4

Sensorimotor integration

Perception-action relationship

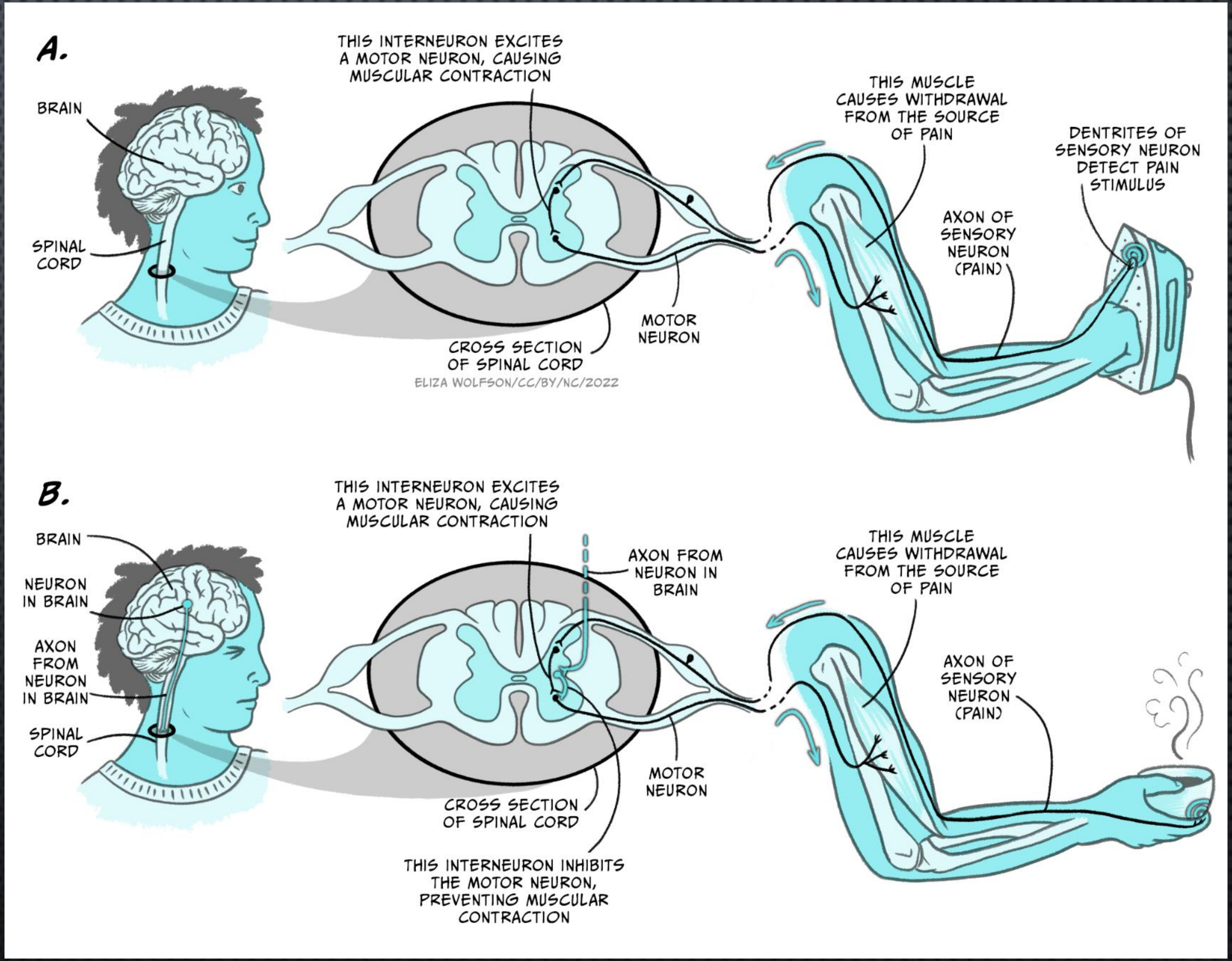
Content

1. Introduction

1. Introduction

1) Reflexes can control actions, by the integration of multiple sources of information to produce reflex actions.

2) The brain **overrode the polysynaptic spinal reflex** that was sensory-activated.

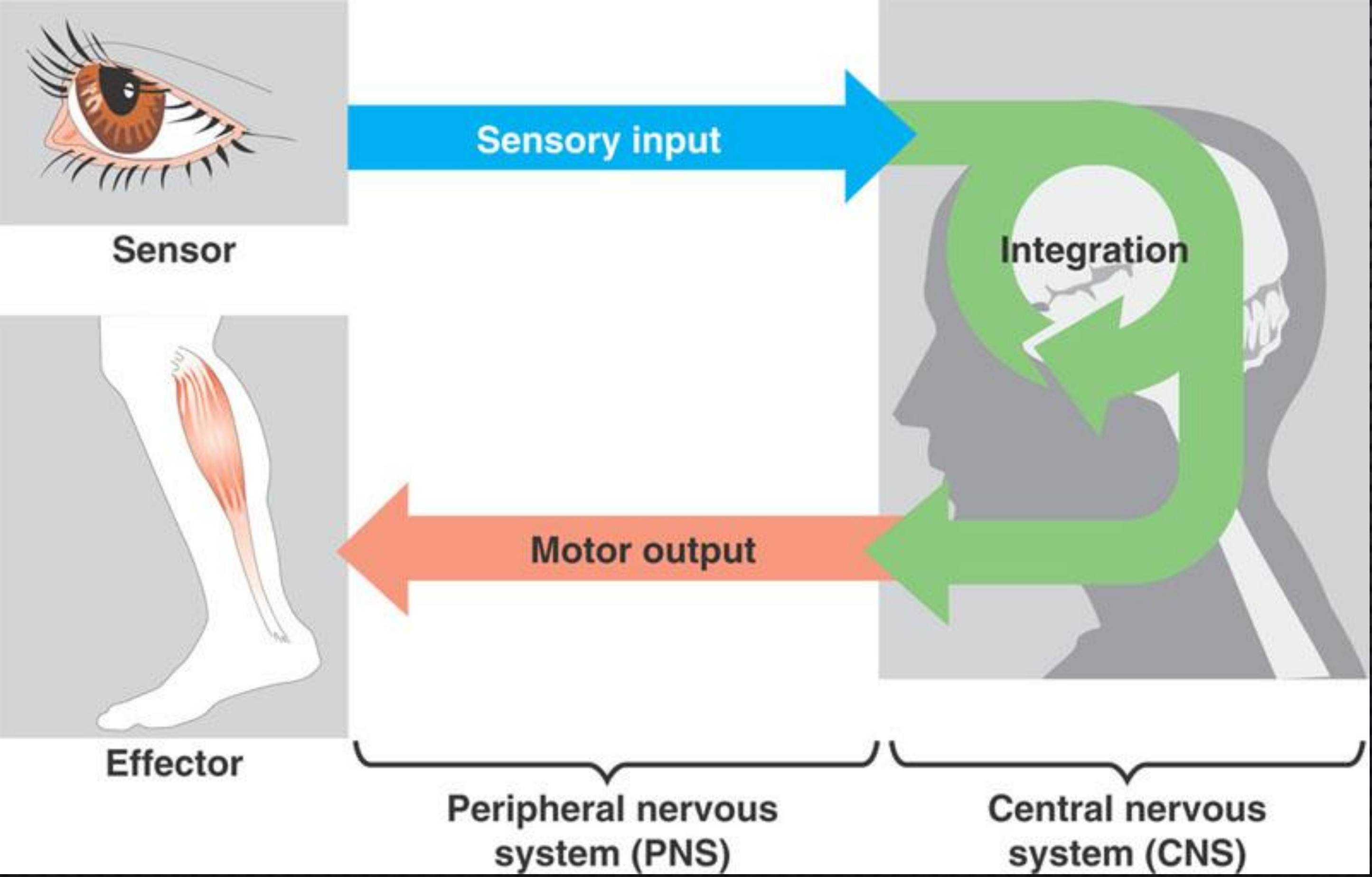


1. Introduction

Prompt: Generate a picture of someone touching an iron sole by mistake

Sensorimotor integration

Sensorimotor integration is a capability of the central nervous system to integrate different sources of stimuli, and parallelly, to transform such inputs in motor actions.

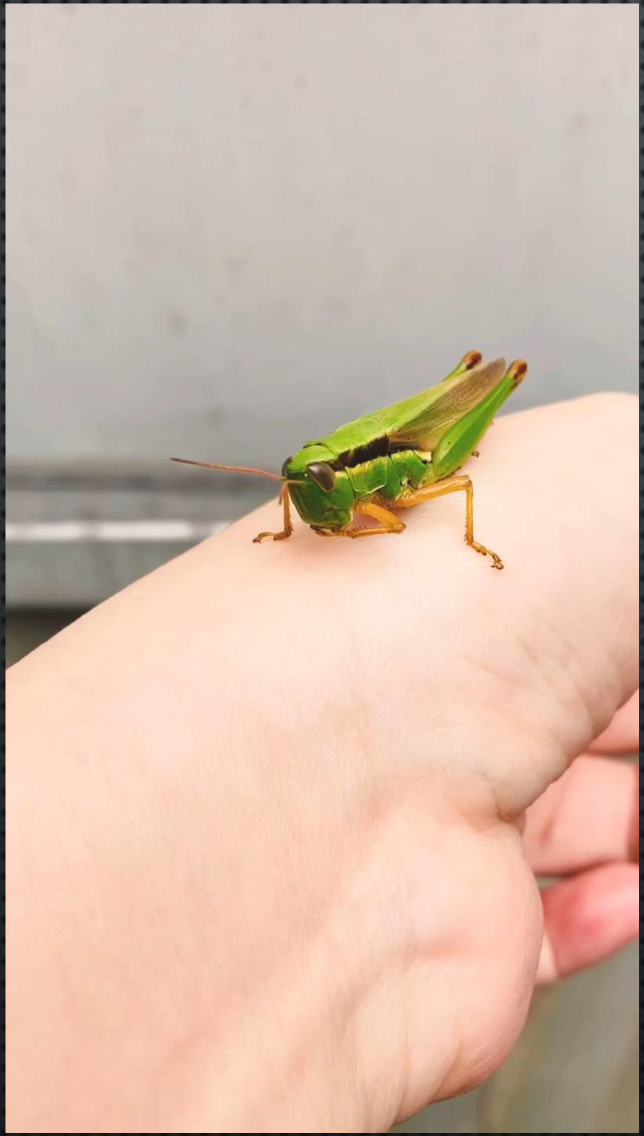


Characteristics

- Task-specific motor output
- Multiple sources
- Flexible
- Dynamic

For a given stimulus (sensor data), there is no one single motor command
→ No one algorithm for “sensorimotor integration”!

Sensorimotor integration in Nature



Grooming

Sensory Input: Mechanosensory (tactile stimuli) or chemosensory noxious stimulus.

Motor Output: Leg scratching

Modulation and plasticity: Leg compensation

Huston, Stephen J; Jayaraman, Vivek (2011). "Studying sensorimotor integration in insects". *Current Opinion in Neurobiology*. doi:10.1016/j.conb.2011.05.030.

Sensorimotor integration in Nature

Table 1

Examples of insect sensorimotor integration.

