Intelligence in Animals and Machines

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Reading List

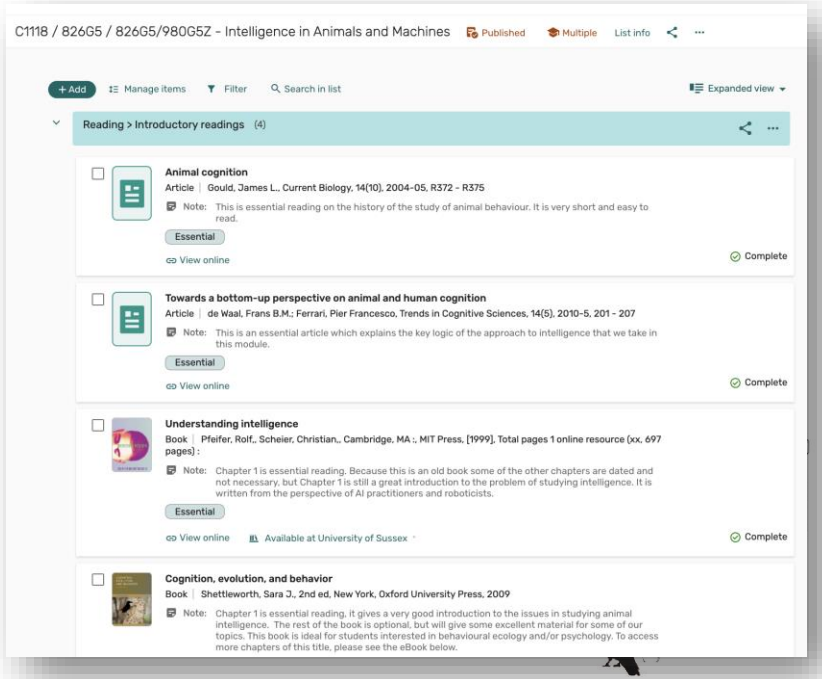
General module reading

- Chapter 1 Understanding Intelligence – Pfeifer and Scheier
- Chapter 1 Cognition, Evolution, and Behavior – Shettleworth
- Towards a bottom-up perspective on animal and human cognition – de Waal and Ferrari
- Animal cognition - Gould

Lecture 1 reading

- A new approach to robotics – Brooks

- Vehicles - Braitenberg
- Plant intelligence - Trewavas
- Slime mold cognition - Reid



Learning Outcomes

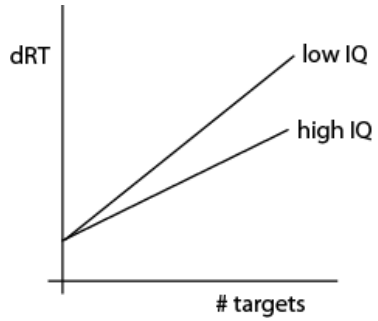
- Defining intelligence in way that allows comparisons between humans, animals and machines is hard.
- If we take human-centric definitions then we can widen gap between humans and other animals.
- If we take biological definitions then they are very inclusive.

- But we can still study where intelligent behaviour ‘comes from’.
- Behaviour emerges from the interactions between brains, bodies and the environment.

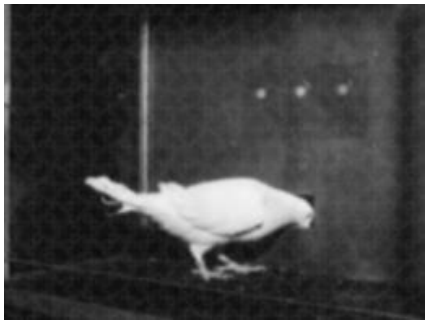
Part 1
What is intelligence?

Comparative Psychology is hard?

In humans, high IQ is associated with fast information processing

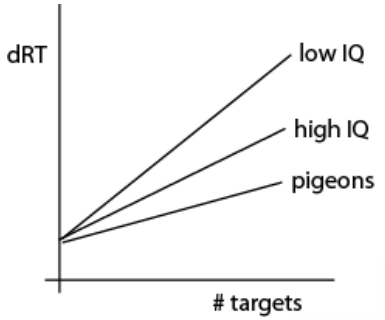


- Hick's law states that reaction time increases as number of possible targets increases.
- The rate of increase is less for people with high IQ (Roth, 1964).



- Hick's law generalises to pigeons
- But the rate of RT increase is much less than for high IQ people (Vickrey and Neuringer, 2000)

- Does this mean pigeons are better at processing information?
- Does this mean that pigeons are intelligent?



Hick (1952) Quart J Exp Psyc
Roth (1964) Zeit Exper Ange Psyc
Vickrey and Neuringer (2000) Psyc Bull Rev

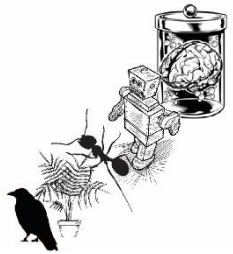
Comparative Psychology is hard?

In humans we associate learning speed with intelligence

Increasing K-index*

Animal	# Rewards
Bees	2
Quail	8
Pigeons	10
Rats	22
Rabbits	24
Human Infants	28

- Can we use learning speed as a way to compare across species?
- Angermeier (1984) tried to perform a meta-analysis on learning speeds.
- Learning speeds actually seem to be inverse to brain size.
- What does this tell us about intelligence?



*K-index measures brain folding, higher values mean greater cortical surface area

Angermeier (1984) The Evolution of Operant Learning and Memory. Karger

Anthropocentric definitions of intelligence

- Tool-use
- Theory of mind
- Numeracy
- Language
- Social skill

We can define certain human abilities as intelligent…

…and look for these abilities in animals

Anthropocentric definitions of intelligence

Let's take the example of complex language in humans

- If we fostered different primates and taught them sign-language, we could look for their ability to produce complex language.
- No species would be capable of the complex language that humans use.

- Human language depends on specialised skill with: hearing, memory, motor-behaviour, breathing, turn taking, social observation.
- Did all these things appear in a brief period of evolutionary time … …?

Language?

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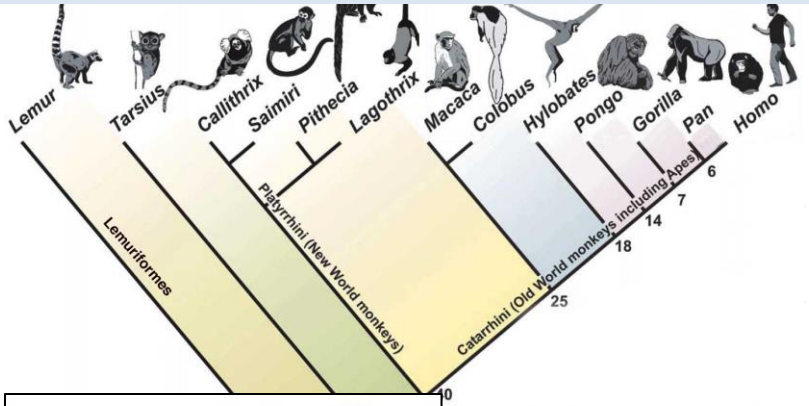
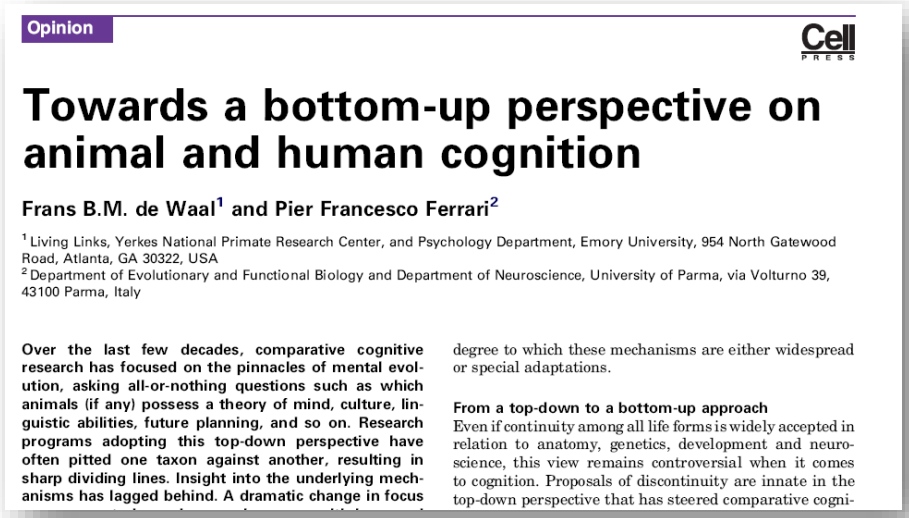


