# Adaptive Systems

# Lecture 4.1: Braitenberg's vehicles


## University of Sussex

## Chris Johnson


## Spring 2026

# Contacting me

## Email

- I will normally reply within 2 working days
- c.a.johnson@sussex.ac.uk

## Canvas discussions

- Everyone can see my answers
- I will normally check these at least twice a week

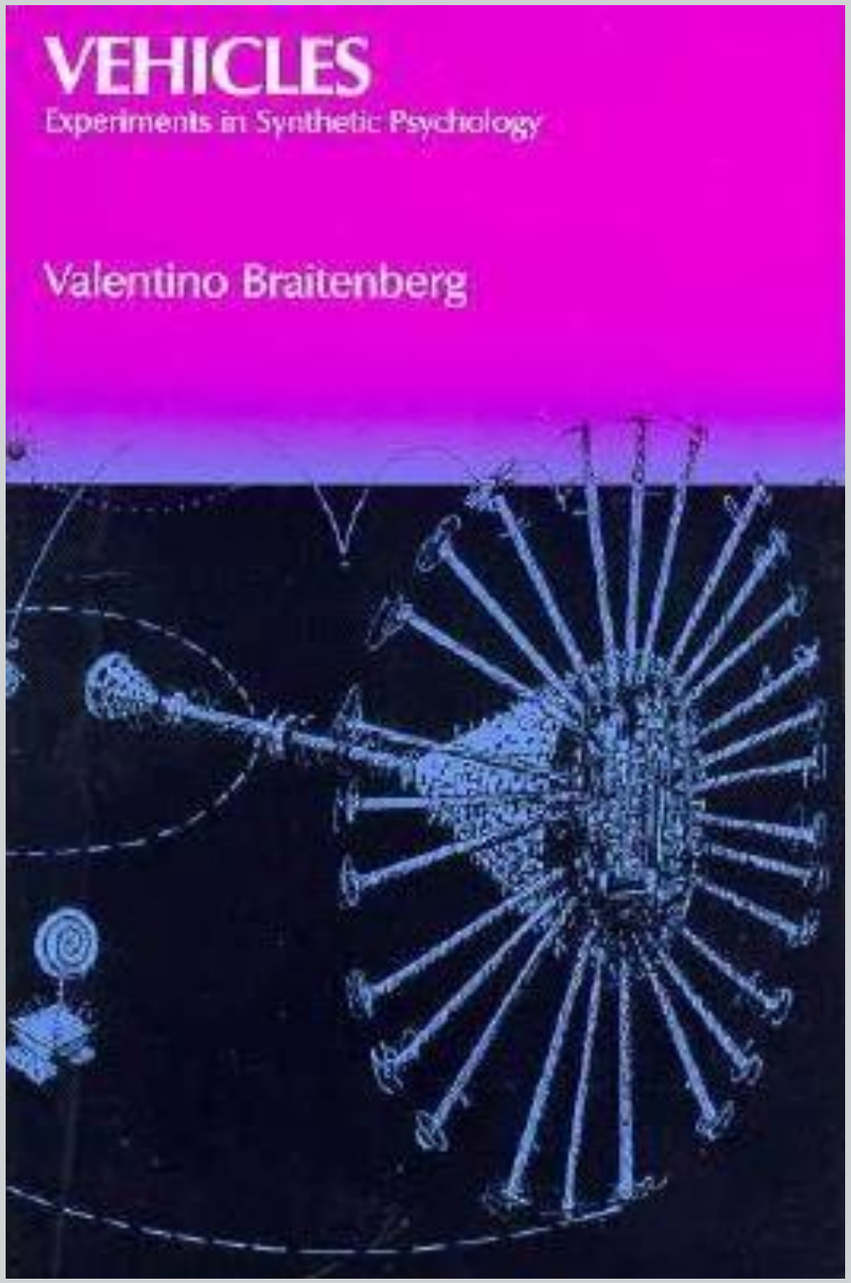
## My office hours

- 12-1pm Wednesday, Chi 2R308

# Lecture learning outcomes

**Main points:**

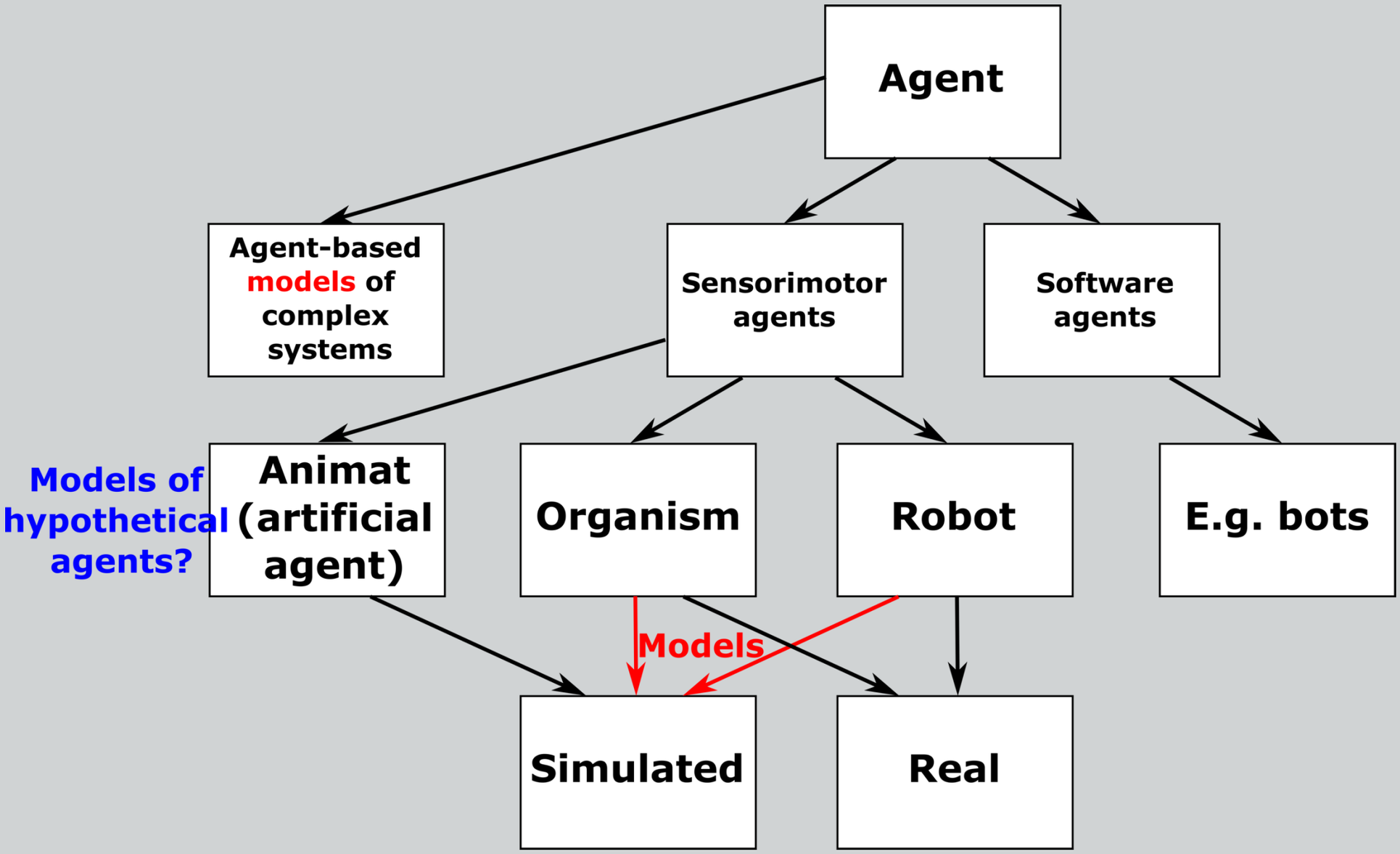
- **An introduction to:**
  - **The sensorimotor loop: a new kind of feedback loop, which we can't necessarily characterise as positive or negative**
    - **For living agents (organisms) and robots, all "external" (or *observed*) behaviour is sensorimotor behaviour**
- **Braitenberg's vehicles: a thought experiment with simple sensorimotor systems**
  - **Which we will build upon in lab classes**




[1]

