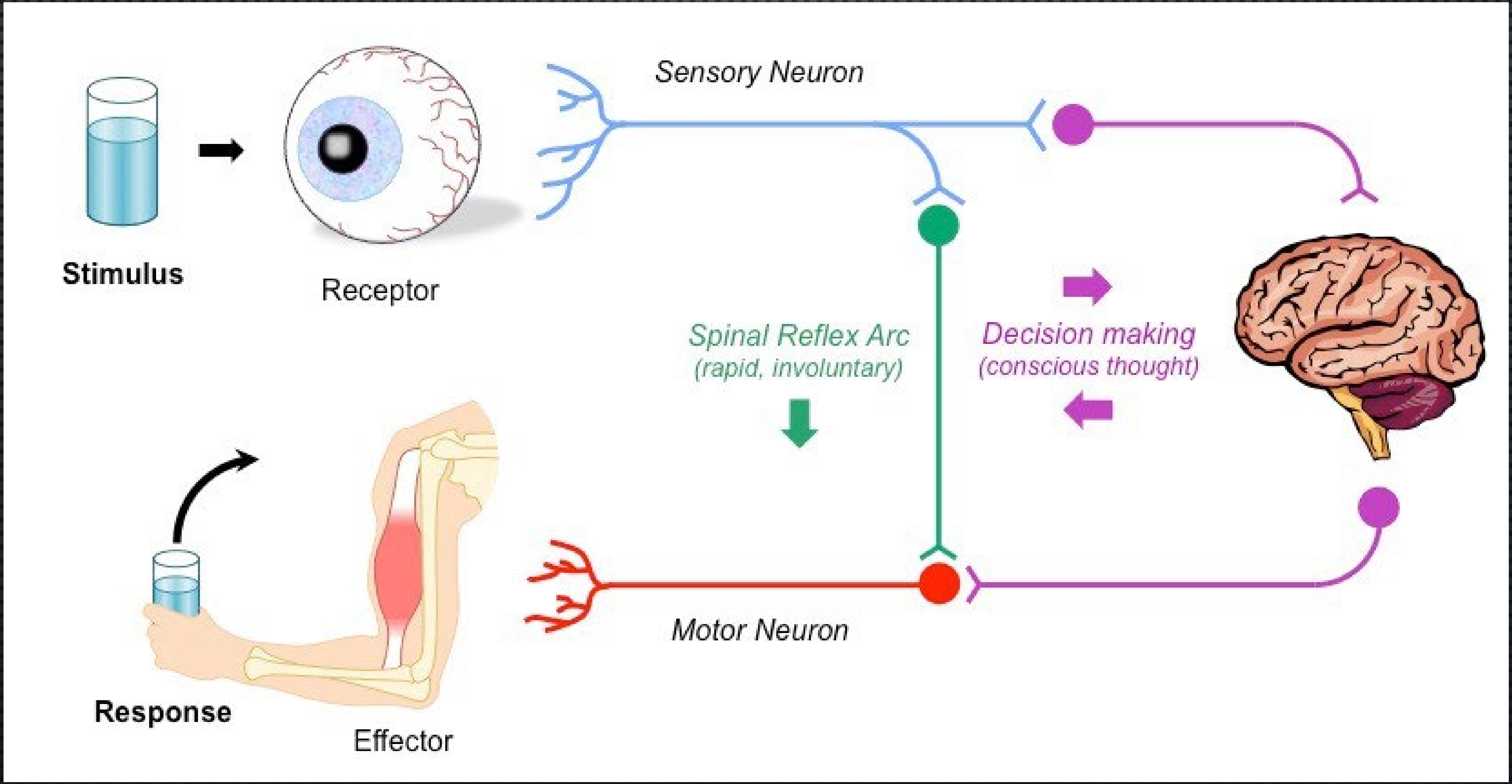
3 Simple artificial neural brains for sensing and control

A simple template for an artificial brain



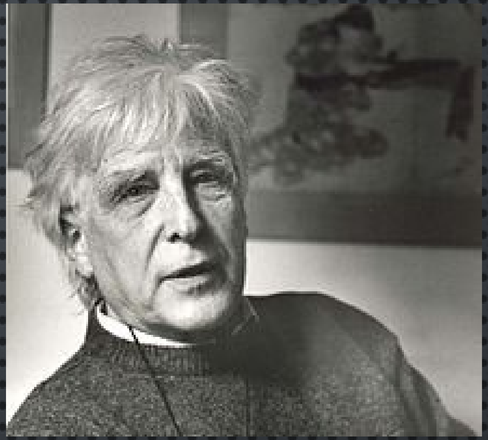
Braitenberg vehicles: a simple neurorobot

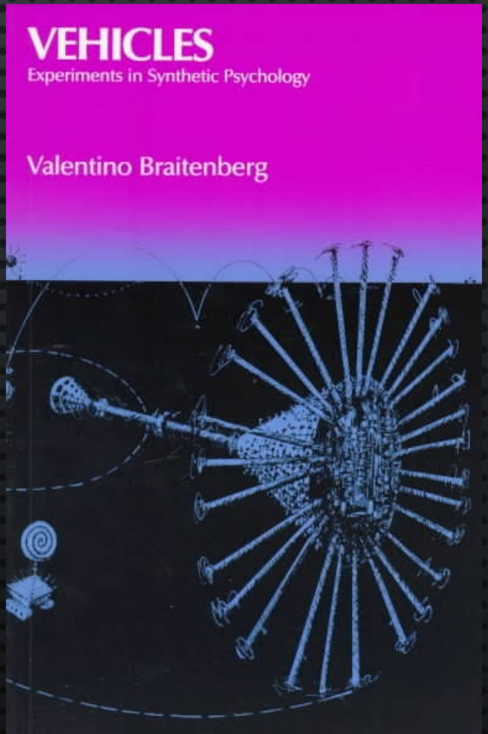
- Proposed by Valentino Braitenberg in 1984 book “Vehicles: Experiments in synthetic psychology”

- Exploring relation between structures and functions of the brain

- Hypothetical analogue vehicles (a combination of sensors, actuators and their interconnections)

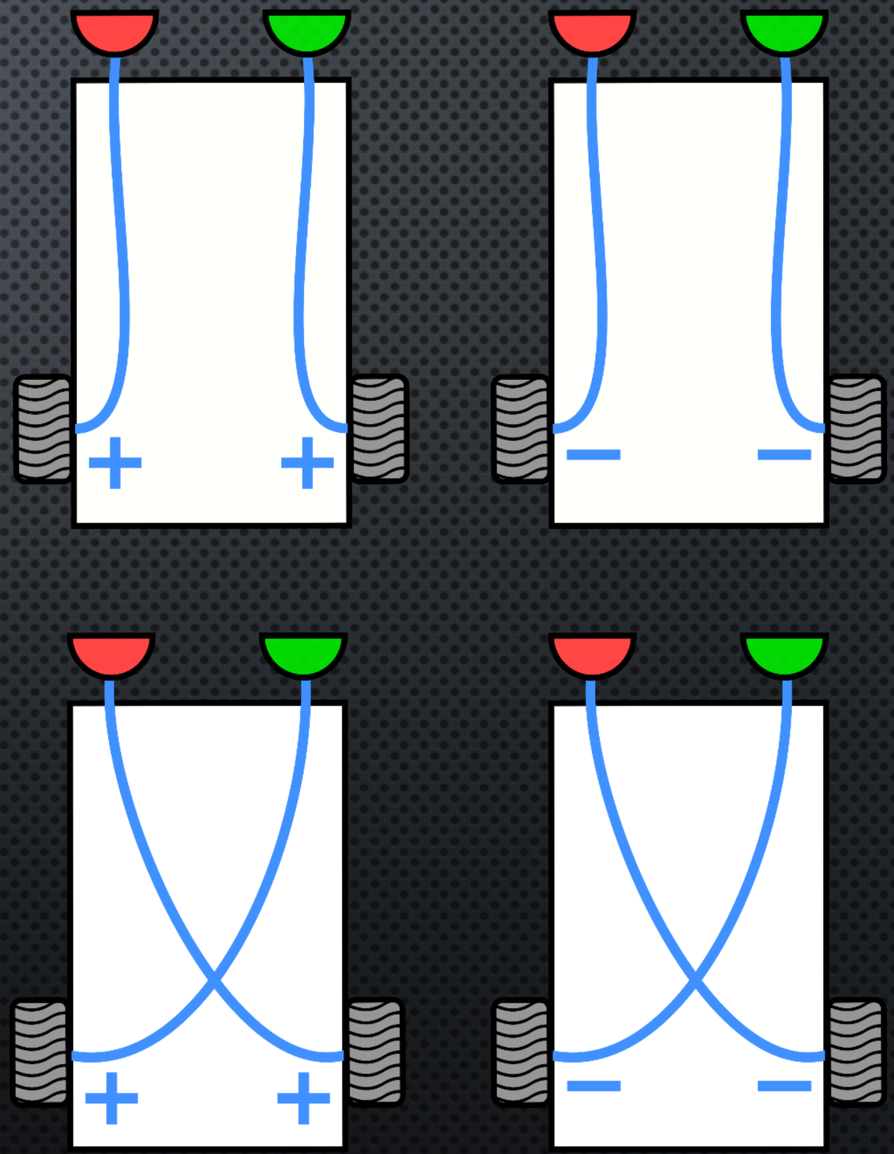
- Vehicles displayed behaviours akin to aggression, love, fear, and exploration





Braitenberg vehicles: a simple neurorobot

- A sensor is directly connected to an actuator (e.g. light sensor → wheel motor)
- Sensorimotor connections can be ipsilateral or contralateral and excitatory or inhibitory
- Depending on how sensors and wheels are connected, the vehicle exhibits different movement behaviours
- In a complex environment with several sources of stimulus, vehicles exhibit complex and dynamic behaviour
- Functioning of the vehicle is purely mechanical, without any information processing or other apparently cognitive processes.



Some basic Braitenberg vehicles

$$v_{left} = k \times \frac{1}{s_{right}}$$
$$v_{right} = k \times \frac{1}{s_{left}}$$

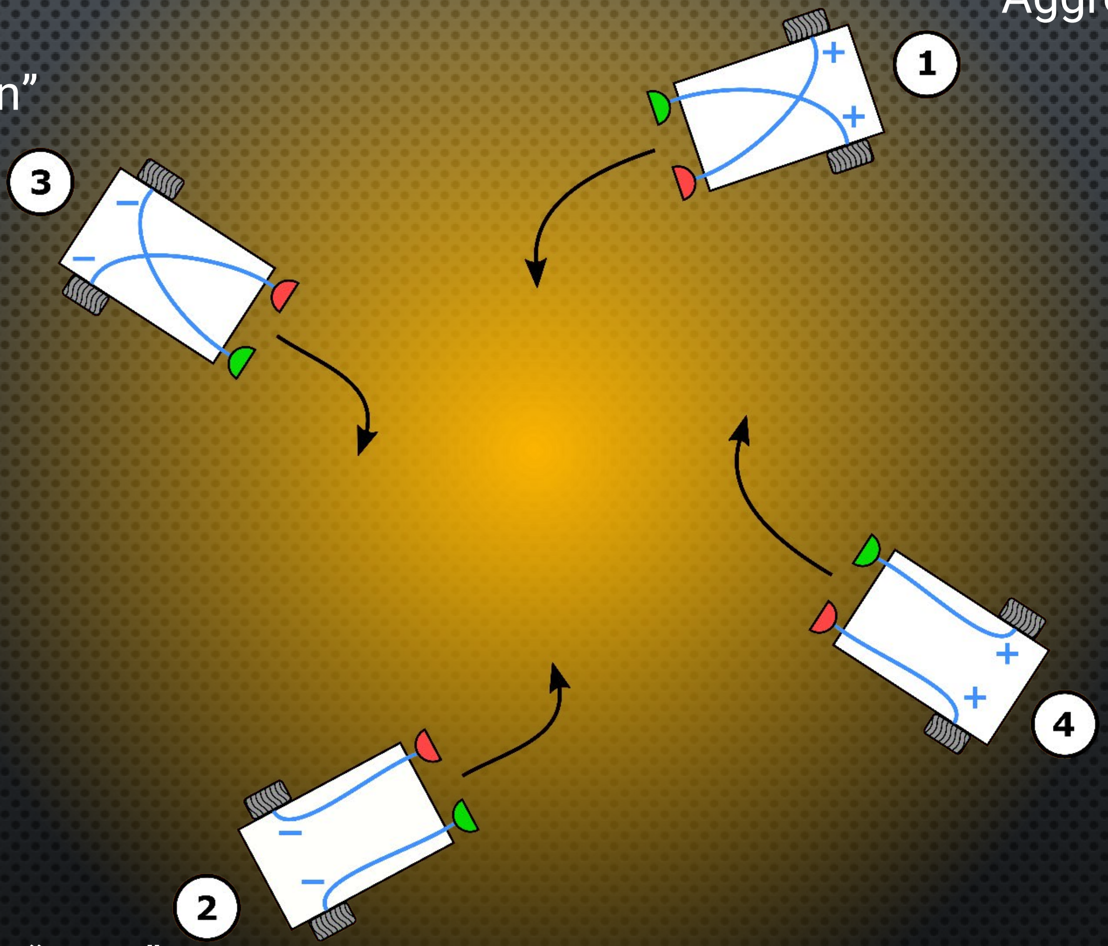
"Exploration"

OR

$$v_{left} = k \times (s_{max} - s_{right})$$
$$v_{right} = k \times (s_{max} - s_{left})$$

"Aggression"

$$v_{left} = k \times s_{right}$$
$$v_{right} = k \times s_{left}$$



$$v_{left} = \frac{1}{k} \times \frac{1}{s_{left}}$$
$$v_{right} = \frac{1}{k} \times \frac{1}{s_{right}}$$

OR

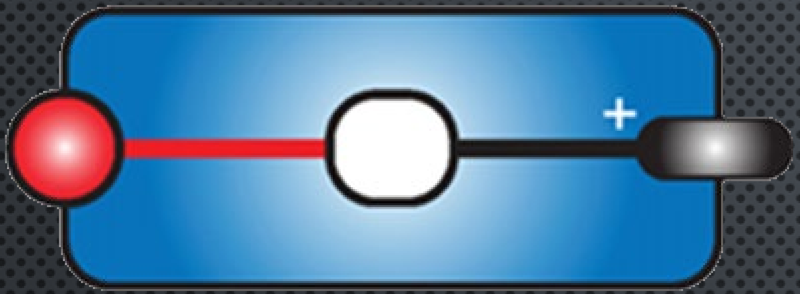
$$v_{left} = k \times (s_{max} - s_{left})$$
$$v_{right} = k \times (s_{max} - s_{right})$$

"Love"