} evolution of language

Anthropocentric definitions of intelligence

- When researchers start with a human-behaviour and look for it in animals, this is ‘top-down’*
- Failure to find these human-like abilities gets undue publicity and widens the gap between humans and other animals
- This is anti-evolutionary as well integrated capacities seem to appear in a brief evolutionary time



Opinion

Cell PRESS

Towards a bottom-up perspective on animal and human cognition

Frans B.M. de Waal[1] and Pier Francesco Ferrari[2]

[1] Living Links, Yerkes National Primate Research Center, and Psychology Department, Emory University, 954 North Gatewood Road, Atlanta, GA 30322, USA
[2] Department of Evolutionary and Functional Biology and Department of Neuroscience, University of Parma, via Volturno 39, 43100 Parma, Italy

Over the last few decades, comparative cognitive research has focused on the pinnacles of mental evolution, asking all-or-nothing questions such as which animals (if any) possess a theory of mind, culture, linguistic abilities, future planning, and so on. Research programs adopting this top-down perspective have often pitted one taxon against another, resulting in sharp dividing lines. Insight into the underlying mechanisms has lagged behind. A dramatic change in focus

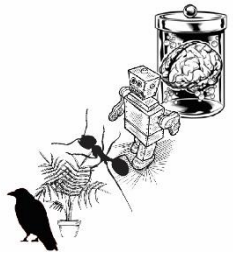
degree to which these mechanisms are either widespread or special adaptations.

From a top-down to a bottom-up approach

Even if continuity among all life forms is widely accepted in relation to anatomy, genetics, development and neuroscience, this view remains controversial when it comes to cognition. Proposals of discontinuity are innate in the top-down perspective that has steered comparative cogni-

de Waal and Ferrari (2010) TiCS is an essential module reading

They explain how a top-down approach ignores evolution and makes it harder to think about the mechanisms that produce intelligent behaviour.



* Be careful when searching ‘top-down and bottom-up’ they can mean very different things

Anthropocentric definitions of intelligence

- Why are ‘top-down’ approaches to animal intelligence so problematic?
- Definitions of behaviour have to be applied to animals, so identifying intelligent behaviour hinges on semantics.

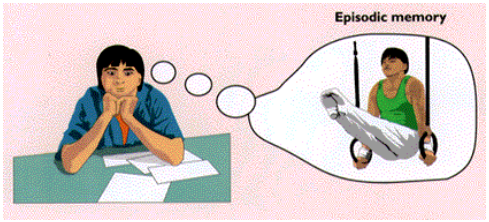
Episodic-like memory during cache recovery by scrub jays

Nicola S. Clayton* & Anthony Dickinson†

* *Section of Neurobiology, Physiology & Behavior, University of California at Davis, California 95616, USA*
† *Department of Experimental Psychology, University of Cambridge, Downing Street, Cambridge CB2 3EB, UK*

The recollection of past experiences allows us to recall what a particular event was, and where and when it occurred[1,2], a form of memory that is thought to be unique to humans[3]. It is known, however, that food-storing birds remember the spatial location[4–6] and contents[6–9] of their caches. Furthermore, food-storing animals adapt their caching and recovery strategies to the perishability of food stores[10–13], which suggests that they are sensitive to temporal factors. Here we show that scrub jays (*Aphelocoma coerulescens*) remember ‘when’ food items are stored by allowing them to recover perishable ‘wax worms’ (wax-moth larvae) and non-perishable peanuts which they had previously cached in

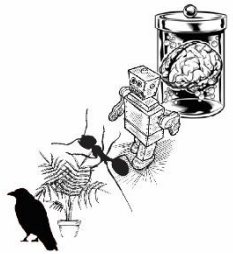
Episodic memory



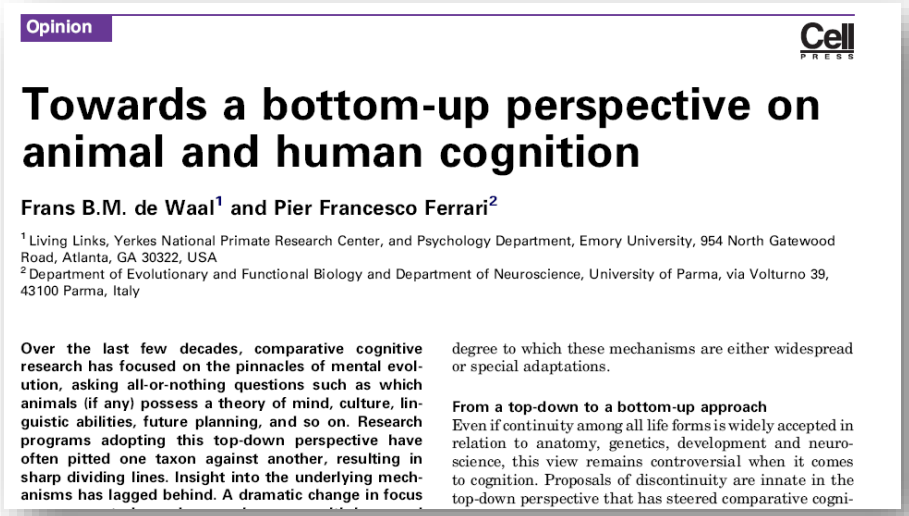
Teaching

Dancing

- But if you take a ‘top-down’ approach and decide that ants can teach, or that birds have mental time travel, you still don’t know how that intelligence comes about.



A bottom-up* approach to animal intelligence



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de Waal and Ferrari (2010) TiCS

- A bottom-up approach appreciates that the basic building blocks of cognition might be shared across a wide range of species.
- Focussing on the constituent capacities underlying larger cognitive phenomena, is more in line with neuroscience and evolutionary biology.

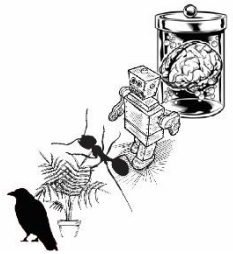
* Be careful when searching ‘top-down and bottom-up’ they can mean very different things

Biological definitions of intelligence?

- Evolution doesn't care about semantics
- Can we define intelligence using evolutionary fitness?

