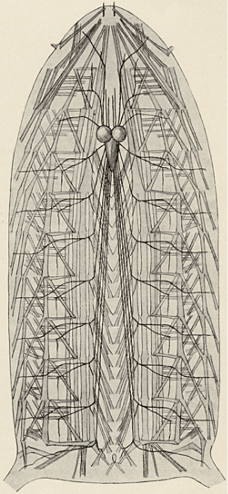
July 24, 2011

Introduction

We will look at the motor behaviour of the *Drosophila* larva during navigational motion, paying attention to which segments are used, in which order, etc.

We want to get some insight into the circuits that control this behaviour and the role of sensory feedback by quantifying the motor output at high resolution.

Drosophila larva



[Hertweck (1931)]

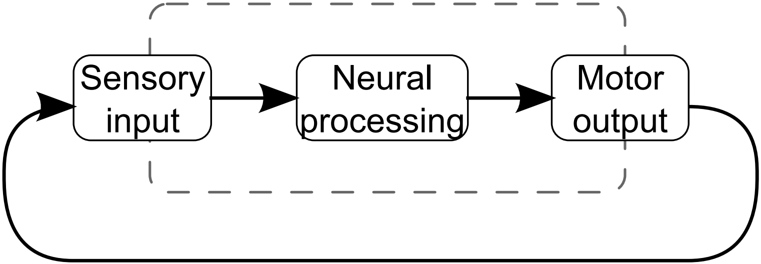
$\sim 10^4$ neurons.

Has CNS, spiking neurons,...

Many genetic tools.

Transparent $\implies$ optogenetics.

Navigation



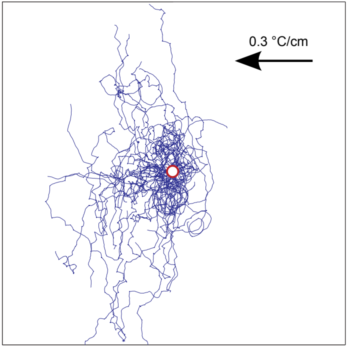
Outline

1. Navigation and locomotion
2. Fluorescent muscles
3. Imaging and analysis
4. Results
5. Conclusions and remaining issues

Section 1

Navigation and locomotion

Biased random walks



Alternating runs and reorientations.

Like *E. coli* and *C. elegans*.

Effectively point-like sensor.

Head-sweeps

Moves head from side-to-side to sample environment and pick a direction to travel.

Navigation strategy

For thermo-/chemo-/photo-taxis, larva modulates:

- head-sweep frequency
- head-sweep size
- head-sweep acceptance probability

Depending on whether conditions are improving/worsening.

[Luo et al. (2010)]

Locomotion and sensory feedback

Several types of Multidendritic (md) neurons:

- tracheal dendrite (td),
- bipolar dendrite (bd)
- class I-IV dendritic arborisation (da).

Possibly used for proprioception/pathfinding.

[Bodmer and Jan (1987), Grueber et al. (2002)]

md neurons are used for locomotion:

- Turn off all types → no locomotion [Song et al. (2007)]
- Turn off bd and class I da → disrupt pattern (toothpasting)

[Hughes and Thomas (2007)]

For finer analysis: quantify patterns of muscle use.

Questions

Different types of head-sweep:

- Different circuits?
- When is decision made? With what info?
- Mechano-sensory input?

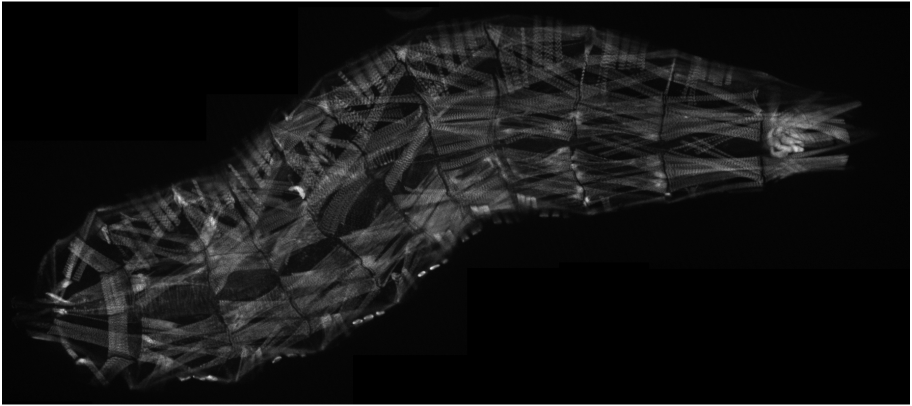
Look for differences in mechanics of different types of head-sweep.