# 1. The sensorimotor loop

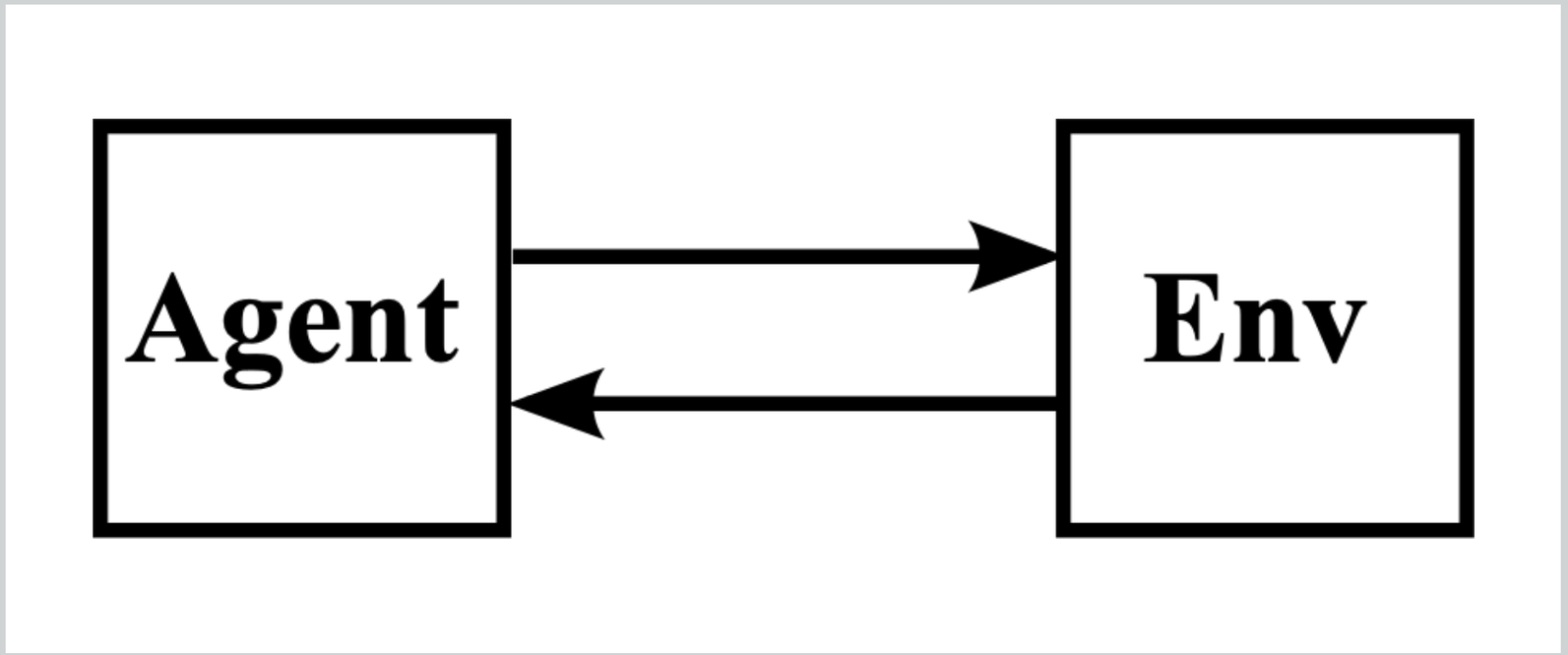
# Agents




- Agents are systems which act in and on their environments
- Most of the systems we study on this module are agents
- Today, and often, we focus on the sensorimotor agents

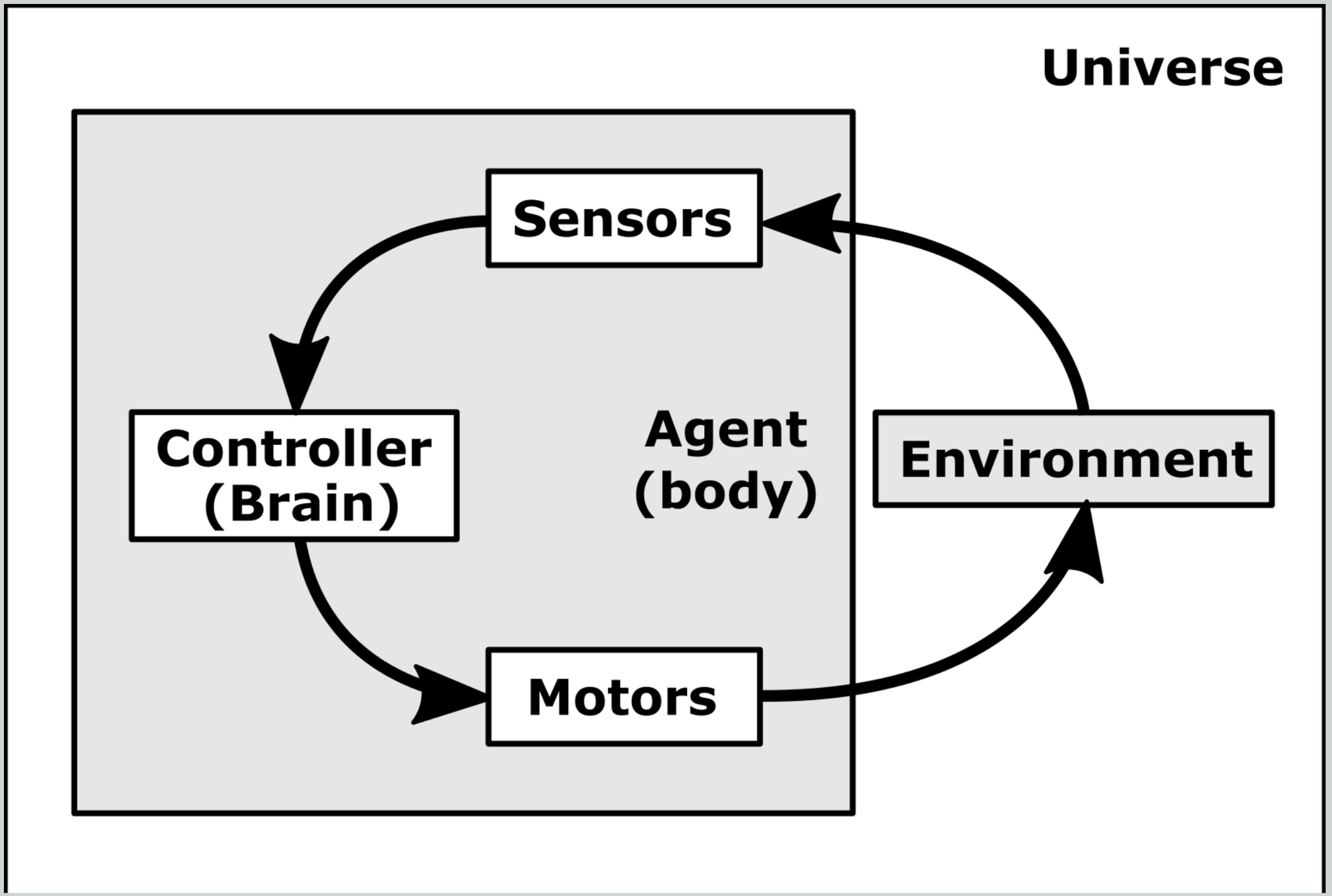
# Sensorimotor Agents

- Agents are systems which act in and on their environments
- i.e. they are coupled to their environments