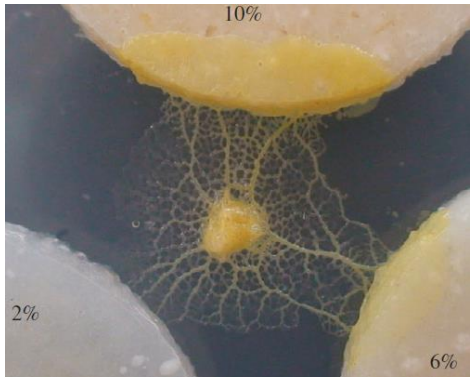
Intelligence is what organisms do

- Pro: we can focus on how intelligent behaviours evolve and what mechanisms are involved.
- Con: it is an inclusive definition that does not 'care' if "intelligent" behaviour is a product of "unintelligent" mechanisms

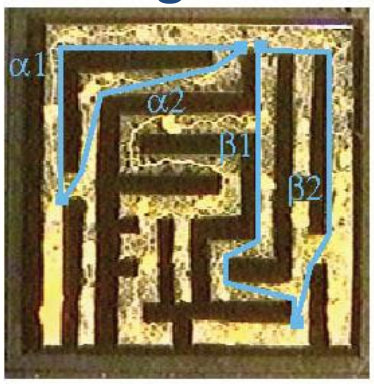


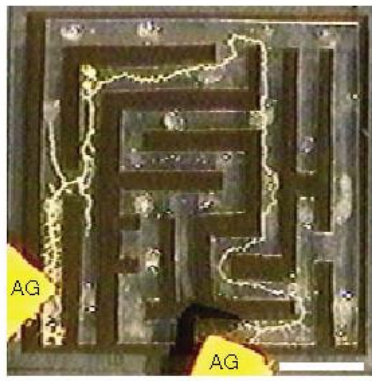
Inclusive definitions of intelligence

Sensible

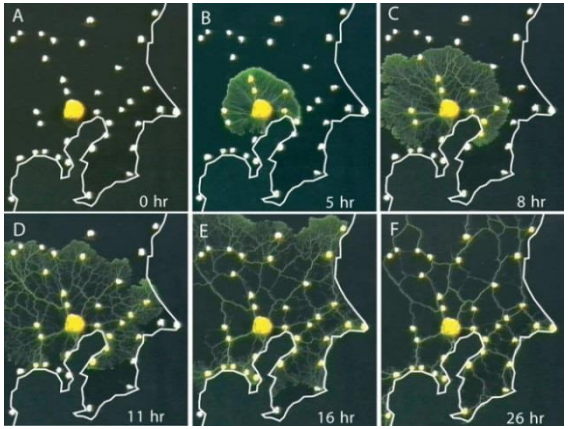


Maze solving





Town planning



- Single-celled organisms can produce behaviour and make ‘intelligent’ decisions.
- Slime-mold produce multiple tendrils that can transport nutrients around the organism.
- They explore areas with new tendrils and those that don’t carry nutrients will retract.
- This distributed algorithm leads to optimal spatial solutions

Reid et al. (2012)
Tero et al. (2010)

Inclusive definitions of intelligence

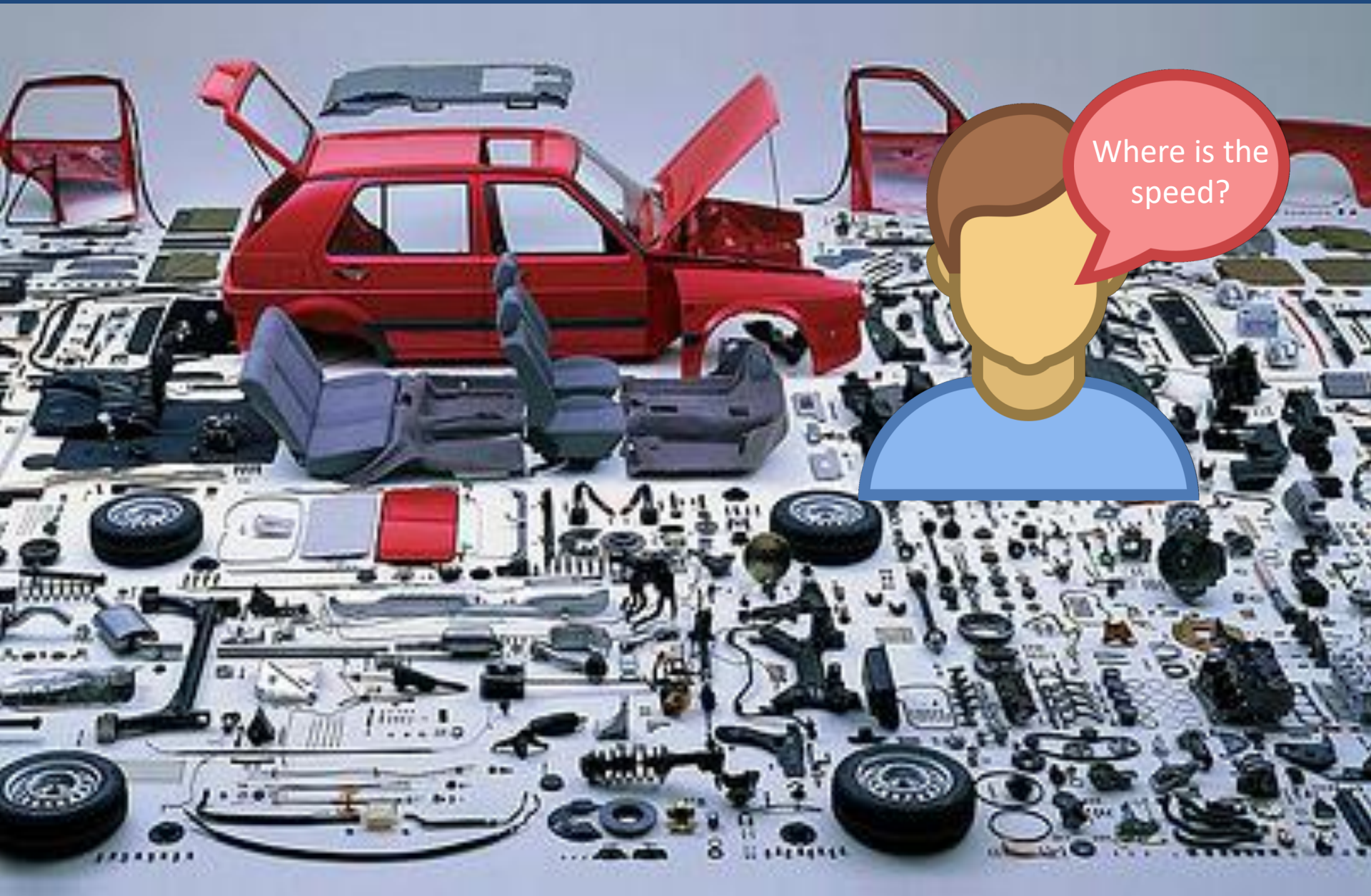
- Plants are mobile, reactive, communicative and can be said to ‘have behaviour’.
- Adaptive behaviour can be said to be intelligent.



Trewavas (2016) Biosciences

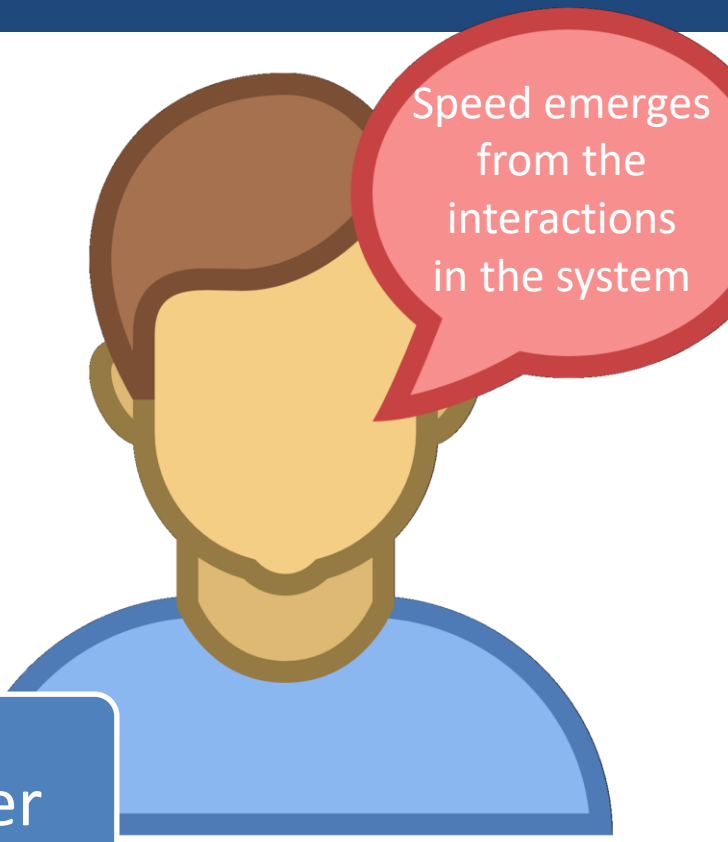
Part 2
Where does behaviour come from?