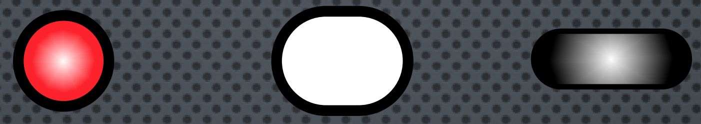
"Fear"

$$v_{left} = k \times s_{left}$$
$$v_{right} = k \times s_{right}$$

Braitenberg vehicles as animal models



Alex Gomez-Marin et al., 2010

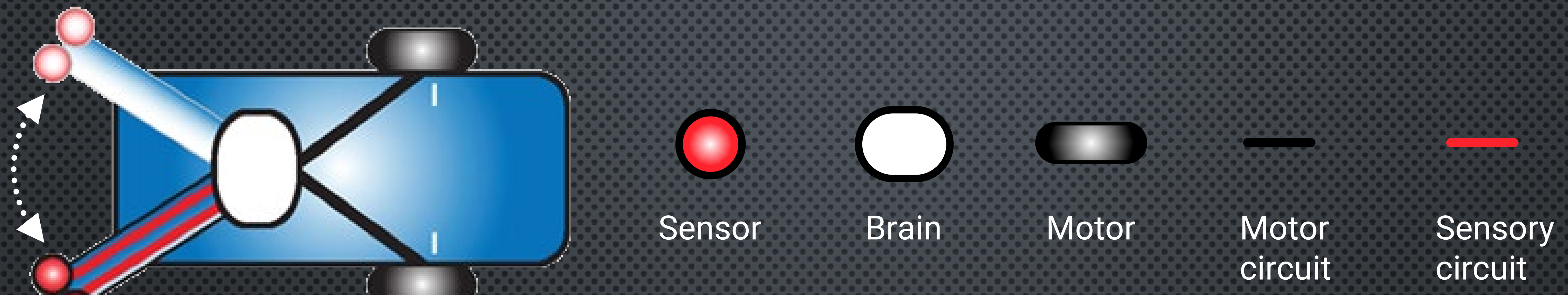


Escherichia coli

Roundworm (*Caenorhabditis elegans*)

http://labs.bio.unc.edu/Goldstein/movies.html

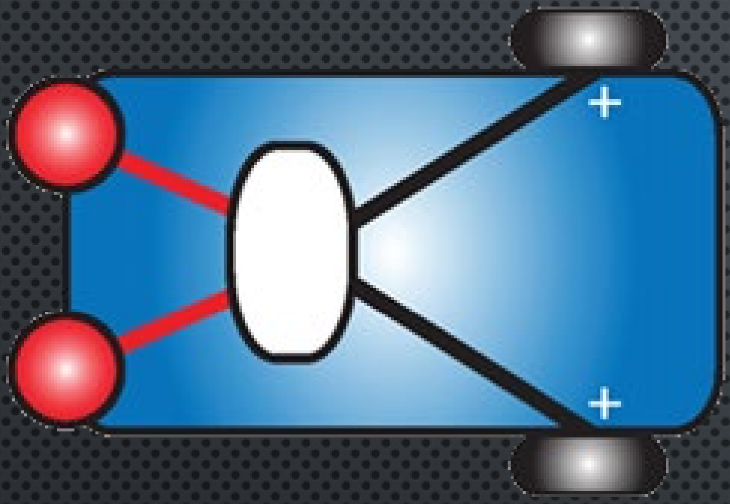
Braitenberg vehicles as animal models



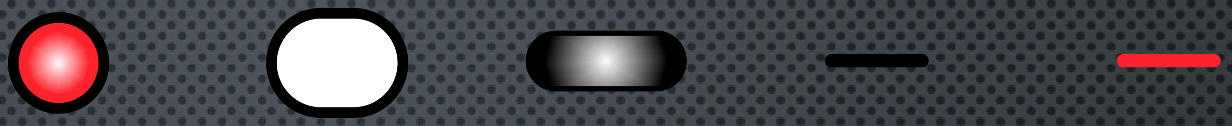
Alex Gomez-Marin et al., 2010

Drosophila melanogaster or common fruit fly, larval stage

Braitenberg vehicles as animal models

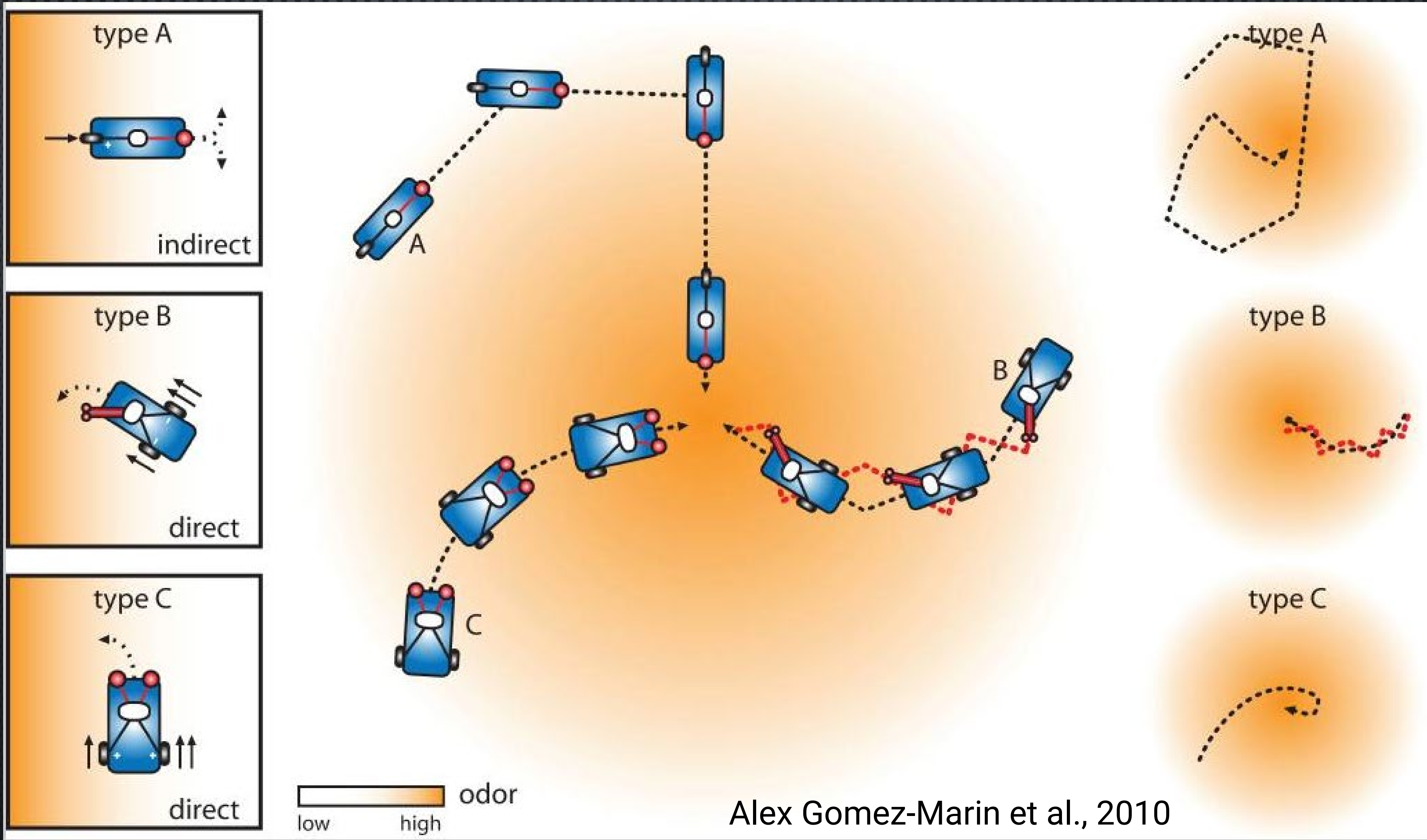


Alex Gomez-Marin et al., 2010



Drosophila melanogaster or common fruit fly, adult stage

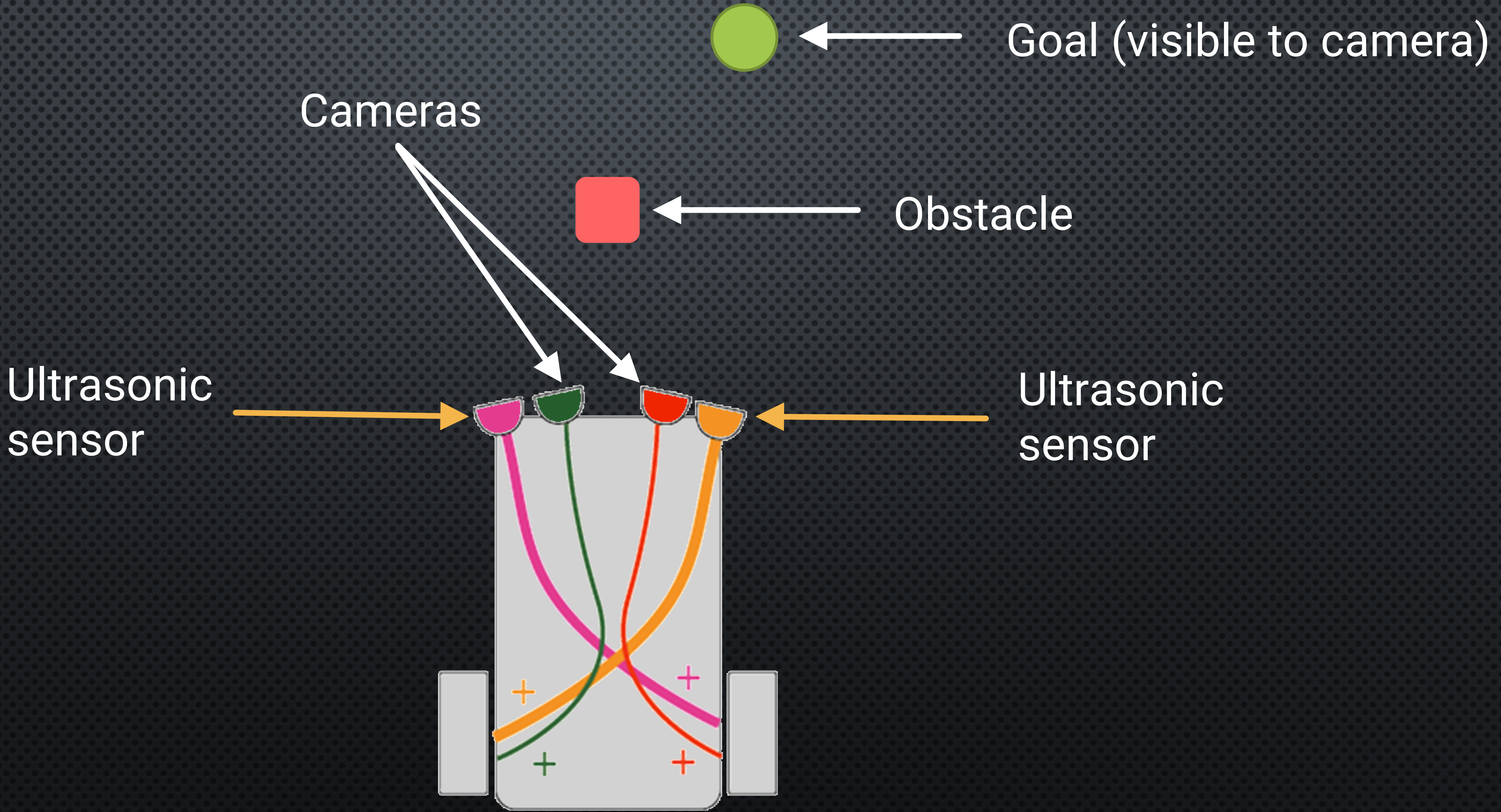
Braitenberg vehicles as animal models



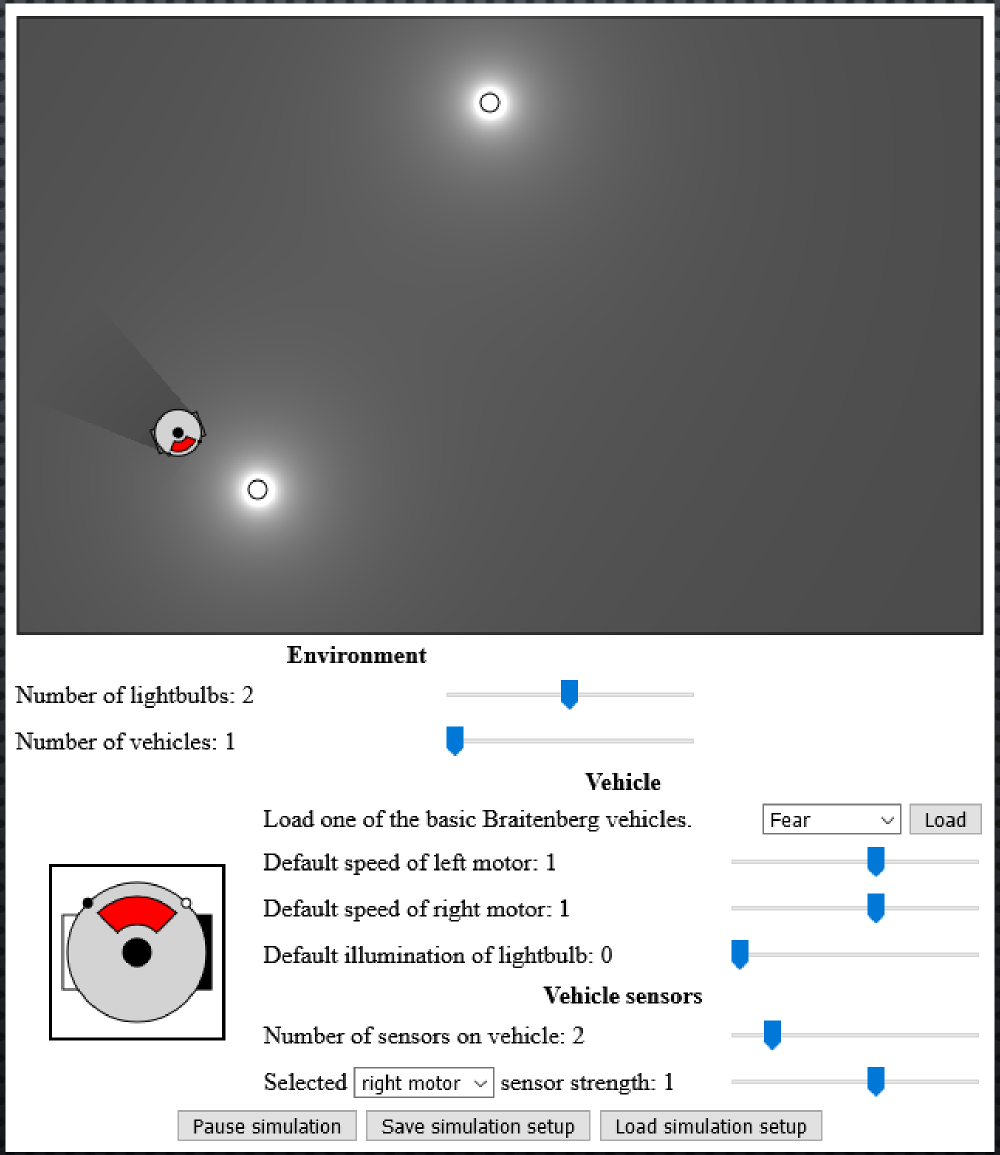
Alex Gomez-Marin et al., 2010

Some examples

How will this vehicle behave?



Play time: Braitenberg vehicle playground



http://www.harmendeweerd.nl/braitenberg-vehicles/

A case for Braitenberg controllers

The artificial solution

https://www.youtube.com/watch?v=umRdt3zGgpU

The natural solution

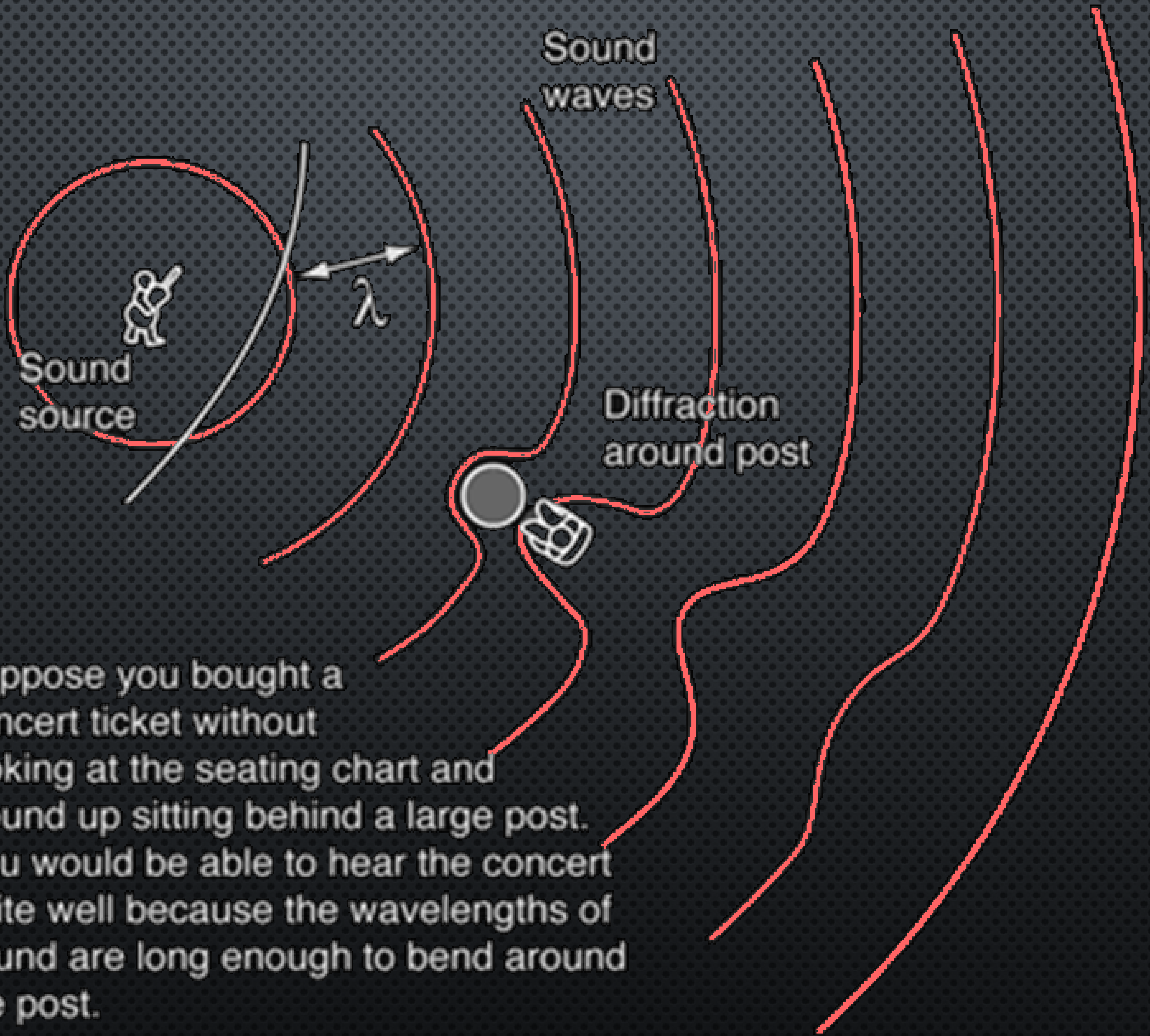
https://www.youtube.com/watch?v=p-_RHRAzUHM

Case study 1

A lizard-inspired sound localising robot

Lizard audition

Ecological niche: physics of sound propagation



Suppose you bought a concert ticket without looking at the seating chart and wound up sitting behind a large post. You would be able to hear the concert quite well because the wavelengths of sound are long enough to bend around the post.