**Coupled systems**

# The sensorimotor loop

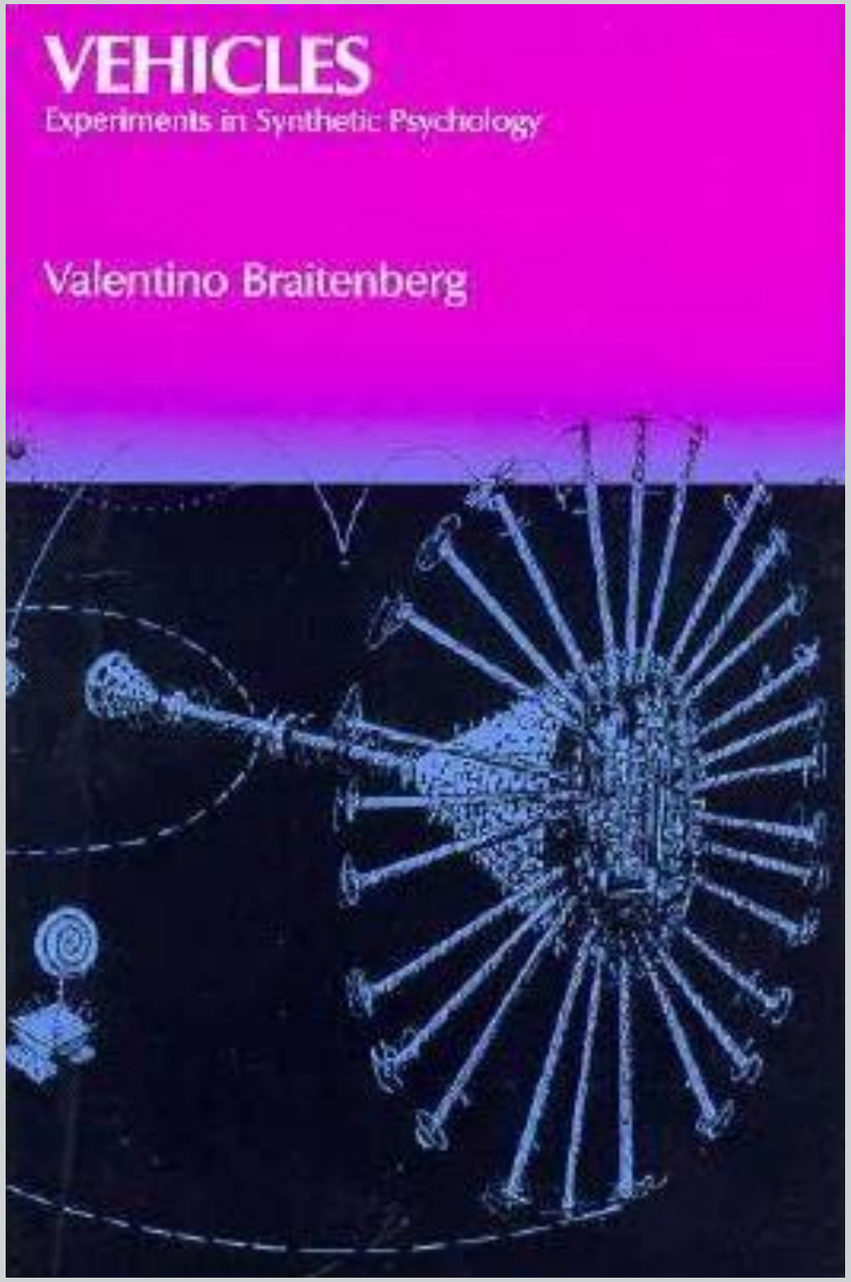



- **Circular causality** in the context of behaviour

# 2. A cybernetic thought experiment

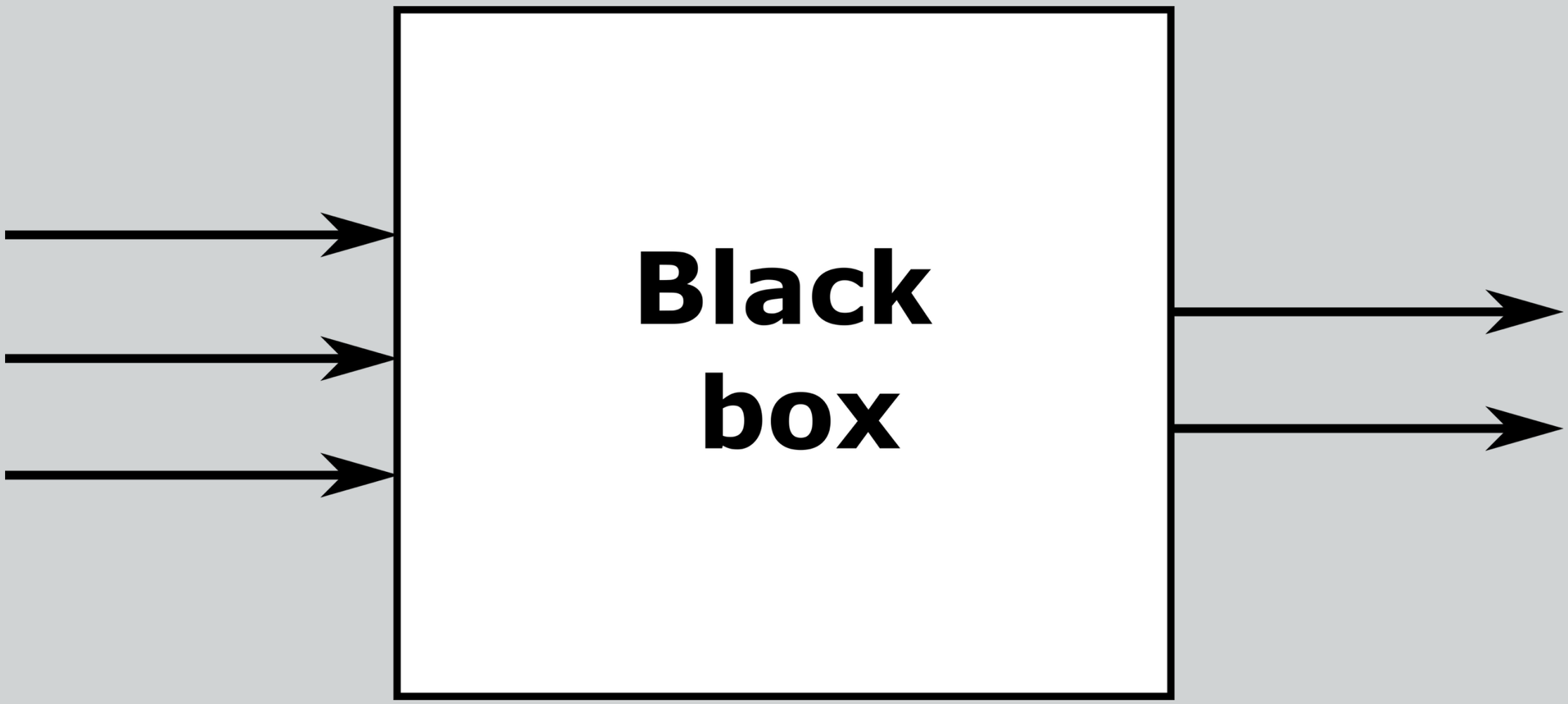
# Cybernetic agents - Braitenberg

- Neuroscientist and cybernetician (1926-2011)
- His book Vehicles [1] describes a series of thought experiments involving mobile agents (we might call them animats)
- He doesn't refer to robots even once in his book!
    - Not even Grey Walter's Tortoises!!!




[1]

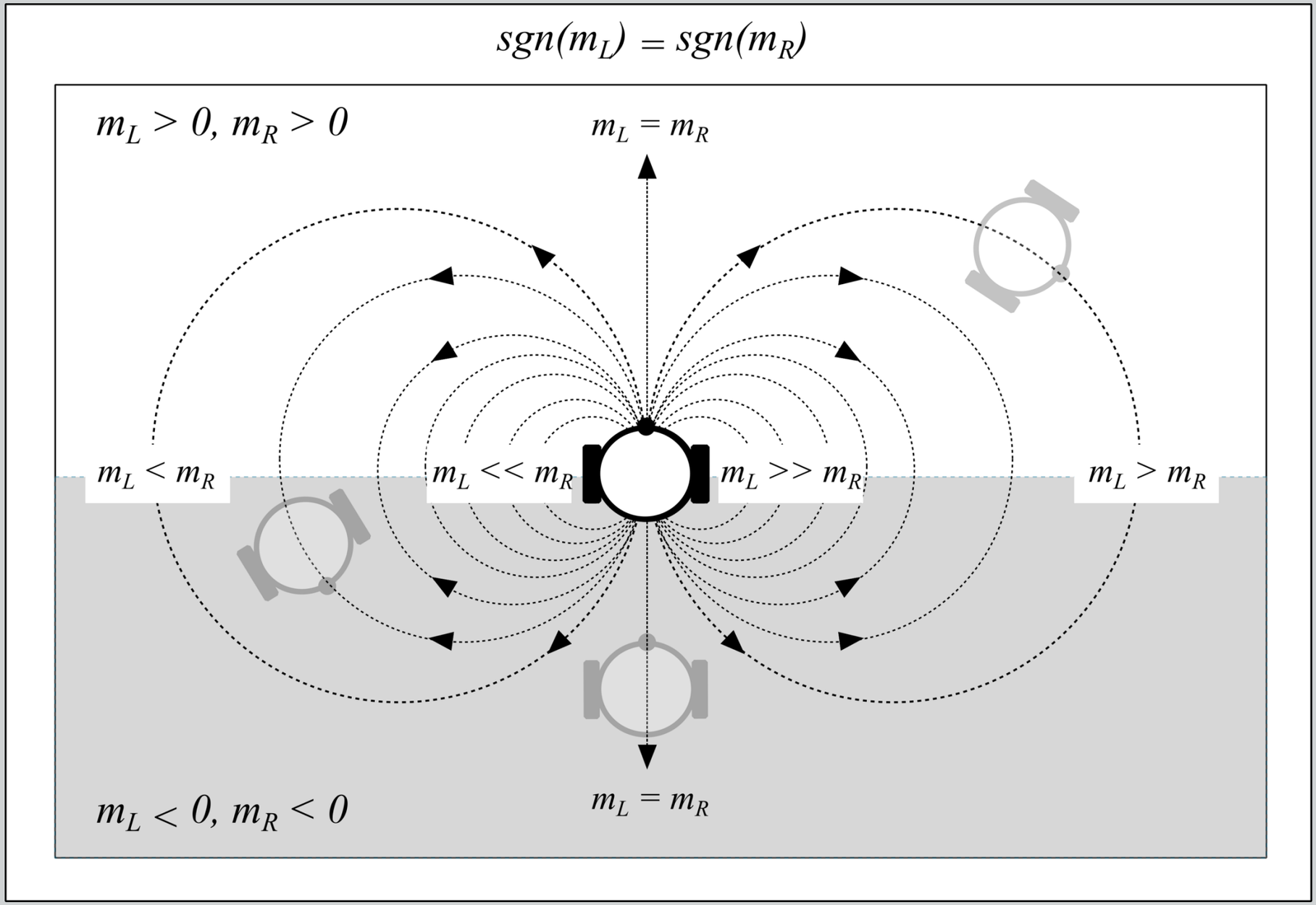
# The black box




**The Problem of the Black Box arose in electrical engineering. The engineer is given a sealed box that has terminals for input, to which he may bring any voltages, shocks, or other disturbances he pleases, and terminals for output, from which he may observe what he can. He is to deduce what he can of its contents. [12]**

