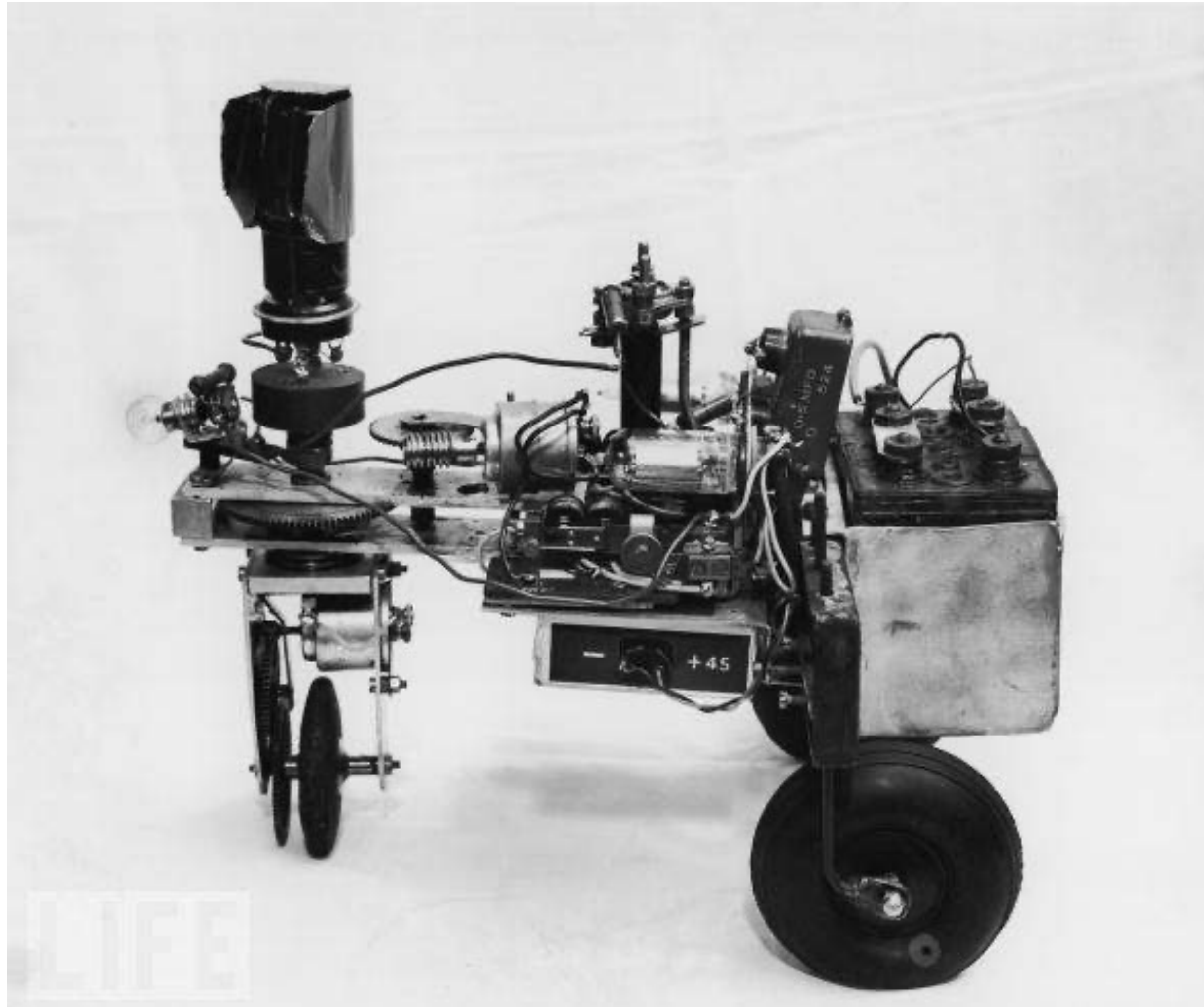
BIOENG-456

Controlling Behavior in Animals and Robots

Week 3: Taxis toward an odor source

Tortoises: Elmer & Elsie



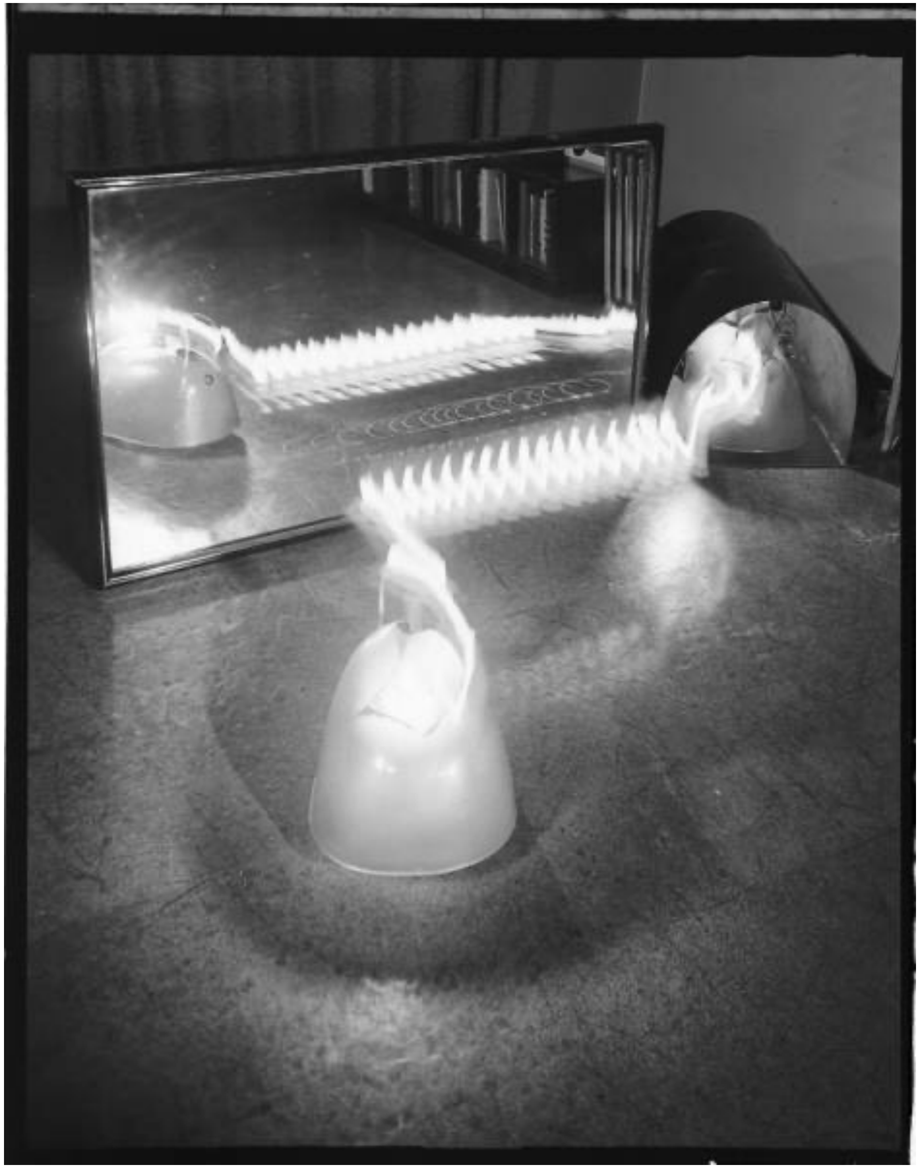
William Grey Walter, 1948-49

Tortoises: Elmer & Elsie

https://www.youtube.com/watch?v=lLULRlmXkKo

William Grey Walter, 1948-49

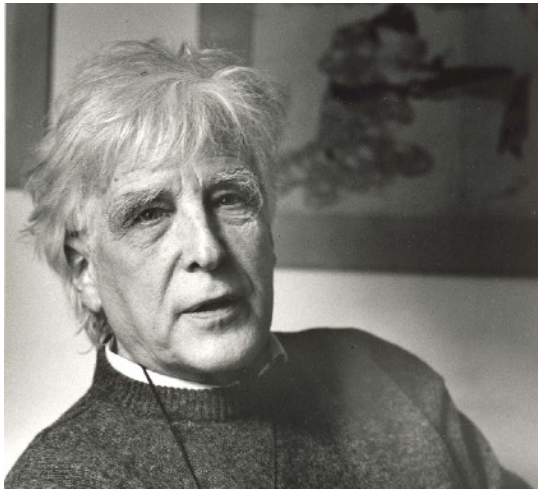
"Mirror dance - narcissistic behavior"



http://cyberneticzoo.com/tag/tortoise/

William Grey Walter, 1948-49

Experiments in Synthetic Psychology



Introduction

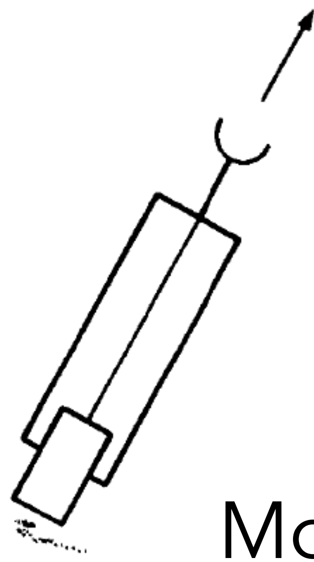
Let the Problem of the Mind Dissolve in Your Mind

This is an exercise in fictional science, or science fiction, if you like that better. Not for amusement: science fiction in the service of science. Or just science, if you agree that fiction is part of it, always was, and always will be as long as our brains are only minuscule fragments of the universe, much too small to hold all the facts of the world but not too idle to speculate about them.

