Adaptive Systems

Lecture 4.2: Cybernetics and sensorimotor systems

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Canvas discussions

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

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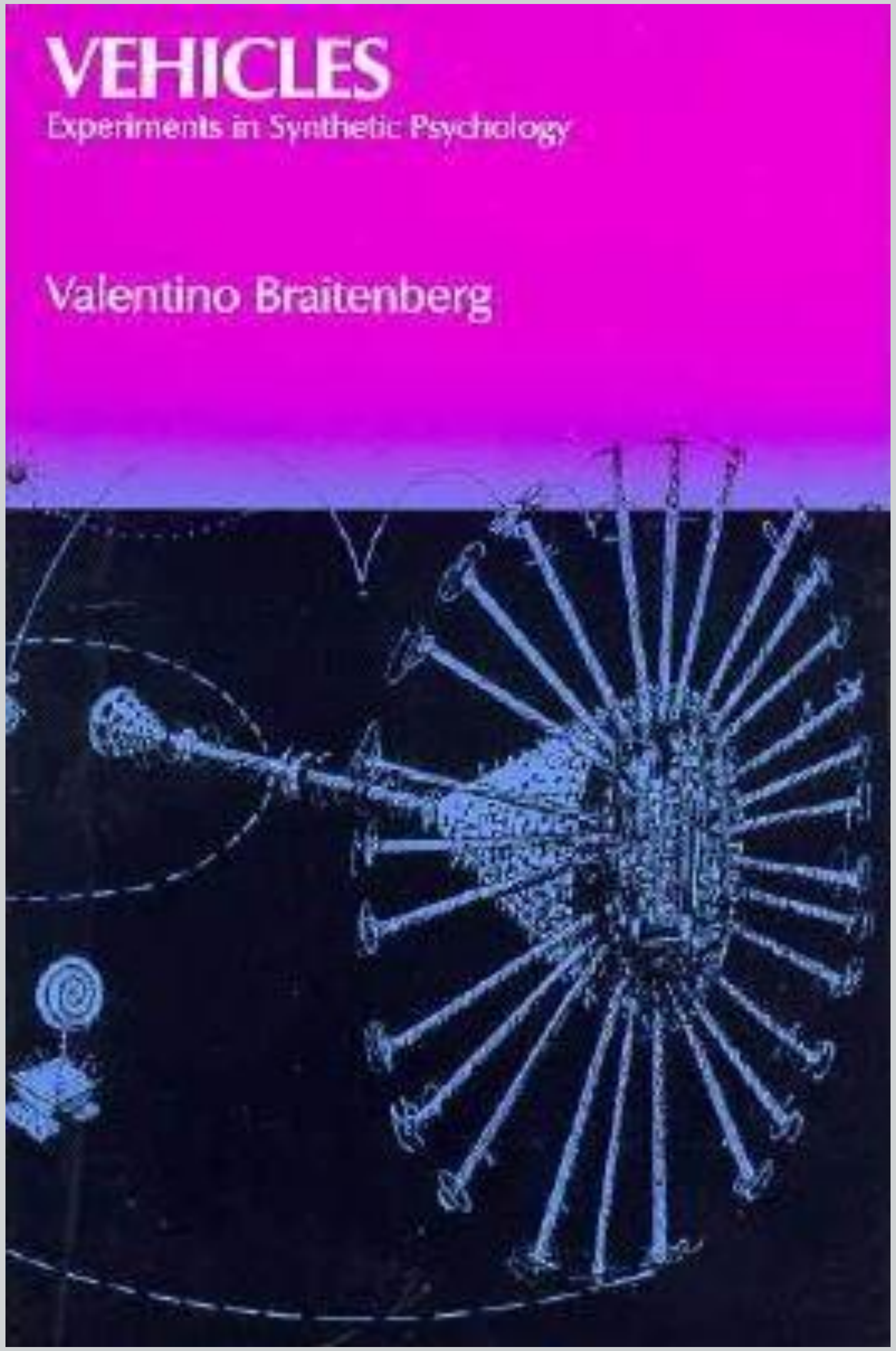
Lecture learning outcomes

Main points:

- Situated and embodied robotics began in cybernetics
- Grey Walter was very successful in this area in the 1950s, but his ideas were forgotten for decades
- In the 1980s, frustration with conventional AI led to a new cybernetics-inspired approach: Behaviour-based robotics
- Behaviour-based robotic behaviours are often not self-adaptive, but as we will see in later lectures, they can be made self-adaptive if we follow Ashby's theory of ultrastable systems



[1]

Lecture outline

1) Recap on the sensorimotor loop

2) Behaviour-based robotics, part 1 – cybernetic pets

    1. Cybernetic tortoises

3) AI Robotics - what not to do in the 1980s

    1. The Stanford Cart - how not to do robotics

4) Behaviour-based robotics, part 2 – goodbye GOFAI!

    1. Rodney Brooks and the subsumption architecture

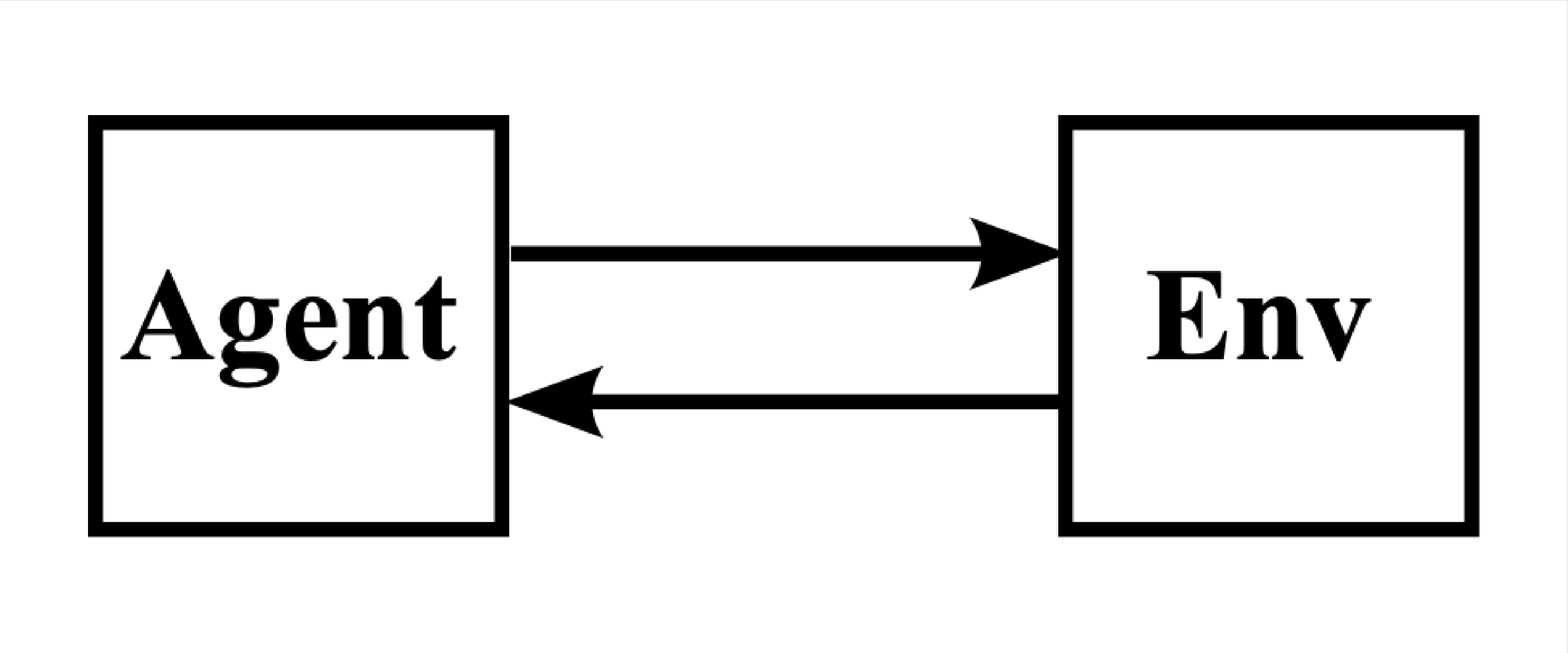
    2. The Extended Braitenberg Architecture

[4]