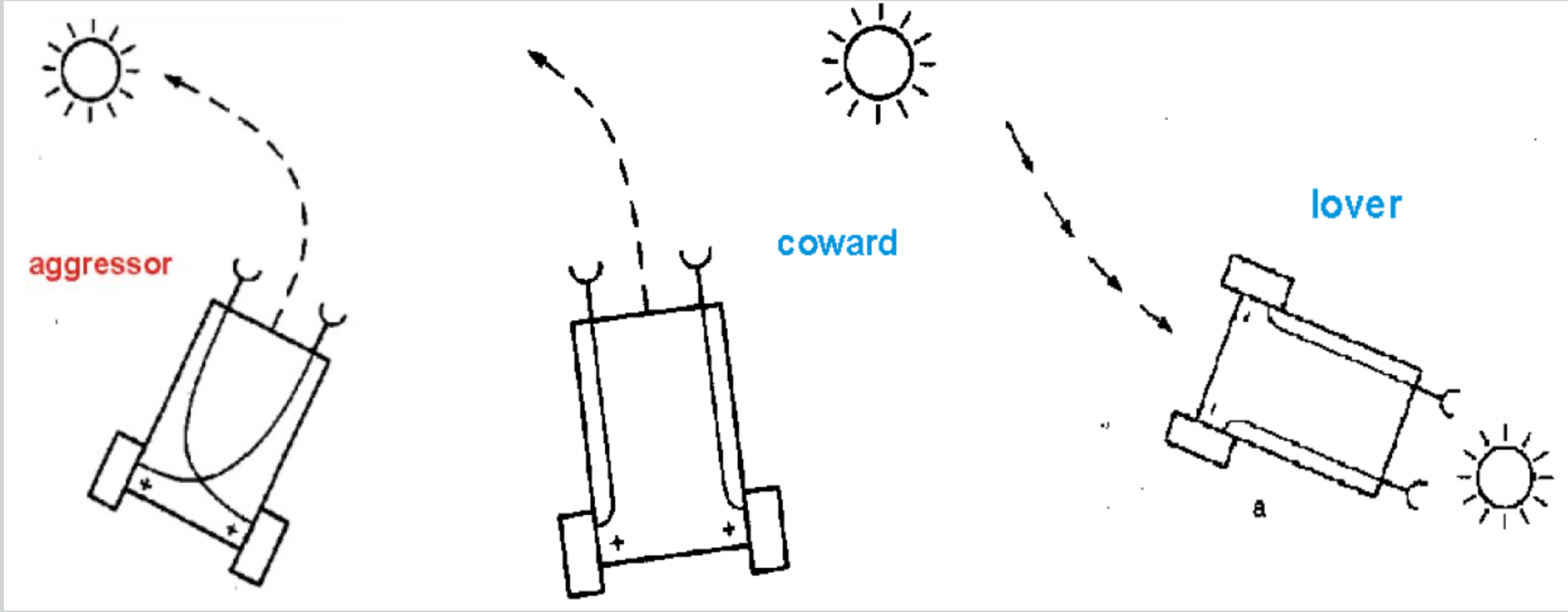
# The differential drive

- **Like the robots that we will use later in lab classes with *Sandbox*, Braitenberg's vehicles have differential drives**

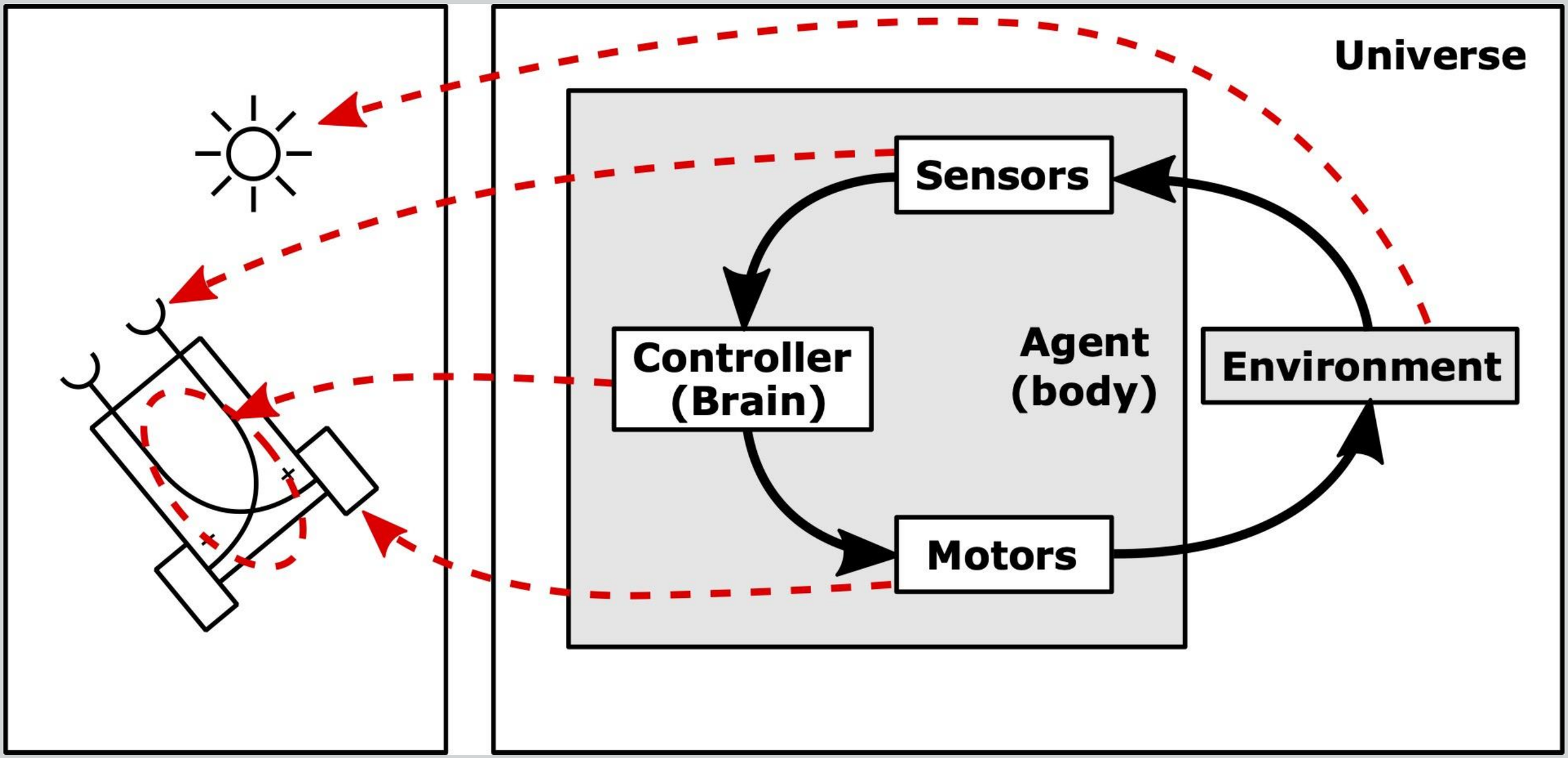


# Braitenberg's vehicles

- We connect their motors to light sensors, either directly or through very simple controllers
- In the sensorimotor loop, even systems like these, with simple elements can behave in surprising and sometimes complex ways
- Braitenberg imagined how we might perceive these behaviours if the vehicles were black boxes



