The motor programs underlying navigation in *Drosophila* larva

based on *PLoS ONE*, 6:e23180 (2011), with K. Shen, M. Klein, A. Tang, E. Kane, M. Gershow, P. Garrity, and A.D.T. Samuel

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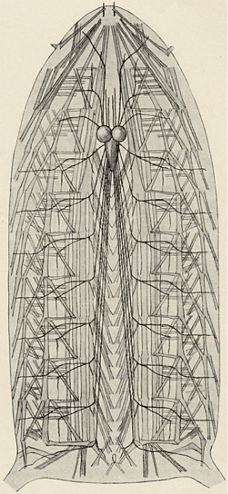
December 12, 2011

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.

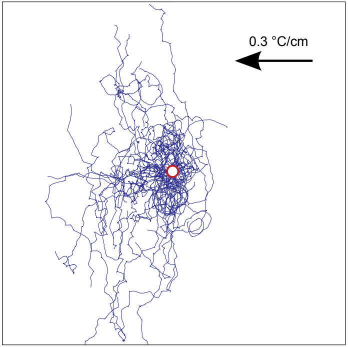
Transparent $\implies$ optogenetics.

Outline

Section 1

Navigation and locomotion

Biased random walks

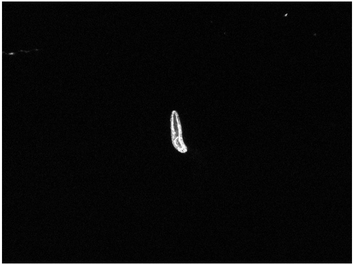


Alternating runs and reorientations.

Effectively point-like sensor.

Similar to *E. coli* and *C. elegans*.

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)]

Questions

Different types of head-sweep:

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

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

Locomotion and sensory feedback

Crawl using peristaltic waves from posterior to anterior that lift and push the body forwards.

Several types of Multidendritic (md) sensory neurons.
Repeated in each segment. Possibly used for proprioception.

[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 certain subsets → disrupt pattern (toothpasting)

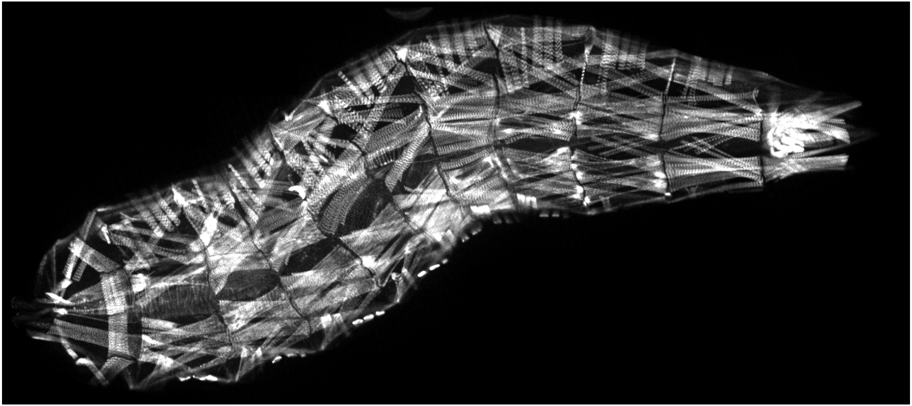
[Hughes and Thomas (2007)]

Section 2

Imaging and analysis of fluorescent muscles

Fluorescent muscles

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

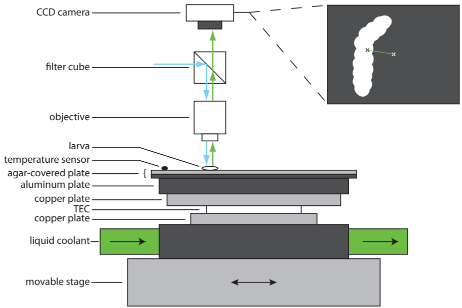


Can see segment boundaries $\rightarrow$ measure length $\rightarrow$ which segment contracts.