Braitenberg, *Vehicles*, 1984

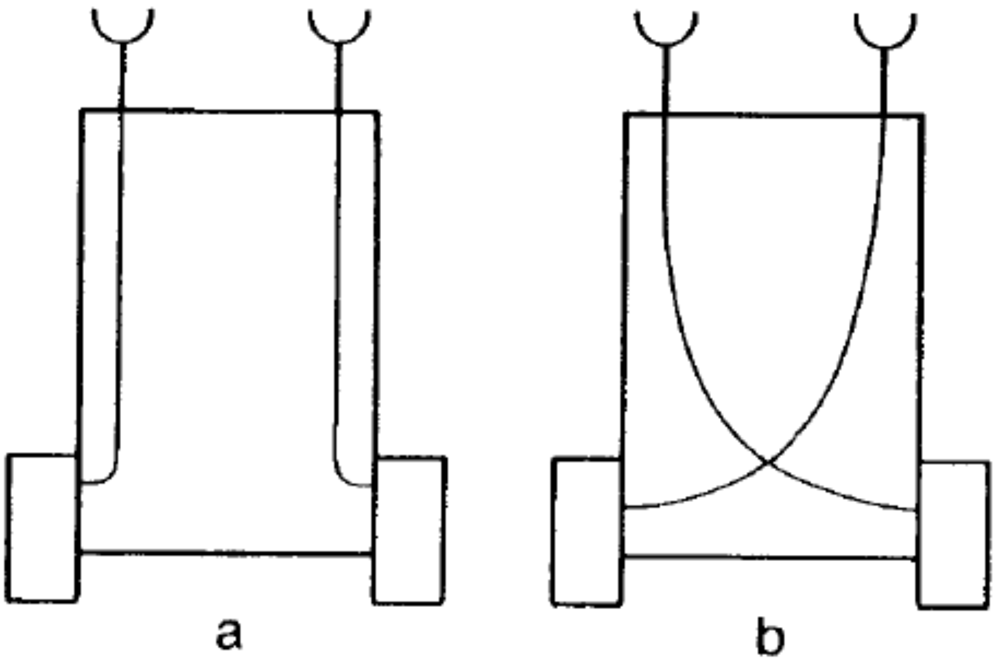
Experiments in Synthetic Psychology

Vehicle 1



Braitenberg, *Vehicles*, 1984

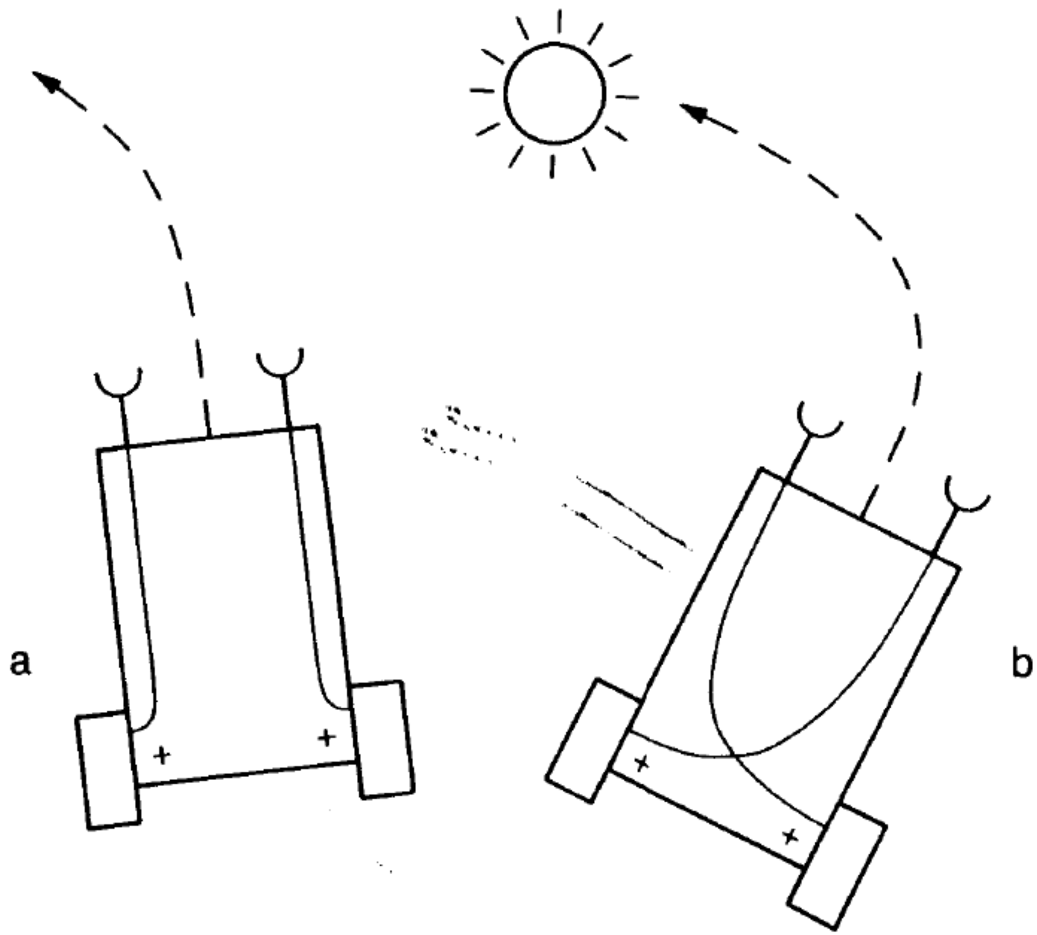
Vehicle 2



Braitenberg, *Vehicles*, 1984

Experiments in Synthetic Psychology

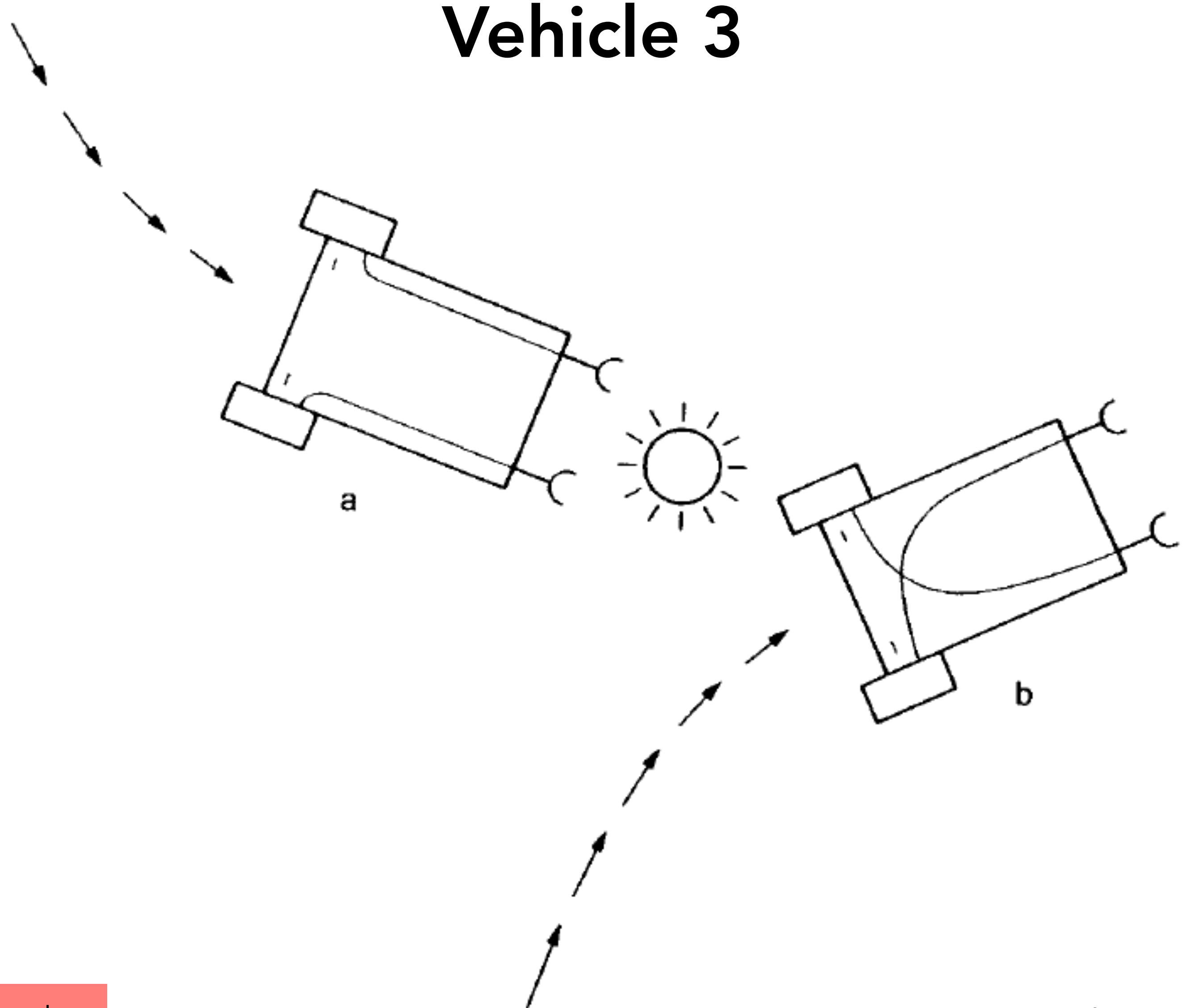
Vehicle 2 Fear & aggression



Braitenberg, *Vehicles*, 1984

Inverting weights

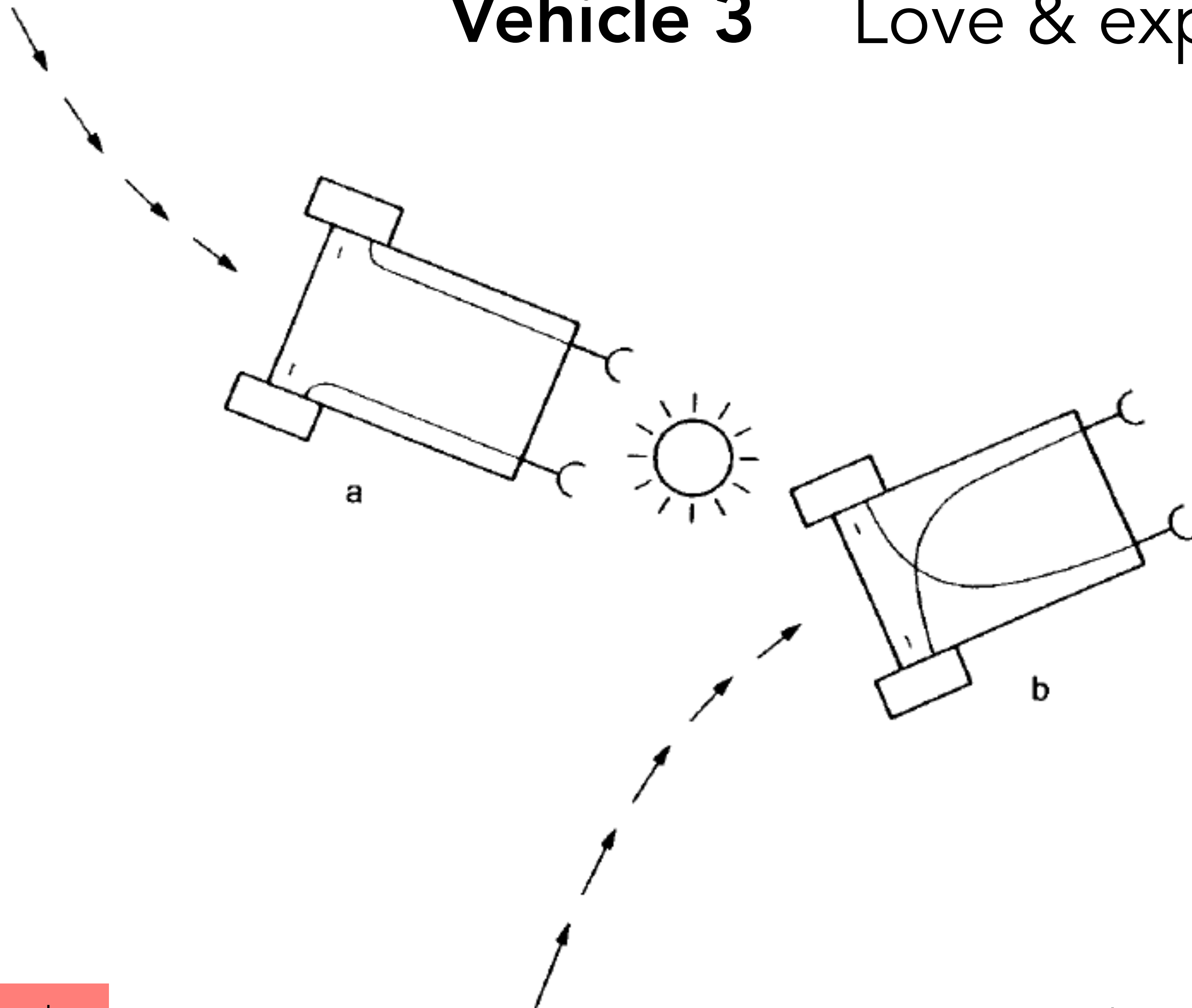
Vehicle 3



Braitenberg, *Vehicles*, 1984

Inverting weights

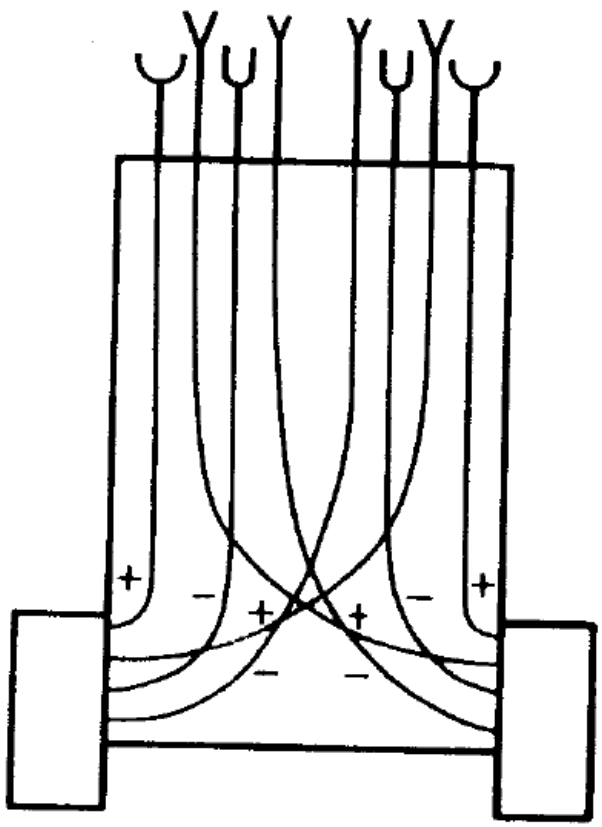
Vehicle 3 Love & explorer



Braitenberg, *Vehicles*, 1984

Multisensory integration

Vehicle 3 Multisensorial

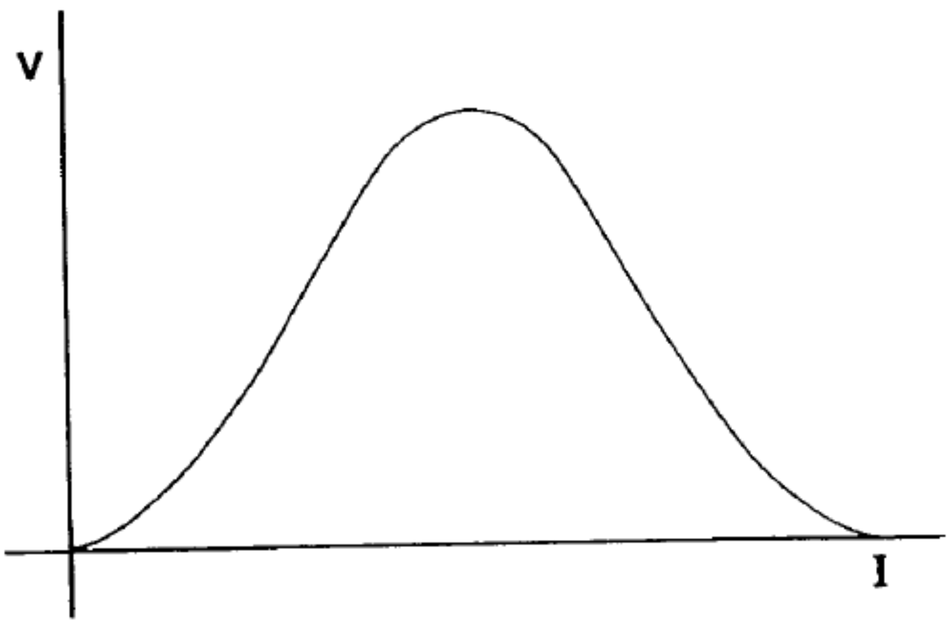


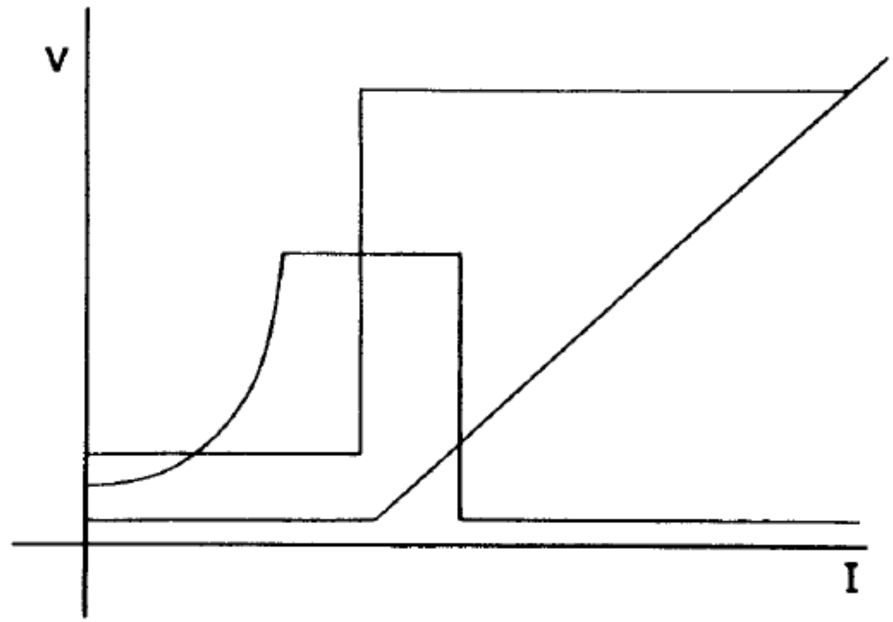
Braitenberg, *Vehicles*, 1984

Complex sensor functions

Vehicle 4

v = motor speed
i = stimulus intensity





Braitenberg, *Vehicles*, 1984

Reactive behavior - line following

3.4 Line Following

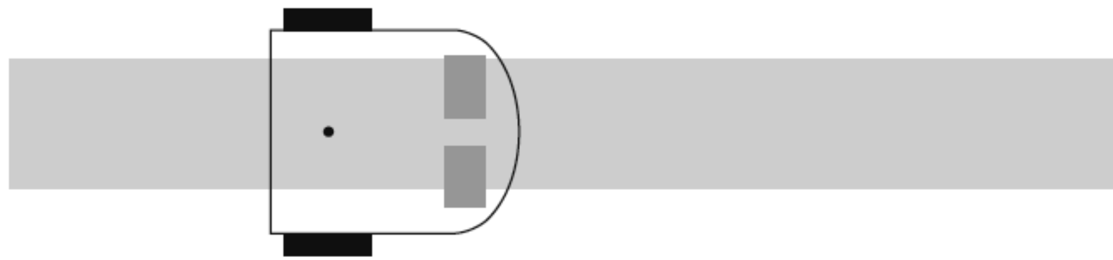


Fig. 3.3 A robot with two ground sensors over a line

Fig. 3.4 Leaving the line

Mondada, *Elements of Robotics*, 2018

Reactive behavior - line following

Algorithm 3.4: Line following with two sensors

```
when both sensors detect black
    left-motor-power ←
    right-motor-power ←

when neither sensor detects black
    left-motor-power ←
    right-motor-power ←

when only the left sensor detects black
    left-motor-power ←
    right-motor-power ←

when only the right sensor detects black
    left-motor-power ←
    right-motor-power ←
```


Mondada, *Elements of Robotics*, 2018

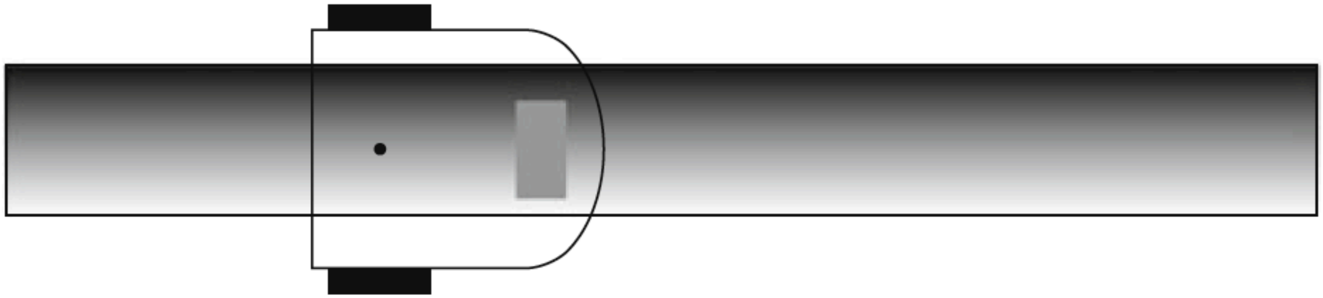
Reactive behavior - line following

Algorithm 3.4: Line following with two sensors

```
when both sensors detect black
    left-motor-power ← 100
    right-motor-power ← 100

when neither sensor detects black
    left-motor-power ← 0
    right-motor-power ← 0

when only the left sensor detects black
    left-motor-power ← 0
    right-motor-power ← 50

when only the right sensor detects black
    left-motor-power ← 50
    right-motor-power ← 0
```


Mondada, *Elements of Robotics*, 2018

Reactive behavior - one sensor



Algorithm 3.5: Line following with one sensor

```
integer black-threshold ← 20
integer white-threshold ← 80

when black-threshold ≤ sensor value ≤ white-threshold
      left-motor-power ← 100
      right-motor-power ← 100

when sensor value > white-threshold
      left-motor-power ← −50
      right-motor-power ← 50

when black-threshold < sensor value
      left-motor-power ← 50
      right-motor-power ← −50
```


Mondada, *Elements of Robotics*, 2018

Any questions?