Behavioral goal	Sensory input	Motor output	Modulation and plasticity	Example model systems
Grooming	Mechanosensory, for example, tactile stimulation of wing. Chemosensory, for example, localized noxious stimulus.	Targeted leg scratching movements.	Leg trajectory compensates for leg initial position [5]. Leg movements adapt to changes in proprioceptive feedback [9].	Locust [5].
Gap crossing/ Obstacle avoidance	Visual, for example, terrestrial edges. Mechanosensory, for example, antennal contact.	Reaching leg movements. Changes in step size and posture.		Locust [6], fly and cockroach [10,11].
Course and gaze stabilization	Visual: optic flow.	Change in direction of locomotion and gaze.	Behavioral gain depends on state: flight, walking or standing [12].	Fly, bee, snout beetle
Feeding	Gustatory, for example, sugar water. Olfactory, for example, food odor.	Extension of proboscis.	Modulated by: Hunger state. Olfactory conditioning [8].	Bee [8], fly [13].
Sound localization	Auditory, for example, species specific song.	Change in direction of locomotion.		Parastitoid fly (*Ormia*) [14], cricket [15].
Chasing	Visual: small objects, for example, prey or conspecifics.	Change in direction of locomotion.		Housefly, hoverfly [16], dragonfly [2].
Object fixation/ discrimination	Visual patterns.	Change in direction of locomotion.	Behavioral choices modulated by prior experience [17–19].	Bee [17], fly [18,19].
Olfactory localization/ Discrimination	Olfactory, for example, attractive odor.	Change in direction of locomotion.	Modulated by visual surround [20]. Can be modified by prior experience [21].	Moth, fly [22].
Escape	Visual: looming. Mechanosensory: wind cues.	Jump, flight initiation or avoidance maneuvers.	Preparatory leg movements for escape jump depends on initial posture [23]. Behavior can habituate.	Locust [4•], fly, cockroach, cricket.
Navigation	Skylight; polarization pattern.	Change in direction of locomotion.		Cricket, locust [24•], butterfly [25], honeybee [26].

Huston, Stephen J; Jayaraman, Vivek (2011). "Studying sensorimotor integration in insects". *Current Opinion in Neurobiology*. doi:10.1016/j.conb.2011.05.030.

Sensorimotor integration

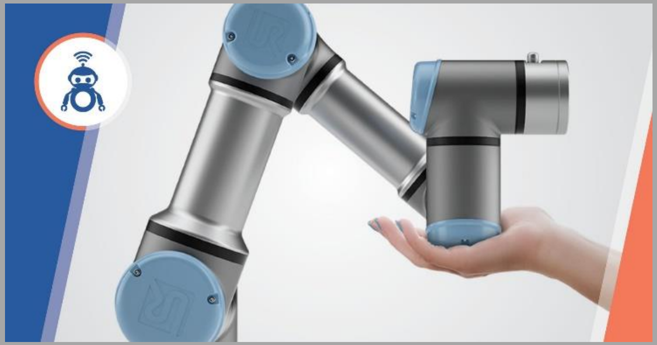
Find an example or application of sensorimotor integration.

You might use your robot as an example and present how you could implement a simple sensor motor integration.

https://padlet.com/juanesheme/real-world-applications-brainstorm-mn1ux87c90ytpnei

Sensorimotor integration

Example: Collision Detection in Collaborative Robots

Sensing: Force, torque sensors, or camera

Integration: Determine if the perturbance is a collision.

Action: Engage the brakes

Sensorimotor integration

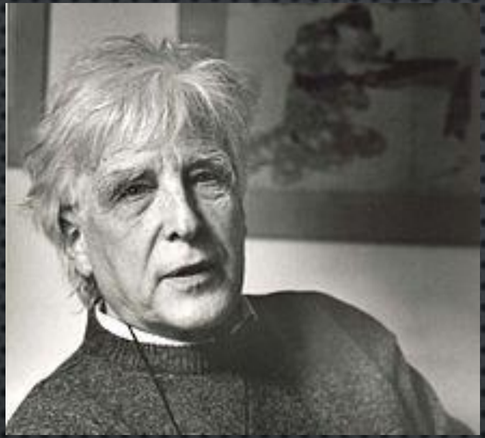
Find an example or application of sensorimotor integration.

You might use your robot as an example and present how you could implement a simple sensor motor integration.

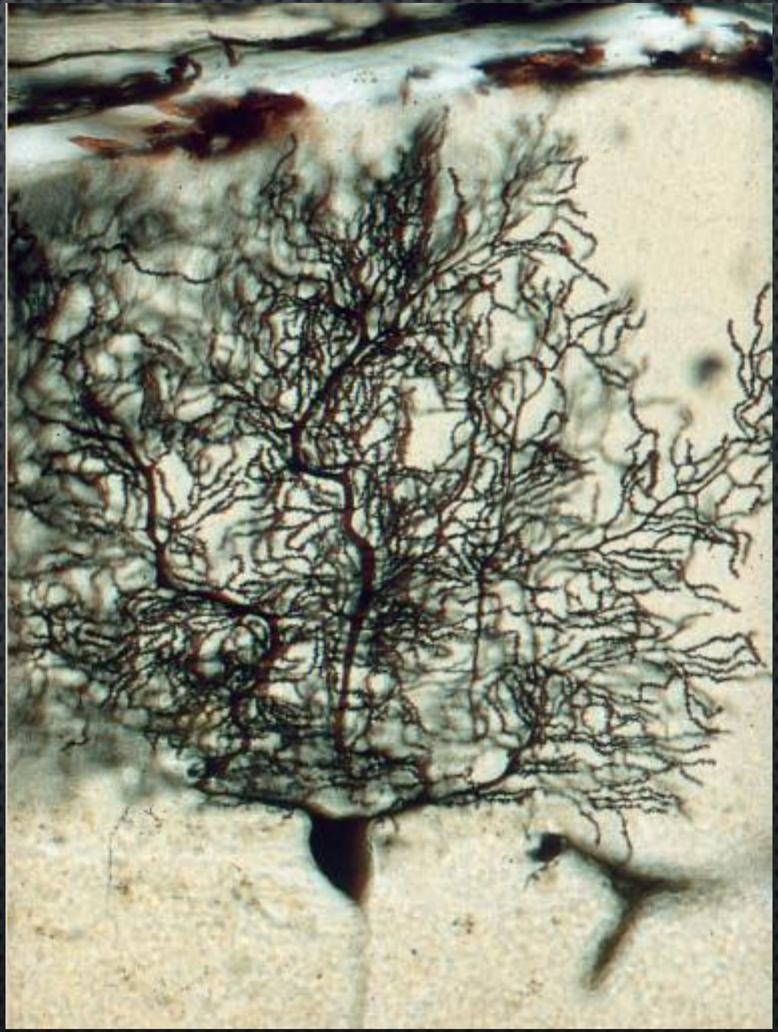
https://padlet.com/juanesheme/real-world-applications-brainstorm-mn1ux87c90ytpnei

2. Braitenberg Vehicles

Braitenberg vehicles: simple sensorimotor integration



Describe the typical structure of a certain part of the brain in order to deduce its function (SPYING on GOD).



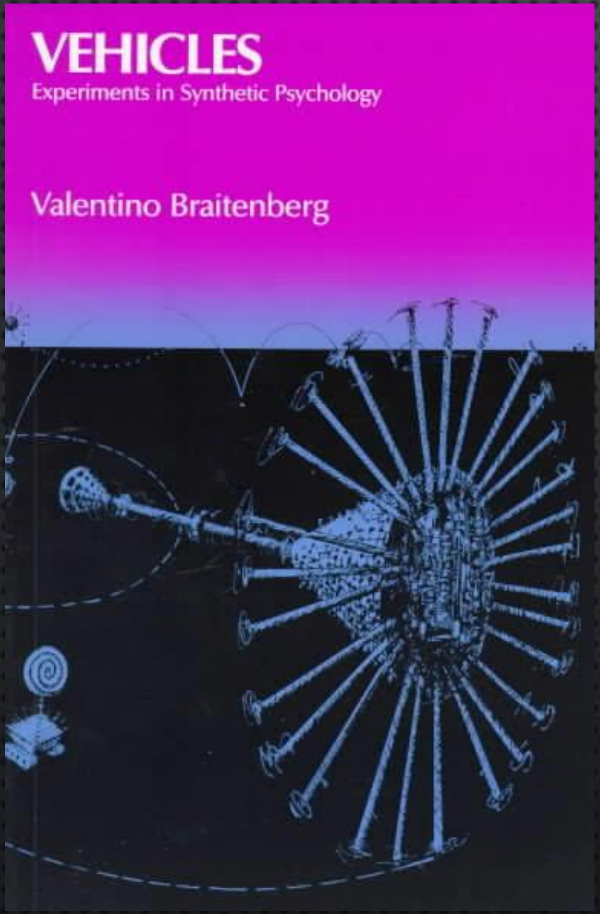
Spying on God

For **Valentin Braitenberg**, the brain was the most interesting research subject in the world, apart from the world itself. A former Director at the **Max Planck Institute for Biological Cybernetics** in Tübingen, he spent thousands of hours poring over a microscope to get to the bottom of this most complex of organs. His purpose was to examine the fiber pathways in various areas of the brain and to search for their functions.

TEXT **ELKE MAIER**

Braitenberg vehicles: simple sensorimotor integration

The brain connections are unbelievably complex, computers could serve as a useful model for understanding the brain.



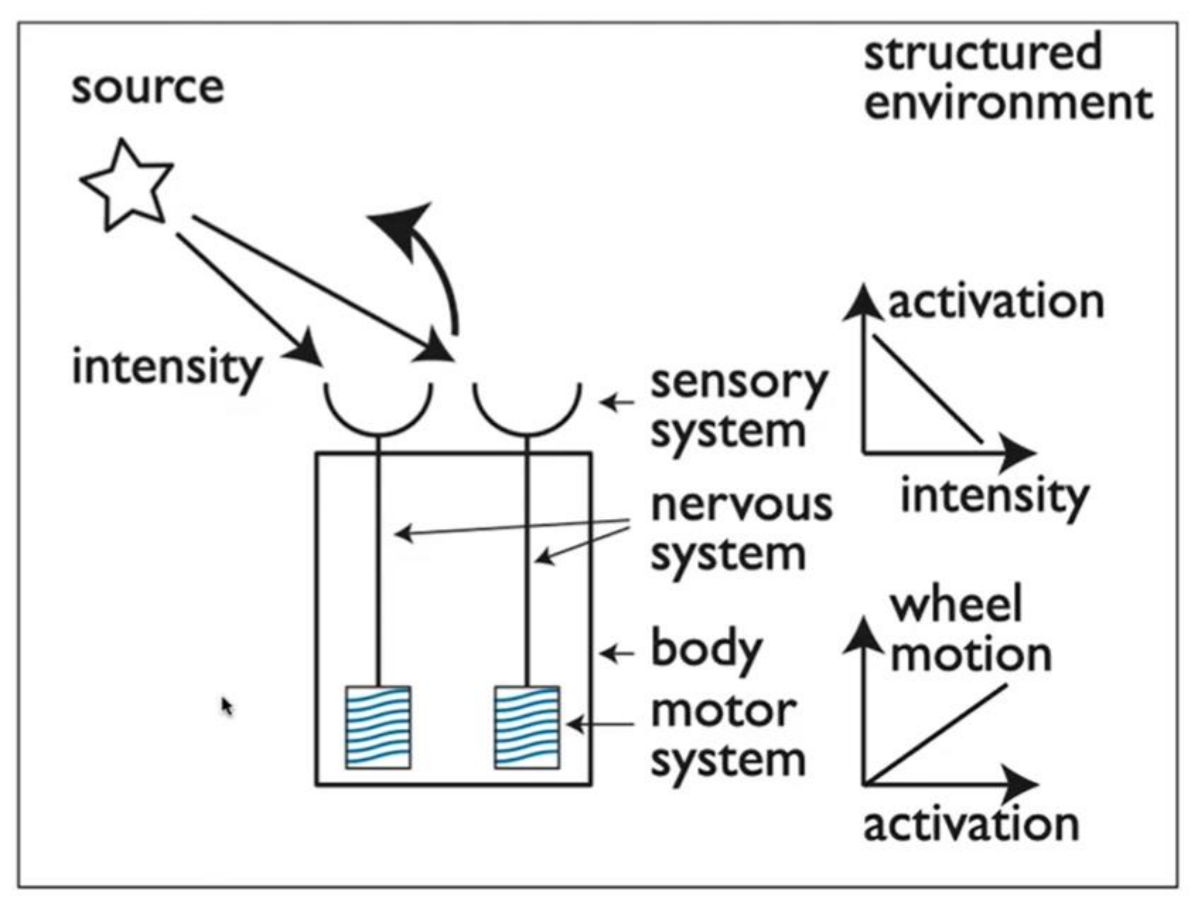
- Proposed by Valentino Braitenberg in 1984 book "Vehicles: Experiments in synthetic psychology"
- Exploring relation between structures and functions of the brain
- Hypothetical analogue vehicles (a combination of sensors, actuators and their interconnections)
- Vehicles displayed behaviours akin to aggression, love, fear, and exploration