Section 2

Fluorescent muscles

Fluorescent muscles

Mutant: $w^{-}; \frac{mhc-GFP^{0110}}{CyO}$ [Hughes and Thomas (2007)]



Can see segment boundaries $\rightarrow$ measure length $\rightarrow$ which segment contracts.

Intensity pattern

Muscles contract $\rightarrow$ same GFP in smaller volume $\rightarrow$ increase concentration $\rightarrow$ increase brightness.

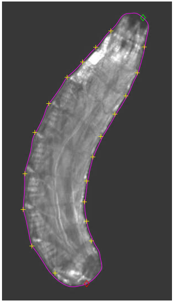
Section 3

Imaging and analysis

Image analysis

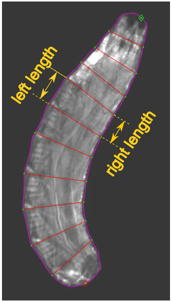
Find boundary, head and tail automatically

Image analysis



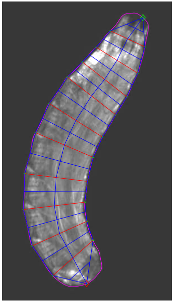
User clicks on segment boundaries

Image analysis



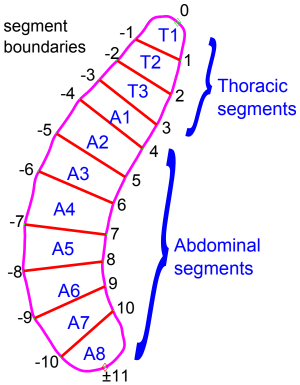
Map to boundary. Find segment lengths.

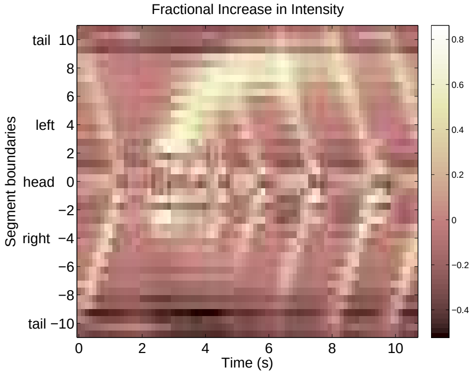
Image analysis



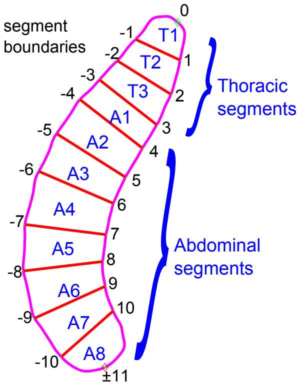
Split segment into quadrants. Mean pixel value → intensity.

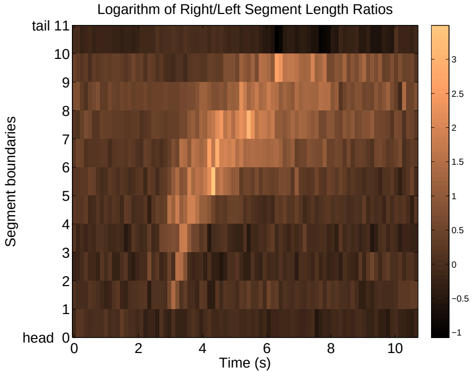
Coordinate system





Coordinate system





Section 4

Results

Forward motion

Pulse travels from tail to head. New pulse starts after previous reaches head.

Small accepted head-sweep

Basic pattern: Kink starts around (T3,A1,A2) and propagates back. Subsequent peristalsis starts before kink reaches tail.

