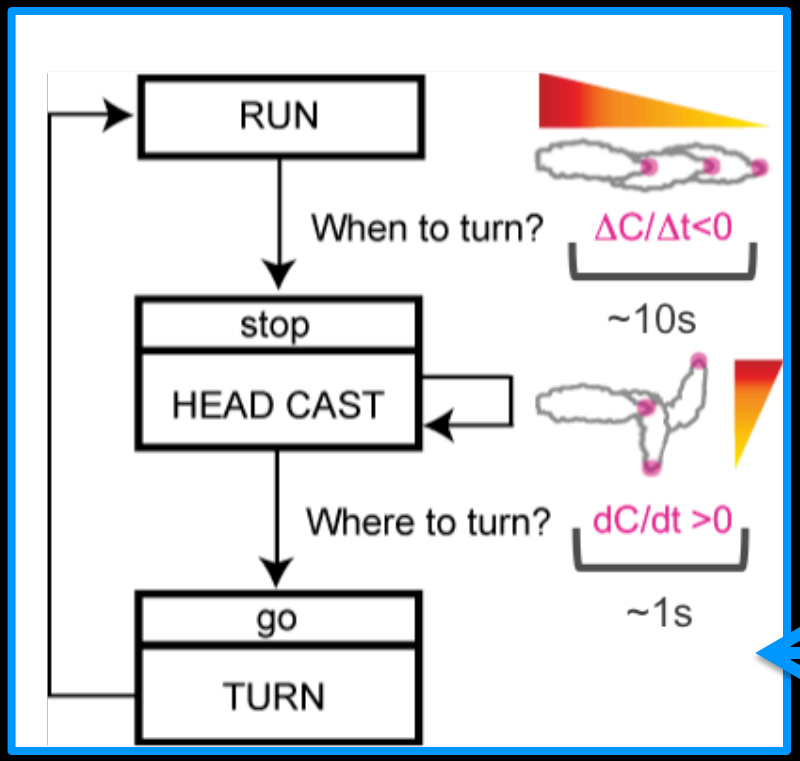
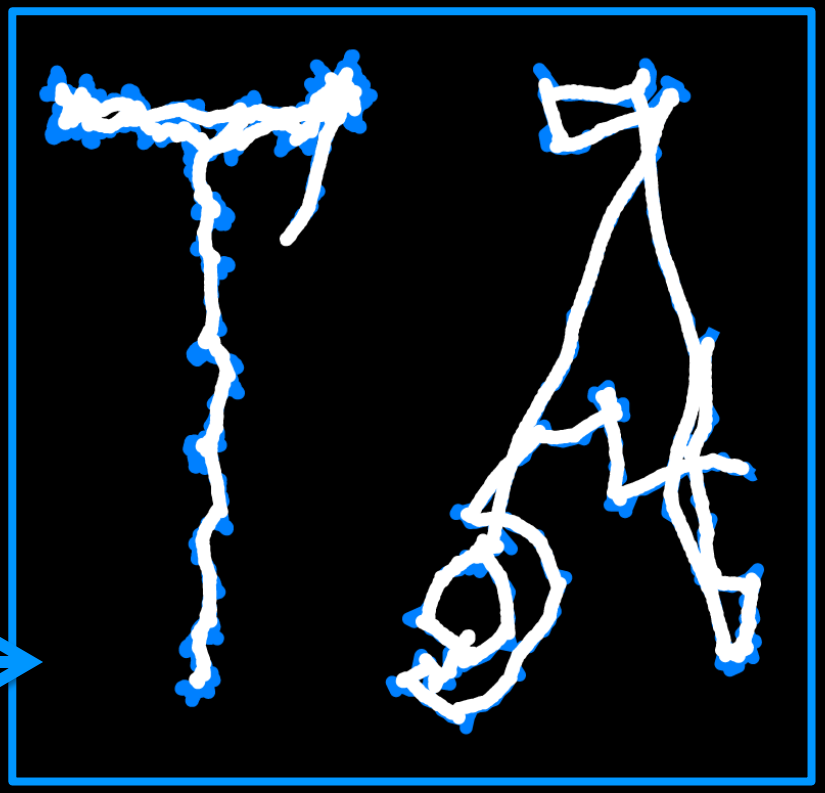
TAXIS

Matthieu Louis, UCSB

Remote-controlling the orientation behavior of *Drosophila* larvae

Remote-controlling the orientation behavior of *Drosophila* larvae

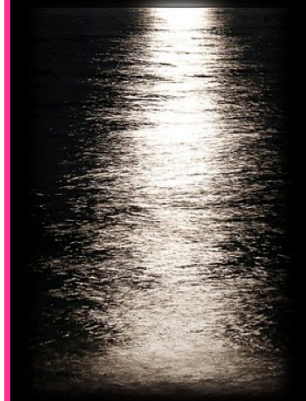




algorithmic/mechanistic models

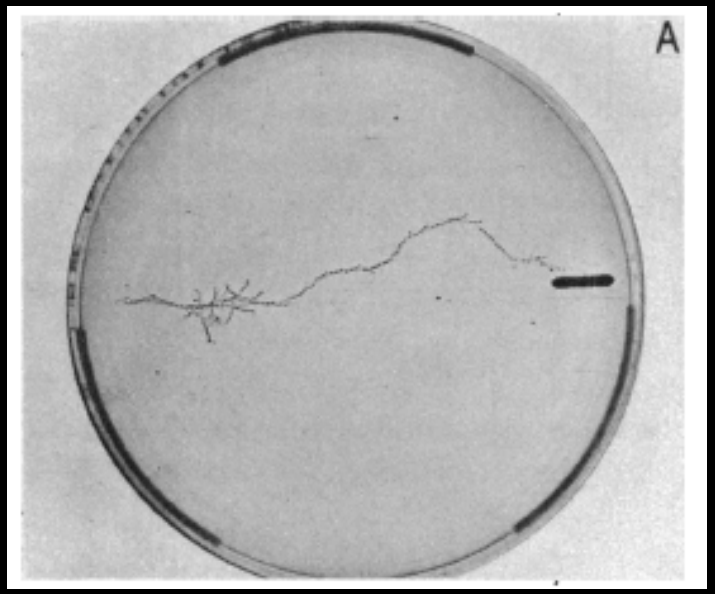
experimental test/model refinement

Fly larvae orient to light



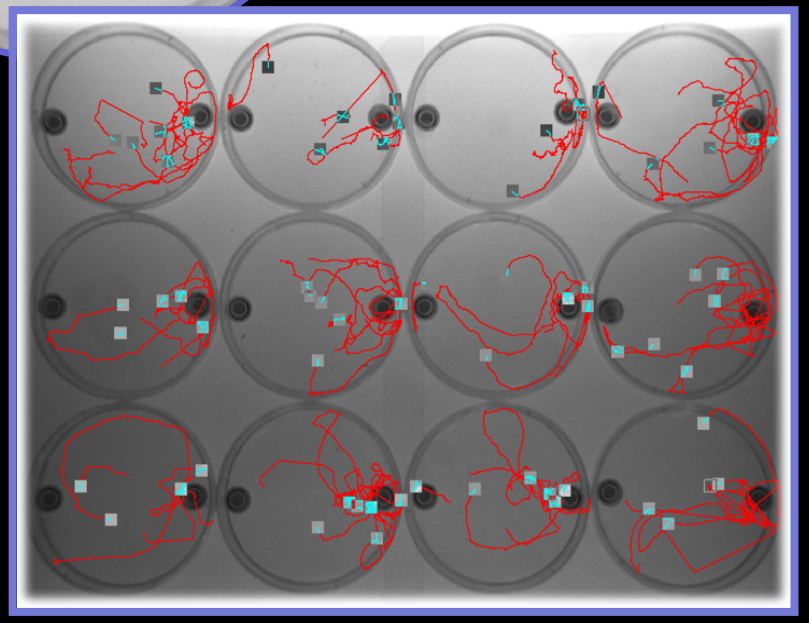
G. Pouchet (1800-1872)

Fly larvae orient to odors



Aceves-Pina & Quinn, Science 1979

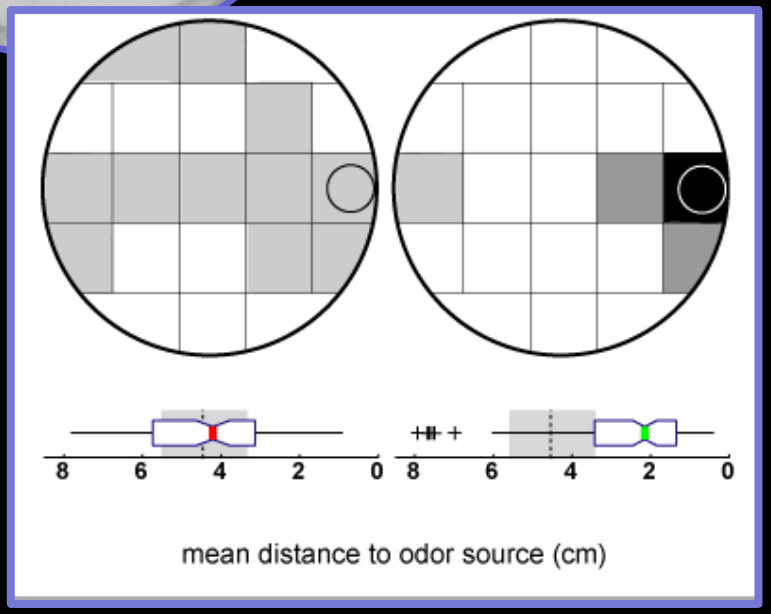
Early computational tracking of larval behavior



Vosshall lab, 2003

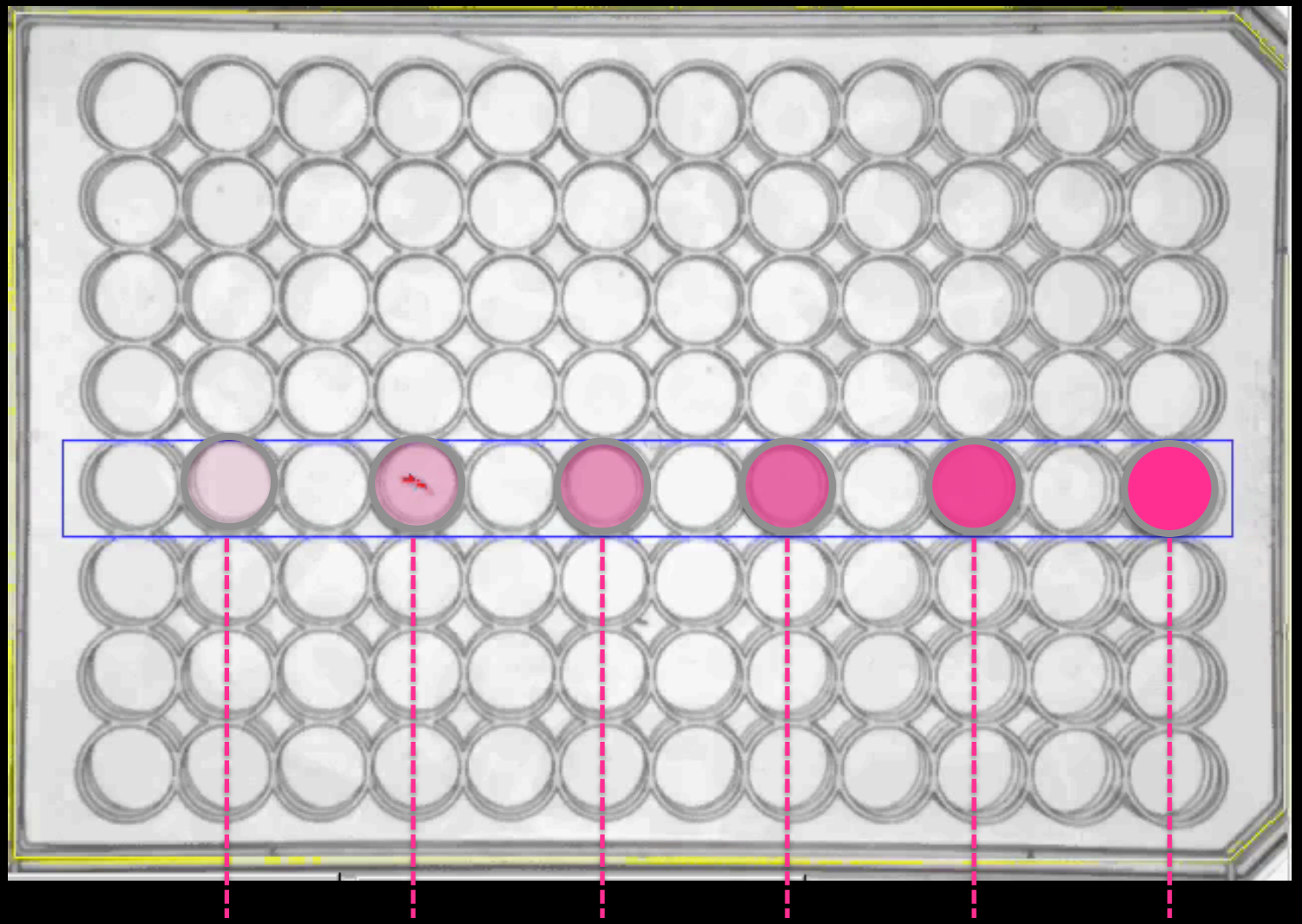
Behavioral tracking & fly genetics permit a molecular deconstruction of the olfactory system

Orco null mutant wild type

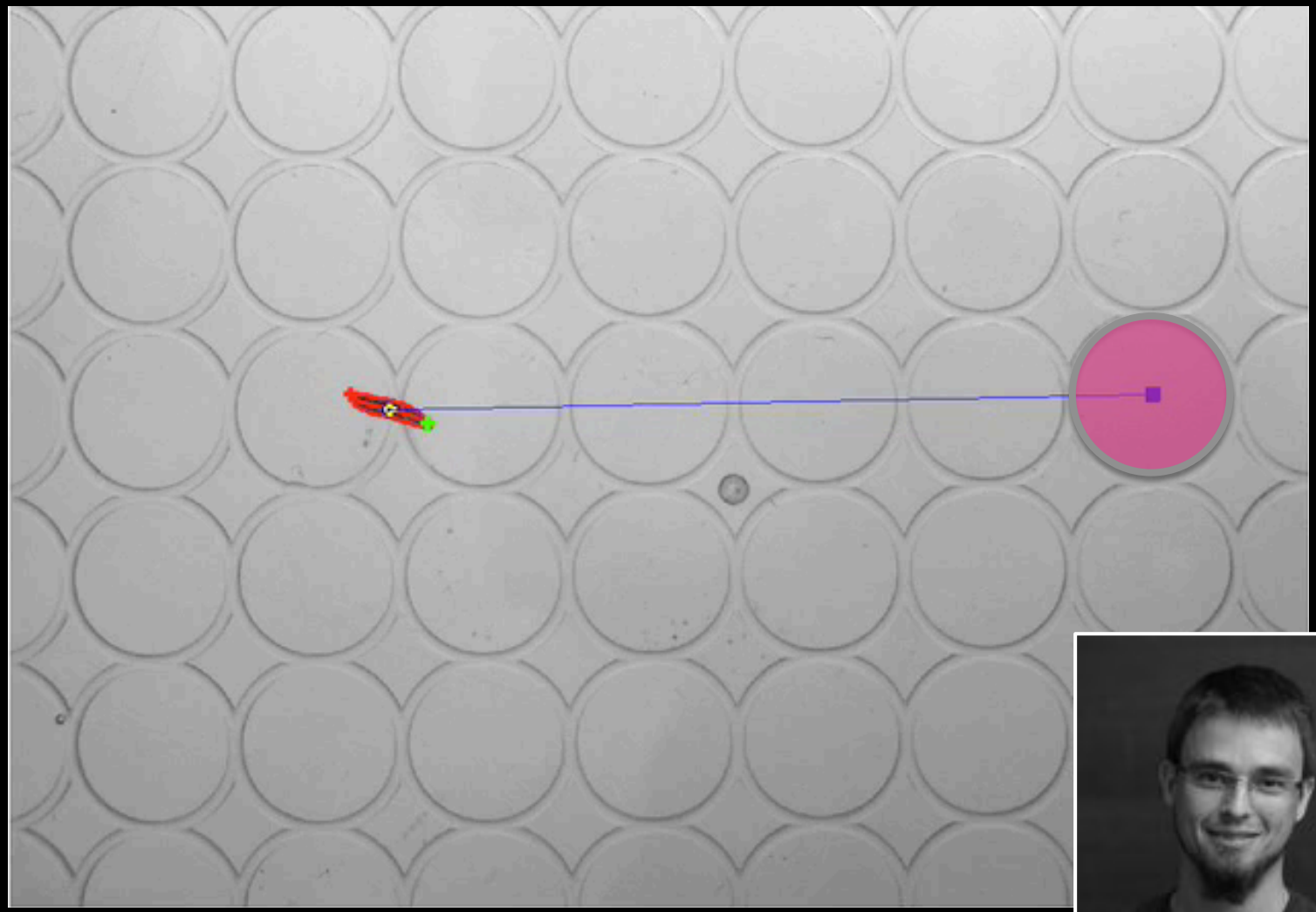


Larsson et al., Neuron 2004
Fishilevich et al., Current Biology 2005

Are *Drosophila* larvae capable of odor trail-tracking?