Basics of acoustics: diffraction

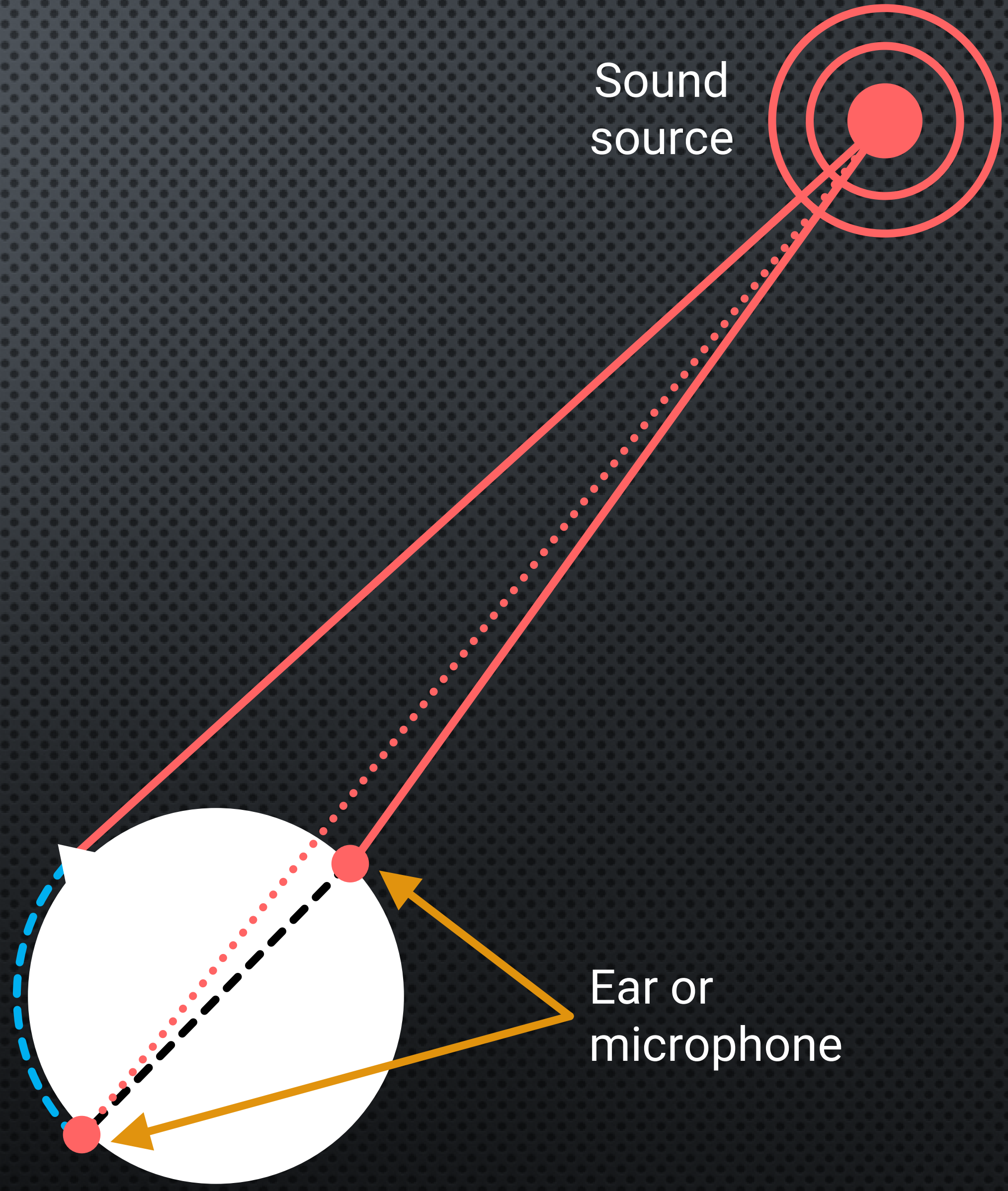
- Two ways to determine sound direction
  - Inter-aural level difference (ILD)
  - Inter-aural time difference (ITD)

- ILD = difference in sensed loudness (in dB) of sound at each ear

- ITD = difference in time of arrival (in μs) of sound at each ear

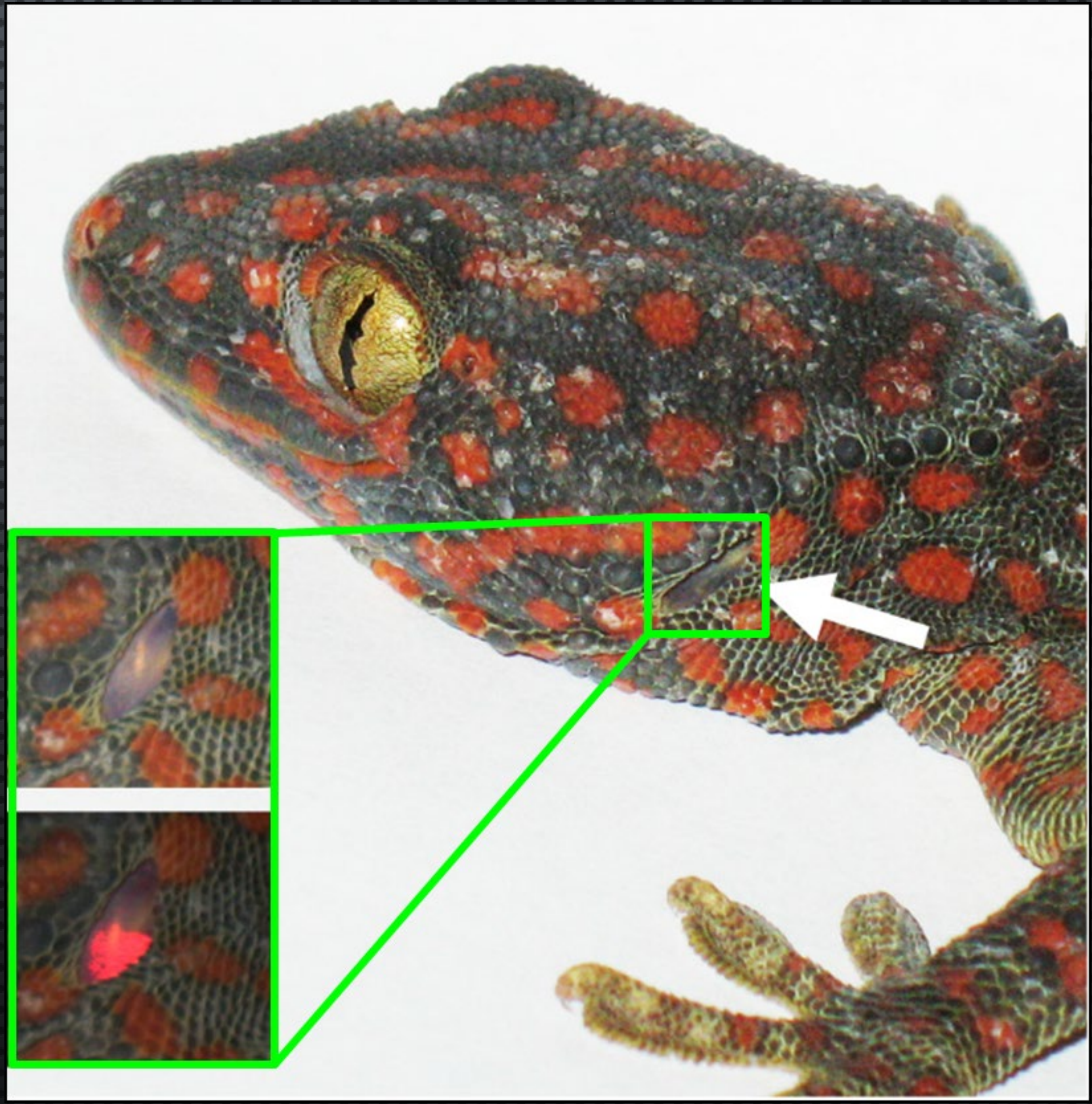
- If sound frequency is high (wavelength > distance between ears), ILD is significant

- If sound frequency is low (wavelength < distance between ears) ITD is significant



Characteristics of lizard hearing

- Small size (10—20 mm) w.r.t sound wavelengths (85–340 mm) → sound diffracts around the head
- Diffraction leads to small inter-aural level difference (ILD) (typically 1-2 dBs → too small to measure without special, big, heavy and expensive equipment)
- Tiny (μs scale) inter-aural time difference (ITD) information available to determine sound direction