1. Recap on the sensorimotor loop

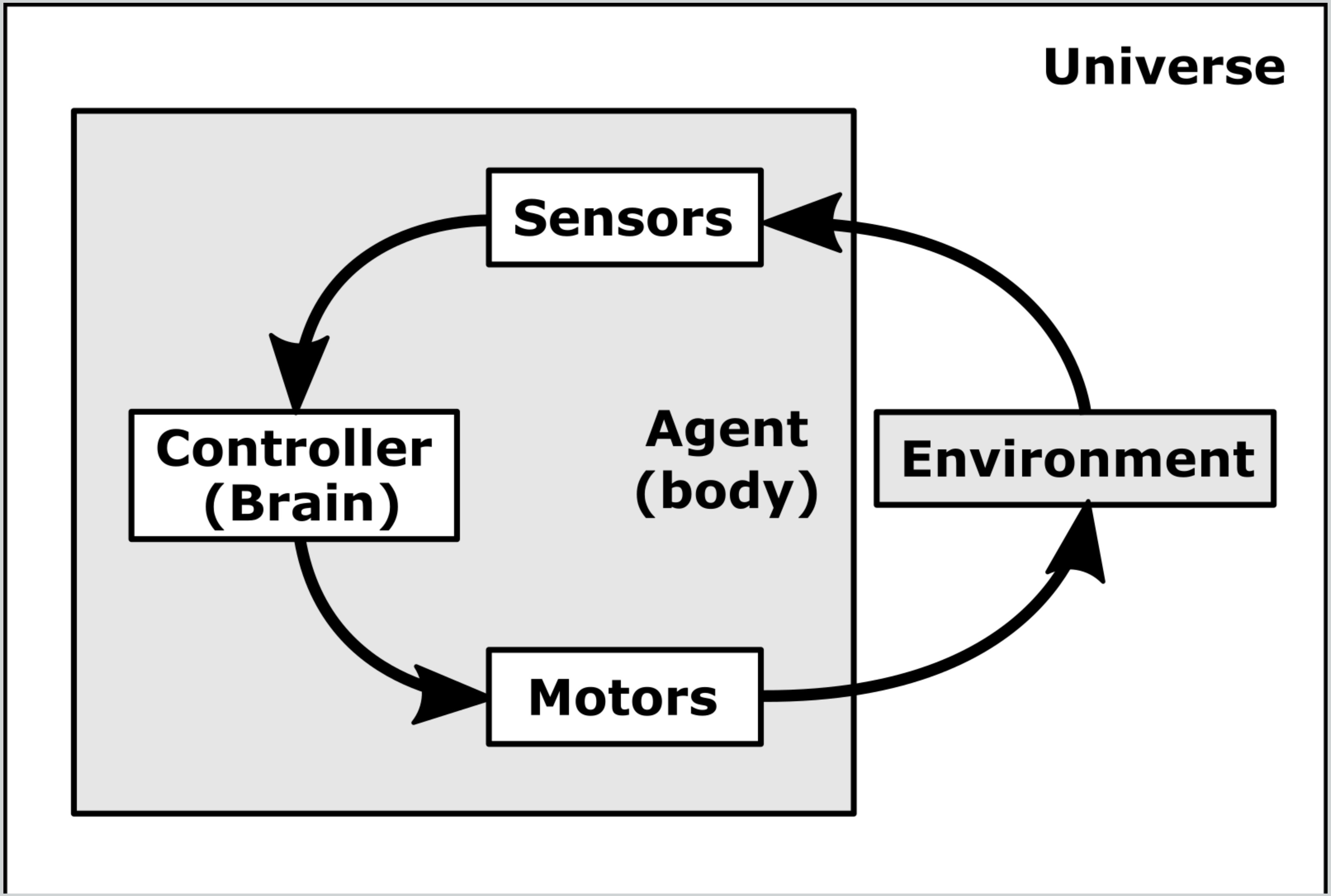
Sensorimotor Agents

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



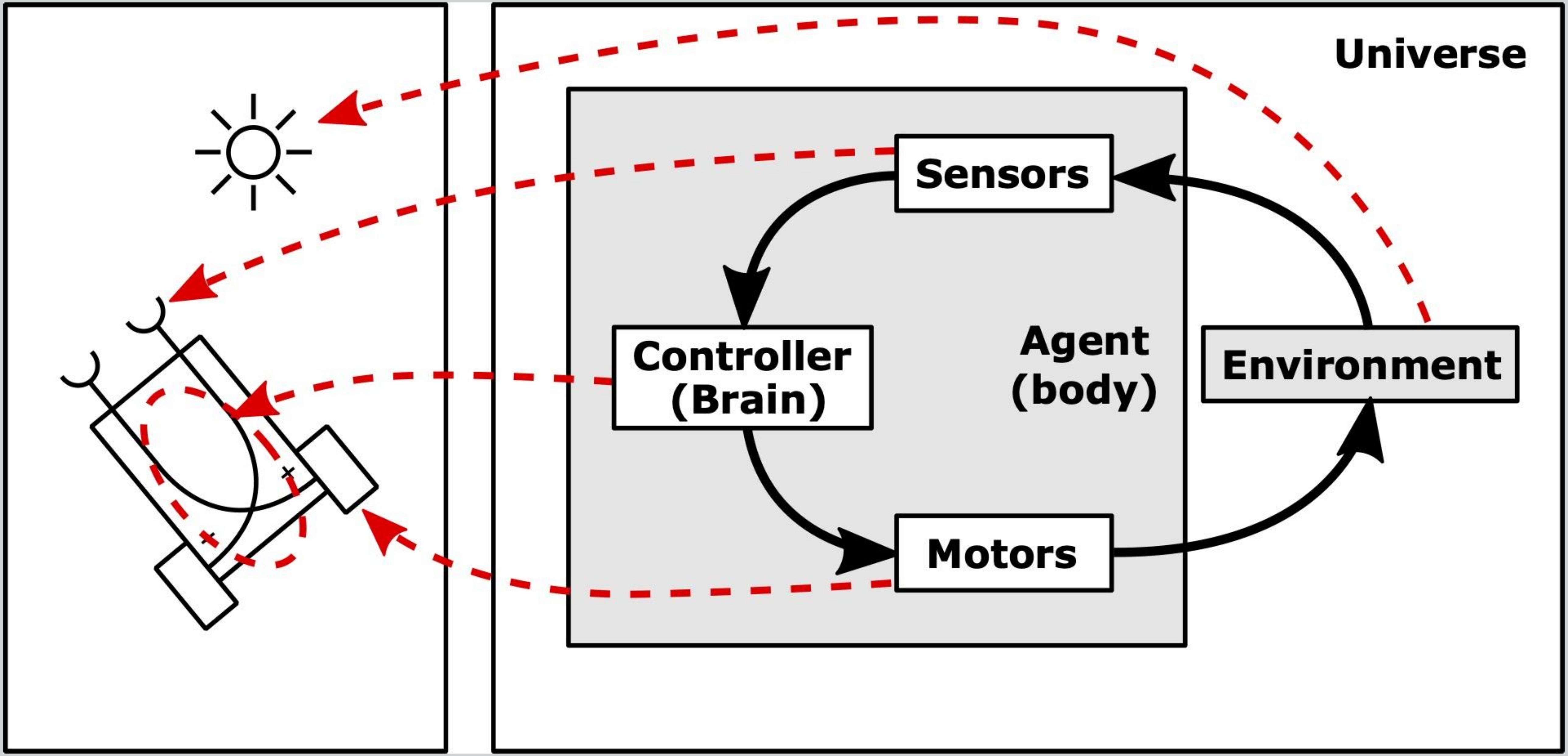
Coupled systems

The sensorimotor loop



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

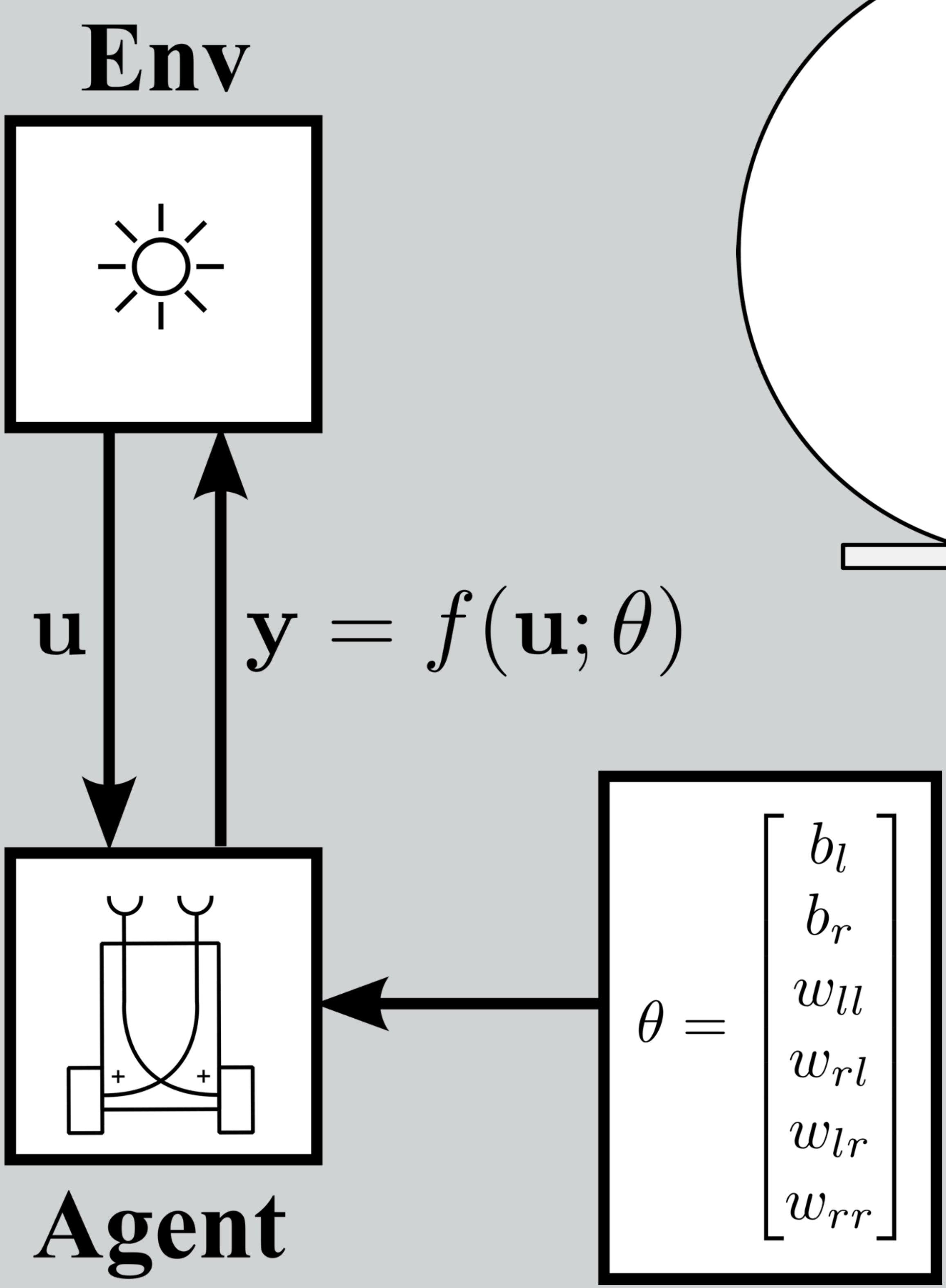
Braitenberg's vehicles

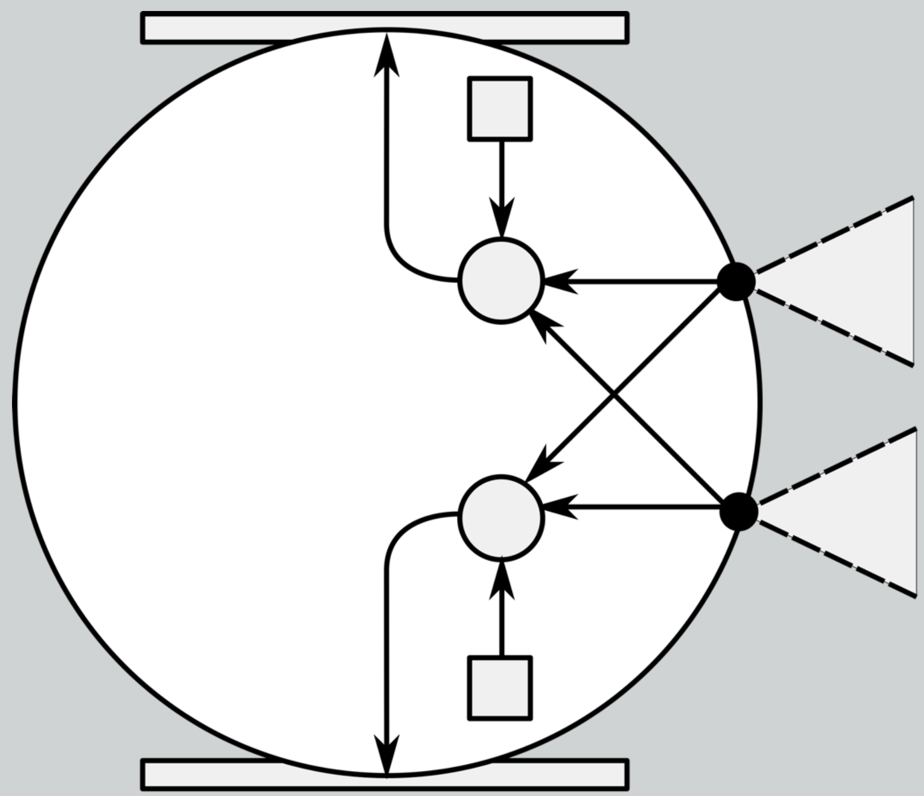


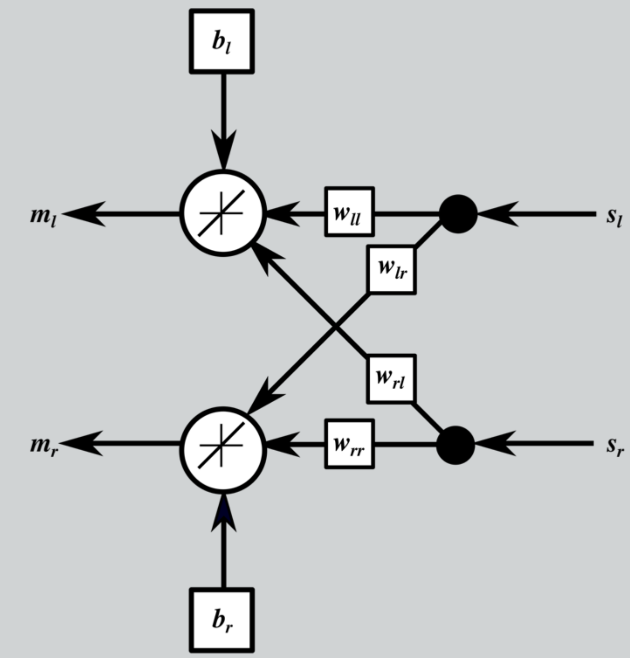
Braitenberg vehicles in the sensorimotor loop

- a case of what early cyberneticians called circular causality

Sensorimotor coupling – Lab 1





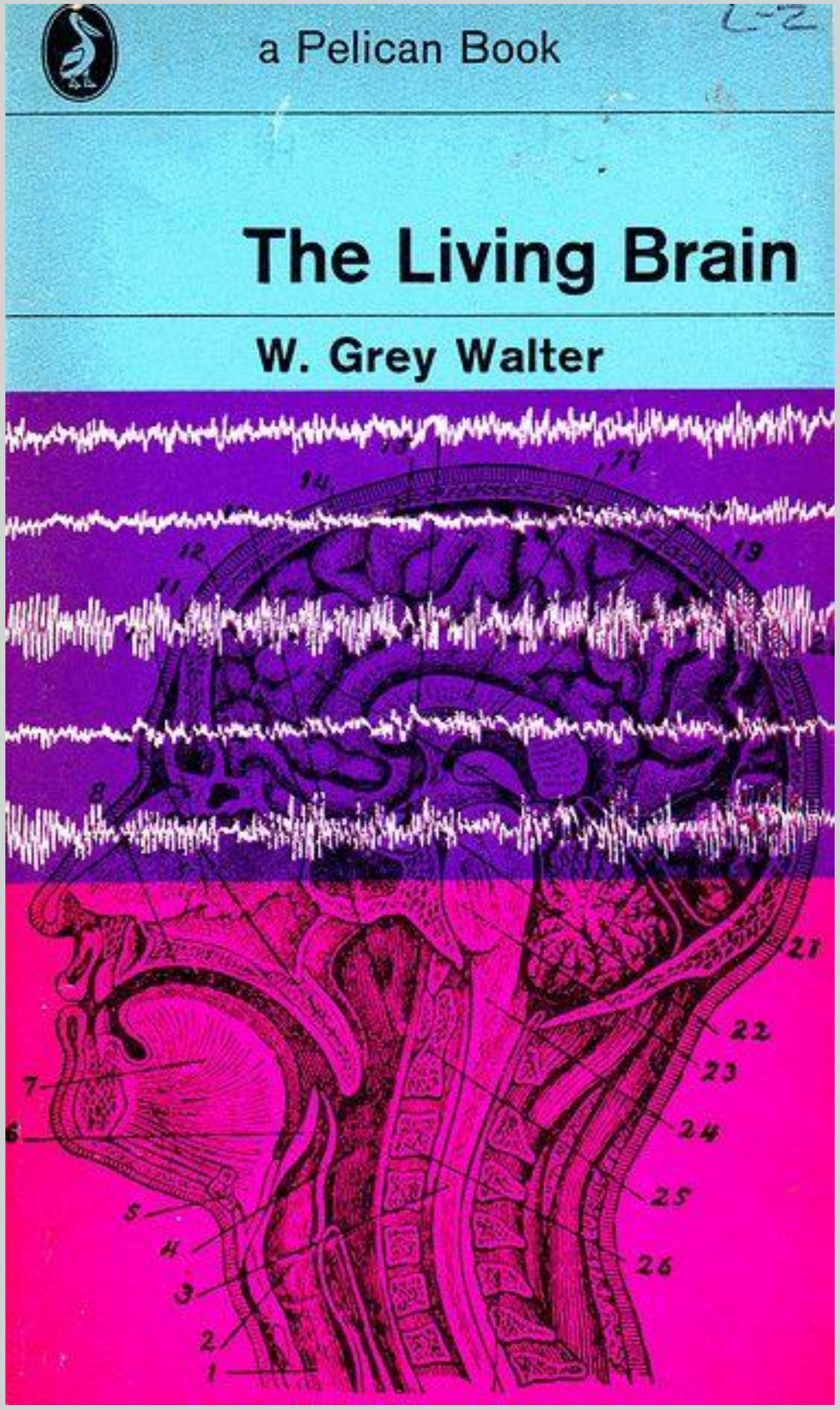


- We can **parameterise** sensorimotor systems
- A look ahead: by writing algorithms which modify the parameters, we can make these systems **self-adaptive**