Taxis in biological systems…

Odor taxis in animals

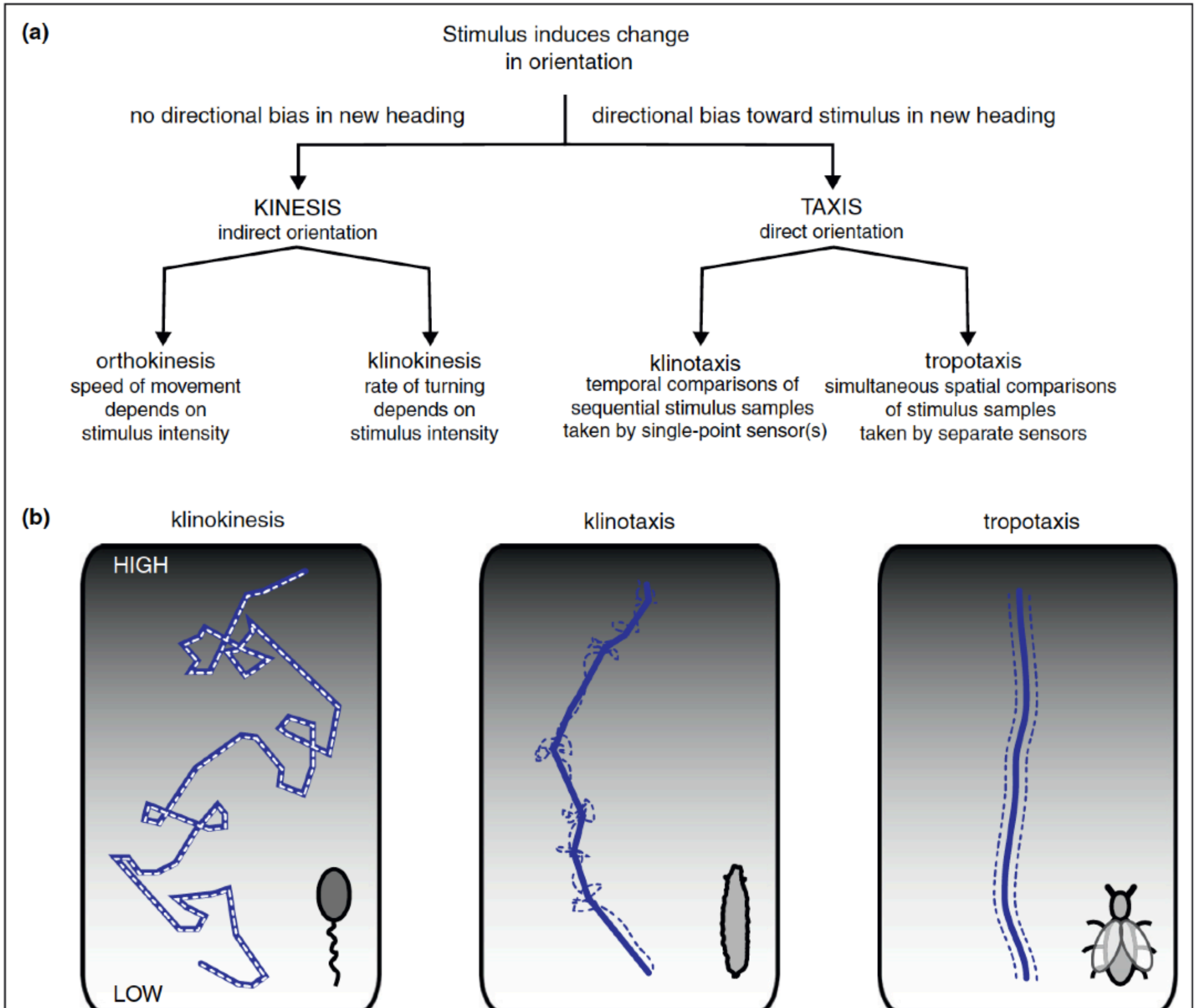
“Hounds on the Scent”, John Emms

Porter et al., *Nature Neuroscience*, 2007

Odor taxis in humans

Porter et al., *Nature Neuroscience*, 2007

Some taxis mechanisms

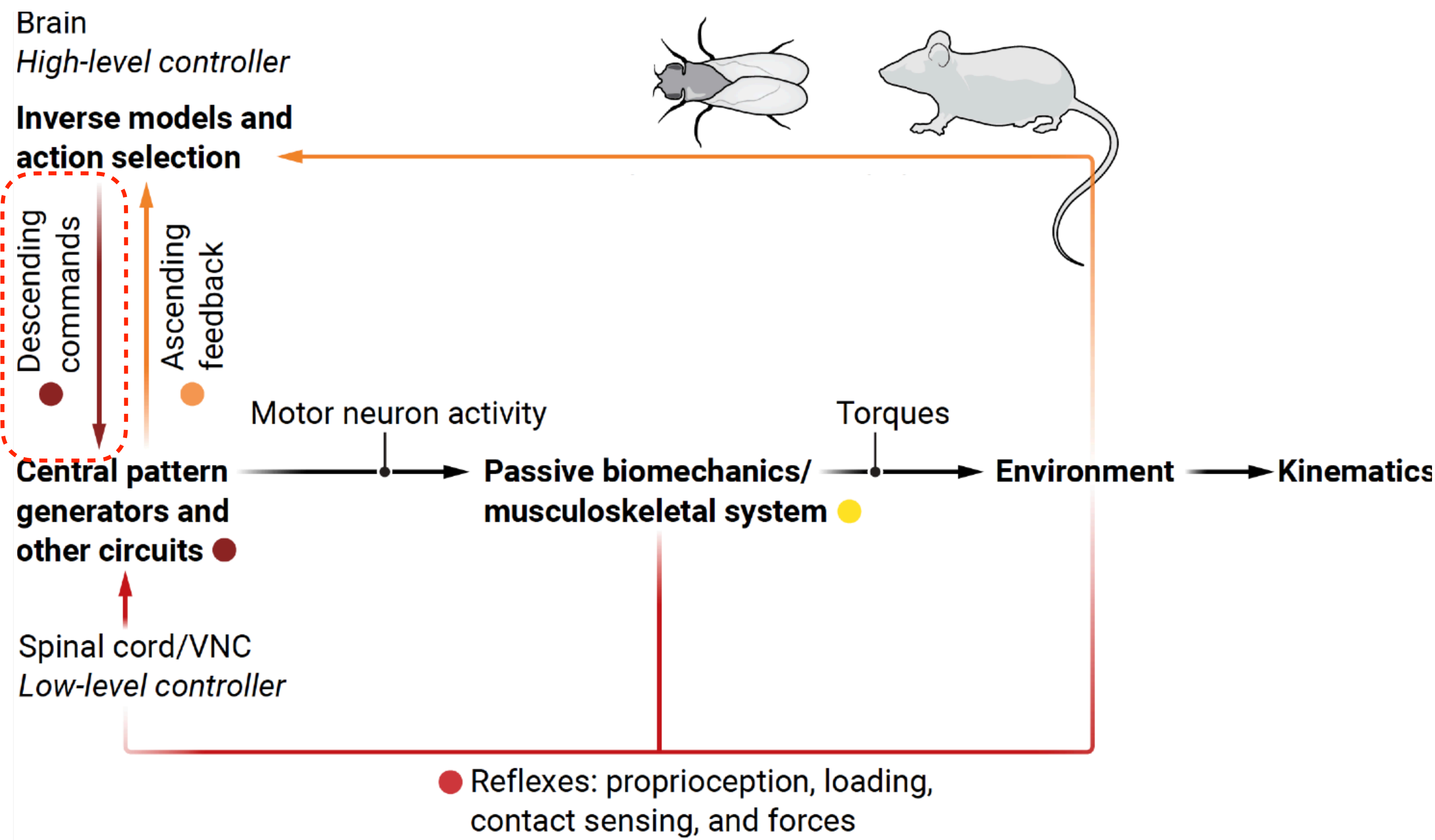


Gomez-Marin & Louis, *Current Opinion in Neurobiology*, 2012

Any questions?

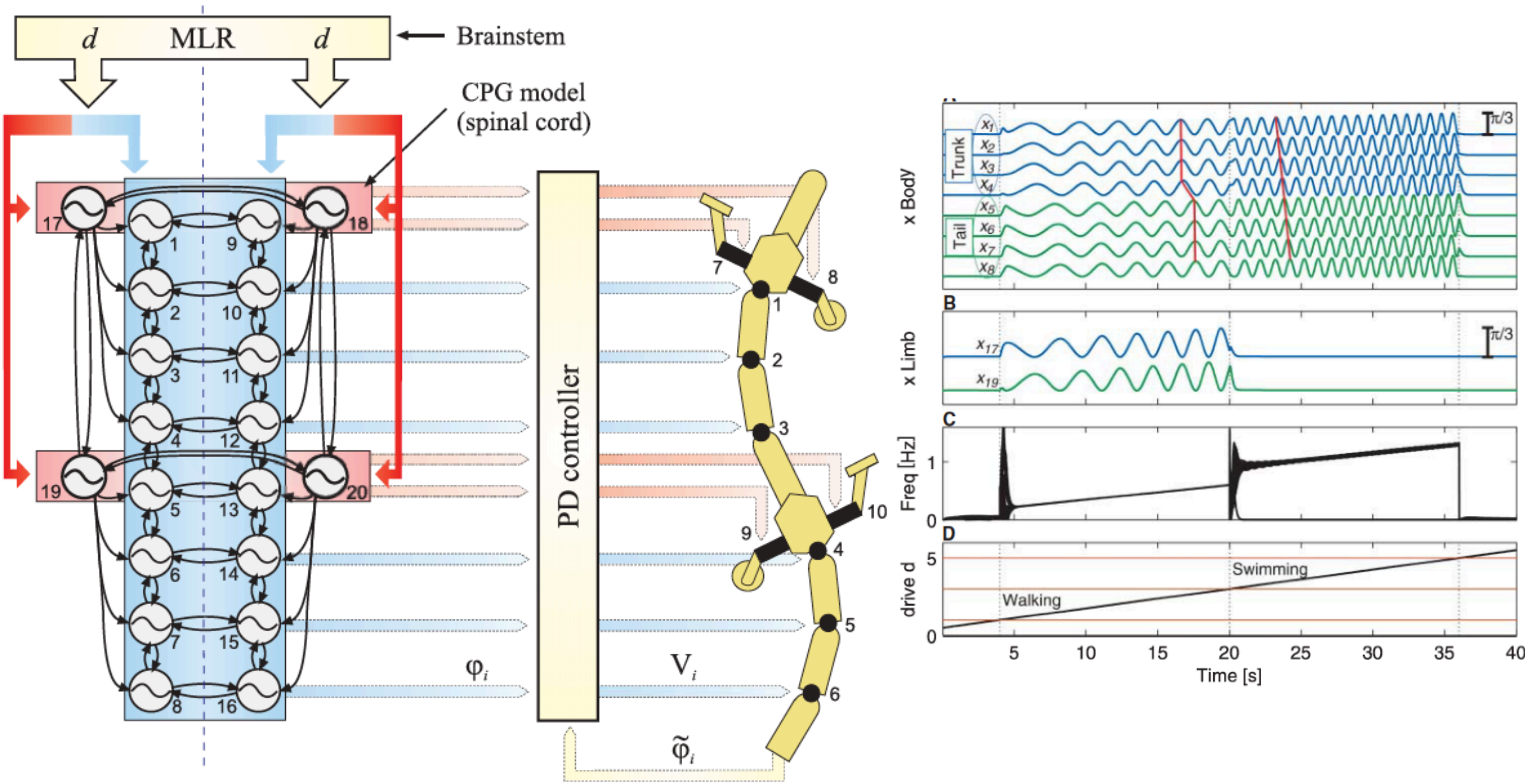
Descending control of behavior…

Descending neurons



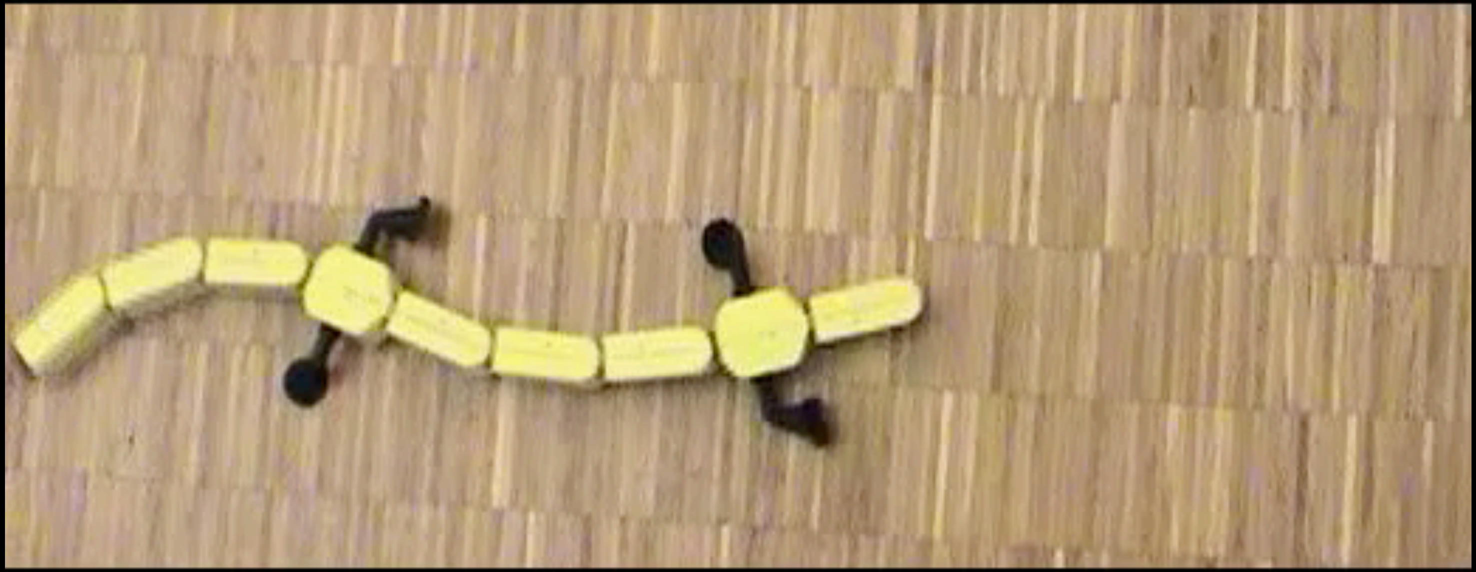
Ramdya & Ijspeert, *Science Robotics*, 2023