Shaikh et al., 2016

Auditory directional cues

Image: reptilepark.com.au

Auditory directional cues

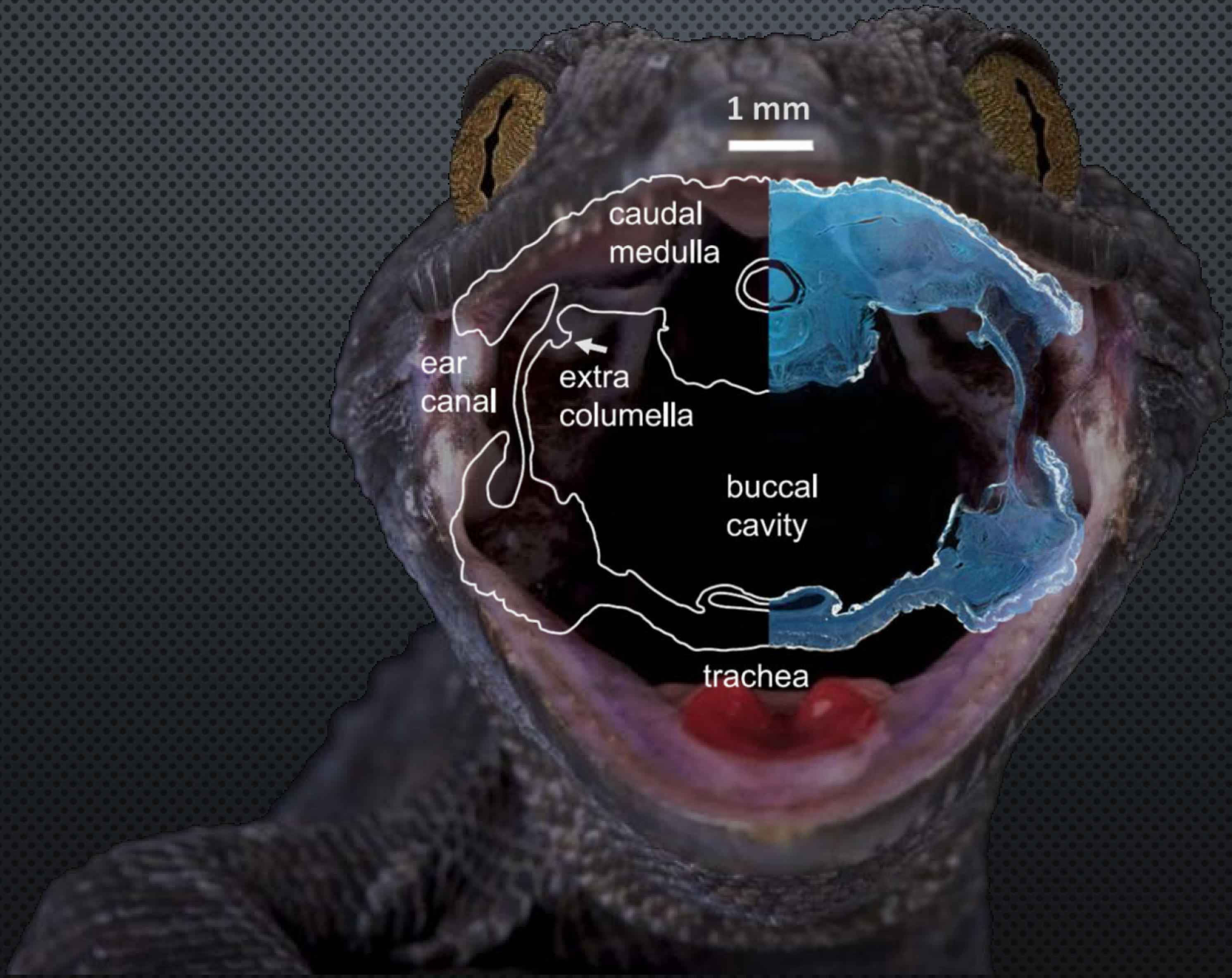


Image: reptilepark.com.au

Auditory directional cues

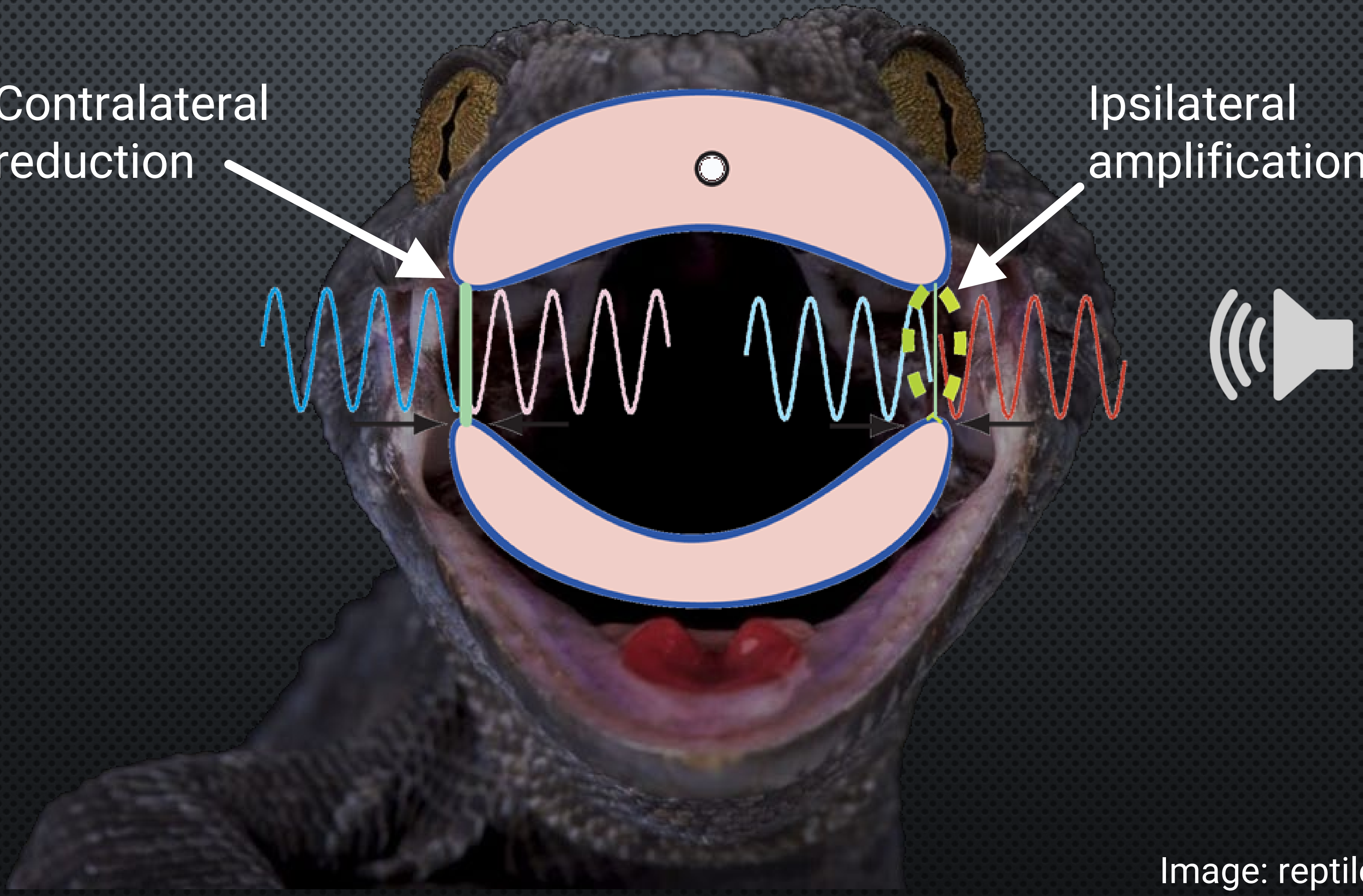
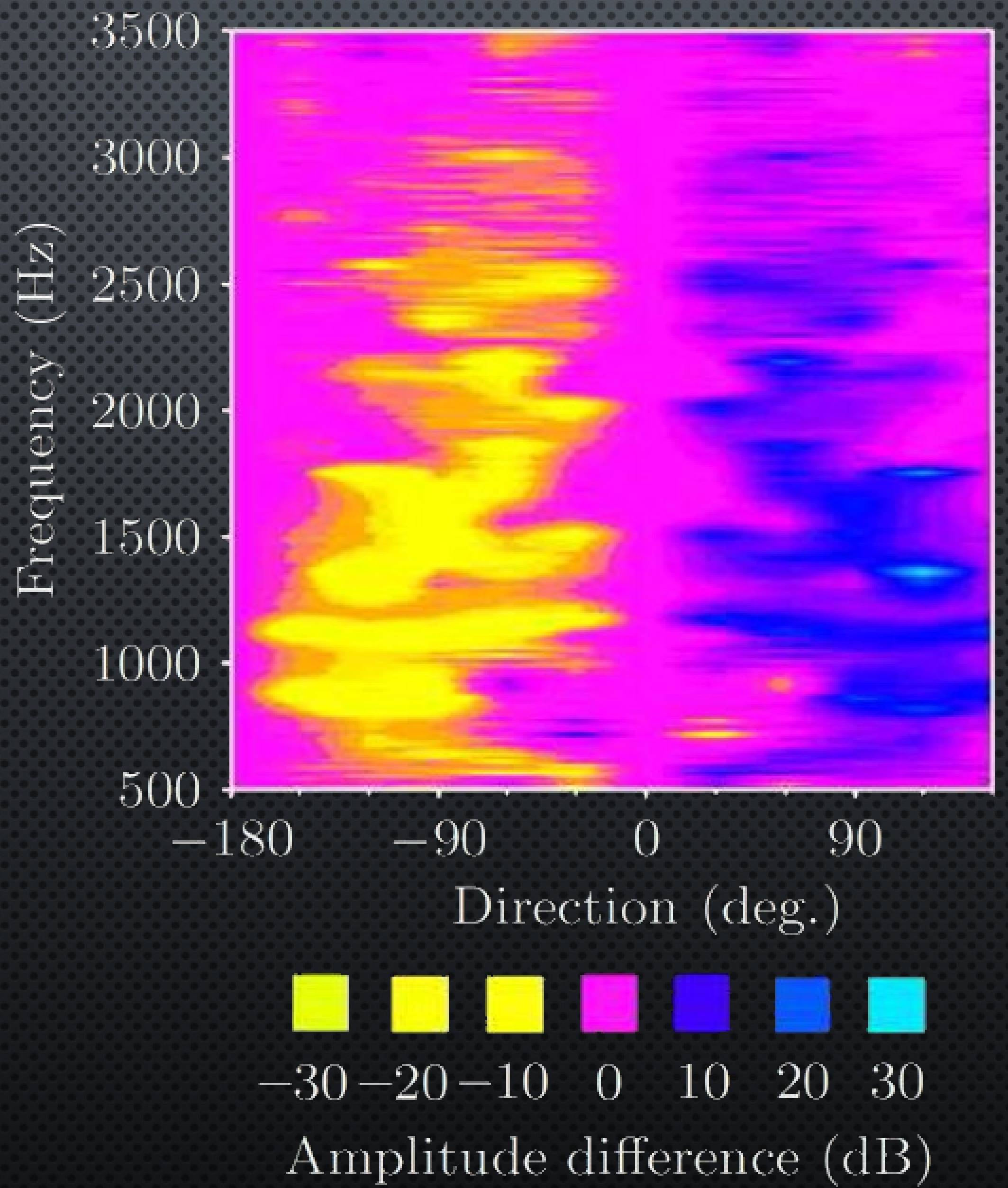
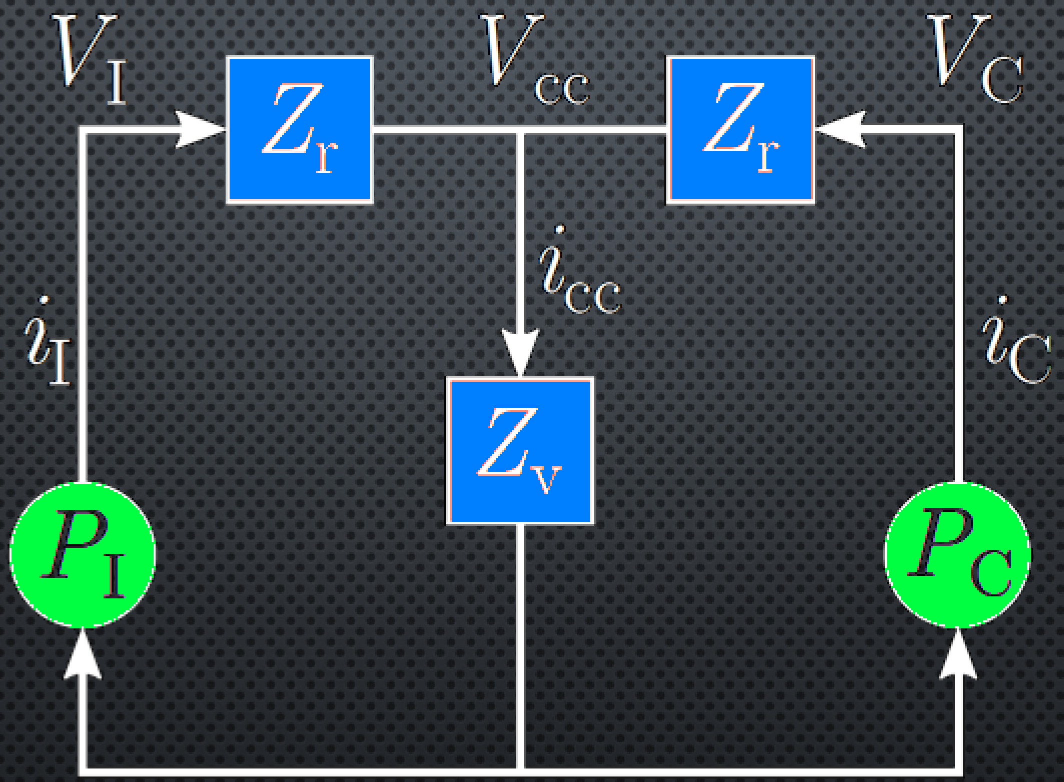


Image: reptilepark.com.au

Sound direction informtion

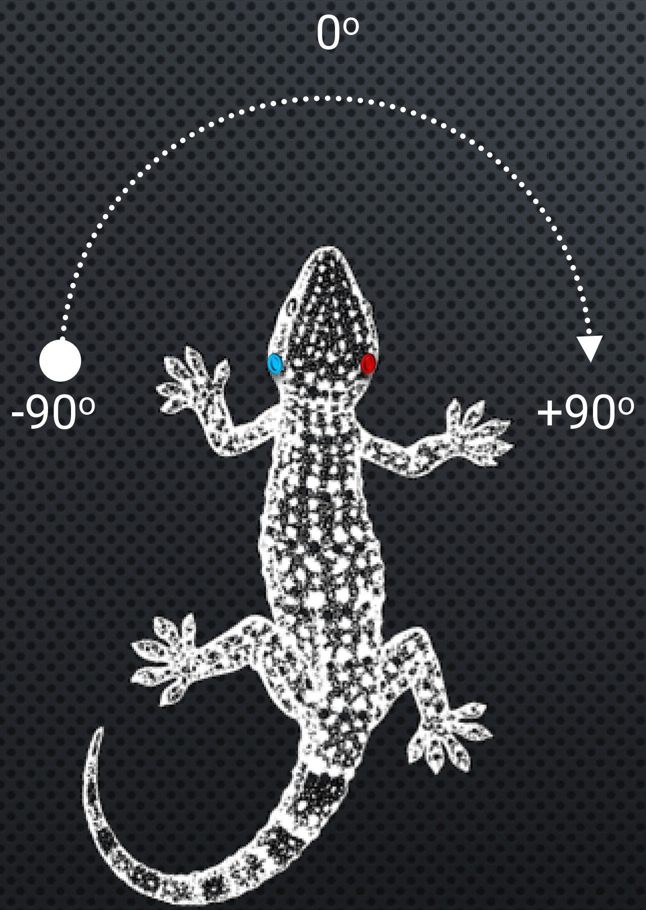


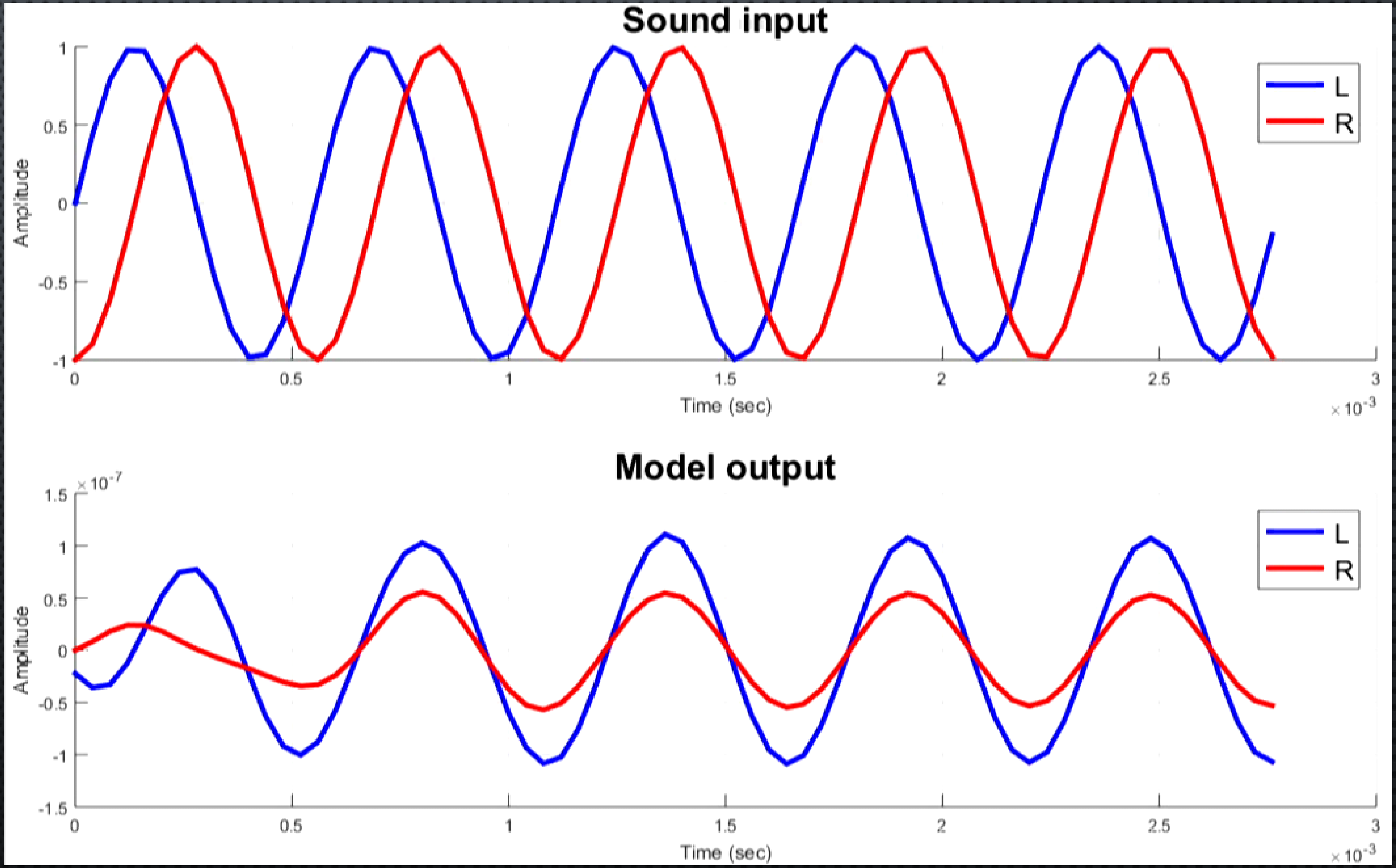
Sensor model



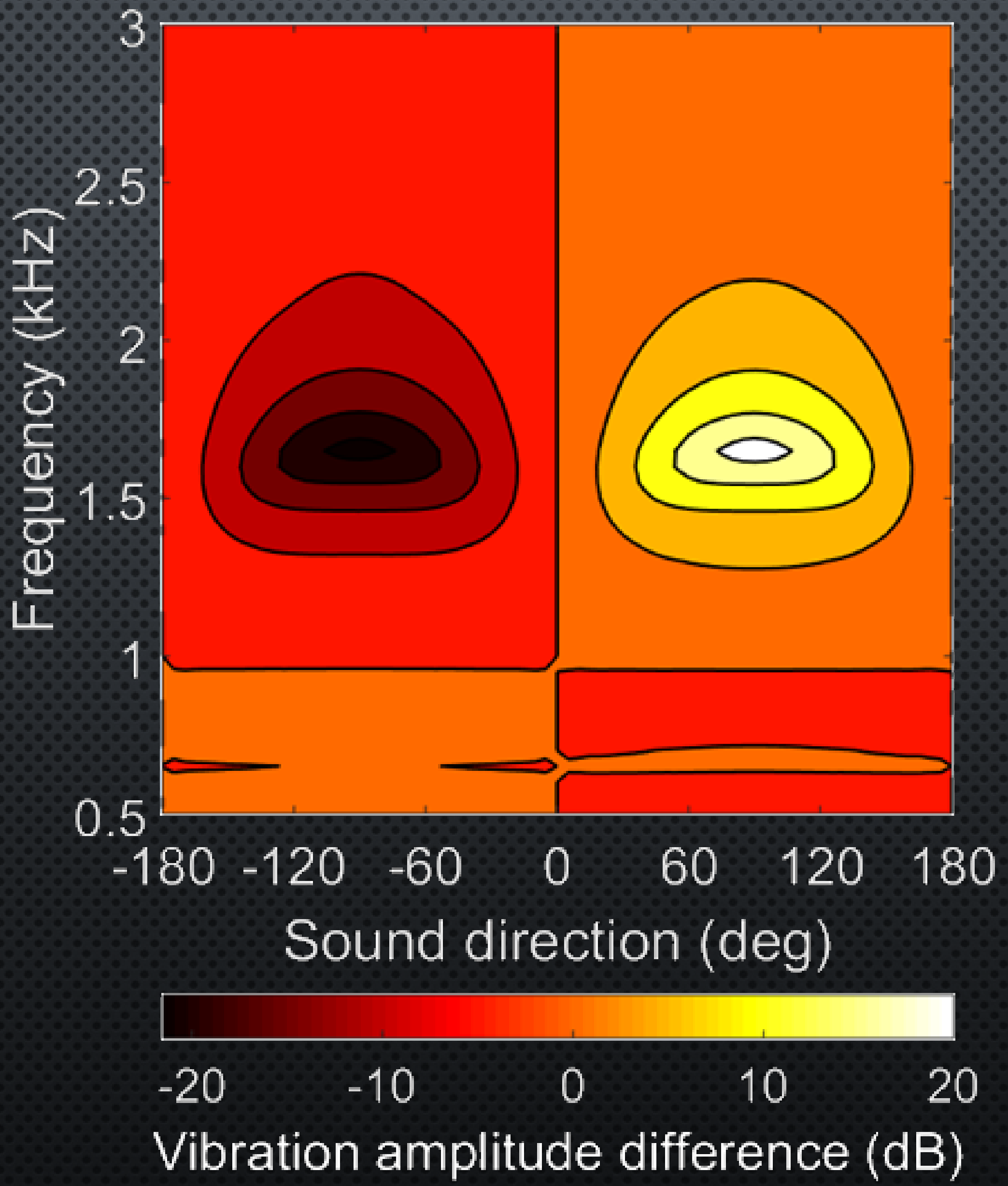
$$\left|\frac{i_\mathrm{I}}{i_\mathrm{C}}\right| = \left|\frac{G_\mathrm{I}\cdot V_\mathrm{I} + G_\mathrm{C}\cdot V_\mathrm{C}}{G_\mathrm{C}\cdot V_\mathrm{I} + G_\mathrm{I}\cdot V_\mathrm{C}}\right| \equiv 20\left(\log|i_\mathrm{I}| - \log|i_\mathrm{C}|\right)\ \mathrm{dB}$$

