3

Bio-inspiration in Embodied AI

Perception and action

Agenda

1) Introduction

2) Bioinspired Principles

3) Motion and Locomotion

4) Sensing and Perception

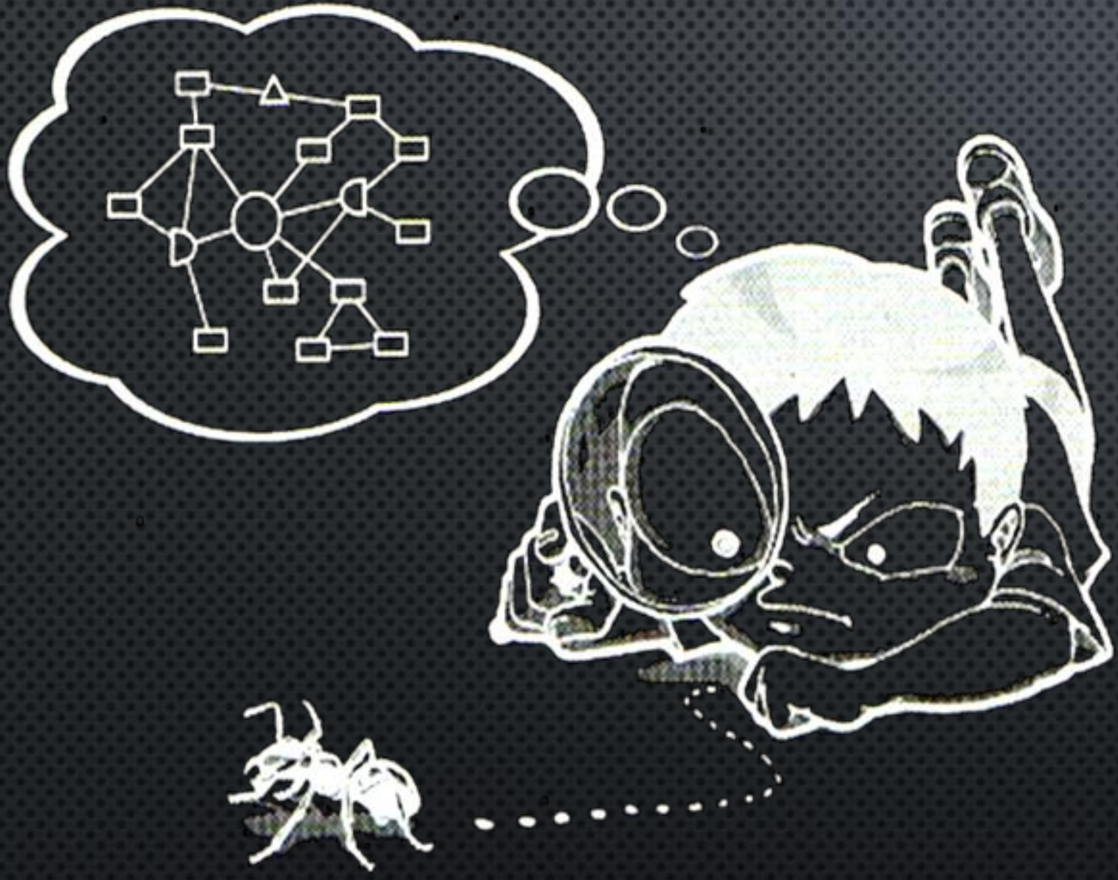
5) Conclusions

1. INTRODUCTION

PollEv.com/juanes

Biologically-inspired robotics

using biological systems as inspiration for robotic design…

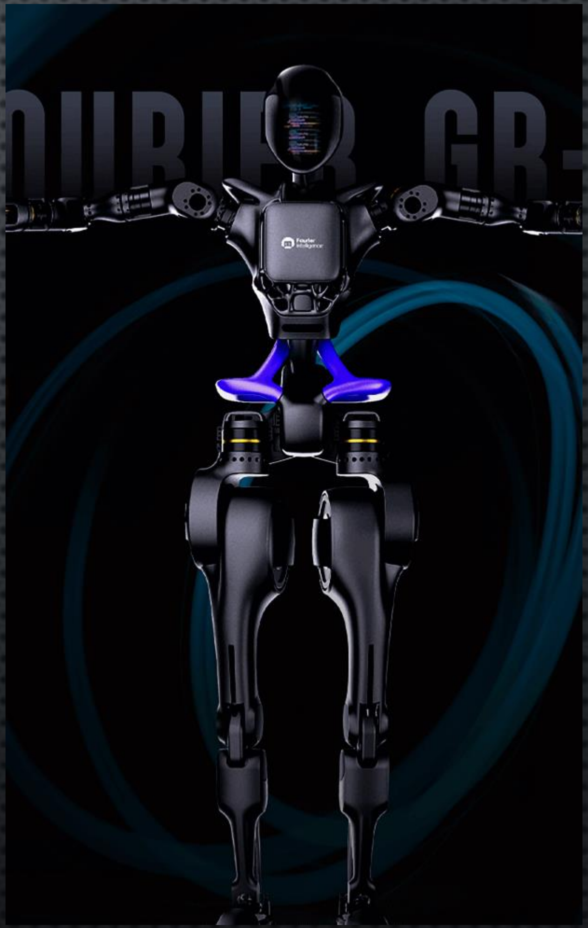


Images: Pfeifer, R. & Bongard, J. C. (2007), "How the Body Shapes the Way We Think: A New View of Intelligence", MIT Press, Cambridge, MA

Biomimetics /Bioinspiration

Bioinspiration (abstracting principles from nature)

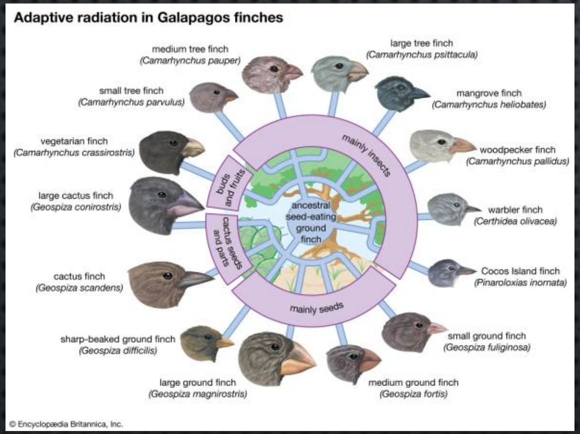
Biomimetics (imitating nature)



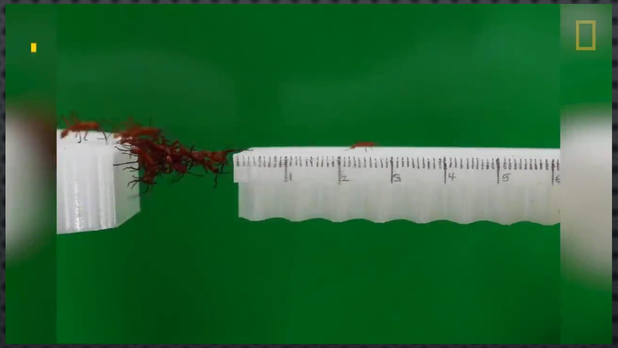
Why Nature?

The Power of 3.8 Billion Years of R&D

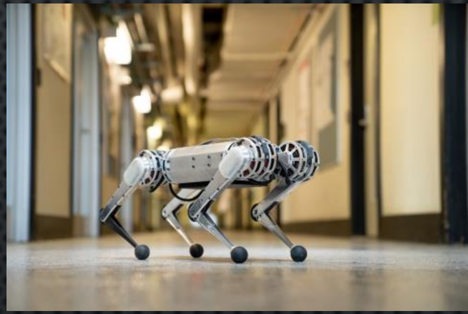
Adaptability



Resilience



Performance



Synthetic Methodology for Biologically-inspired robotics

Understanding

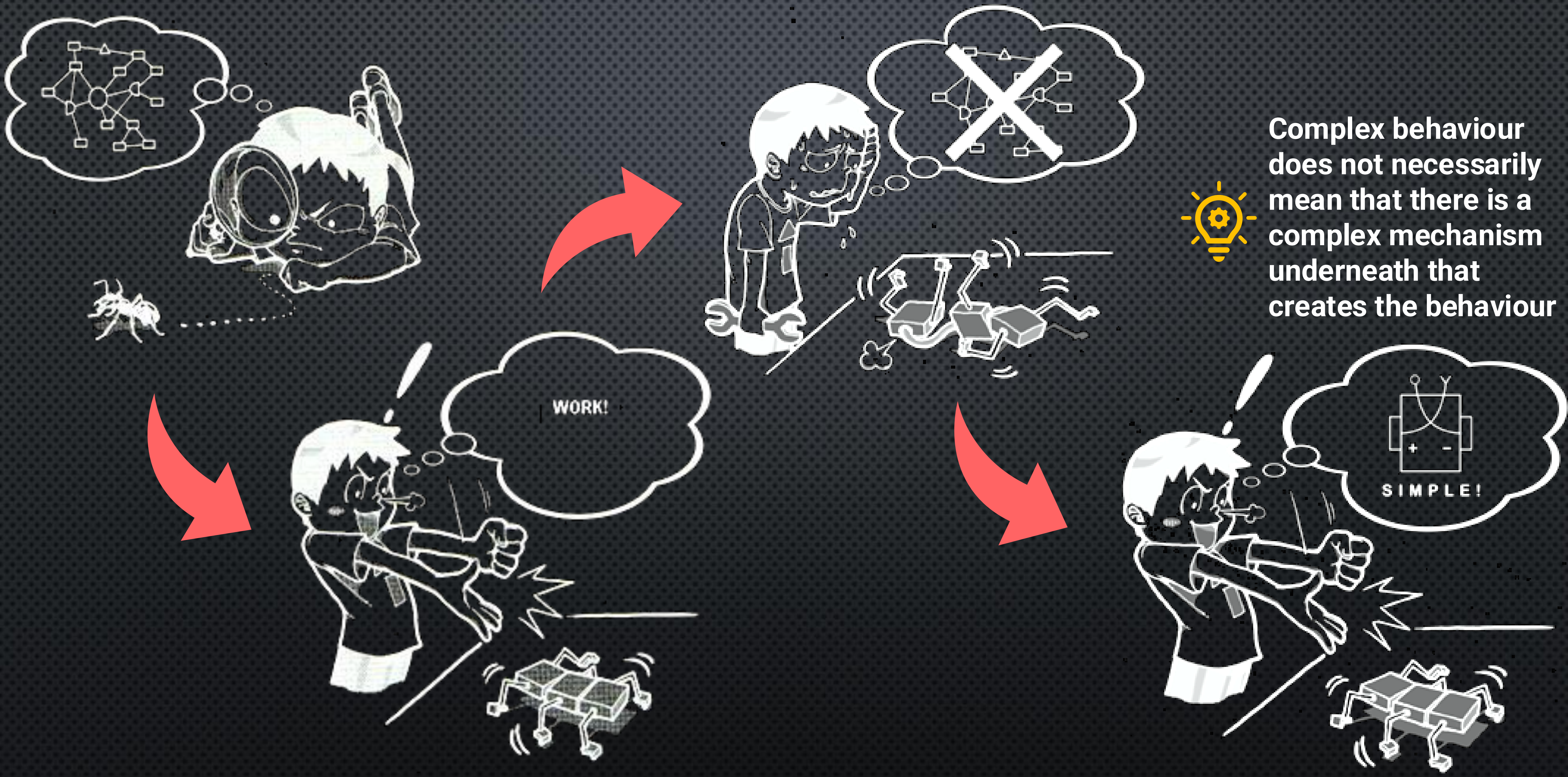
Abstracting

Building

“Understanding by building”

Images: Pfeifer, R. & Bongard, J. C. (2007), “How the Body Shapes the Way We Think: A New View of Intelligence”, MIT Press, Cambridge, MA