Braitenberg vehicles: simple sensorimotor integration

Components of the vehicle:

- Sensors
- Nervous System
- Actuators
- Body
- Environment

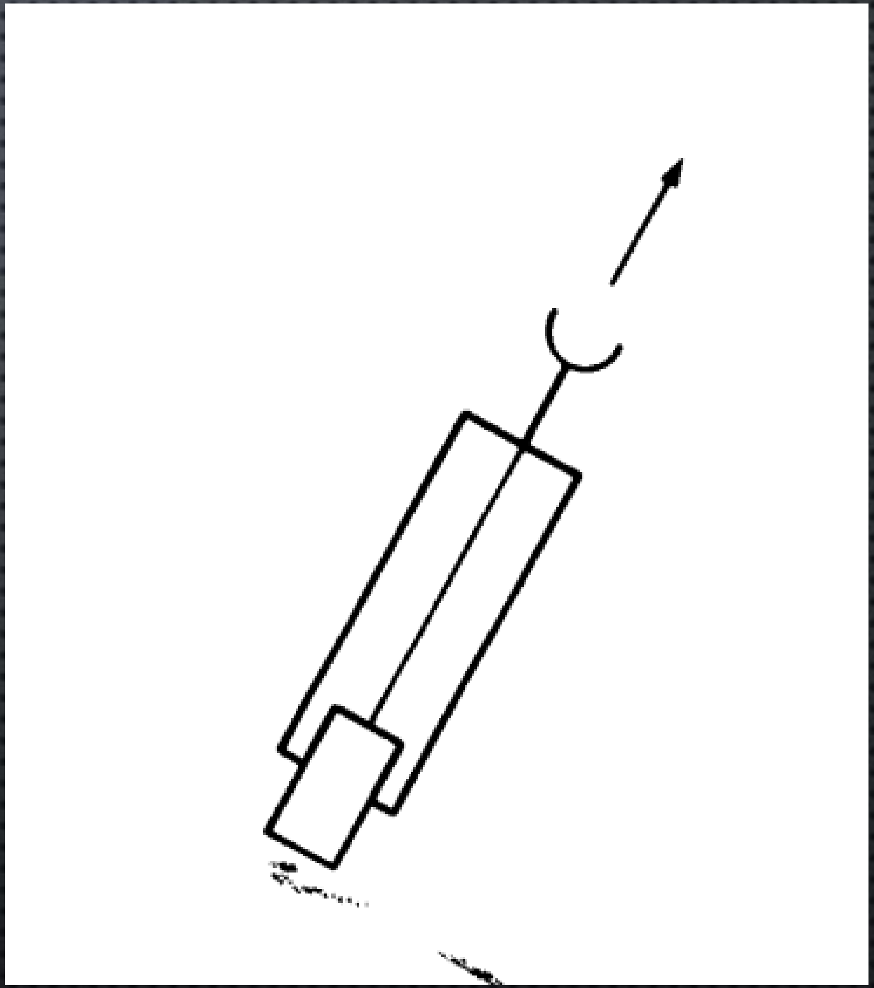
Emergent Function



Braitenberg vehicles: simple reactive control

- Functioning of the vehicle is purely mechanical, without any information processing or other apparently cognitive processes.
  - A sensor is directly connected to an actuator (e.g. light sensor → wheel motor)

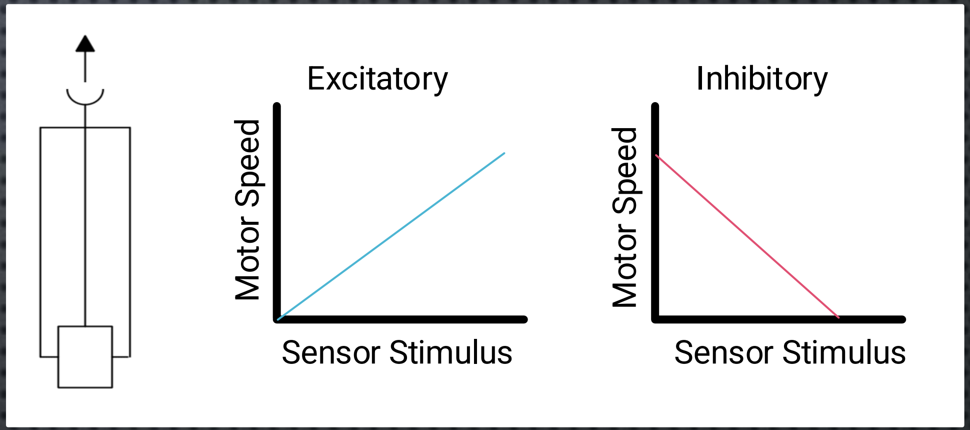
- Depending on how sensors and wheels are connected, the vehicle exhibits different movement behaviours.



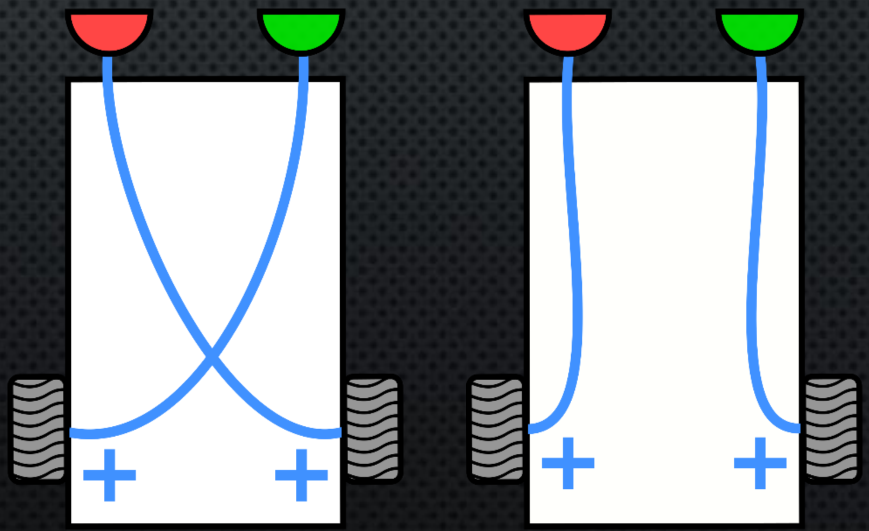
Braitenberg vehicles: simple reactive control

Connections

- Excitatory or inhibitory connections

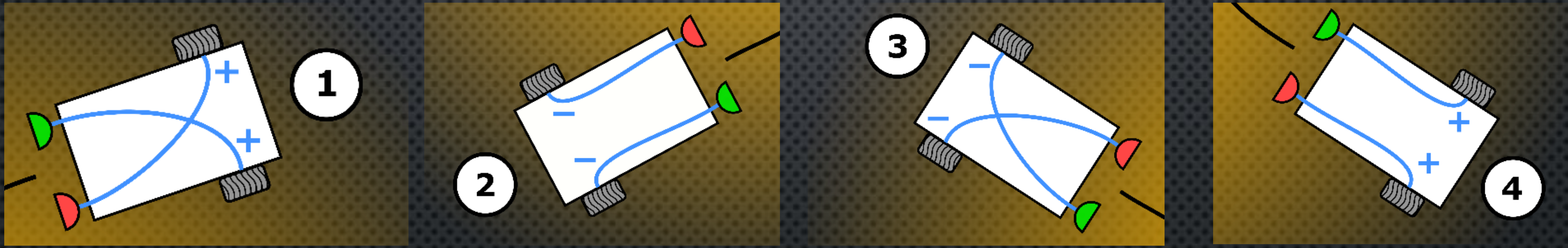


- Ipsilateral or contralateral connections



Some basic Braitenberg vehicles

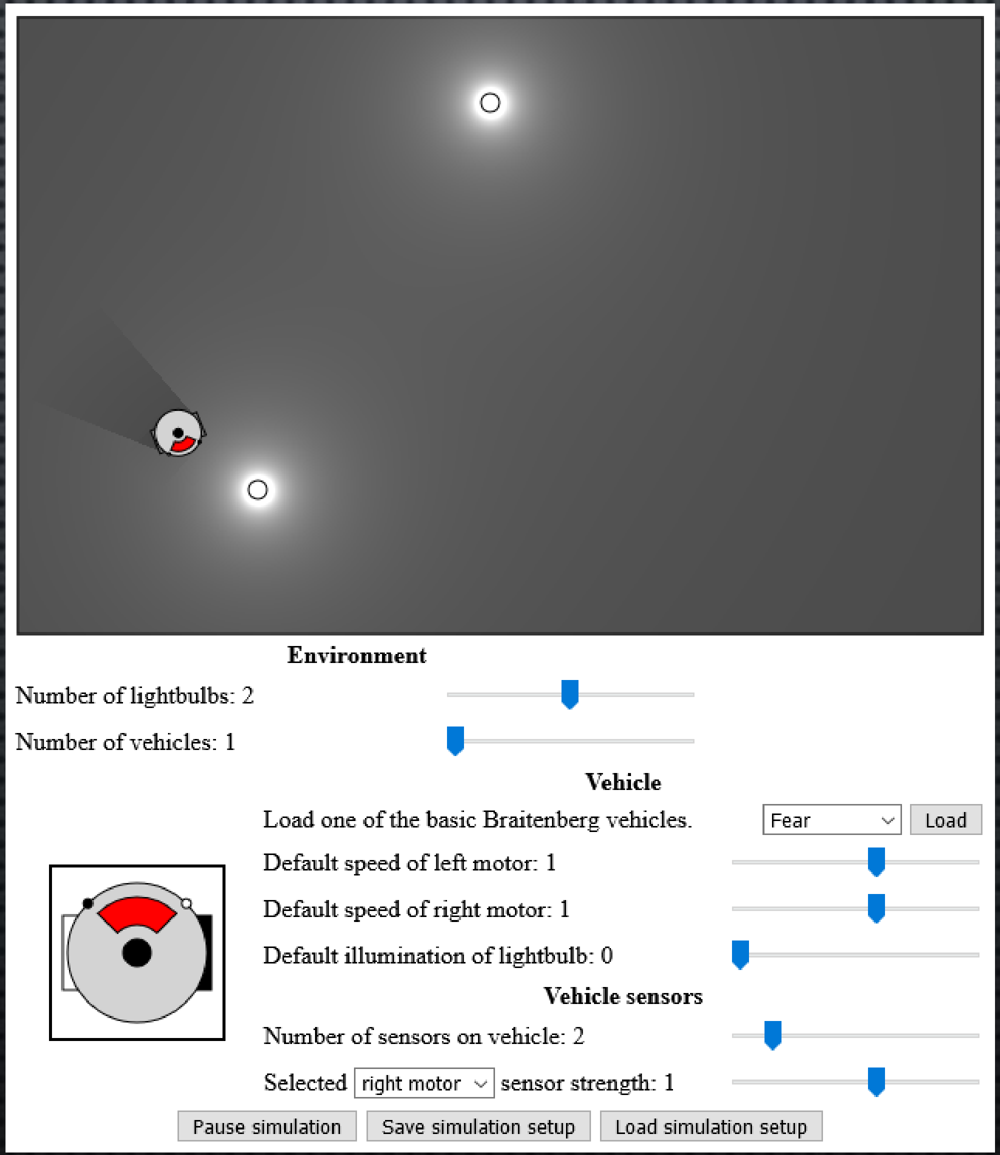
Fear, Aggression, Exploration, Love ?