Descending neurons act as low-dimensional signals that engage downstream CPGs



Ijspeert, et al. *Science*, 2007

Descending neurons act as low-dimensional signals that engage downstream CPGs

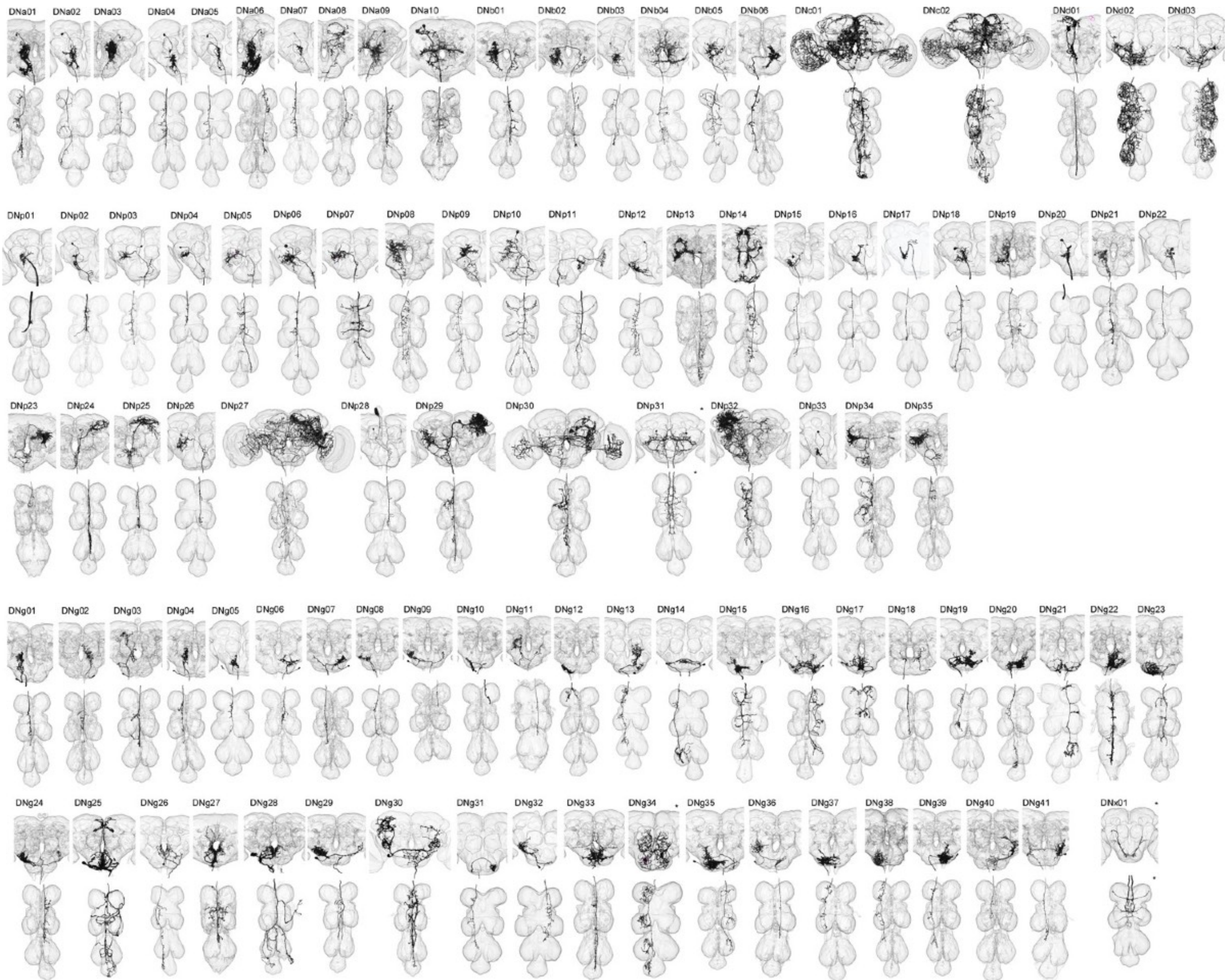


Ijspeert, et al. *Science*, 2007

Moonwalker Descending Neurons (MDNs)

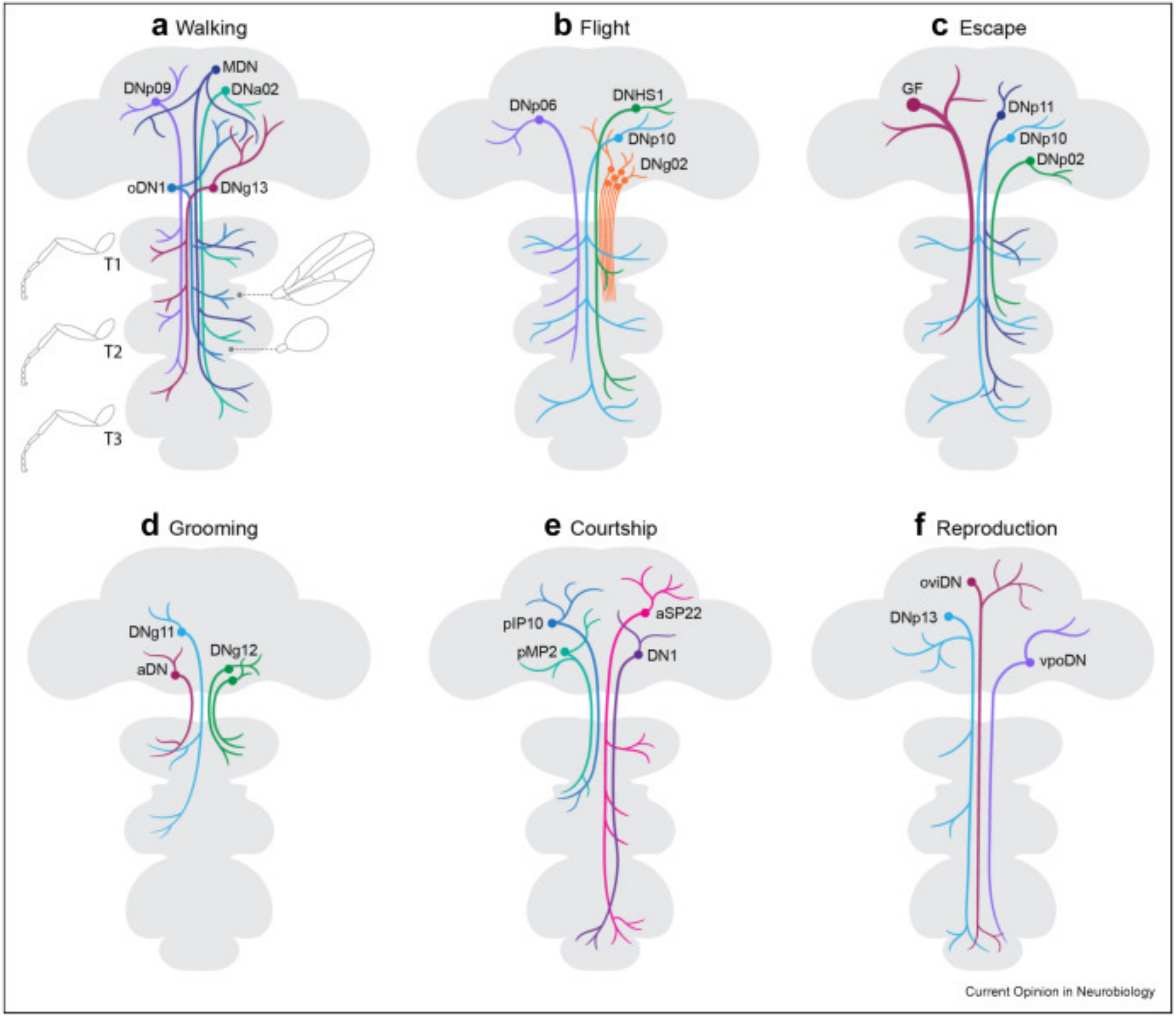
Bidaye et al., *Science*, 2014

There are many classes of descending neurons



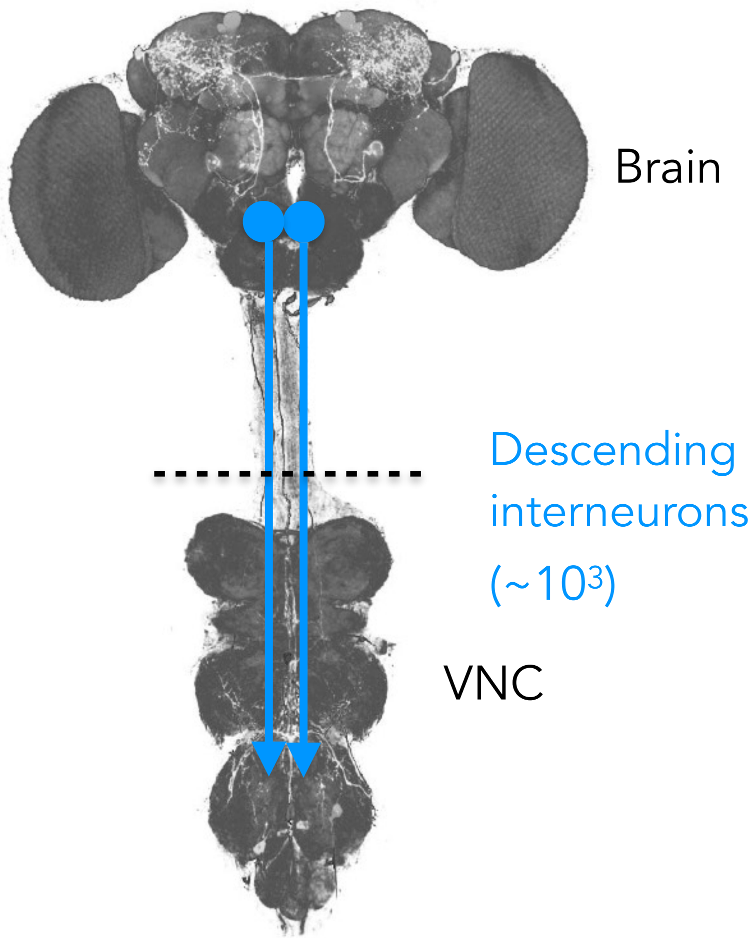
Namiki et al., *eLife* 2018

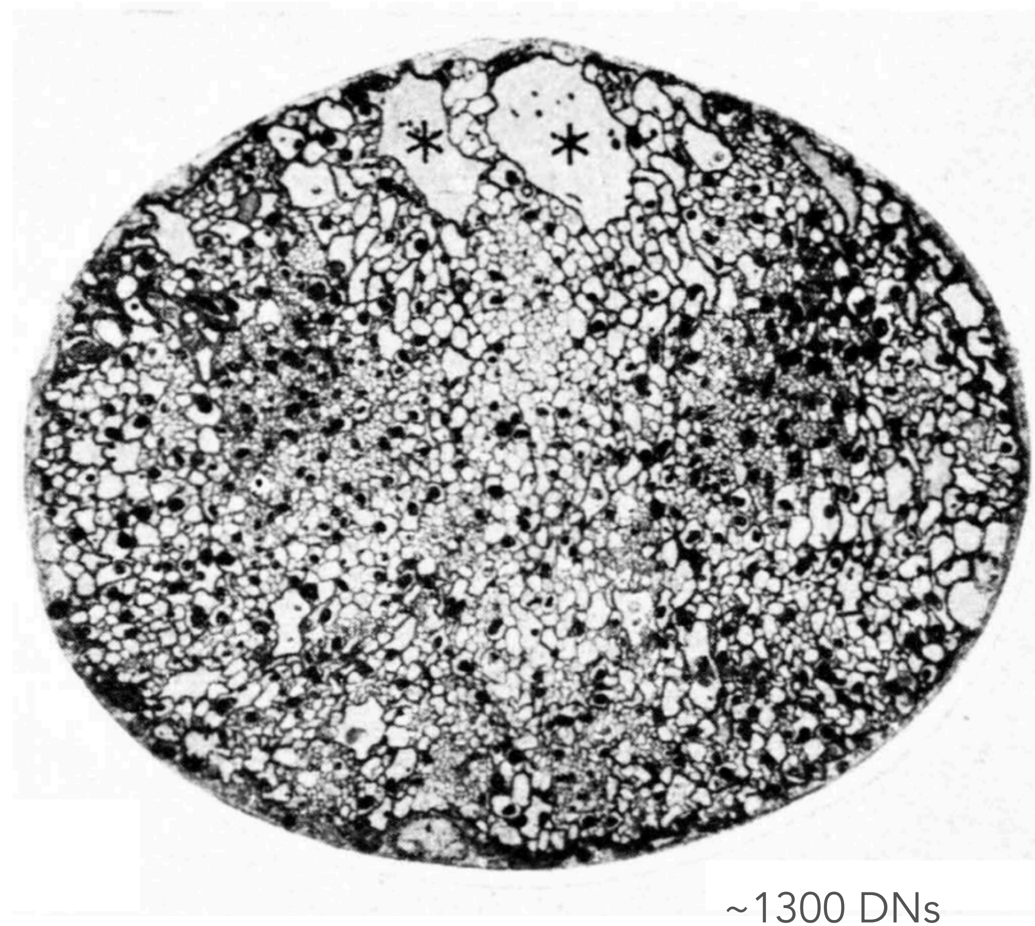
Descending neurons drive many behaviors



Simpson et al., *Curr. Opin. Neuro.* 2024

Paper 1: How do DN populations work together?

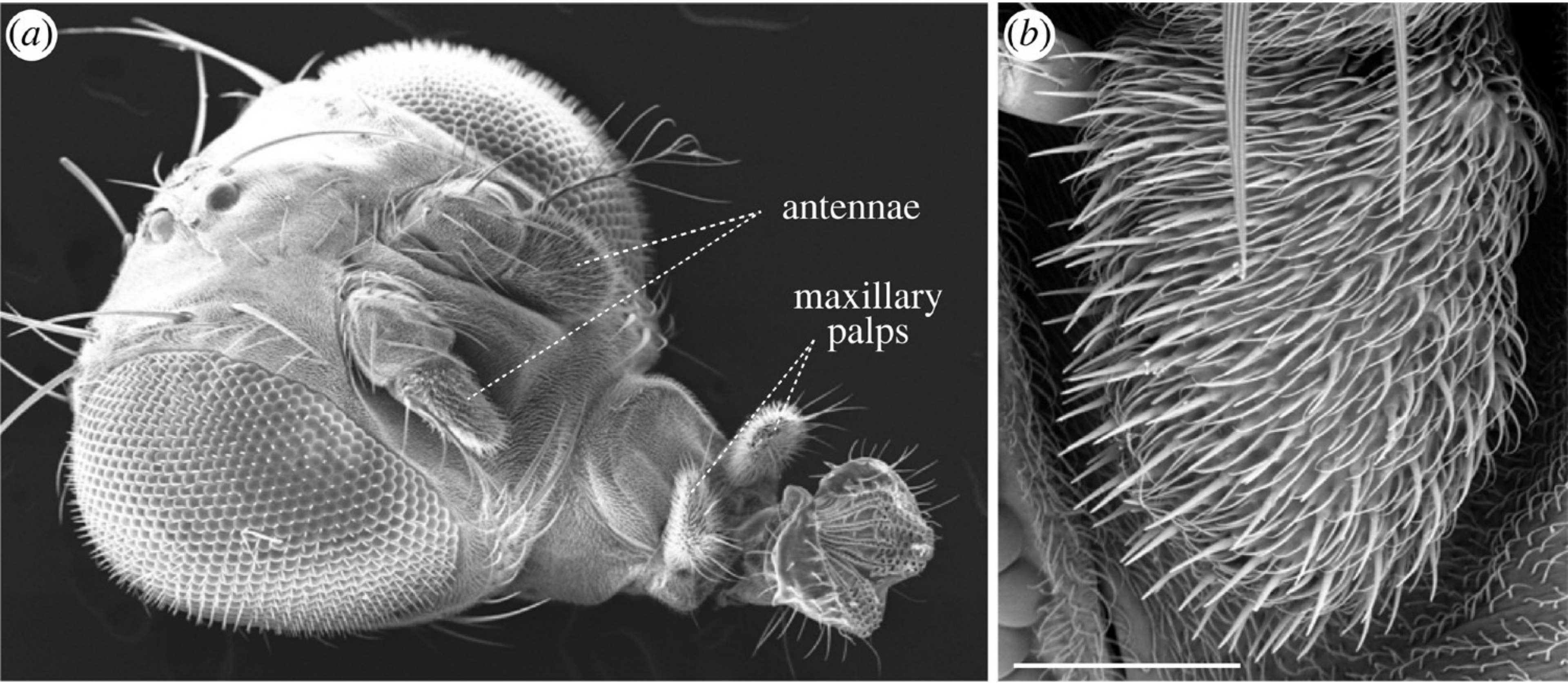




Any questions?