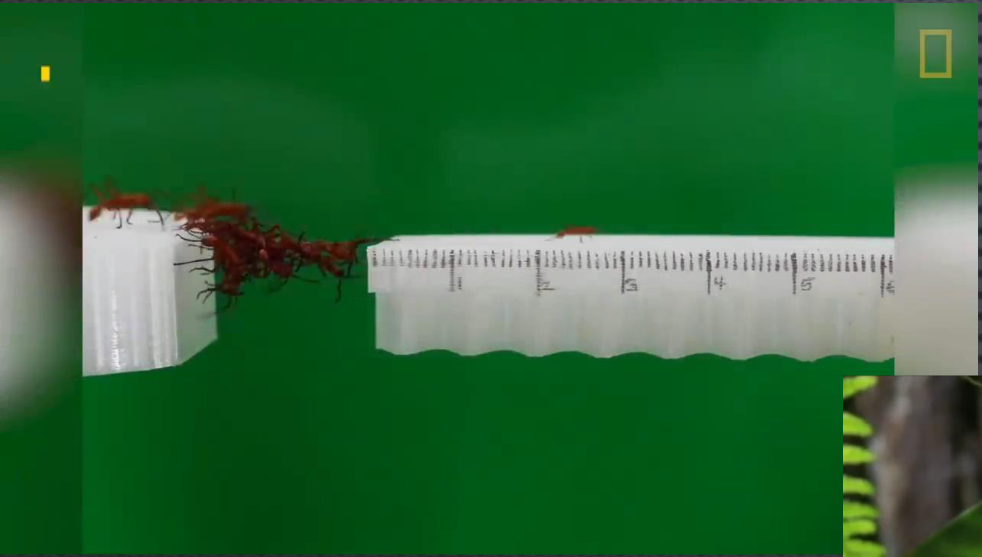
Reality check

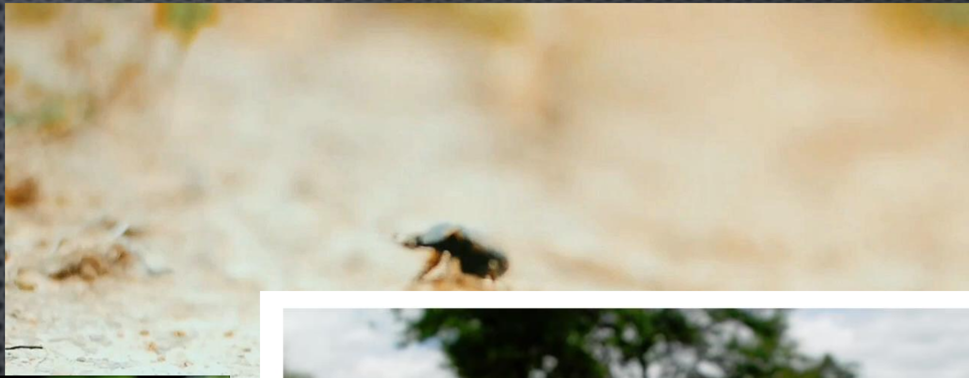


Complex behaviour does not necessarily mean that there is a complex mechanism underneath that creates the behaviour

Images: Pfeifer, R. & Bongard, J. C. (2007), “How the Body Shapes the Way We Think: A New View of Intelligence”, MIT Press, Cambridge, MA

Cool animal videos for motivation…

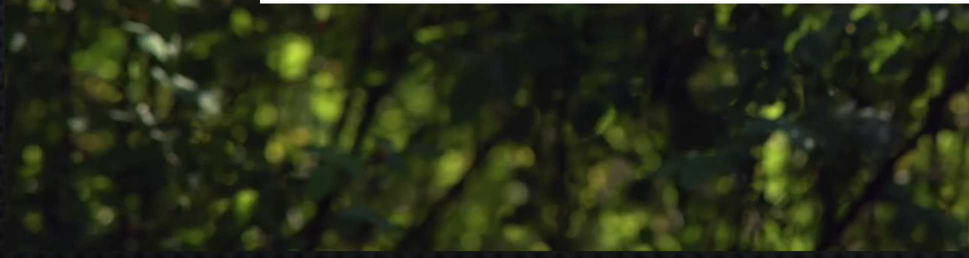





Dung beetle, by Eric Warrant.

SCIENCE | NOT EXACTLY ROCKET SCIENCE

Dung Beetles Watch the Galaxy (That's How They Roll)



Cool robot videos for further motivation…

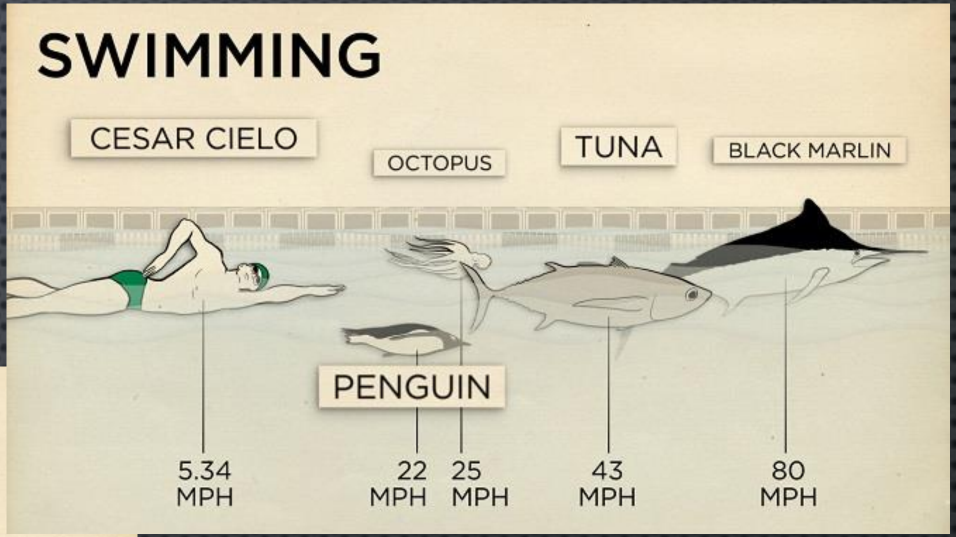
2. Bioinspired Principles

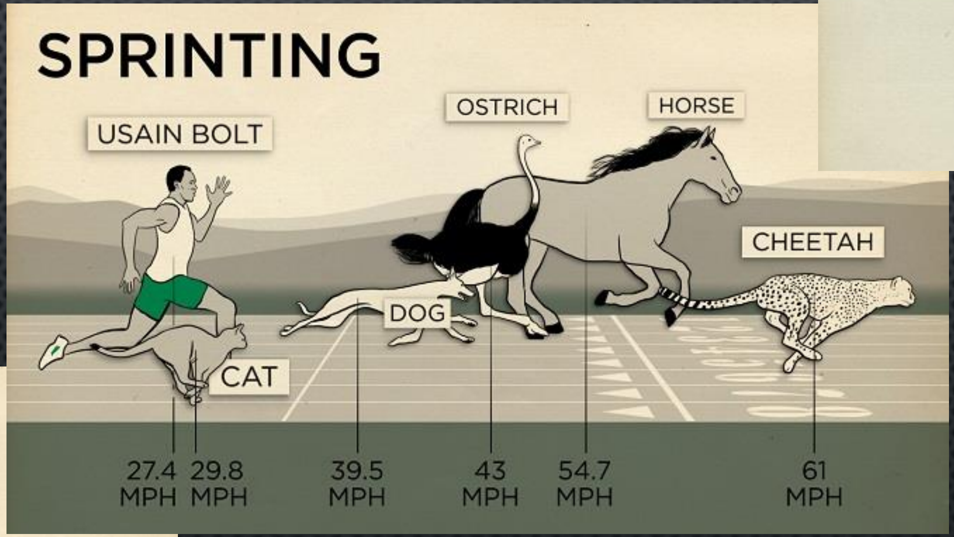
Bioinspired Principles

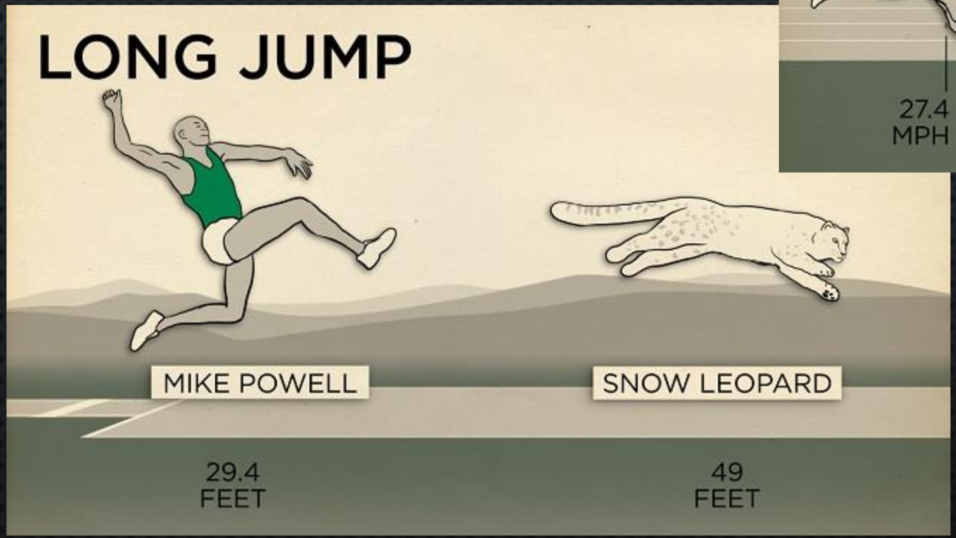
- Motion and Locomotion
- Sensing and perception
- Adaptation and learning
- Energy efficiency
- Material design and structure
- Navigation and mapping
- Communication and swarm behavior
- Immunity and defense mechanisms