Aggression vs Fear

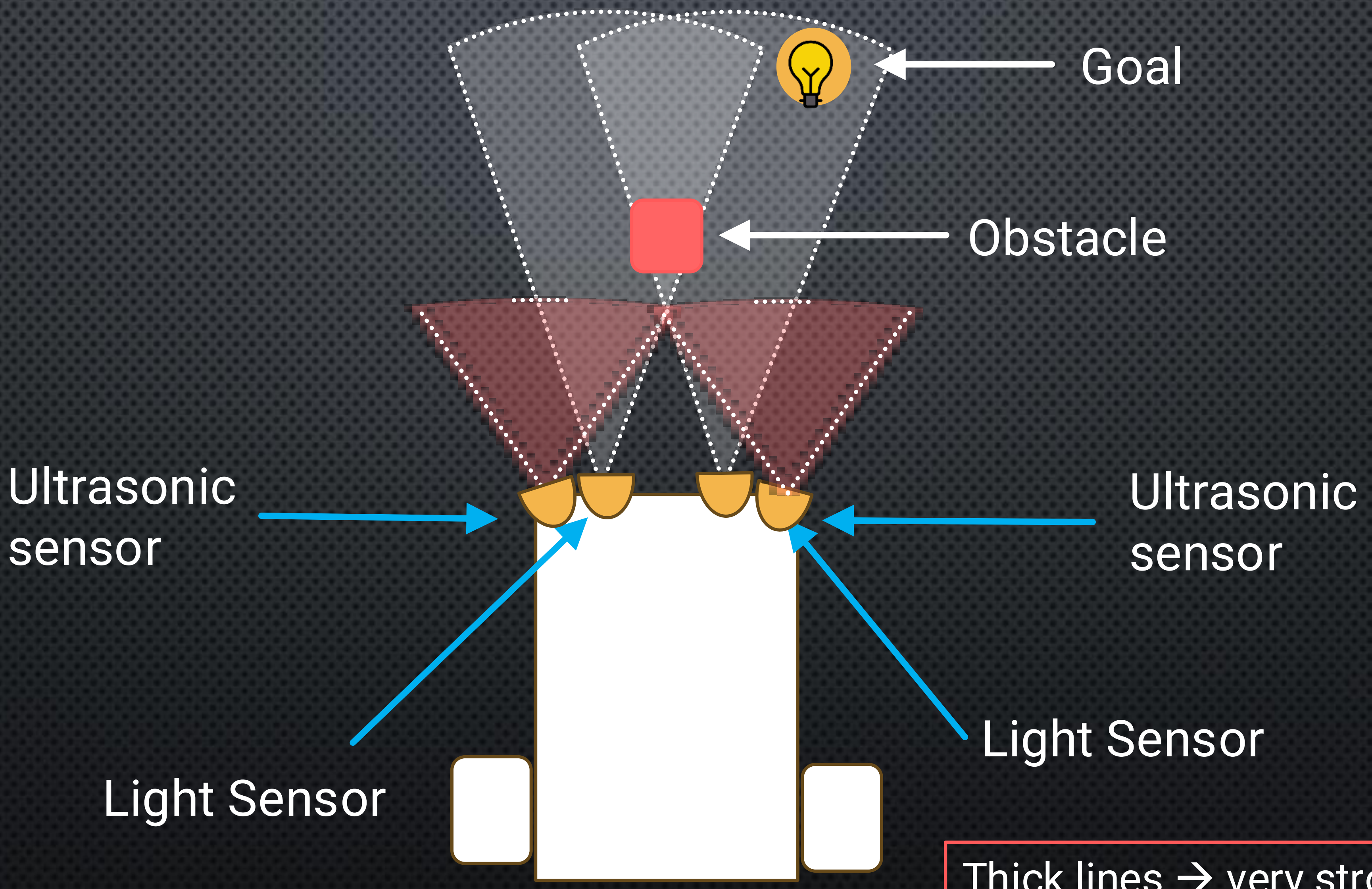
https://www.youtube.com/watch?v=NJo5HEdq6y0

Play time: Braitenberg vehicle playground



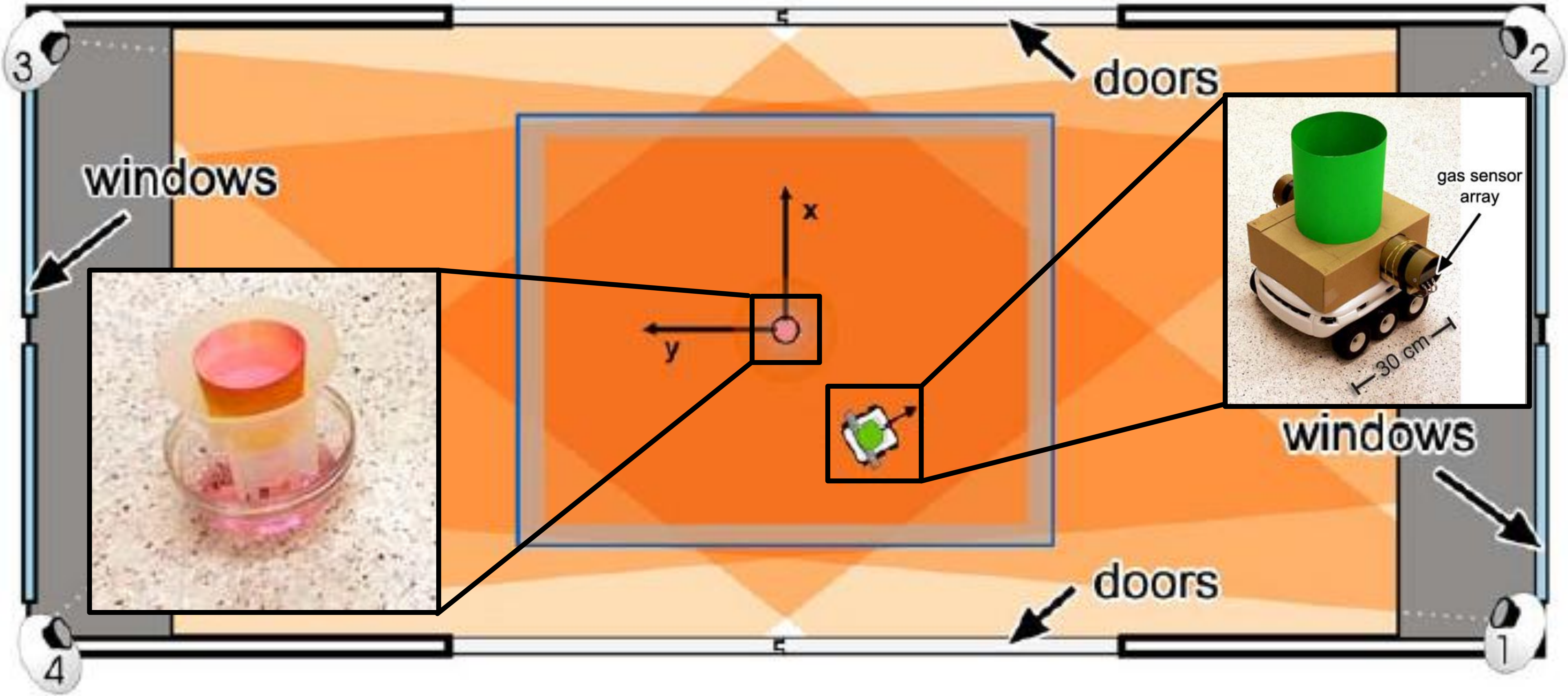
http://www.harmendeweerd.nl/braitenberg-vehicles/

How will connect this vehicle?



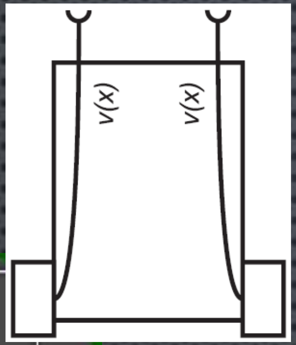
Thick lines → very strong coupling
Thin lines → very weak coupling

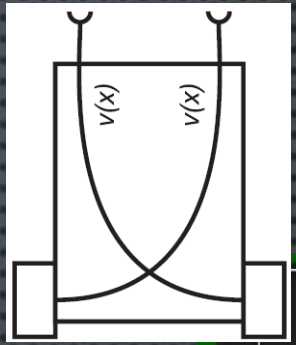
Example: gas mapping with Braitenberg vehicles



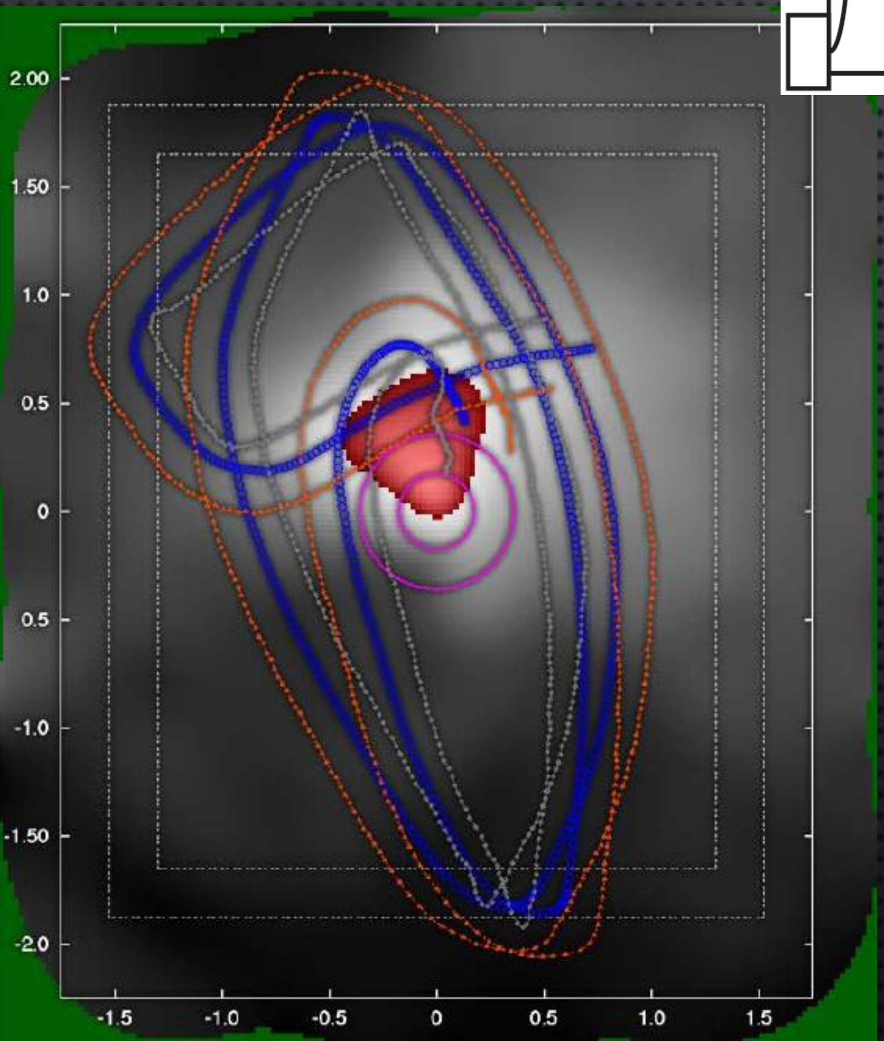
Achim Lilienthal & Tom Duckett (2004) Experimental analysis of gas-sensitive Braitenberg vehicles, Advanced Robotics, 18:8, 817-834, DOI: 10.1163/1568553041738103