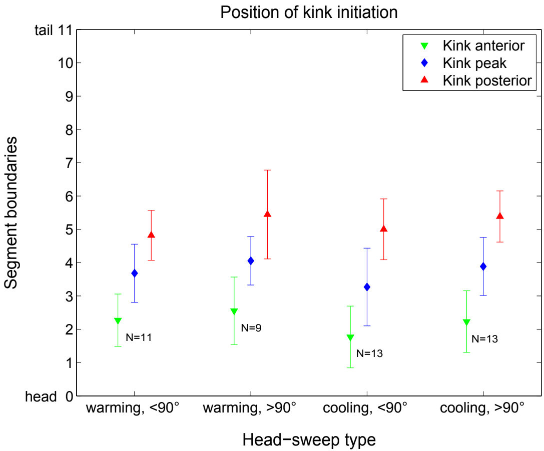
Large accepted head-sweep

Basic pattern: Kink starts around (T3,A1,A2) and propagates back.
Subsequent peristalsis starts from kink, not tail.

Rejected head-sweep

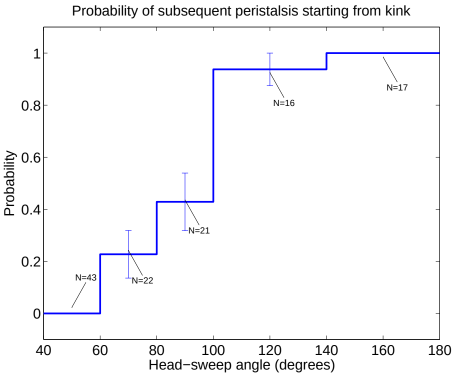
Rejected head-sweep not undone until next one.

Position of initial bend



Little dependence on size or temperature.

Position of start of peristalsis



- Transition is around $90 - 100^\circ$.
- Varies from animal to animal.
- Not fully determined by angle.

Possible explanations

- Mechanical reason?
  $> 90^\circ$ tail would move wrong way.
  $< 90^\circ$ starting from kink would be slower.

- Neural circuit?
  Stretch-sensors involved in locomotion pattern. If one side is already contracted, segment just anterior to kink might think peristaltic pulse has already reached it

Section 5

Conclusions and remaining issues

Conclusions

Navigation results from combining two basic motor programs: peristalsis and asymmetric contraction.

All head-sweeps start at the same segments. Same circuits? Decision on size of head-sweep made later?

Large head-sweeps: subsequent peristalsis starts at kink. Shows that peristalsis can start anywhere. Implications for circuits that control forward motion.

Acknowledgements

Thanks to:

- Konlin Shen
- Anji Tang
- Mason Klein
- Liz Kane
- Ashley Carter
- Aravi Samuel
- Garrity lab

References I

L. Luo, M. Gershow, M. Rosenzweig, K. Kang, C. Fang-Yen, P. A. Garrity, and A. D. Samuel.

"Navigational decision making in Drosophila thermotaxis".

J. Neurosci., 30:4261–4272, Mar 2010, PubMed:20335462.

9

Rolf Bodmer and Yuh Nung Jan.

"Morphological differentiation of the embryonic peripheral neurons in *Drosophila*".

Development Genes and Evolution, 196:69–77, 1987.

ISSN 0949-944X.

10

References II

W. B. Grueber, L. Y. Jan, and Y. N. Jan.

"Tiling of the Drosophila epidermis by multidendritic sensory neurons".

Development, 129:2867–2878, Jun 2002, PubMed:12050135.

10

W. Song, M. Onishi, L. Y. Jan, and Y. N. Jan.

"Peripheral multidendritic sensory neurons are necessary for rhythmic locomotion behavior in Drosophila larvae".

Proc. Natl. Acad. Sci. U.S.A., 104:5199–5204, Mar 2007, PubMed:17360325.

10

C. L. Hughes and J. B. Thomas.

"A sensory feedback circuit coordinates muscle activity in Drosophila".

Mol. Cell. Neurosci., 35:383–396, Jun 2007, PubMed:17498969.

10 13

Toothpasting

back