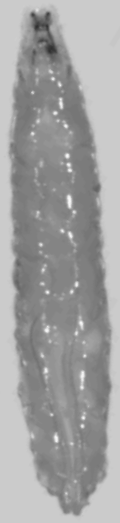
Multi-point tracking of navigational behavior



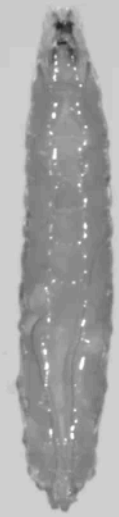
Alex Gomez-Marin

Main behavioral routine underlying larval chemotaxs

RUN

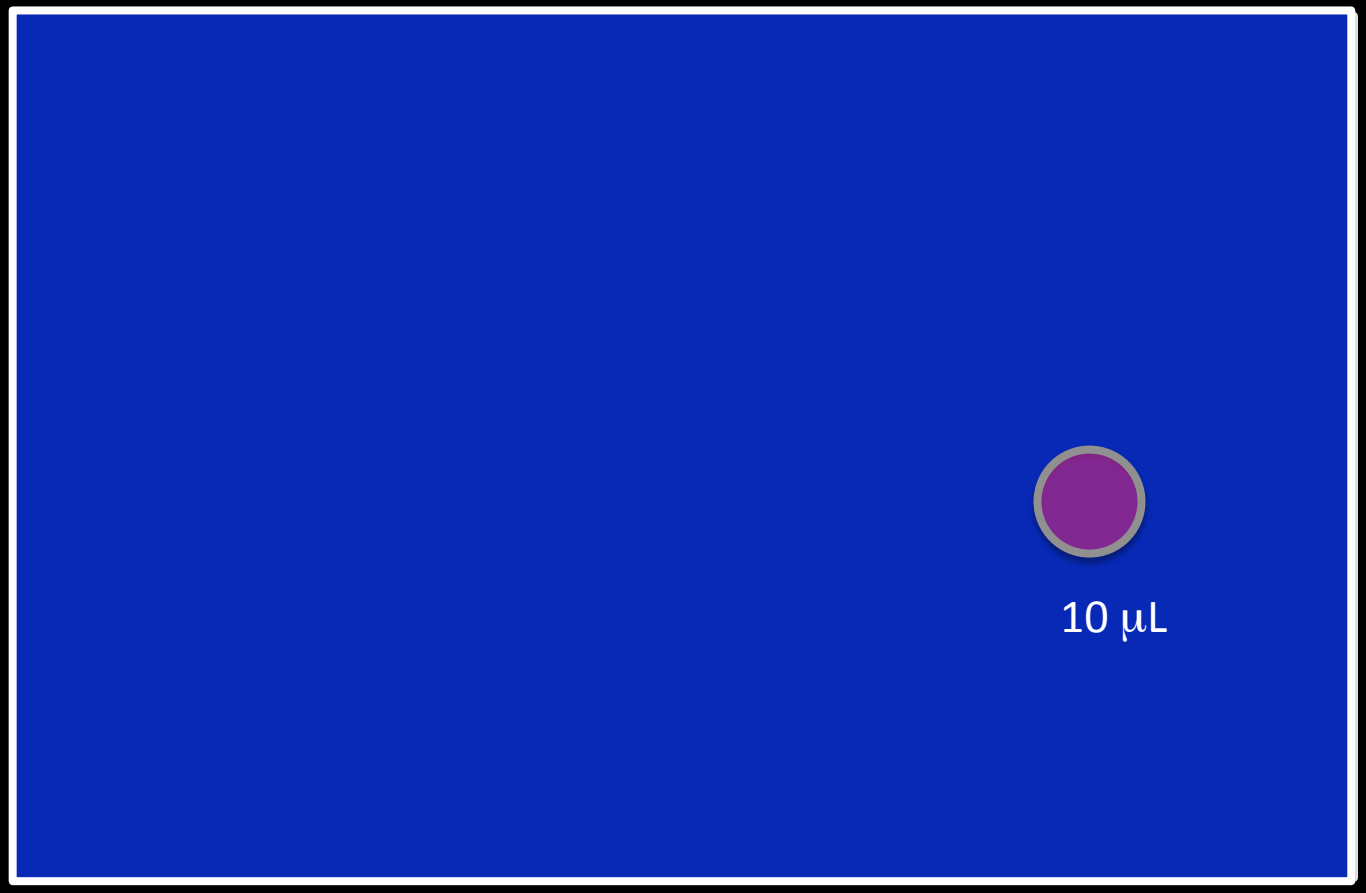


HEAD CAST



TURN

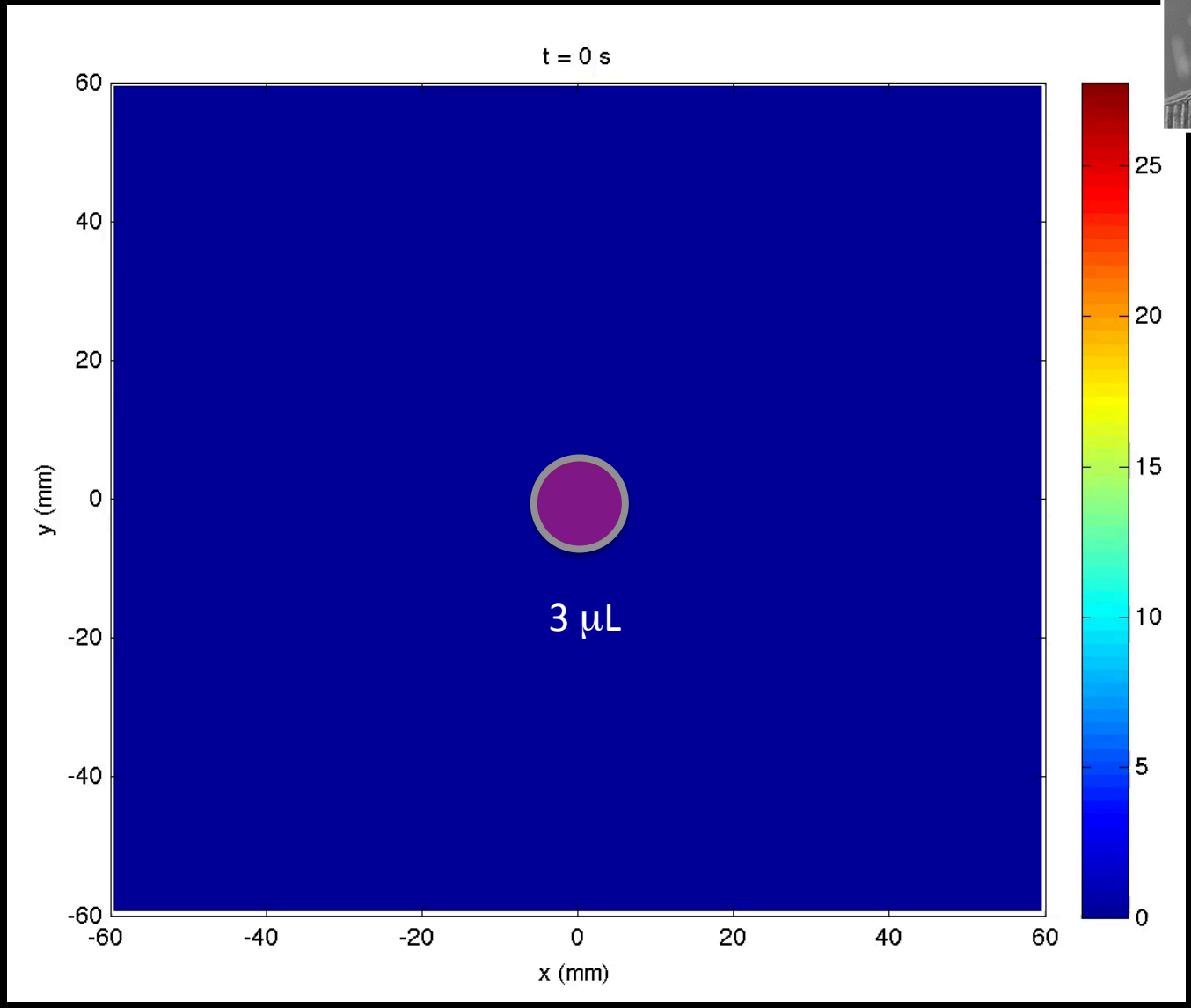
Experimental quantification of the olfactory space



quantification of stimulus concentration by infrared spectroscopy

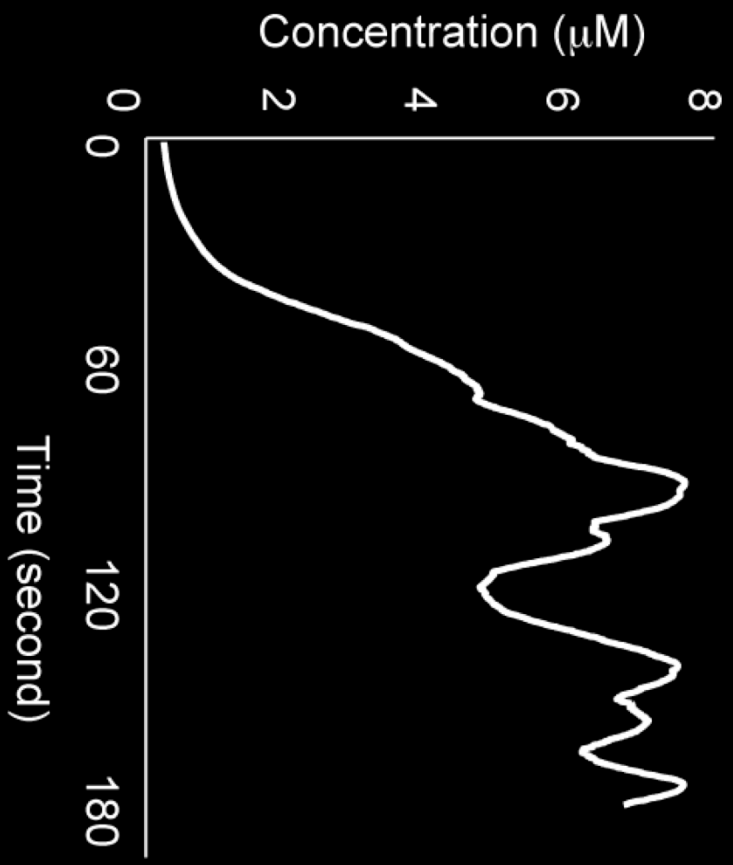
Physical modeling of the odor diffusion problem

Mahu Venkadesan

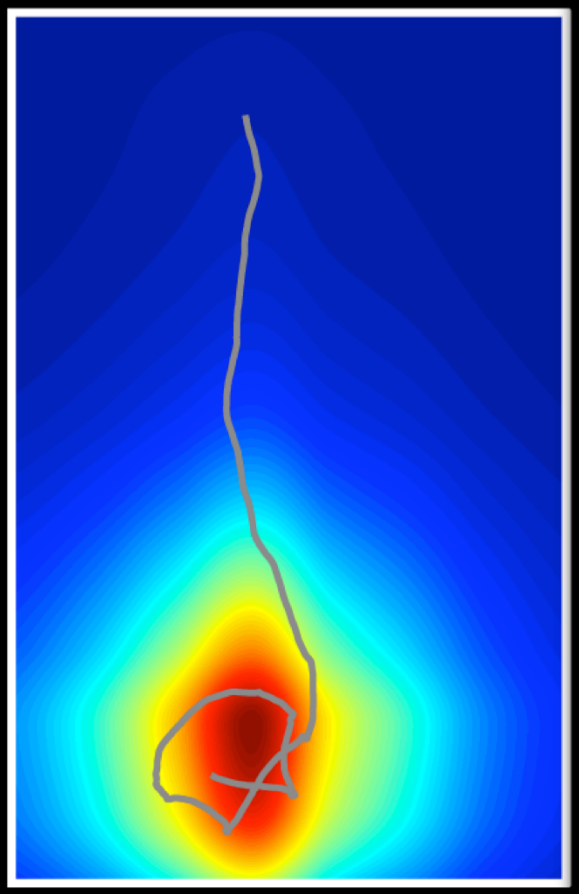


Correlating sensory input with behavioral output

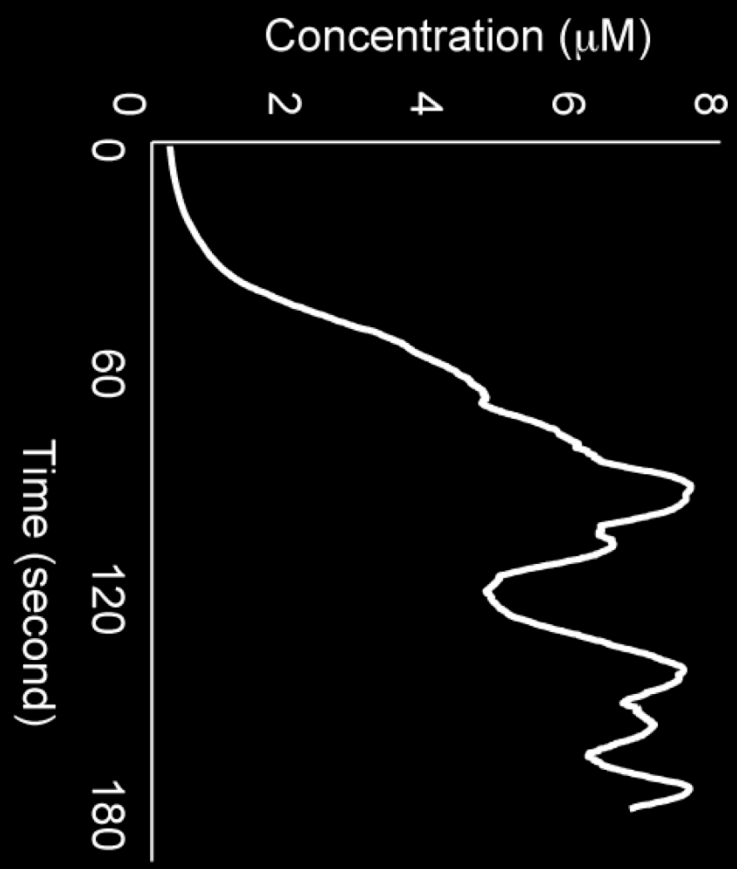
Sensory space



Behavioral space



Sensory space



Behavioral space

National Geographic, 1986

Questions addressed by our work:

Navigational algorithm:

- *What is the orientation algorithm directing larval chemotaxis?*
- *What are the basic sensorimotor computations behind this algorithm?*

Mechanistic implementation by neural circuits:

- Sensory coding: *How are behaviorally-relevant signals represented by the peripheral olfactory system?*
- Sensorimotor conversion*: How are peripheral olfactory inputs converted into action selection?*

How have sensorimotor functions evolved during the course of speciation?