The emergence of behaviour



The emergence of behaviour

Environment



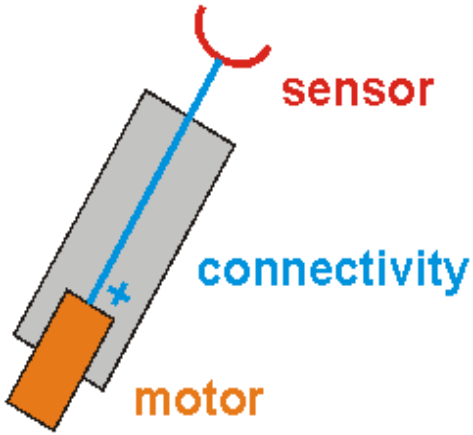
Body

Controller

Braitenburg's Vehicles

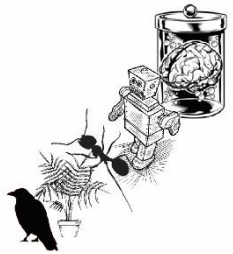
Braitenberg (1984), Vehicles: Experiments in Synthetic Psychology, MIT Press.

We can think about the behaviour of agents with simple mechanisms that we have designed



Situatedness: Agents interact with an environment

It does not like warmth, but … …"*overshoots cold in it's restlessness… …you would say it is ALIVE since you have never seen dead matter move around like that*" -VB



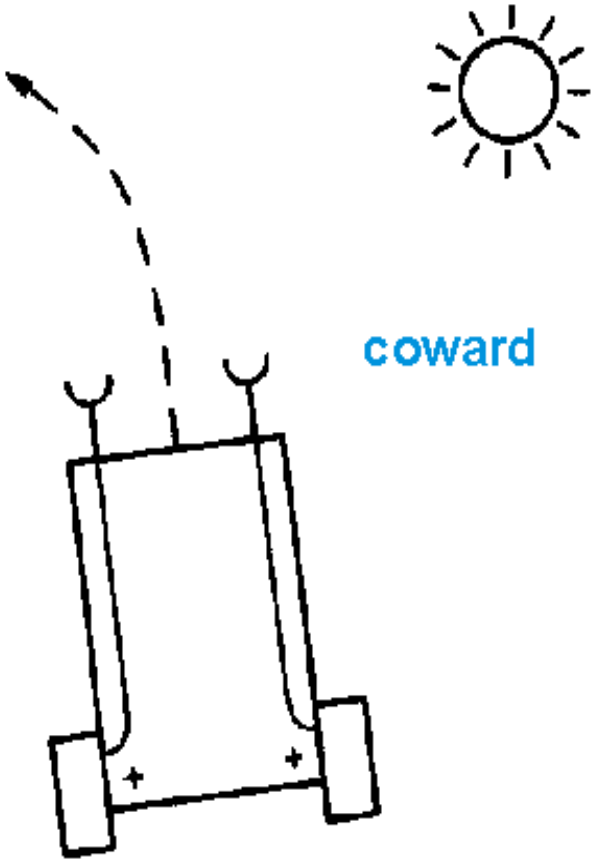
BV

Crossed positive connections mean that it will turn towards the side with the greater stimulus.

Embodiment:
Give a simple brain a body and it can produce behaviour

BV

If the connections are not crossed, then it turns away from excitation.



**Embodiment:
Shifting sensors
makes
a difference**

Mini-break

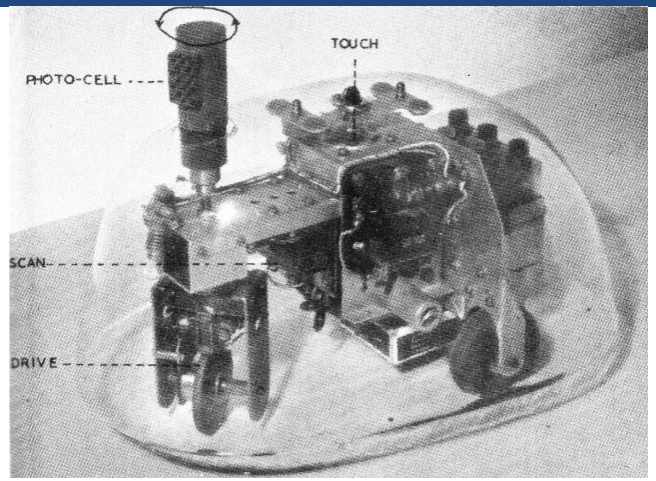
Part 3, same as part 2!

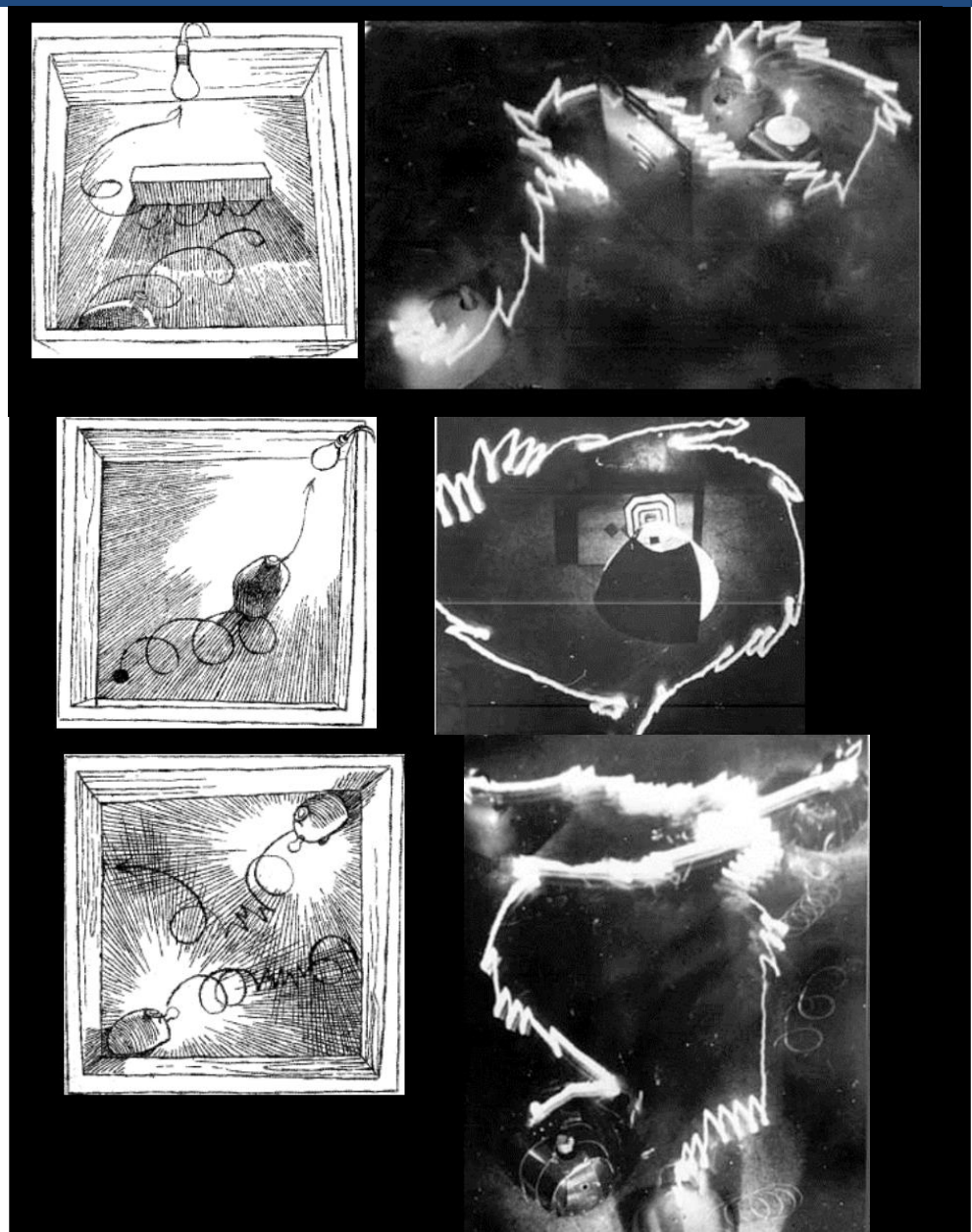
Testudo bristol (Machina Speculatrix)