Model response in the azimuth

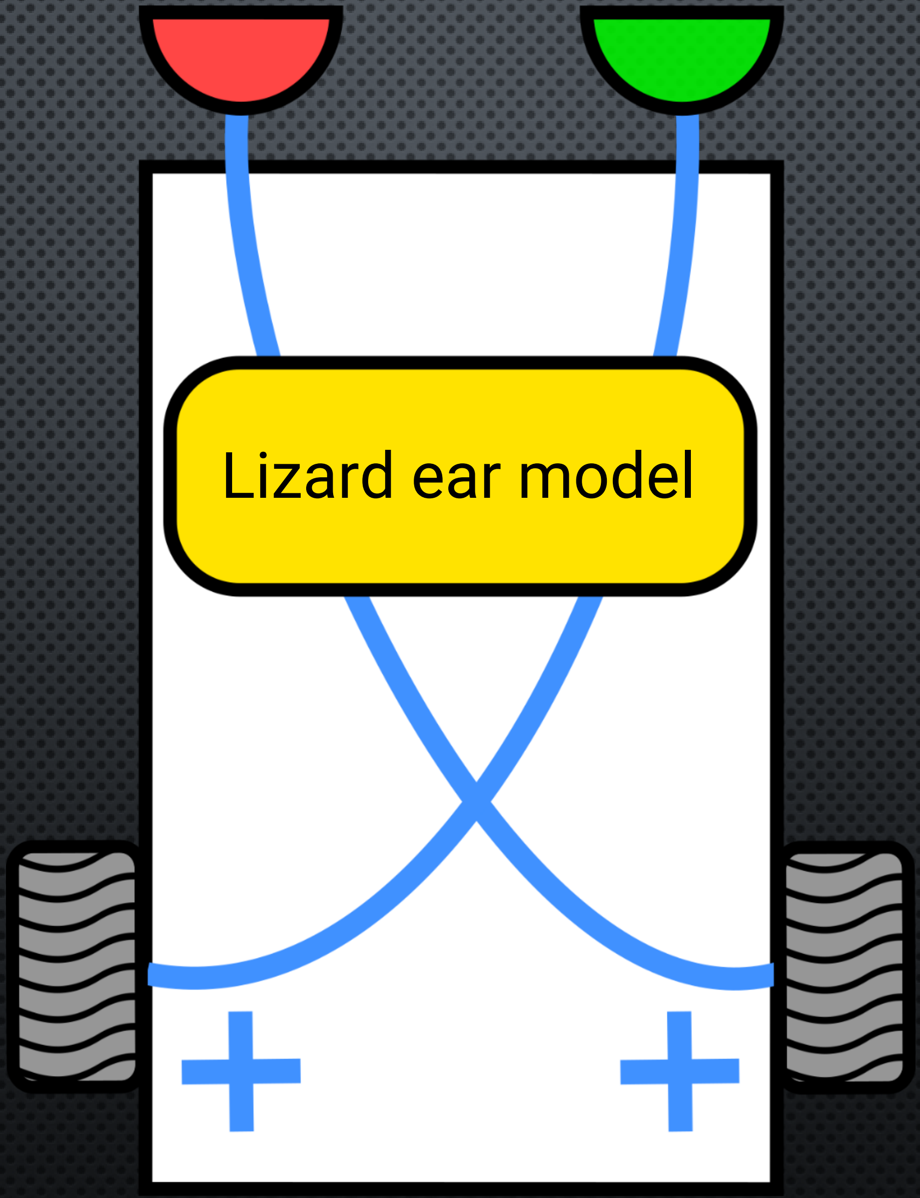




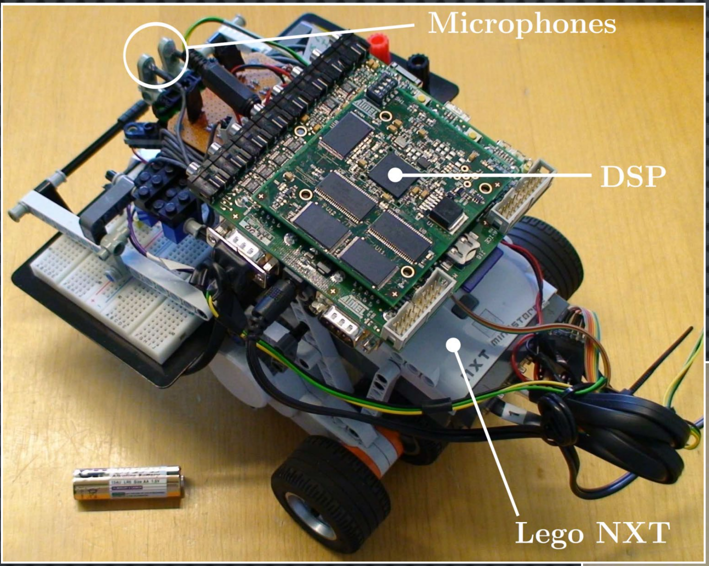
Model response in the azimuth

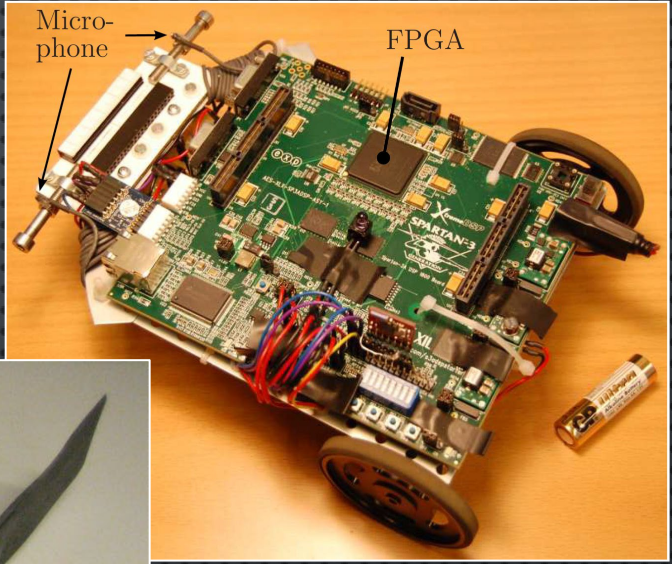


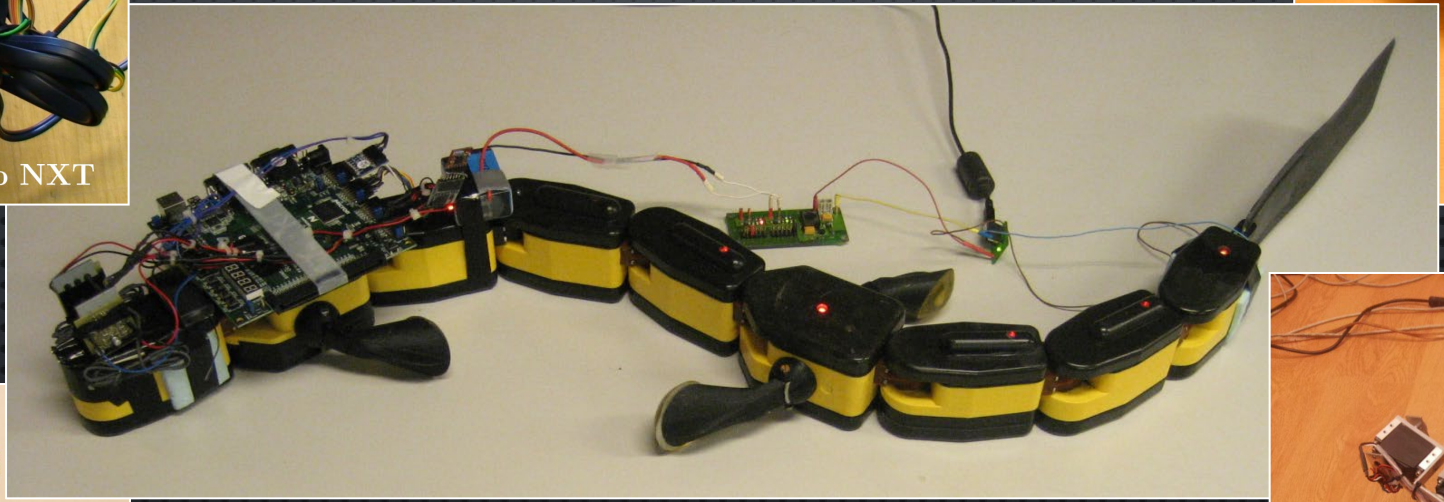
A Braitenberg model for sound localisation

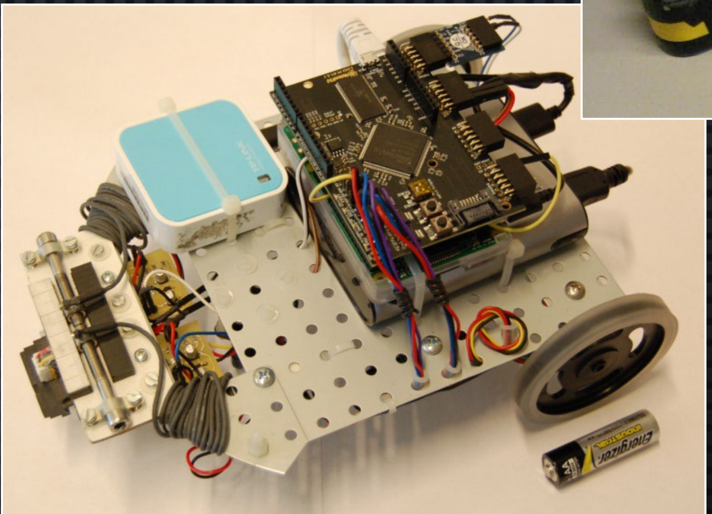


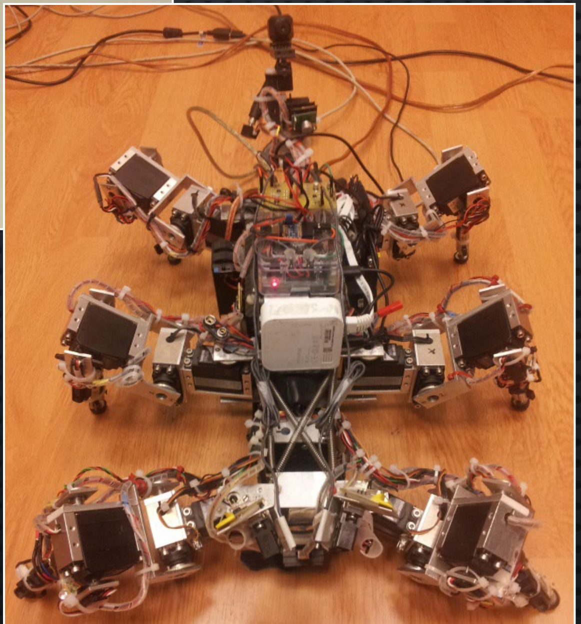
Biologically-inspired sound localising robots (by yours truly)











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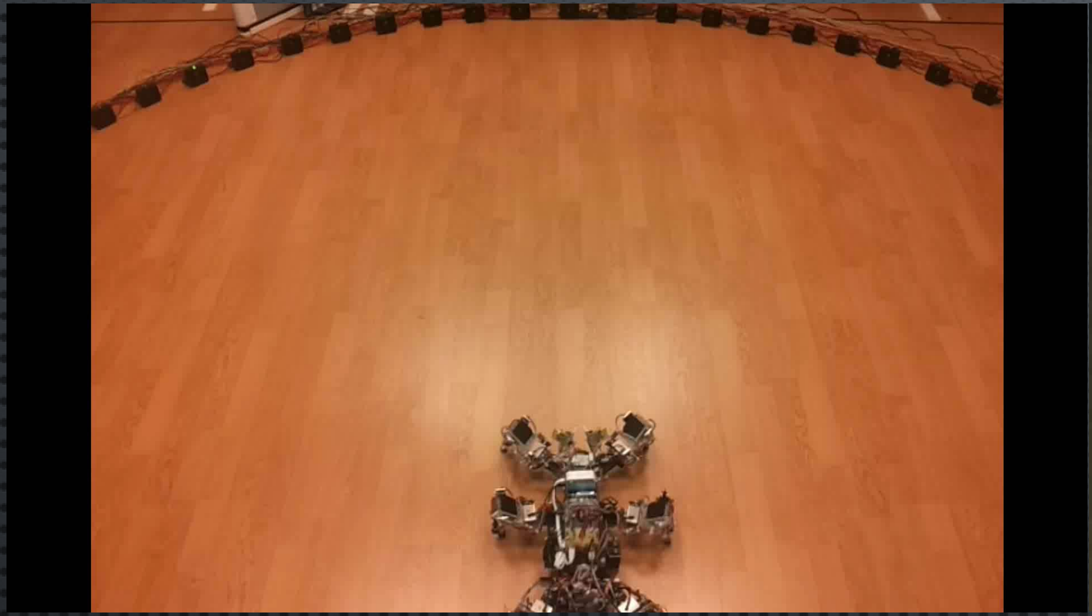
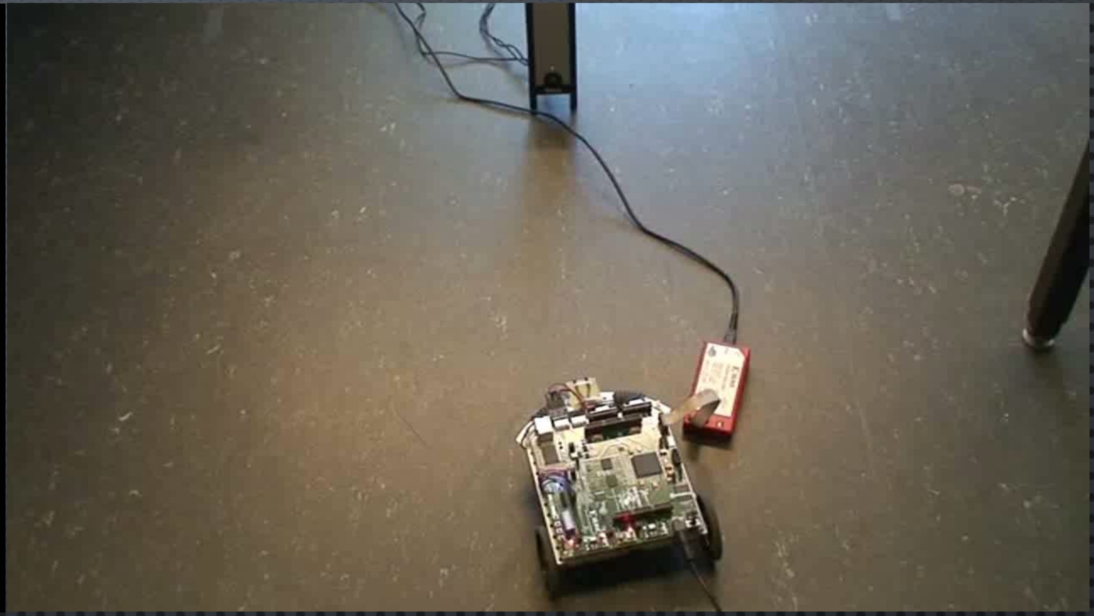
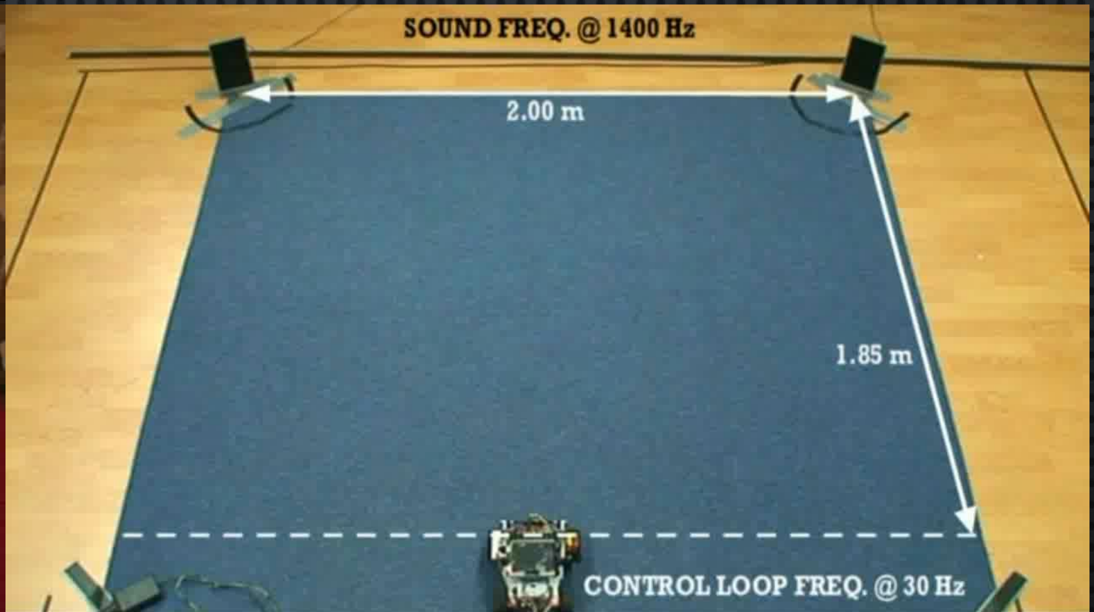