2. Behaviour-based robotics, part 1 – cybernetic pets

Cybernetic robotics - Grey Walter

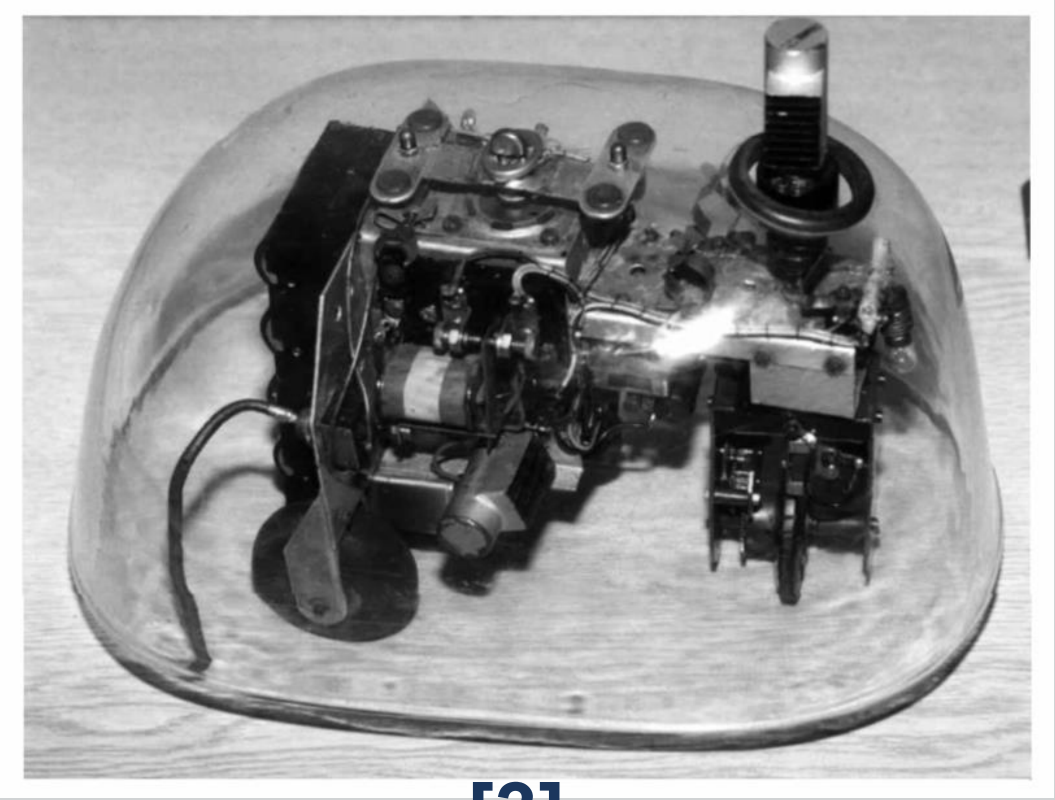
- William Grey Walter (1910-1977)
- A British cybernetician and a member of the Ratio Club
- Neurophysiologist and early roboticist
- Invented a very sensitive electroencephalograph (EEG)
- First to observe theta and delta rhythms in the brain
- Inventor of the groundbreaking 'Tortoise' robot



[2]

Grey Walter's Tortoises

- Like Braitenberg's vehicles, tortoises explore their environments
- But they have important differences in morphology
- Instead of a differential drive, Tortoises have one motor for forwards motion, and one motor steering the front wheel
- They only have a single light sensor, but it turns with the front wheel
- They also have lights on them, and sensors which detect when their shells are bumped



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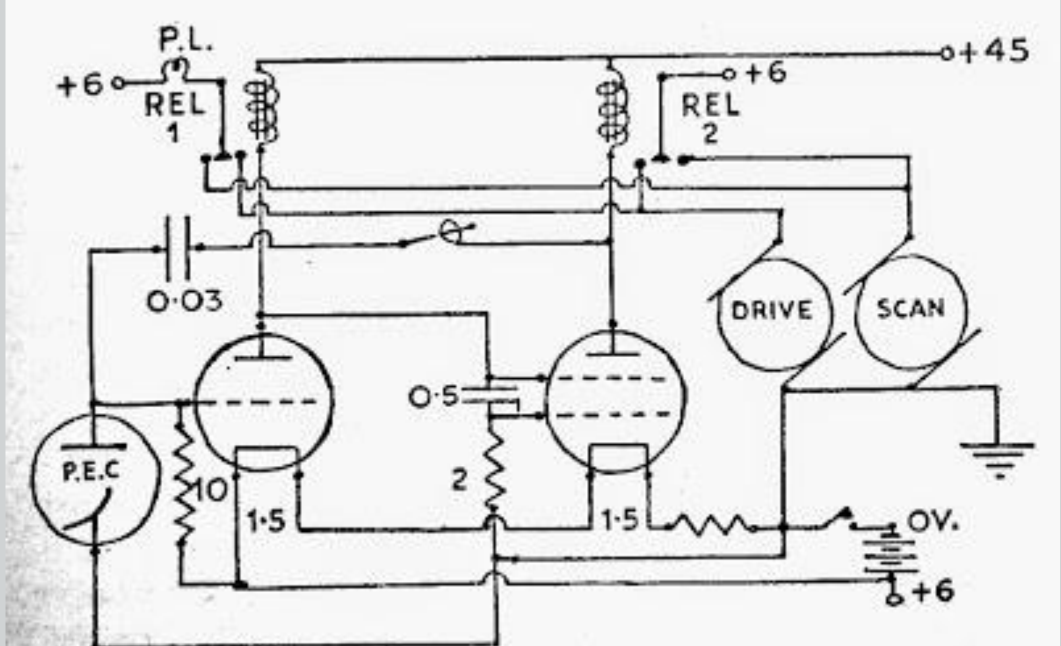


Figure 19. Circuit of *M. Speculatrix*

[2]

Grey Walter’s Tortoises

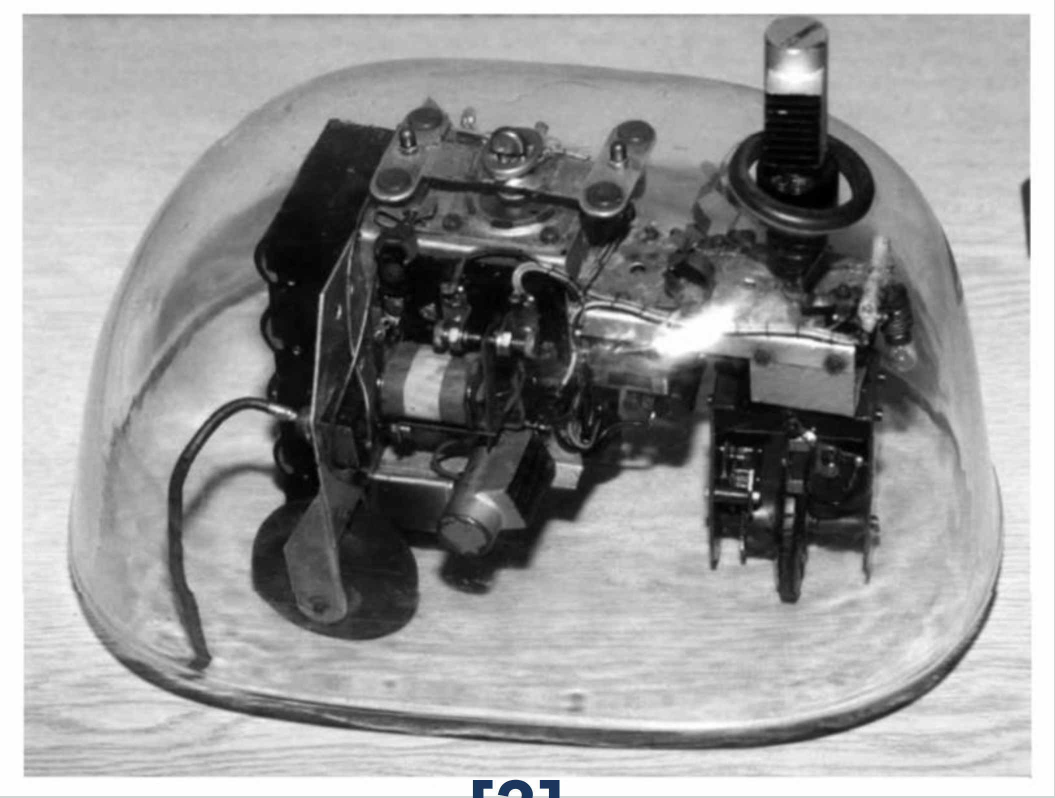
[MECHANICAL TORTOISE - British Pathé (britishpathe.com)]

Grey Walter's Tortoises

- Because of their steering mechanisms, light sensor and light, Tortoises are able to detect each other, and even "see" themselves in mirrors

- They can also detect when they collide with each other, or objects in the environment

- These are all simple mechanisms, and they were connected to relatively simple controllers, but in the sensorimotor loop they interact in complex ways