Questions addressed by our work:

Navigational algorithm:

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Mechanistic implementation by neural circuits:

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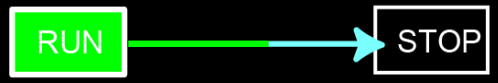
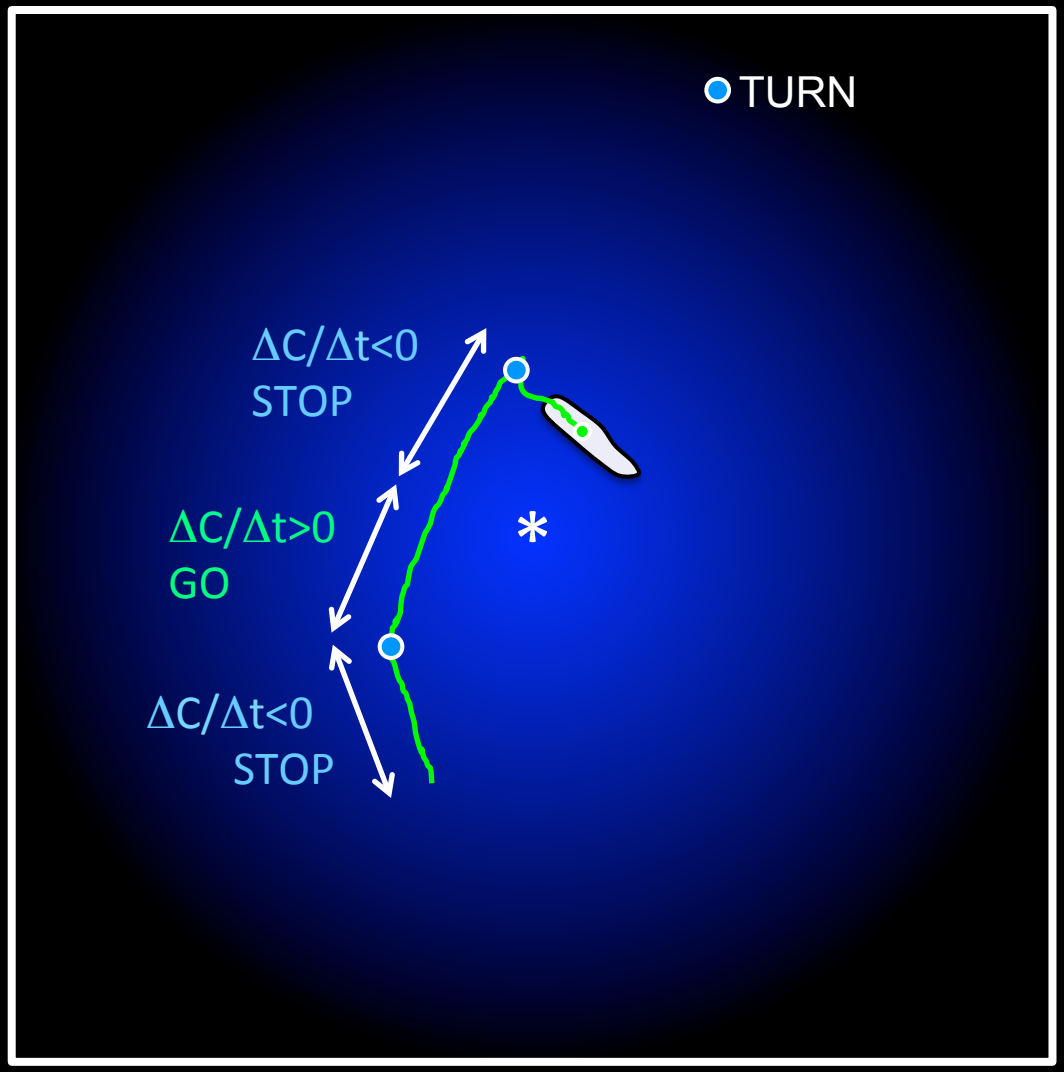
Navigational "decisions" directing larval chemotaxis

When to turn?

turn while down-gradient





Gomez-Marin et al., Nature Communications 2011
Gershow & Samuel labs

Navigational "decisions" directing larval chemotaxis

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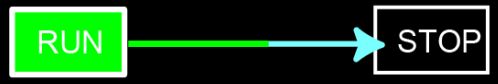
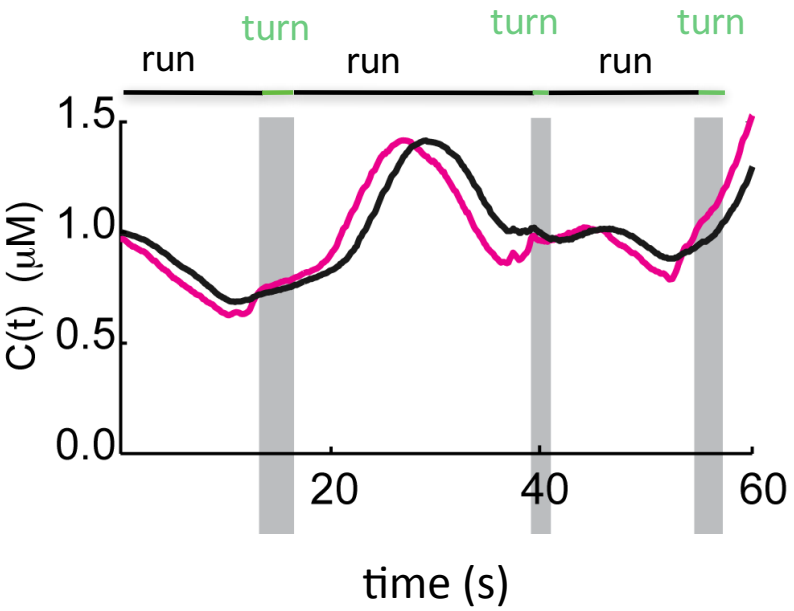


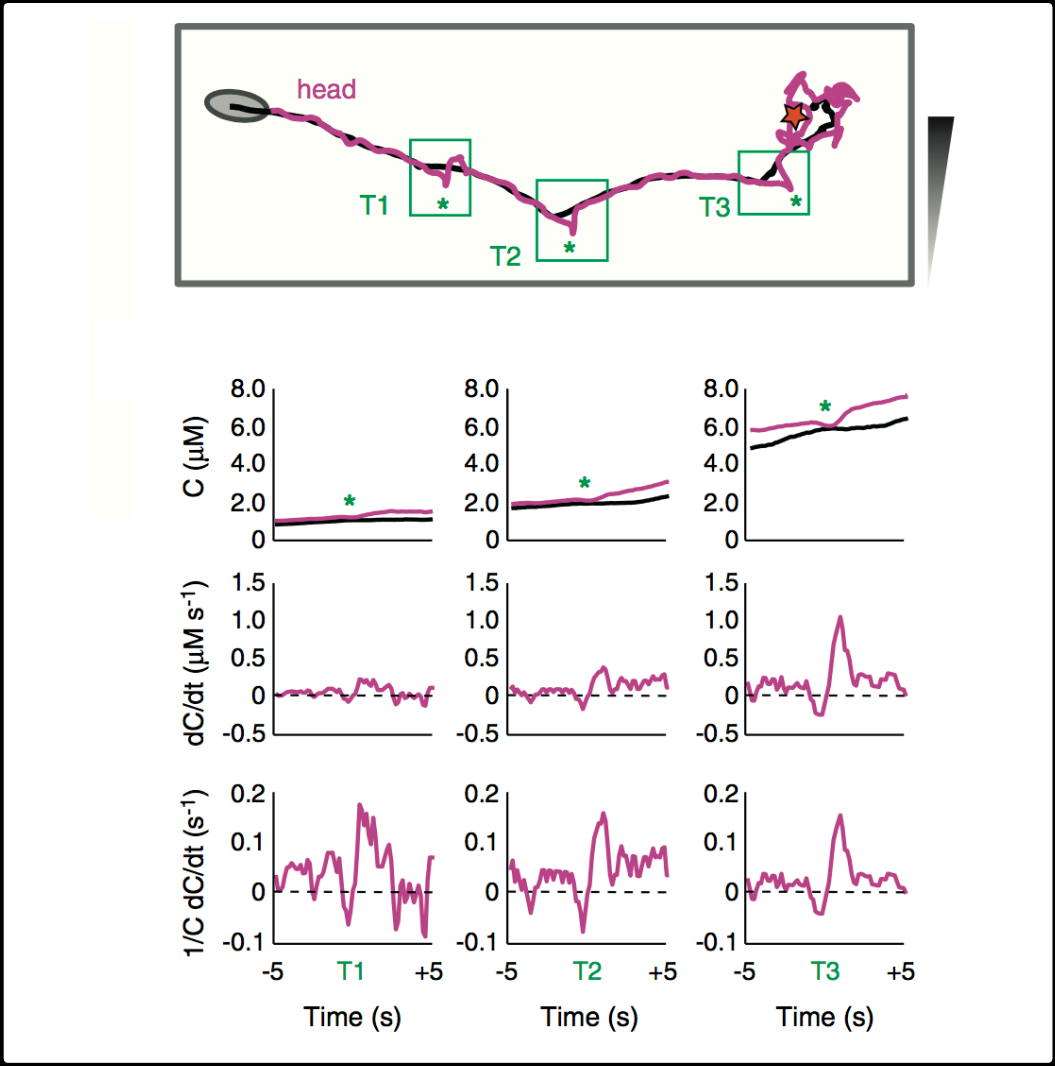
Weber-Fechner law:



Gomez-Marin et al., Nature Communications 2011

Potential advantages of detecting relative changes in odor intensity

Weber-Fechner law:



Gomez-Marin & Louis, Curr. Op. in Neuro. 2011

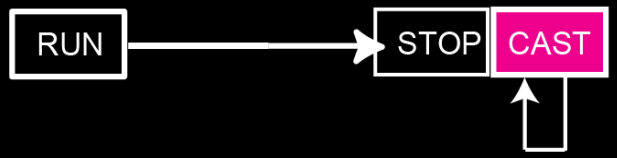
Navigational "decisions" directing larval chemotaxis

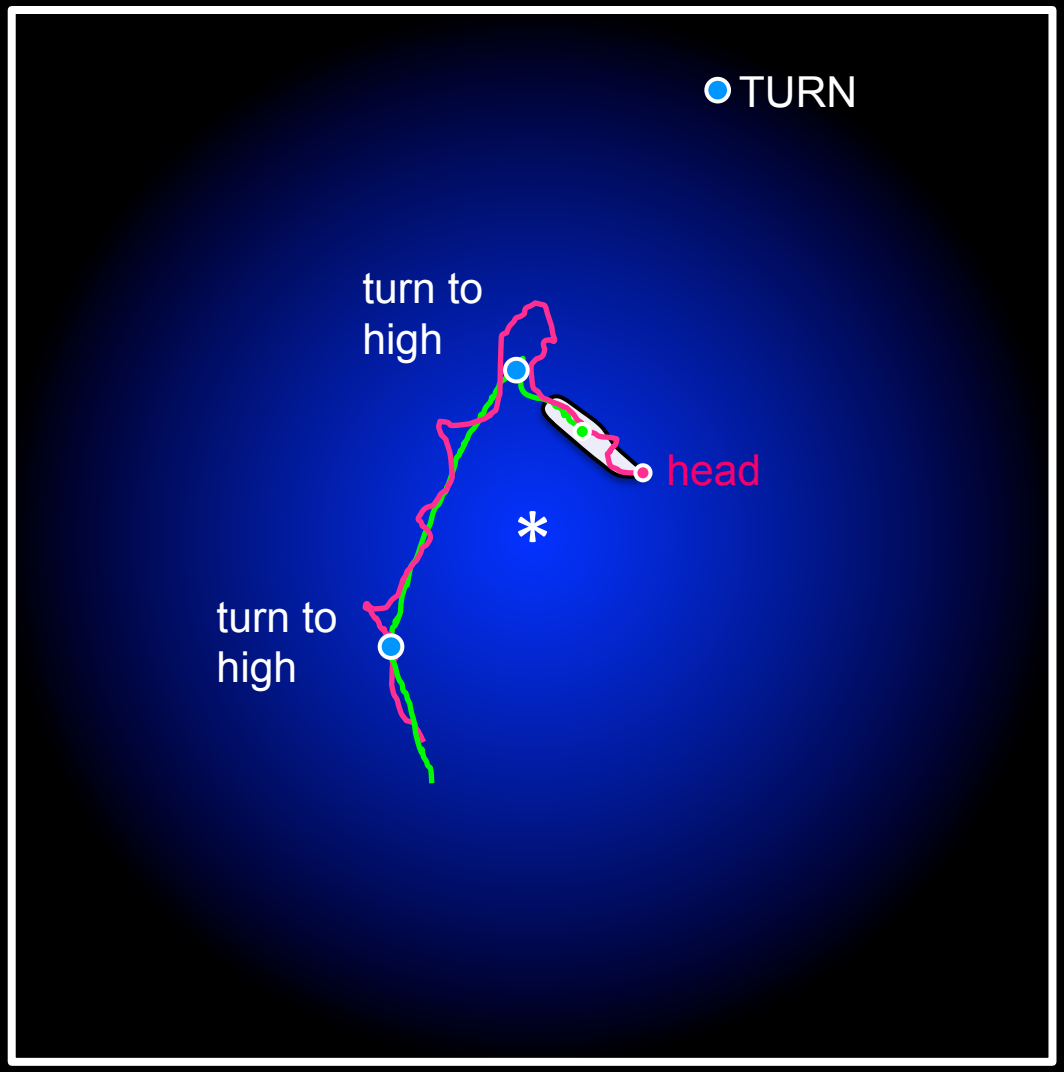
When to turn?

turn while down-gradient

Where to turn to?

turn toward the gradient





Gomez-Marin et al., Nature Communications 2011

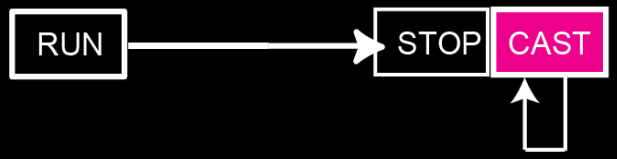
Active sensing through head scanning behavior

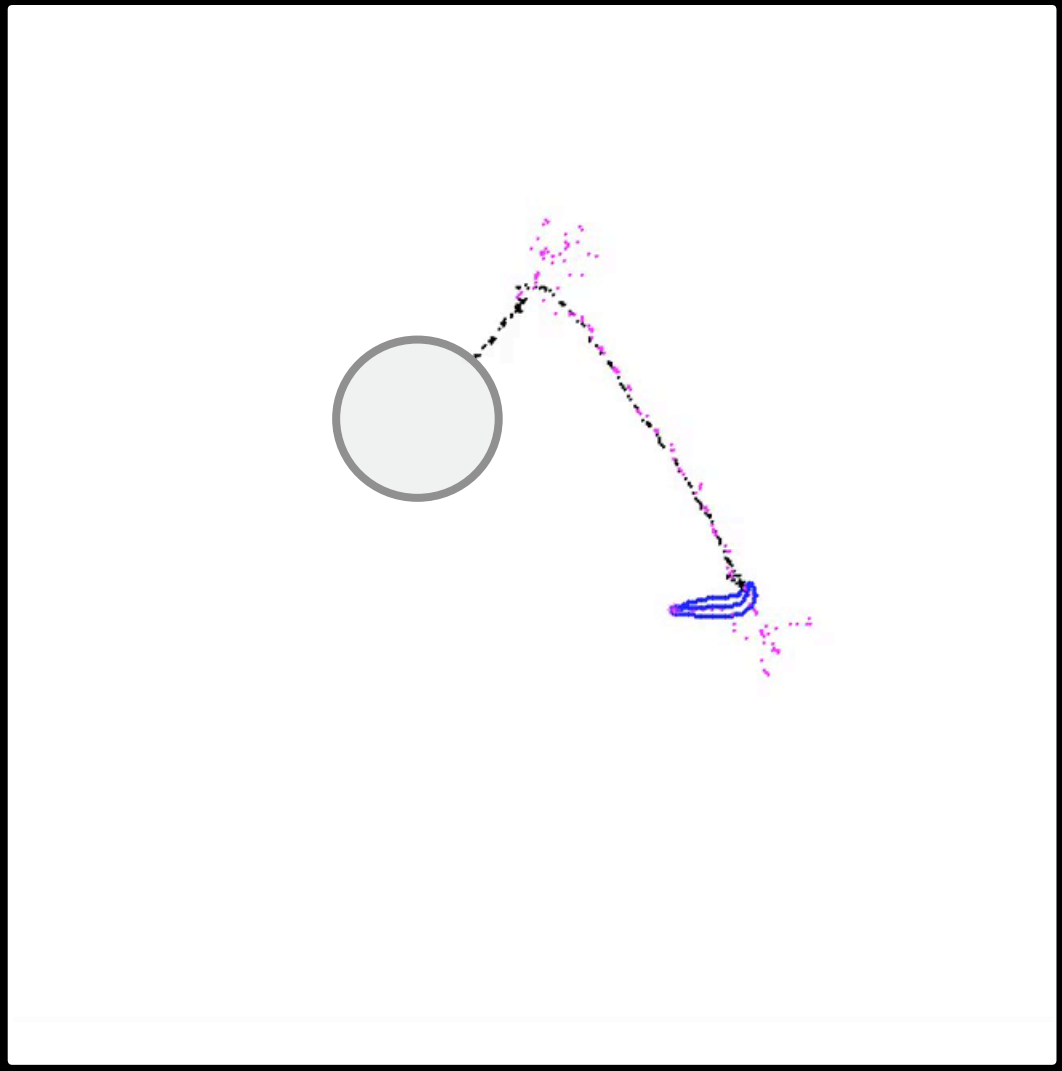
When to turn?