Grey Walter - Wanted to show how rich connections between a small number of brain cells could give rise to complex behaviour.

youtube.com/watch?v=lLULRlmXkKo

Testudo bristol (Machina Speculatrix)





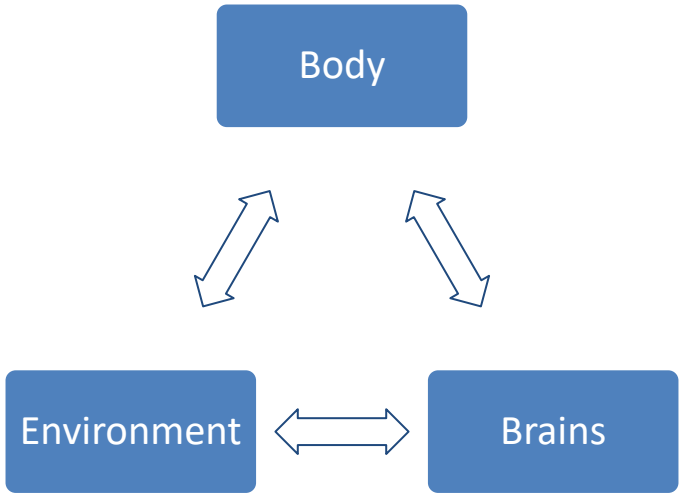
Grey Walter

Wanted to show how rich connections between a small number of brain cells could give rise to complex behaviour.

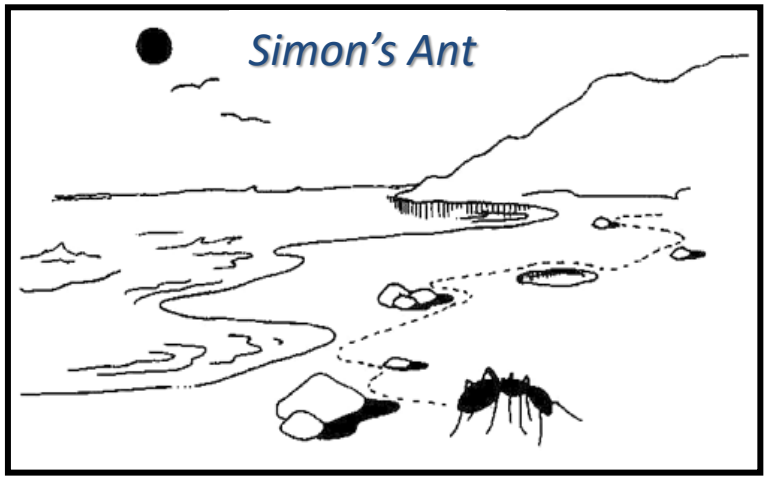
Today's key message: The emergence of adaptive behavior (intelligence)

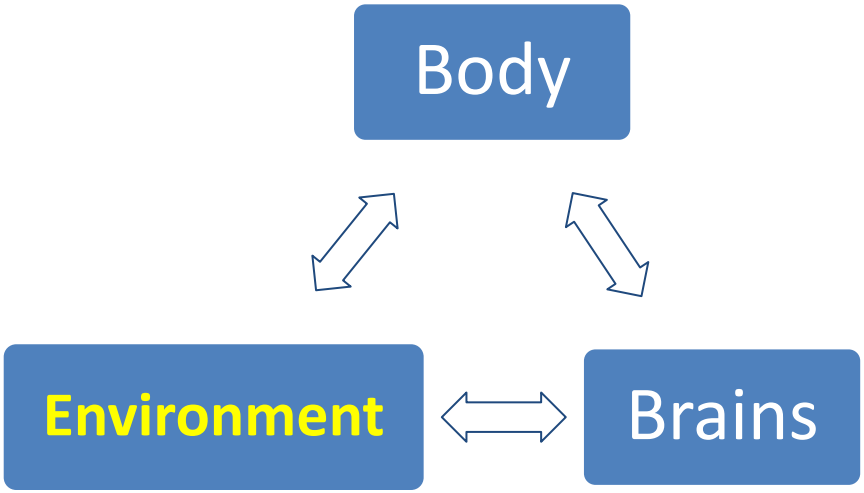
"The [behaviour] of the system emerges from the system's interactions with the world and from sometimes indirect interactions between its components – it is sometimes hard to point to one event or place within the system and say that is why some external action was manifested."

Brooks 1991, Intelligence Without Reason



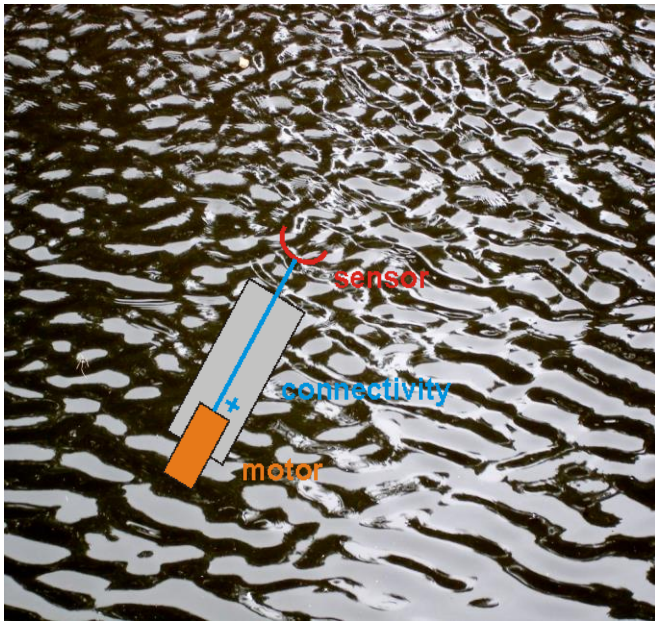
Situatedness (the environment)





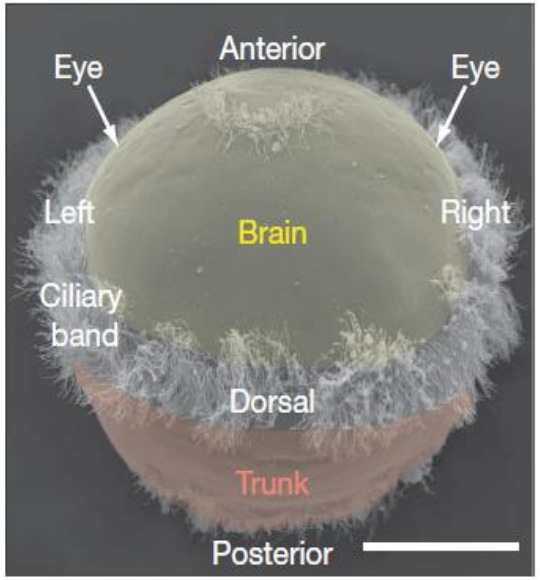
"An ant, viewed as a behaving system, is quite simple. The apparent complexity of its behaviour over time is largely a reflection of the complexity of the environment in which it finds itself."

