Sensing and Perception

Aim

- To control their movement, robots need to sense their internal state or the relevant variables in the external world (feedback)
- To move around and carry out tasks, robots need to perceive their environment

- **Sensing** and **perception** are the backbone processes allowing this
  - Some robot sensors are inspired by biological sensors (cameras/eyes, microphones/ears, sonar/bats. . .)
  - Some perception mechanism are inspired by biological perception (Deep CNN/Cortical Visual Areas)

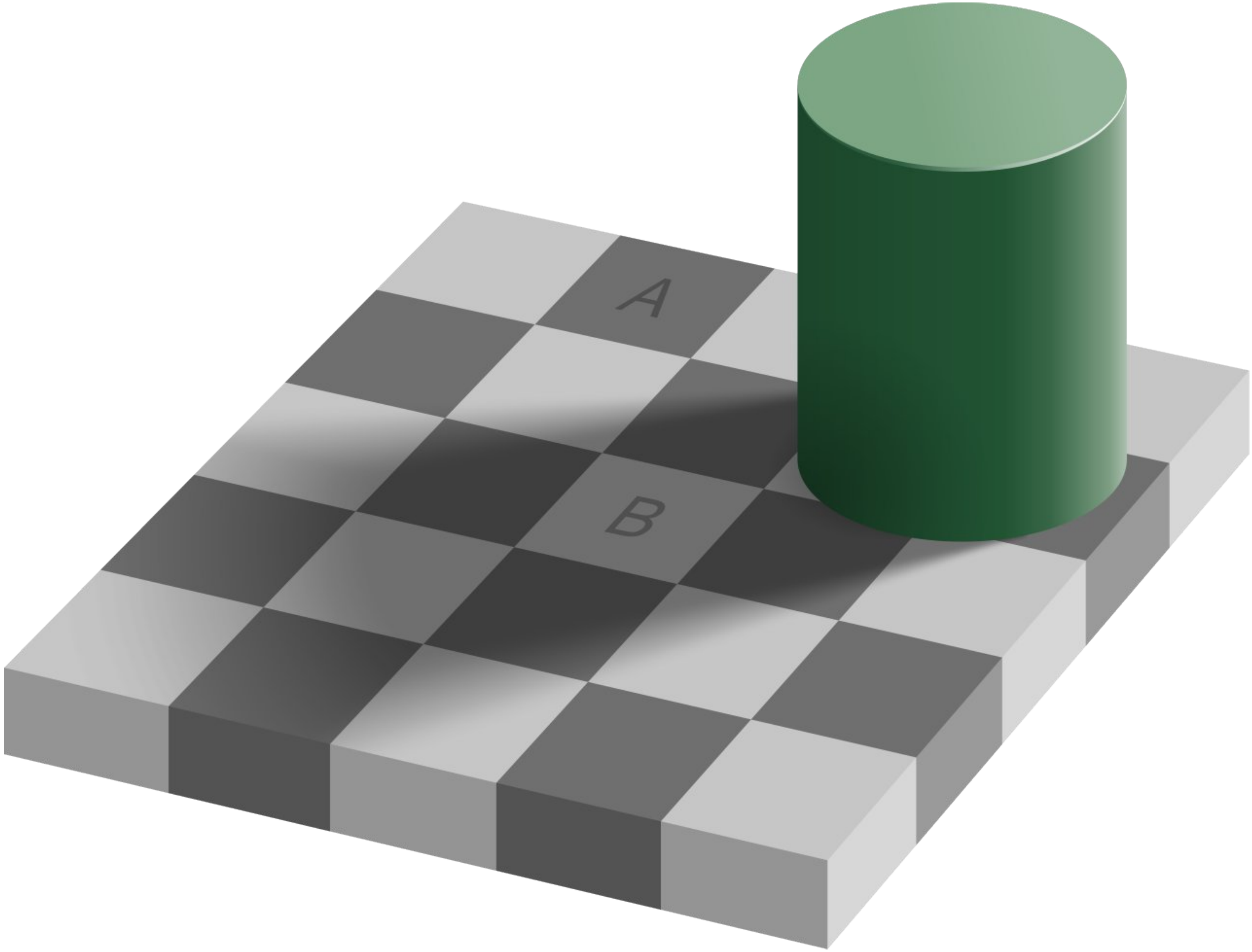
Sensing

- Sensing is the process of acquiring ‘data’/information from the outside world (sometimes own body)
  - In animals this is done through specialised organs
  - Organs convert stimuli into electrical signals
  - . . . but often also include ‘signal processing’ stages
- Sensing organs in humans:
  - Eyes (sense of sight)
  - Ears (audition)
  - Skin, muscles and tendons (somatosensory)
  - Nose (sense of smell)
- Some animals have specialised sensing organs, e.g.:
  - Snakes (infrared/thermal radiation)
  - Platypus (electroreception)
  - Bats (echo location)

Perception

Is the process of selecting, organizing and interpreting the data/information acquired by the sensing organs

- This process is done by the brain (nervous system) in humans
- Part of the processing can be done in the sensing organ (e.g. human eye 260M photoreceptors, 2M ganglion cells in the optic nerve)
- Perception is not purely based on sensing information (experience, context, processing. . .)
- A significant amount of information needs to be discarded:
    - Compression
    - Attention
    - Prediction