turn while down-gradient

Where to turn to?

turn toward the gradient





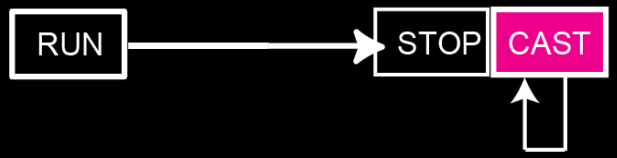
Navigational "decisions" directing larval chemotaxis

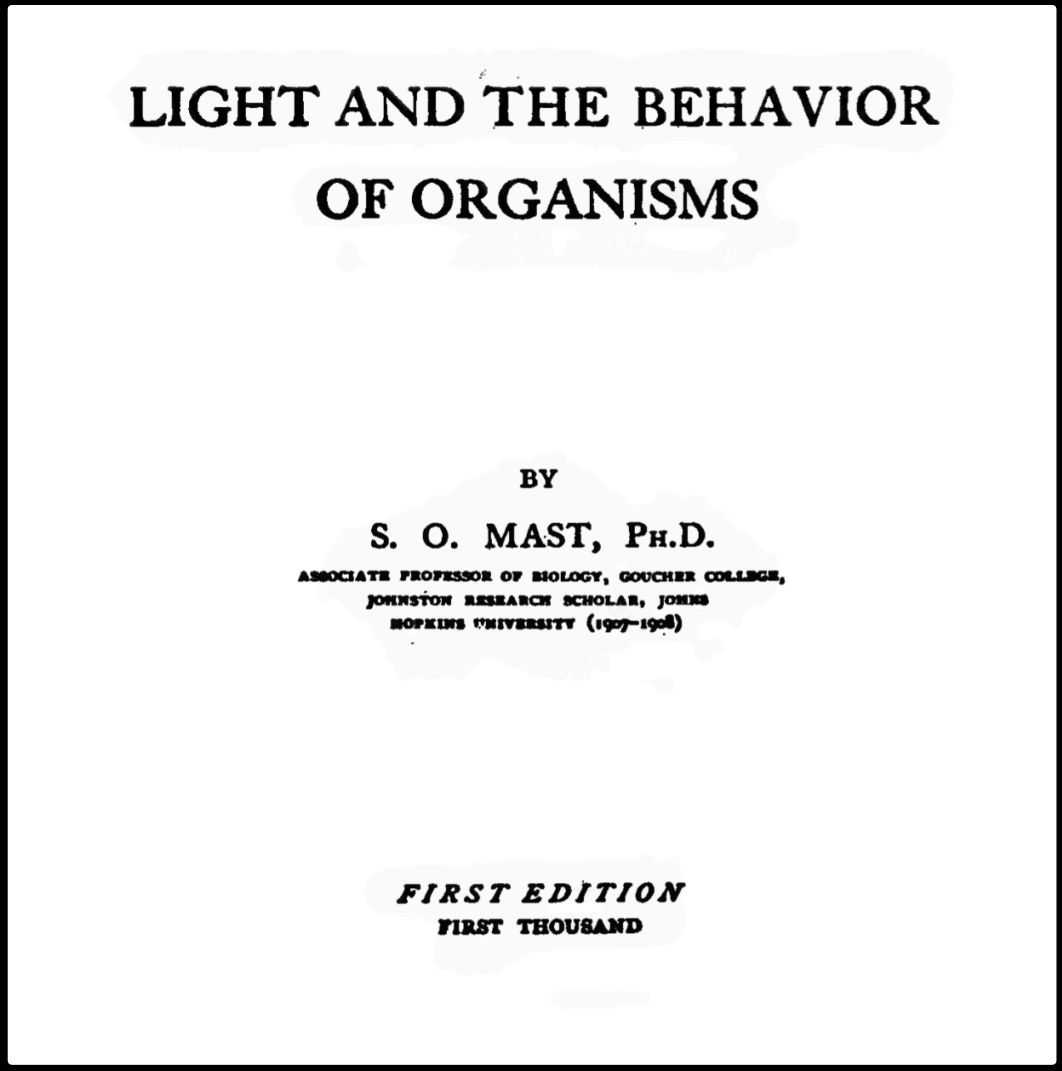
When to turn?

turn while down-gradient

Where to turn to?

turn toward the gradient





LIGHT AND THE BEHAVIOR OF ORGANISMS

BY

S. O. MAST, PH.D.

ASSOCIATE PROFESSOR OF BIOLOGY, GOUCHER COLLEGE, JOHNSTON RESEARCH SCHOLAR, JOHNS HOPKINS UNIVERSITY (1907–1908)

FIRST EDITION

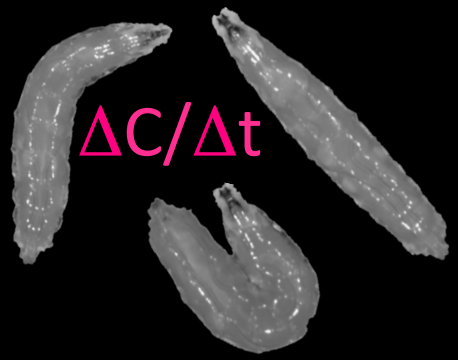
FIRST THOUSAND

Mast, 1911 (Light and the Behavior of Organisms)
Sokolowski, Sprecher & Samuel Labs

Orientation strategy directing larval chemotaxis

Stimulus induces change in orientation

- no directional bias in new heading
  - **KINESIS** — indirect orientation
    - **orthokinesis** — speed of movement depends on stimulus intensity
    - **klinokinesis** — rate of turning depends on stimulus intensity
- directional bias toward simtulus in new heading
  - **TAXIS** — direct orientation
    - **klinotaxis** — temporal comparison of sequential stimulus samples taken by single-point sensor(s)
    - **tropotaxis** — simultaneous spatial comparison of stimulus samples taken at separate sensors



Left-right comparison are not necessary to direct larval chemotaxis

Louis et al., Nat. Neuro 2008

Questions addressed by our work:

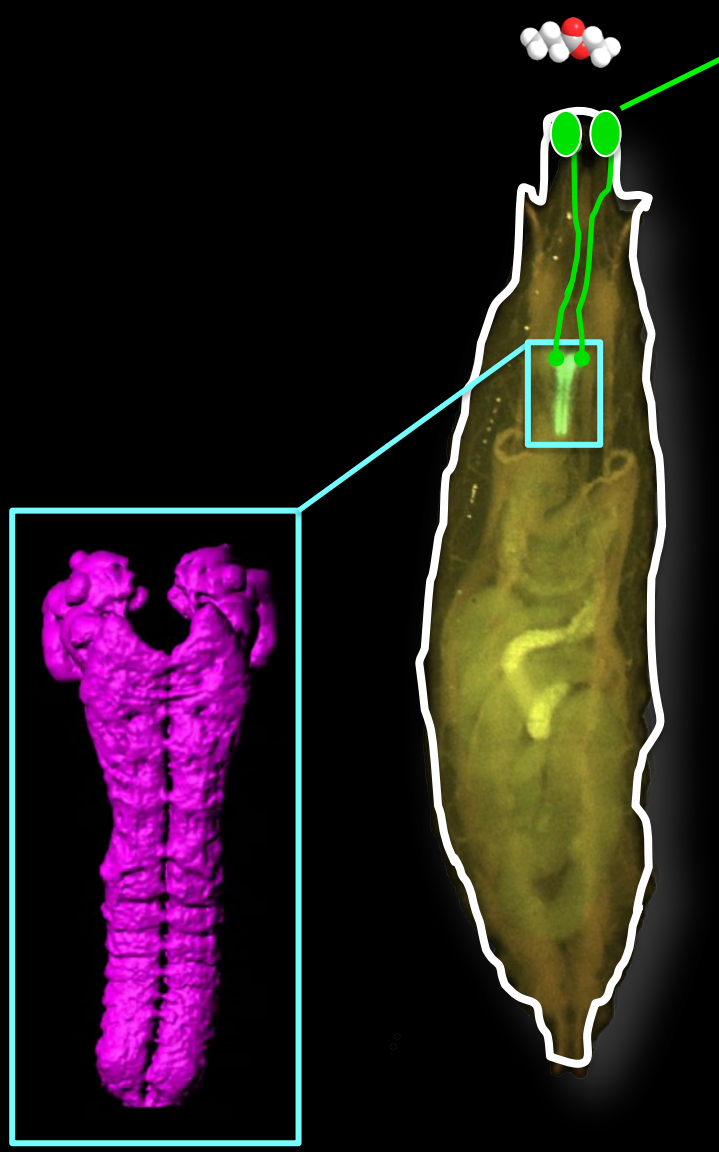
Navigational algorithm:

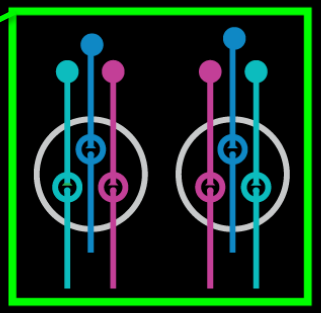
- *What is the orientation algorithm directing larval chemotaxis?*
- *What are the basic sensorimotor computations behind this algorithm?*

Mechanistic implementation by neural circuits:

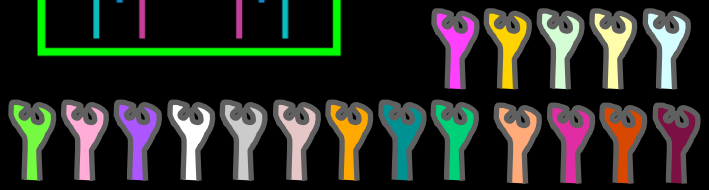
- Sensory coding: *How are behaviorally-relevant signals represented by the peripheral olfactory system? Where is the stimulus derivative calculated?*
- Sensorimotor conversion*: How are peripheral olfactory inputs converted into action selection?*

Odors are coded by an ensemble of olfactory sensory neurons





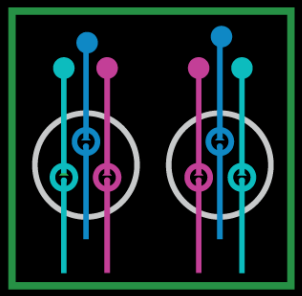
21 olfactory sensory neurons



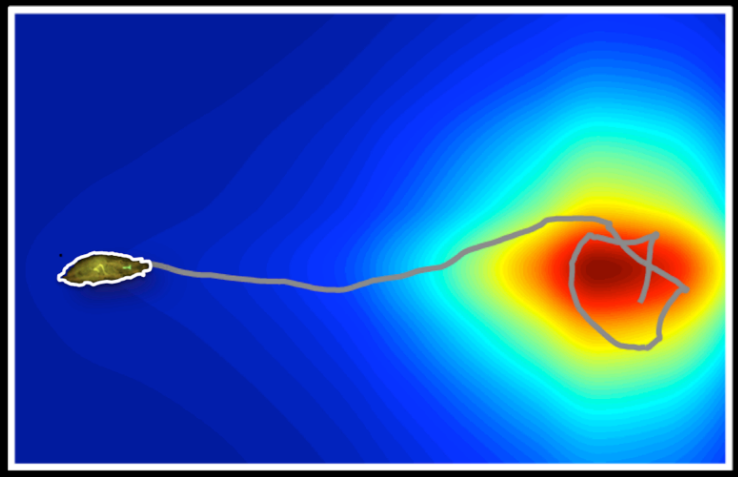
25 odorant receptors (ORs)

Fishilevich et al., Current Biology 2005
Kreher et al., Neuron 2005 & 2008

Navigation guided by a minimal olfactory system

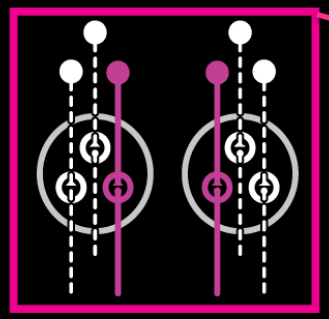


wild type (21 functional OSNS)



Fishilevich et al., Current Biology 2005
Louis et al, Nature Neuroscience 2008

Functional hijacking of the peripheral olfactory system of the larva

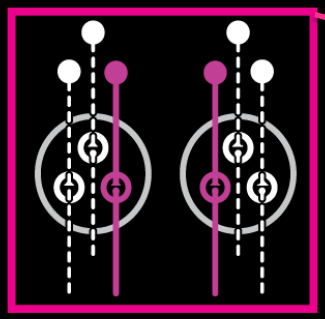


single functional Or42a sensory neuron + Channel-rhodopsin or Chrimson

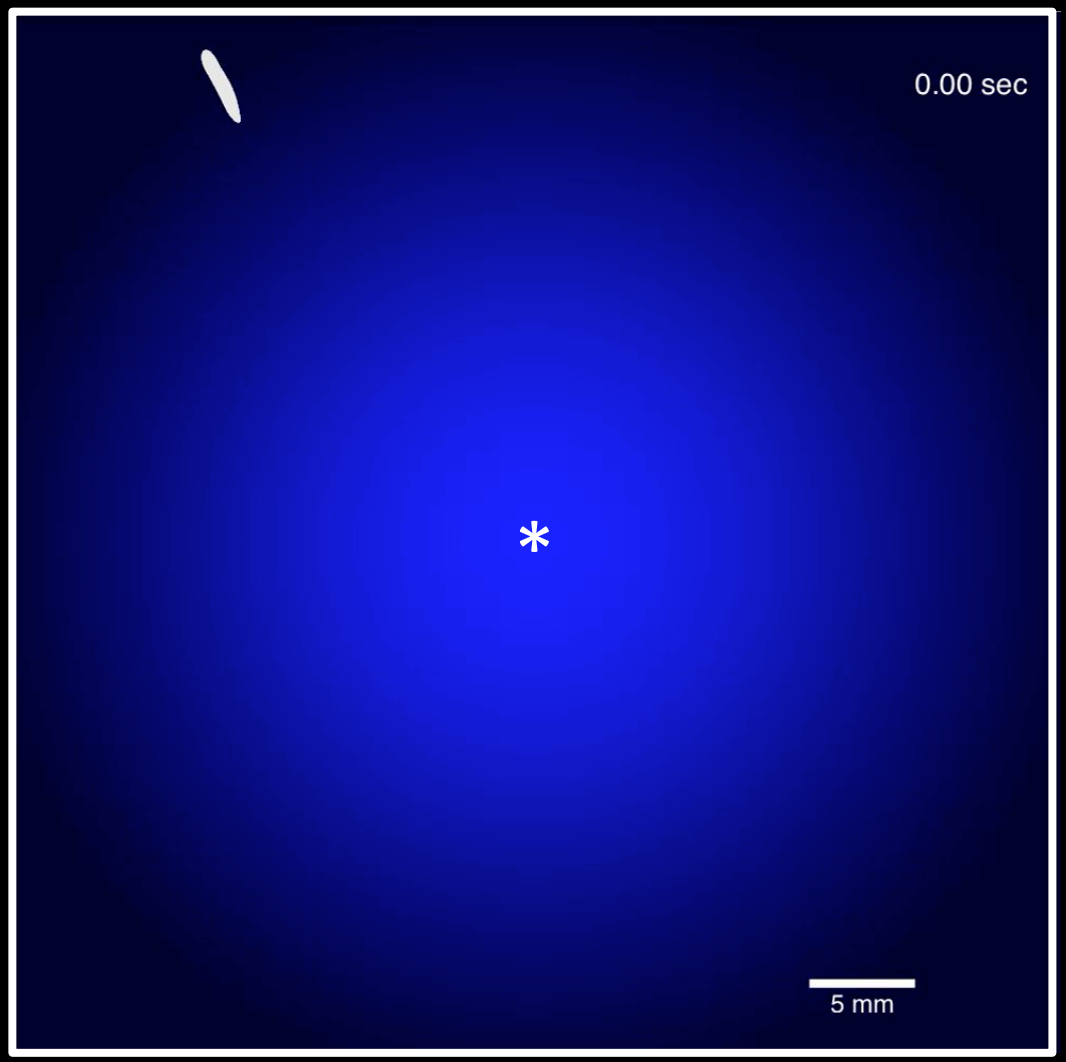
noisy odor → deterministic light

Vivek Jayaraman
Janelia

Navigation behavior in response to virtual olfactory realities



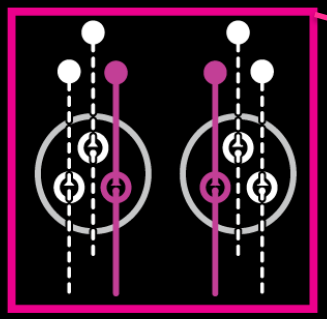
single functional Or42a sensory neuron + Channel-rhodopsin or Chrimson