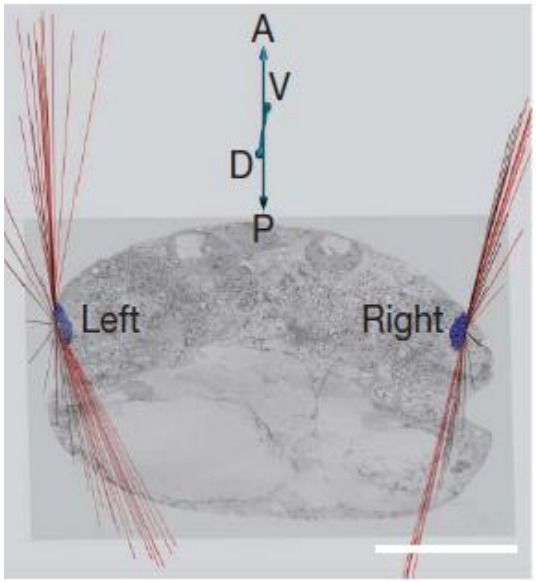
Herbert Simon (The Sciences of the Artificial)



Zooplankton – real Braitenberg vehicles

Mechanism of phototaxis in marine zooplankton, Jekely et al. (2008)





- Zooplankton larvae need warmth
- Photoreceptor and pigment directly connected to cilia allow phototaxis - which in the sea leads to warmth

Key point: Situatedness.
Environment affords simple solution

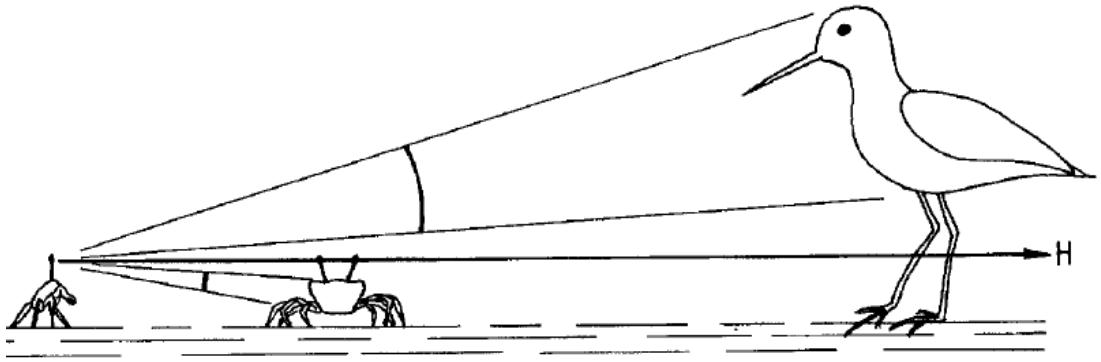
Situatedness

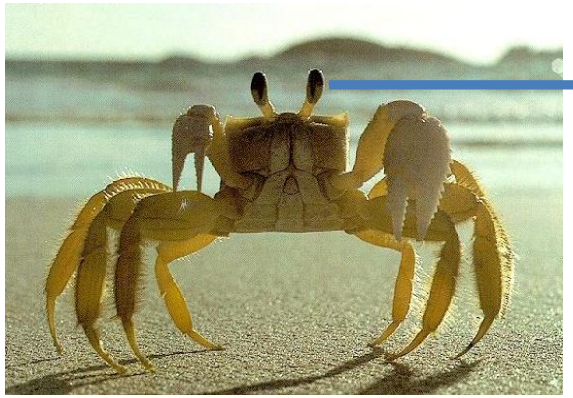
"The agent or animal is in the world: they do not deal with abstract descriptions but with the here and now of the world directly influencing the behaviour of the system"

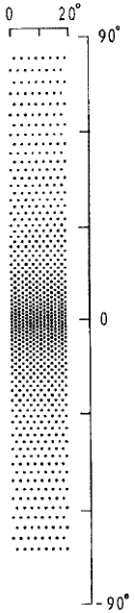
Brooks, 1991, Intelligence Without Reason

Fiddler Crabs

Land and Layne, 1995, The visual control of behaviour in fiddler crabs

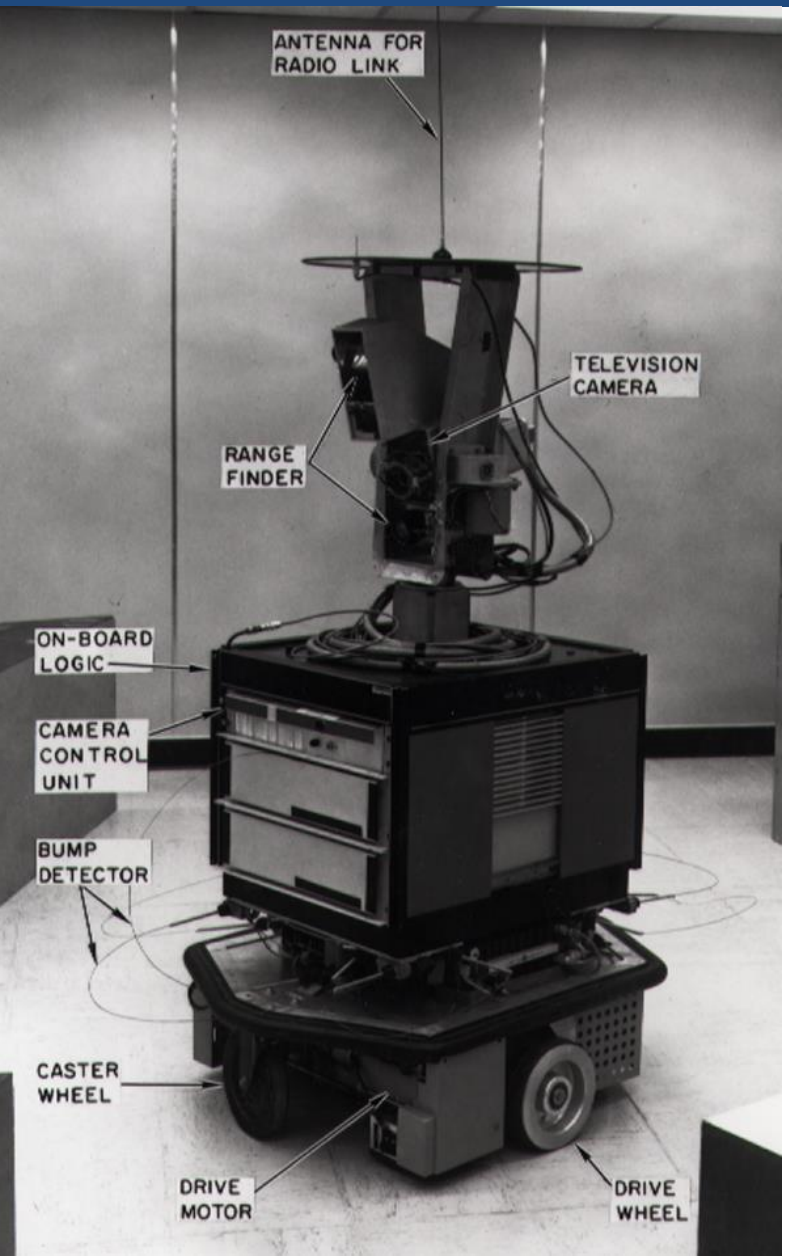


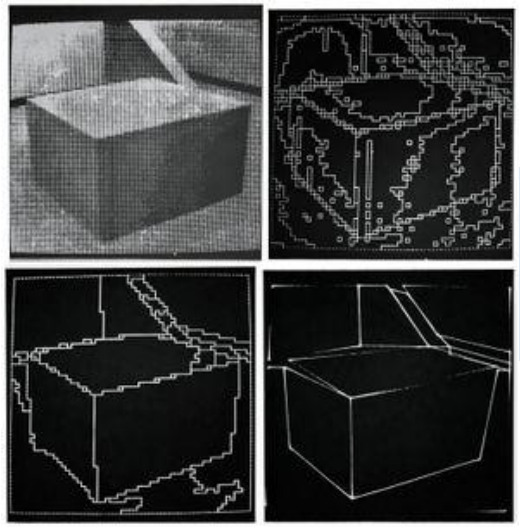




- **Fiddler crabs need to distinguish other crabs from predators.**
- **No visual features available.**
- **If world is flat and eye vertical, anything above horizon is not-crab.**
- **Situated embodied solution: flat world, specialised visual system.**