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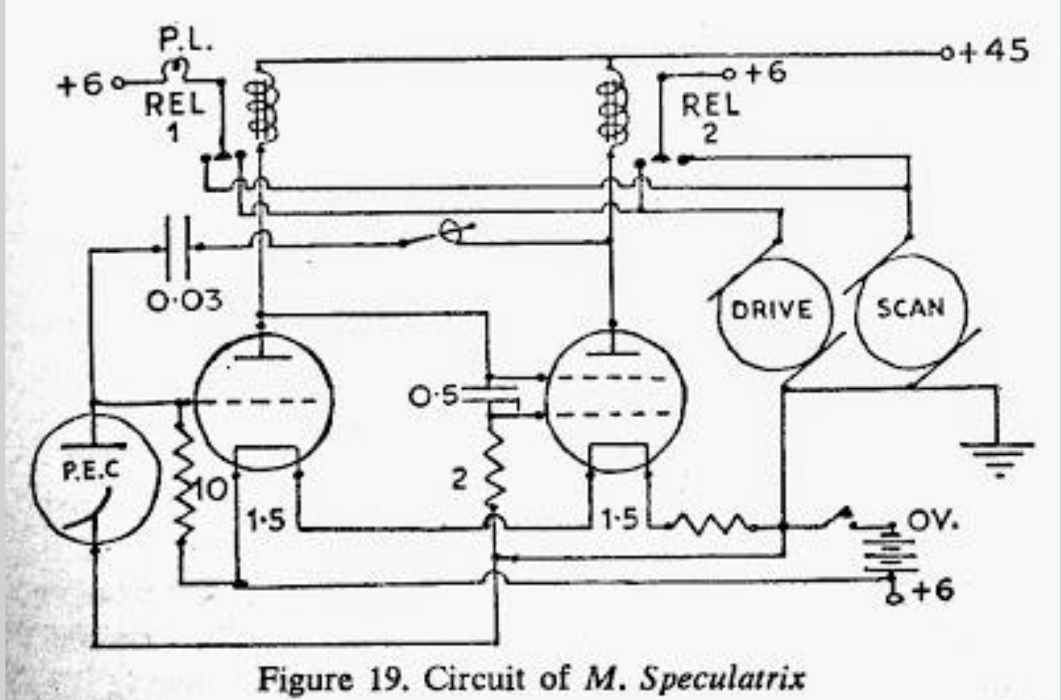
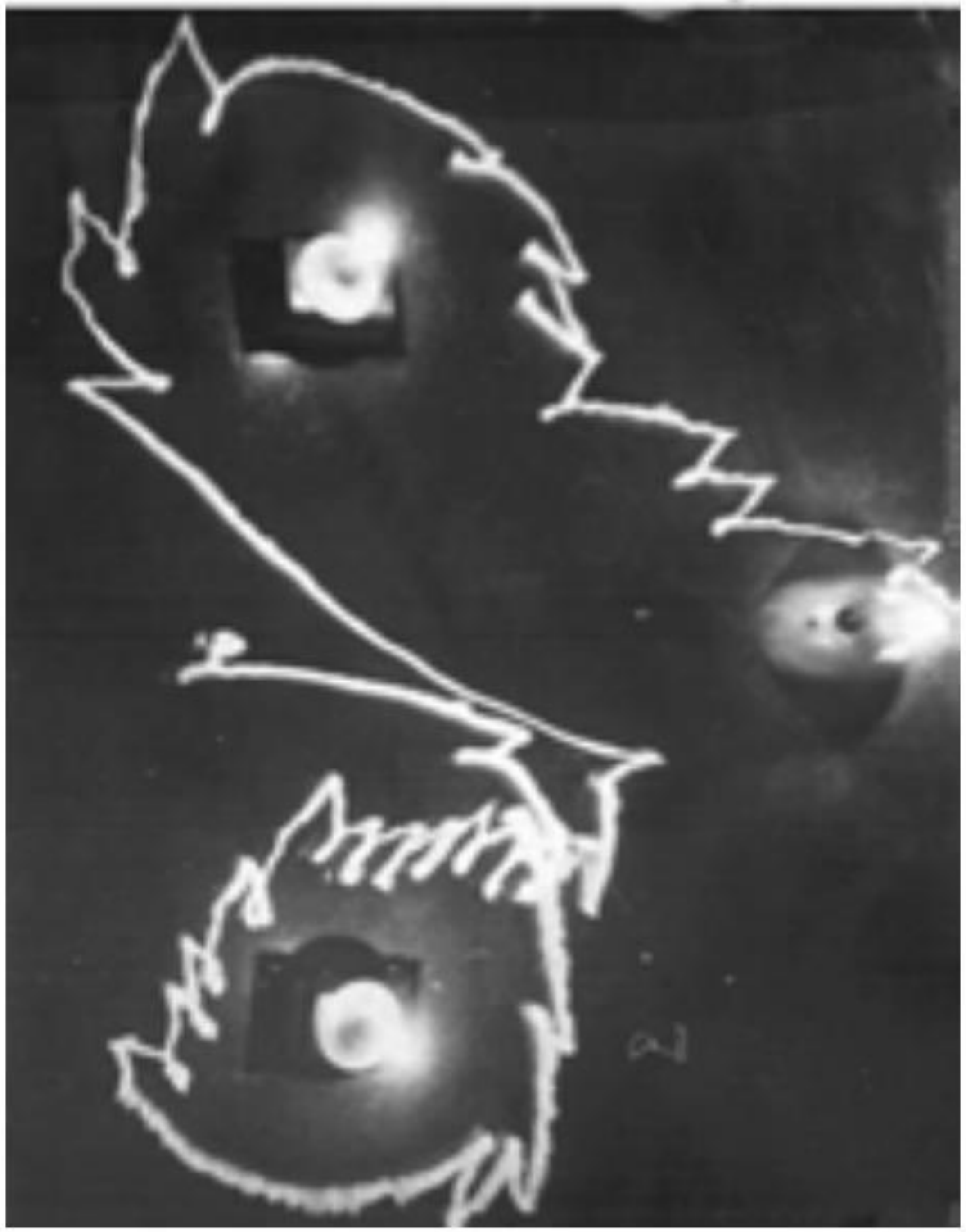


Figure 19. Circuit of *M. Speculatrix*

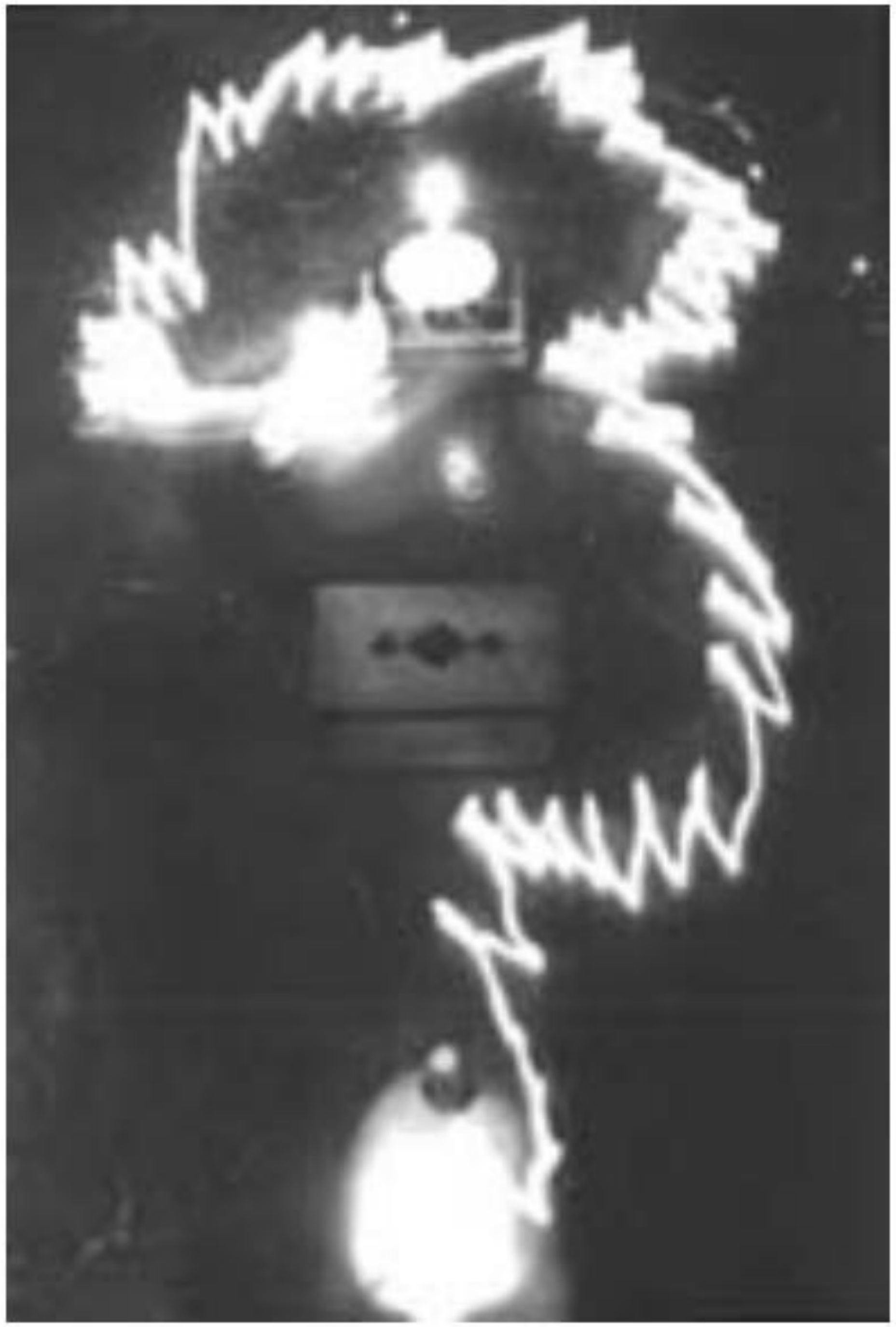
[2]

Grey Walter's Tortoises

Phototaxis



Obstacle avoidance

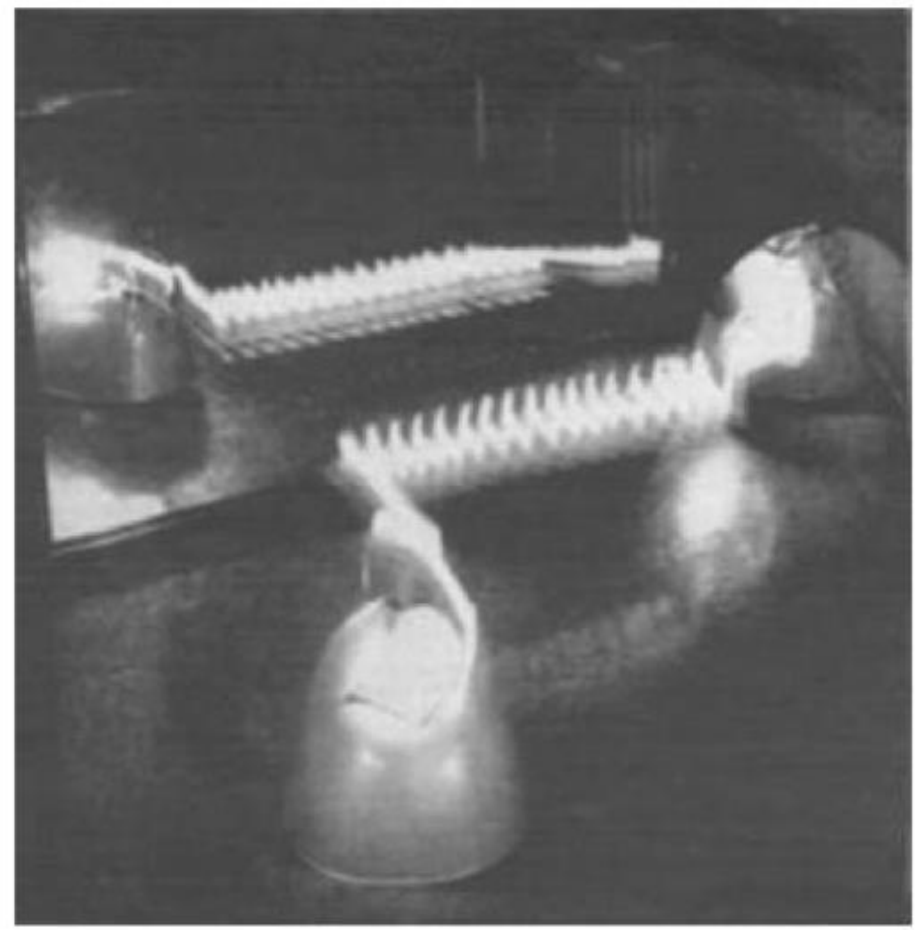


Grey Walter’s Tortoises

Recharging

Interaction

Narcissism

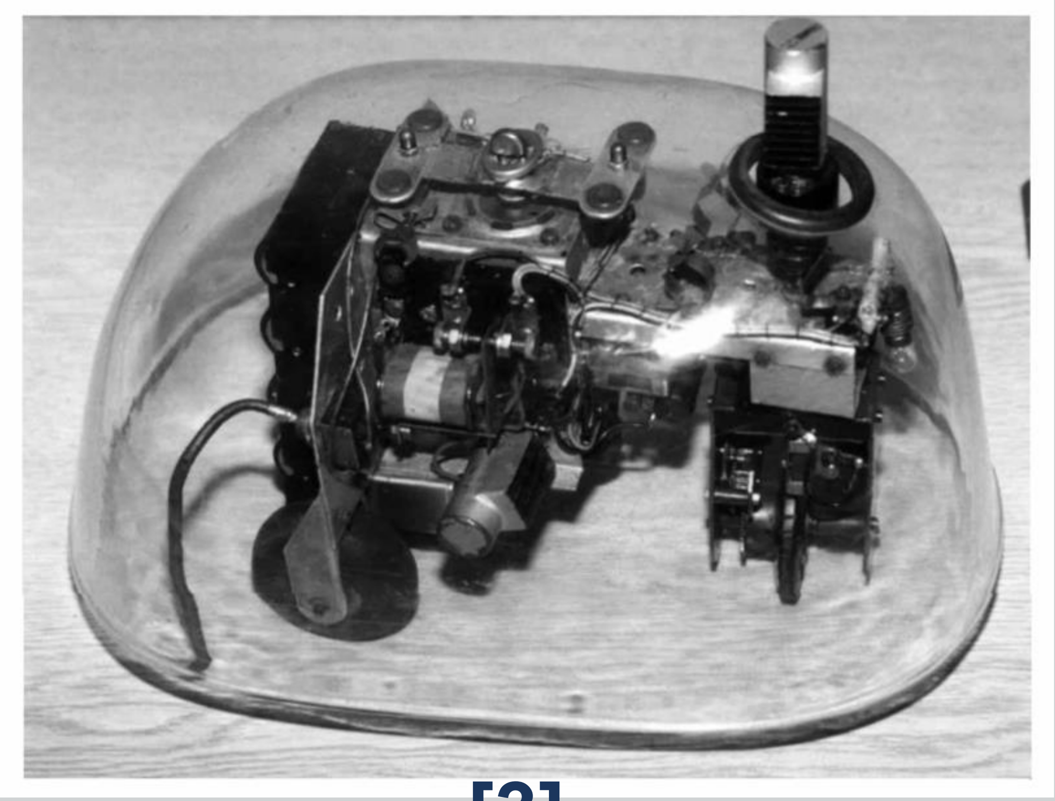


Grey Walter’s Tortoises

- Grey Walter didn’t write much about his Tortoises, so we don’t have the full details of all of their control circuits