A
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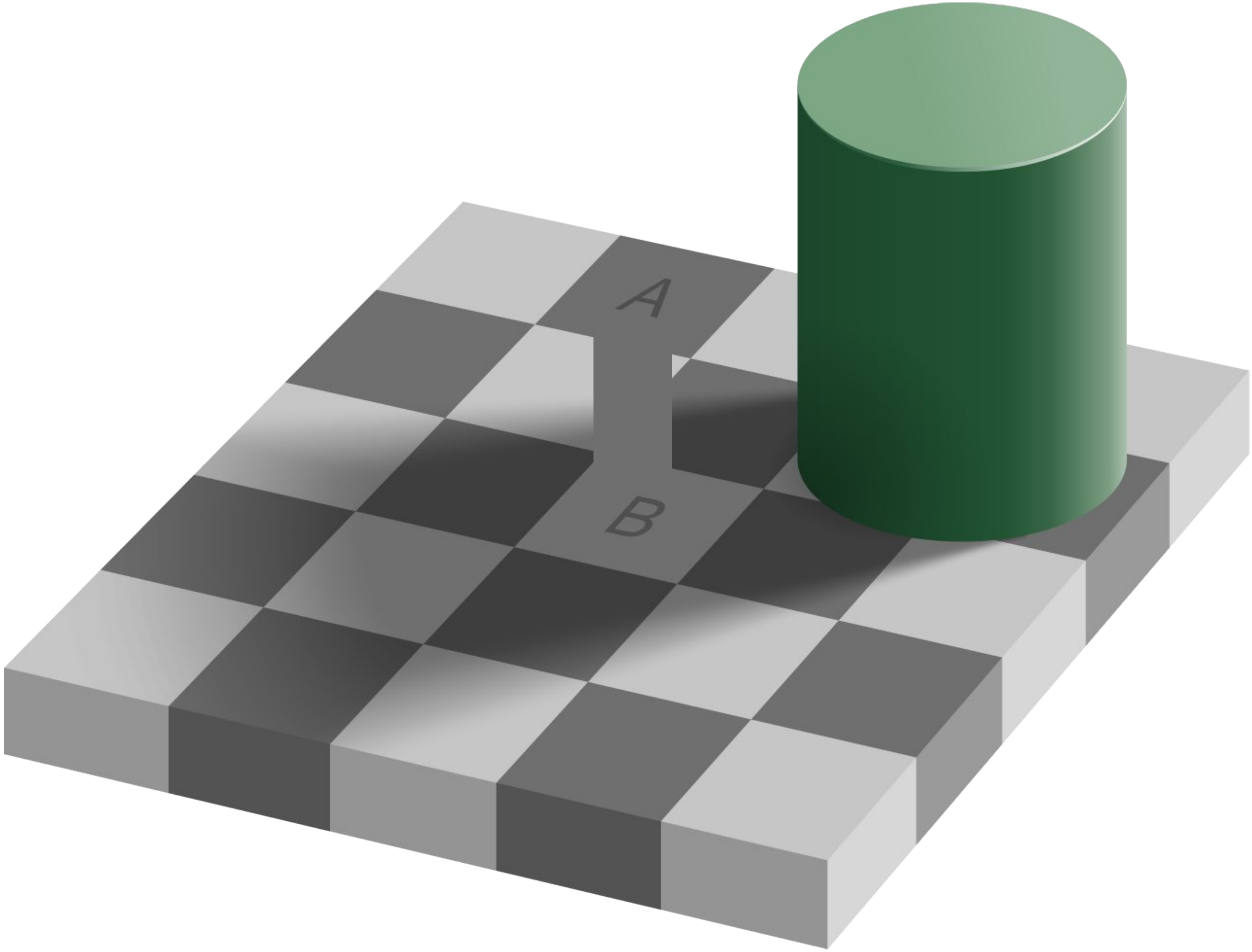
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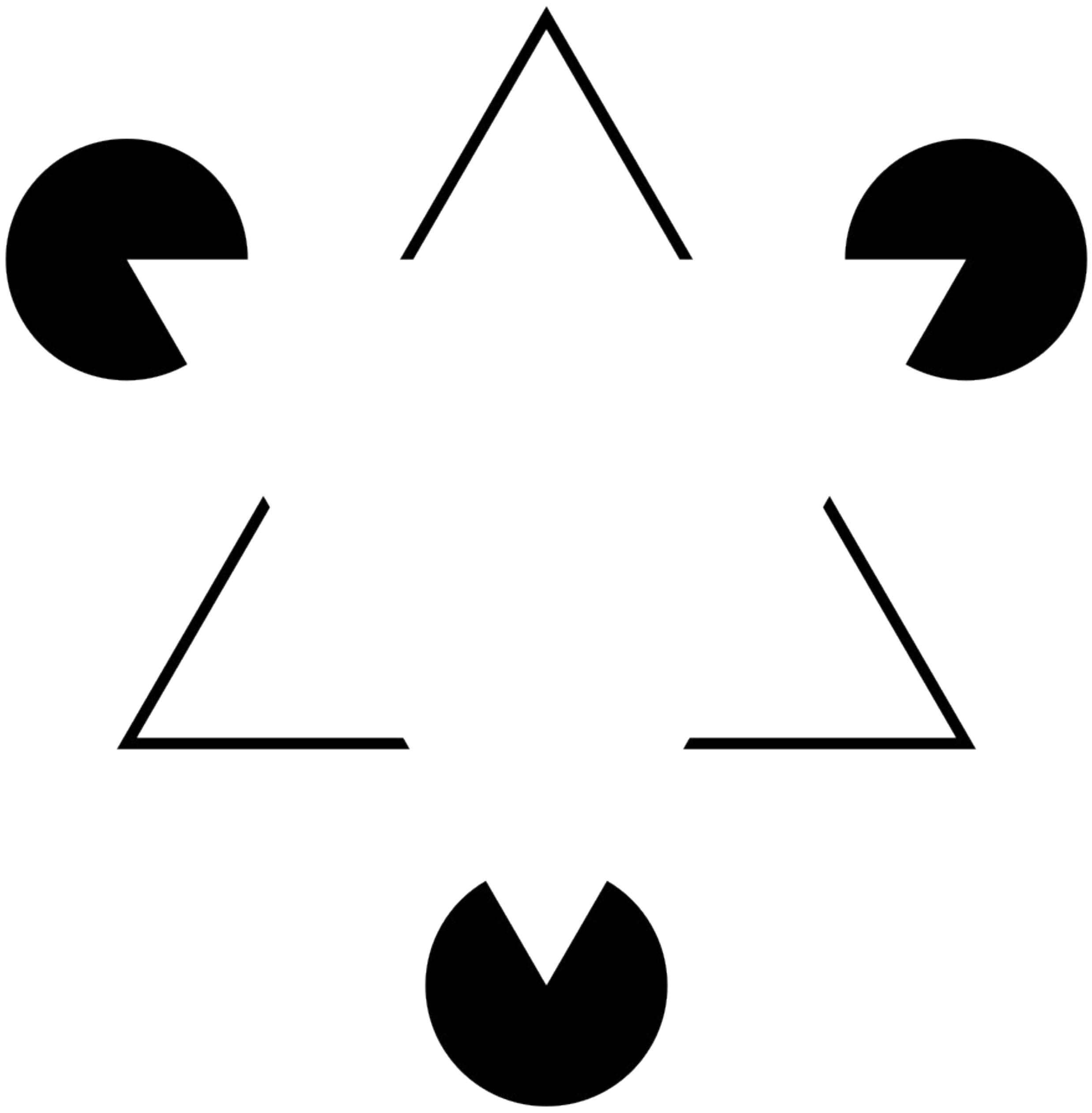
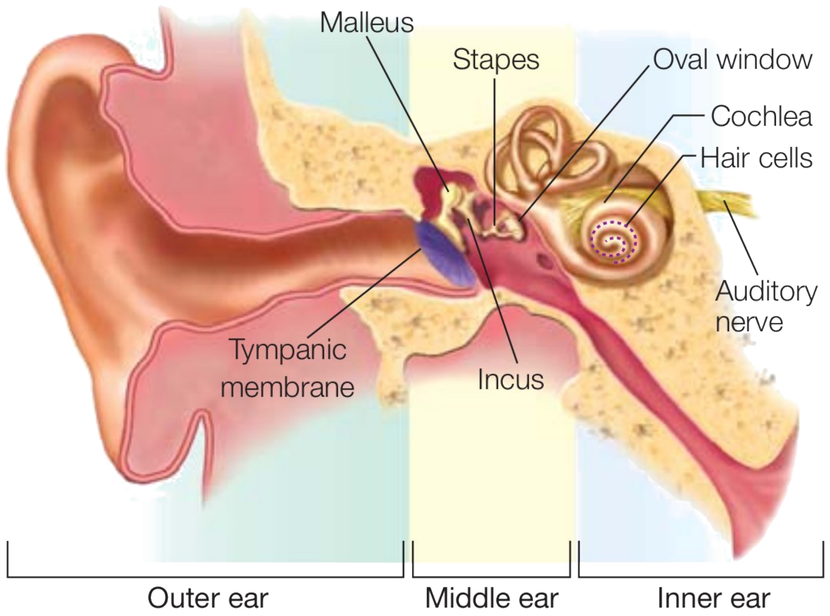




- Pinna collects & directs sound
- Eardrum oscillates following the air
- Small bones transfer vibrations
- Cochlea's inner fluid vibrates
- Hair cells code for sound frequency (from 20Hz to 20000 Hz depending on the position in the cochlea)

The cochlea send signals to the nervous system

- Mechanical waves turned into electrical signals (like microphones)
- Spectral decomposition is done in the cochlea (vs. one signal from microphones)