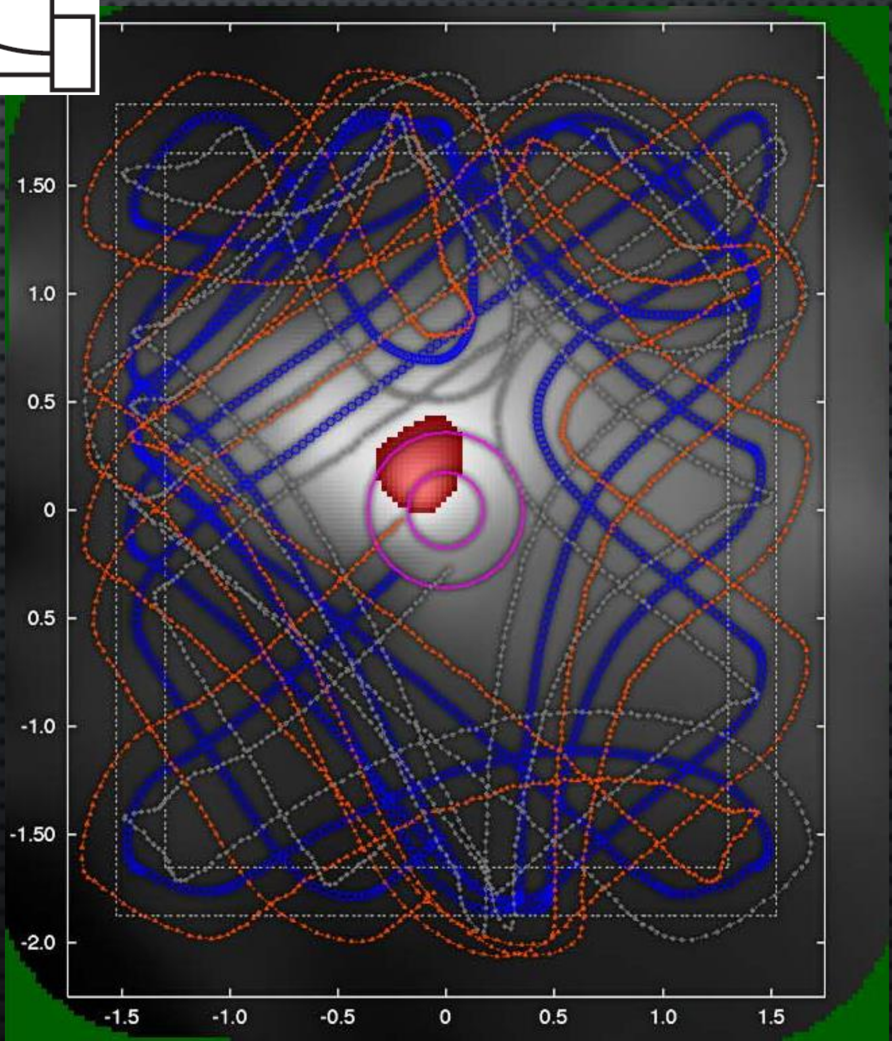
Example: gas mapping with Braitenberg vehicles





$$v(x) = K_v(1 - x)$$





A case for Braitenberg vehicles

The artificial solution

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

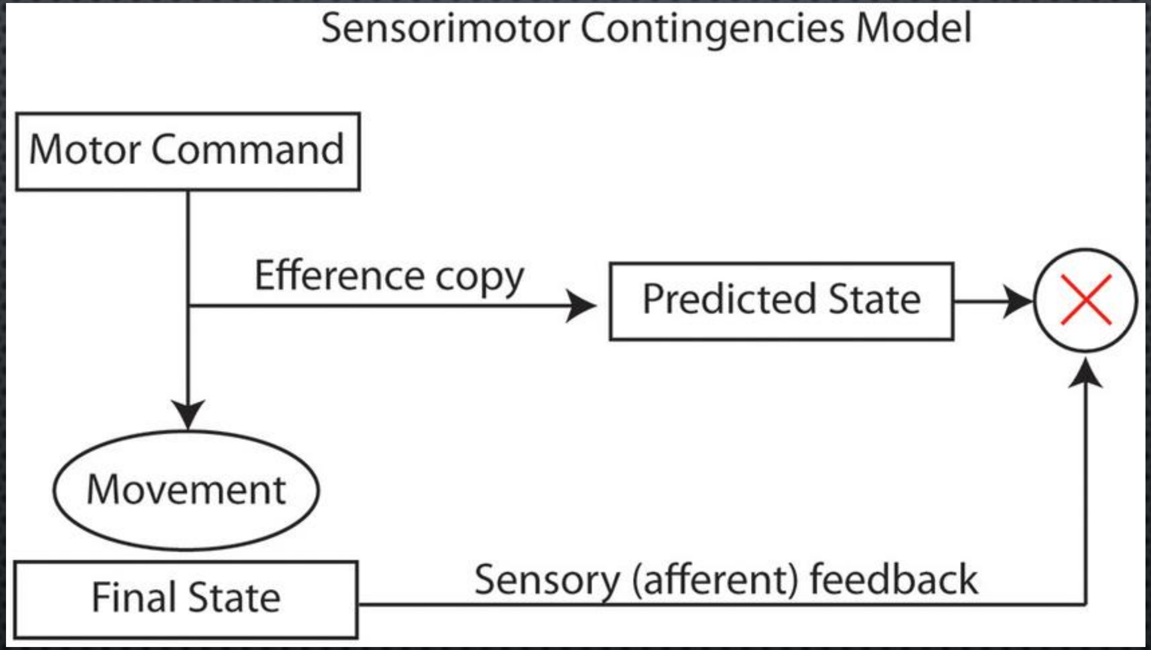
The natural solution

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

3. Sensorimotor Contingencies (SMC)

Contingency: a future event which is possible but cannot be predicted with certainty.

SMCs describe how changes in an agent's actions (motor output) lead to predictable changes in sensory inputs from the environment.



Perception is dependent on the movements of the agent within its environment and how these movements influence what it senses.

3. Sensorimotor Contingencies (SMC)

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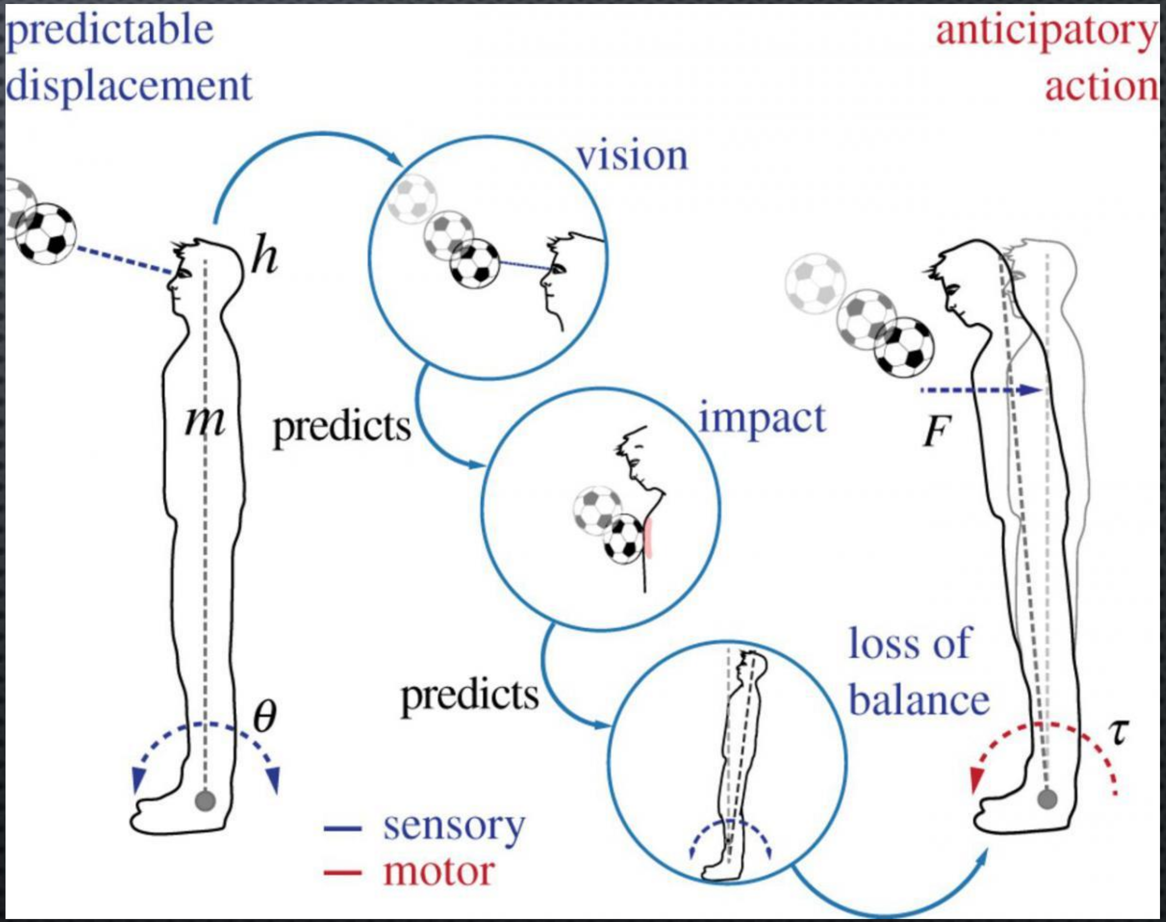
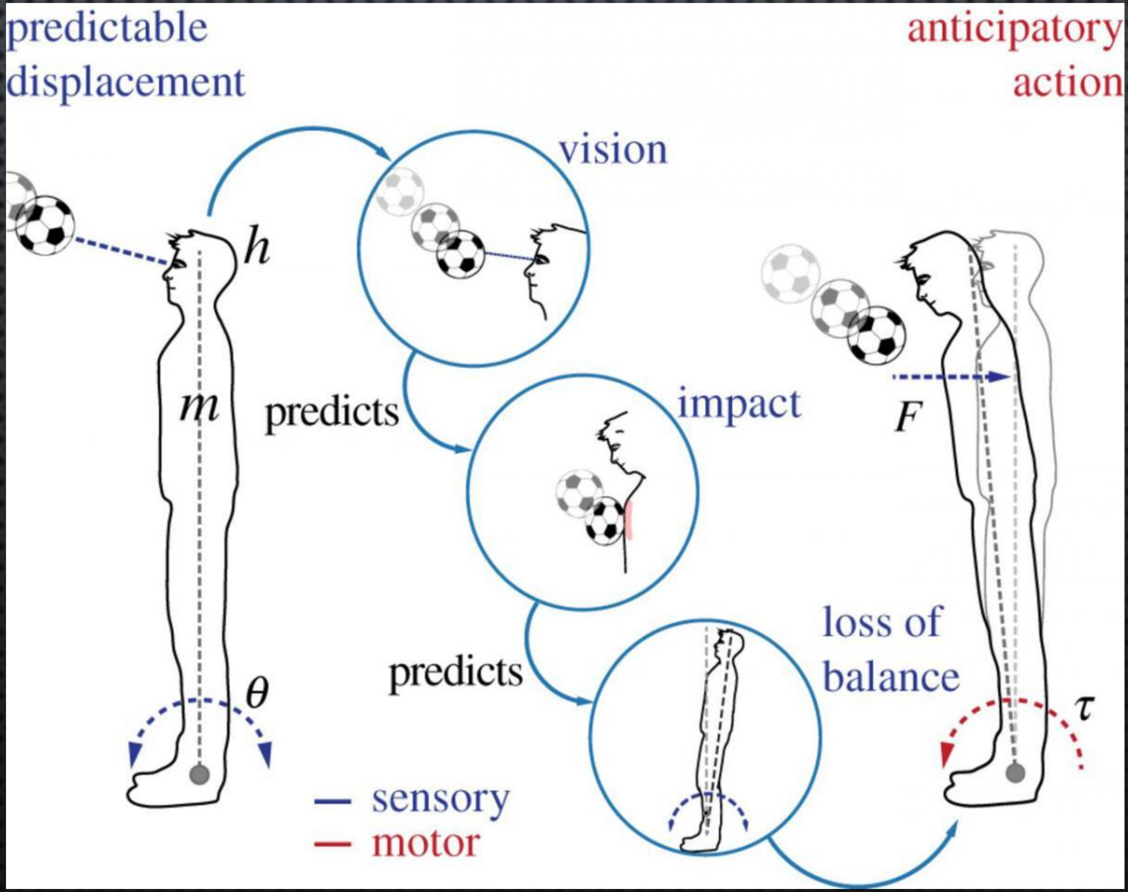
- SMCs exploits regularity in how sensory information depends on movement (motor commands) and vice versa
- Inter-dependence between sensory information and motor commands is captured by internal models



How to use SMCs?