3. MOTION AND LOCOMOTION

Why study animals: motion

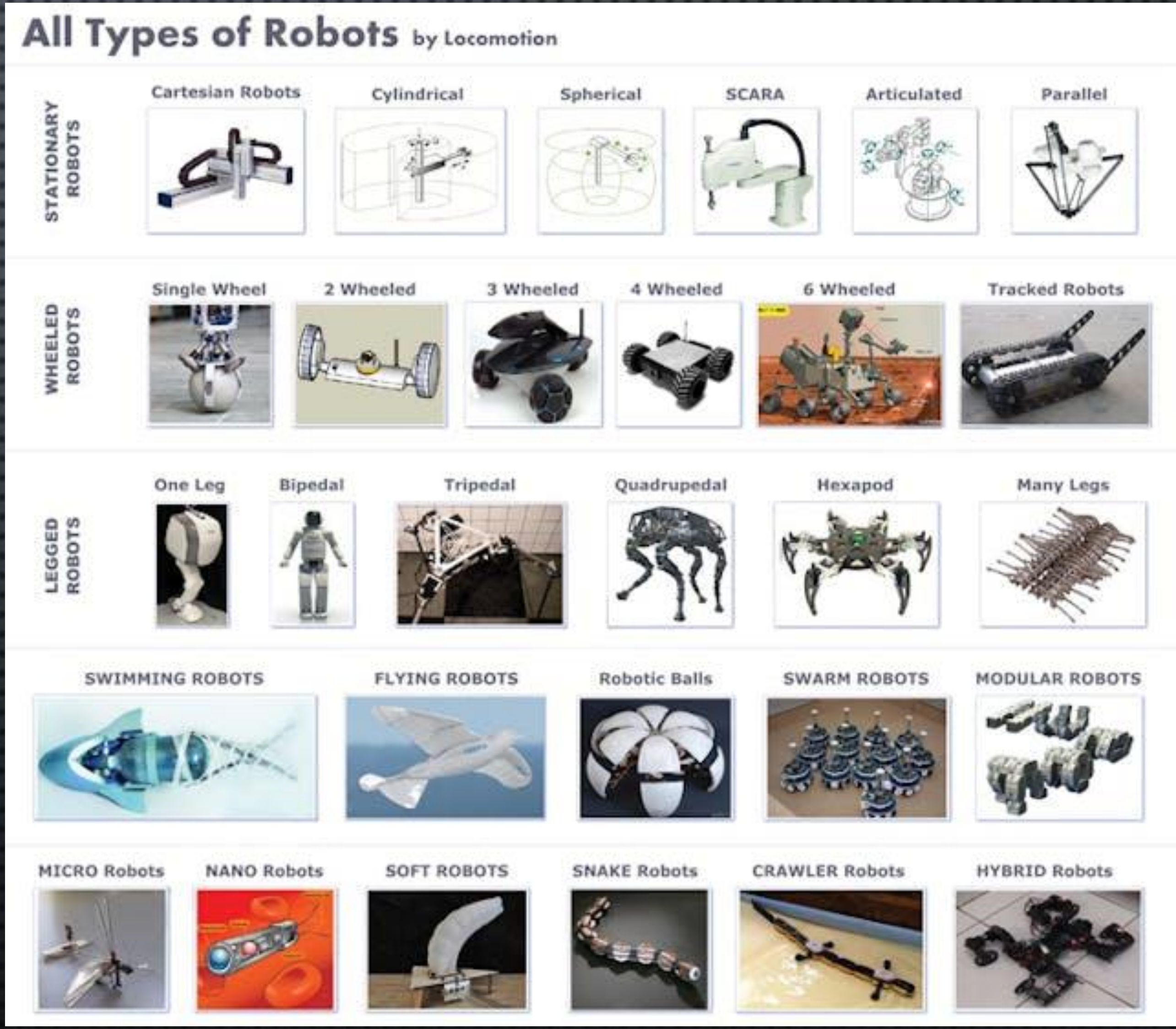






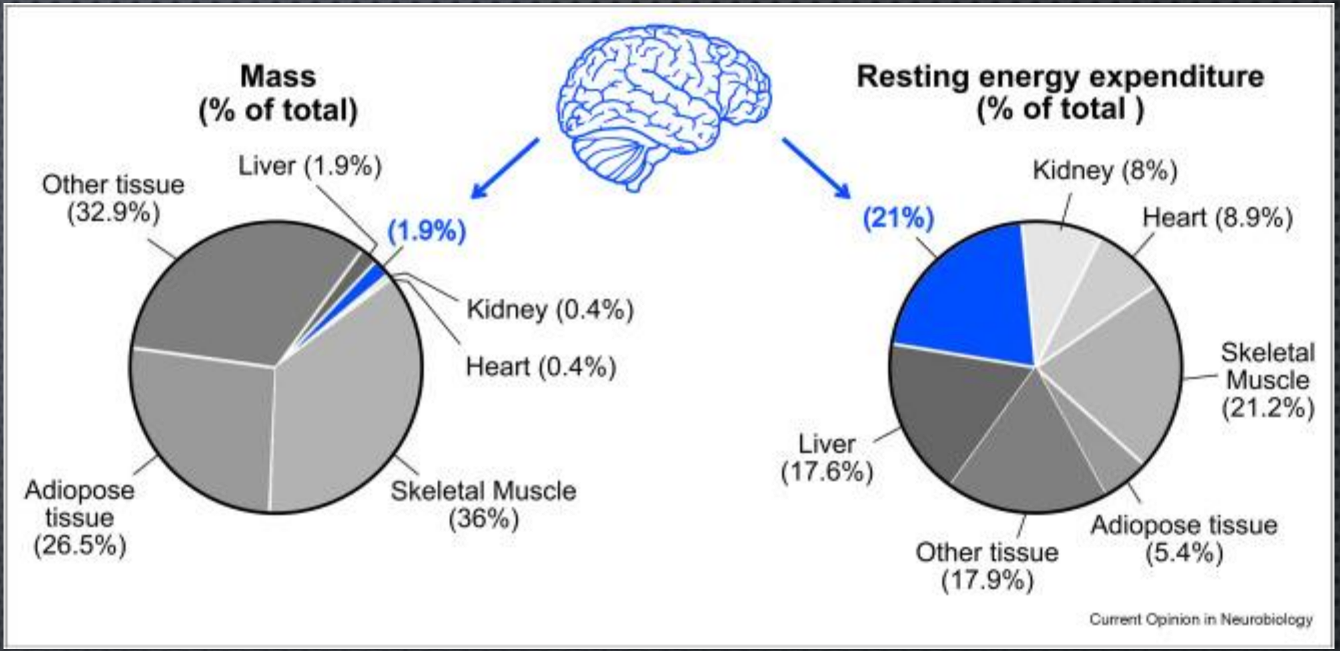
Principles

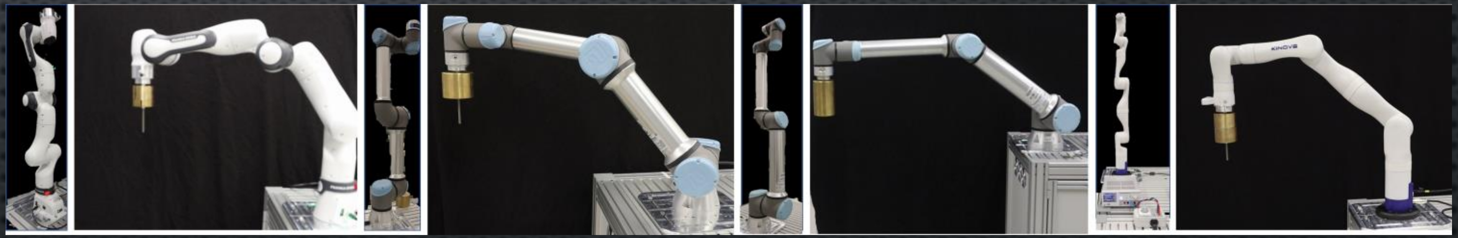
- Locomotion Mechanisms

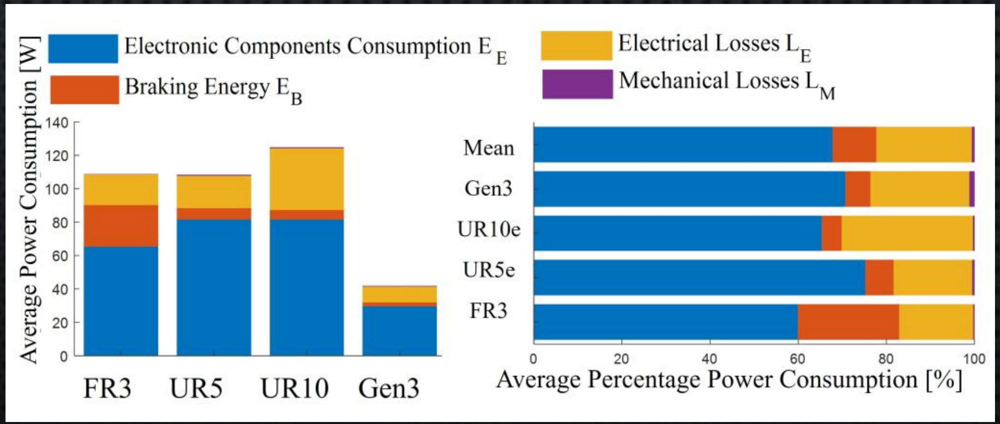


Principles

- Efficient Energy Usage

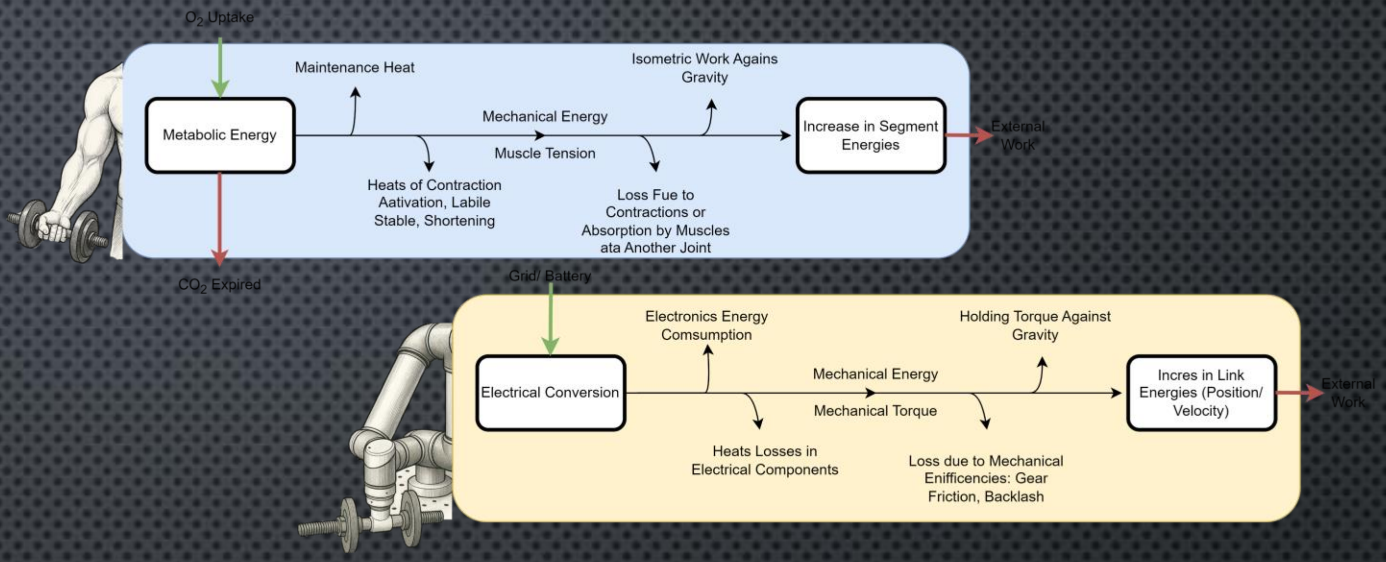


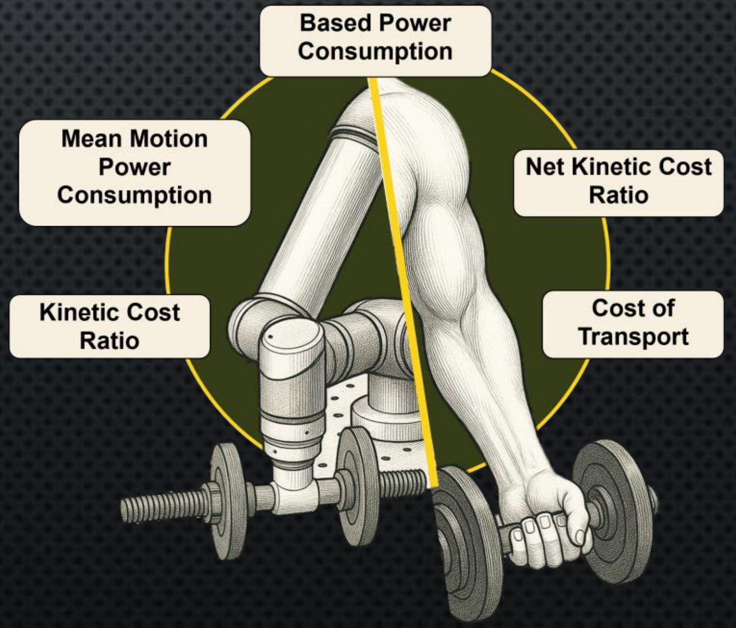




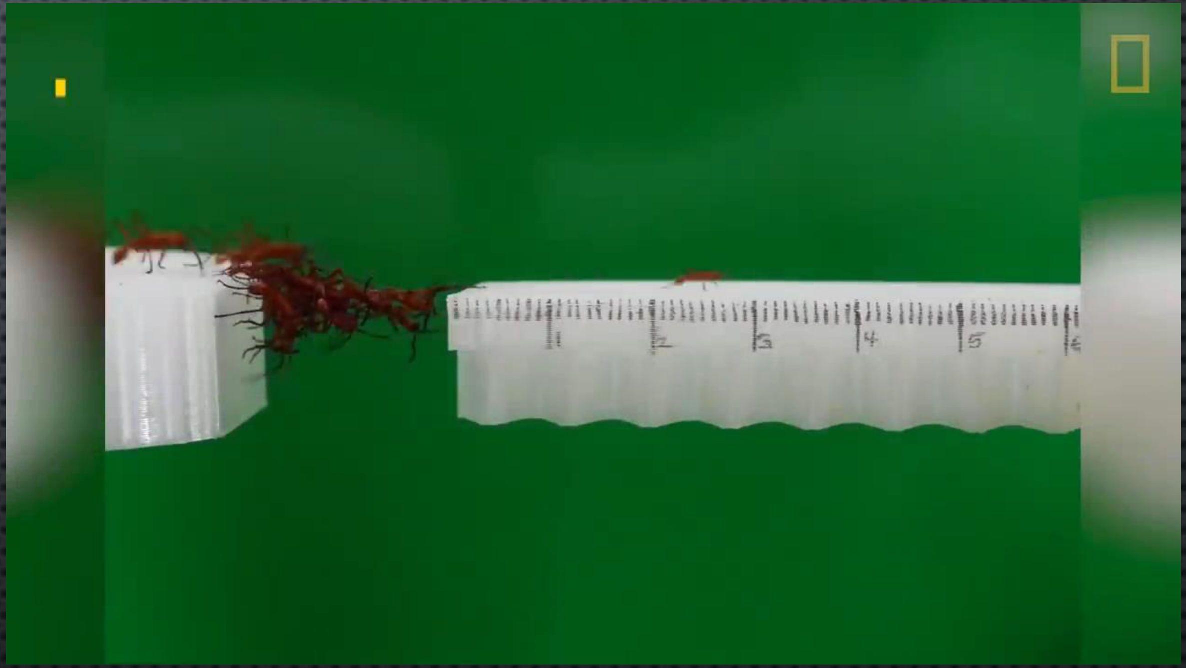
Principles

- Efficient Energy Usage





Principles



- Swarm Intelligence and Collective Motion

Principles

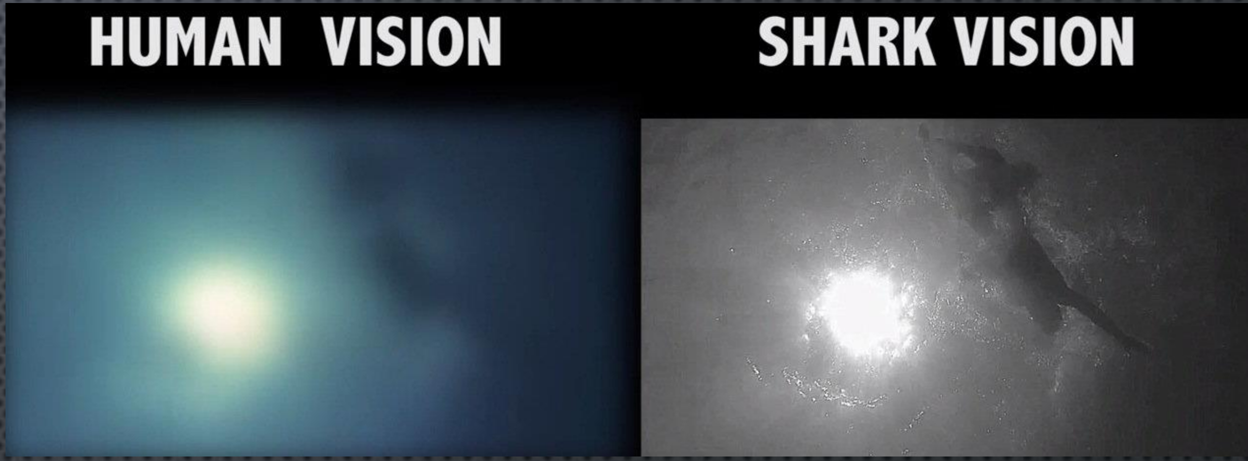
- Locomotion Mechanisms
- Efficient Energy Usage
- Swarm Intelligence and Collective Motion

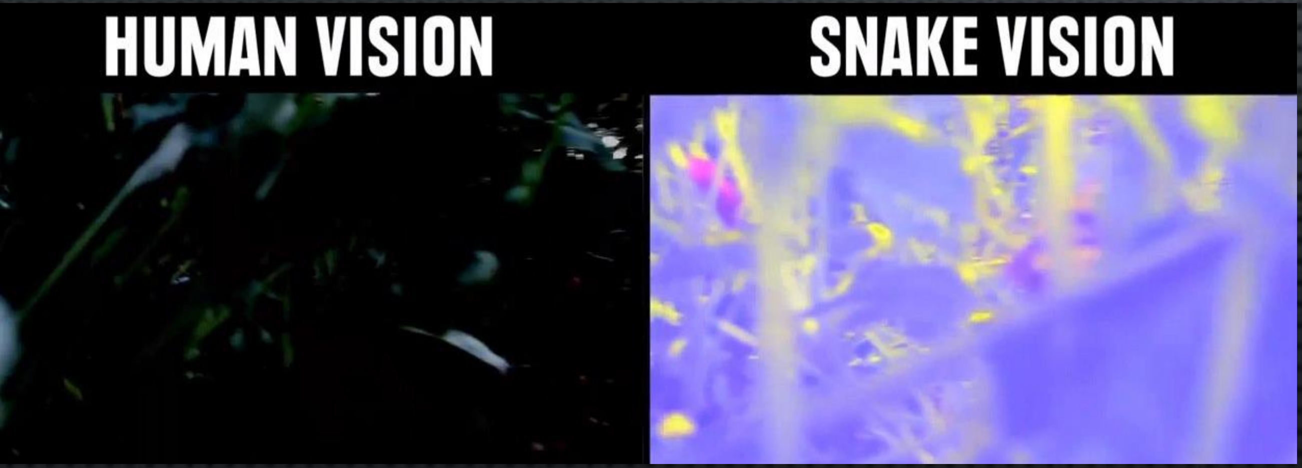
ACTIVITY

- PREPARE A SLIDE WHERE YOU INTRODUCE AN APPLICATION IN ROBOTICS BASED ON BIOINSPIRATION FOR THE DESIGN OF YOUR PROJECT.