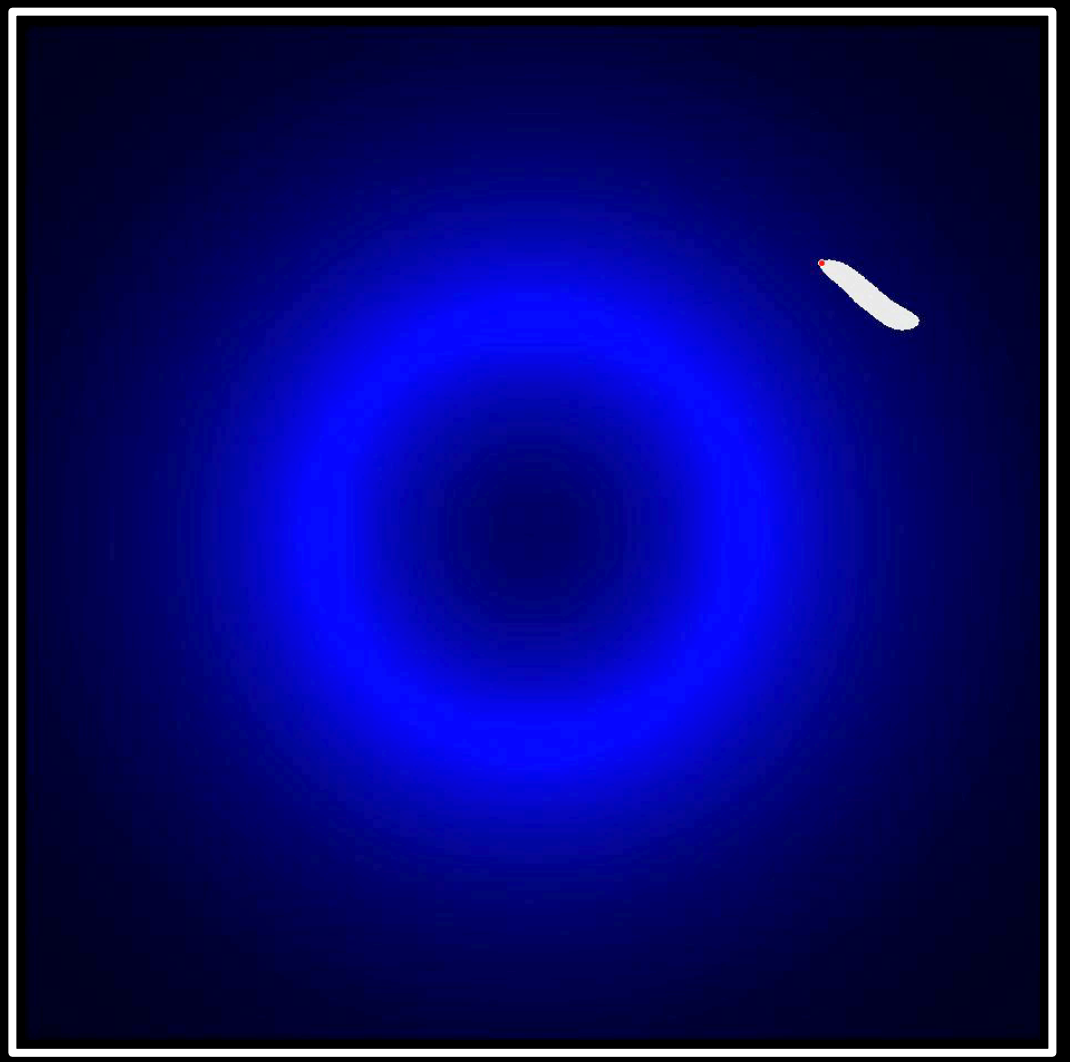
low high

light intensity

Navigation behavior in response to virtual olfactory realities



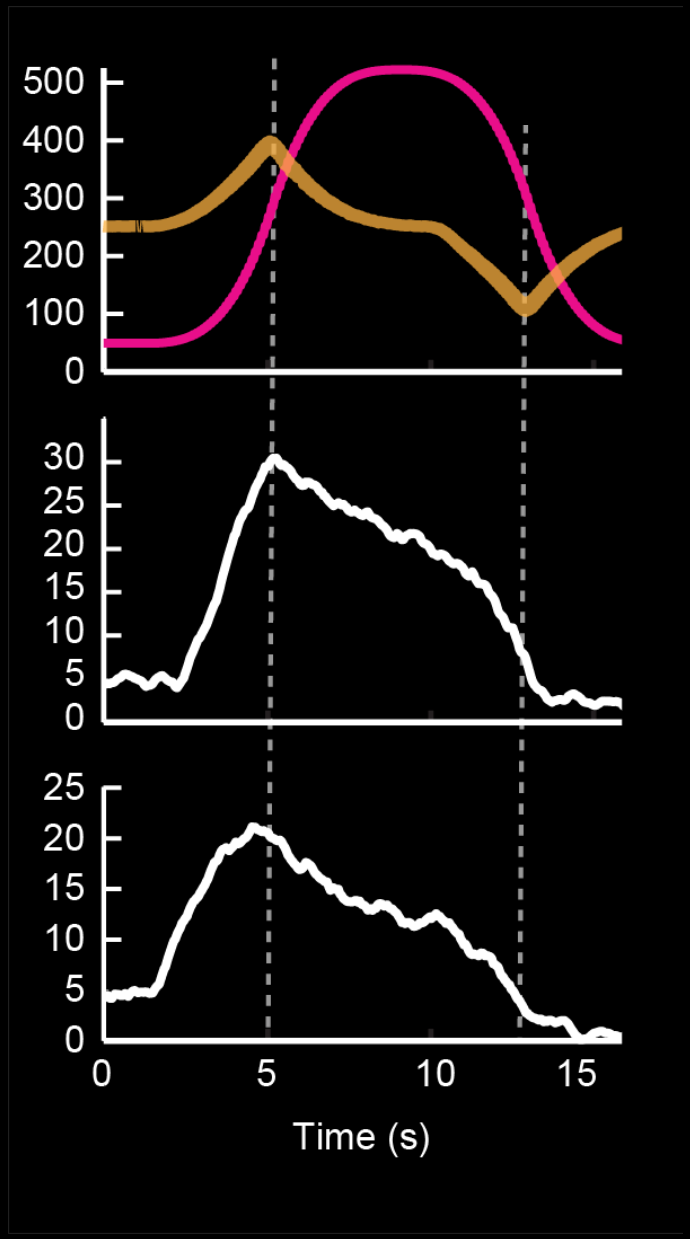
single functional Or42a sensory neuron + Channel-rhodopsin or Chrimson



low high

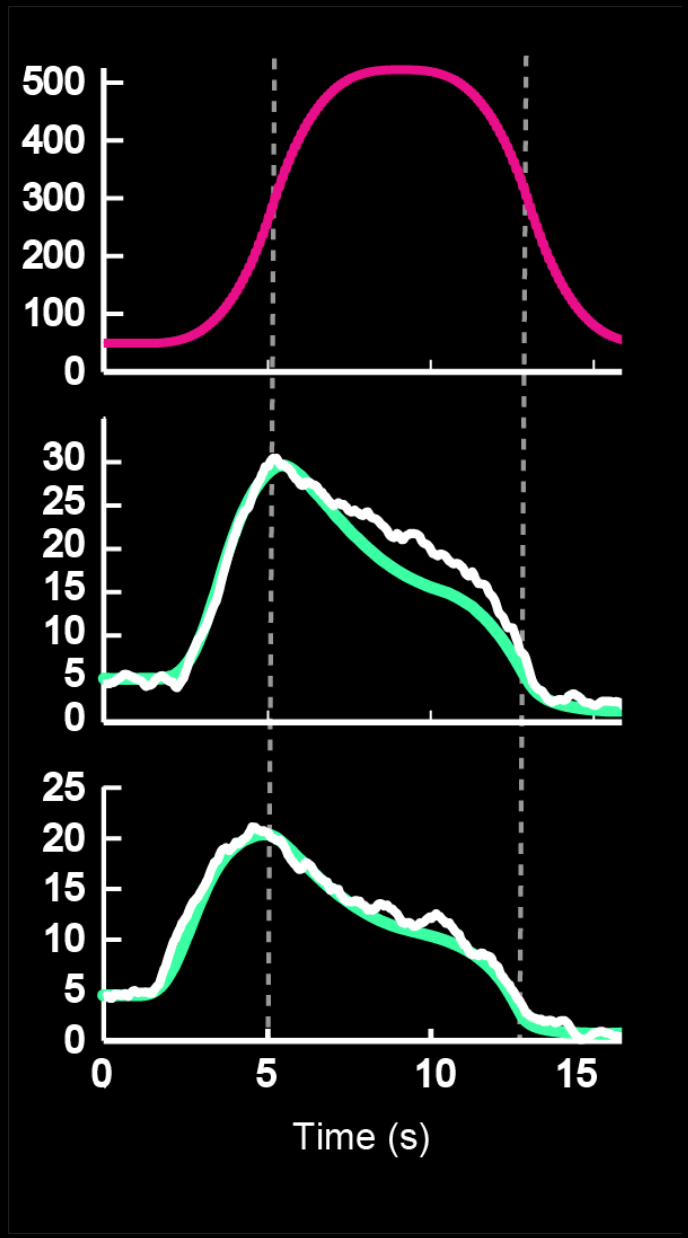
light intensity

What is the nature of the signals detected by the *Or42a* OSN?

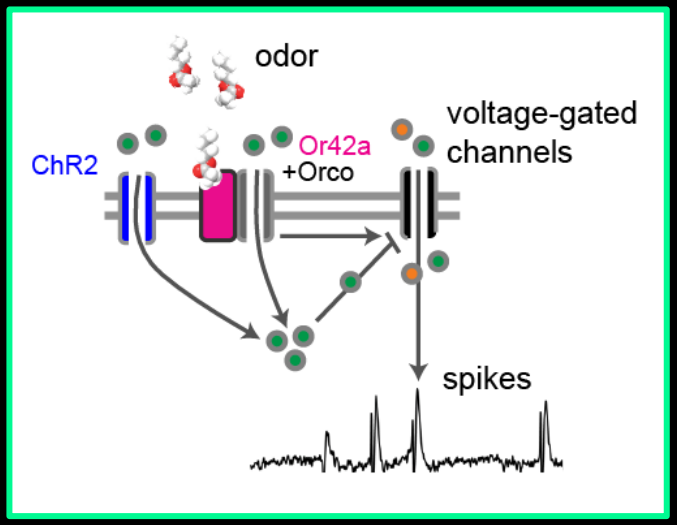


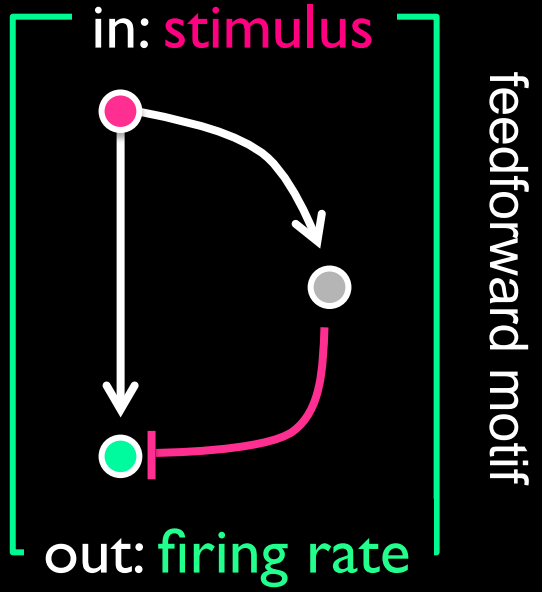
Aljoscha Schulze

Modeling olfactory transduction

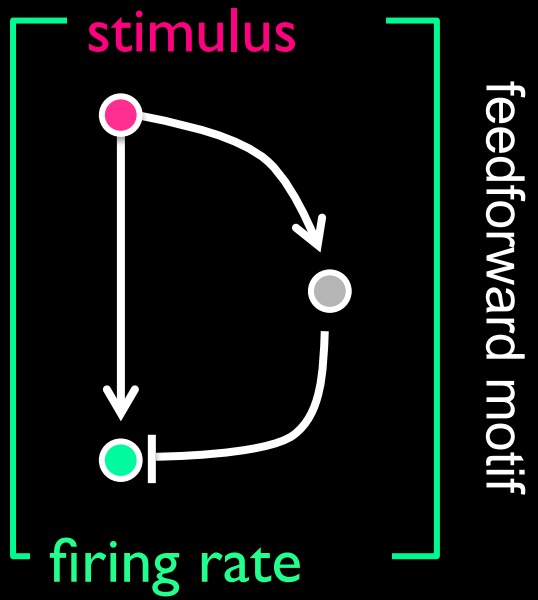


Biophysical model





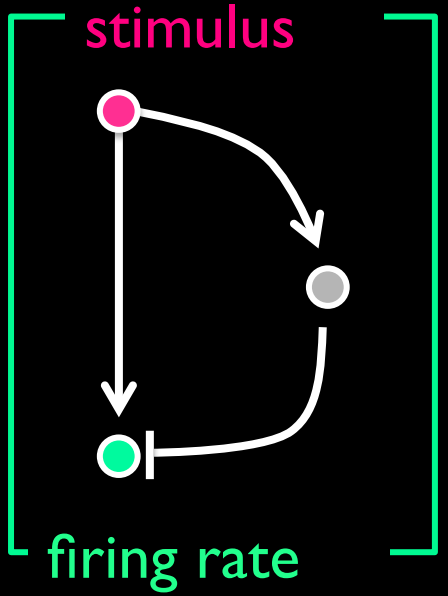
Analytical solution of the incoherent feedforward motif



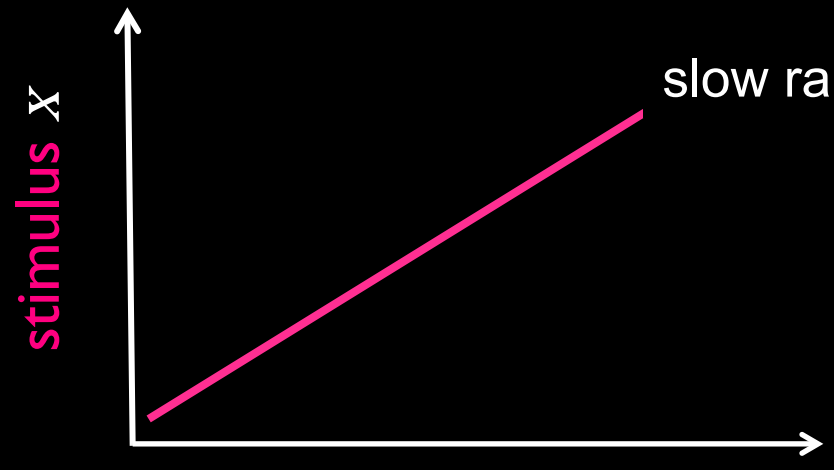
Analytical solution:

where

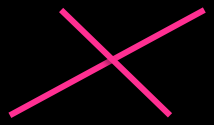
Combined sensitivity to stimulus intensity and rate of change