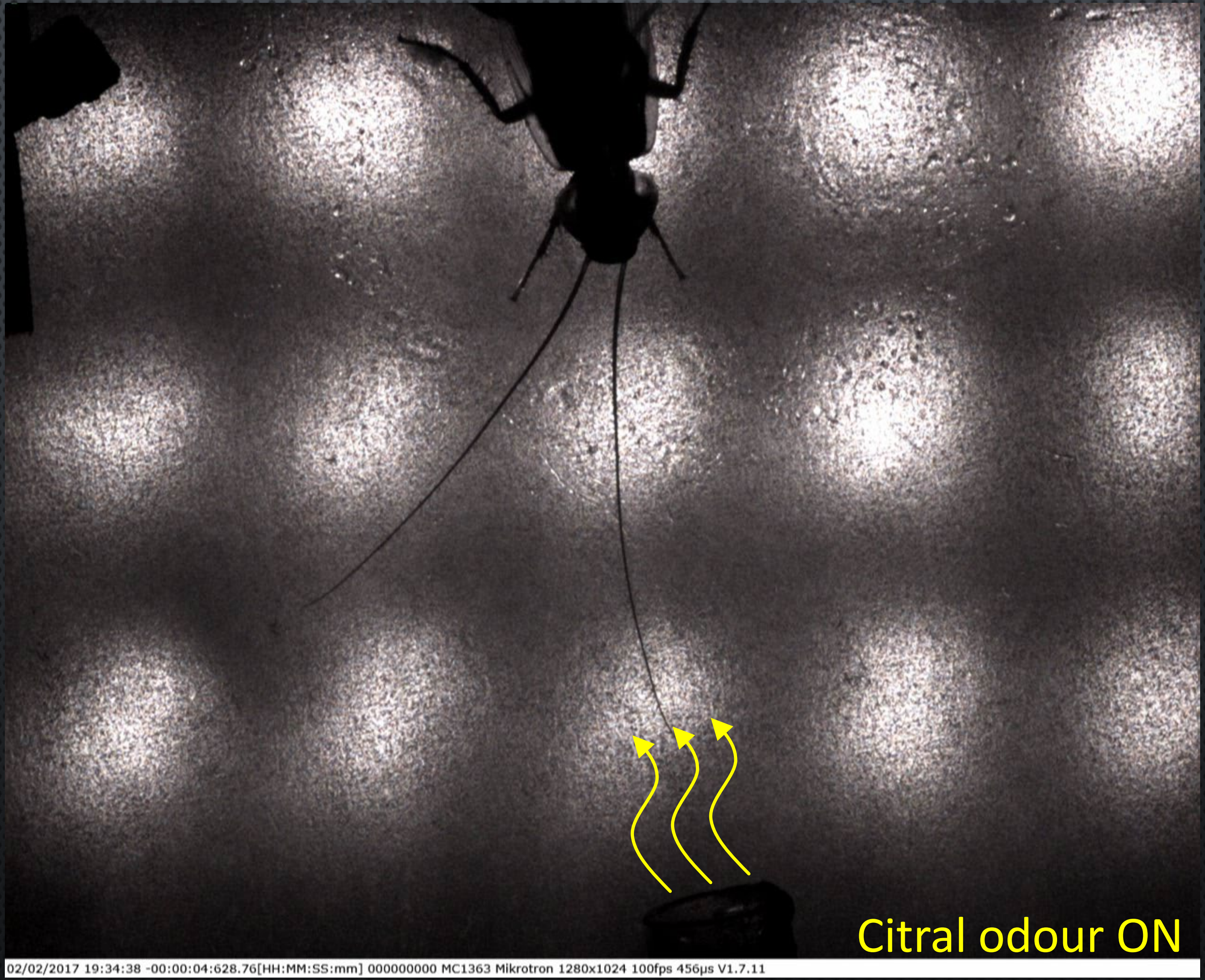
Case study 2

A cockroach-inspired gas leak localising robot

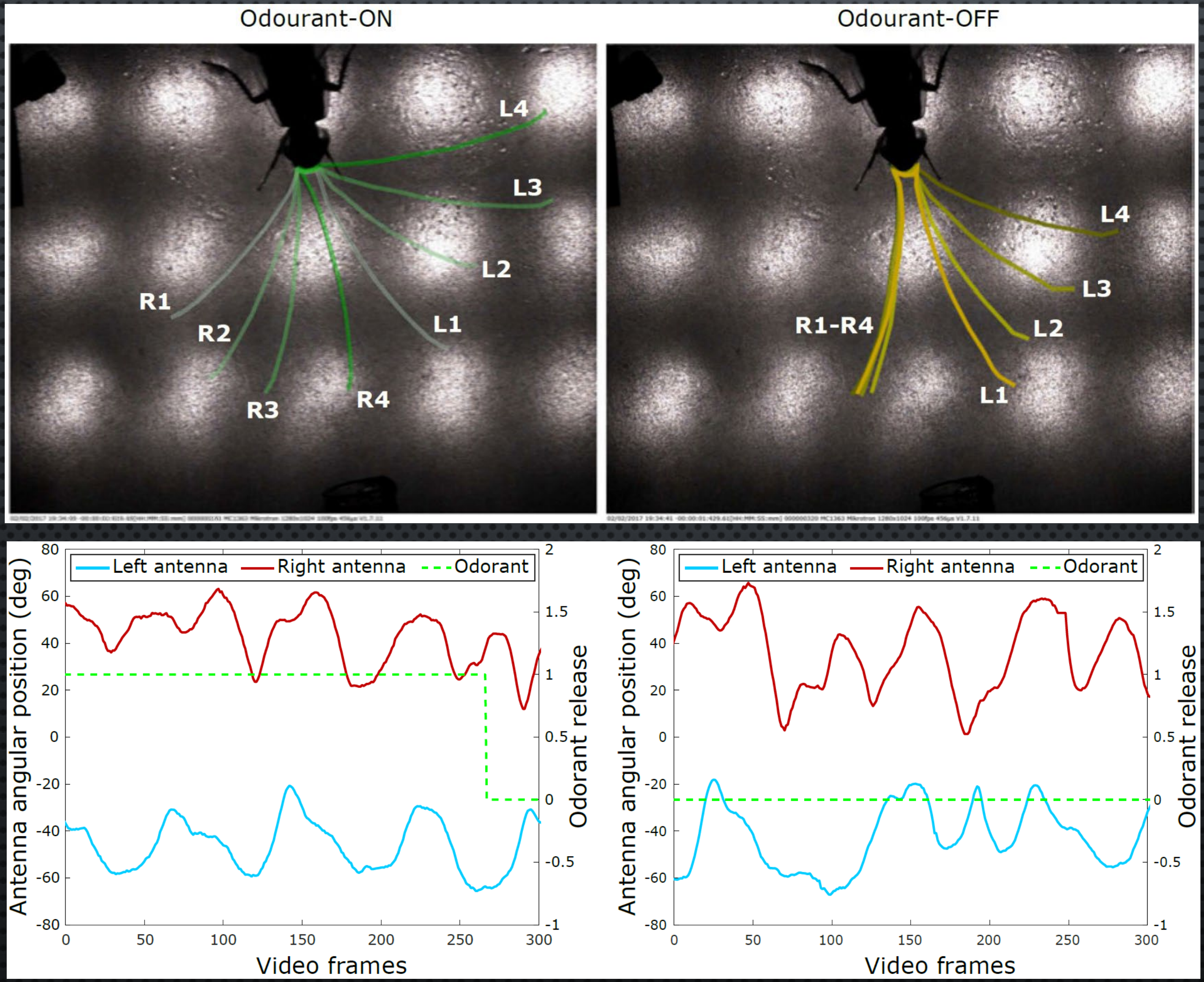
Cockroach olfaction

Observing the animal

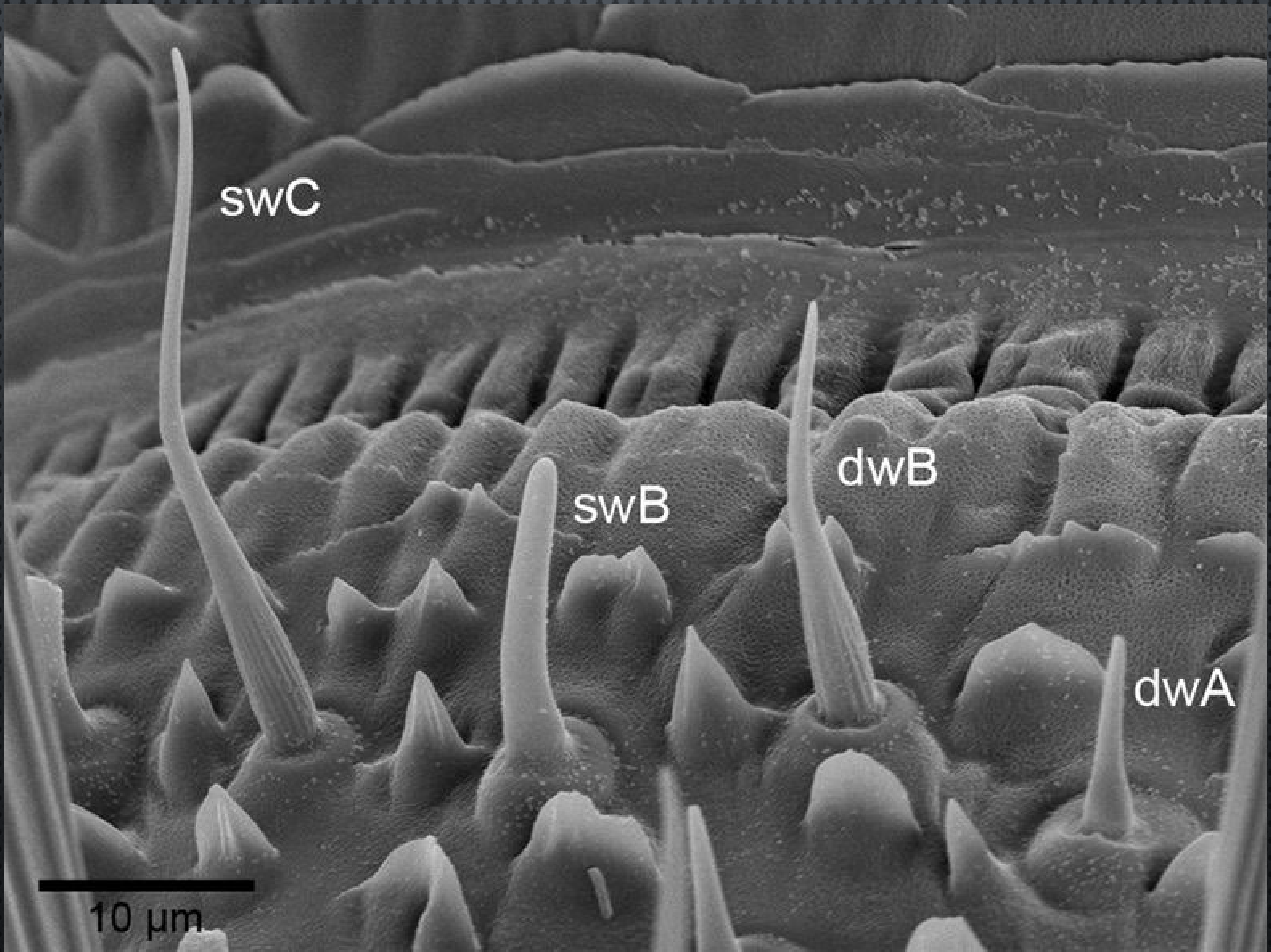
Antennal response to chemical odours



Antennal response to chemical odours

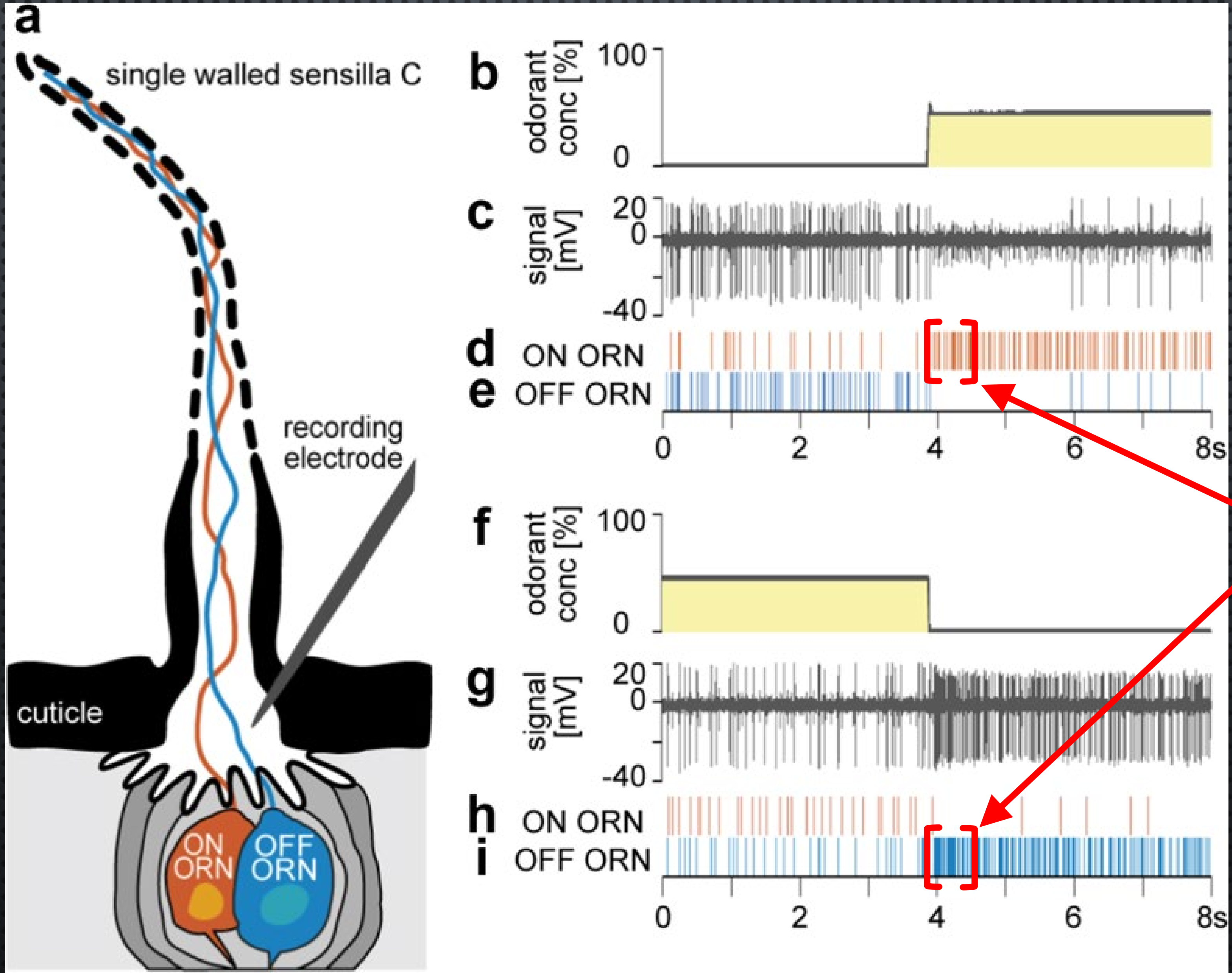


How do cockroaches smell?