- What we do know is that they represent an early example of **situated and embodied** intelligent behaviour in robots

- They were very well known at one time, but then forgotten for decades
  - But Grey Walter’s work became very influential again in the 1980s



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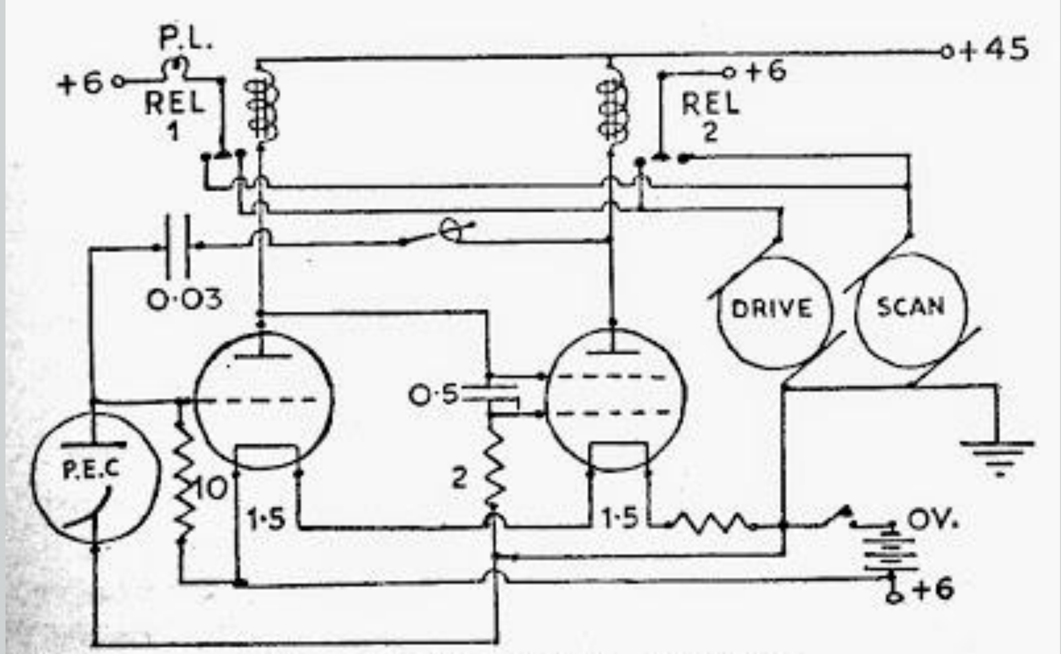


Figure 19. Circuit of *M. Speculatrix*

[2]

Situatedness and embodiment

- *All* animals and robots are situated and embodied
- An animal or a robot is *always* situated in its environment
- And it *always* has a body, and therefore an embodiment
  - But there is also a deeper concept of embodiment
- The questions that matter are:
  - To what extent does an agent *take advantage of* its situatedness?
  - To what extent does the embodiment of the robot affect its behaviour, and is the effect for better or worse?

(all of the above applies to sensorimotor systems more generally)

Umwelten

- Jakob von Uexküll (1934) [13] introduced the *umwelt*
- In simple terms, the aspects of the environment which an agent can sense and have an effect on
  - E.g., Aristotle wrote that we have 5 senses; some would say we have more than 30
  - But other species have senses which we do not, and lack some that we do have
- In any physical space (local environment) there may be as many *umwelten* as there are sensorimotor agents

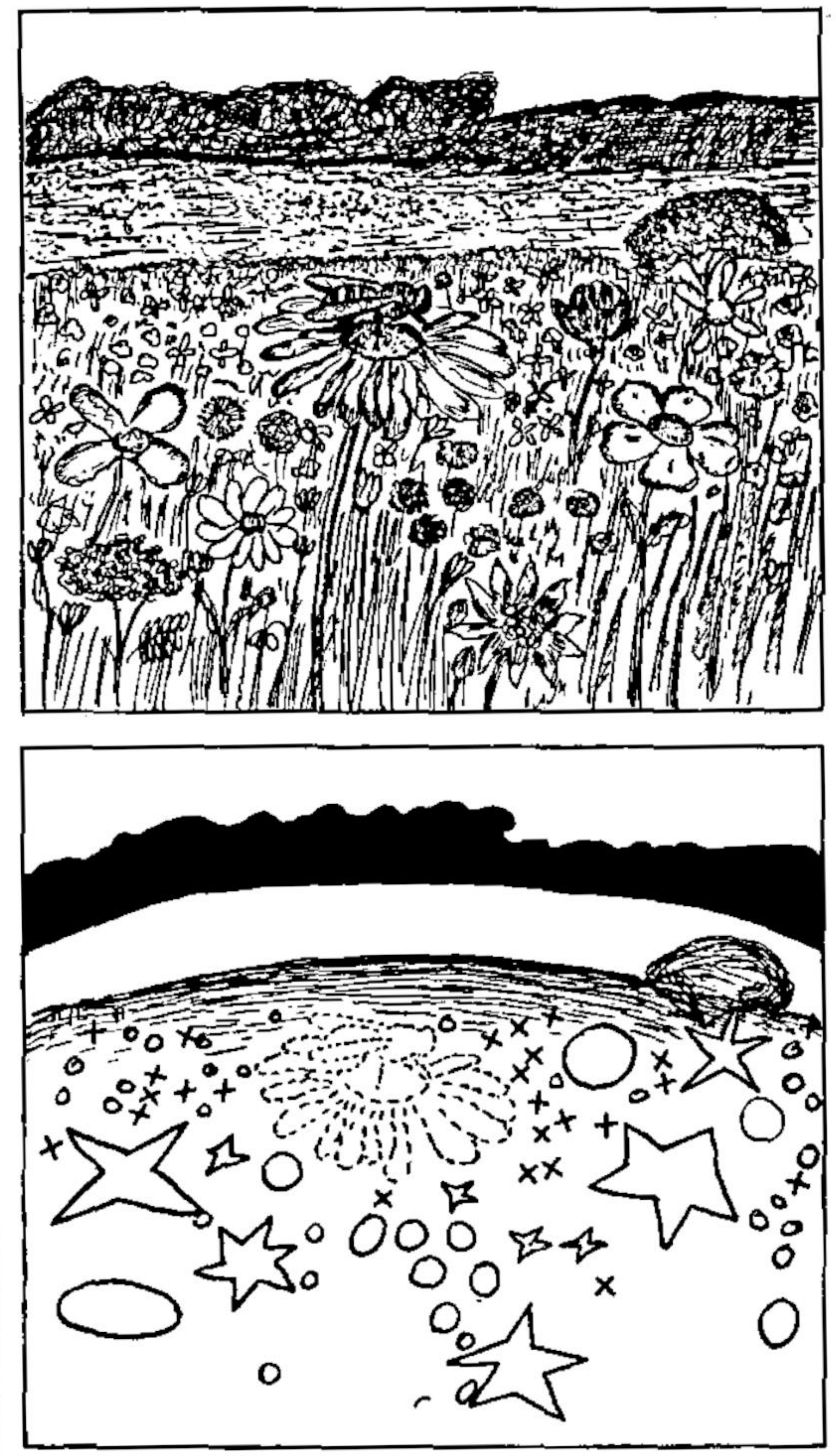


FIGURE 23. Surroundings *(top)* and environment *(bottom)* of the bee

[13]

3. AI Robotics - what *not* to do in the 1980s

AI robotics - what not to do

[4]

- "The cart moved 1m every 10 to 15 min, in lurches. After rolling a meter it stopped, took some pictures, and thought about them for a long time. Then it planned a new path, executed a little of it, and paused again." [Moravec, 1983]

AI robotics - what not to do

[Stanford Cart - The New York Times (nytimes.com)]

How not to do robotics

"Despite the serious intent of the project, I could not but help feeling disappointed. Grey Walter had been able to get his tortoises to operate autonomously for hours on end, moving about and interacting with a dynamically changing world and with each other. His robots were constructed from parts costing a few tens of dollars. Here at the center of high technology, a robot relying on millions of dollars of equipment did not appear to operate nearly as well. [. . .] Were the internal models truly useless, or were they a down payment on better performance in future generations of the Cart?" [Rodney Brooks, 2002] [8]

4. Behaviour-based robotics, part 2 – goodbye GOFAI!

Rodney Brooks

- Rodney Brooks became convinced that a new approach was needed to artificial intelligence for robotics.

- As he mentioned in the quote in the previous slide, he knew about Grey Walter's earlier Tortoises, and considered them superior to what was *supposed to be* the cutting edge of robotics at the time

  - He wondered: If Grey Walter's Tortoises didn't need to create plans of their environments, then what were plans (which took 10 to 15 minutes to make) actually good for?

- As Brooks realised, plans, and the models of the world they are based on, are not required for a lot of sensorimotor behaviour

Rodney Brooks

- “[. . .] the world is its own best model. It is always exactly up to date. It always contains every detail there is to be known. The trick is to sense it appropriately and often enough.” [Brooks, 1990] [5]

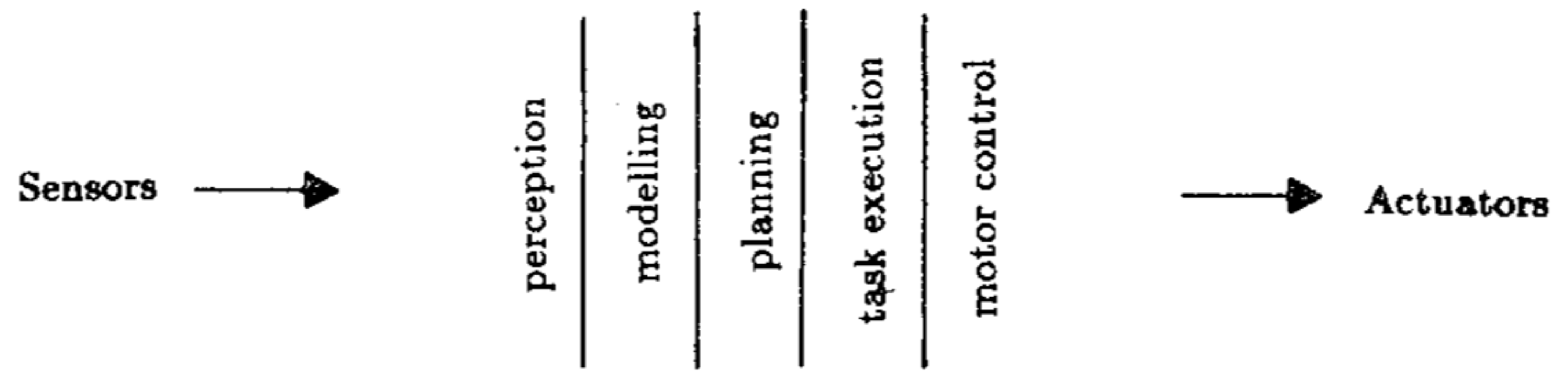


Fig. 1. Traditional decomposition of a mobile robot control system into functional modules.