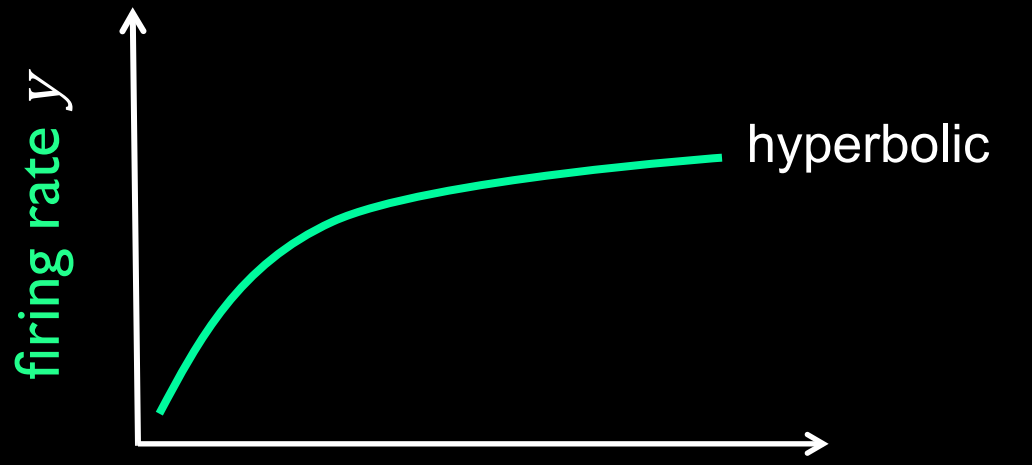


feedforward motif

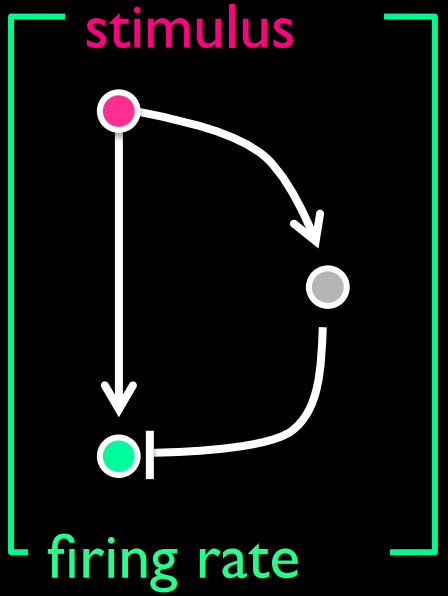


Analytical solution:

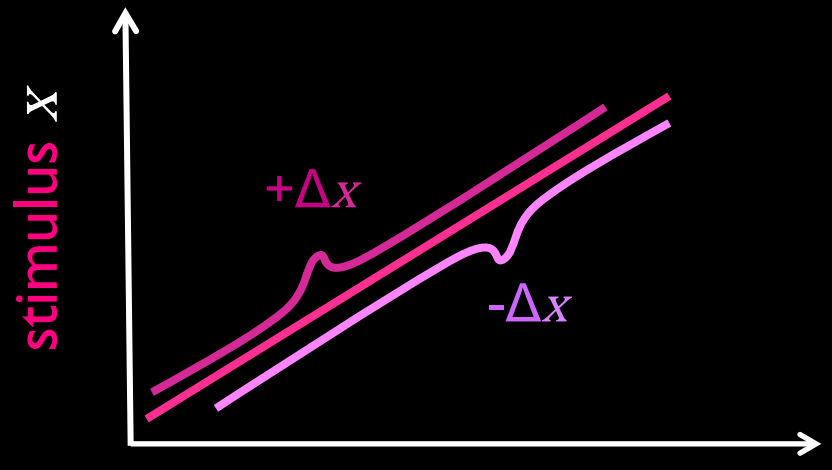


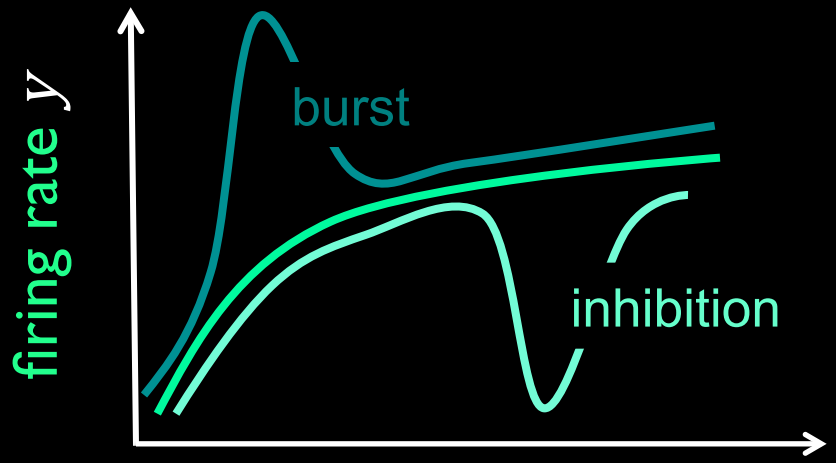


Combined sensitivity to stimulus intensity and rate of change



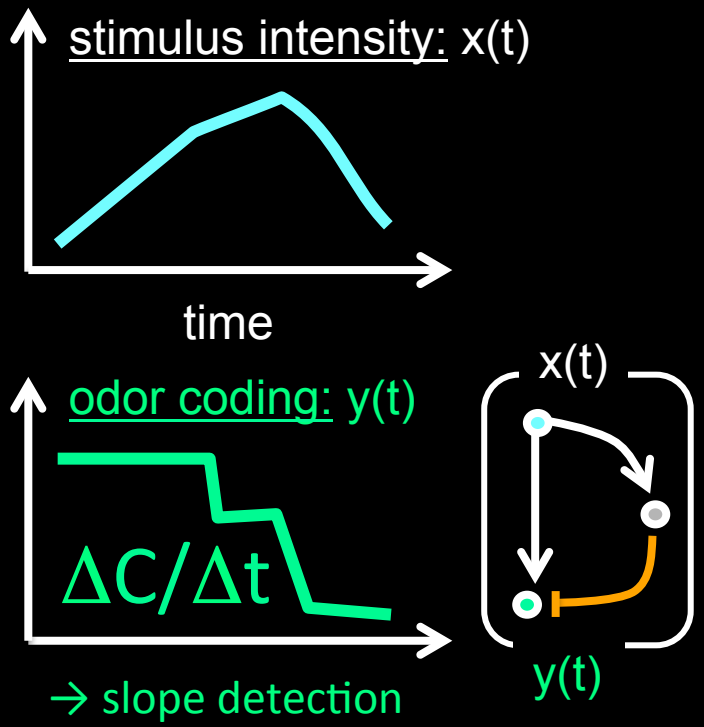
feedforward motif

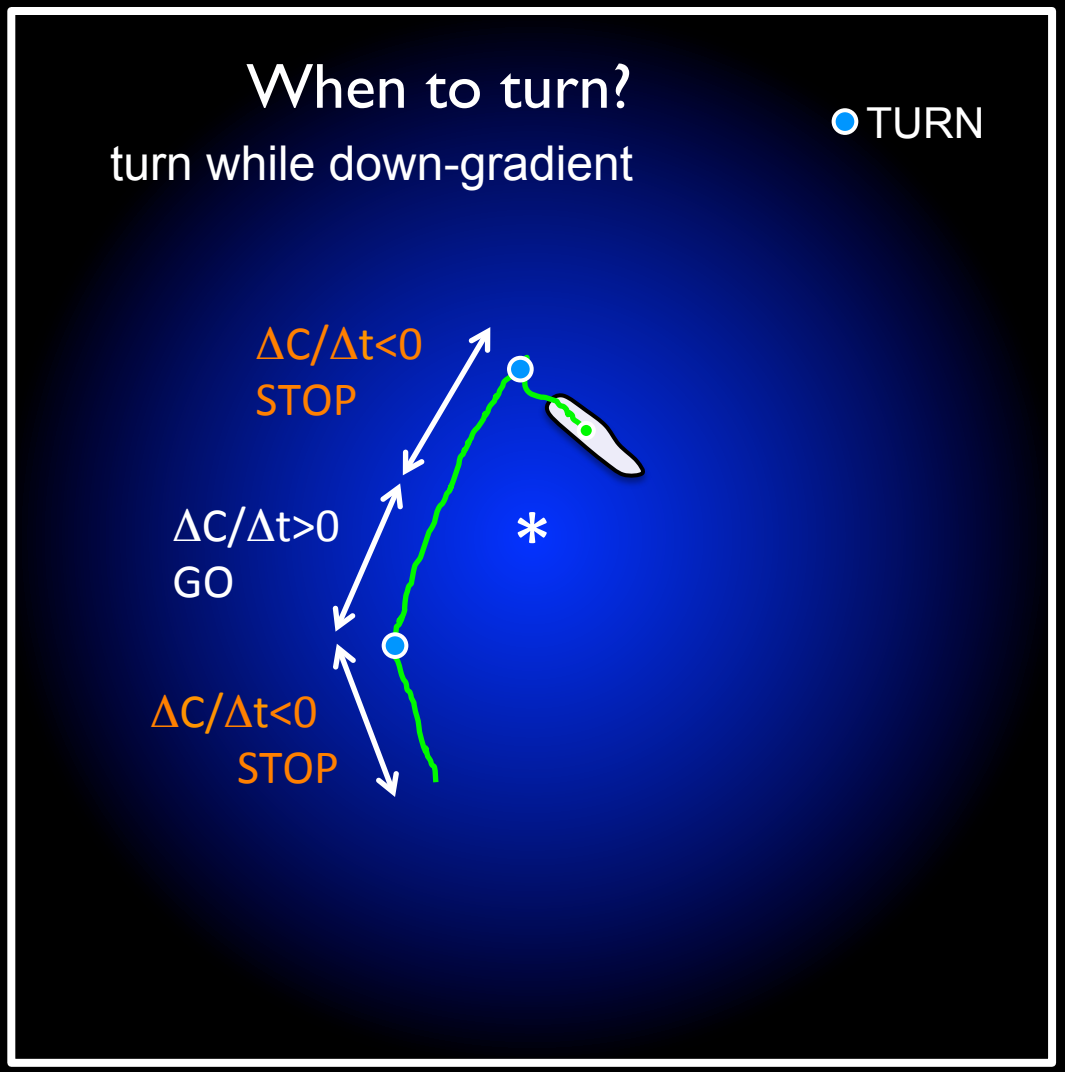




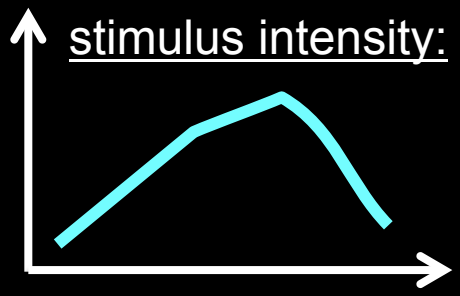
Analytical solution:

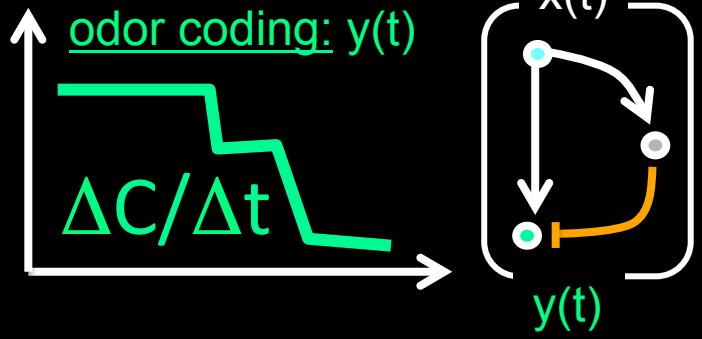
Algorithmic model for the control of when-to-turn decisions

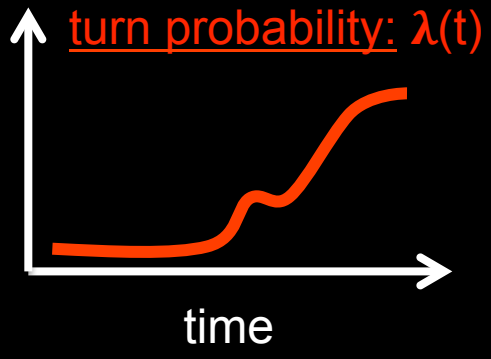




Algorithmic model for the control of when-to-turn decisions

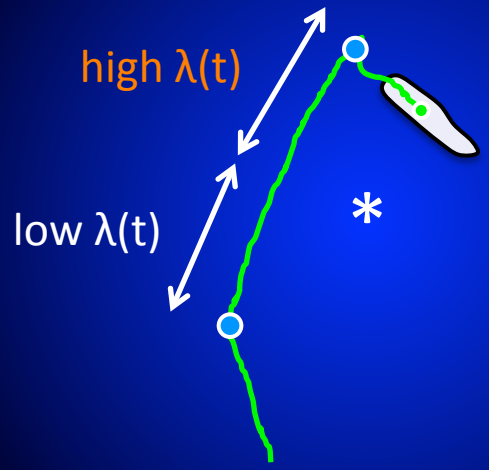






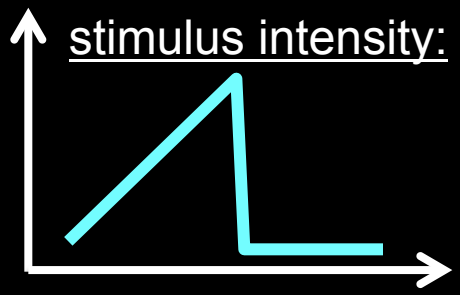
turn probability: $\lambda(t)$

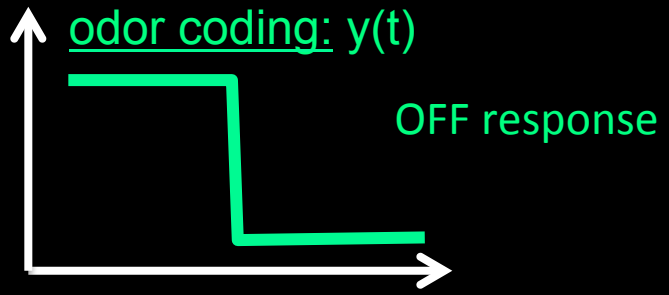
$$\lambda(t) = \lambda_{max} - \gamma * y(t)$$