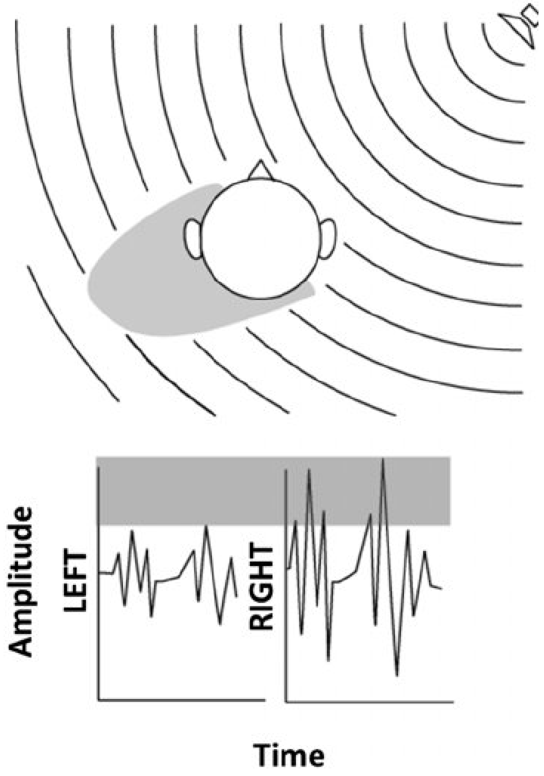
Purpose of Audition

What is audition used for by animals and humans?

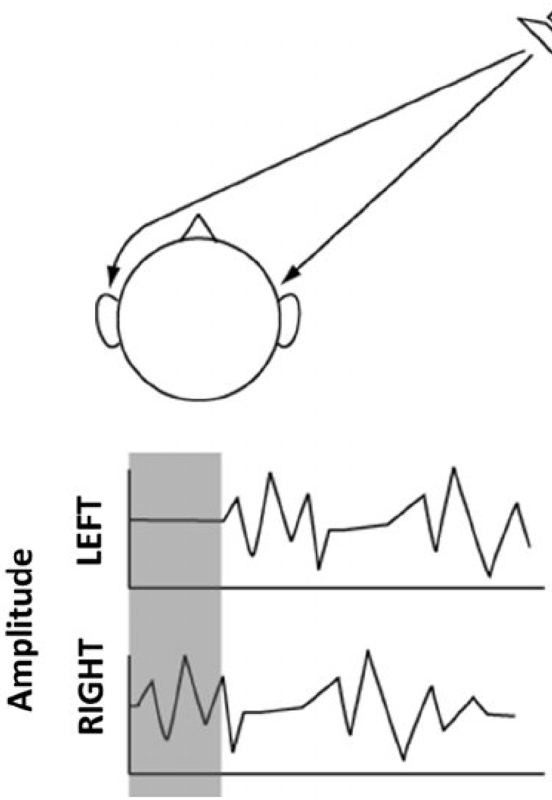
- Sound localisation: Identify the location of a sound-producing object
  - Direction identification: e.g. phonotaxis (navigation towards/away the sound)
  - Environment mapping: e.g. echolocation in bats, dolphins, whales and even some blind humans (https://www.youtube.com/watch?v=2IKT2akh0Ng)
- Sound recognition: Identify the nature of sound-producing objects
  - Speech recognition in humans
  - Object identification: e.g. insect identification by bats

Biological Strategies for Sound Localization (1/3)

Interaural Level Difference (**ILD**)

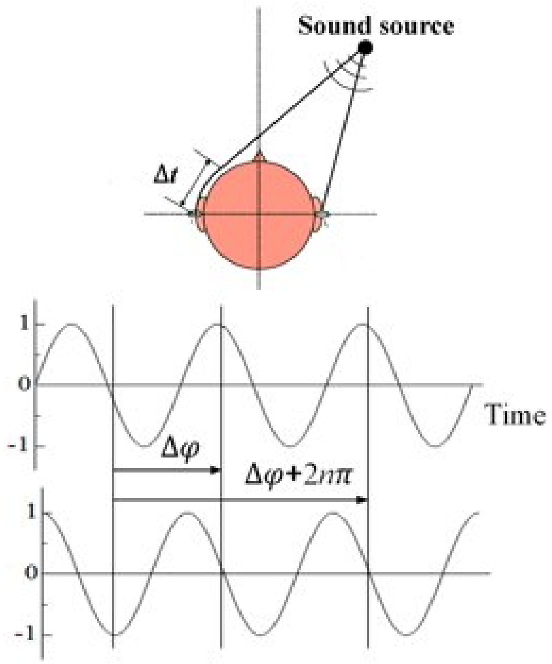


Interaural Time Difference (**ITD**)



Biological Strategies for Sound Localization (2/3)

- Interaural Phase Difference (**IPD**)



Biological Strategies for Sound Localization (3/3)

Brain uses ILD, ITD, and IPD used to find the orientation of a sound source, but

- Orientation in 2D, i.e. cannot resolve the height of the sound source
- Front-back ambiguity, i.e. cannot resolve full range

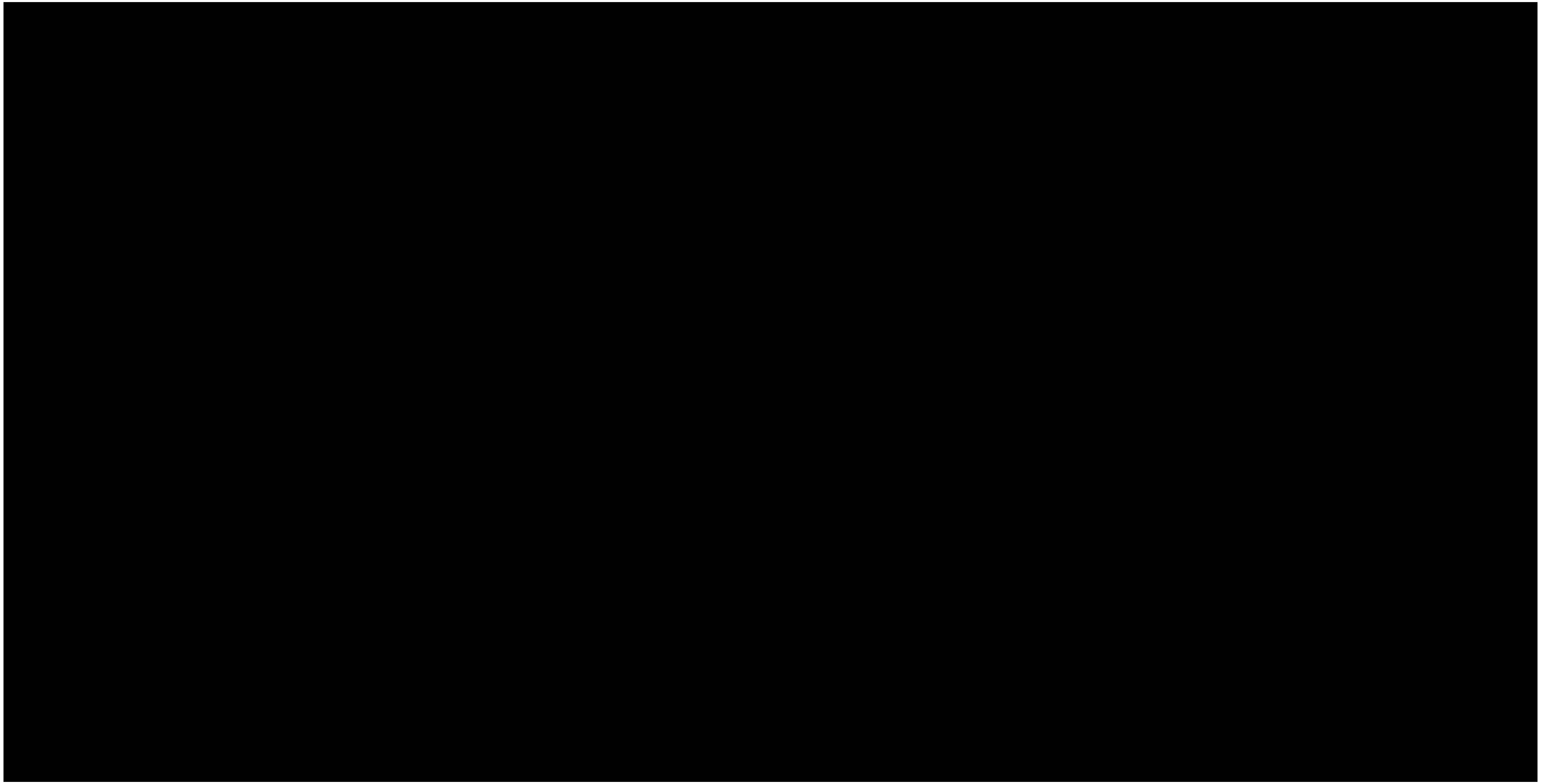
In humans these two issues are solved thanks to the pinnae and the use of spectral cues.