[5]

Good old fashioned AI (GOFAI): sense-plan-act

- Sense-plan-act is serial and slow

Rodney Brooks

- "[. . .] the world is its own best model. It is always exactly up to date. It always contains every detail there is to be known. The trick is to sense it appropriately and often enough."
  [Brooks, 1990] [5]

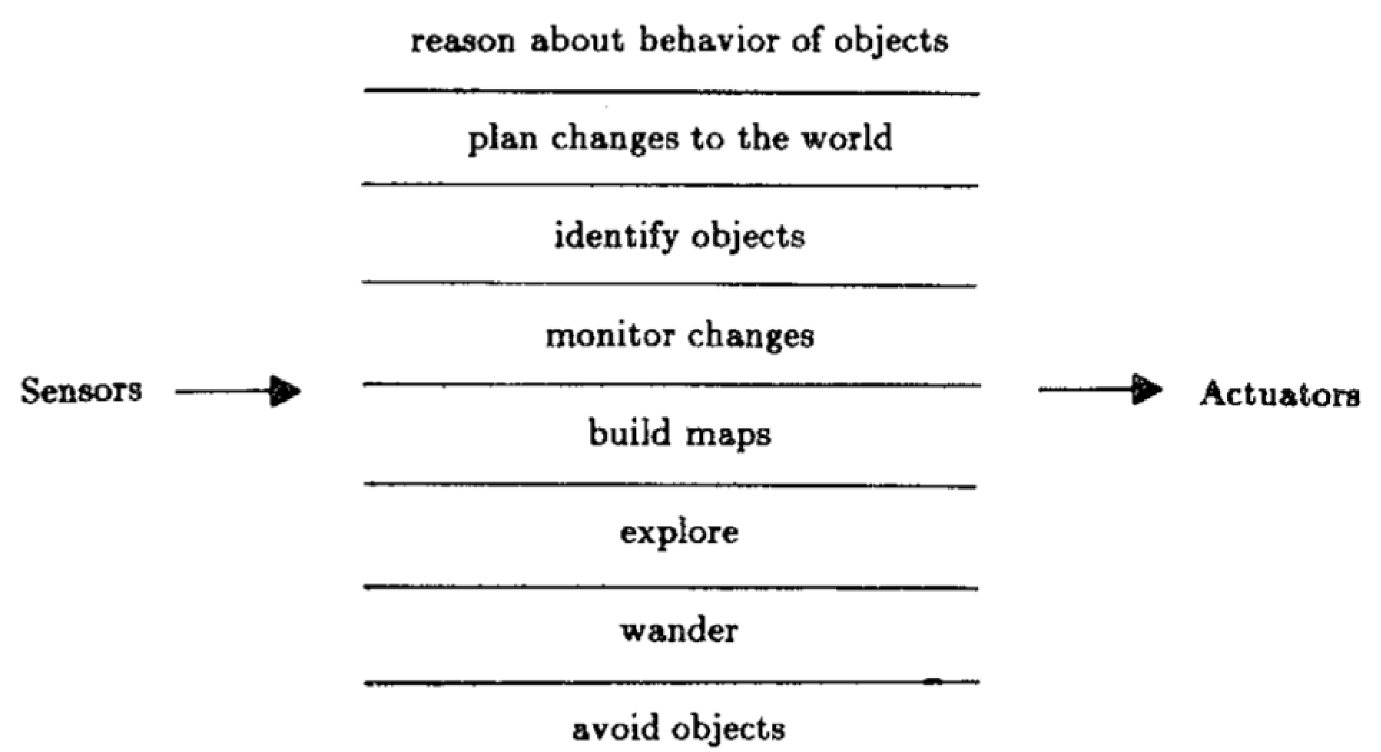


Fig. 2. Decomposition of a mobile robot control system based on task-achieving behaviors.

[5]

Nouvelle AI: sense-act

- Sense-act is parallel and fast

Behaviour-based robotics

- **What's so bad about having a plan?**

  1. **The Stanford cart relied on a very large and very expensive off-board computer for its plan**

  2. **Planning took up most of the robot's time**

  3. **What if the world changes while a plan is being formed?**

Behaviour-based robotics

- What was gained by ditching the central planner?
  - Robots could be smaller, faster and cheaper
  - For simple behaviours, no modelling was required
  - No off-board computing was required
  - Robots were more successful in dynamic environments
- Today's financial and computational constraints may have changed, but these ideas remain influential
- Other constraints are unchanged:
  - e.g. Practical rule of thumb: update and respond to sensors at frequency of 10Hz or more, but this does depend on how fast the robot moves and how dynamic the environment is

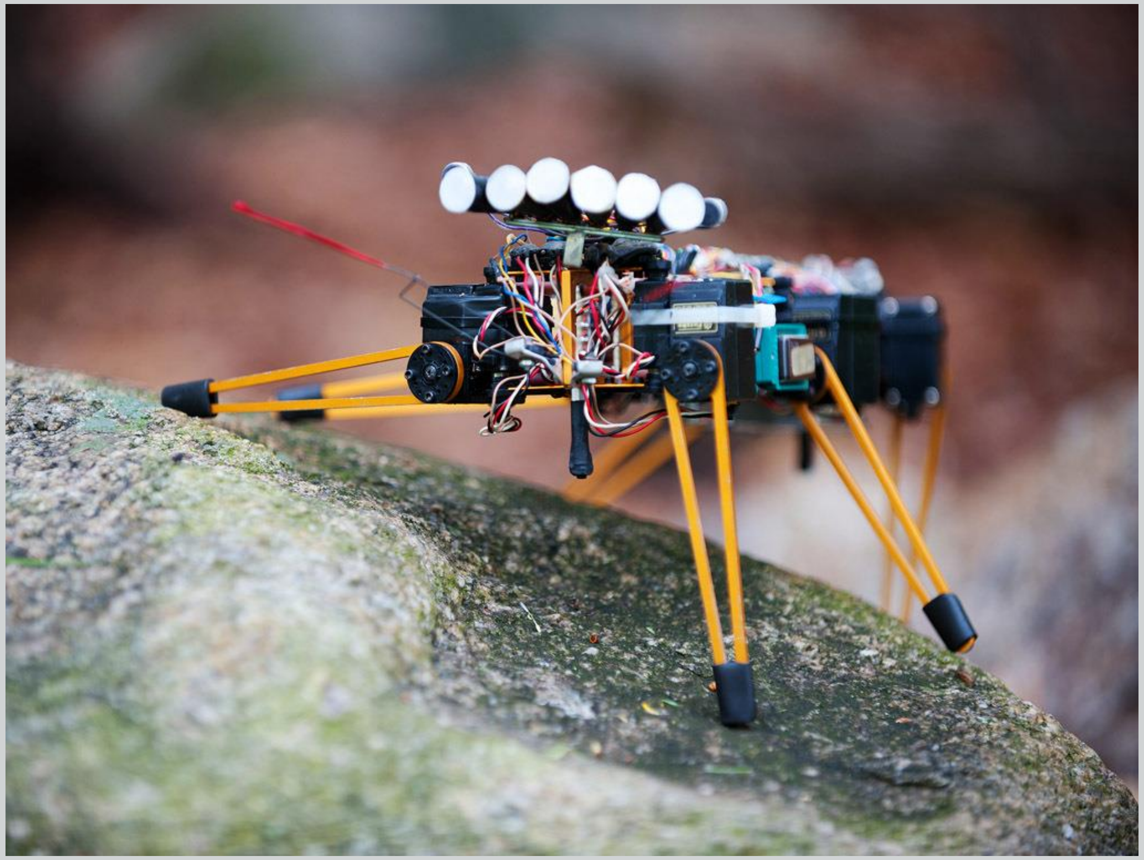
Genghis

https://robots.ieee.org/robots/genghis/?gallery=photo1

Genghis

Genghis

- Hardware:
  - Weight 1kg
  - 35cm long; 25cm leg span
  - 2 servomotors per leg, with force feedback
  - Inclinometers (pitch and roll)
  - 2 front whiskers
  - 6 forward looking passive infrared sensors
  - Power and computing are both on-board
- Software:
  - The subsumption architecture



[6]

The subsumption architecture

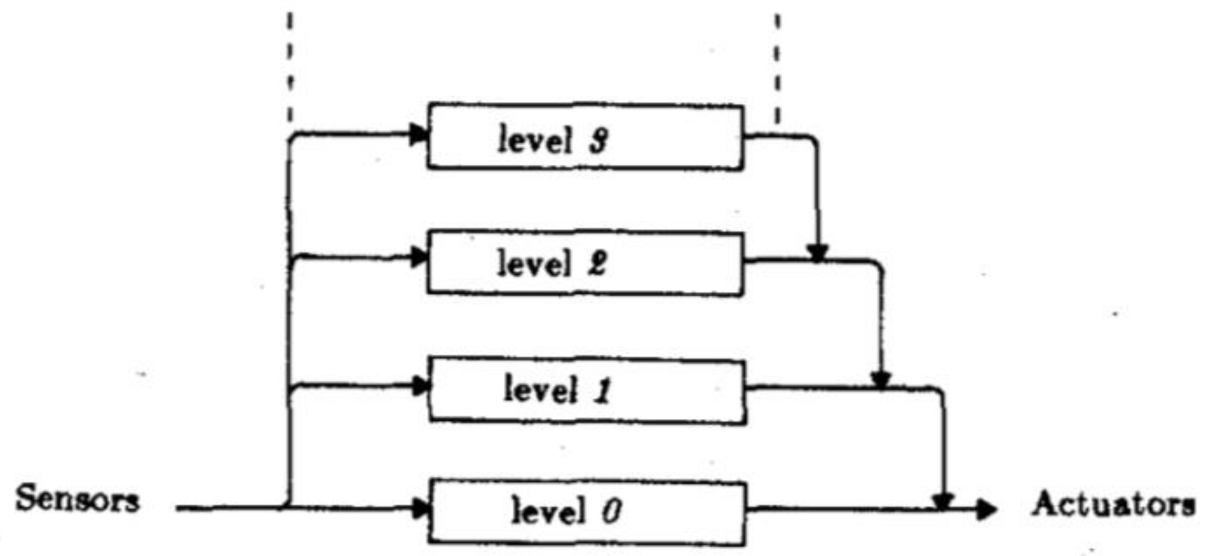


Fig. 3. Control is layered with higher level layers subsuming the roles of lower level layers when they wish to take control. The system can be partitioned at any level, and the layers below form a complete operational control system.

[7]

- The core concept:
  - Behavioural components (or competences) are added in layers
- No central control
  - Higher layers make use of (or subsume) lower layers

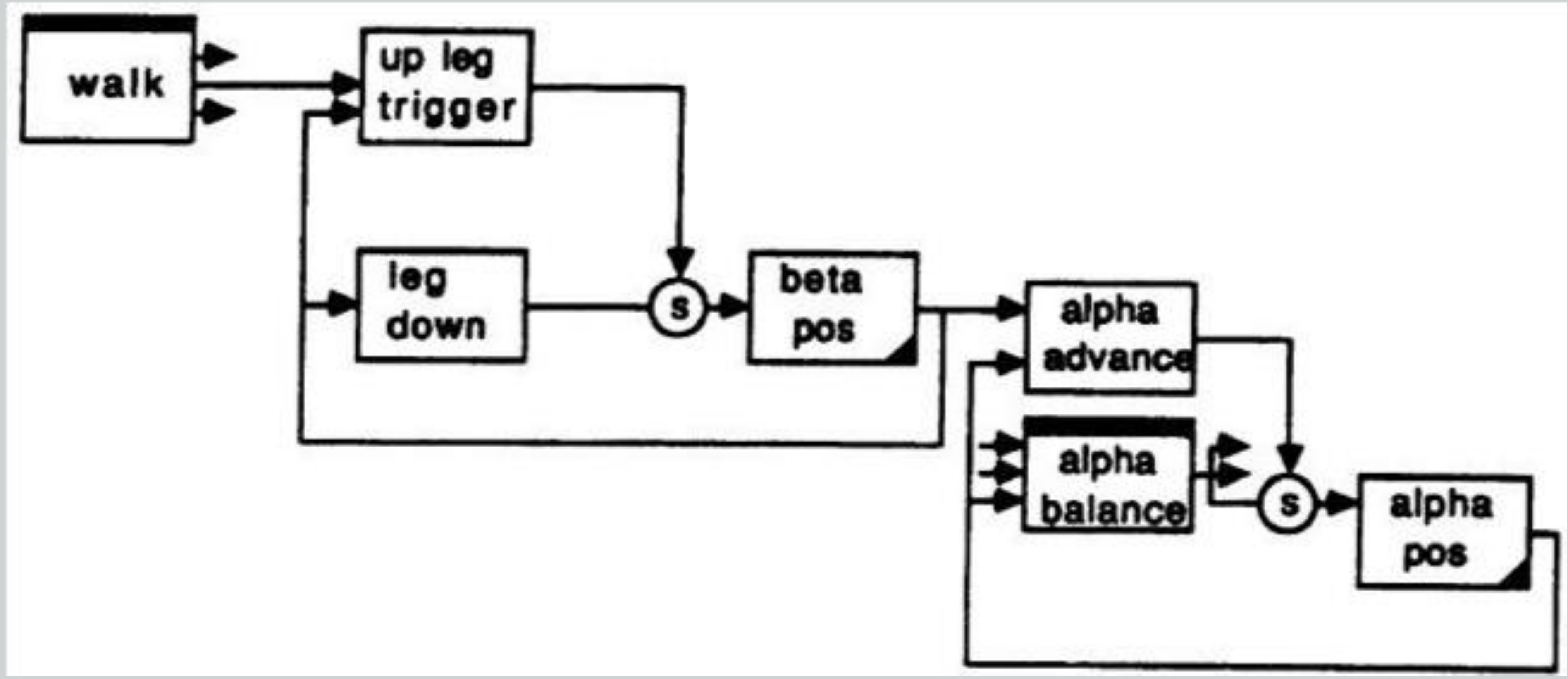
The subsumption architecture

- Example: [Brooks, 1986]

  1. Avoid contact with objects (whether the objects move or are stationary).
  2. Wander aimlessly around without hitting things.
  3. "Explore" the world by seeing places in the distance that look reachable and heading for them.
  4. Build a map of the environment and plan routes from one place to another.
  5. Notice changes in the "static" environment.
  6. Reason about the world in terms of identifiable objects and perform tasks related to certain objects.
  7. Formulate and execute plans that involve changing the state of the world in some desirable way.
  8. Reason about the behavior of objects in the world and modify plans accordingly.