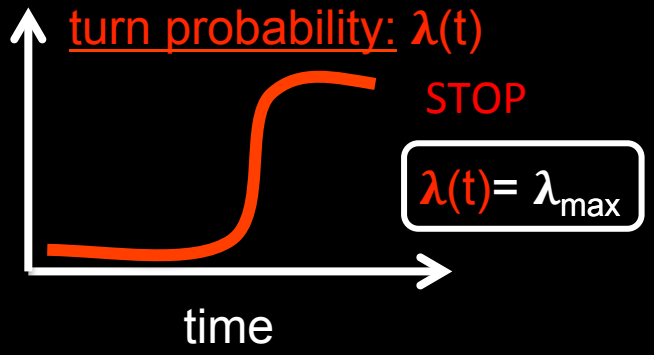


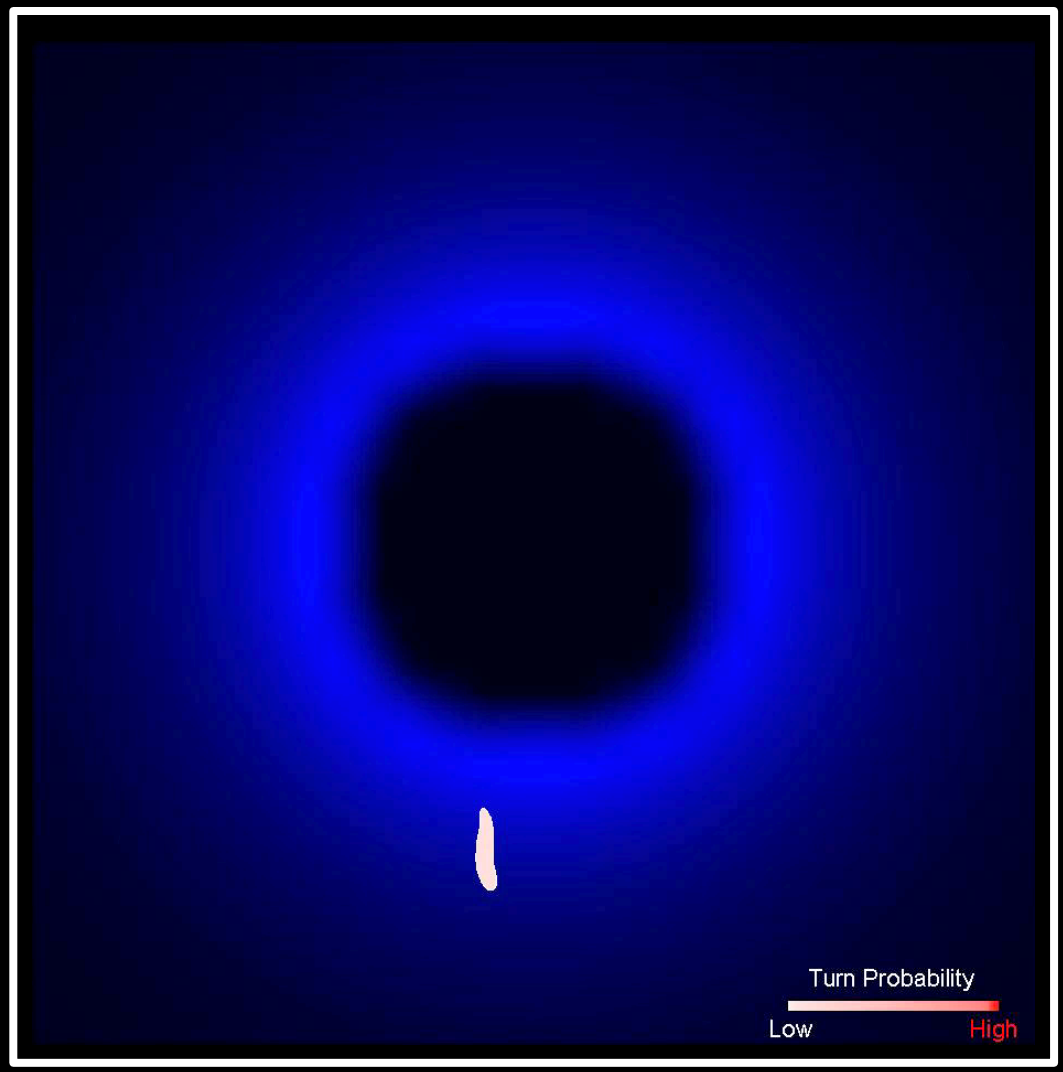
Schulze et al, eLife 2015

Inducing deterministic stop/turn in closed-loop conditions



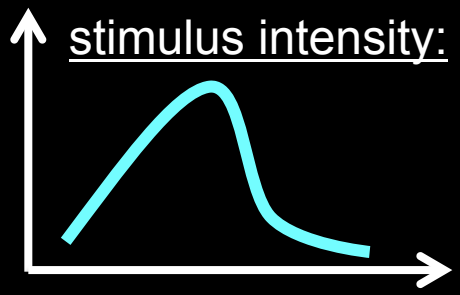


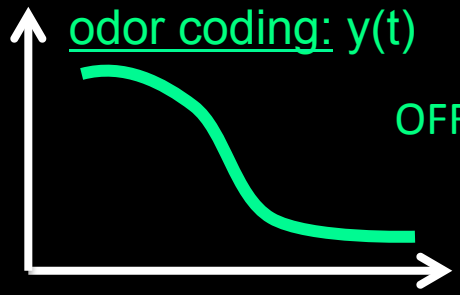


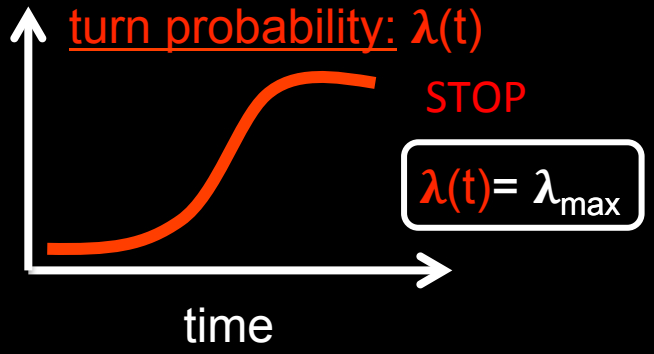


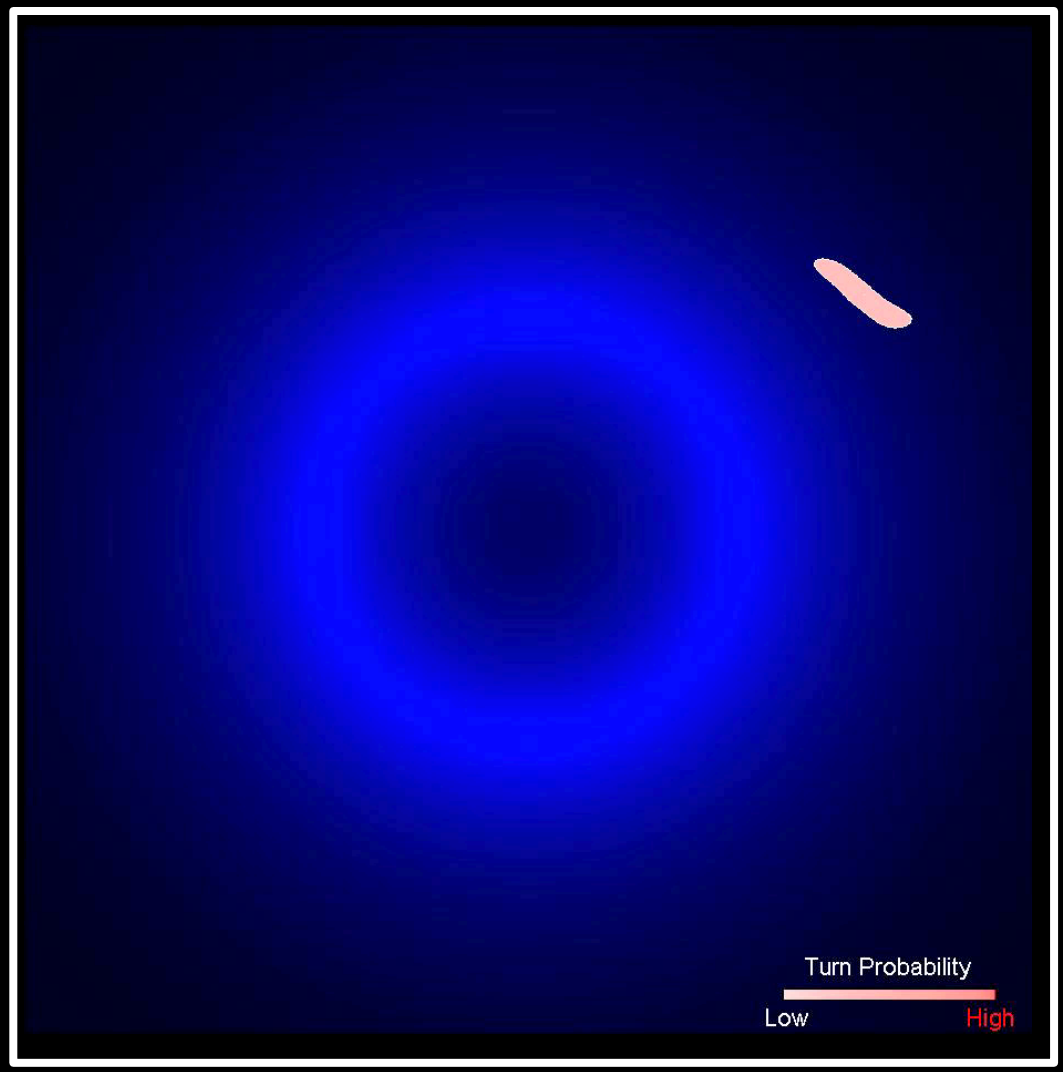
Schulze et al, eLife 2015

Processing graded intensity changes in closed-loop conditions





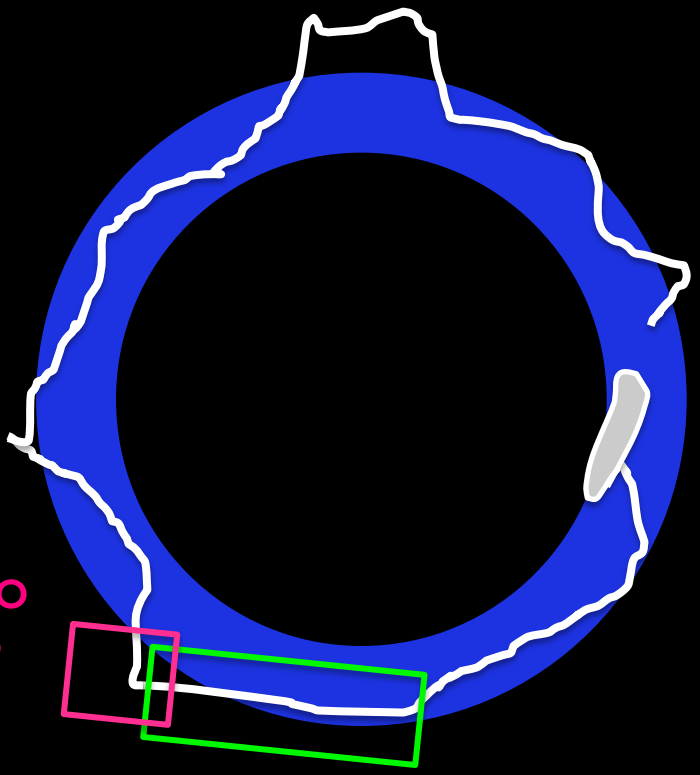




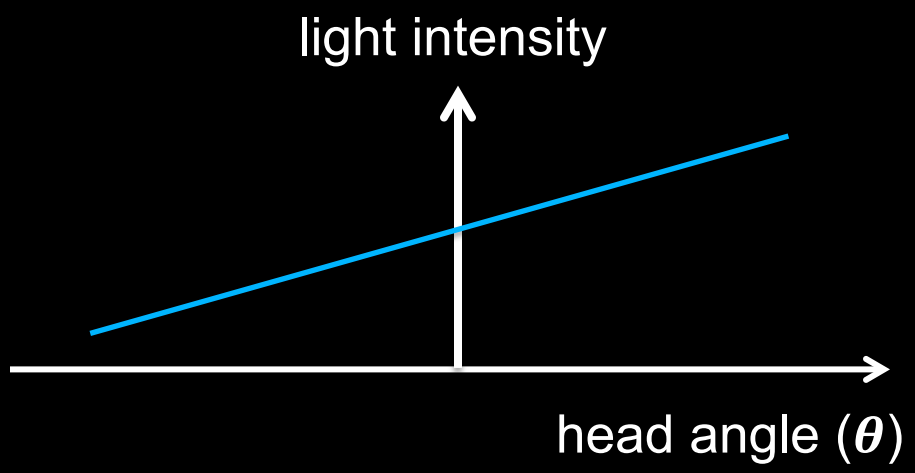
Schulze et al, eLife 2015

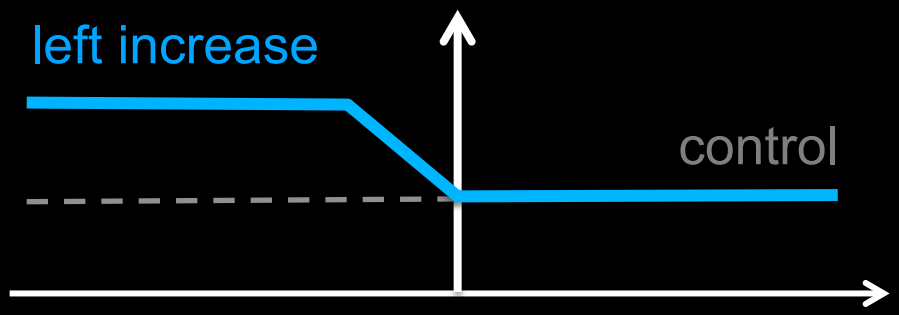
What is the sensorimotor algorithm controlling turn direction?

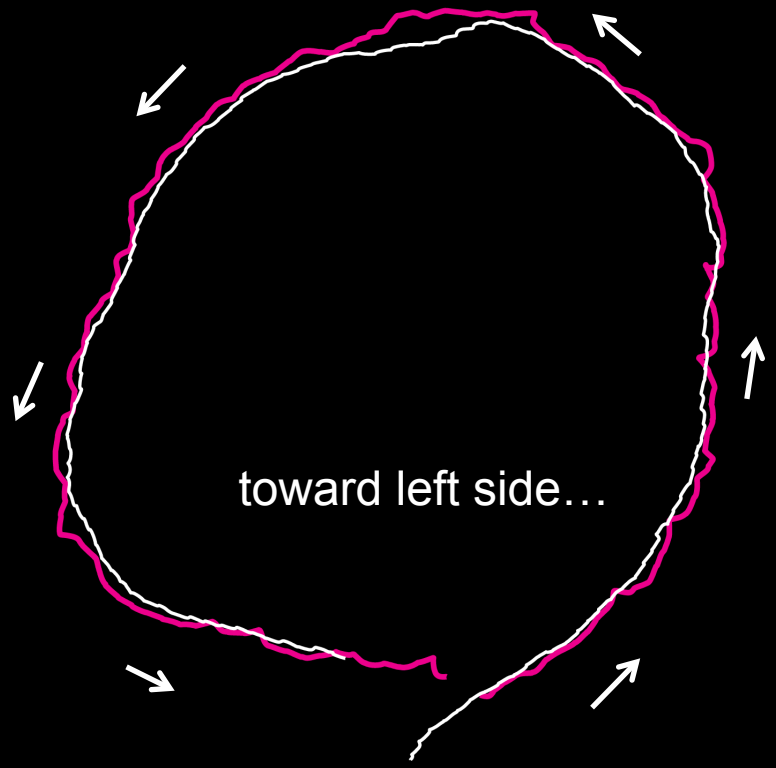
Ajinkya Deogade



Manipulating the head-cast dynamics through optogenetics




left increase
control


toward left side…

Questions addressed by our work:

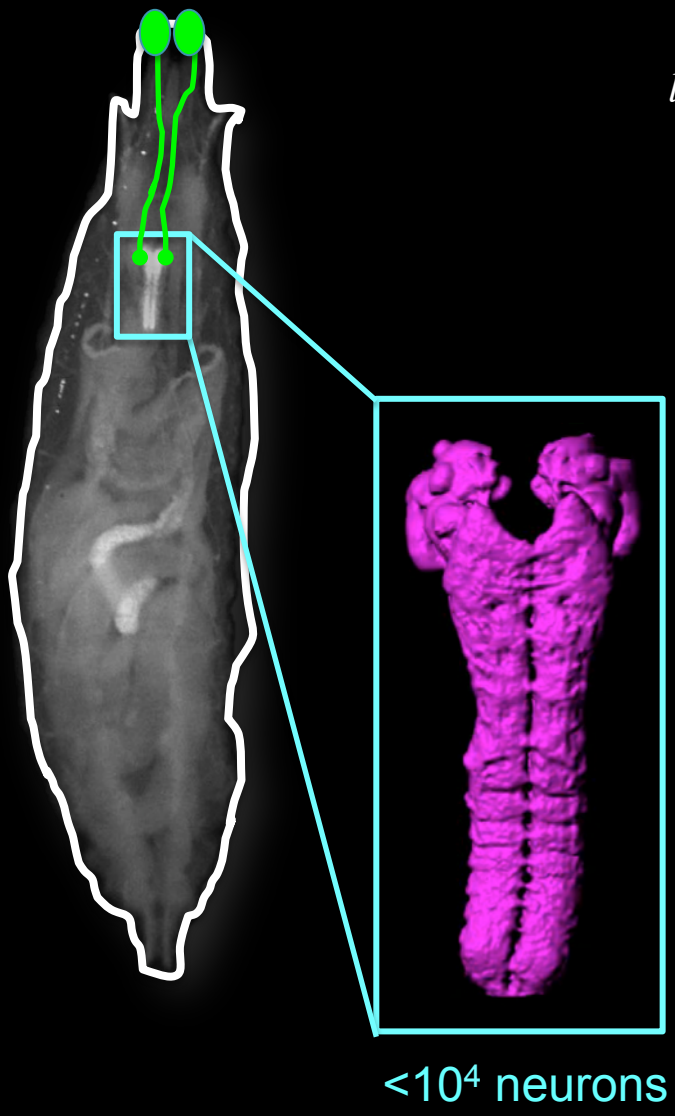
Navigational algorithm:

- *What is the orientation algorithm directing larval chemotaxis?*
- *What are the basic sensorimotor computations behind this algorithm?*

Mechanistic implementation by neural circuits:

- Sensory coding: *How are behaviorally-relevant signals represented by the peripheral olfactory system? Where is the stimulus derivative calculated?*
- Sensorimotor conversion*: How are peripheral olfactory inputs converted into action selection?*

What are the neural correlates of action selection?