Intensity pattern

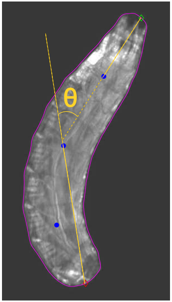
Muscles contract $\rightarrow$ same GFP in smaller volume $\rightarrow$ increase concentration $\rightarrow$ increase brightness.

Apparatus



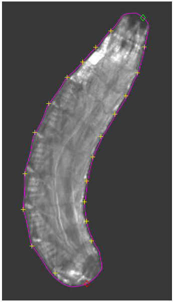
- Temperature varied from $14 - 16^{\circ}\mathrm{C}$ with period $300\,\mathrm{s}$.
- Movable stage keeps larva in camera frame.

Image analysis



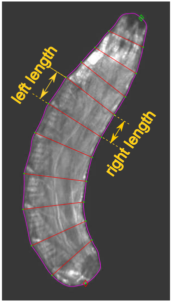
Find boundary, head, tail and bend angle automatically

Image analysis



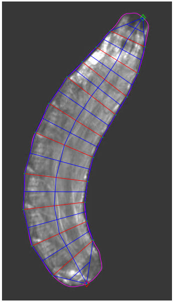
User clicks on segment boundaries

Image analysis



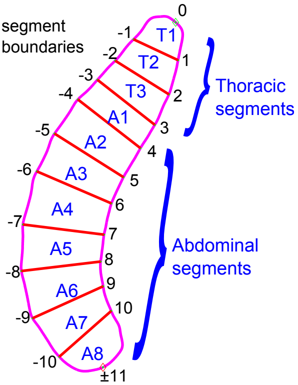
Map to boundary. Find segment lengths.

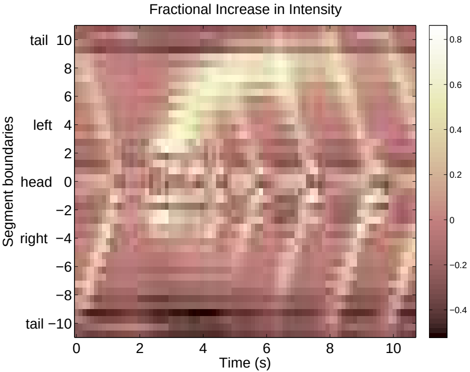
Image analysis



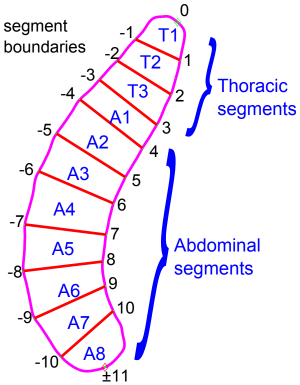
Split segment into quadrants. Mean pixel value $\rightarrow$ intensity.