- Pinna (unique for each person) reflects sound towards the ear
- Attenuation higher for back sound source
- Spectral cues of the sound resolve height (3D) https://www.youtube.com/watch?v=-nAGXmUi6j0

Psikharpax: Phonotaxis Rat

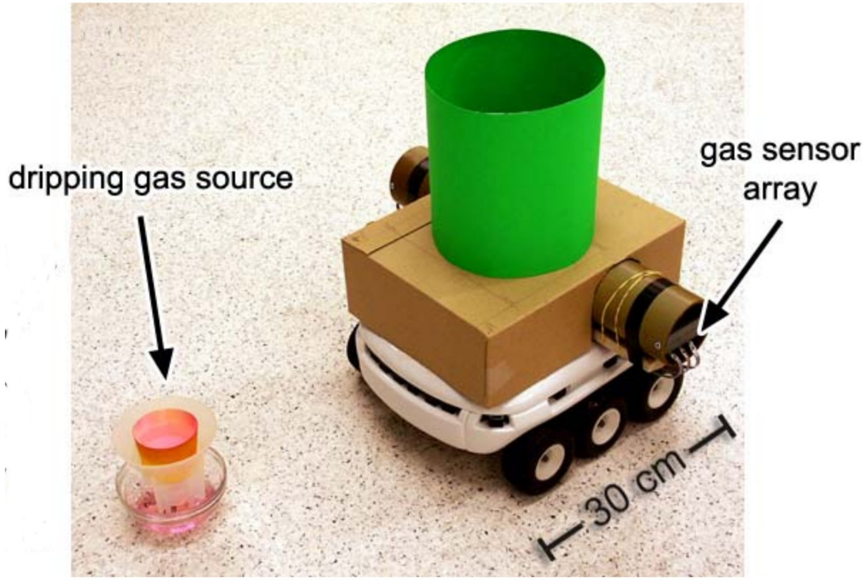
- Artificial rat with bio-inspired audition for sound source localization
- Mobile pinnae with microphones controlled to maximize sound energy
- Wheeled base and turning neck
- Cochlear model output converted into spikes
- Interaural Level Difference in the energy of the spikes

Bernard et al. “Phonotaxis Behaviour in the Artificial Rat Psikharpax” Proc. of IRIS2010



https://www.youtube.com/watch?v=zhrk4egCTJU

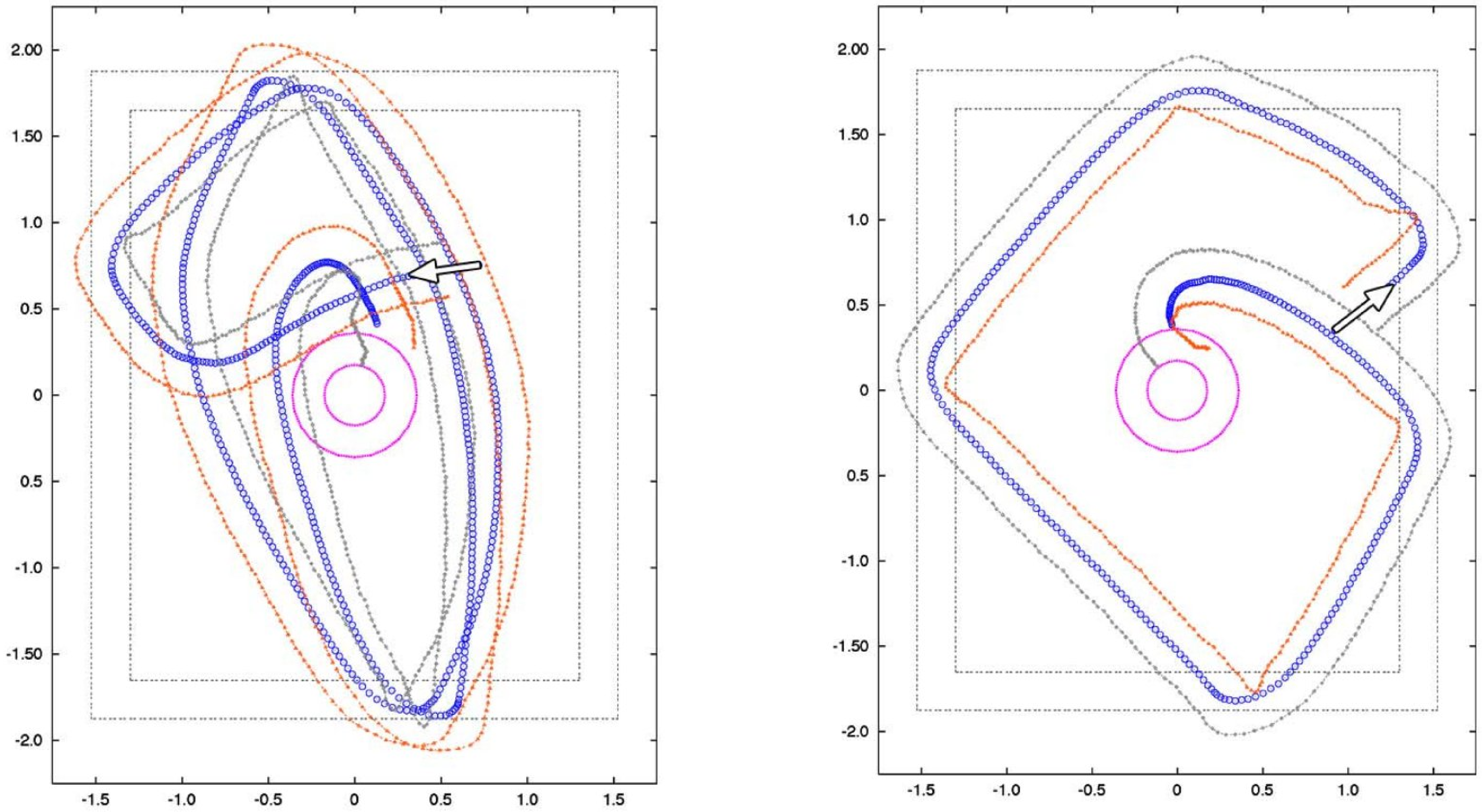
Olfaction (1/4)



Mobile robot with two chemical sensors

- Response time 1.8 sec
- Recovery time: ≈ 11 sec
- Sensory processing:
  - Normalisation
  - Averaging
  - Re-scaling range
- Two bio-inspired navigation strategies tested

Lilienthal et al. “Experimental analysis of gas-sensitive Braitenberg vehicles”. Advanced Robotics, 2004.