- Adaptive Control of Movement

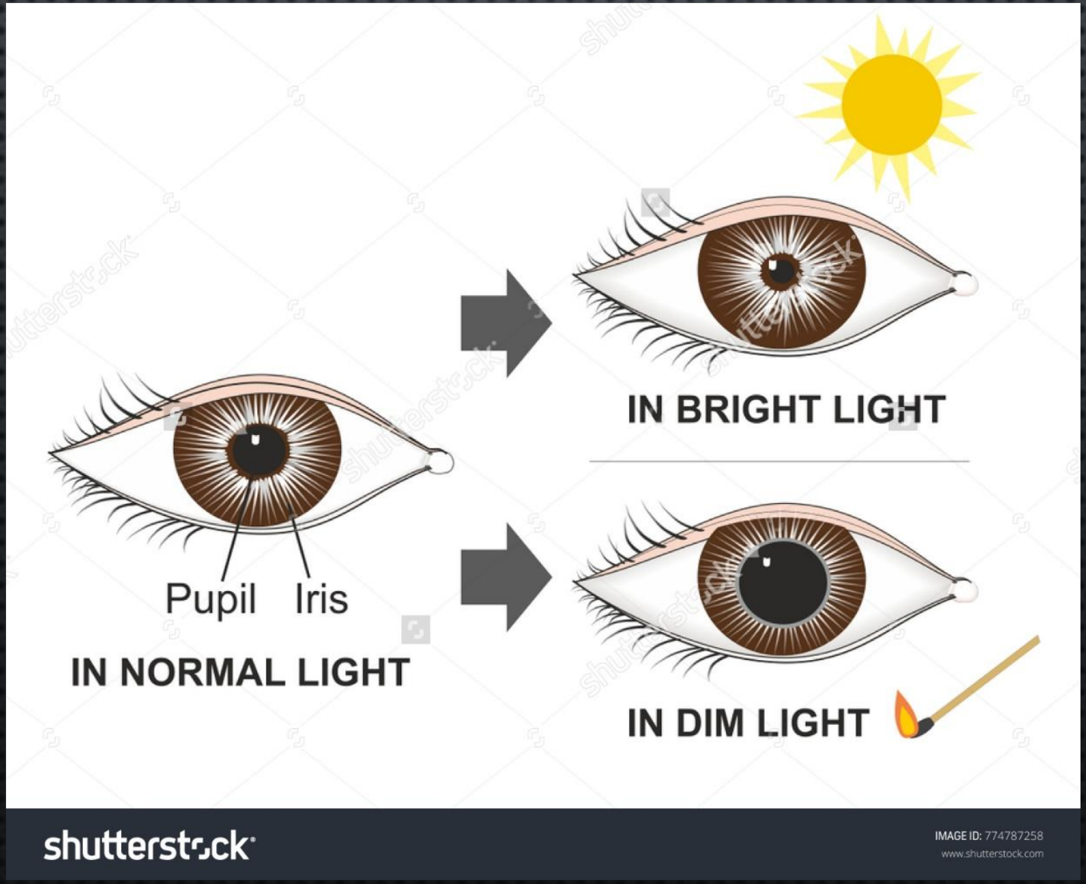
Agents can **predict the consequences of their actions**.



How to use SMCs?

- Enhancing Perception through Action

SMCs suggest that perception is not passive but actively shaped by movement.



How to use SMCs?

- Co-evloutiuon Perception and Action

Perception and action are co-dependent, meaning perception improves as motor skills improve and vice versa.

How to use SMCs?

- Learning and Generalizing from Experience

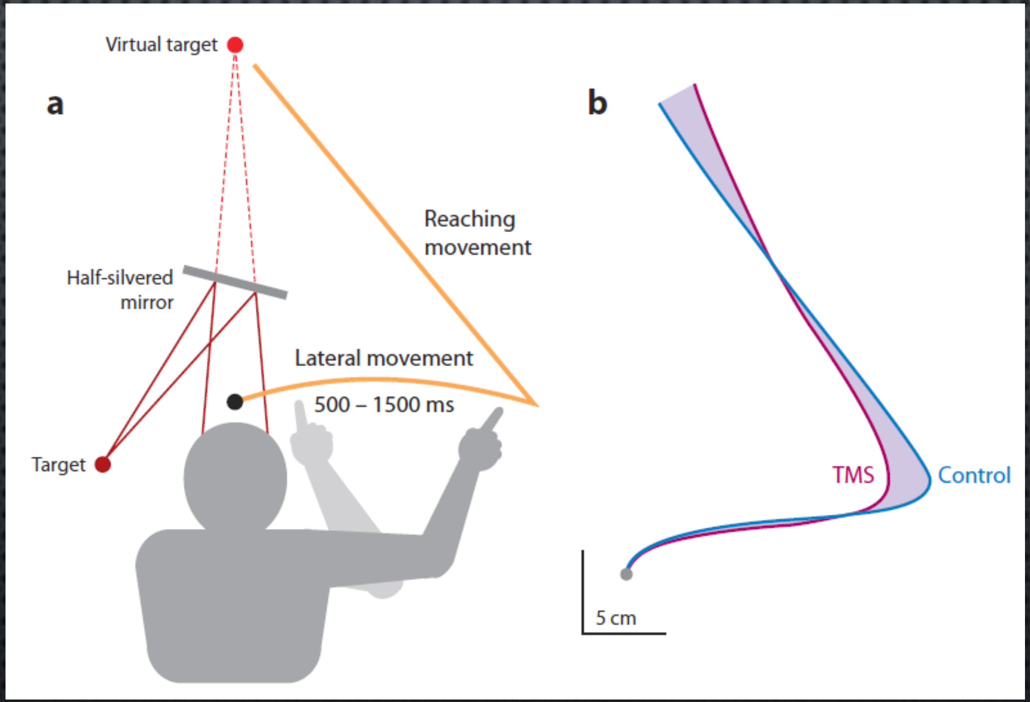
Agents (robots or humans) learn sensorimotor contingencies through experience and adapt them to new situations.

How to use SMCs?

- **Active Perception:** How action shapes sensory input (e.g., moving a camera to get better visual data).
- **Adaptive Control:** Using sensory feedback to adjust and refine motor actions in real-time.
- **Learning SMCs:** How agents (robots or humans) learn sensorimotor contingencies through experience and adapt them to new situations.
- **Perception-Action Co-evolution:** As motor skills improve, perception becomes more refined, and vice versa.

Sensorimotor contingencies (SMC)

Volunteers were asked to move their hand laterally until they heard a tone, at which point they would reach toward a target.
1) Normal Control
2)The cerebellum was disrupted via a TMS pulse soon after the tone.



The brain appears to maintain accuracy by using a forward model that predicts the sensory consequences of motor commands.

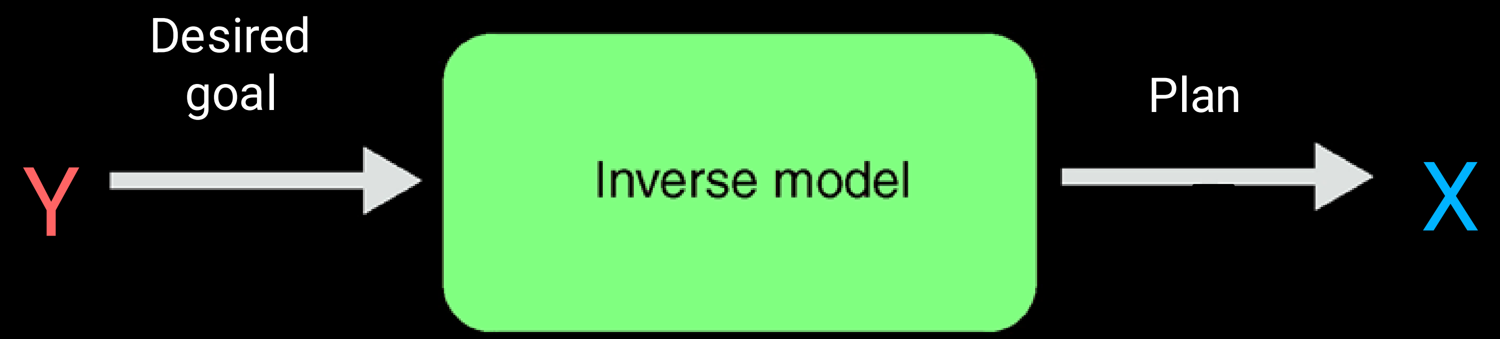
Shadmehr, Reza; Smith, Maurice A.; Krakauer, John W. (2010). " (PDF). *Annual Review of Neuroscience*.

4. Internal Models

Inverse model

I want Y to happen , what do I need to do to achieve it? X!

- Takes a desired goal as input and determines a plan to achieve the goal
- Can be either without or with sensory feedback
- Using only sensory feedback can be slow to respond because of delays in environment generating feedback



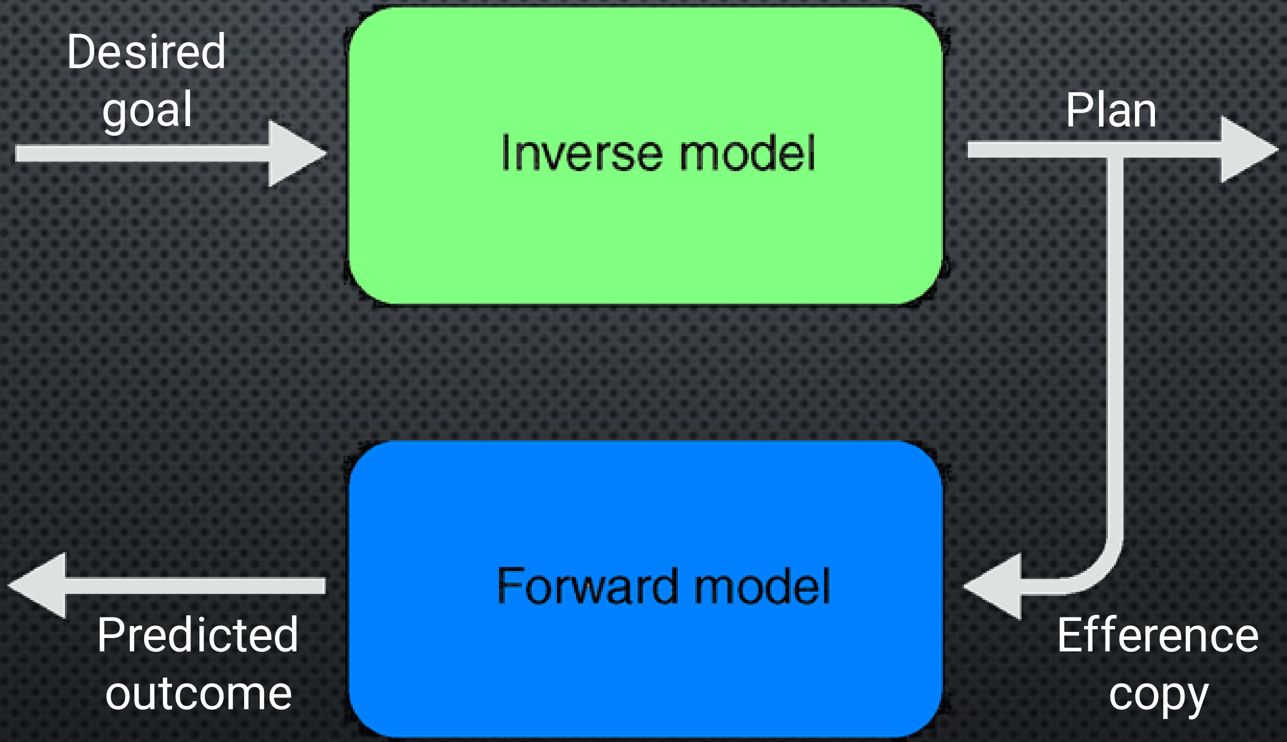
4. Internal Models

Forward model

If I do X , Y will happen!