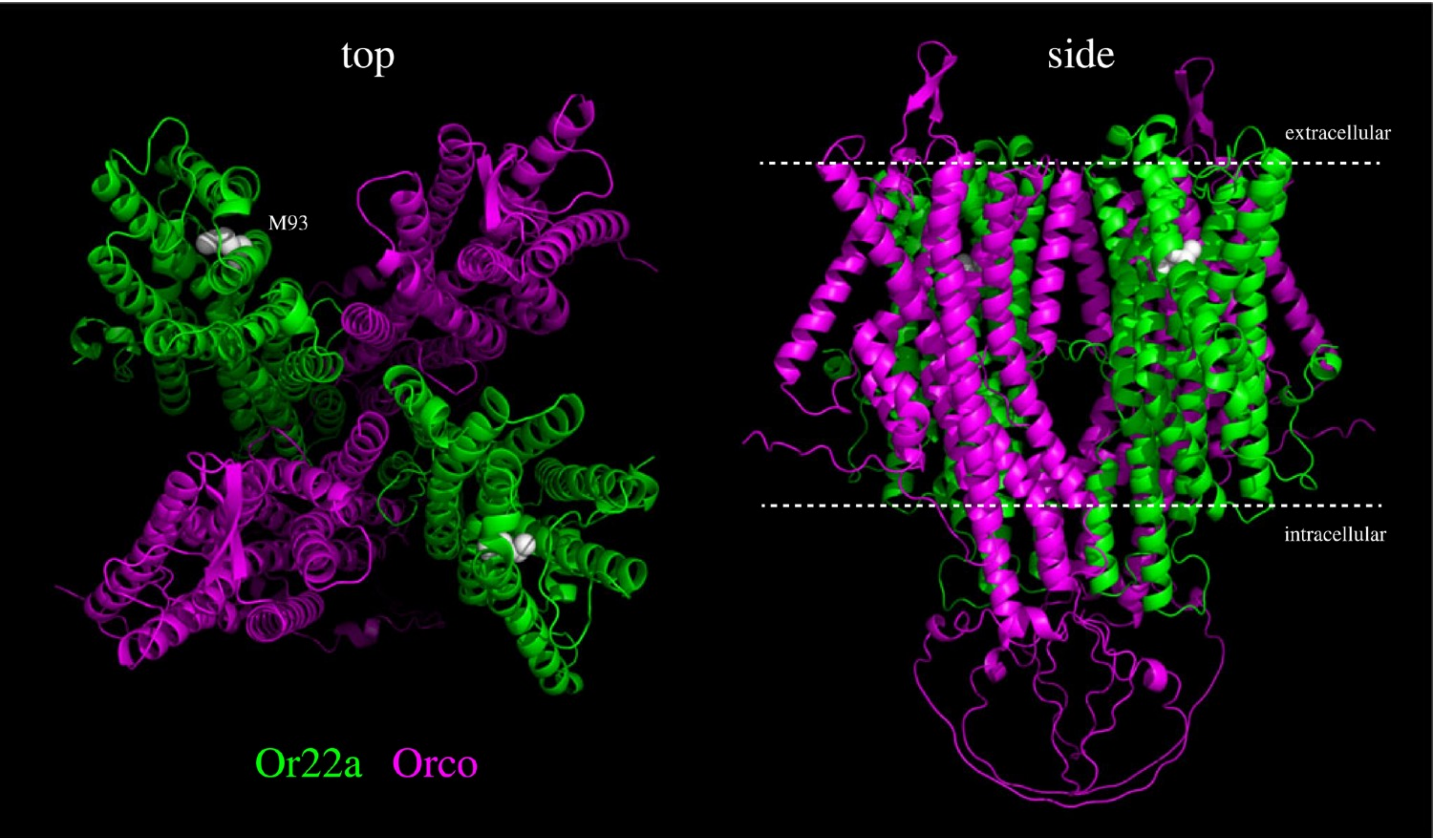
Adult fly olfaction…

Drosophila olfactory organs



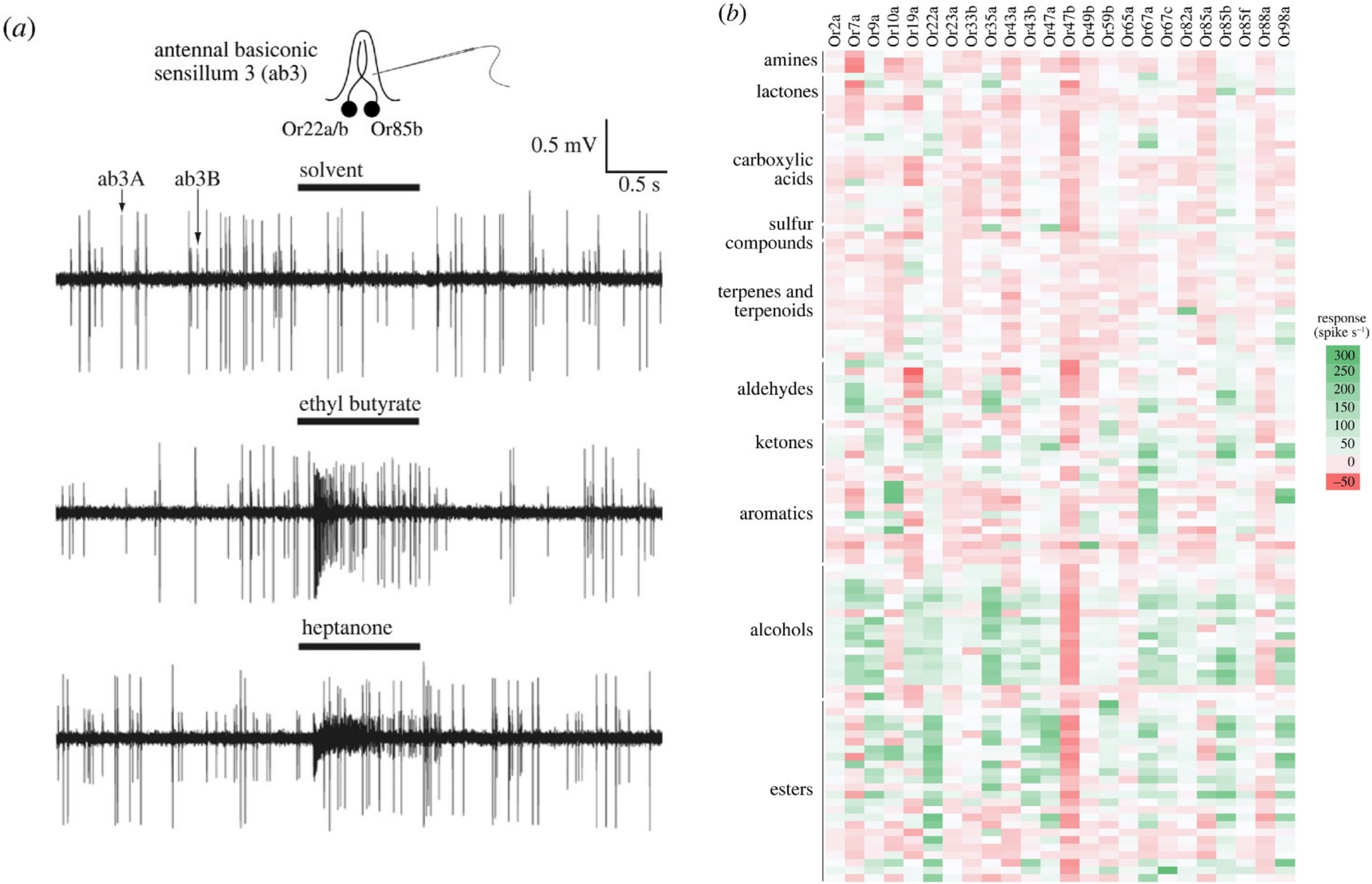
Benton, *Proc. Royal Society B*, 2022

Drosophila olfactory receptors



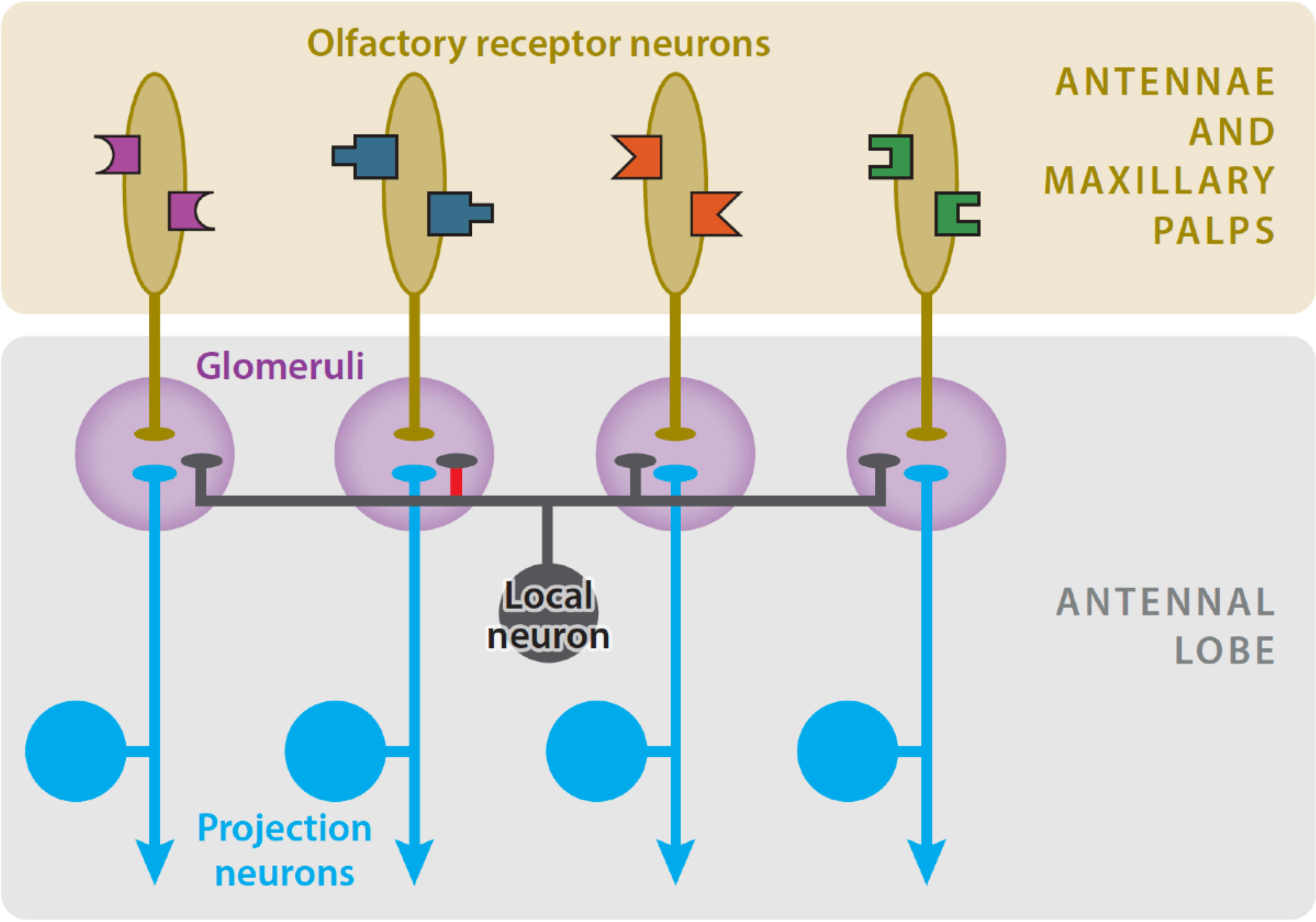
Benton, *Proc. Royal Society B*, 2022

Olfactory Receptor Neuron (ORN/OSN) responses



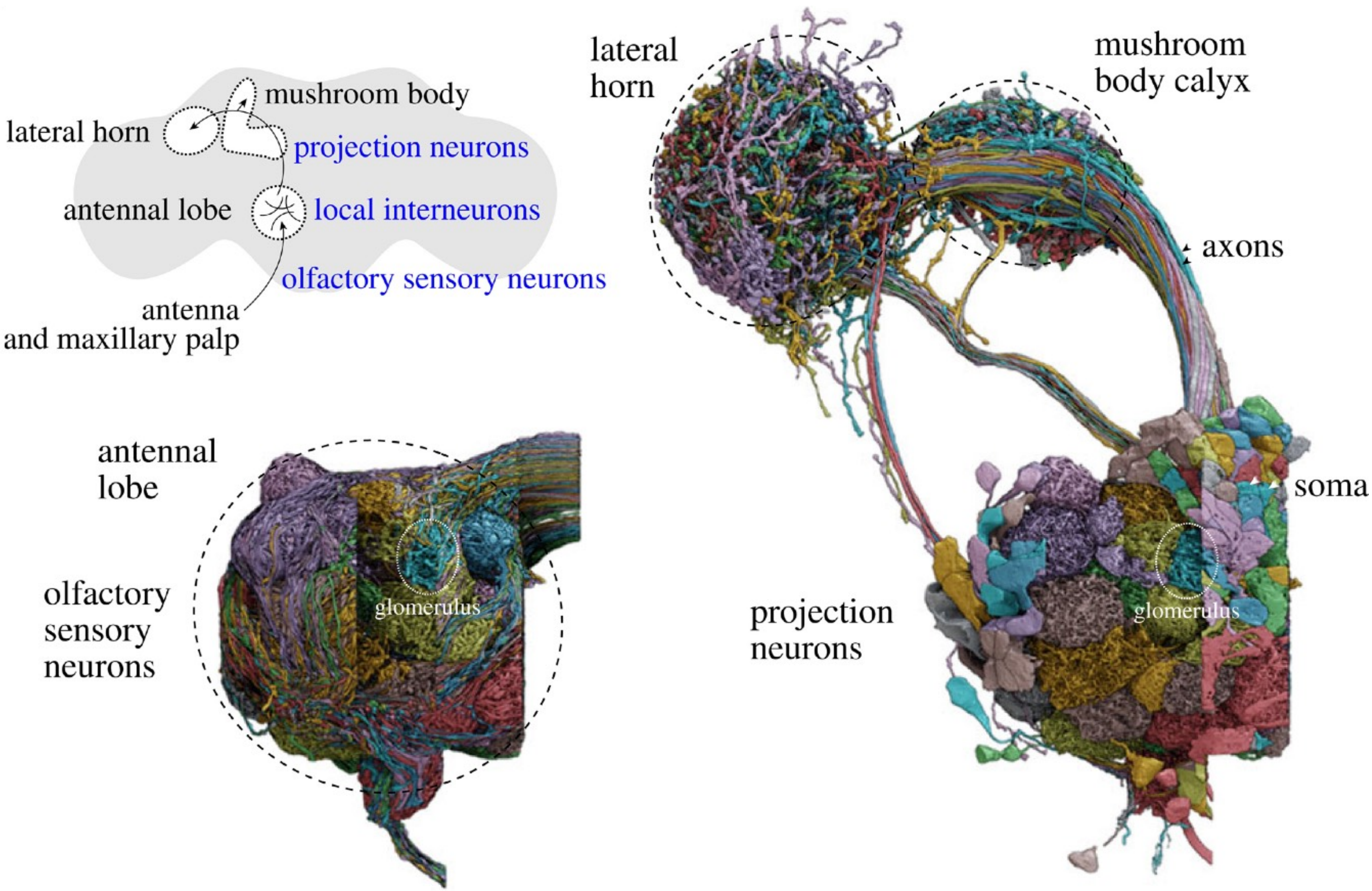
Benton, *Proc. Royal Society B*, 2022

Drosophila olfactory pathways



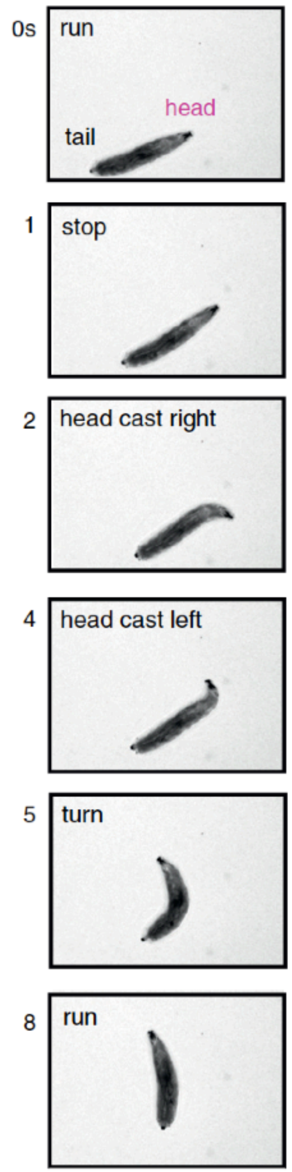
Wilson, *Annual Review Neurosci.*, 2013

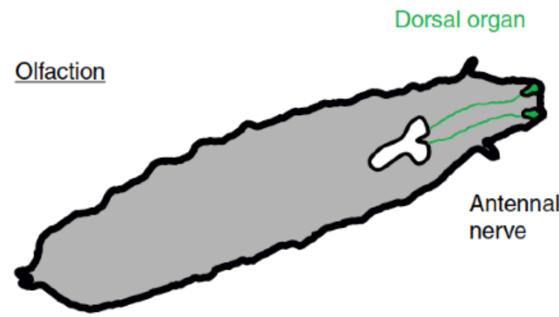
Drosophila olfactory pathways



Benton, *Proc. Royal Society B*, 2022