Tichy & Hellwig, 2018

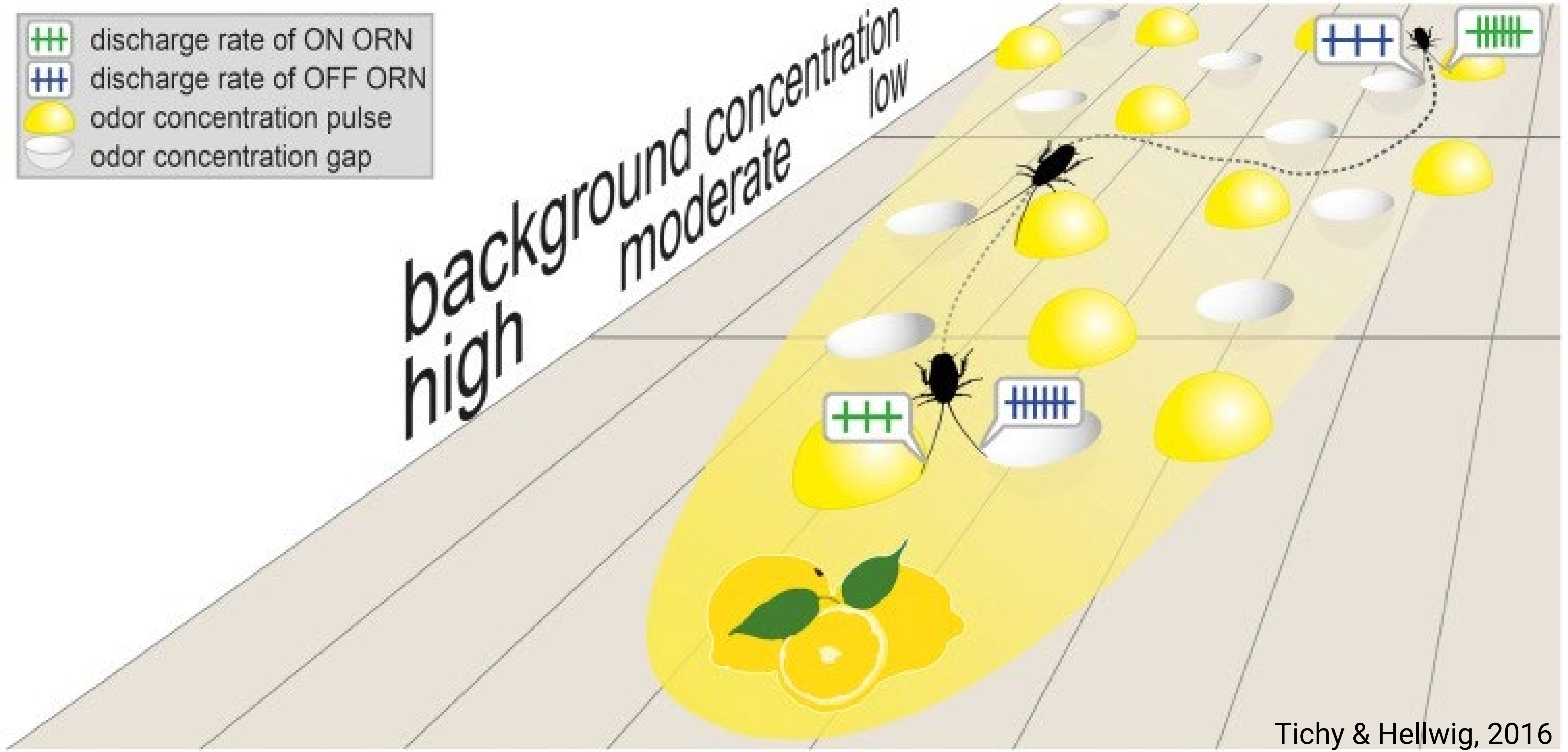
Olfactory neurons (ORNs) encode odour concentration gradient



Highest spiking due to odour gradient

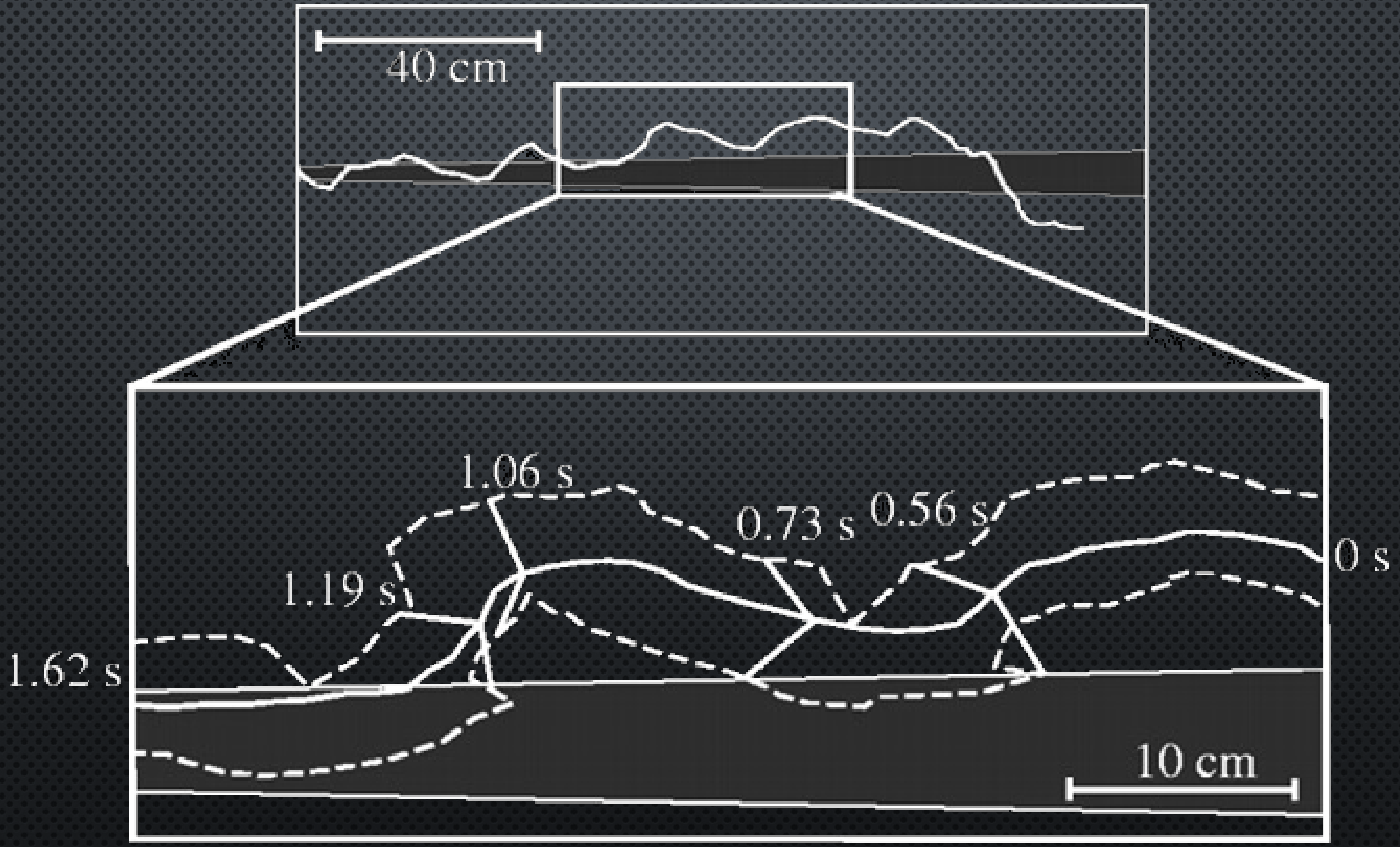
Tichy & Hellwig, 2018

From neurons to behaviour: a hypothesis



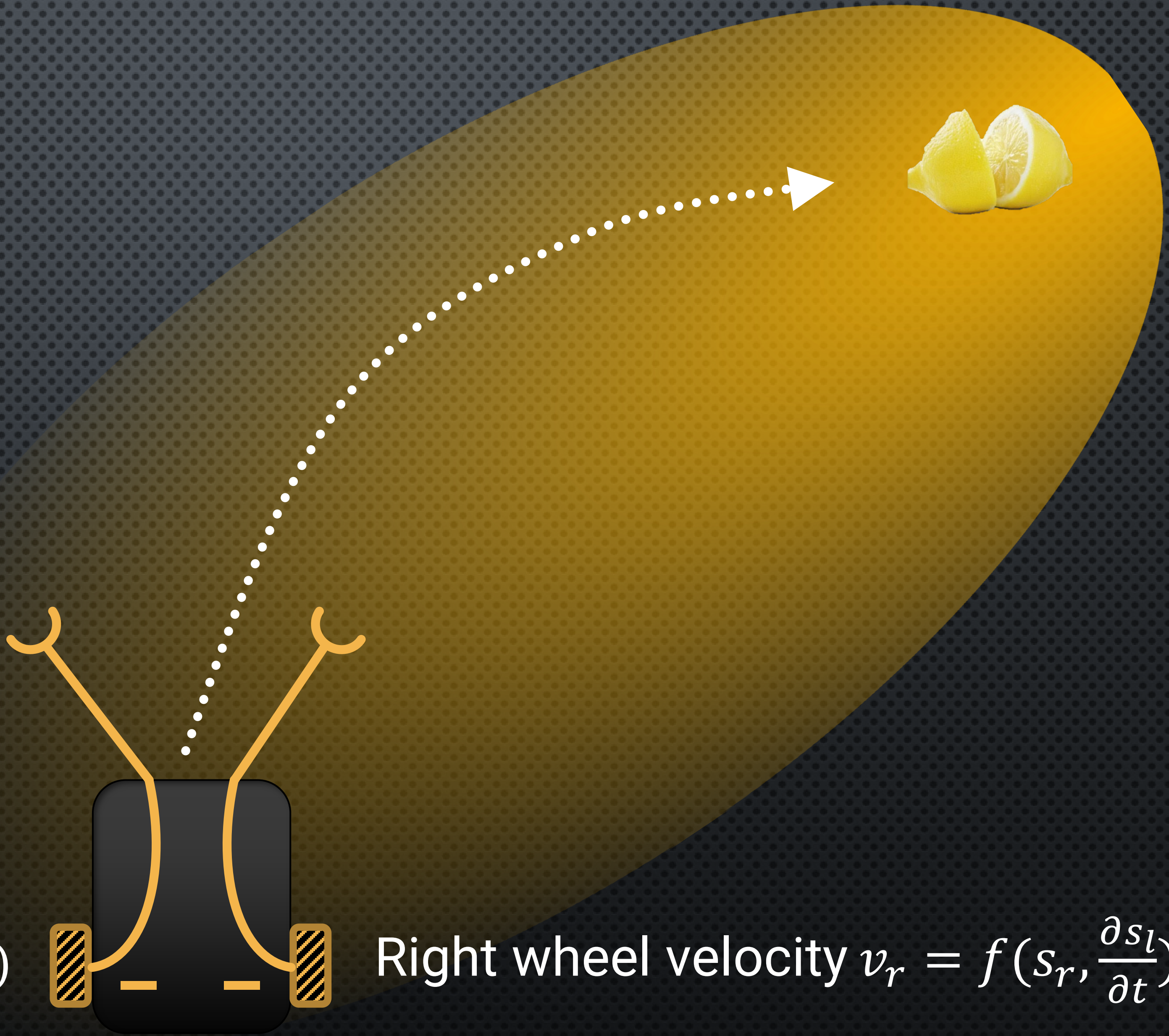
Tichy & Hellwig, 2016

Biological cockroach trajectories



Willis & Avondet, 2005

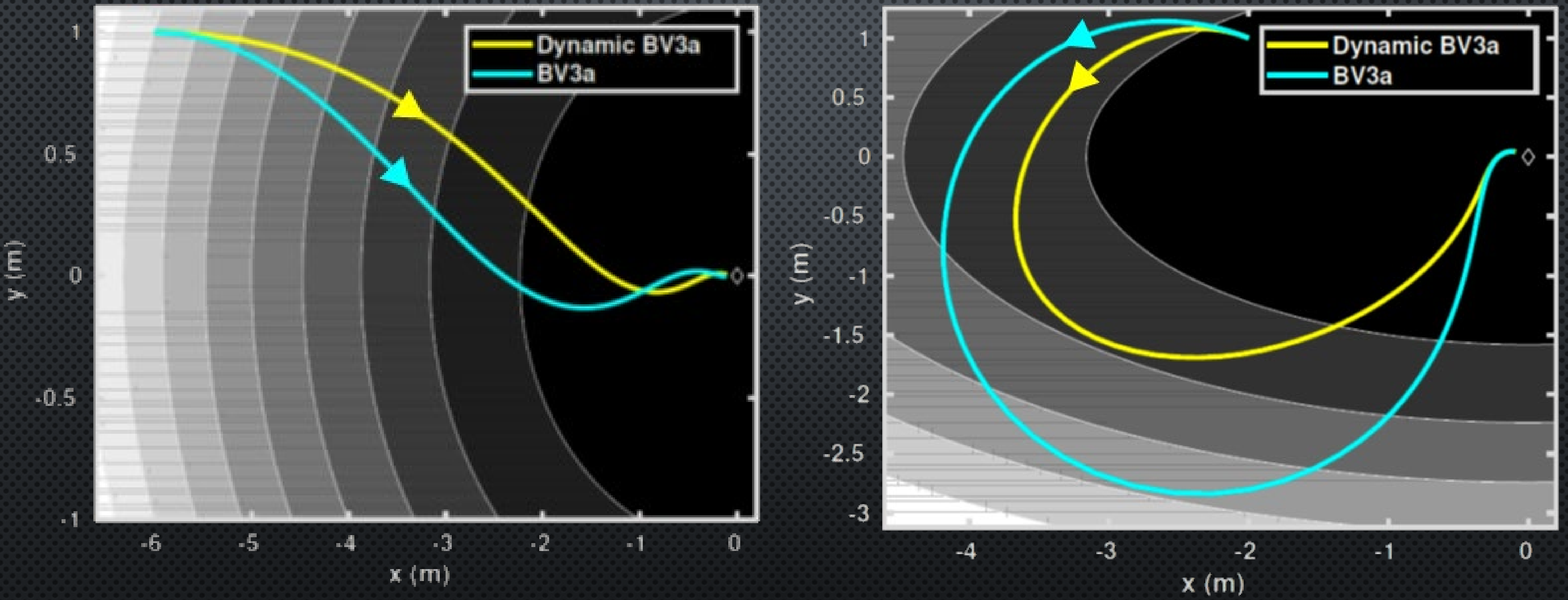
A Braitenberg model for odour localisation (static antennae)



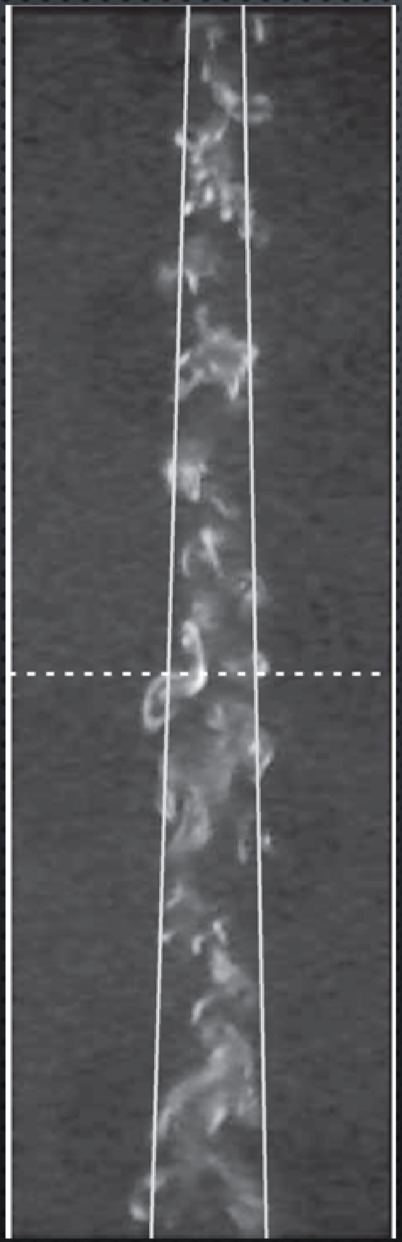
Left wheel velocity $v_l = f(s_l, \frac{\partial s_r}{\partial t})$

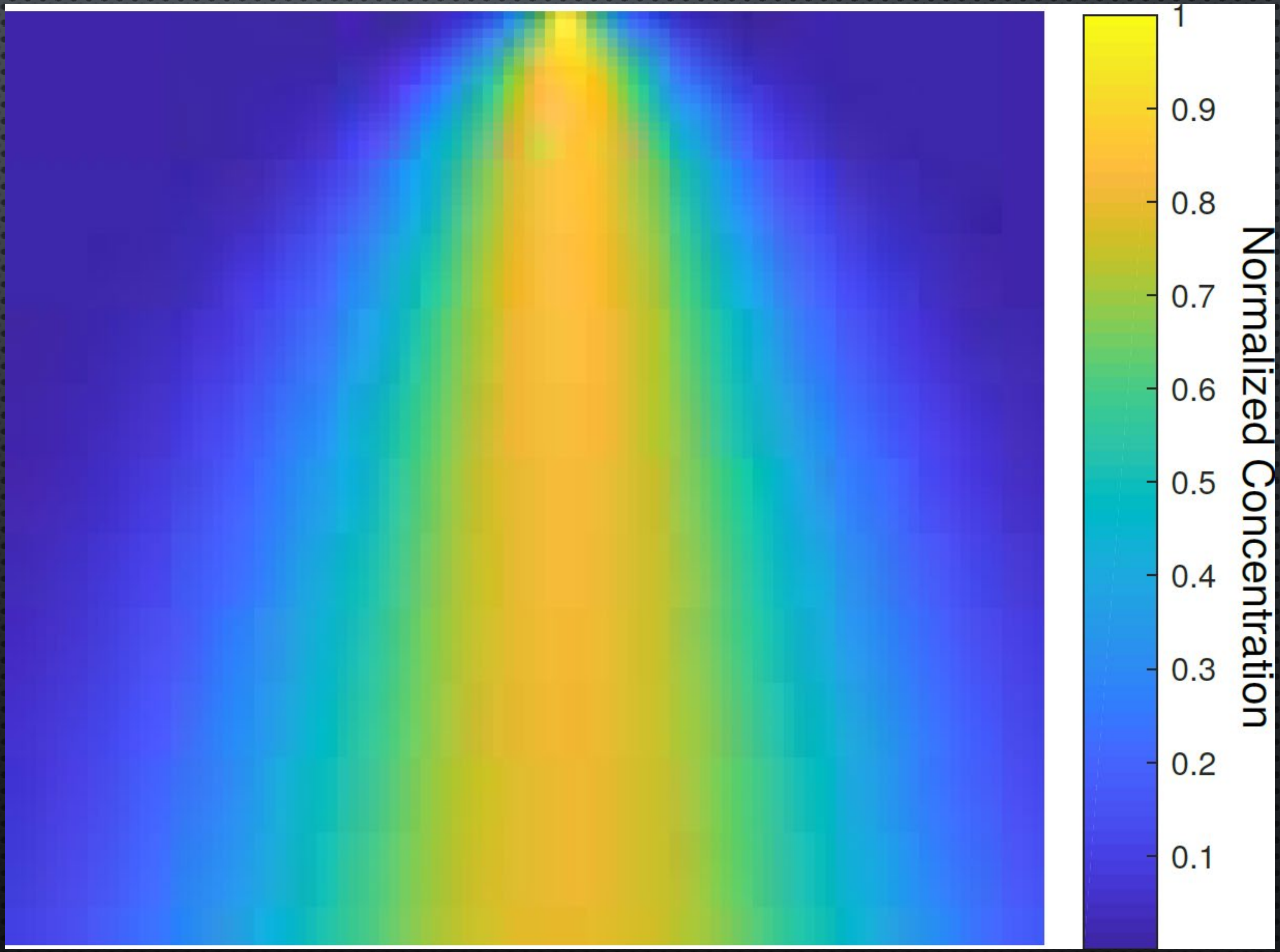
Right wheel velocity $v_r = f(s_r, \frac{\partial s_l}{\partial t})$