  - BE ORIGINAL
  - UNDERSTANDING, ABSTRACTING, BUILDING

4. SENSING AND PERCEPTION

Why study animals: perception

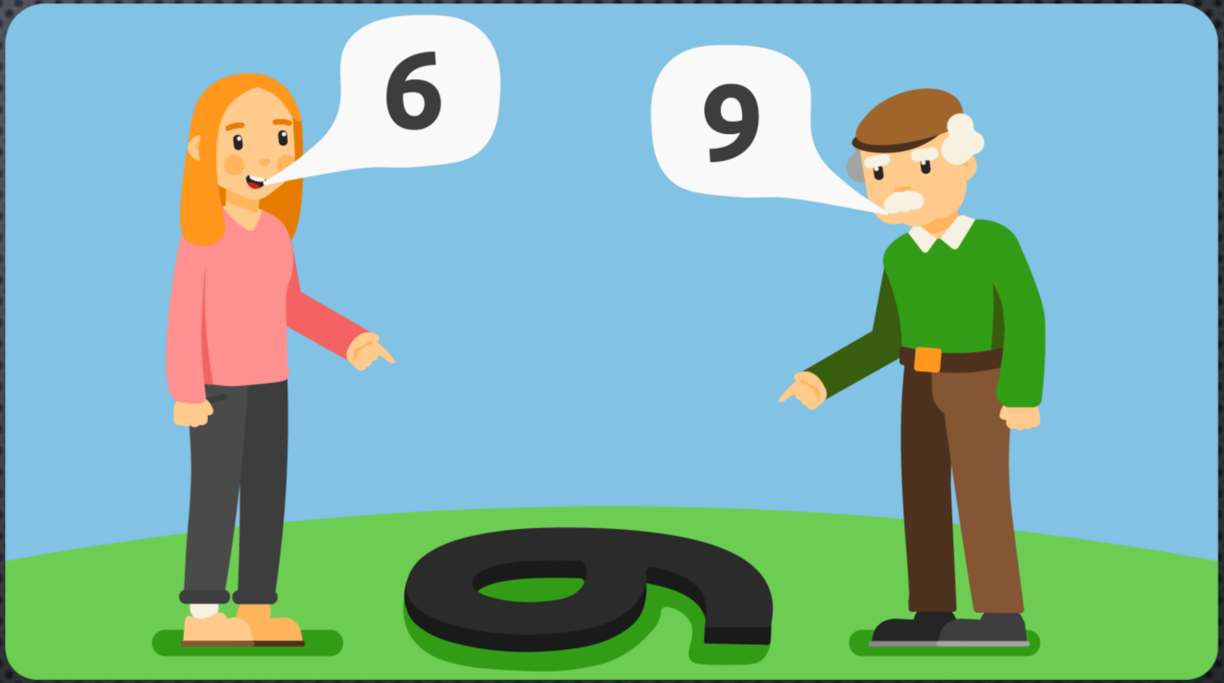




What can we learn about perception?

Biological perception typically involves movement

- Movement can imply either moving relevant sensors (such as eyes) or moving the entire body (walking around, turning etc.) or both
- Moving sensors changes incoming sensory information
- Allows the brain to fill in the gaps in information and form a sufficiently complete representation of the world



- "We see in order to move, and we move in order to see"

– James Gibson

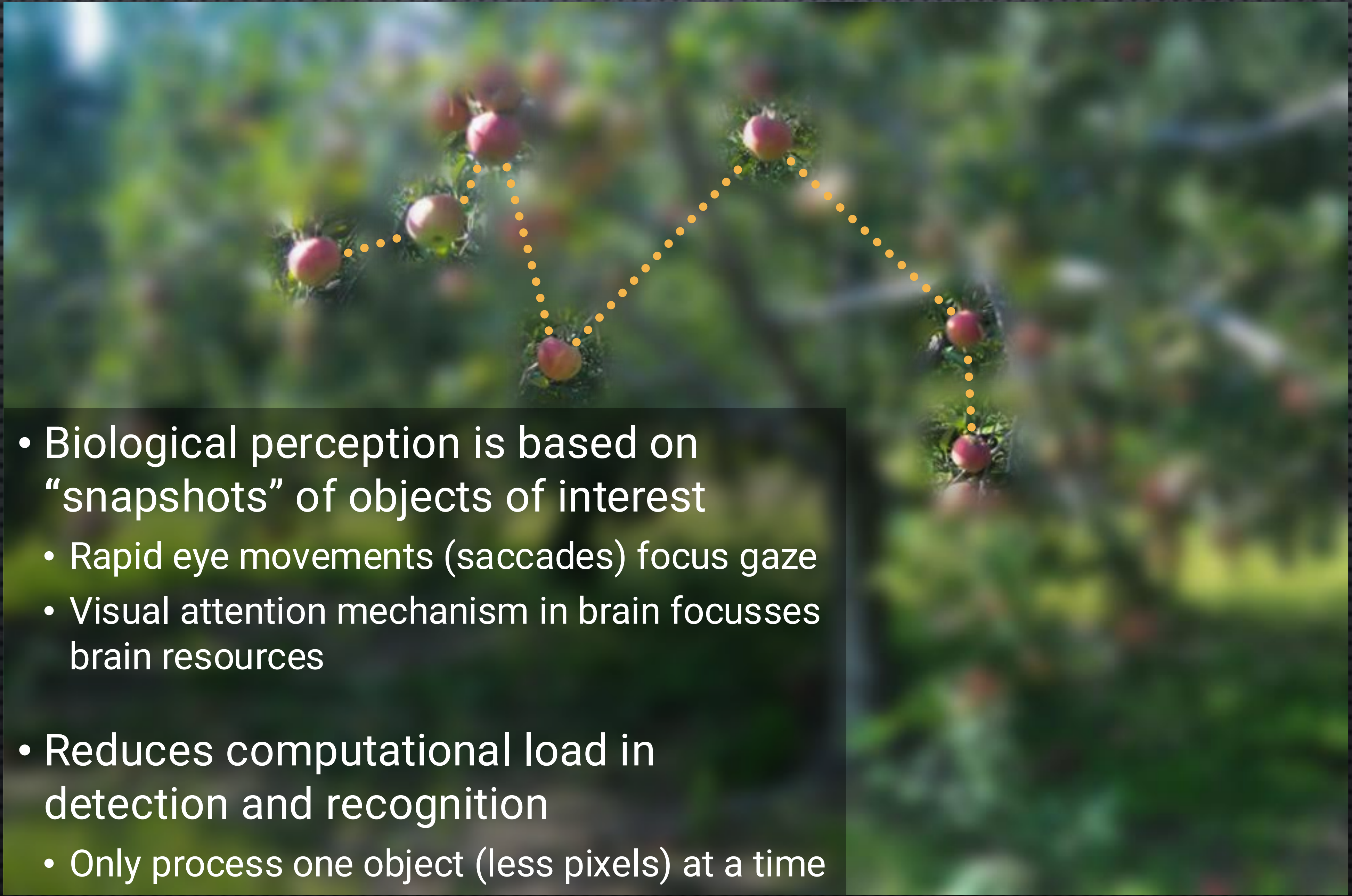
Sensing and perception

- Sensing is detecting a physical object obtained by sensory receptors in biological agents (or by sensor hardware in robotic agents)
  - deals with collection of data