Active sensing of odor gradients in *Drosophila* larvae





Gomez-Marin & Louis, *Current Opinion in Neurobiology*, 2012

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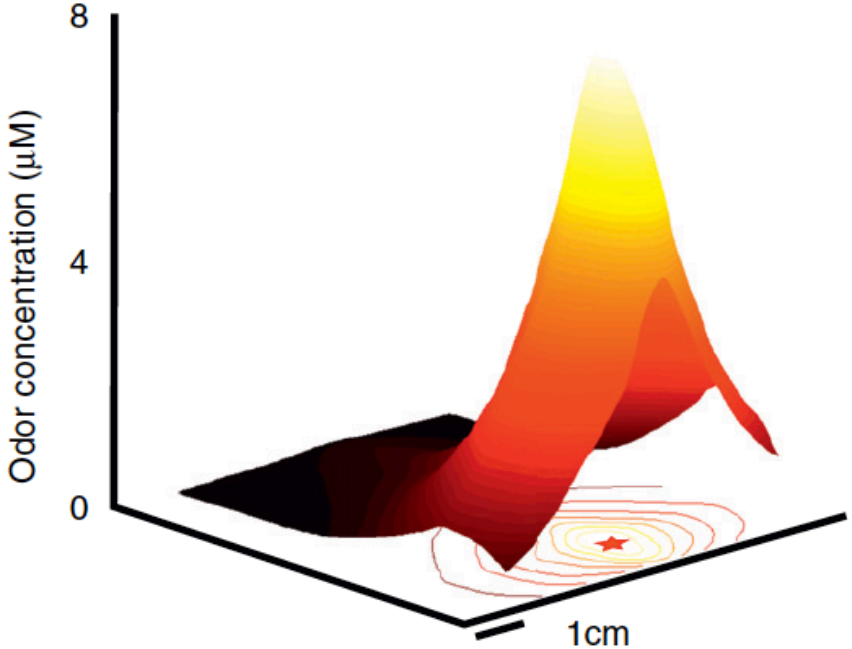
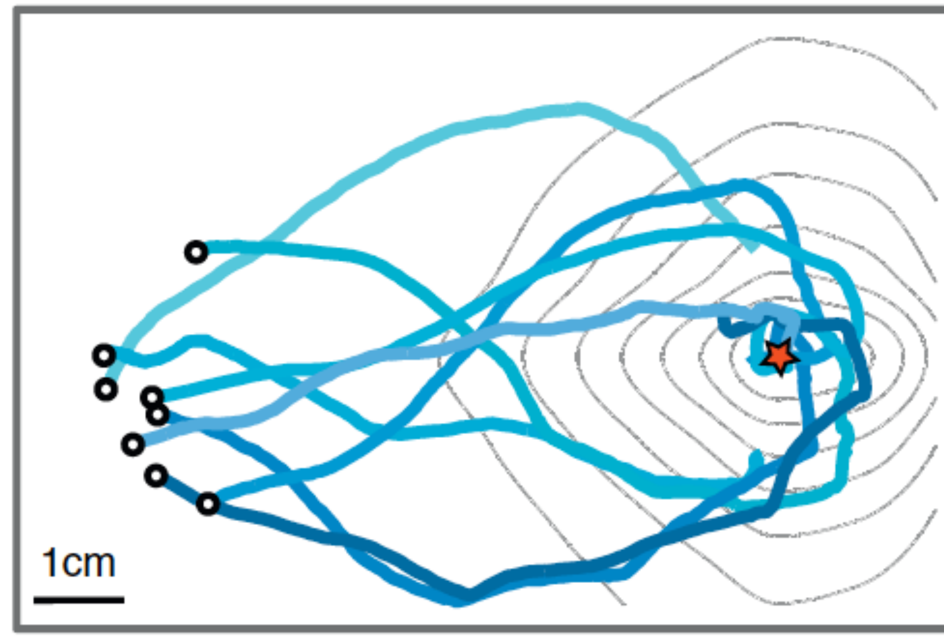
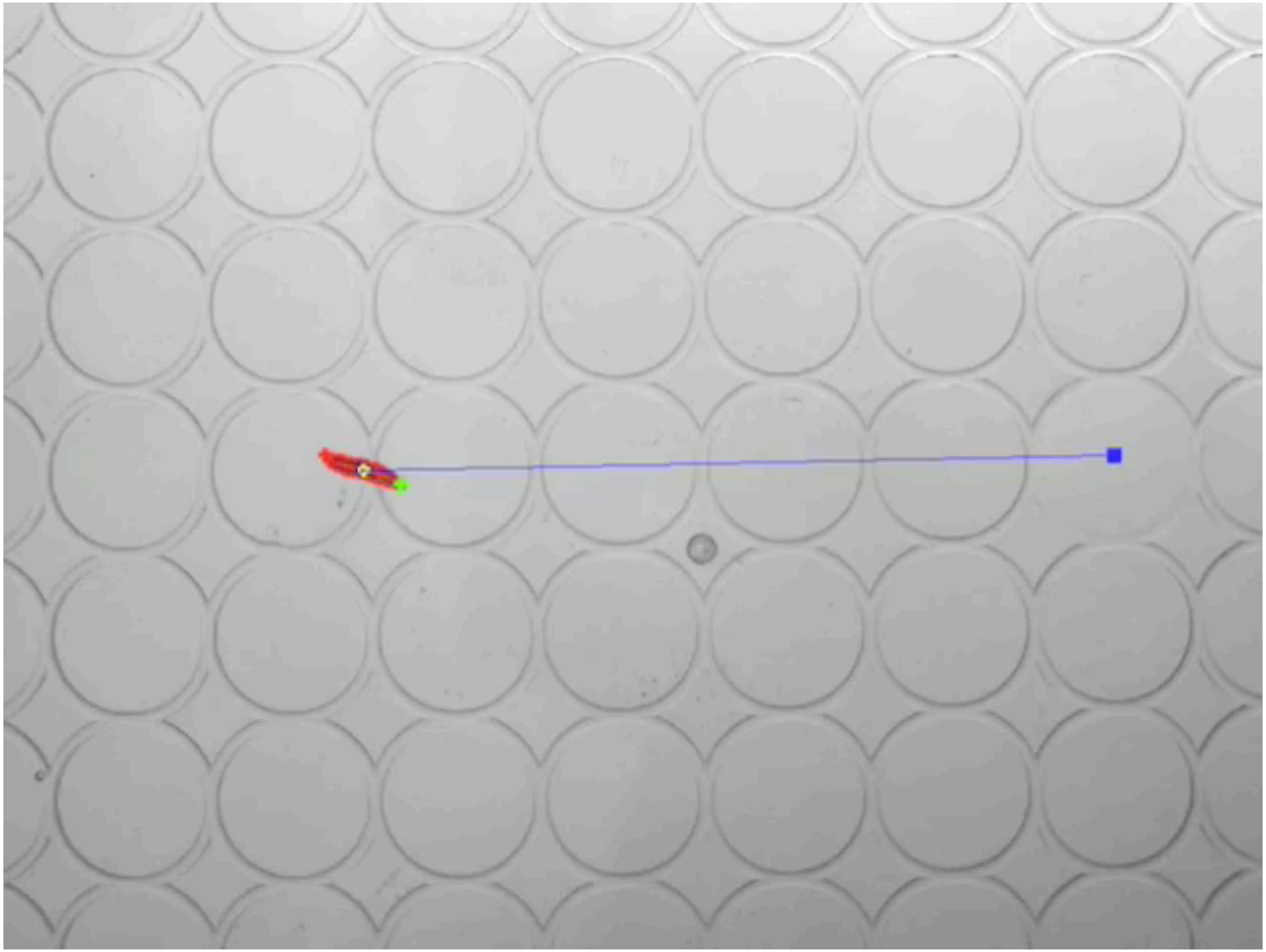




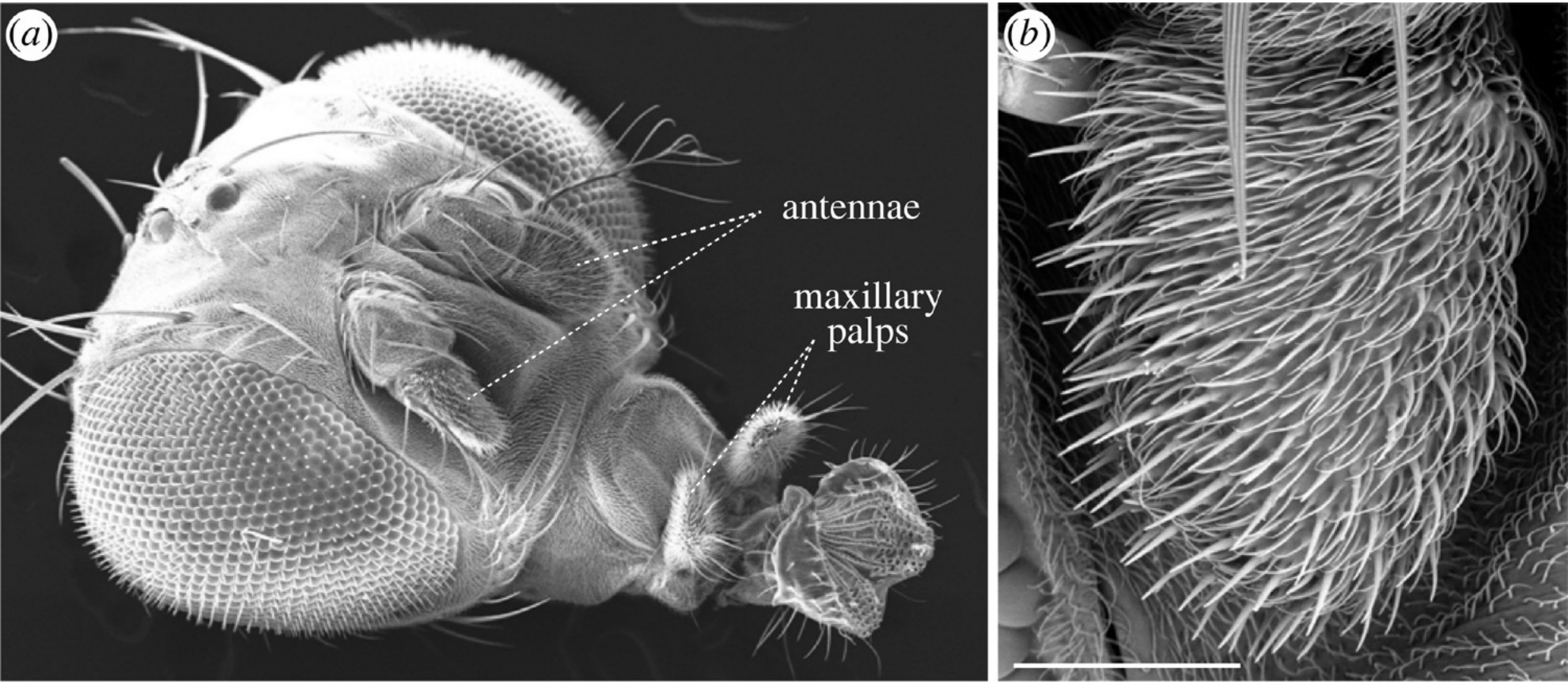
Gomez-Marin & Louis, *Current Opinion in Neurobiology*, 2012

Active sensing in *Drosophila* larvae



Gomez-Marin et al., *Nature Communications*, 2011

Paper 2: How do *adult* flies track odor sources?

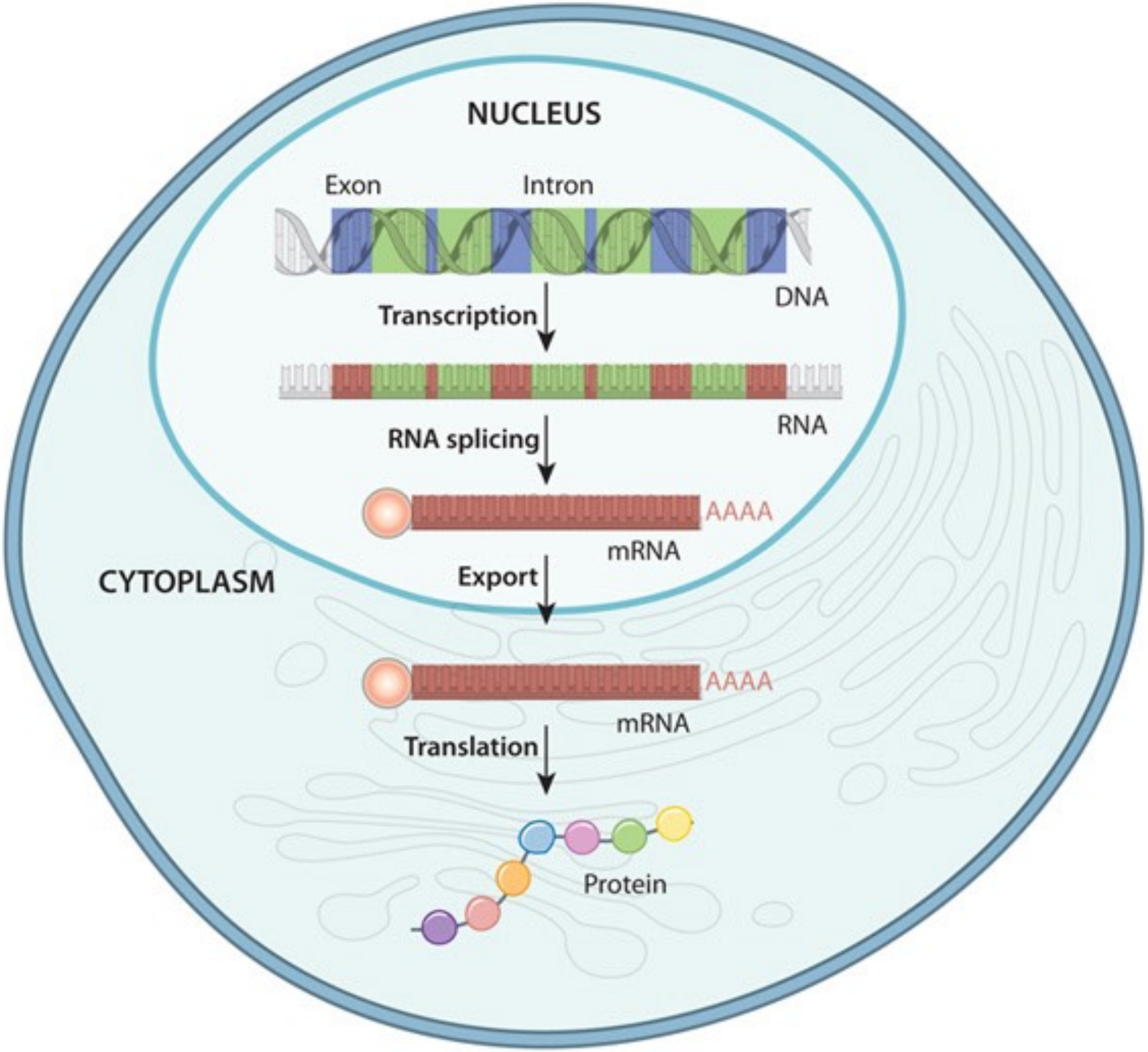


Benton, *Proc. Royal Society B*, 2022

Any questions?