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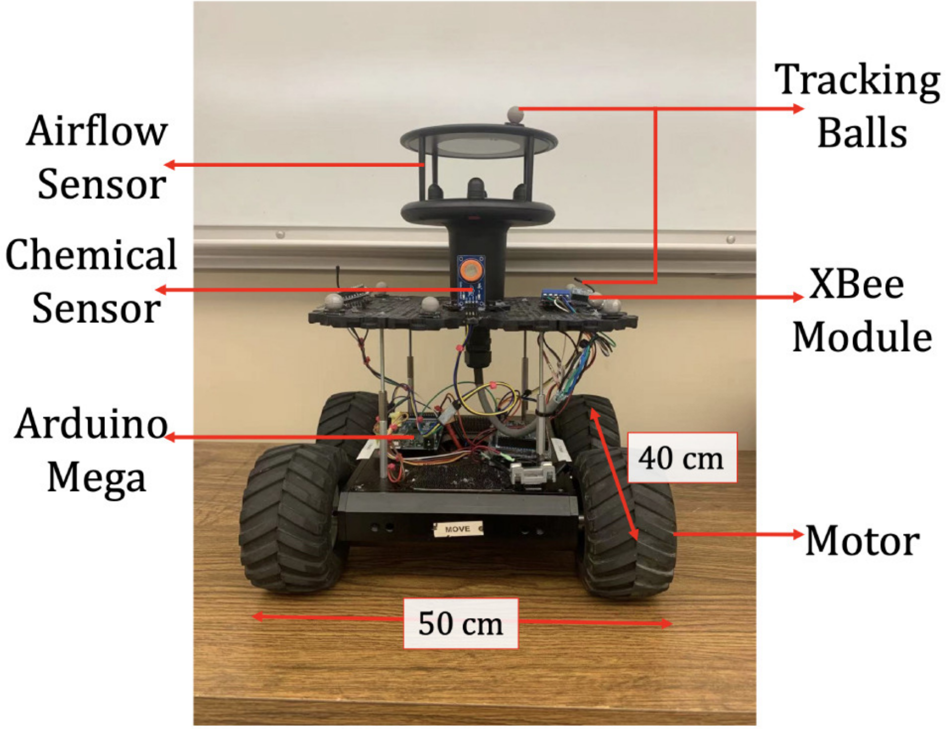
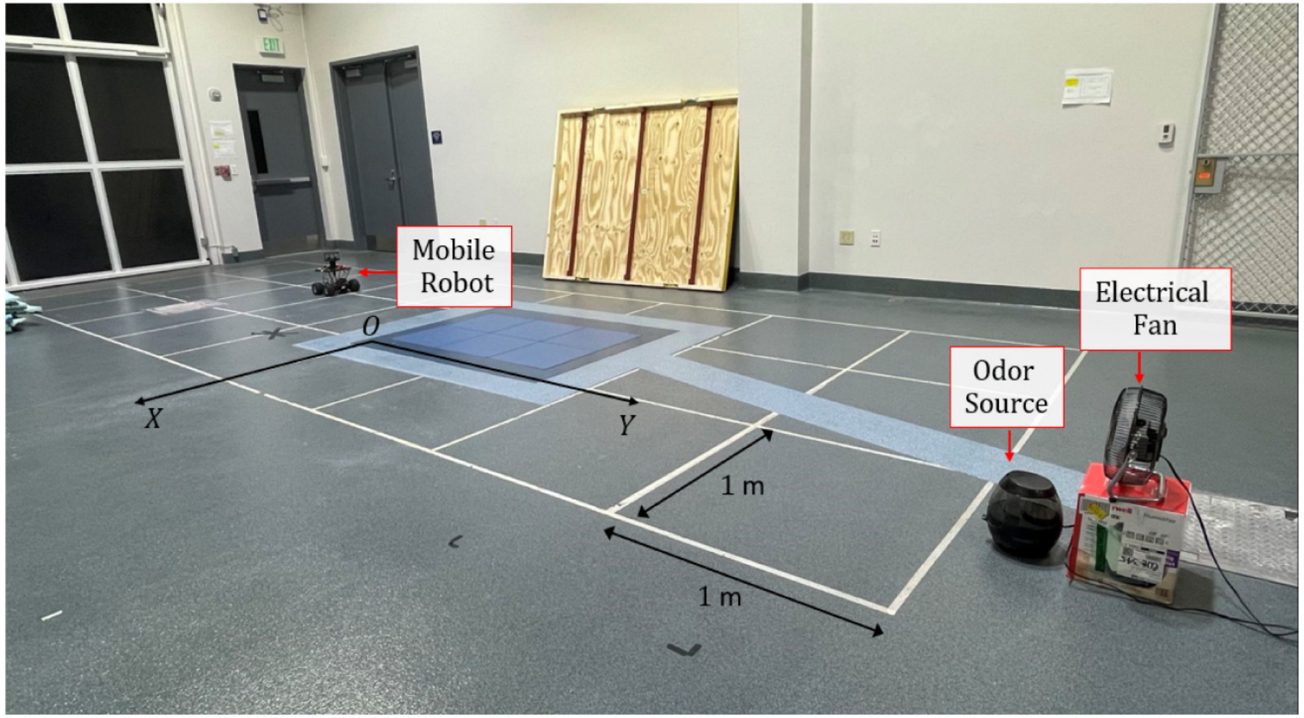
Olfaction (3/4)

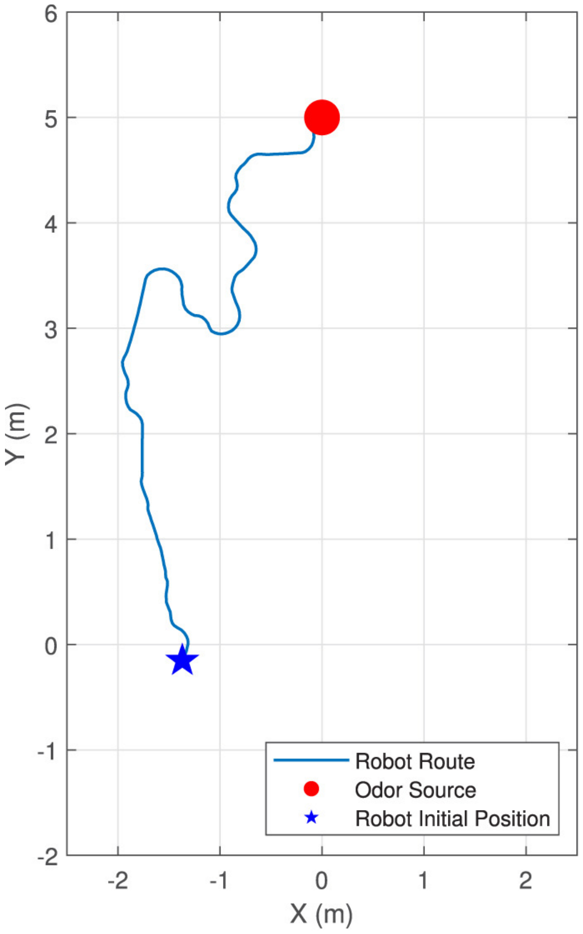


(a)