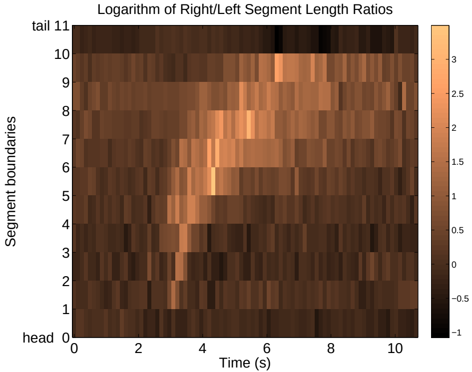
Coordinate system





Coordinate system

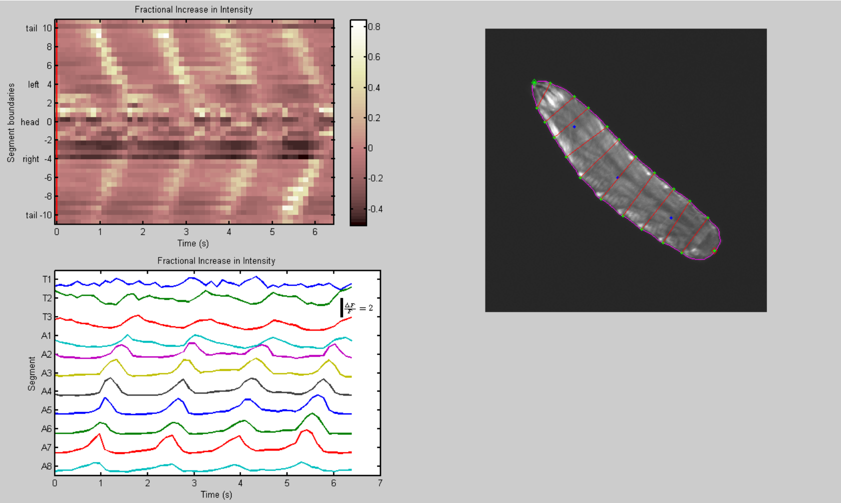




Section 3

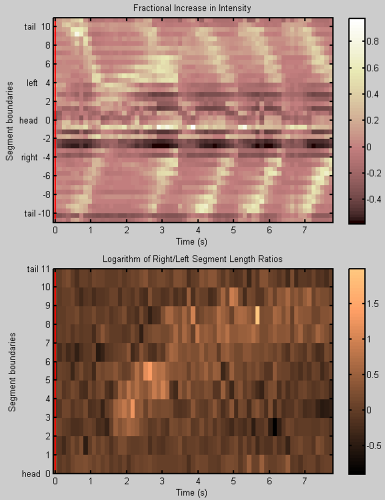
Results

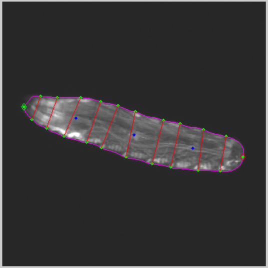
Forward motion



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

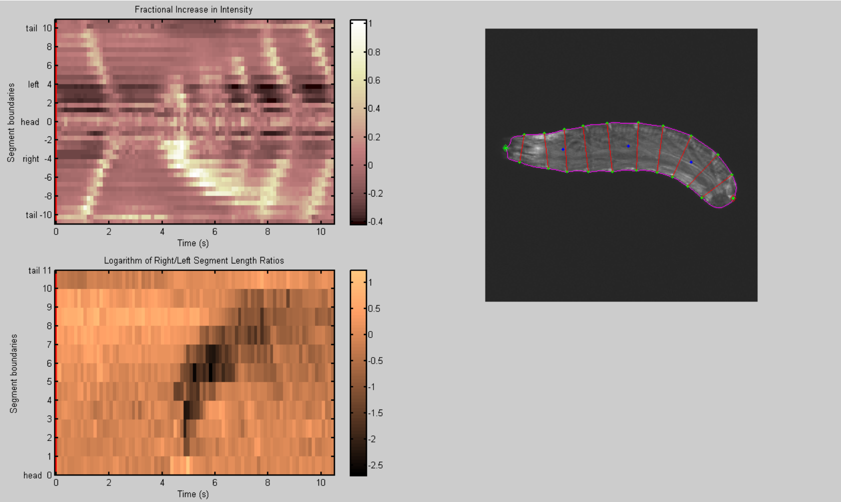
Small accepted head-sweep





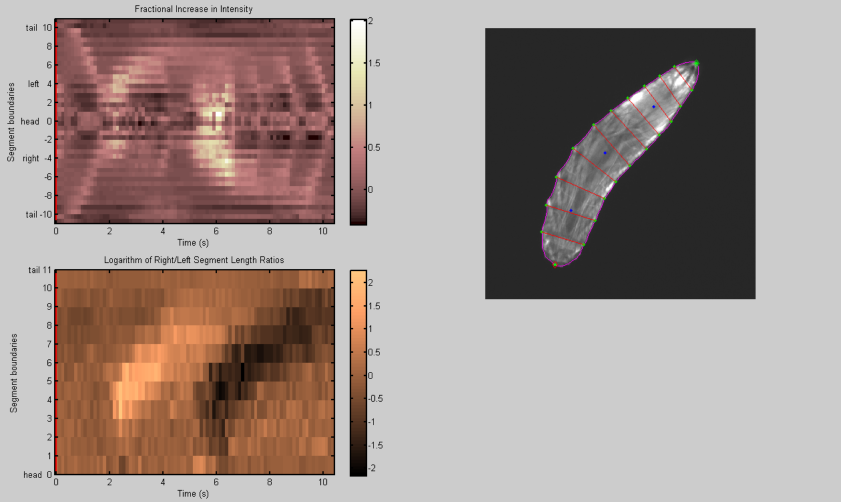
Basic pattern: Kink starts around (T3,A1,A2) and propagates back.
Subsequent peristalsis starts before kink reaches tail.

Large accepted head-sweep



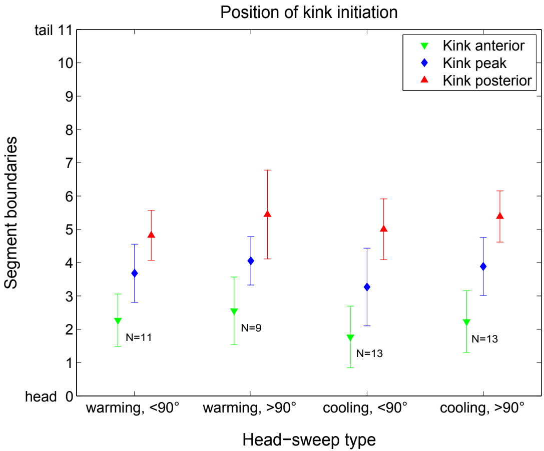
Basic pattern: Kink starts around (T3,A1,A2) and propagates back.
Subsequent peristalsis starts from kink, not tail.

Rejected head-sweep



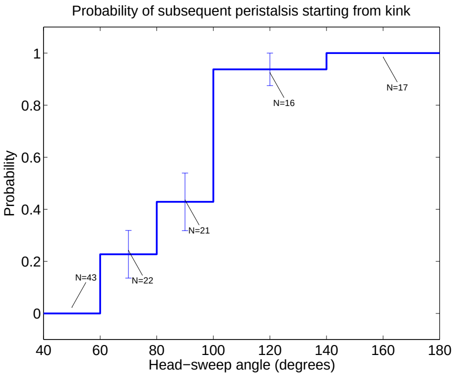
Rejected head-sweep not undone until next one.

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

- Central pattern generator?