[7]

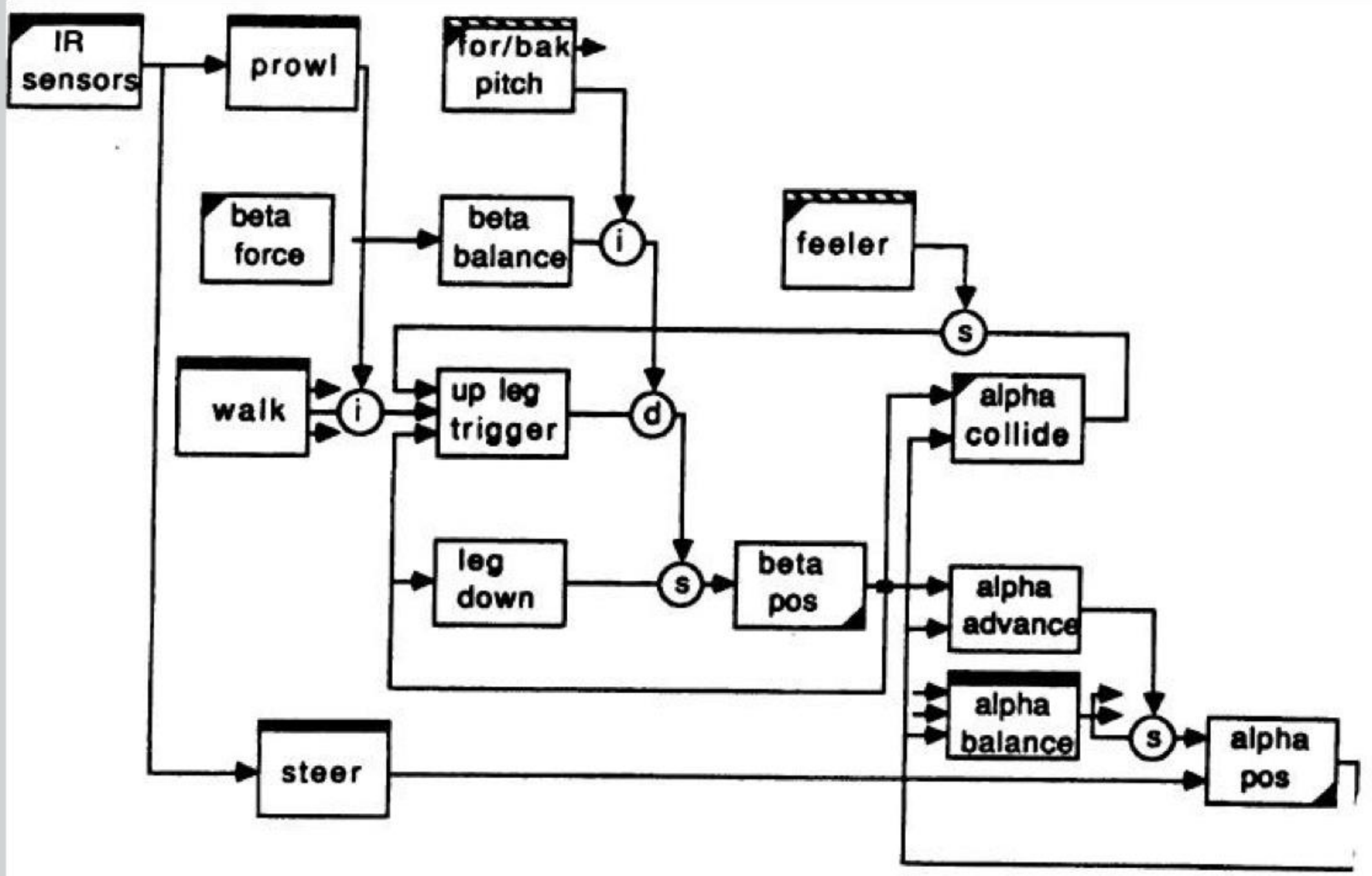
The subsumption architecture



[7]

- The diagram shows the controller for a single leg on Genghis
  - Each block in the diagram is a relatively simple finite state machine (FSM)

The subsumption architecture



[7]

- The diagram shows Genghis’ complete controller, although only one leg controller is drawn
  - 57 FSMs in total
- Later robots had 1500 FSMs, which Brooks argued proves scalability . . . [Brooks, 2002]

The subsumption architecture

- Although Brooks argued otherwise, most researchers would probably agree that the subsumption architecture *is* tricky to work with, and difficult to scale up to complex behaviours

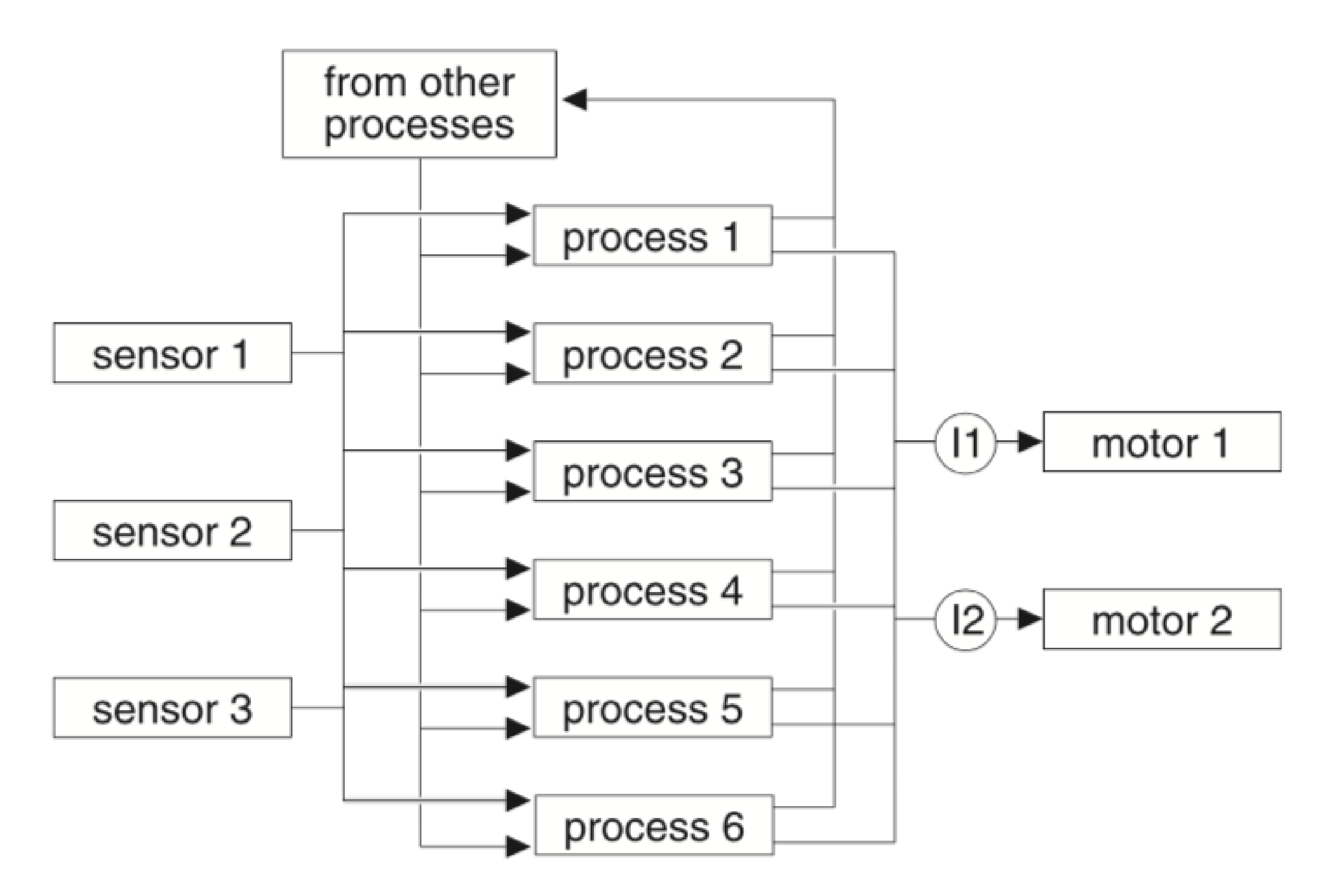
- The principles which underly subsumption methods remain influential:

    - In situated and embodied artificial intelligence, models and plans are not normally included unless absolutely necessary

    - Many other approaches, such as the extended Braitenberg architecture, are modular in a similar way to the subsumption architecture

    - The benefit of parallel processing is clear in both AI and biology: e.g. it is what makes brains so powerful compared to computers which run at very high clock speeds

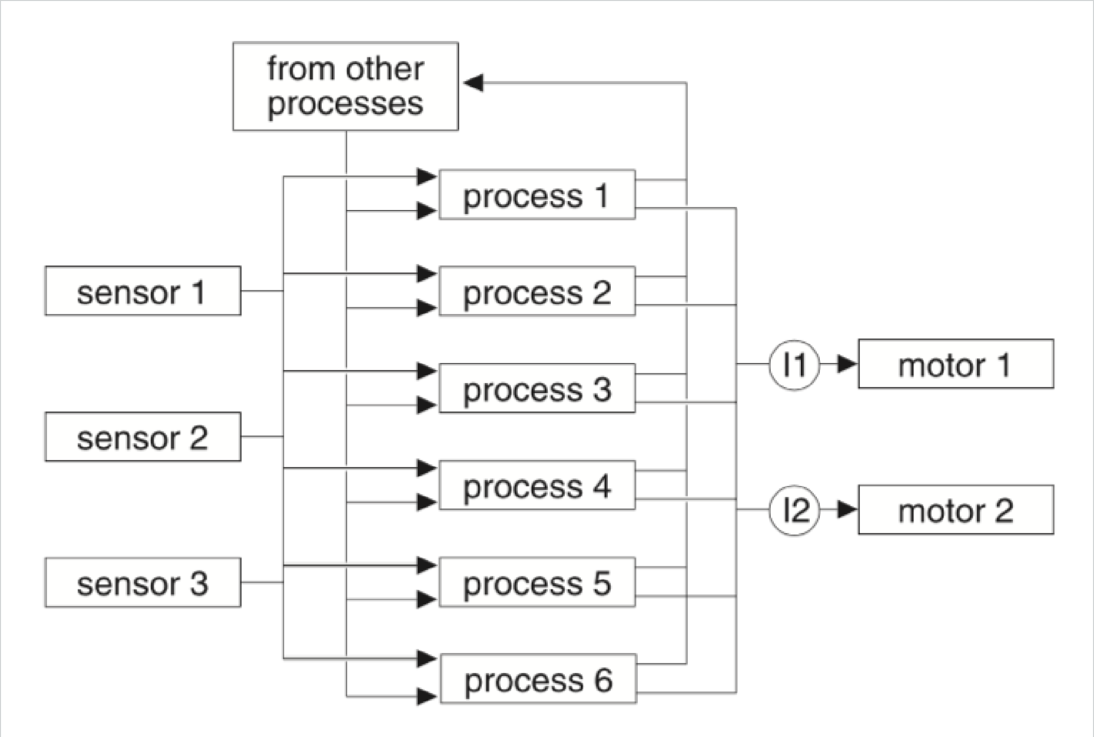
The Extended Braitenberg Architecture



[9]

- For both learning and evolved robot controllers, neural networks are a very common choice
- However, if you want to hand-design a controller (e.g. in your coursework assignments), the Extended Braitenberg Architecture (EBA) might be a sensible place to begin