- Perception is the process of selecting, organizing, representing and interpreting sensations (or sensor data)
  - deals with understanding data

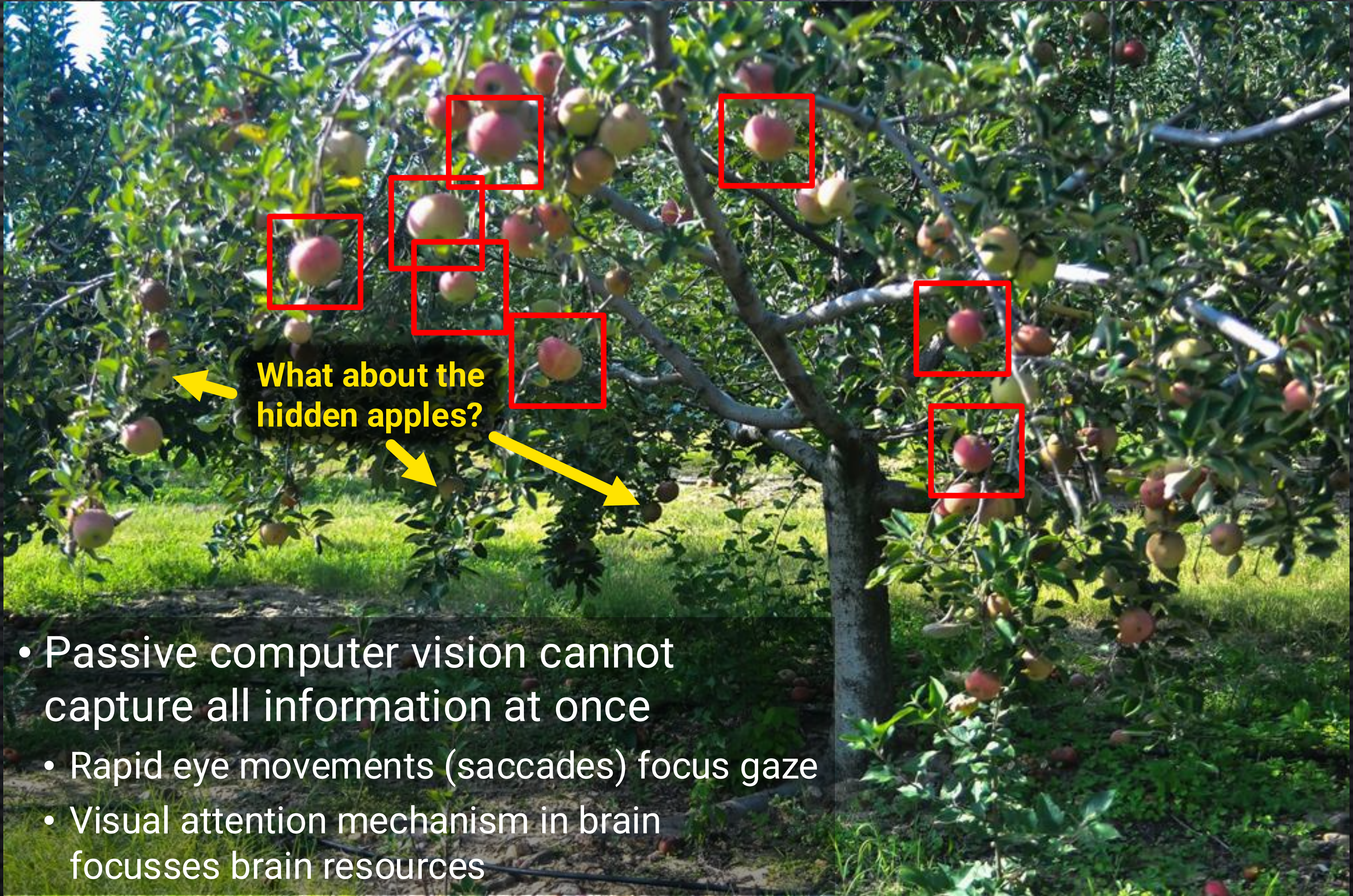
4.1 Biological perception: sampling space over time

Biological perception: sampling space over time



- Biological perception is based on “snapshots” of objects of interest
  - Rapid eye movements (saccades) focus gaze
  - Visual attention mechanism in brain focusses brain resources
- Reduces computational load in detection and recognition
  - Only process one object (less pixels) at a time

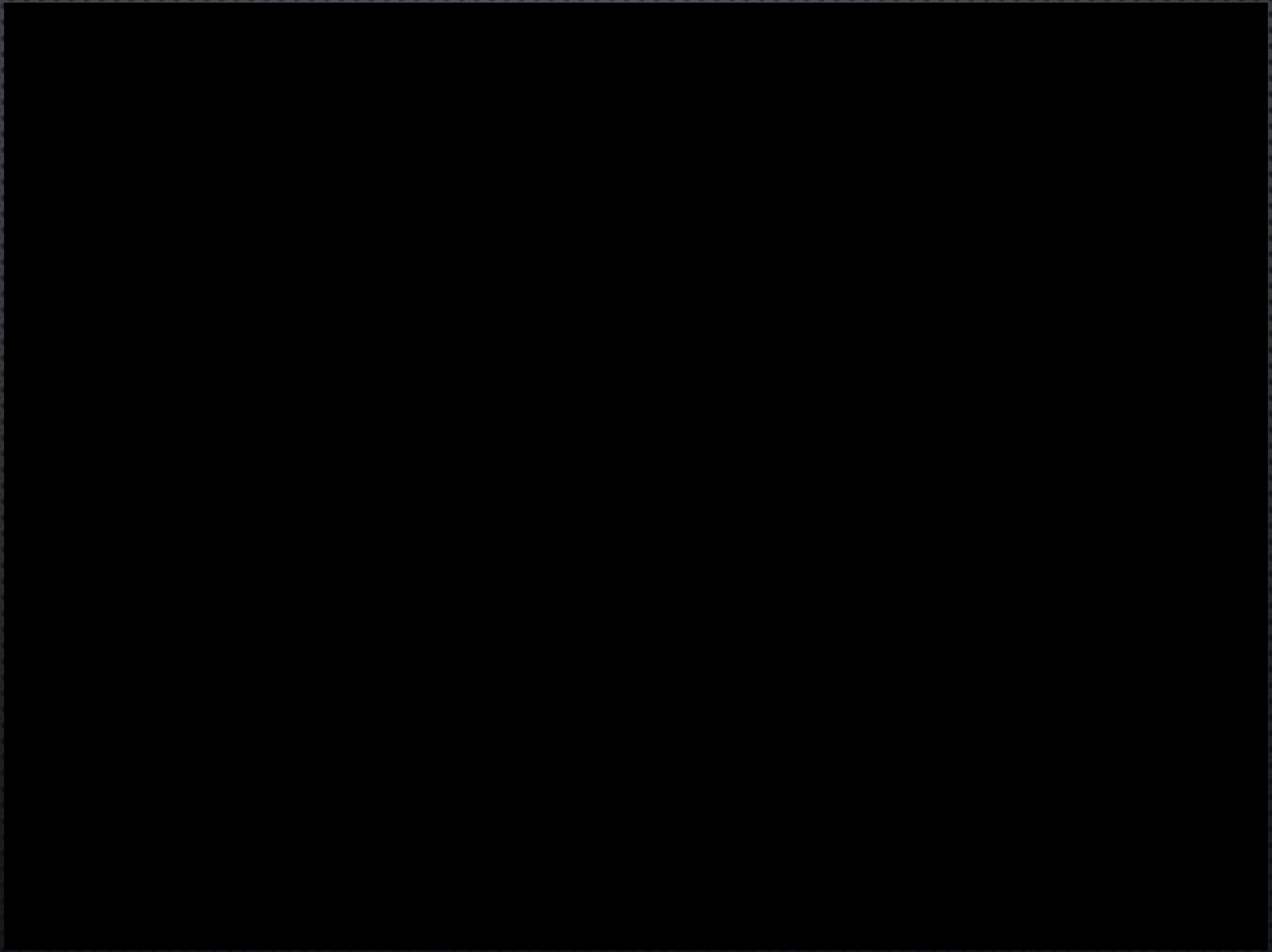
Artificial perception: passive computer vision



- Passive computer vision cannot capture all information at once
  - Rapid eye movements (saccades) focus gaze
  - Visual attention mechanism in brain focusses brain resources

A more complex situation…

How human perception work?



How should robots see (and perceive) the world?

Perception for action: lizard hearing

- Small head size (10—20 mm) w.r.t sound wavelengths (85–340 mm)
  - This means that sound diffracts around the head

- Diffraction leads to negligible difference in sound volume between the ears

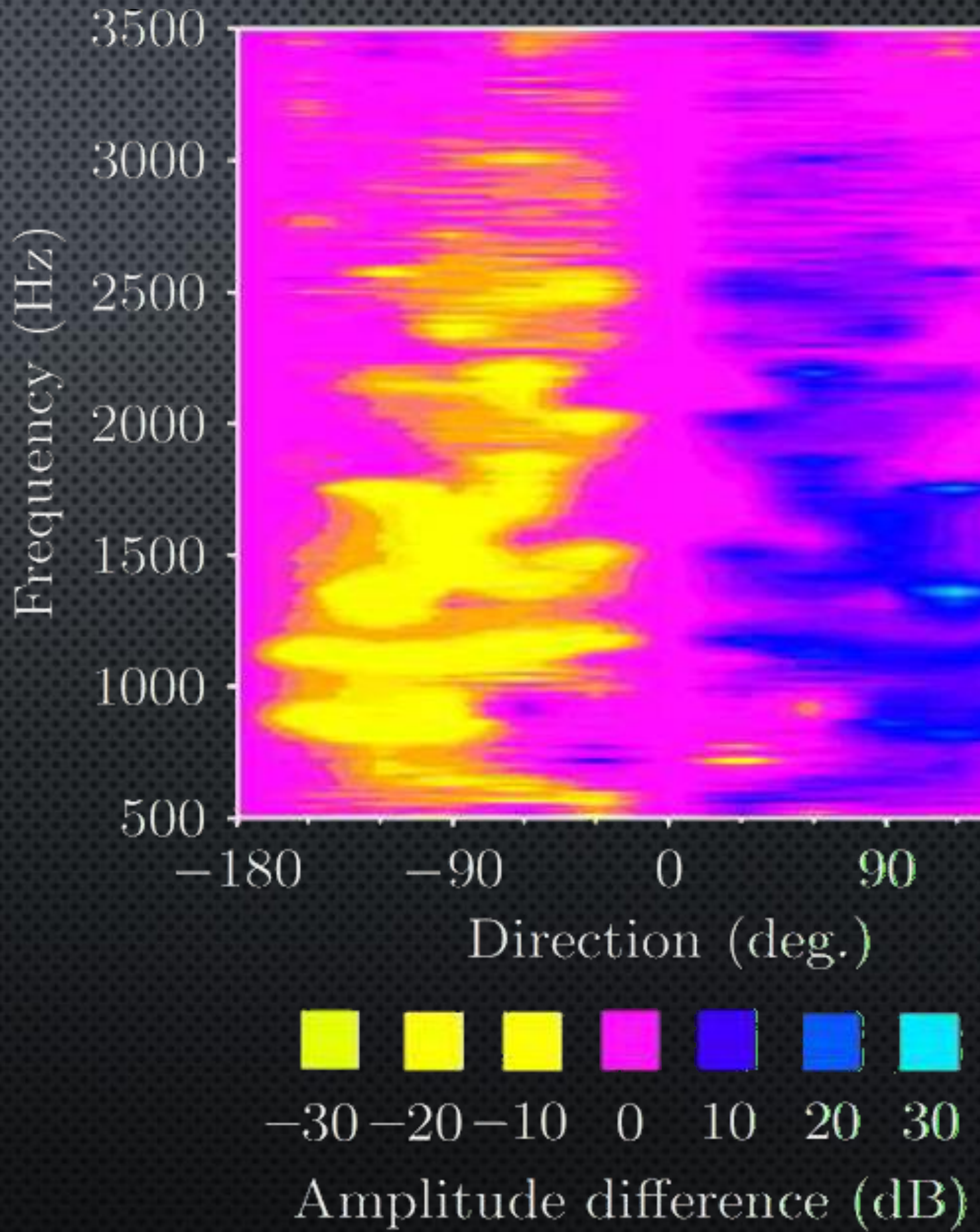
- Diffraction also leads to tiny (μs scale) but finite difference in times of arrival of sound
  - This can be used to determine sound direction