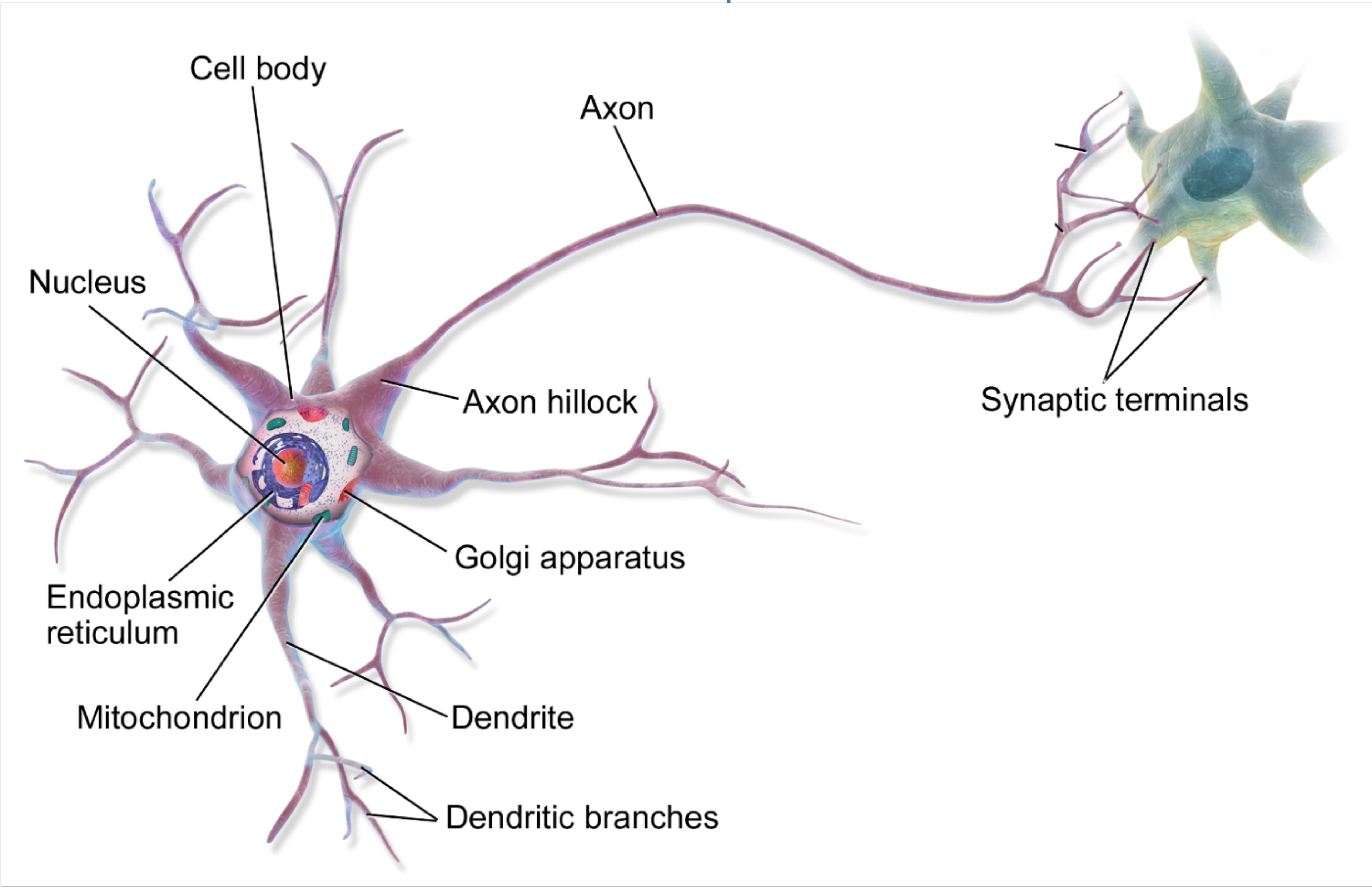
Neuroscience Bootcamp/AMA

From gene to protein in the cell



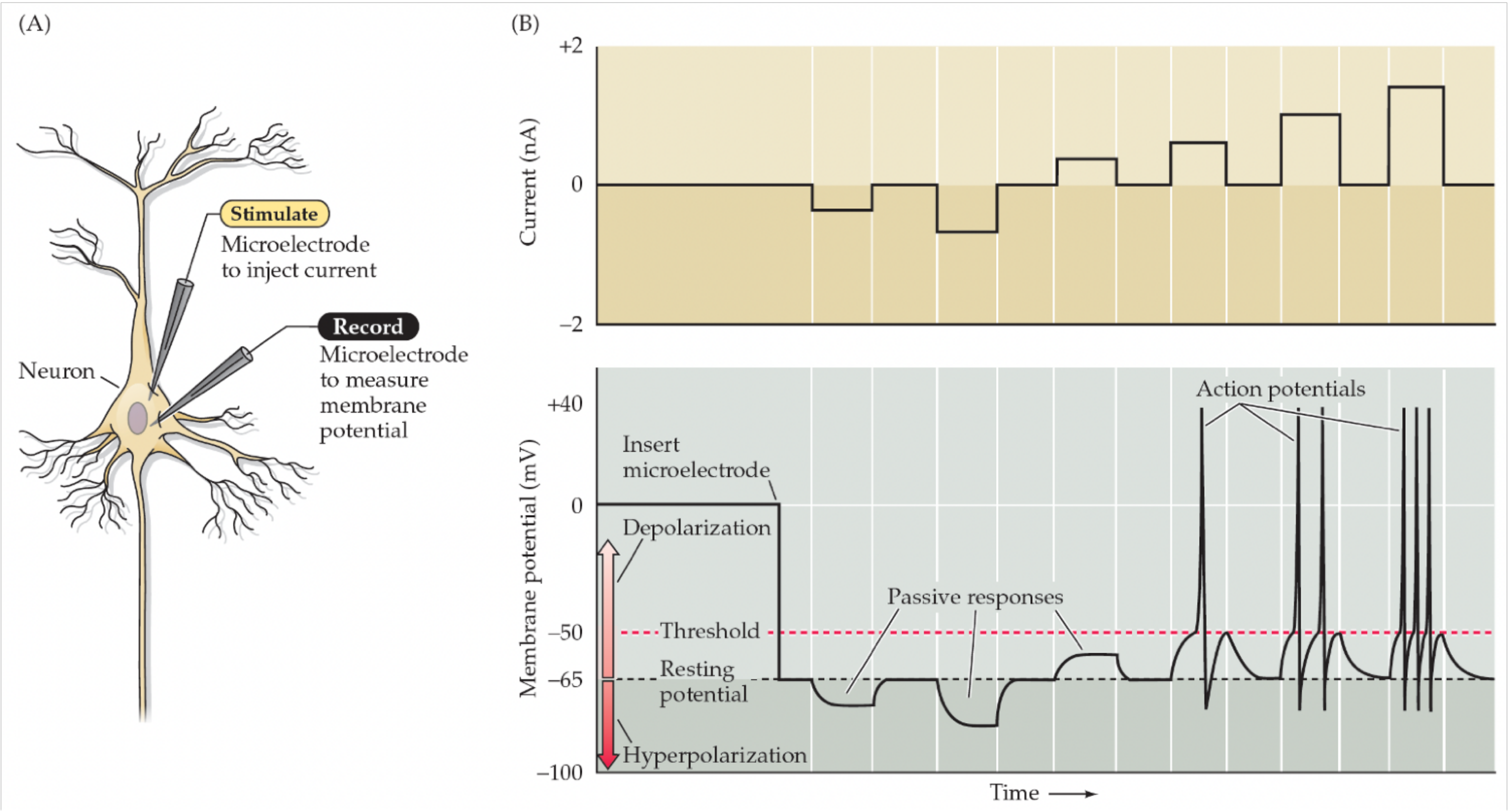
https://www.nature.com/scitable/topicpage/gene-expression-14121669/