- Takes a copy of the plan as input and predicts outcome of the plan as output
- Predicted feedback can compensate for delay in real sensor feedback ➔ faster response

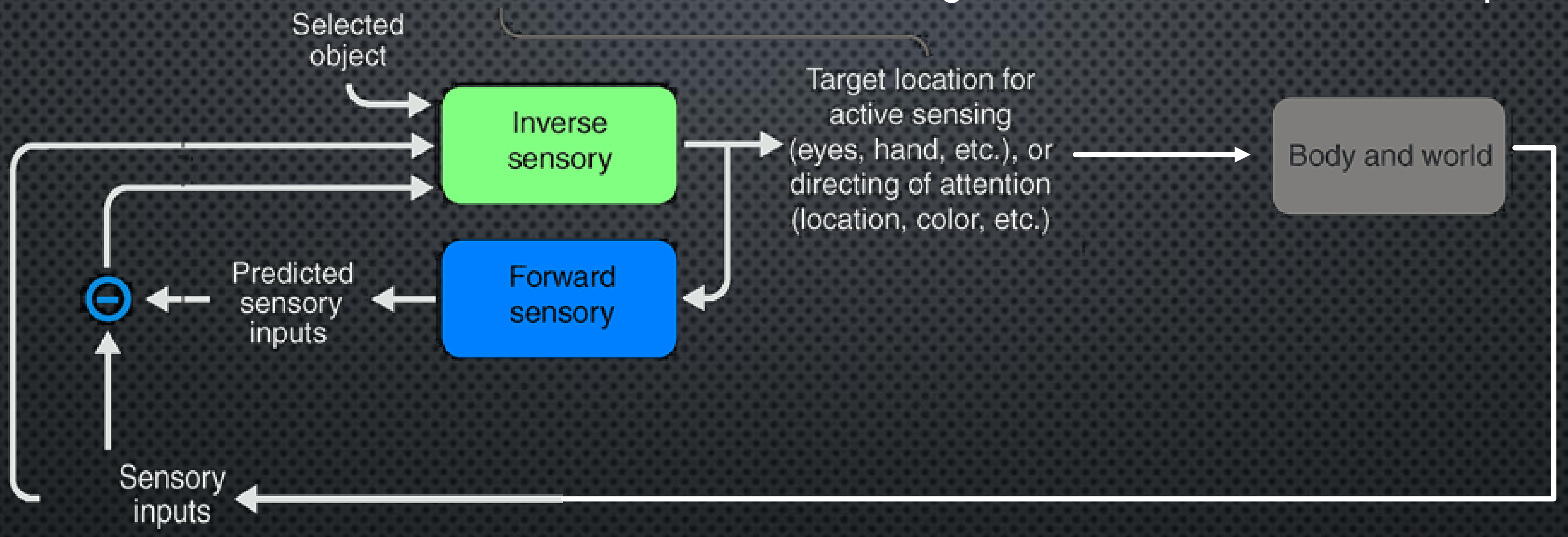
4. Internal models



Why Internal Models are Important ?

Error Correction: They help agents anticipate errors and correct movements in real time

Efficiency: Internal models allow systems to act proactively, reducing the need for constant feedback loops and making actions more fluid and adaptive



Adaptation: Internal models can be updated based on experience, making systems more adaptable to changing environments or body dynamics (e.g., growing children or robots carrying different payloads).

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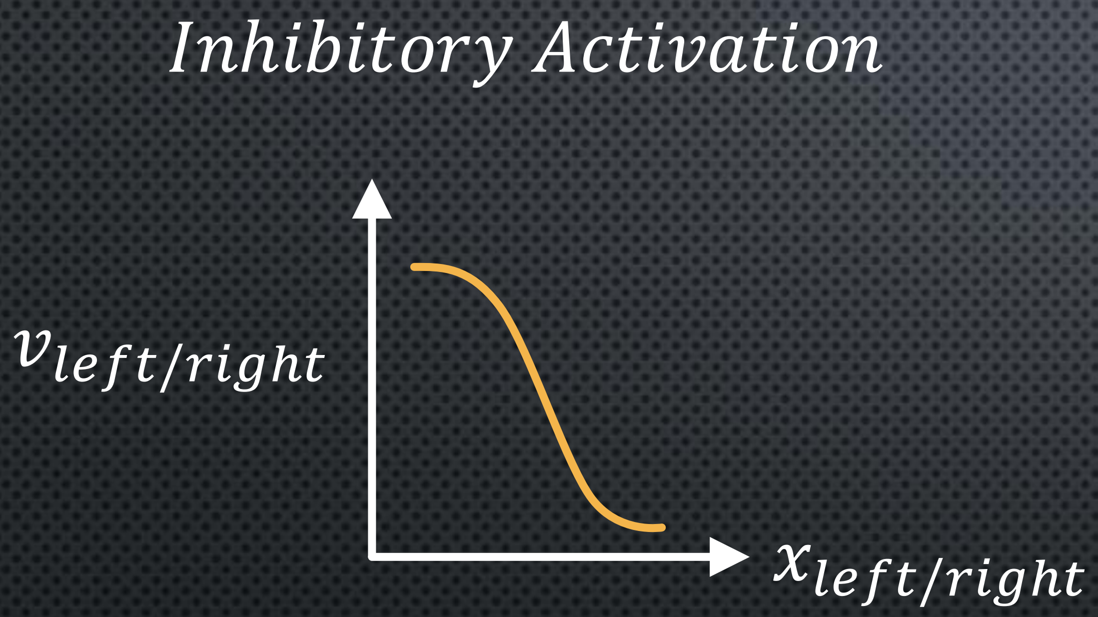