Sound direction representation in 2D (horizontal) plane

- Difference in times of arrival of sound between ears encodes sound direction

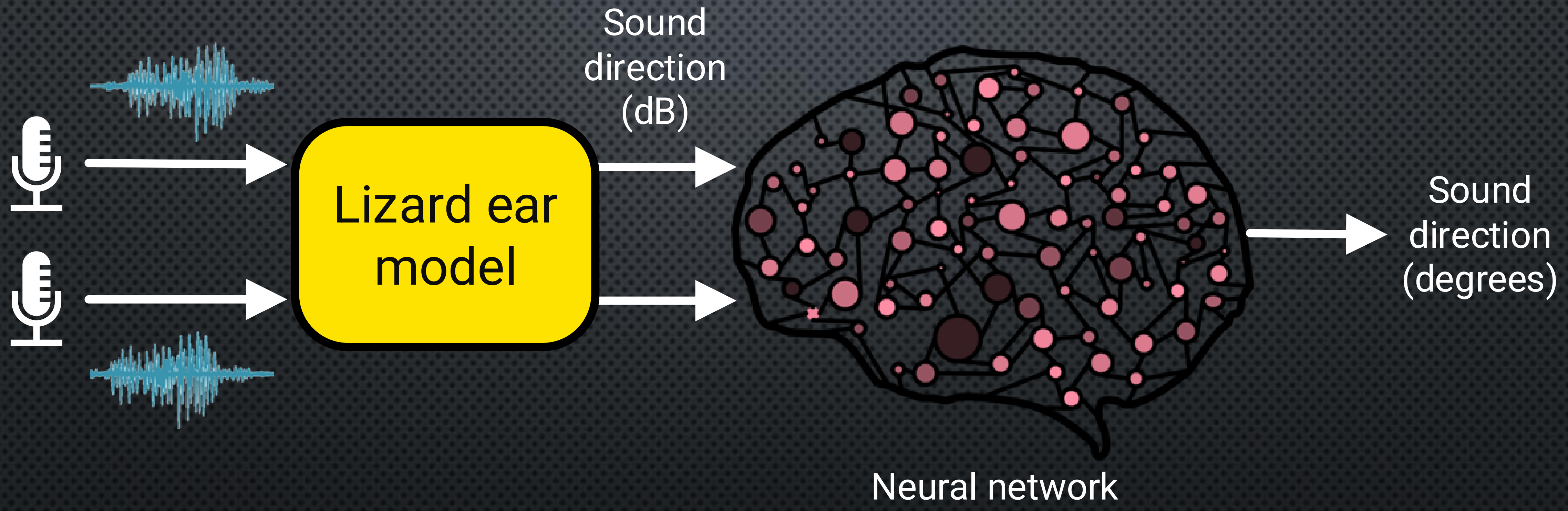
- Difference in times of arrival of sound (in μs) is converted into difference in amplitude of eardrum vibration (in dB)

- The ear closer to the sound source vibrates more strongly than the eat further away from the sound source

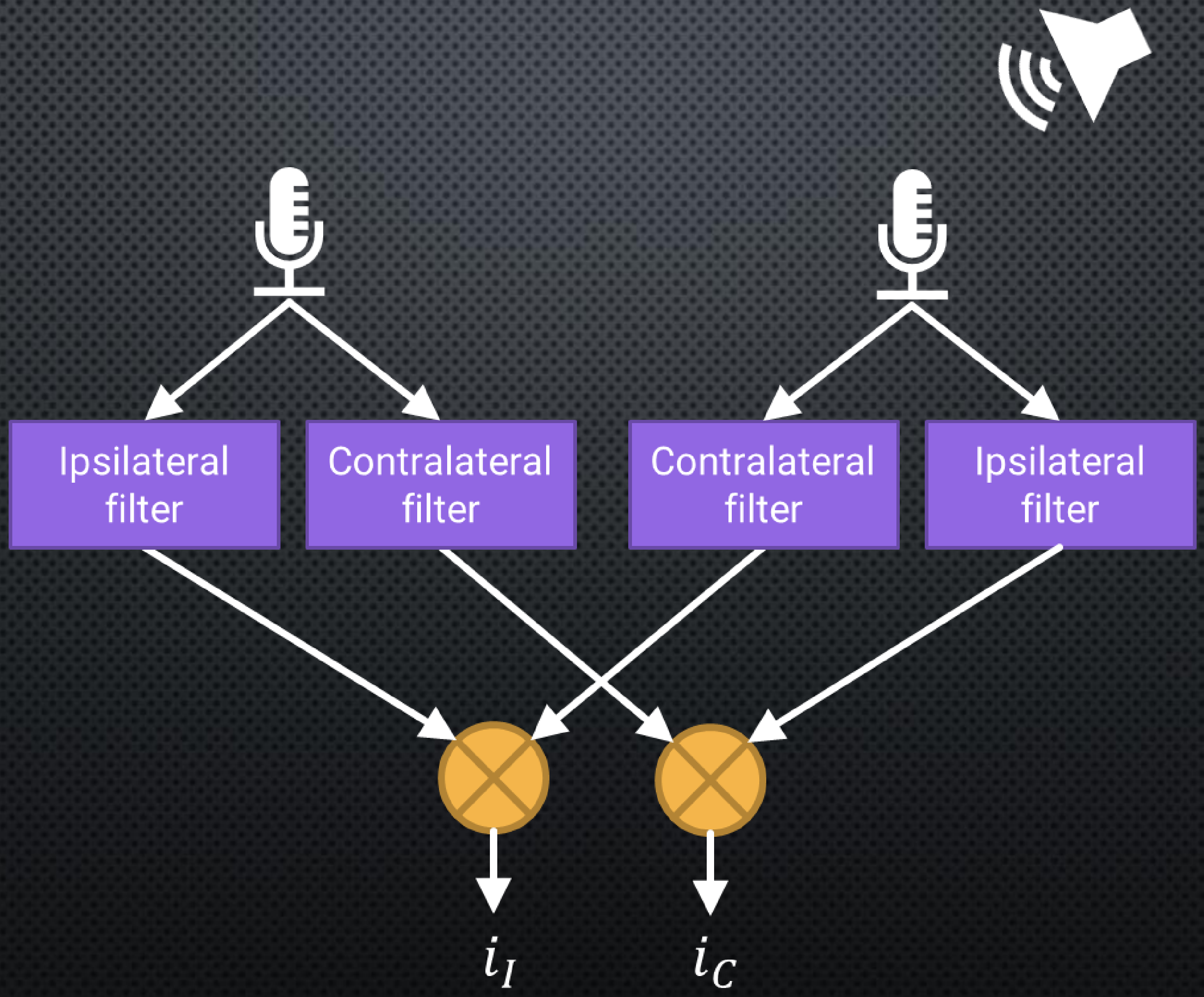


How to convert model output into sound direction?