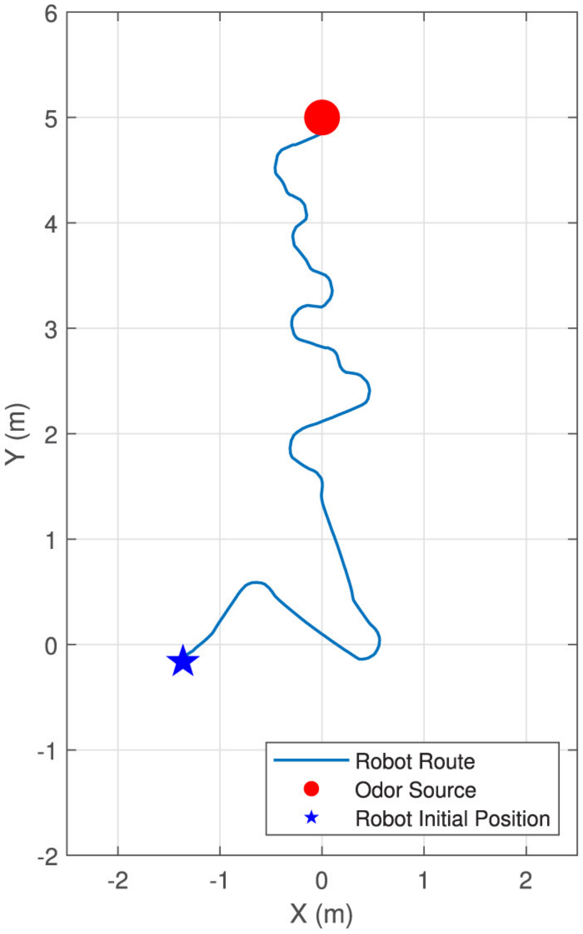


(b)

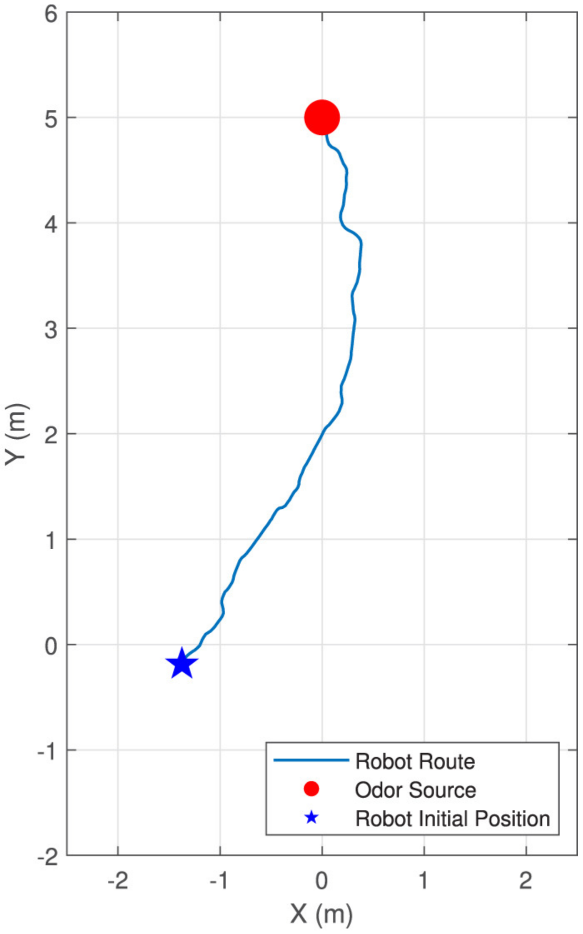
Wang, Lingxiao, and Shuo Pang. "Robotic odor source localization via adaptive bio-inspired navigation using fuzzy inference methods." *Robotics and Autonomous Systems* 147 (2022): 103914.



Old bio-inspired method

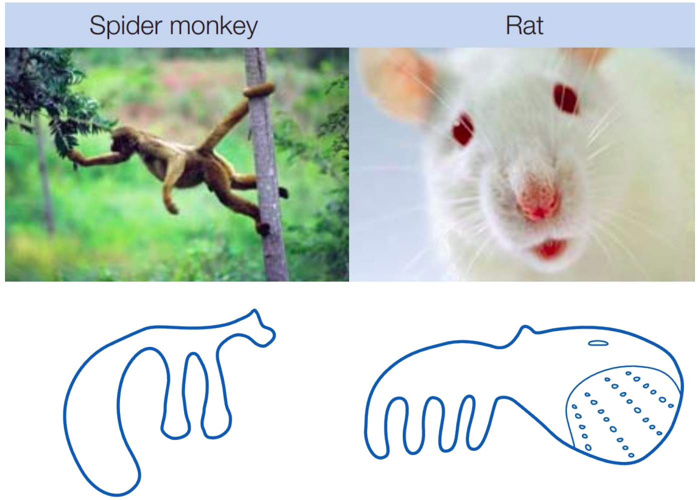


Engineering-based method (model-based reinforcement learning and fuzzy inference)



New adaptive bio-inspired method

Somatosensory Perception



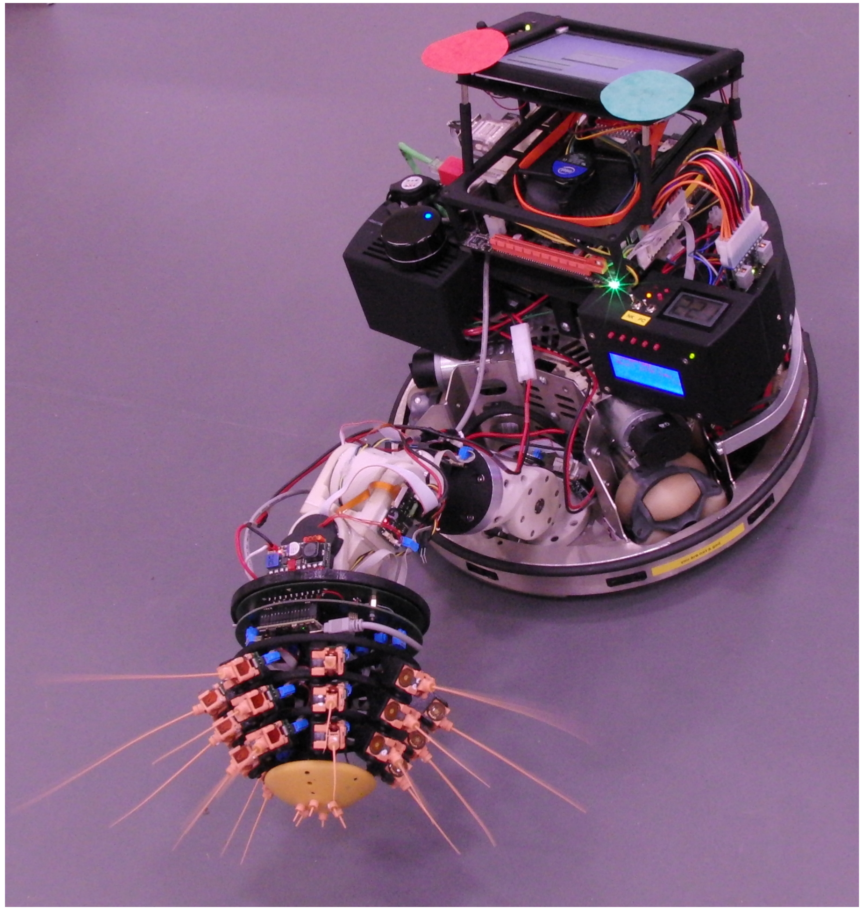
Somatosensory Perception:

- Touch (Skin) contact, pressure, temperature and pain
- Proprioception (musculoskeletal junctions) state of muscles and limbs