Early GOFAI* robots – Shakey (*good old fashioned AI)





Hard computer vision tasks for ~1970

Camera

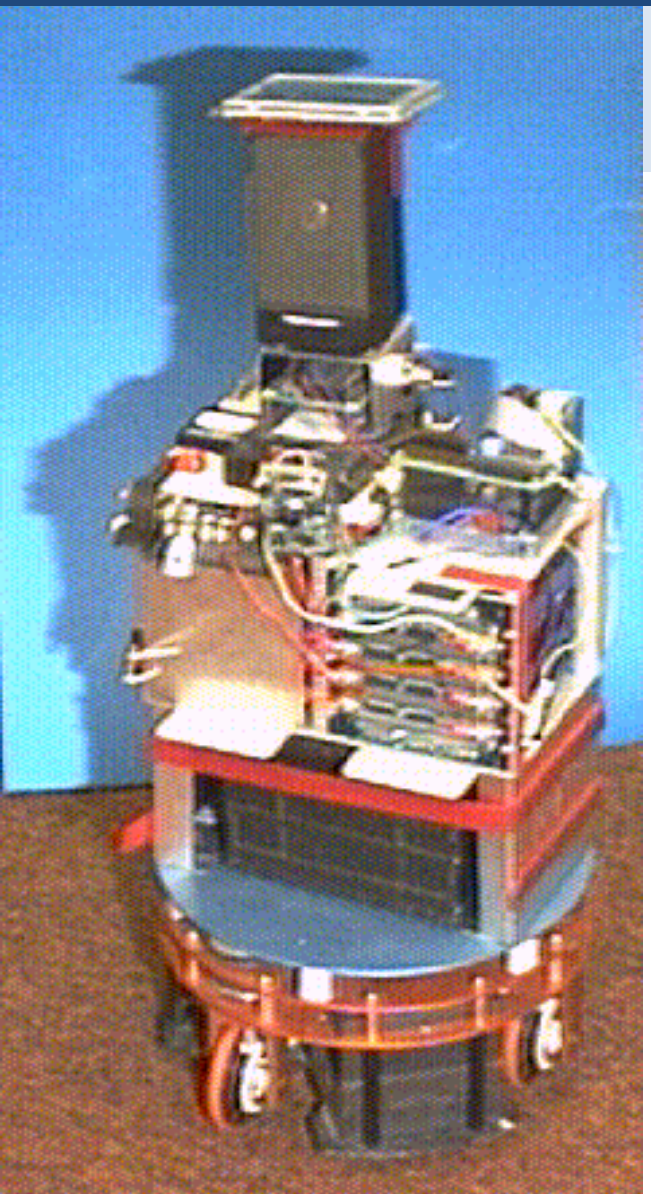
World Model

Graph- search

Action

Shakey the Robot", Nils J. Nilsson (ed), SRI A.I. Center Technical Note 323, April, 1984.

Early behaviour based robotics



Polly: A Vision-Based Artificial Agent
Horswill, 1994

Q: How to do obstacle avoidance and path planning with low resolution image?

A: Think about the situatedness

Polly “Habitat constrained vision”

Camera image

Uniform texture

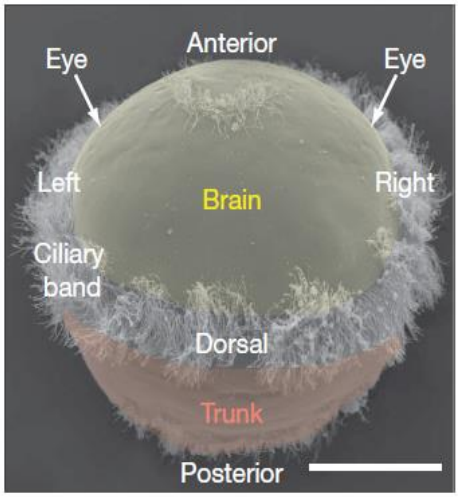
Depth map

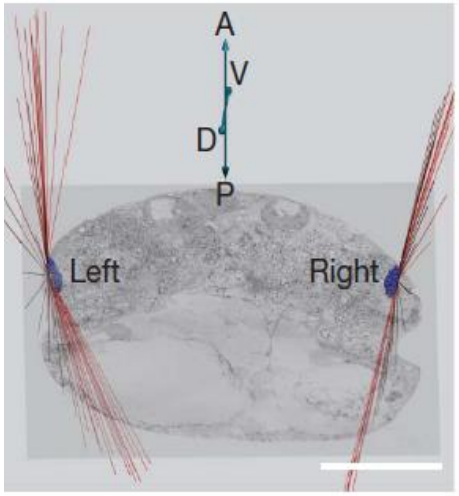
Height of untextured region gives distance to obstacles:

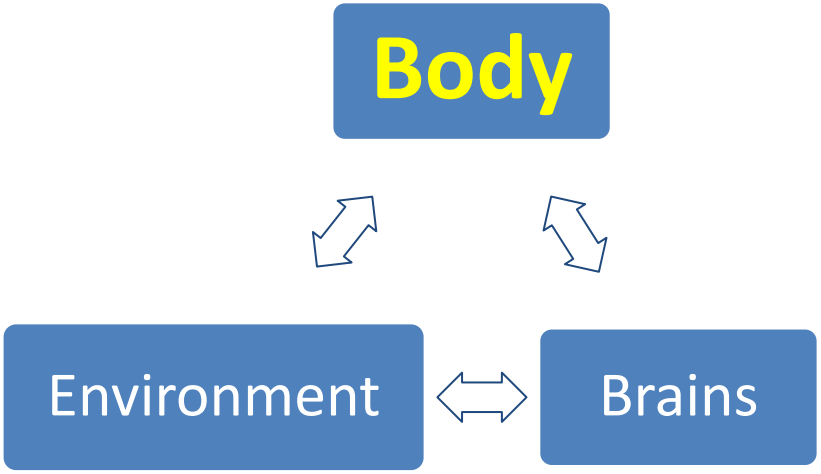
- **Floor is flat**
- **Carpet unpatterned grey**
- **Camera always level**

Situatedness allows a simple but specific solution

Embodiment







- Body shape and cilia position mean usual movement is helical.
- Illuminating eyespots inhibits adjacent cilia, biasing spiral so movement is towards light

Key point: Embodiment.
Part of the solution is embodied

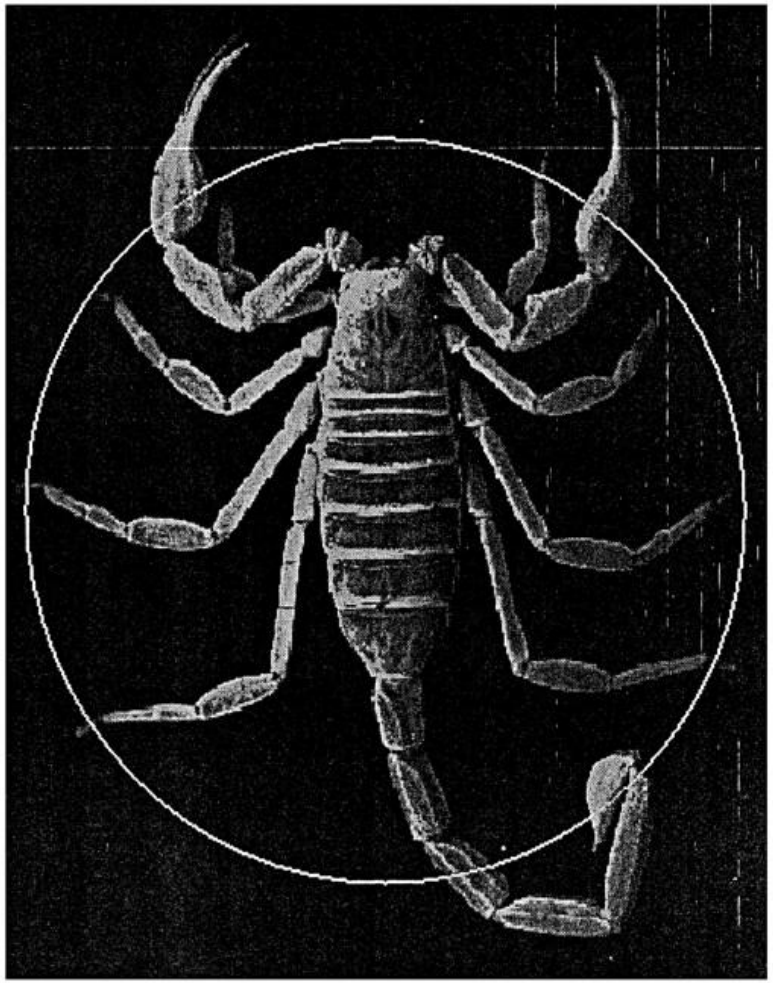
Embodiment

"Robots and animals have bodies and experience the world directly."