Neurons are special cells



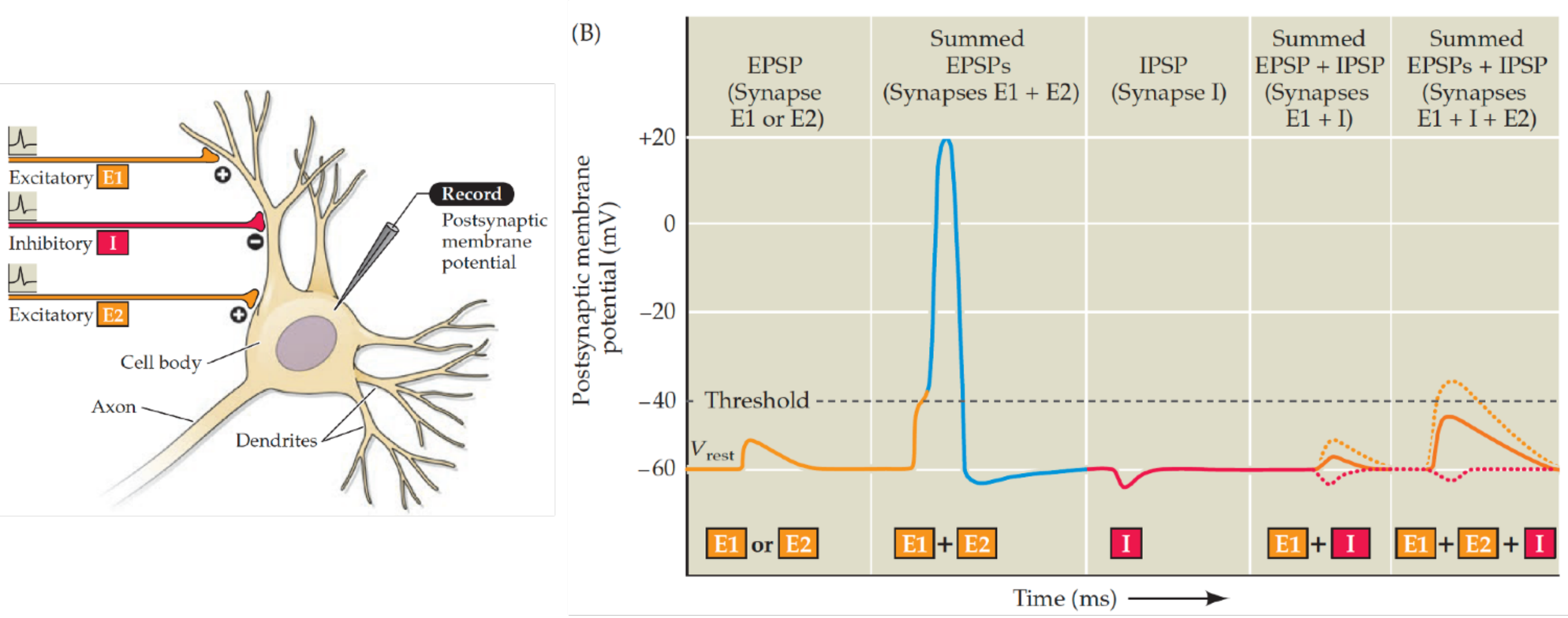
Wikipedia

Neurons signal activity by 'firing' action potentials



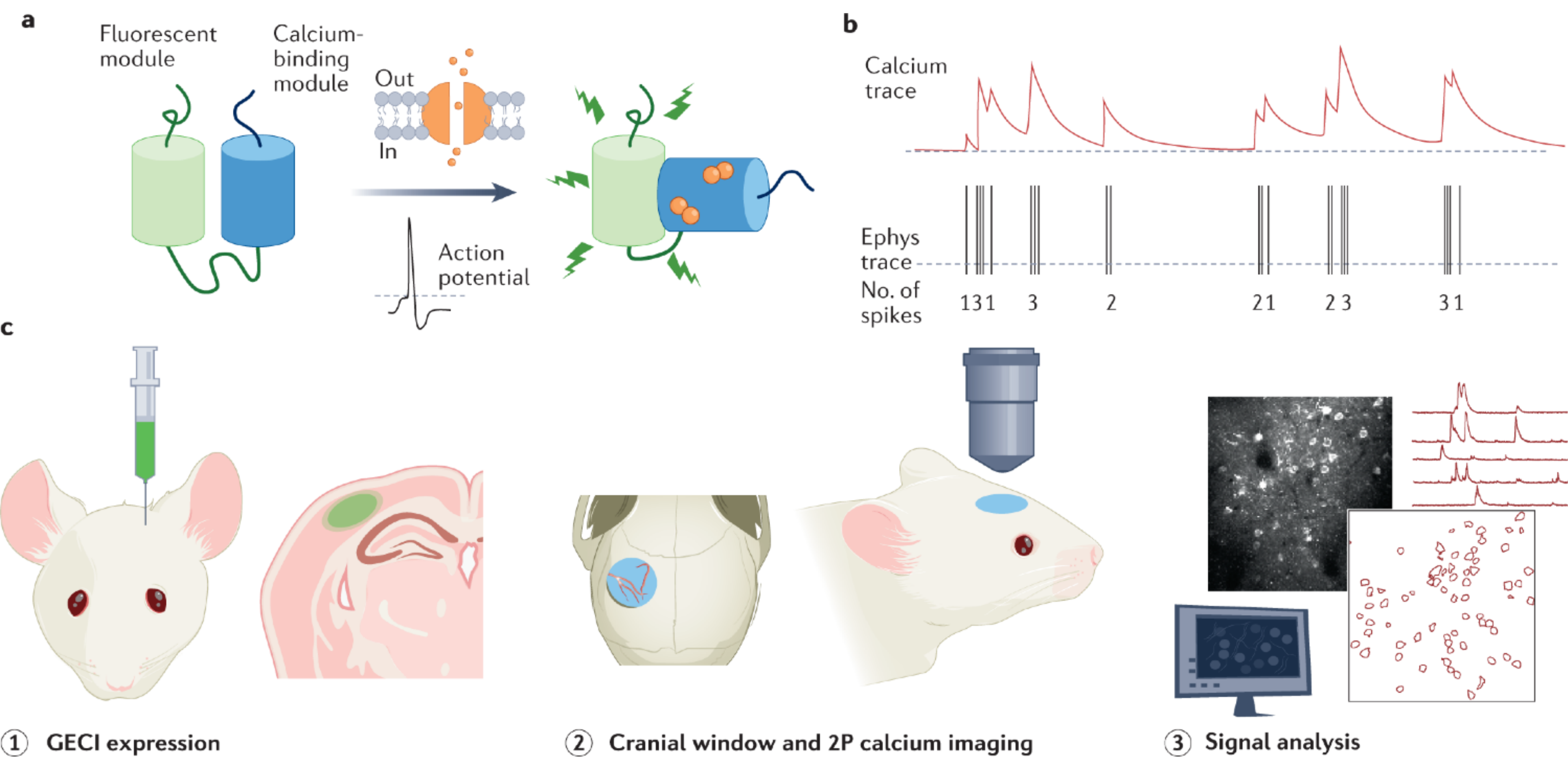
Purves

Neurons talk to one another by synaptic connections



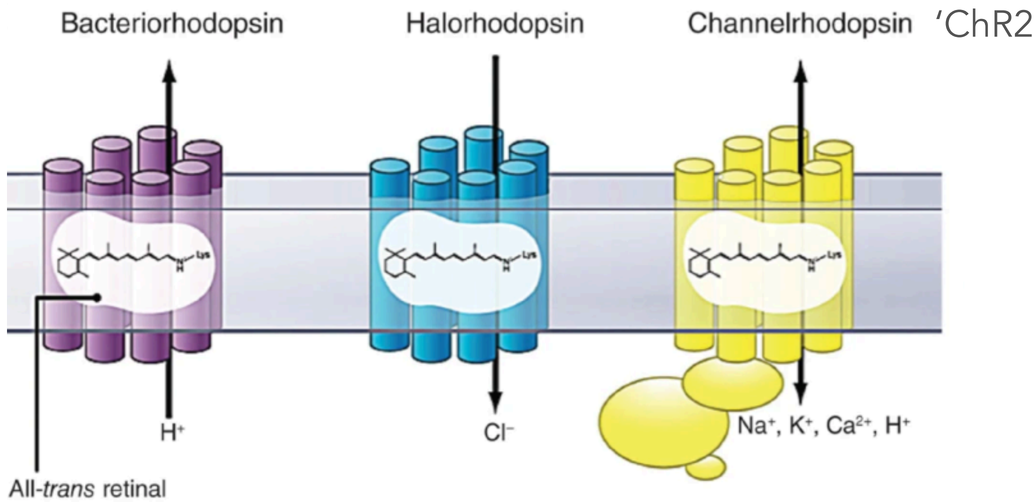
Purves

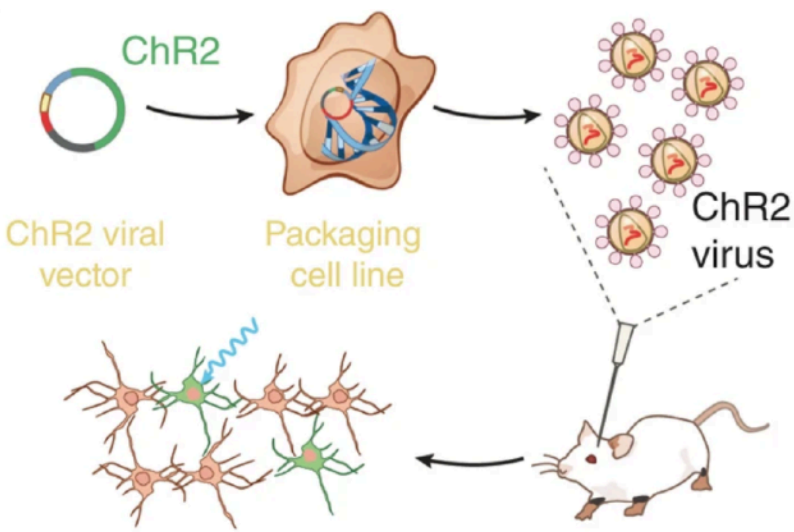
Calcium imaging of neural activity

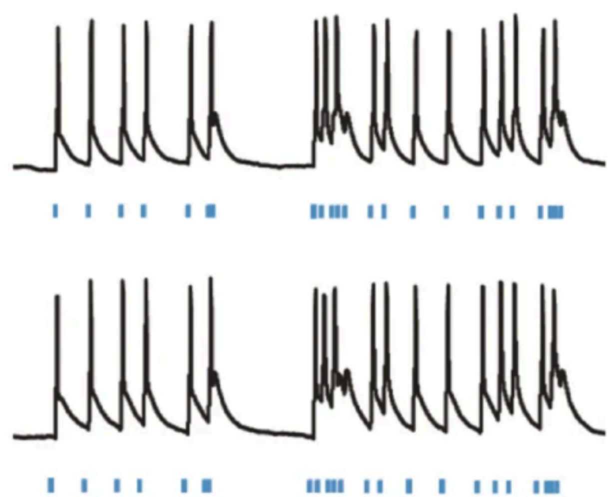


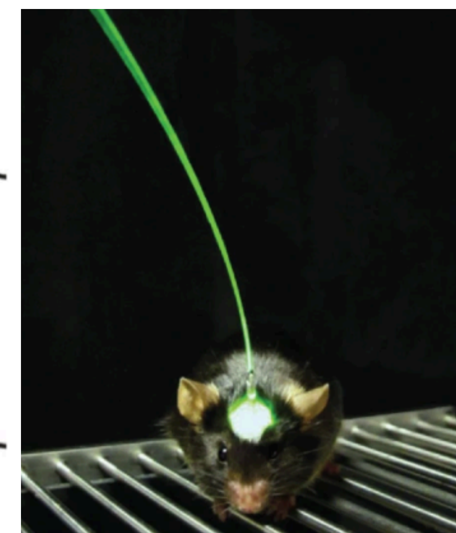
Grienberger et al., *Nature Reviews Methods Primer* 2022

Optogenetic stimulation of neural activity





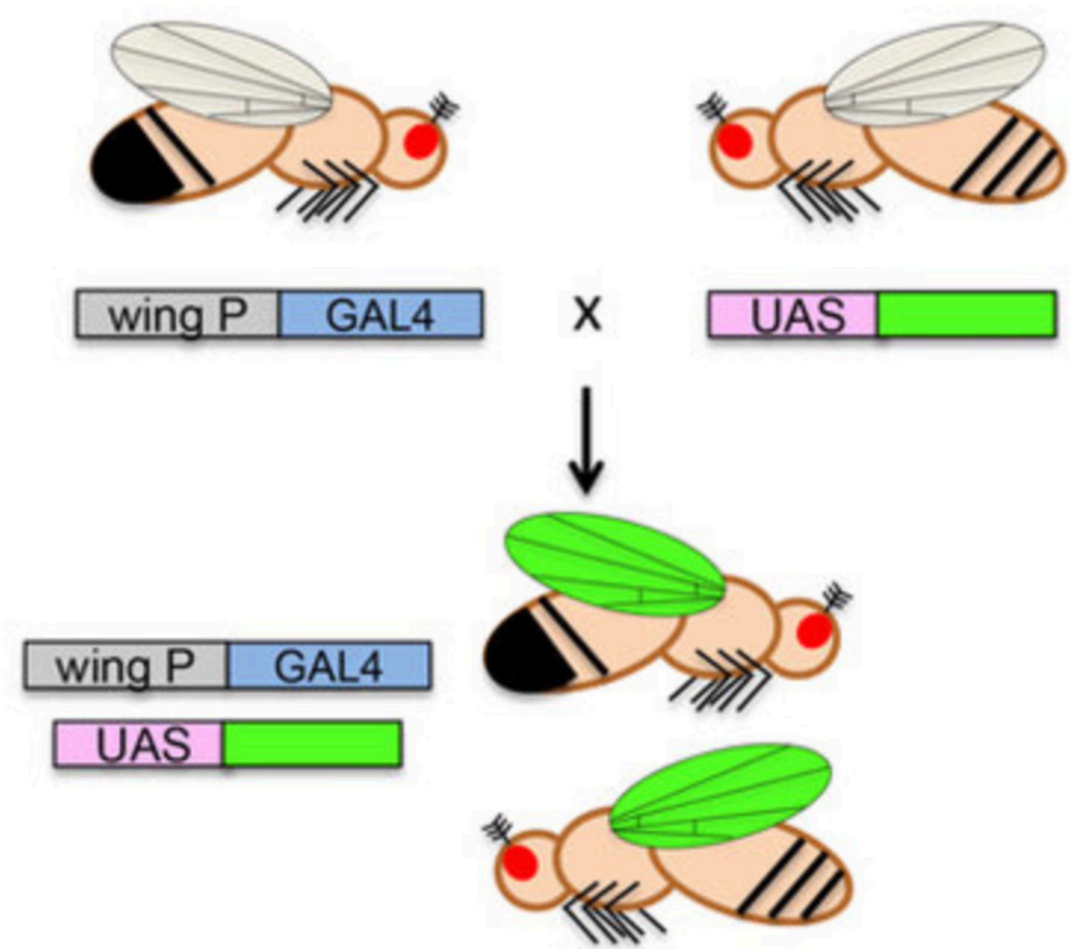




Deisseroth et al., *Nat. Neuro.* 2015

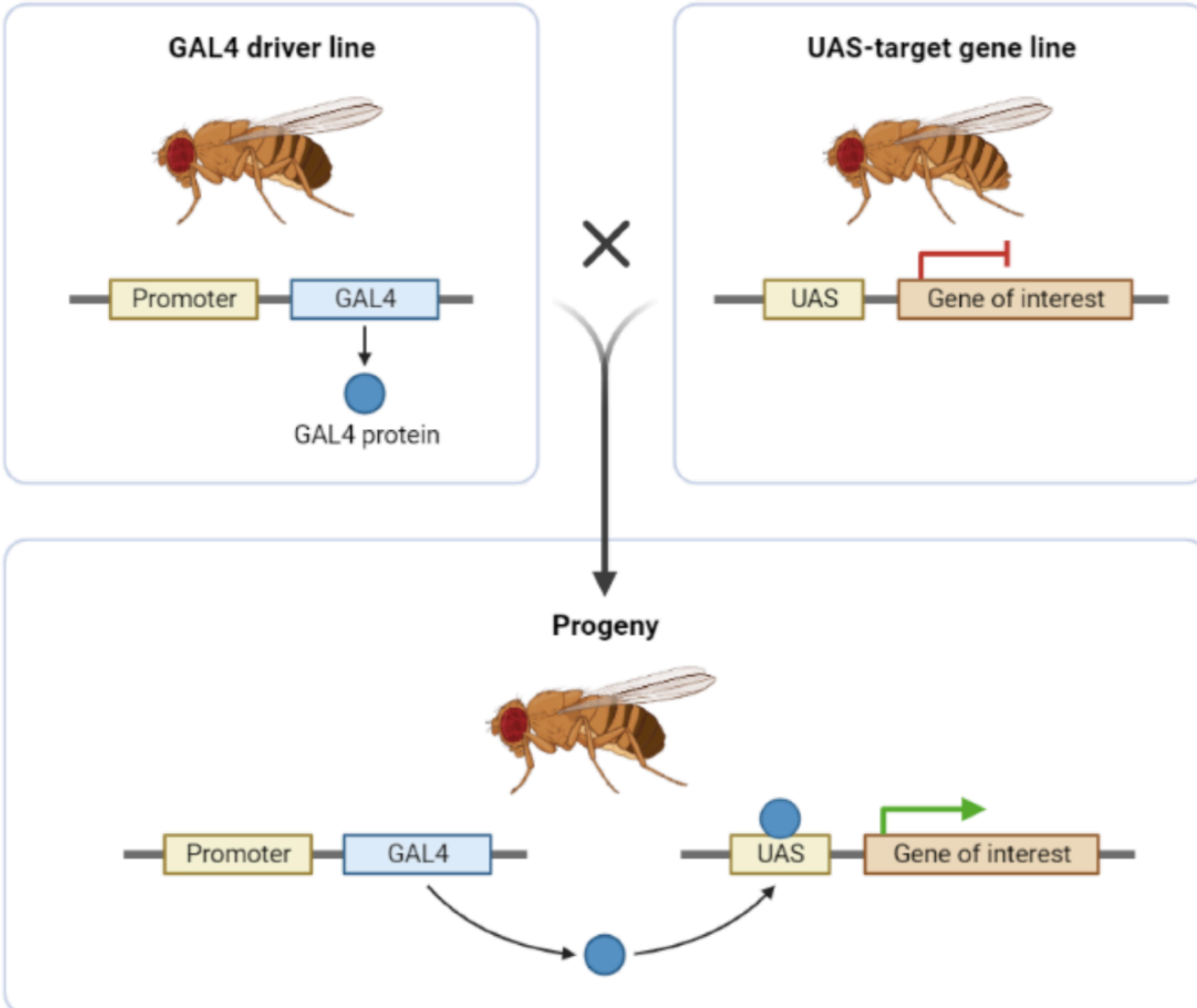
Some tools for experimenting with *Drosophila*

UAS-Gal4 gene expression system in flies



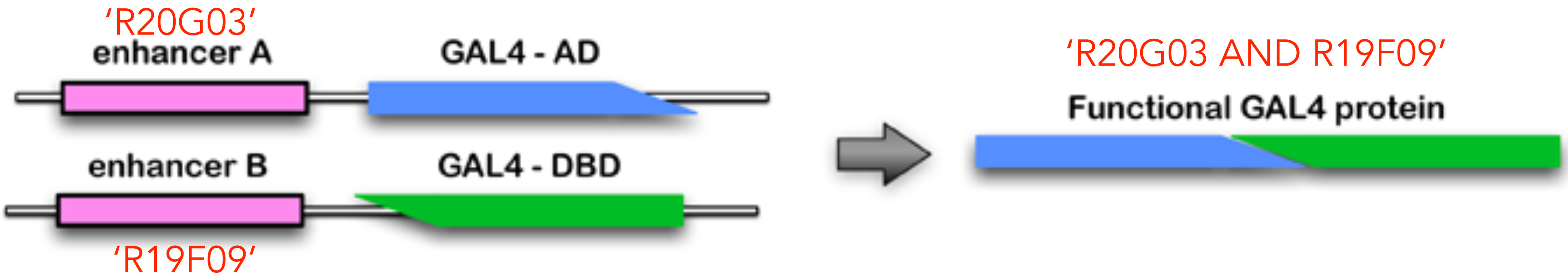
Hales et al., *Genetics* 2015

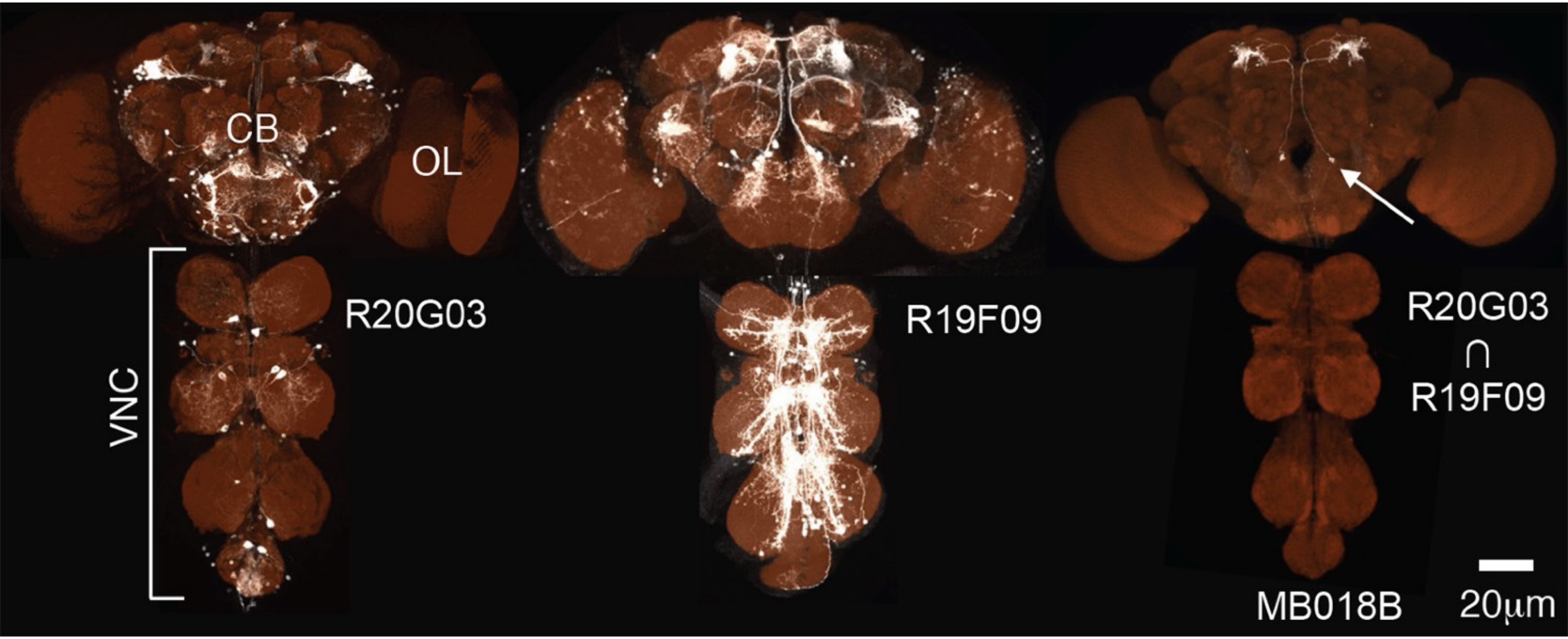
UAS-Gal4 gene expression system in flies



https://www.biorender.com/template/drosophila-gal4-uas-system

Sparser expression of gene with UAS-“split-Gal4”





Janelia Research Campus

UAS-Gal4 targeting of MDNs

Moonwalker Descending Neurons (4)

Optogenetic stimulation of MDNs

Light ON =
neurons activated

Any questions?

Today's papers:

How do descending signals drive locomotion and grooming?

What algorithms allow flies to find an odor source?