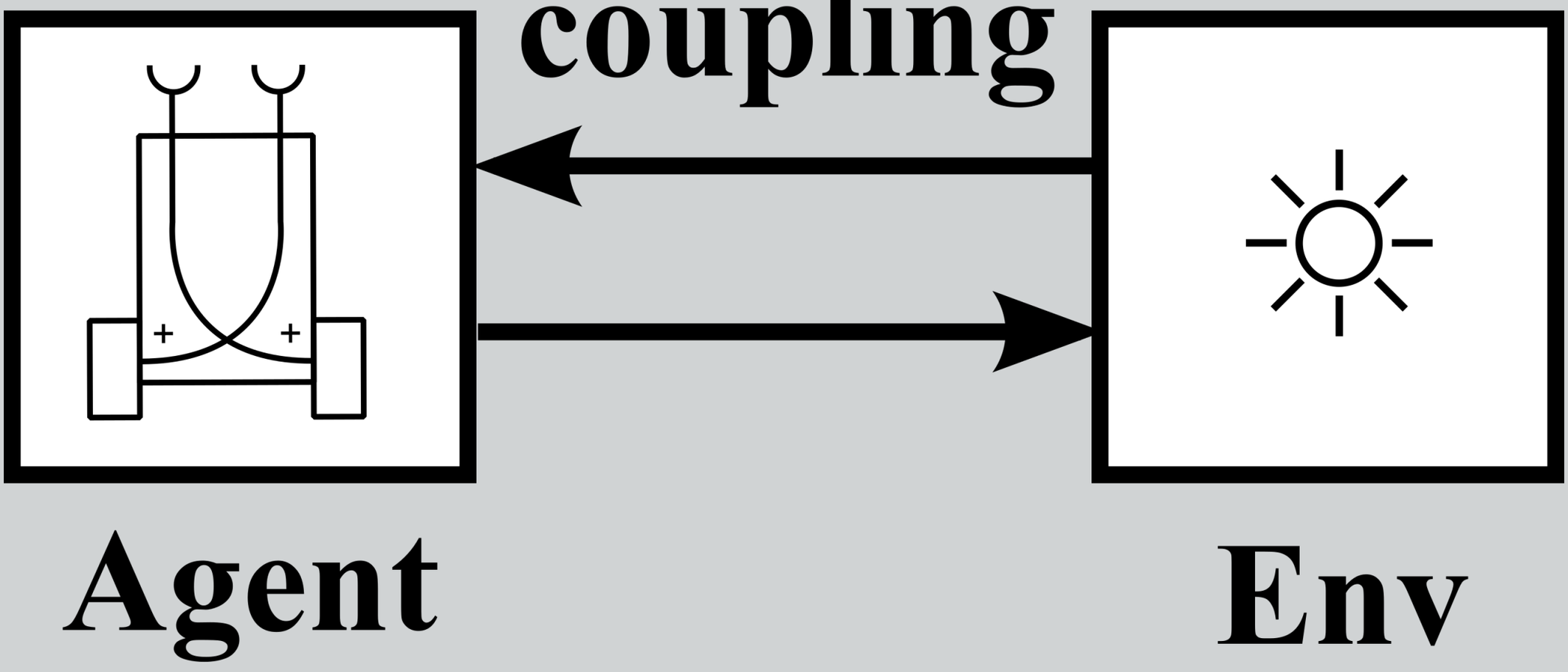
# Braitenberg's vehicles




Braitenberg vehicles in the sensorimotor loop

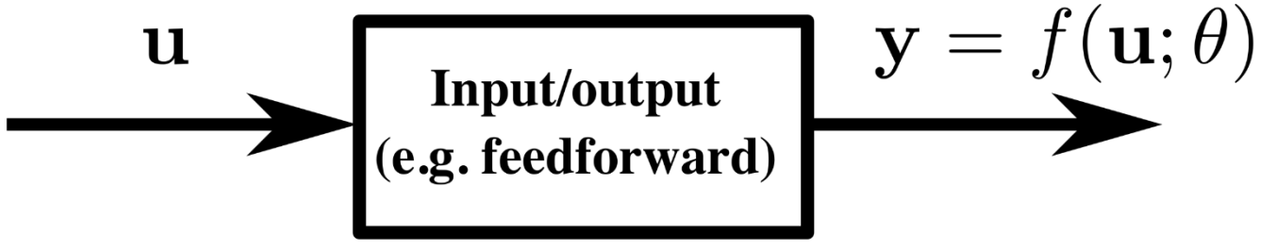
- a case of what early cyberneticians called circular causality

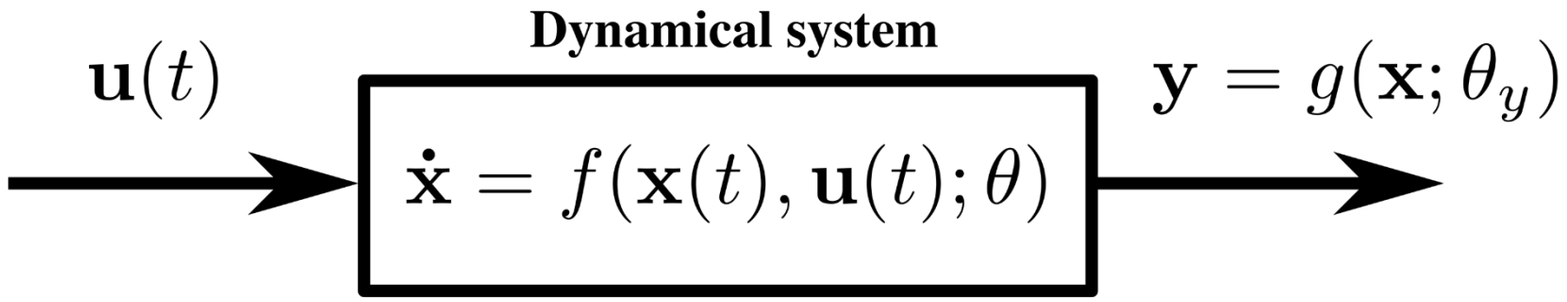
# Sensorimotor coupling




- a case of what early cyberneticians called circular causality

# Systems and their parameters



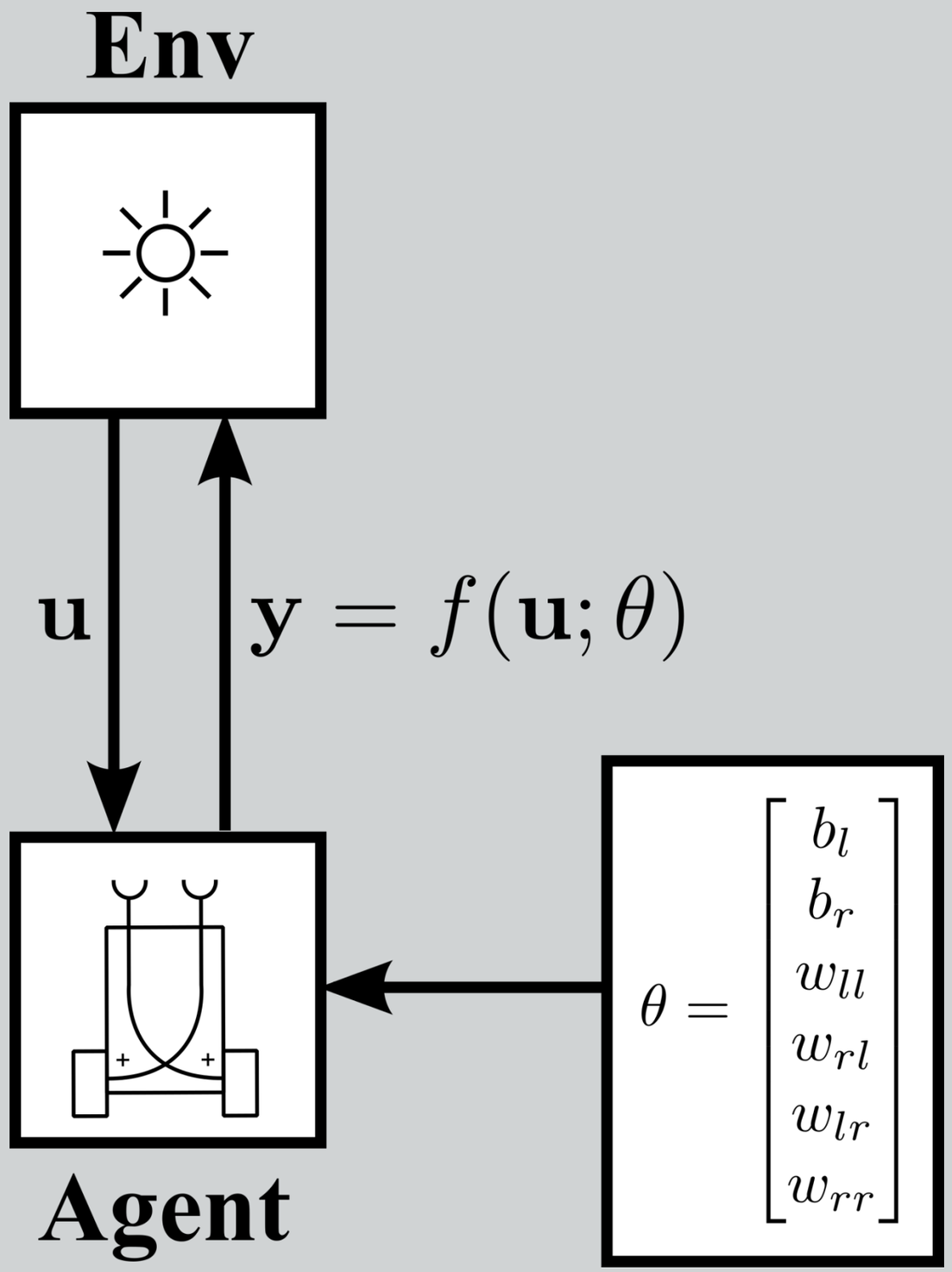




$$\theta = \begin{bmatrix} \theta_1 \\ \theta_2 \\ \vdots \\ \theta_p \end{bmatrix}$$