The Extended Braitenberg Architecture

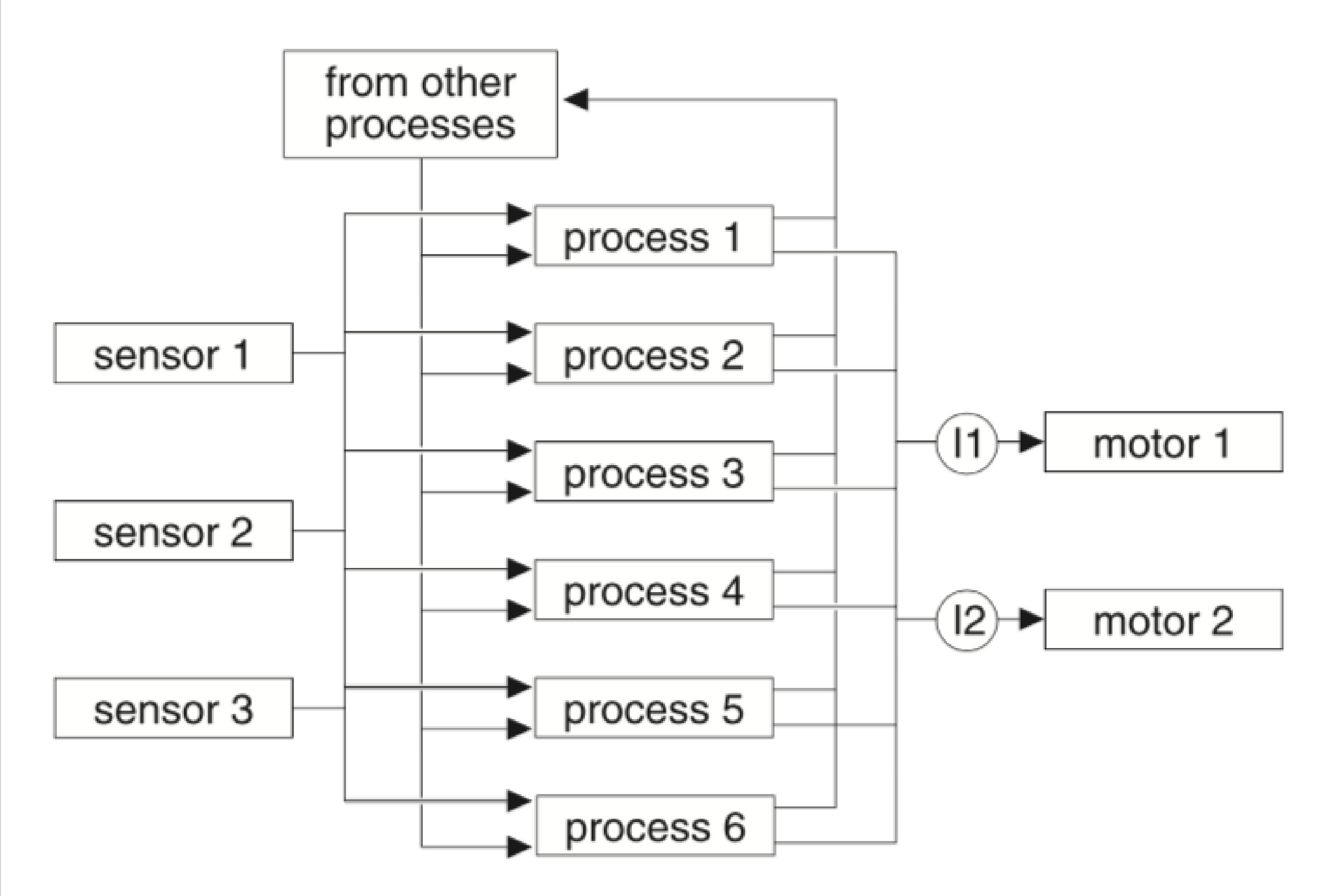


[9]

[Pfeifer and Scheier, 2001]

- The EBA has similar benefits to the subsumption architecture,
    - Modularity
    - Simpler behavioural elements (processes) combine to produce more complex behaviours
    - Processes (potentially) run in parallel
- But it is more flexible and easier to work with

The Extended Braitenberg Architecture

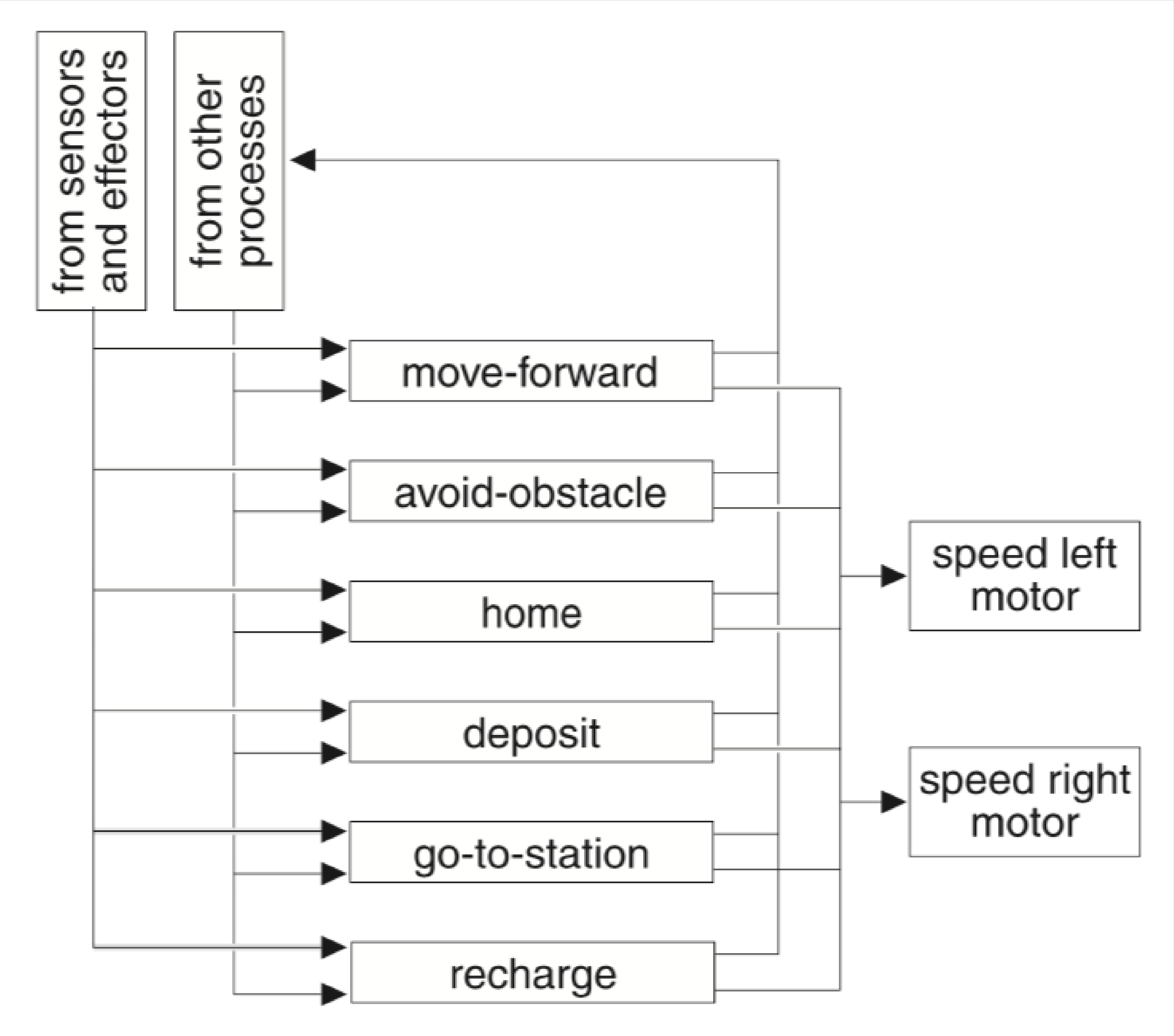


[9]

- A number of sensorimotor processes run in parallel
- Each process connects some subset of the robot's sensors to some subset of its motors
- Processes may be implemented in various ways, e.g. using neural networks
- All processes can feedback to all processes
- All connections can be weighted to set the strengths of their influences

EBA example: garbage collection

- In the absence of sensory stimuli, the robot drives forwards
- Obstacle avoidance adds to the forwards driving commands, rather than replacing them
  - a simple example of how this *might* be achieved (not how it actually does):
    - If motor commands for forwards are [5, 5] and commands for obstacle avoidance are [0, -10], then the resulting motor commands are [5, -5], which can make a robot turn on the spot
- Some processes might temporarily override others, e.g. “recharge”

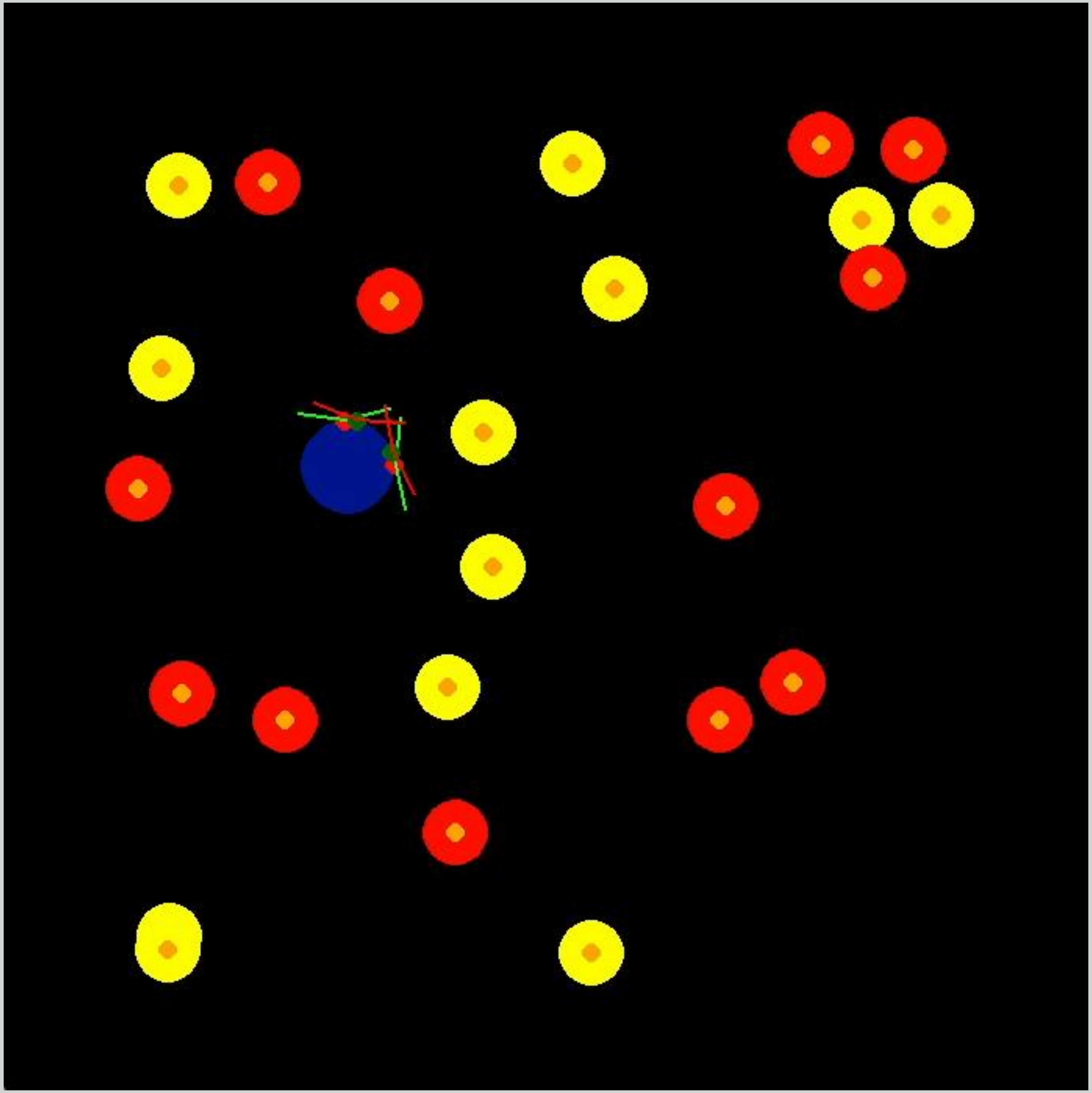


Control architecture [9]

$$\mathbf{s}(t) = (s_l(t), s_r(t)) = \left(\sum_{i=1}^{N} o_i^l(t), \sum_{i=1}^{N} o_i^r(t) \right)$$

Motor equation

Simple EBA example - Sandbox



Summary

Main points:

- **Situated and embodied robotics began in cybernetics, but at first, AI robotics research was focussed on a more computational approach.**

- **Grey Walter was very successful in this area in the 1950s, but his ideas were forgotten for decades.**

- **In the 1980s, frustration with conventional AI led to a new cybernetics-inspired approach: Behaviour-based robotics**

- **None of the systems we have looked at in these slides are *self-adaptive*. This is a severe limitation, which we can view in terms of how flexible and adaptable the systems are, and in terms of how little autonomy they have (according to Pfeifer and Scheier)**

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.

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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.

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

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Bibliography

Relevant websites

Other websites (sources of pictures)

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