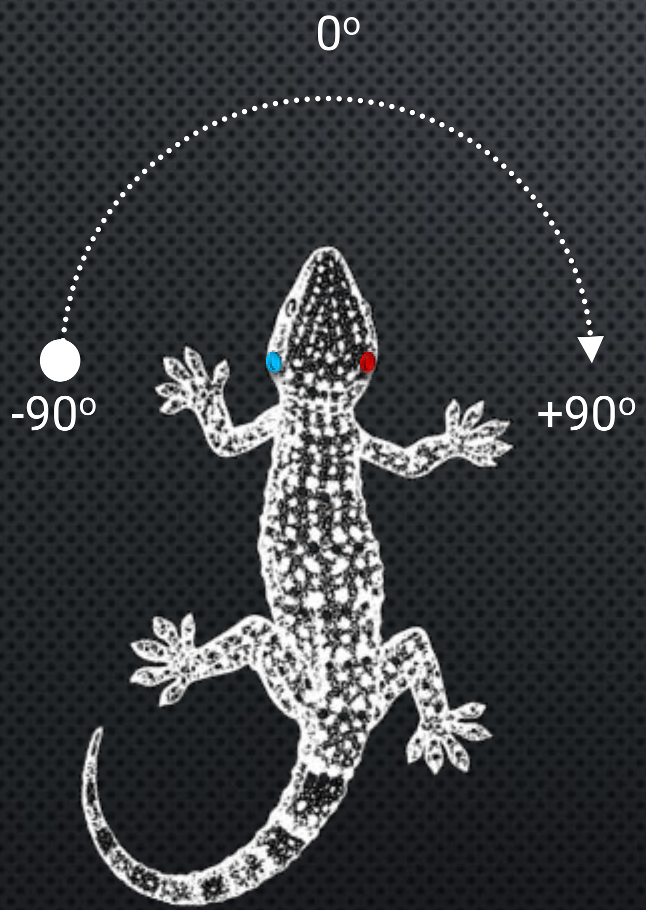
- If you are not able to move…

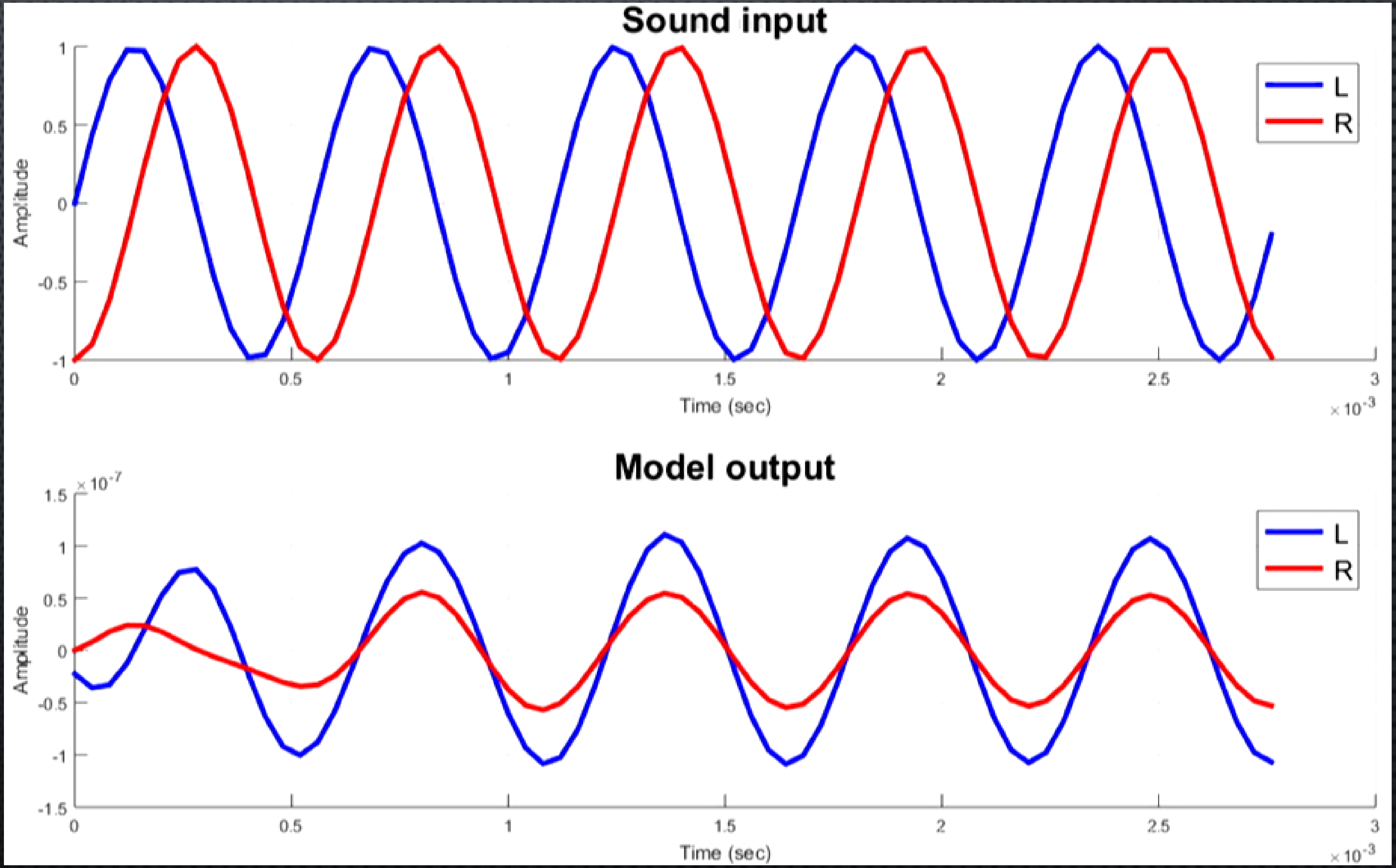


Lizard ear model for sound localisation in 2D (horizontal) plane



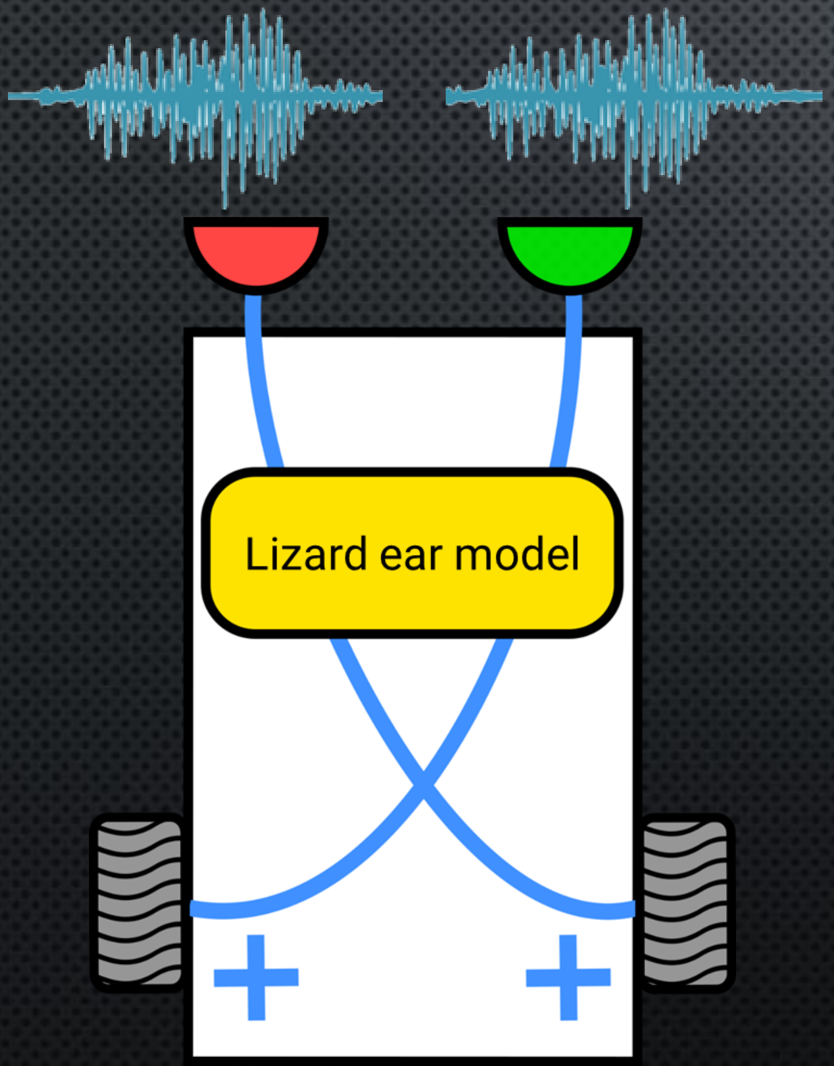
Model response in 2D (horizontal) plane

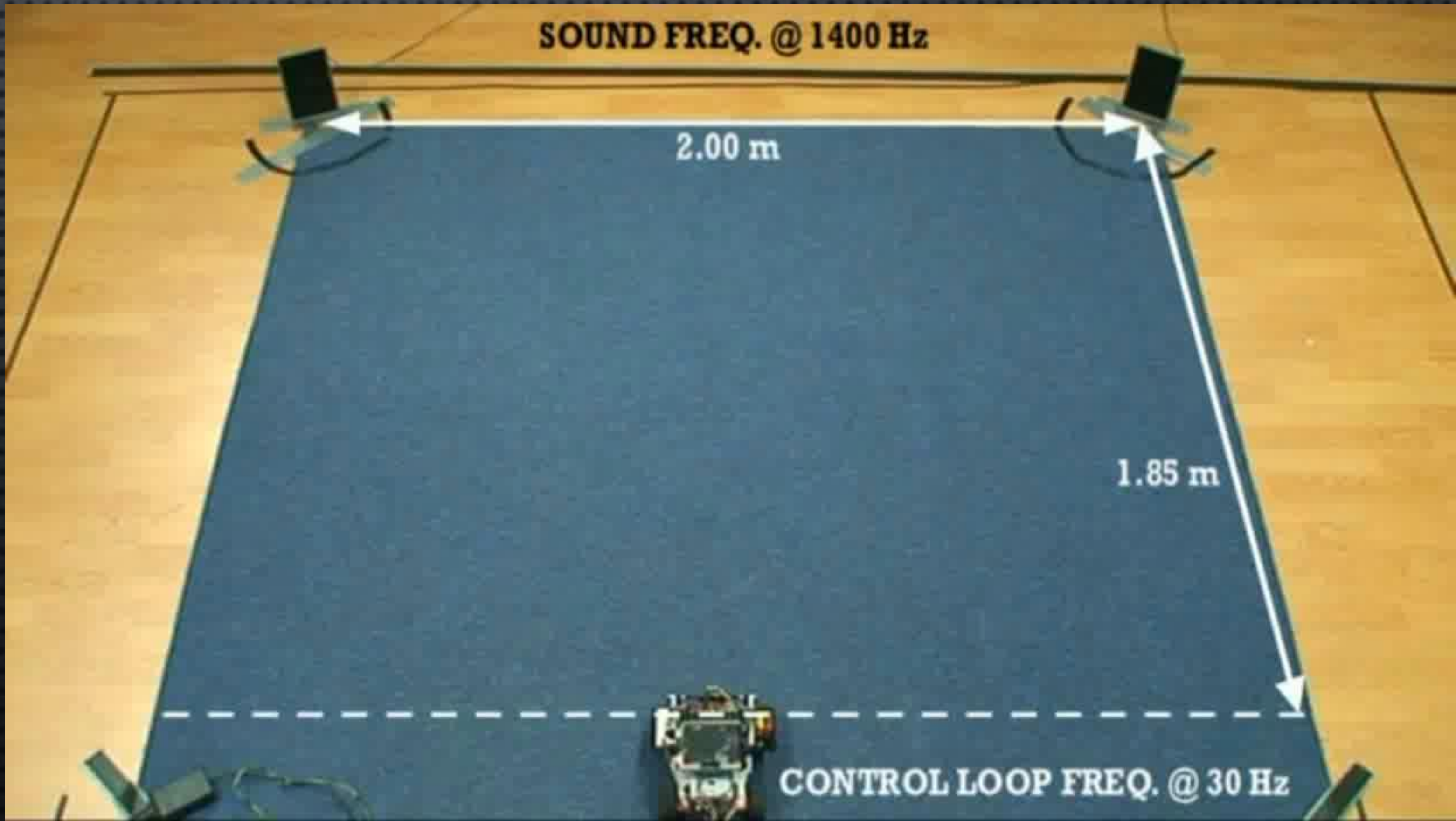




How to convert model output into sound direction?

- But if you are able to move, no need for a neural network…





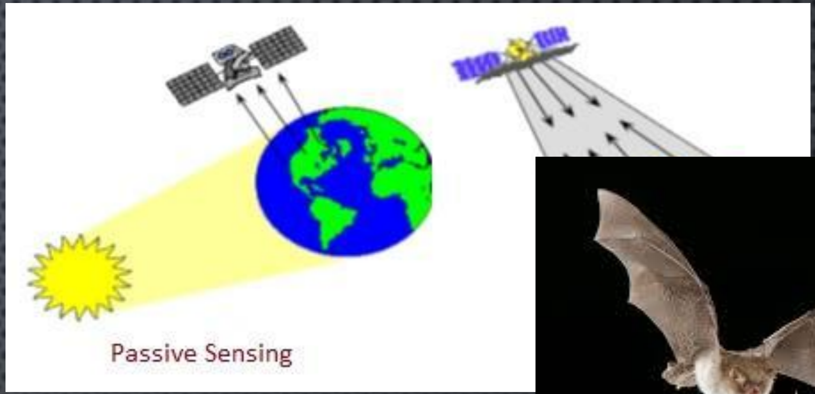
4.2 Active sensing and perception

- Active sensing is the problem of applying intelligent control strategies to collect data
  - the detection, processing and representation of sensory information is heavily influenced via the sensor's (or robot's) movements
  - movement control strategy depends on the current state of data interpretation and recognition
- Active sensing allows a biological agent (or a robotic agent) to
  - selectively sample sensor information in space and in time
  - vary stimulus (sensor data) intensity and dynamics to improve sensory processing
  - extract relevant features

4.2 Active sensing and perception

- **Active Sensors (hardware level)**

Devices that **emit energy** into the environment (sonar, lidar, radar, echolocation, electrolocation).



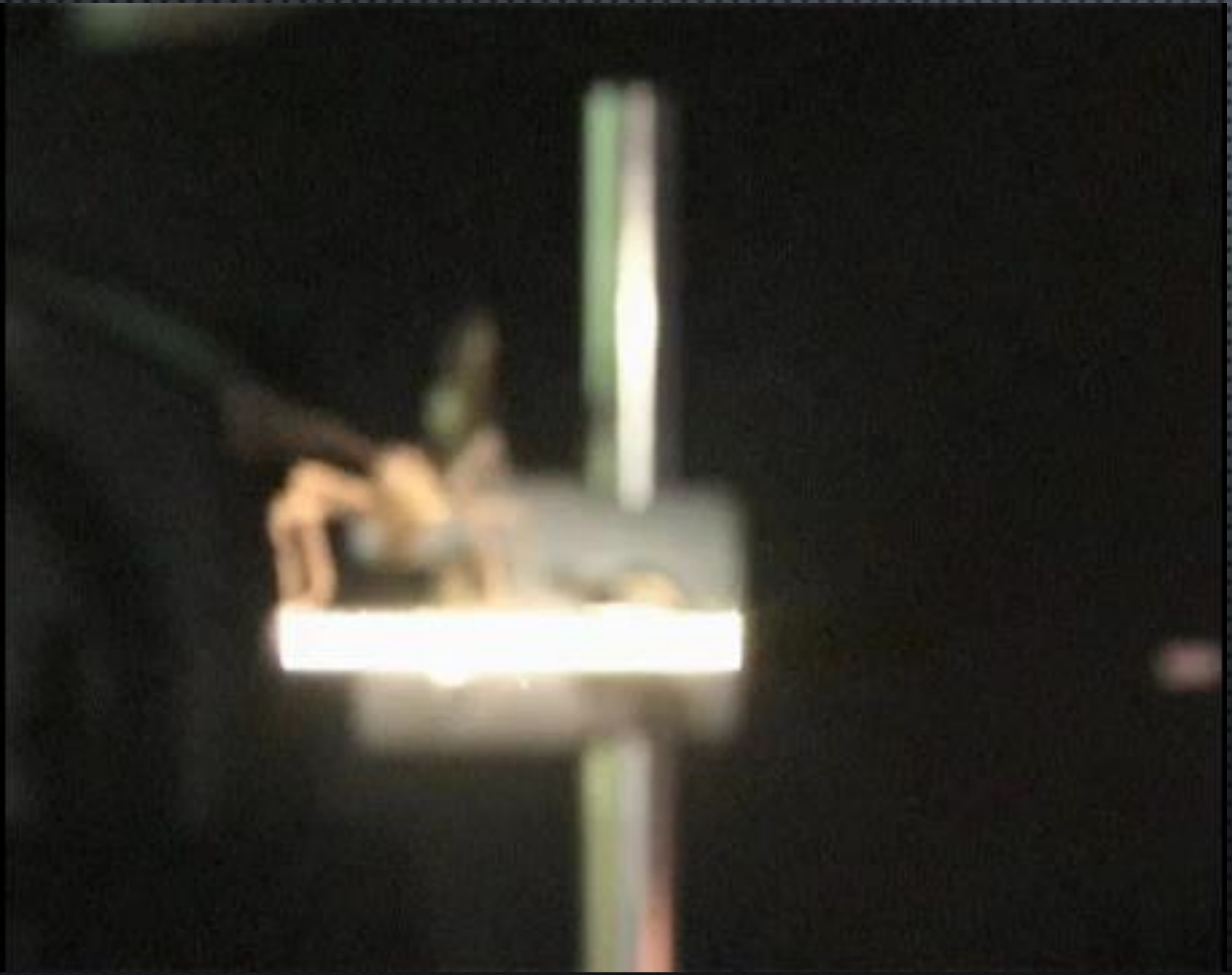
- **Active Sensing:** How to gather data (control of sensors)