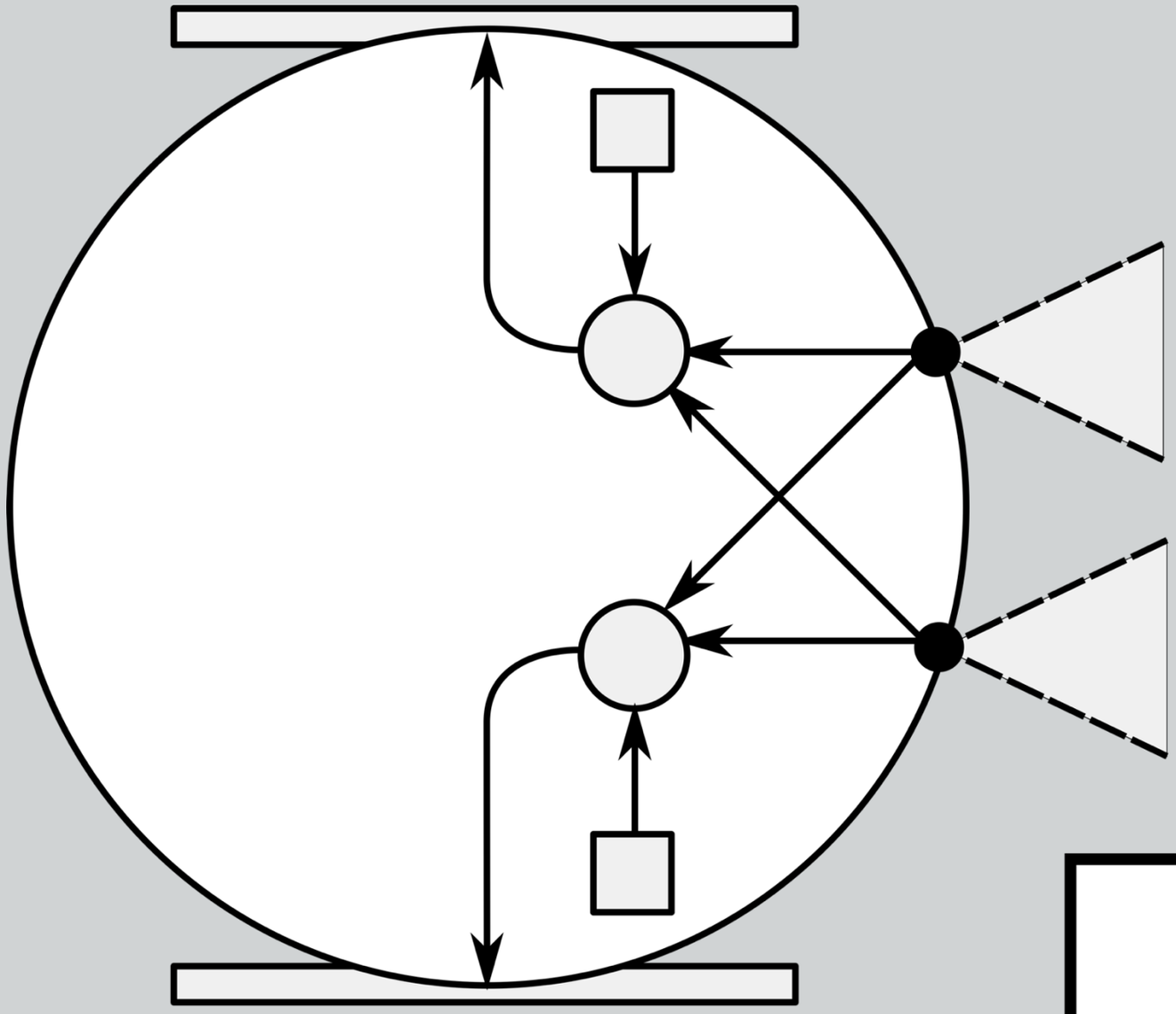
$$\mathbf{u} = \begin{bmatrix} u_1 \\ u_2 \\ \vdots \\ u_l \end{bmatrix} \qquad \mathbf{x} = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix} \qquad \mathbf{y} = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_m \end{bmatrix}$$

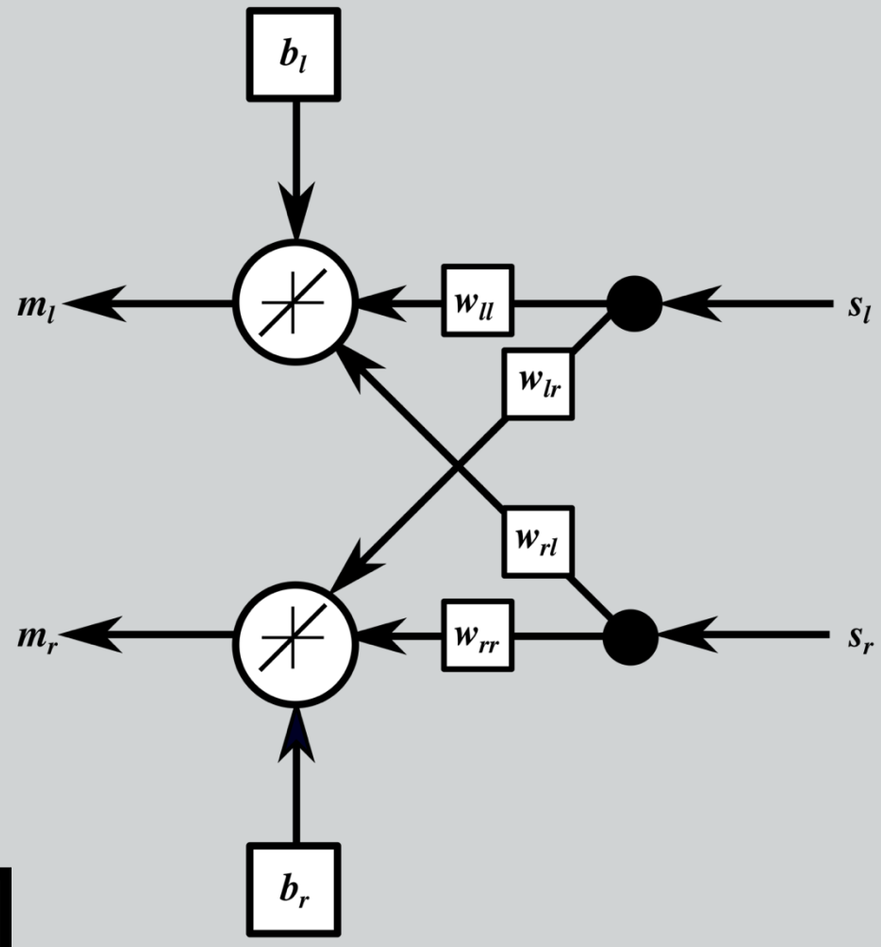
# Sensorimotor coupling – Lab 1

- Braitenberg's vehicles are coupled to their environments
- We can change (adapt) the nature of that coupling by modifying the system parameters on the agent's side
    - This is what you will do in our second lab
- In this case, the Braitenberg vehicles are not self-adaptive
    - They are adapted by external processes (according to our designs)