  Body re-coupling in mid-cycle – dependence on head-sweep size?

Section 4

Conclusions and future directions

Conclusions

All head-sweeps start at the same segments. Same circuits? Decision on size of head-sweep made later?
Navigation results from combining two basic motor programs: peristalsis and asymmetric contraction. Pathway from sensory input $\rightarrow$ motor output simpler than previously thought.

No "unbending" motor program.

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

Future directions

Interfere with motor patterns (optogenetically).

Fully automate image analysis.

Other stimuli.

Reverse crawling, hunching, and rolling.

Acknowledgements

Thanks to:

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

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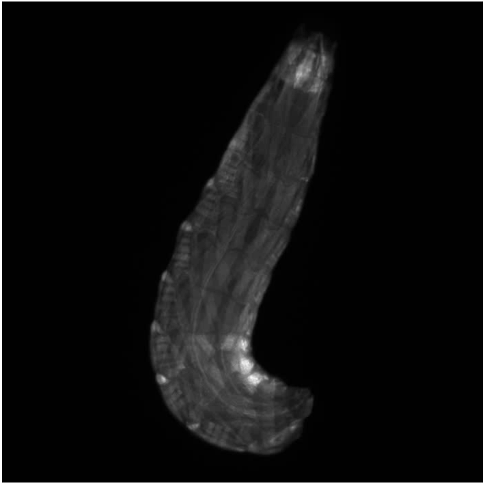
Toothpasting



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