Signals go through the spinal cord

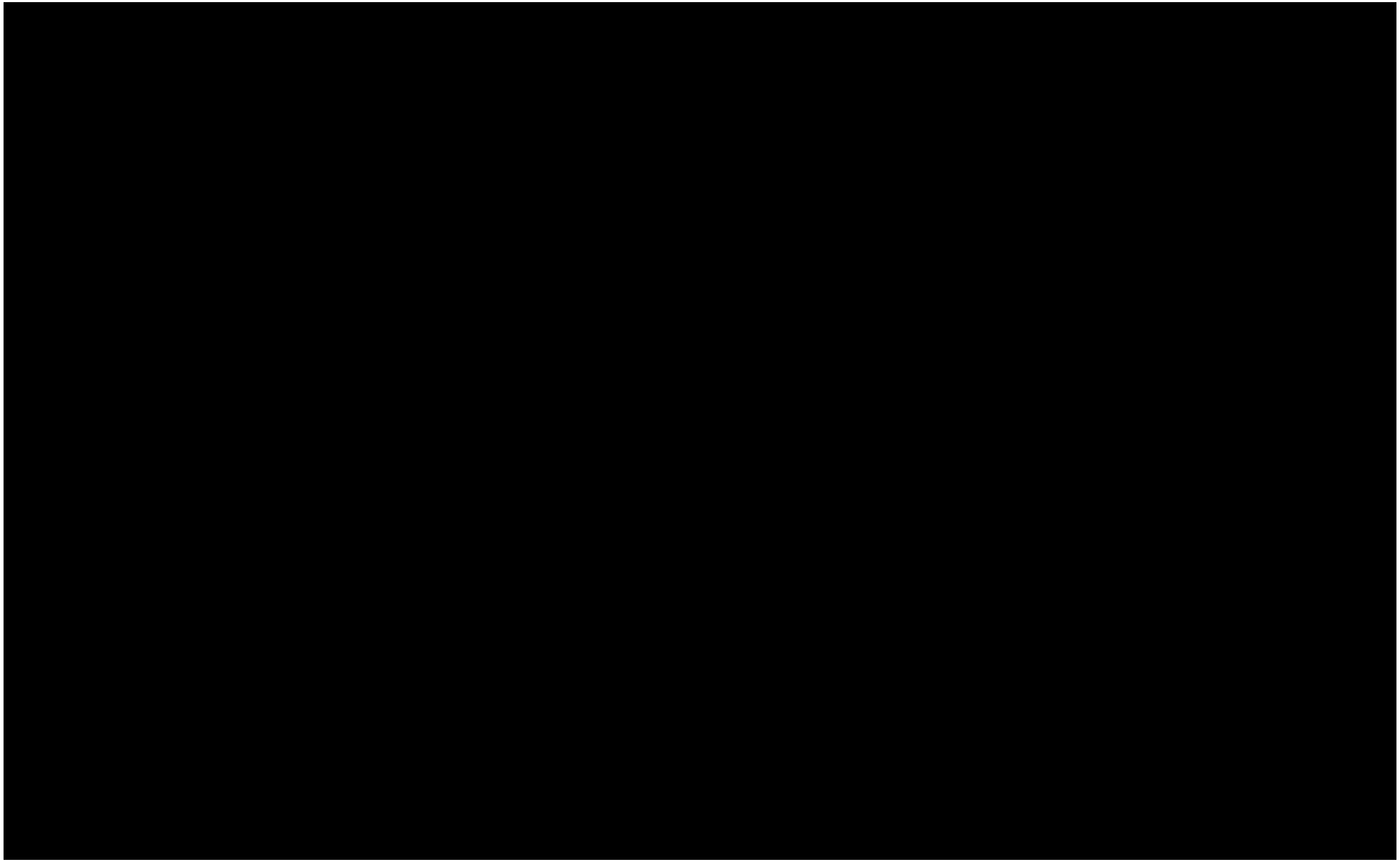
- Primary somatosensory cortex (S1); size related to importance (homunculus)
- Secondary somatosensory cortex (S2);
  - Builds complex representations (e.g. texture, size)
  - Signals from both sides of the body (unified)

Shrewbot



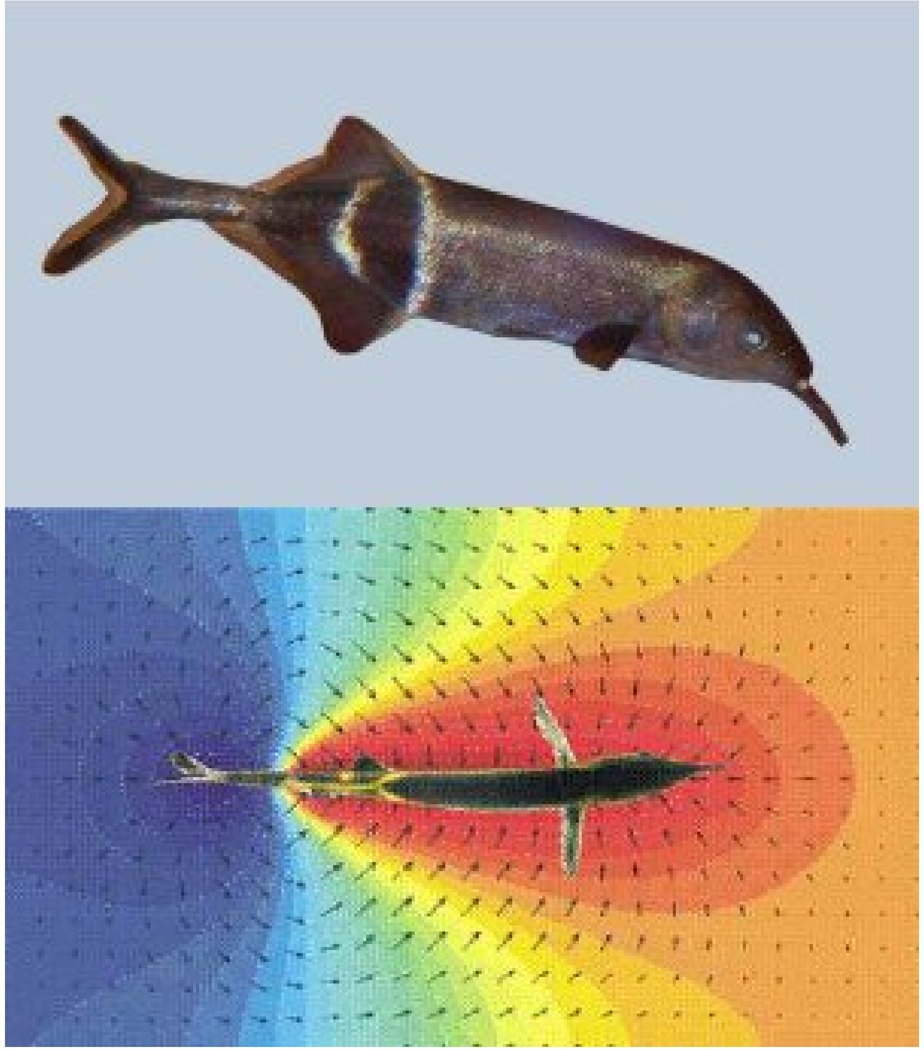
- Robot with 18 whiskers, oscillate every second
- Cheek angles can change
- Bioinspired hardware, not perception
- Cheek movement controlled through local 3D contact map
- Reconstruction of surface patches upon contact

Mitchinson et al “Perception of simple stimuli using sparse data from a tactile whisker array”, Living Machines, 2013



https://wyss.harvard.edu/media-post/3d-printing-soft-robots-with-embedded-sensors/