# Sensorimotor coupling – Lab 1

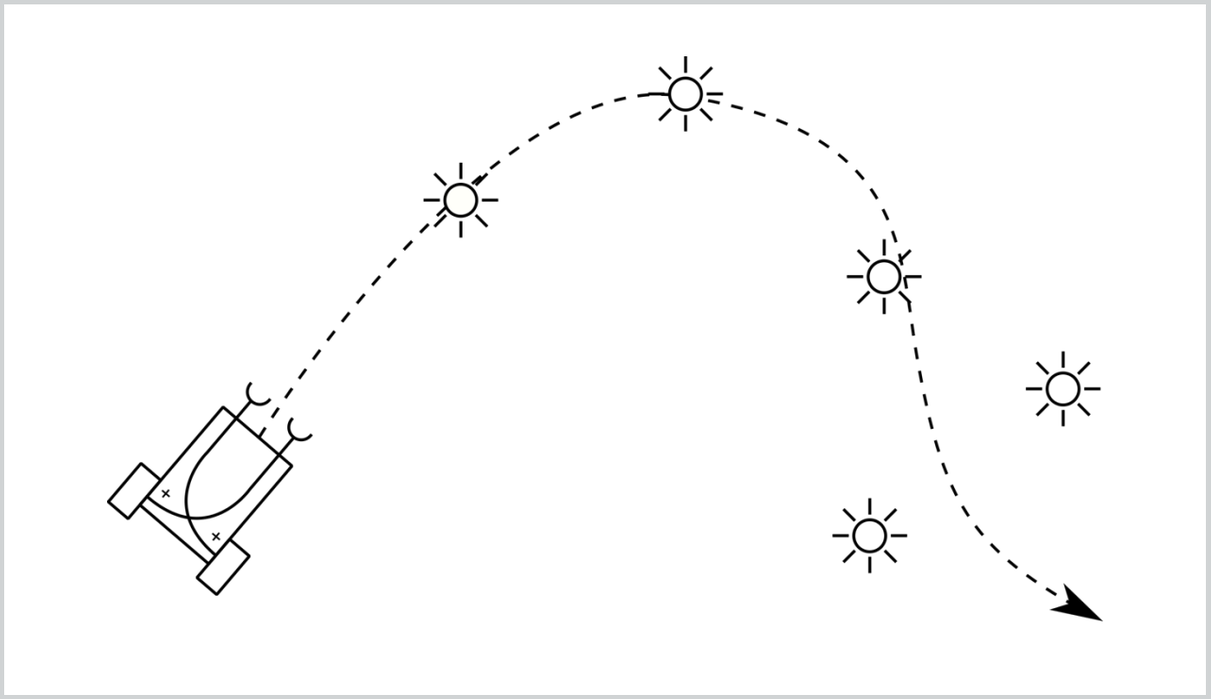




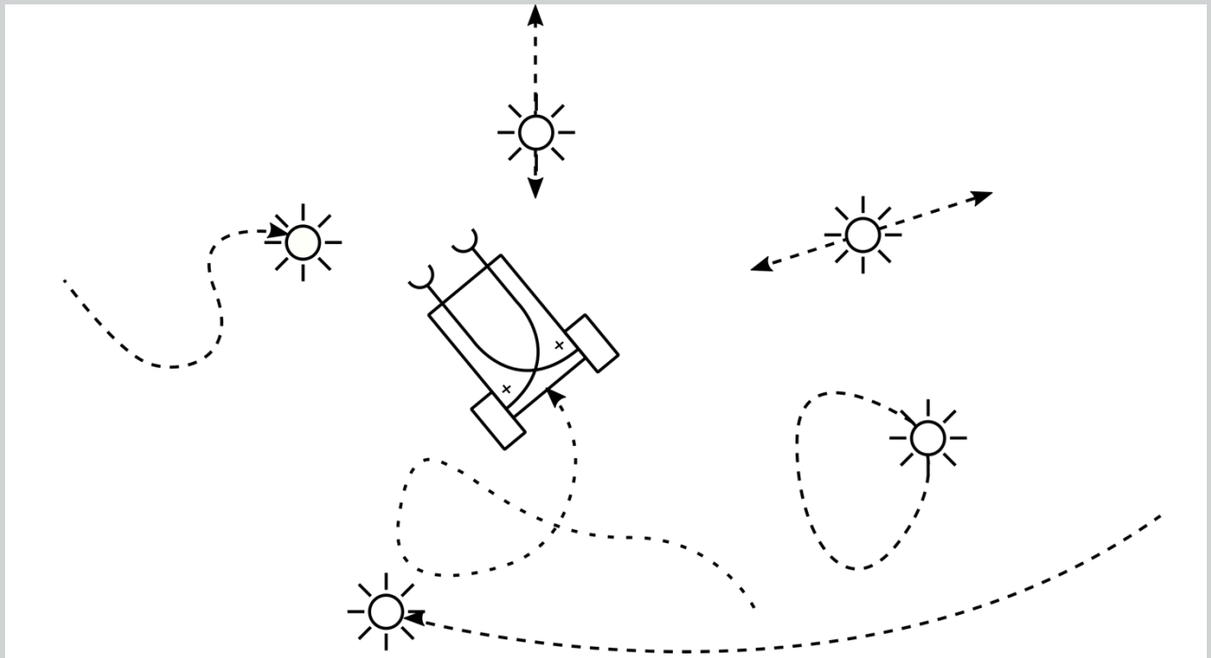

$$\theta = \begin{bmatrix} b_l \\ b_r \\ w_{ll} \\ w_{rl} \\ w_{lr} \\ w_{rr} \end{bmatrix}$$

# Braitenberg's vehicles

- If we arrange lights in interesting patterns, or have moving lights, then we can make Braitenberg vehicles behave in ways that appear complex