A driver moving their eyes between mirrors.

- **Active Perception =** Why to gather data (goal-driven strategy for interpretation & action)

A driver looks at the side mirror (**active sensing**) *because* they plan to change lanes (**active perception**).

Active sensing in animals



Active sensing in humans

Example: Active sensing in robots

Multi-View Picking:
Next-best-view Reaching for Improved Grasping in Clutter

Doug Morrison, Peter Corke and Juxi Leitner

AUSTRALIAN CENTRE FOR ROBOTIC VISION

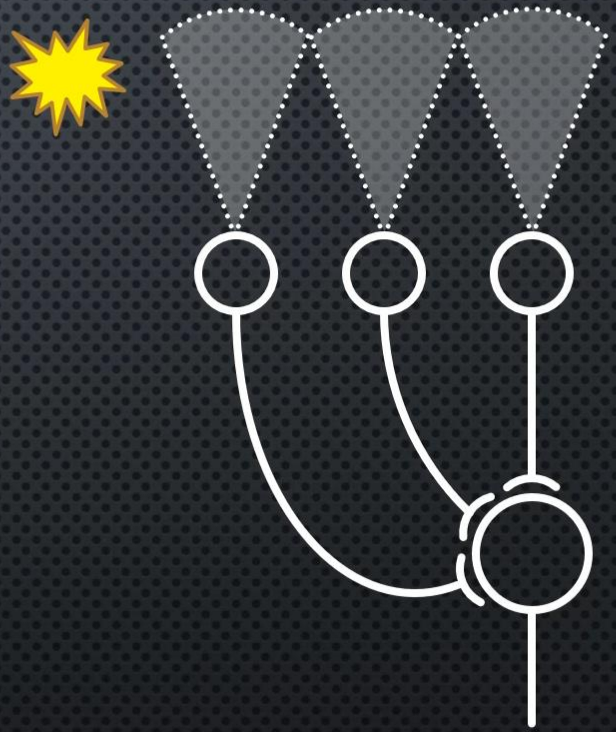
QUT

4.3 Motion perception

- Motion perception is the process of estimating the speed and direction of elements in a scene based on sensory information
  - Sensory information could be visual, vestibular (balance and spatial orientation) and proprioceptive (self-motion and body position)

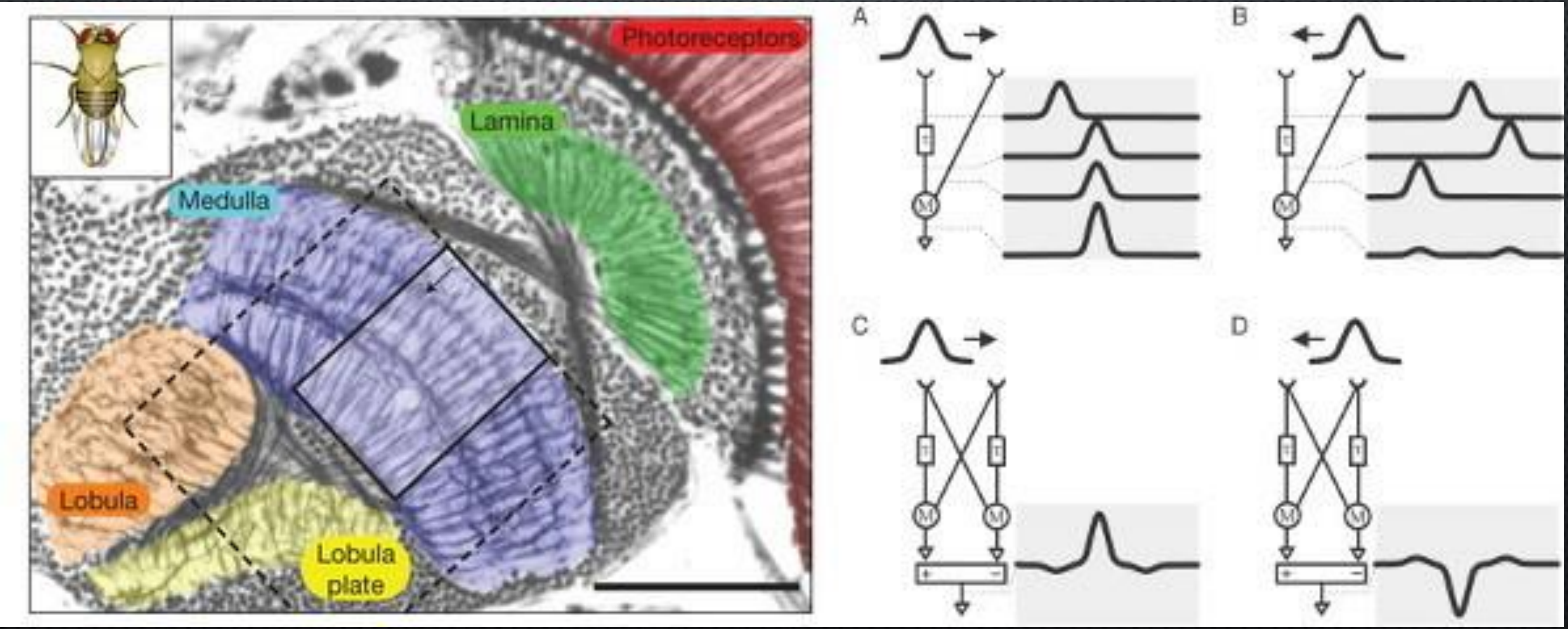
Motion detection in the brain

- Motion perception starts with the detection of motion itself, i.e., that something in the scene has moved
- Motion detection requires an elementary detector circuit in the brain
- Detector circuit must have knowledge of time
  - Time is encoded by delaying the signal transmitted by neurons in the brain
  - Delays are literally implemented by having longer sensory neurons – longer a neuron, more time it takes to transmit signal
  - Grouping neurons with different lengths as inputs to another neuron allows for exploiting delays to detect motion

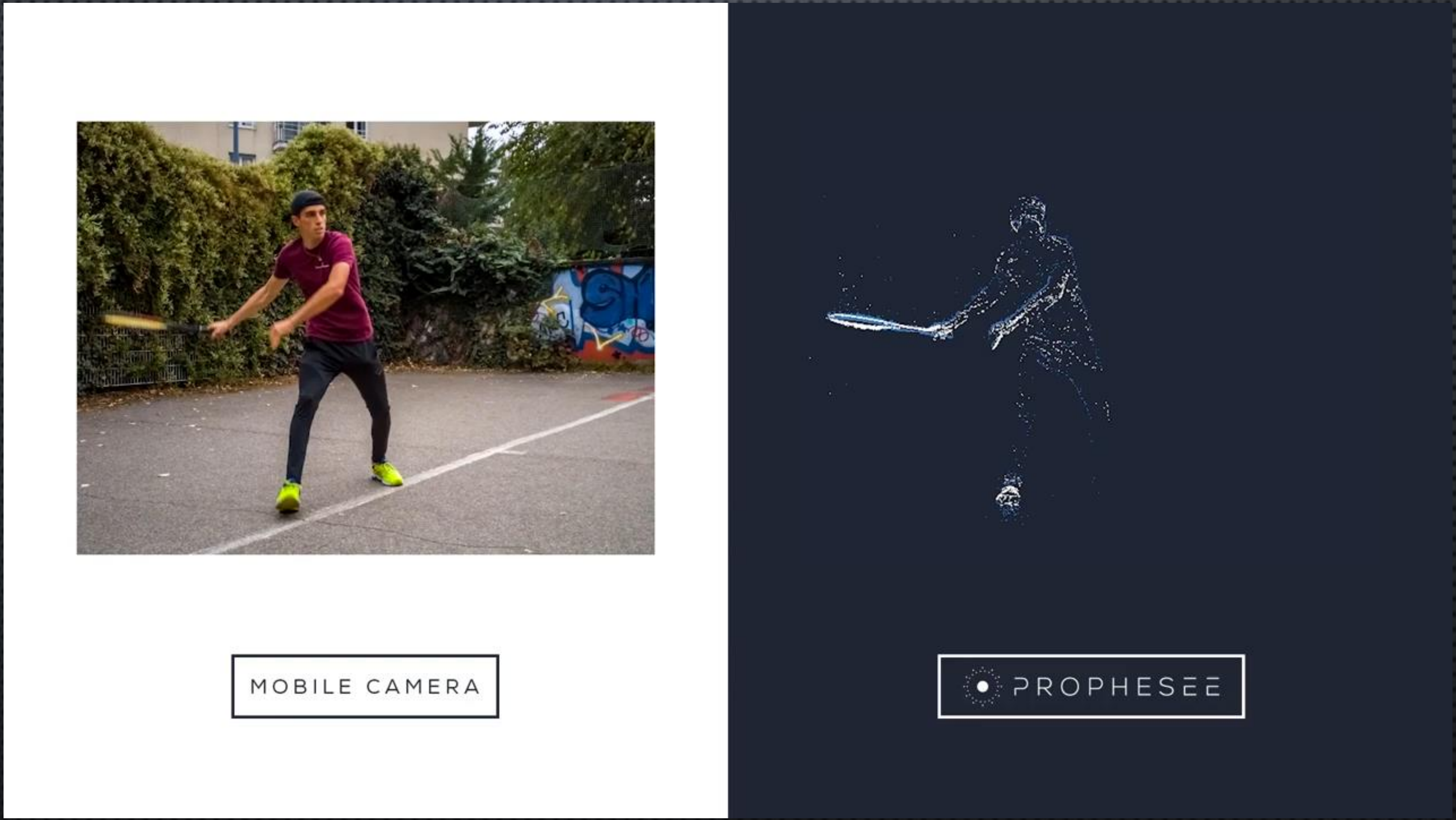


Motion detection: Hassenstein-Reichardt detector

- The "Hassenstein-Reichardt-Detector" represents a purely algorithmic model of motion detection to explain how visual systems, particularly in insects, detect and process motion.



Event Based Cameras



To summarise…

- Active
- Multimodal
- Vision-based perception

Intelligent perception can help generate intelligent actions…

Perception
- **Attention**
- **Motion perception**

Action

Intelligent action can lead to intelligent perception…

4.4 Multimodal Systems

To summarise…

1 Biological perception: sampling space over time

2 Active Sensing

3 Motion Perception

4 Multimodal System

7. CONCLUSIONS

“Those who side with any flag other than nature – the master of all masters – labour in vain.” Da Vinci