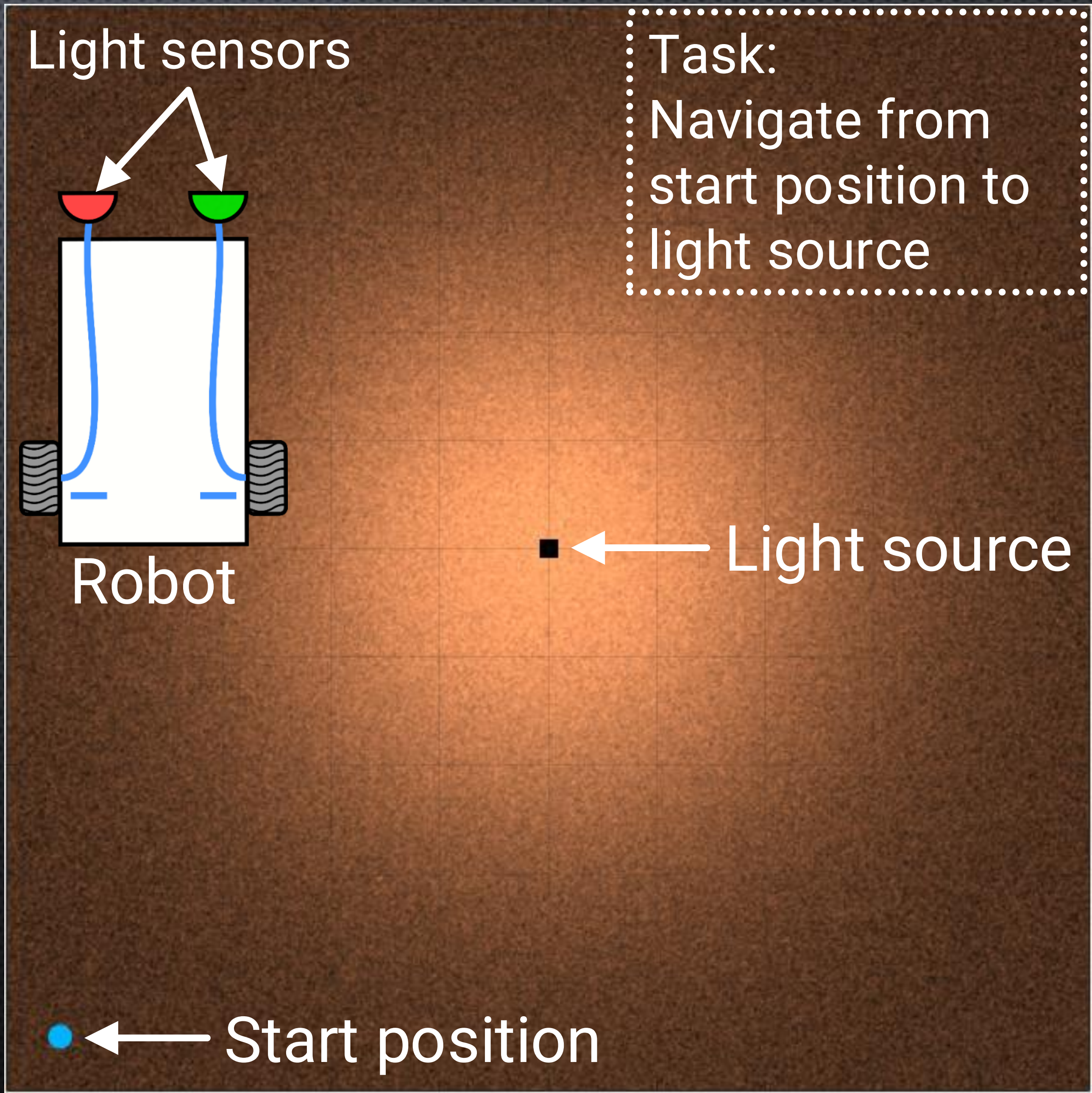

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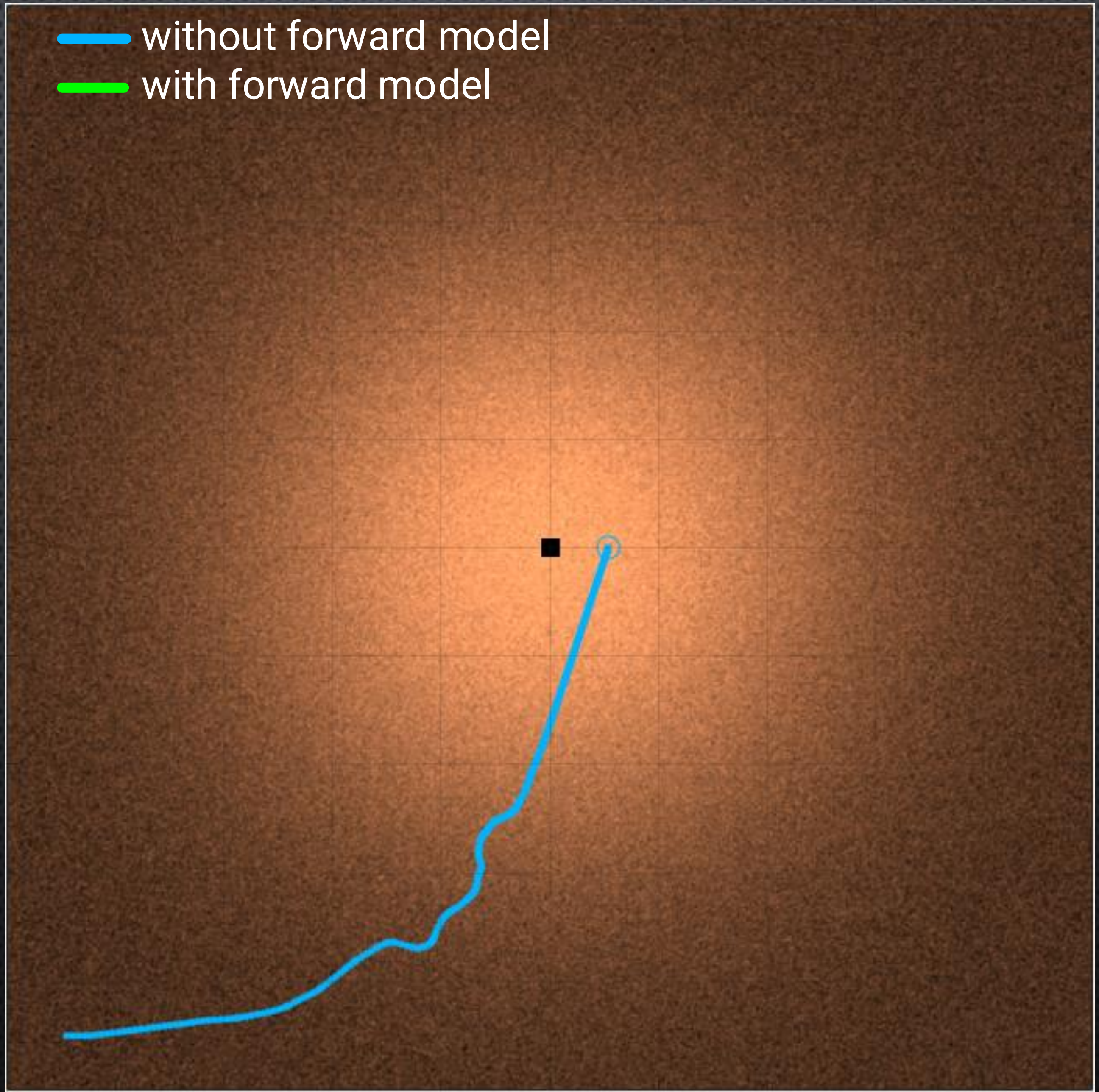
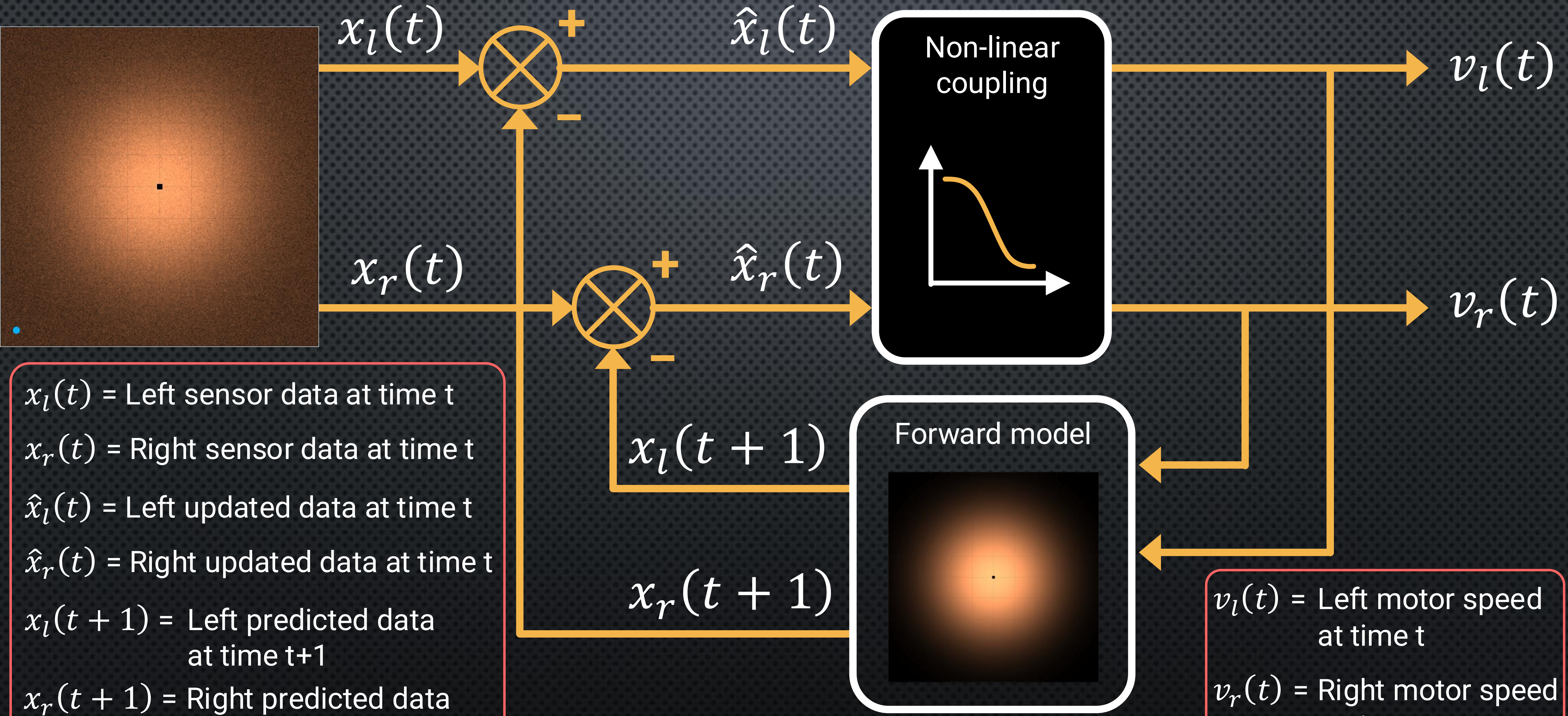


Example: forward models to predict and correct sensor values



$x_l(t)$ = Left sensor data at time t

$x_r(t)$ = Right sensor data at time t

$\hat{x}_l(t)$ = Left updated data at time t

$\hat{x}_r(t)$ = Right updated data at time t

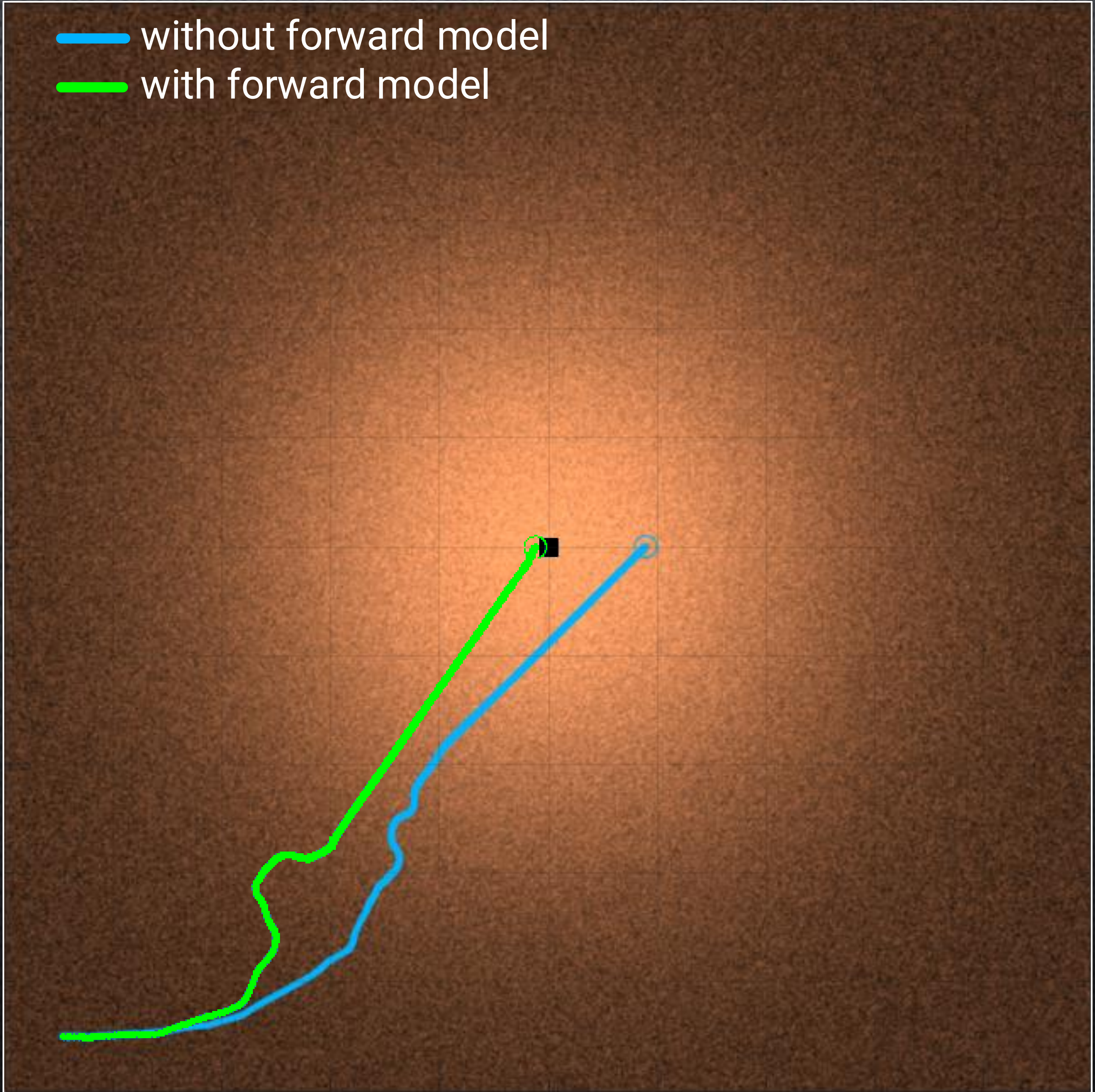
$x_l(t+1)$ = Left predicted data at time t+1

$x_r(t+1)$ = Right predicted data at time t+1

$v_l(t)$ = Left motor speed at time t

$v_r(t)$ = Right motor speed at time t

Example: forward models to predict and correct sensor values



5 Adaptation and Learning

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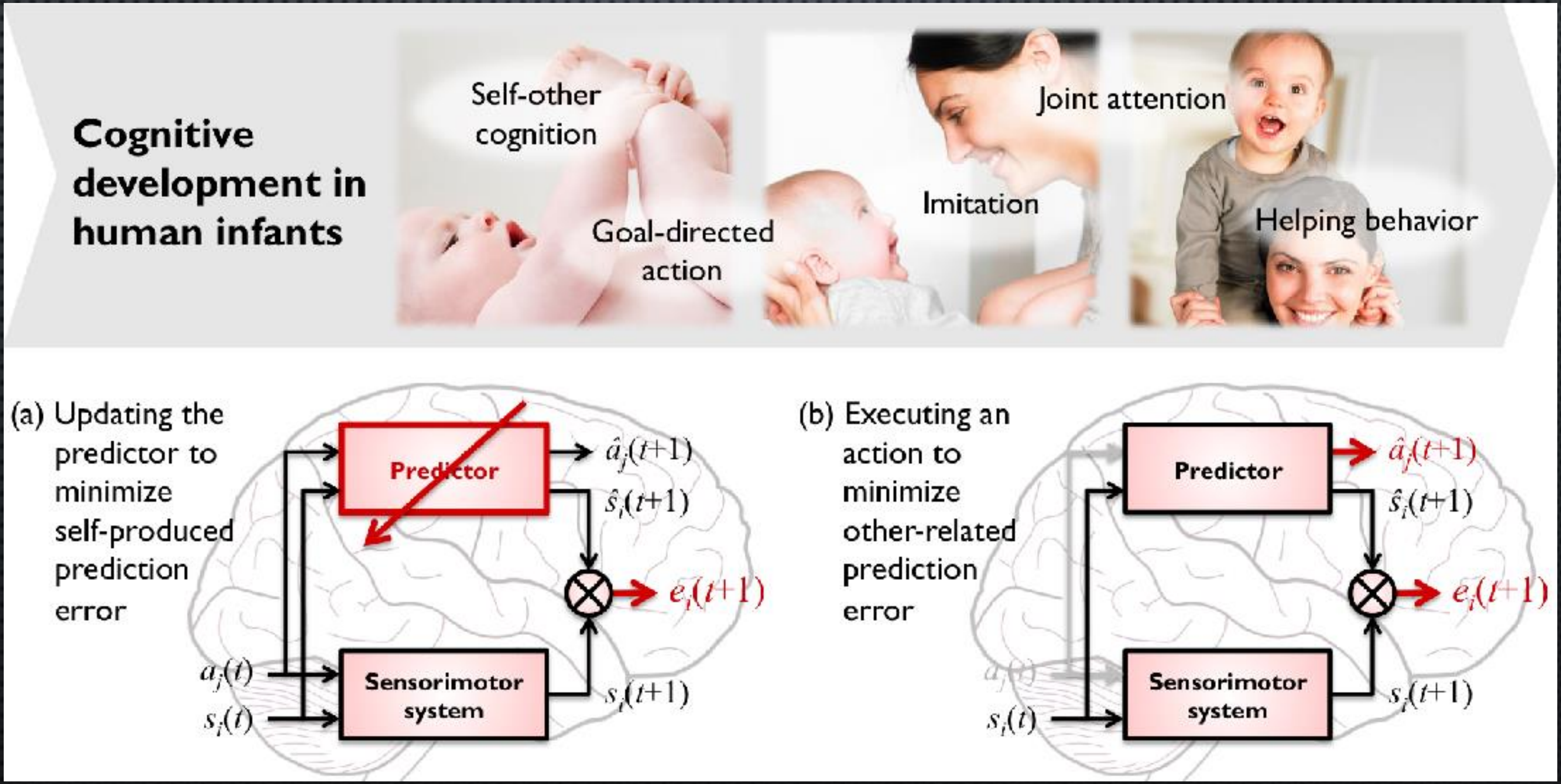
The brain will integrate error information through the reward system dependent on the neurotransmitter dopamine.



Conclusions