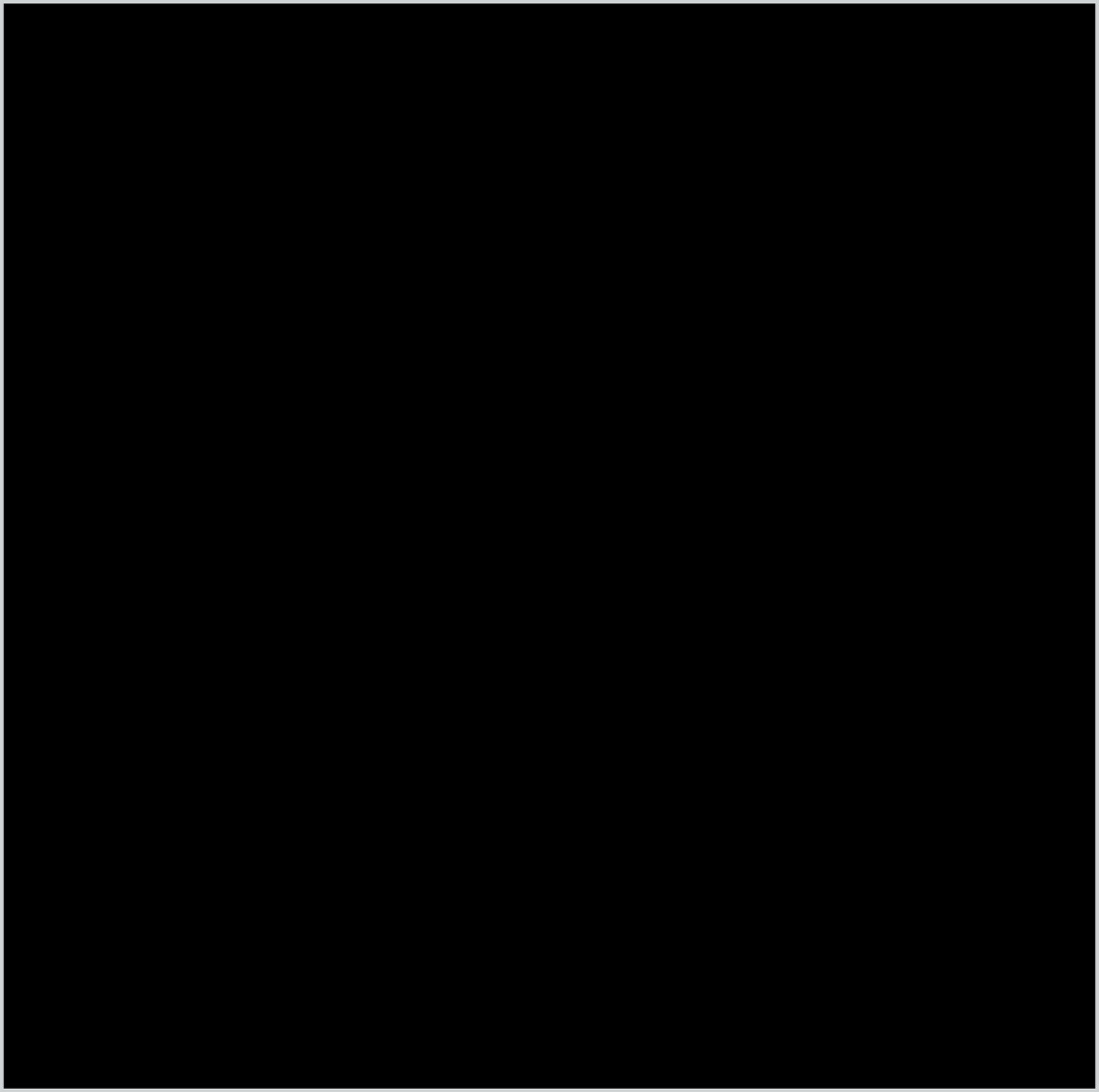


A complex environment

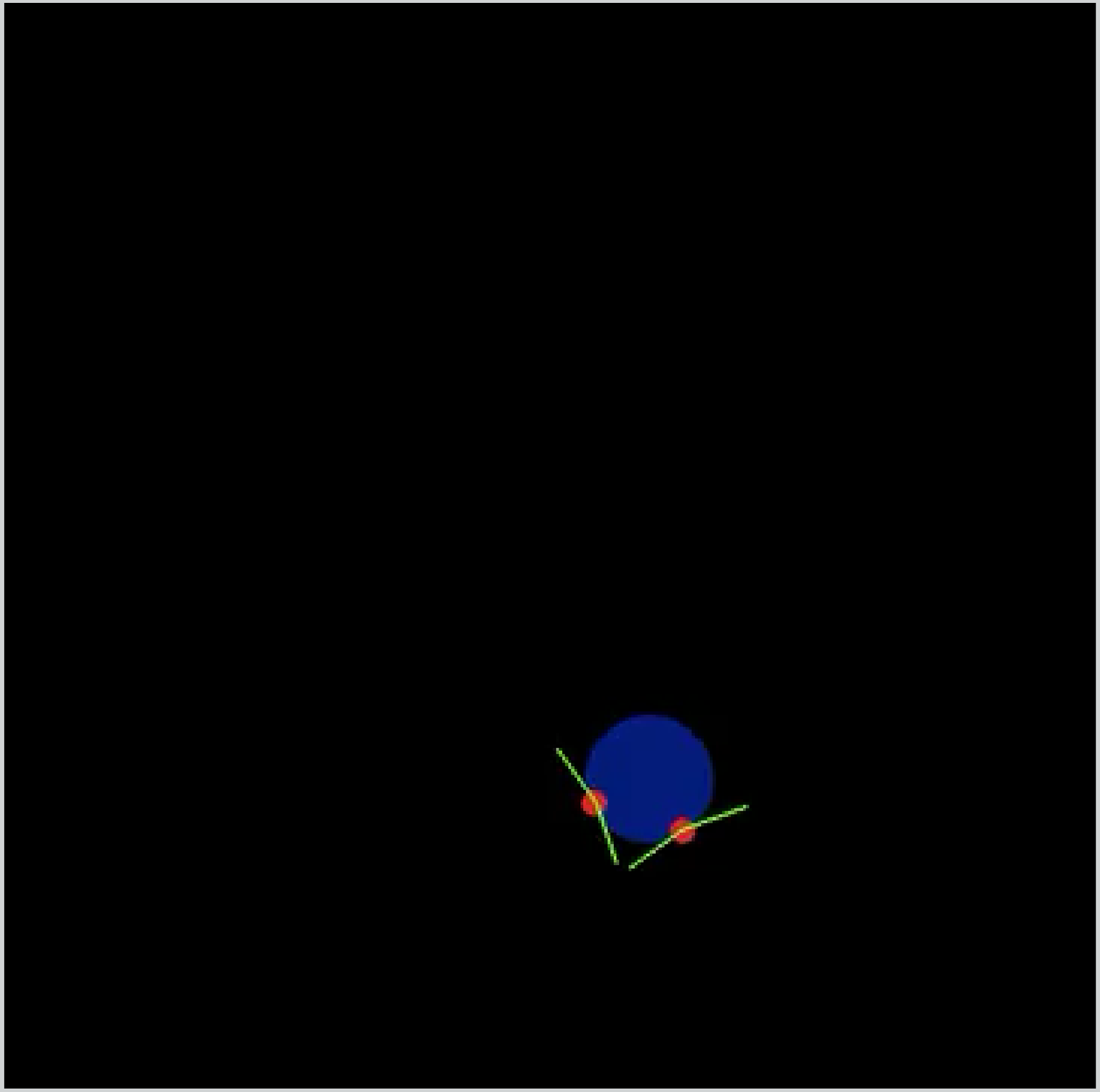


A dynamic environment

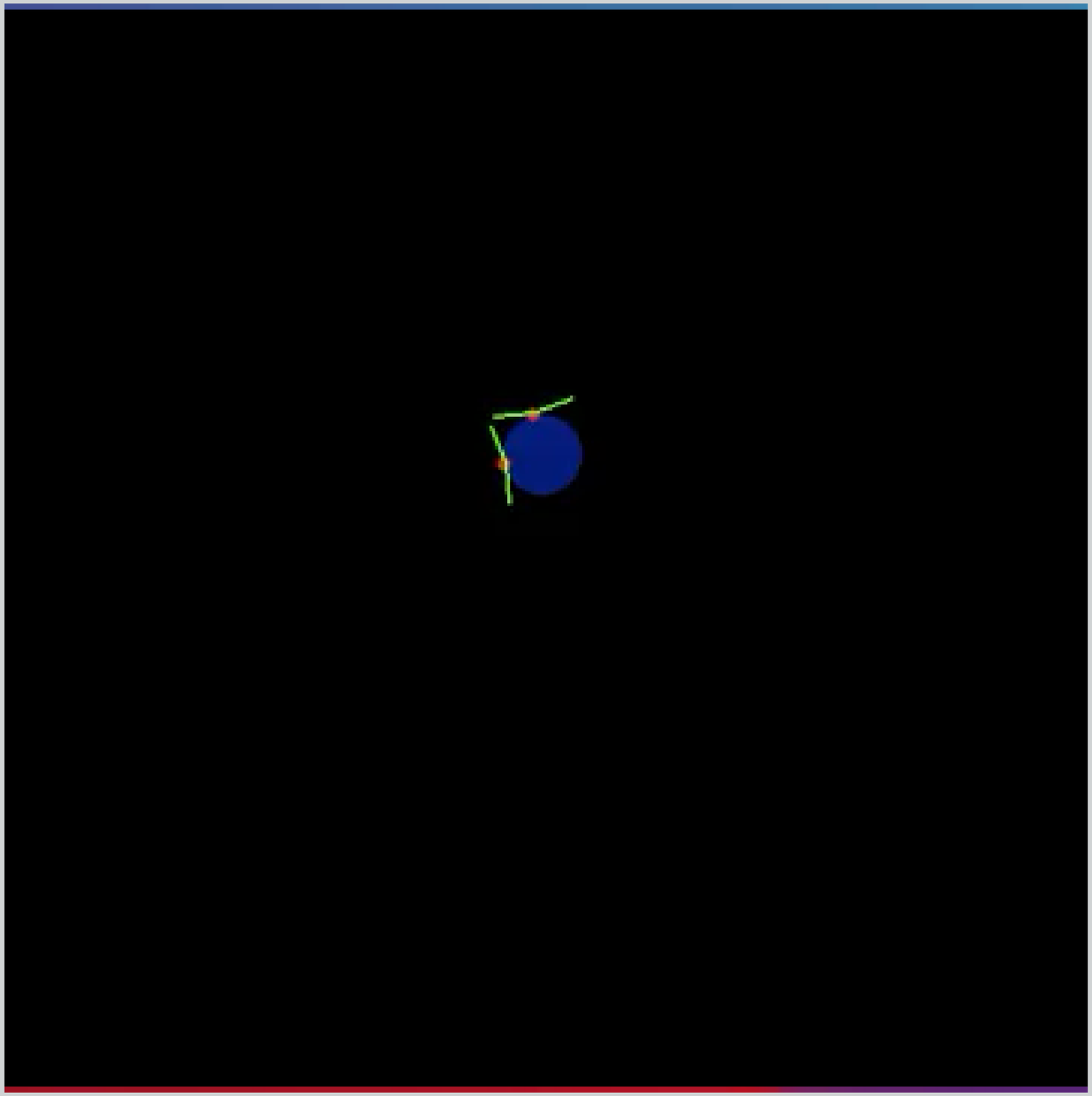
# Braitenberg’s vehicles



# Braitenberg’s vehicles



# Braitenberg’s vehicles



# Braitenberg's vehicles

- As we just saw, if we arrange lights in interesting patterns, or have moving lights, then we can make Braitenberg vehicles behave in ways that appear complex

- This is because behaviour is the product of interactions between brains (or controllers), bodies and environments

    - i.e. the interactions between coupled systems

- As we will see later, Ashby distinguished between two kinds of activity in nervous systems

    1. hardwired / reflex behaviour (adapted by evolution)

    2. learned behaviour (lifetime adaptation)

    - The behaviours of Braitenberg vehicles are reflexive or reactive

# Autonomy for robotics

- Autonomy is variously defined, but for a working definition (*in the context of robotics*) we can refer to Pfeifer and Scheier:
  - Autonomy means independence from external control.
  - “Autonomy is not an all-or-nothing issue, but a matter of degree.”
  - “Controllability and the capability of acquiring one’s own history are correlated: The more an agent can have its own history, the less controllable it will be.”
    - i.e. internal state can make an agent’s behaviour difficult to predict, and therefore also to control
    - controllability and autonomy are set up as opposites
- Given two agents, A and B, “The less knowledge A has about B’s internal state, the less A can control B. Thus, autonomy is not so much a property of an agent as a property of the relationship between agents (i.e., what one agent knows about the other)." [6]
  - Here, autonomy is defined as a relationship between two systems, i.e. as a property of an agent in a coupled system

# According to Pfeifer and Scheier's definition of autonomy, what is the level of autonomy of Braitenberg's vehicles which we saw earlier?

# How do you think you would have answered if the vehicles were black boxes to us?

# Summary

**Main points:**

- **We have introduced the sensorimotor loop, another example of circular causality, in the context of the "external" or observable behaviour of robots and living systems such as animals**

- **We have met Braitenberg's vehicles, a thought experiment with simple sensorimotor vehicles which can act with surprisingly (apparent) complexity**

- **As with Braitenberg's vehicles, all sensorimotor behaviour is the product of interactions with the environment – behaviour, and by extension intelligent behaviour, arises from the interactions between "brain", body and environment**

- **In preparation for our next lab, we have seen a way to parameterise the behaviours of Braitenberg's simplest vehicles**

# Bibliography

## Recommended articles and books


[1] Braitenberg, V. (1986). *Vehicles: Experiments in synthetic psychology*. MIT press, Cambridge, MA.

[2] Walter, W. G. (1953). *The Living Brain*. Duckworth, New York.

[3] Holland, O. (2003). *Exploration and high adventure: the legacy of Grey Walter*. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 361(1811):2085–2121.

[5] Brooks, R. A. (1990). *Elephants don't play chess*. Robotics and Autonomous Systems, 6(1-2):3–15.

# Bibliography

## Recommended articles and books


[6] Brooks, R. A. (1989). *A robot that walks; emergent behaviors from a carefully evolved network*. In Proceedings, 1989 International Conference on Robotics and Automation, pages 692–4+2 vol.2.

[7] Brooks, R. (1986). *A robust layered control system for a mobile robot*. IEEE Journal on Robotics and Automation, 2(1):14–23.

[8] Brooks, R. A. (2002).
*Flesh and machines : how robots will change us*. Pantheon Books, New York, N.Y., 1st ed.. edition.

[9] Pfeifer, R. and Scheier, C. (2001). Understanding intelligence. MIT press.

# Bibliography

## Other cited articles and books


[10] Klir, J., & Valach, M. (1967). Cybernetic modelling.

[11] Webb, B. (1996). A cricket robot. Scientific American, 275(6), 94-99.

[12] William Ross Ashby.
An introduction to cybernetics. Chapman and Hall, London, 1956.

# Bibliography

## Relevant websites

## Other websites (sources of pictures)

[4] https://www.computerhistory.org/revolution/artificial-intelligence-robotics/13/293/1277