<10^4 neurons

mushroom bodies ("learned")

lateral horn ("innate")

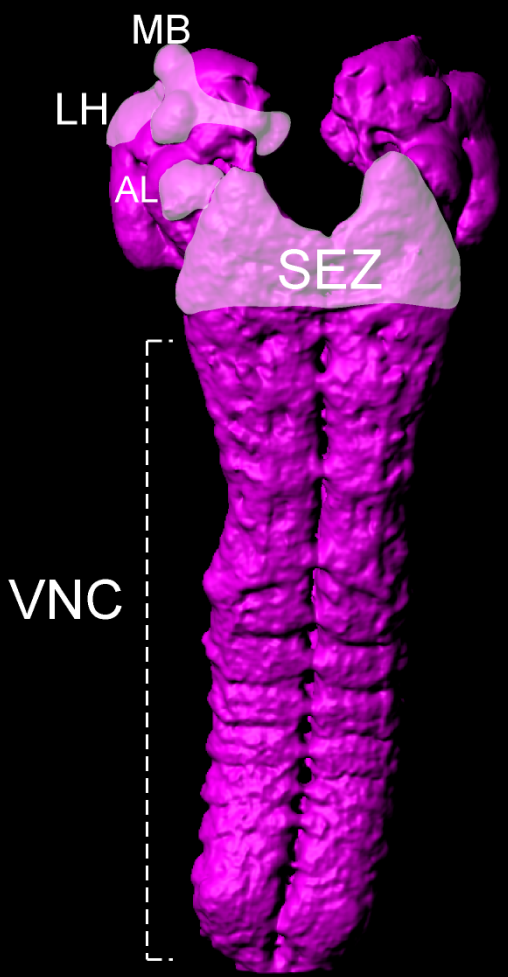
21 olfactory sensory neurons

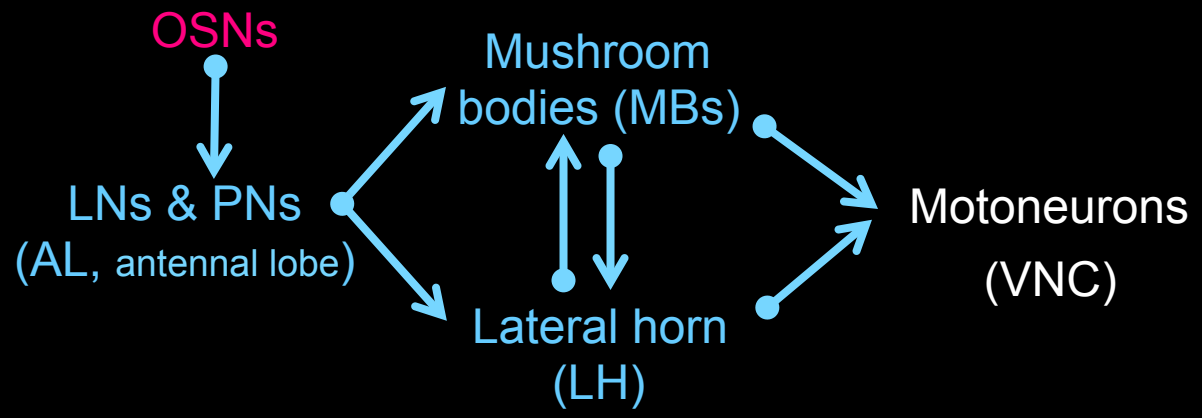
motor neurons

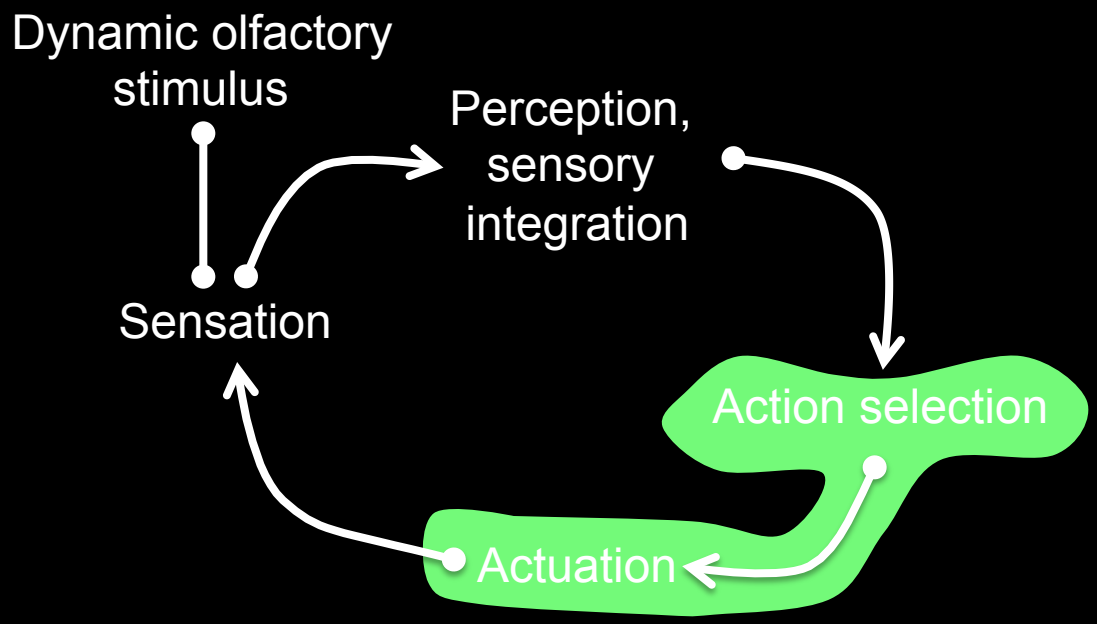
brain lobes

ventral nerve cord

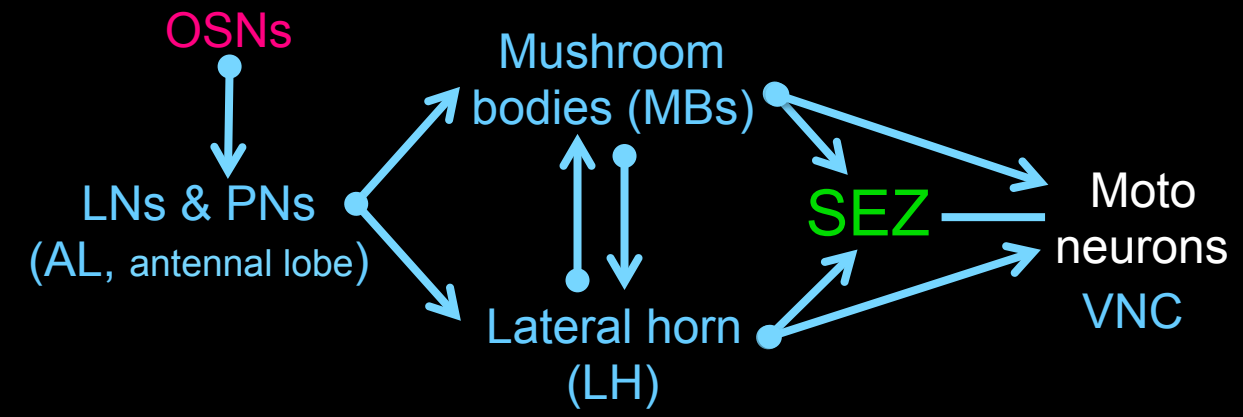
What are the neuronal substrates of sensorimotor control?

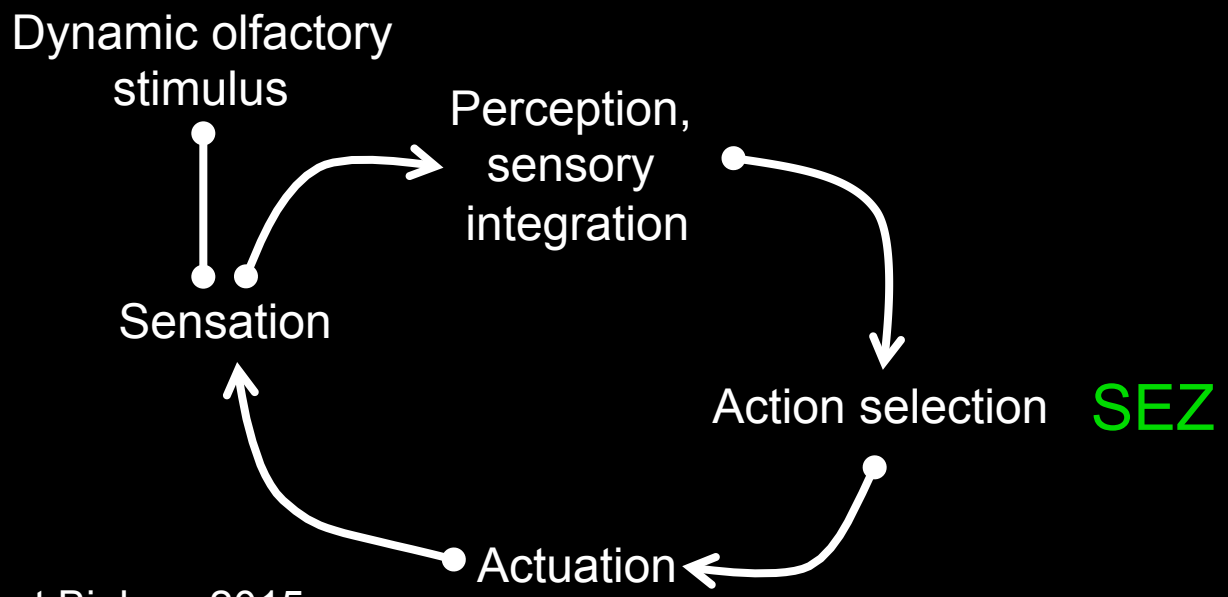






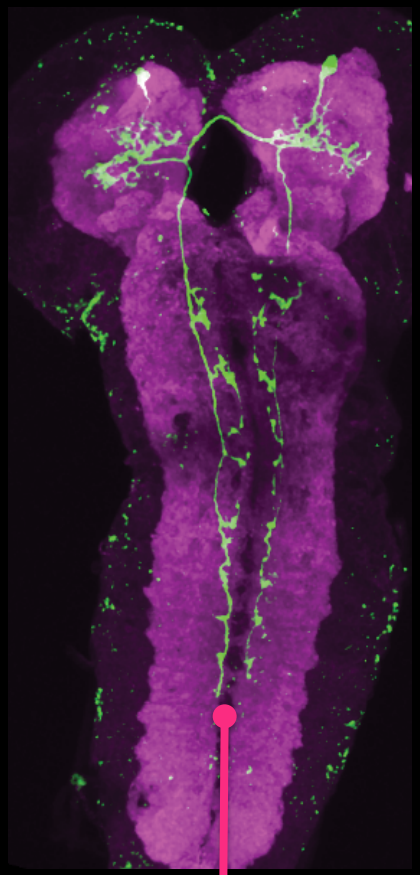
What are the neuronal substrates of this sensorimotor control?





Tastekin*, Riedl* et al, Current Biology 2015

Optogenetic gain-of-function of descending neuron elicits stopping



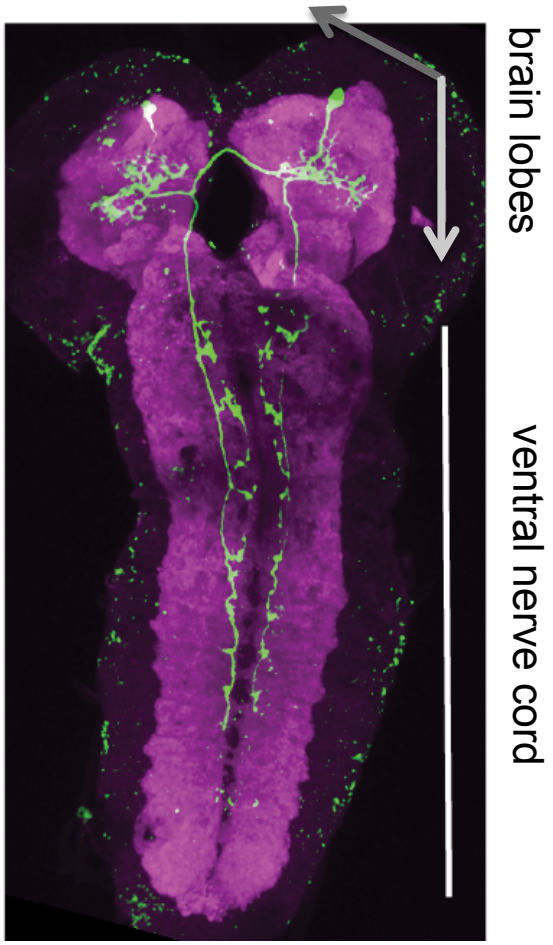
STOP

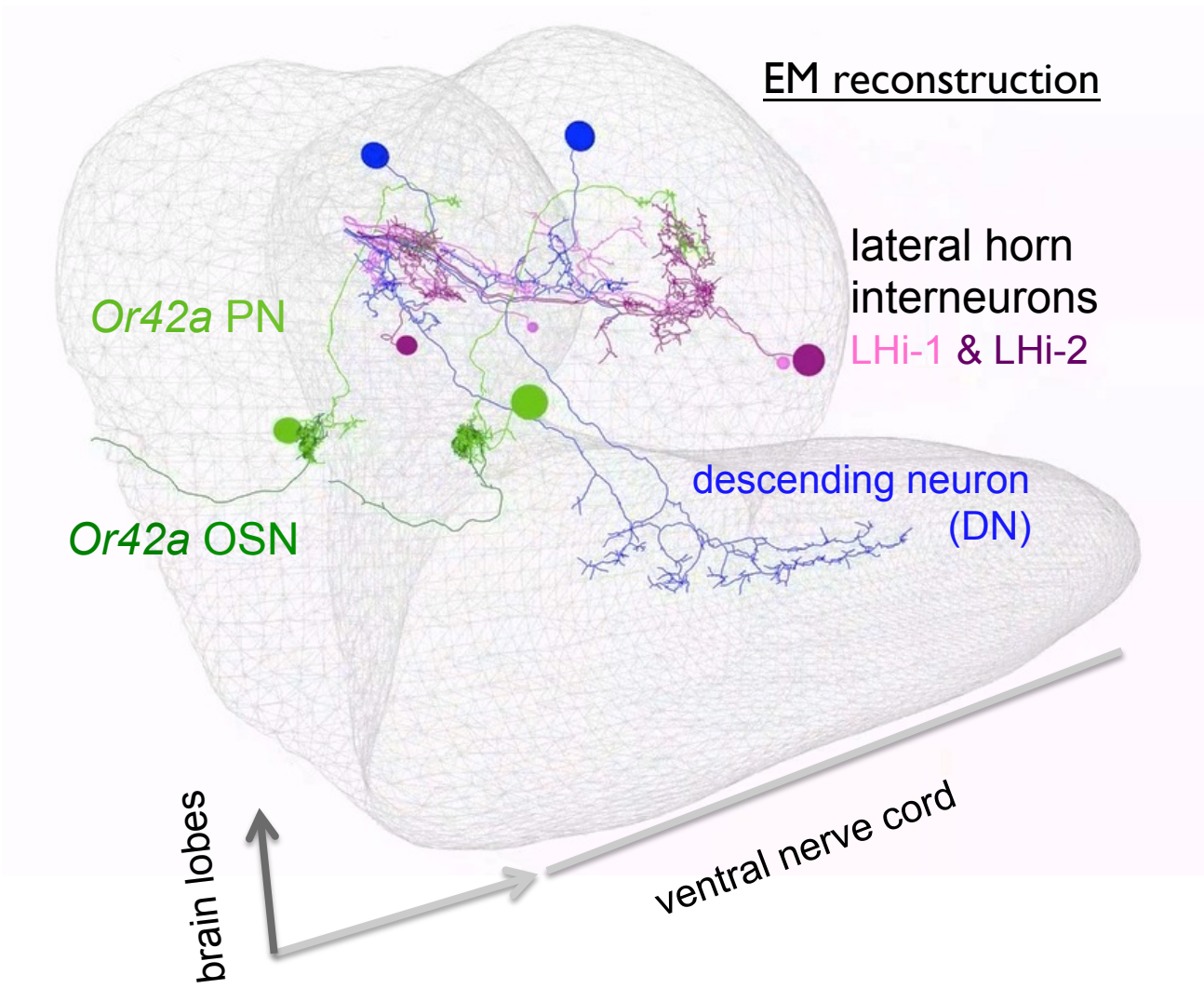
stimulated larva

un-stimulated larva

Ibrahim Tastekin

Mapping & characterizing a complete sensorimotor pathway





hhmi | janelia
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