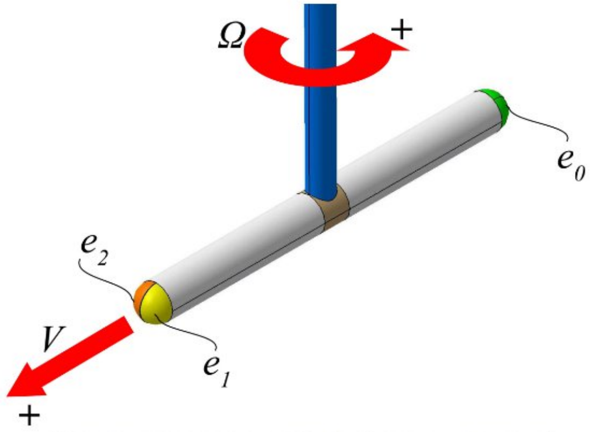
Electrosense

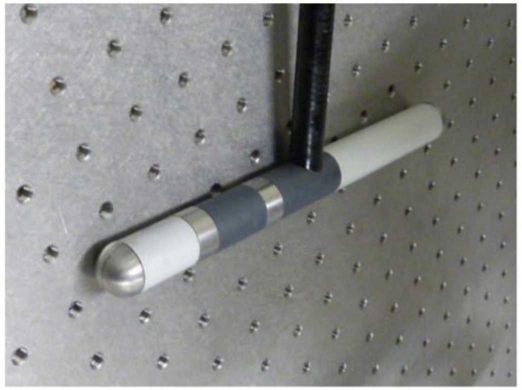


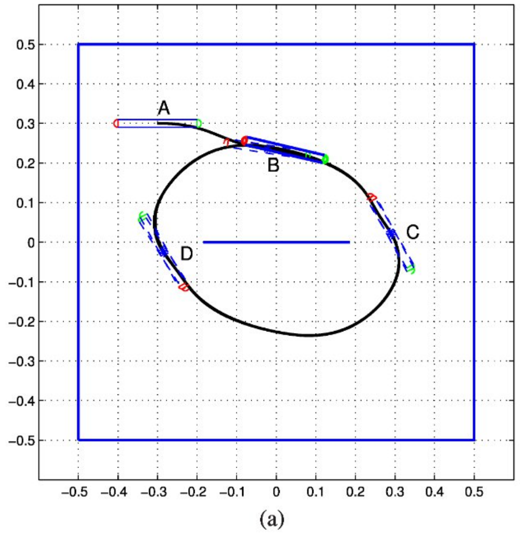
- Evolved independently in American and African fish
- Polarizes its body to create an electric field around
- Surrounding objects distort this field
- Electroreceptors measure field
- Perceives distortion on the electric field

Electrosense

- Electrodes on both sides of the body
- Analysis based on successive reflections
- Fish dipole polarizes object
- Object changes fish polarization
- Measures current (I) at the electrodes
- Currents on both sides (left/right) compared and used to steer the robot

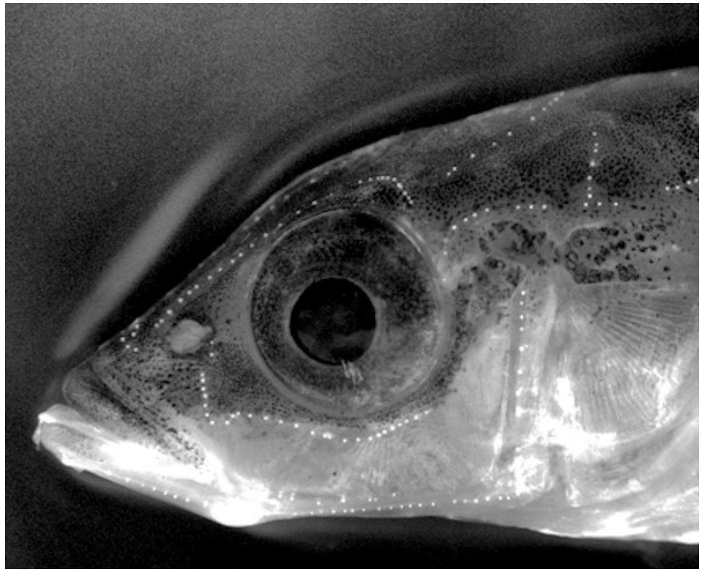


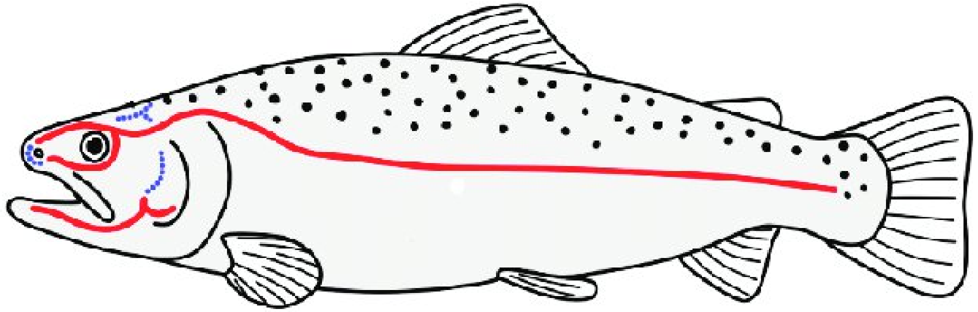




Boyer et al “Underwater Reflex Navigation in Confined Environment Based on Electric Sense”. IEEE T-Ro, 2013

Fish Lateral Line





Sensing organ in fish to detect

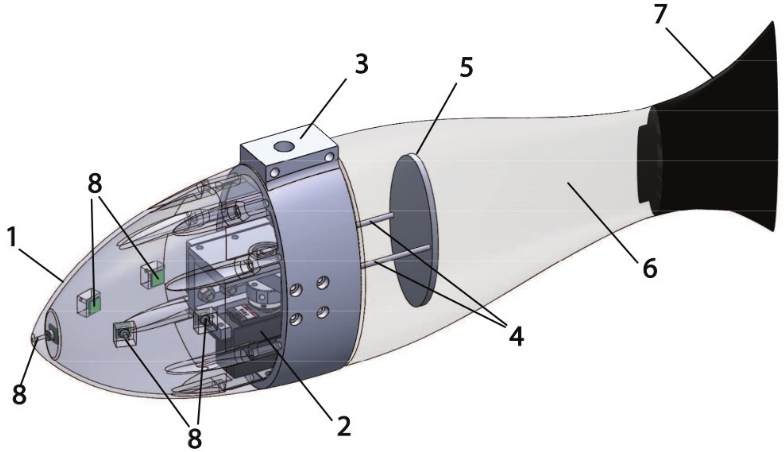
- Movement
- Vibration
- Pressure gradients

Hair-like sensors on the skin or in an open canal

Key sensing organ for

- Fleeing & hunting
- Schooling

Rheotaxis on Fish-robot with Lateral Line



- FILOSE: Rigid head flexible body (One actuator)
- Lateral line: symmetrically located pressure sensors
- Bio-inspired technique to align against laminar flow
- Pressure measurements averaged over time

Salumäe et al “Against the flow: A Braitenberg controller for a fish robot” IEEE ICRA, 2011.

Summary

- Sensing and perception are two different things
- Audition well understood but not fully exploited (e.g. sound localisation)
- Smell highly challenging
- Touch in its infancy with scalability issues (robot skin)
- Other modalities find their niche in robotics (lateral line, electrosense)
- Bio-inspiration can refer to hardware, software, design principles, ...