Taxis with and without stimulus dynamics (static antennae)



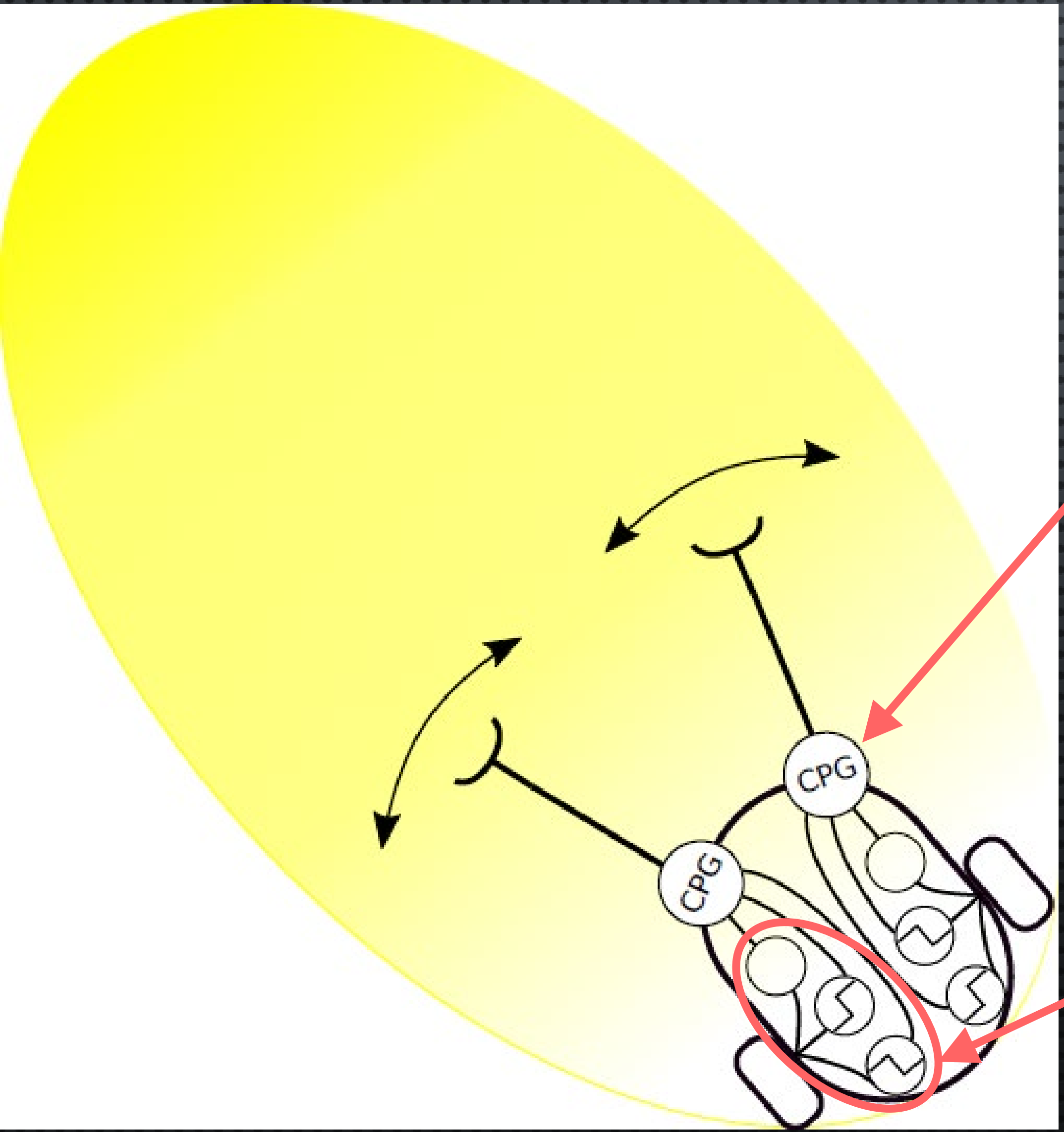
Task environment





Willis, 2008

A Braitenberg model for odour localisation (moving antennae)



$$\dot{u} = (\mu^2 - r) \cdot x + \omega y$$
$$\dot{v} = (\mu^2 - r) \cdot y + \omega x$$
$$r = (x^2 + y^2)$$

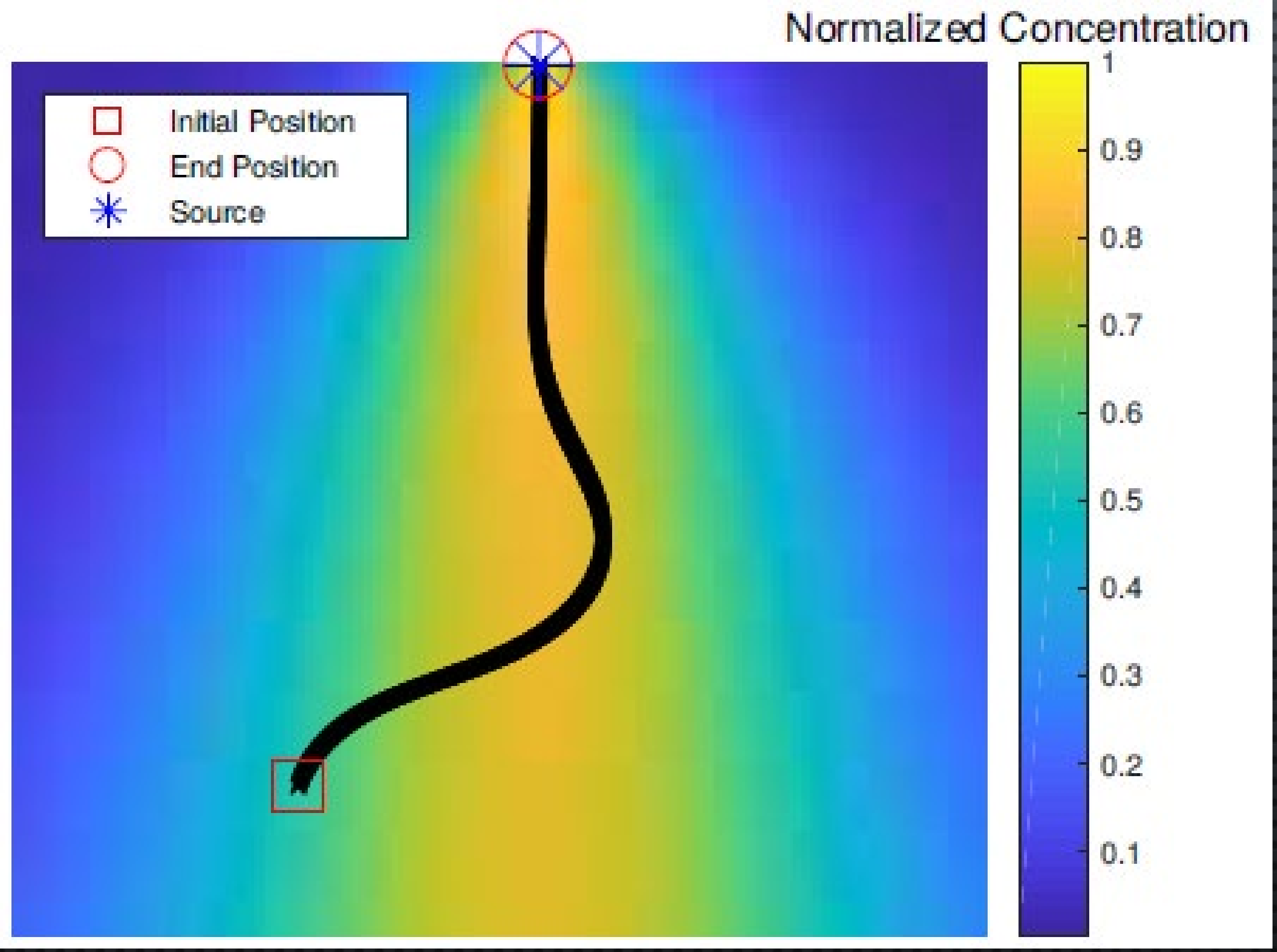
Antenna CPG parameters:
μ = steady state amplitude
$\omega = 2\pi f$ = angular velocity

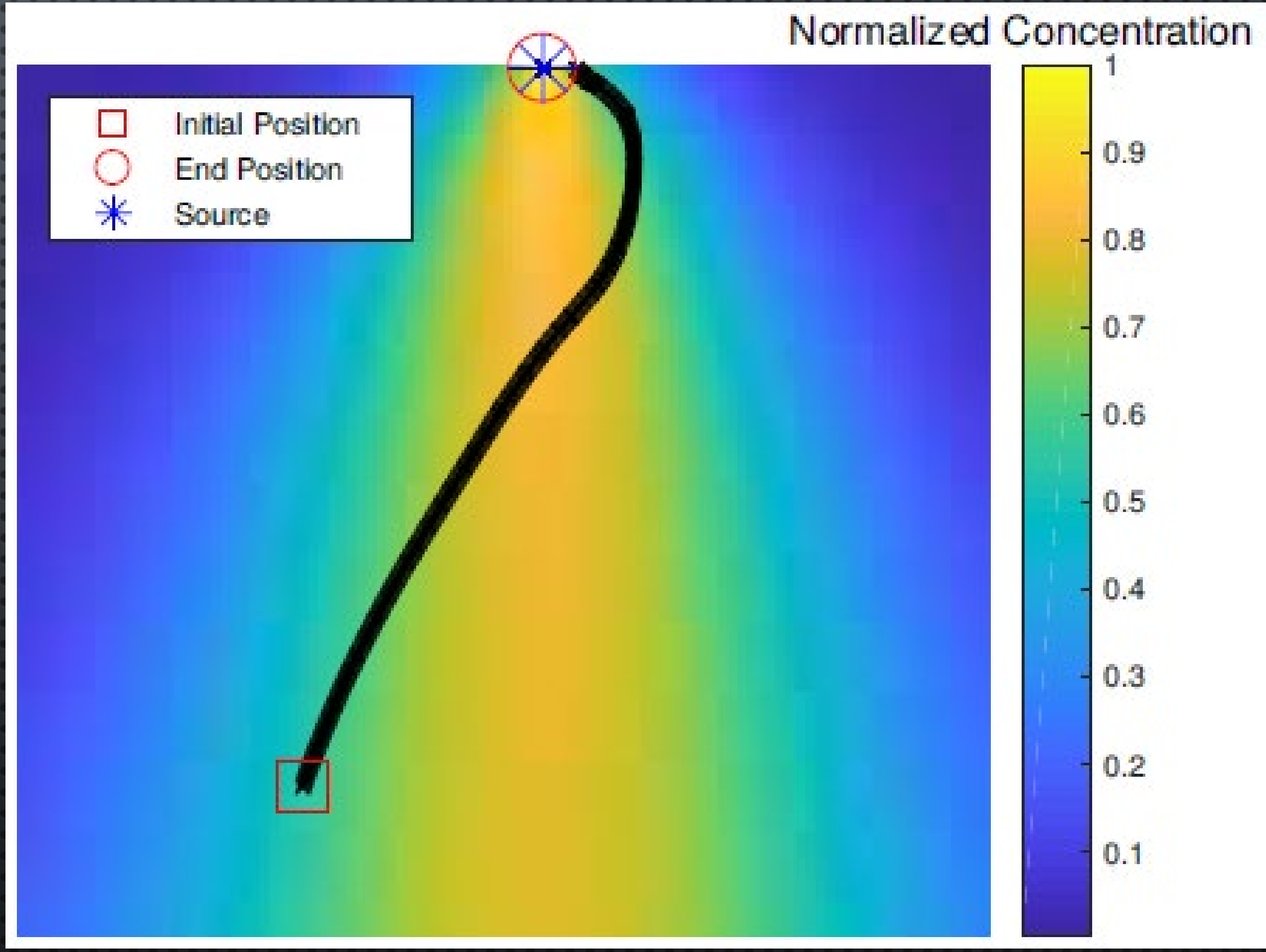
$c_{l/r}$ = instantaneous odour concentration
$s_{l/r}$ = total stimulus
$v_{l/r}$ = wheel velocity
$f(\dot{c}_{r/l})$ = Heaviside step function (ON neuron model)
$f(-\dot{c}_{r/l})$ = Heaviside step function (OFF neuron model)

$$c_{l/r} = \mathrm{C}\,(x_{l/r}\,, y_{l/r})$$
$$s_{l/r} = K_n c_{l/r} + K_d f(-\dot{c}_{r/l}) + K_i f(\dot{c}_{r/l})$$
$$v_{l/r} = \alpha(s_M - s_{l/r})$$

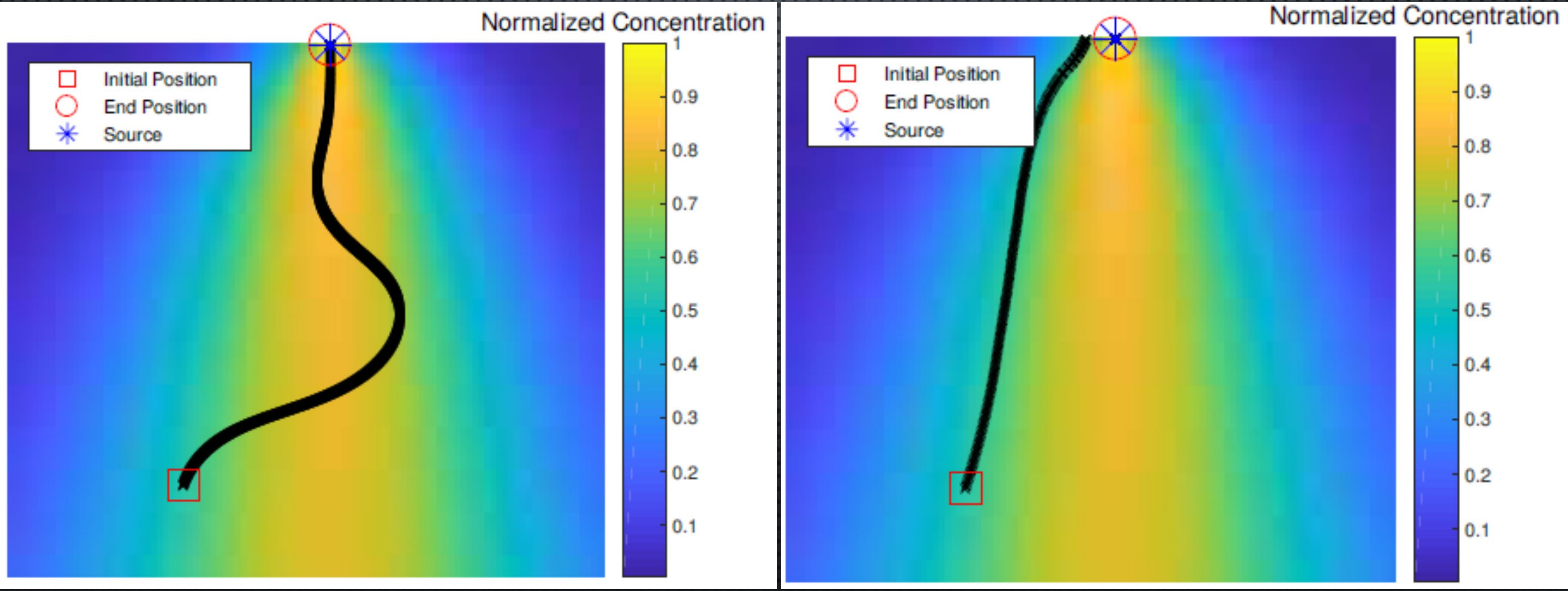
Sensorimotor coupling parameters:
α = gain term
s_M = maximum stimulus
K_n, K_d, K_i = gain terms

Localising odour source (static antennae)





Localising odour source (moving antennae)



Matlab exercises

- Download “braitenberg_gradient.m”

- Implement various light following Braitenberg vehicles and observe their behaviour

- Vary parameters and observe behaviour
  - *sensor_width*
  - *add_noise* and *snr_db*
  - *robot_pose*