Brooks (1991) Intelligence Without Reason

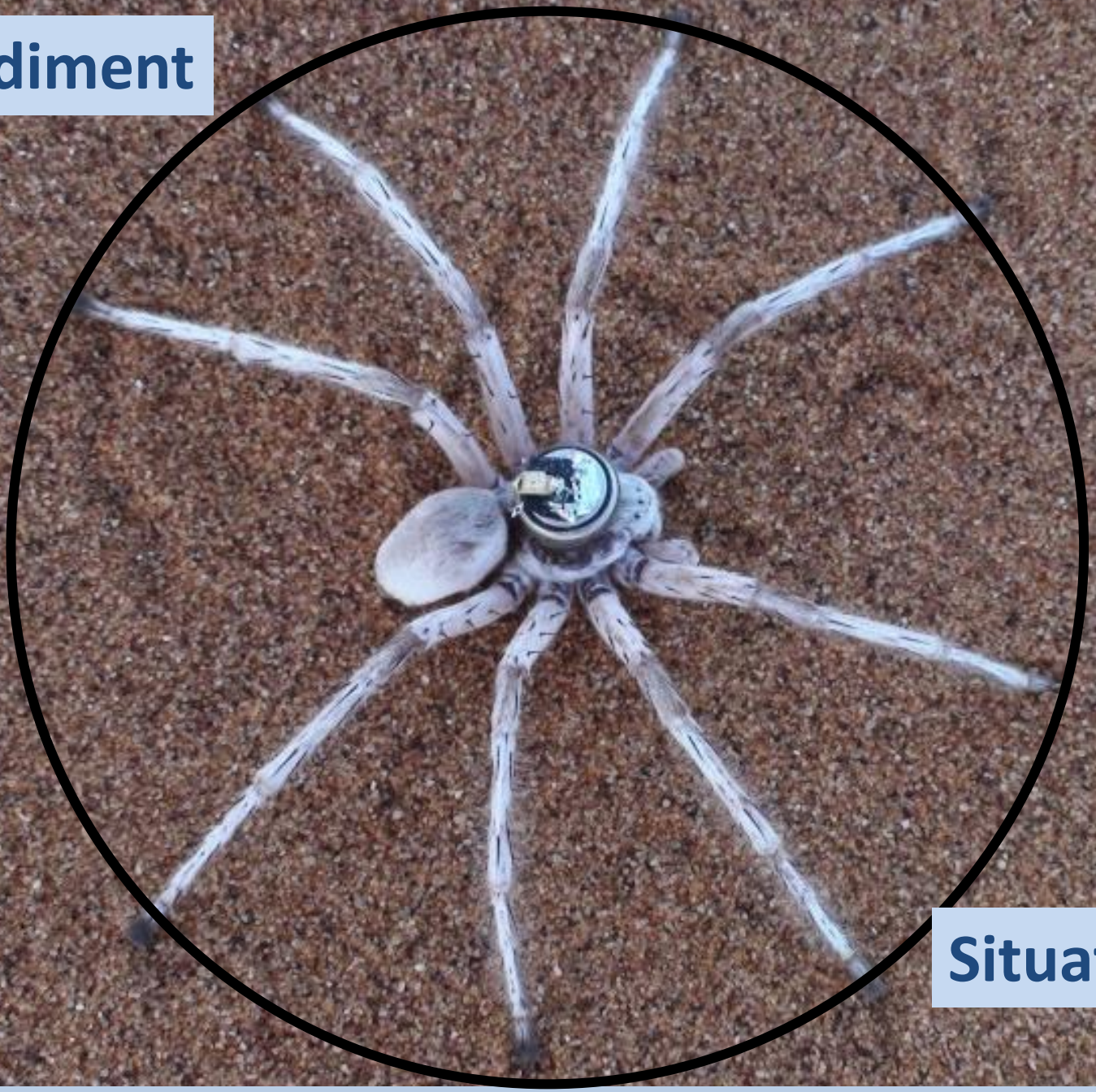
Embodiment

Brownell P H , Leo van Hemmen J Amer. Zool. 2001;41:1229-1240



- Tarsi rest on sand in a circle
- Difference in timing of vibrations gives direction
- Embodiment simplifies the problem

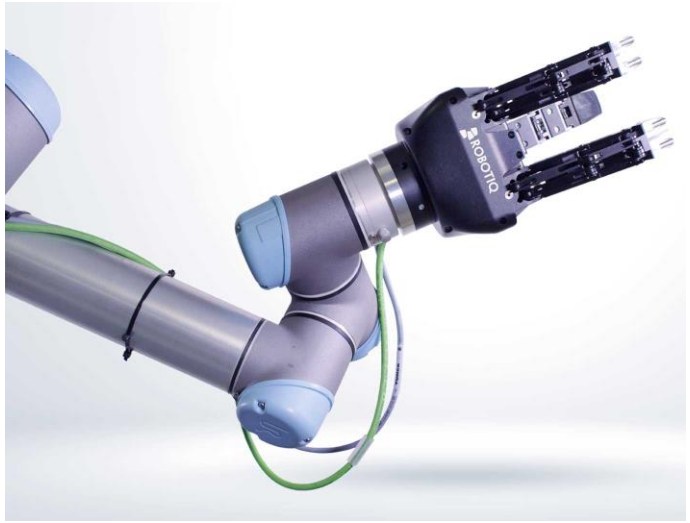
Embodiment



Situatedness

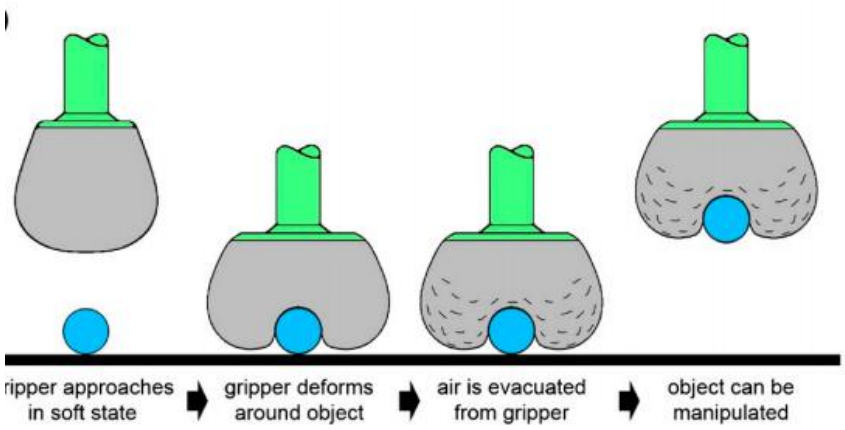
Dancing White Lady, from http://www.tnorgaard.com/site/projects

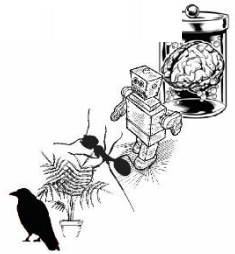
Embodiment can help robot design as well



In week 6 we'll look at how amazingly hard it is to control a multi-jointed body for grasping

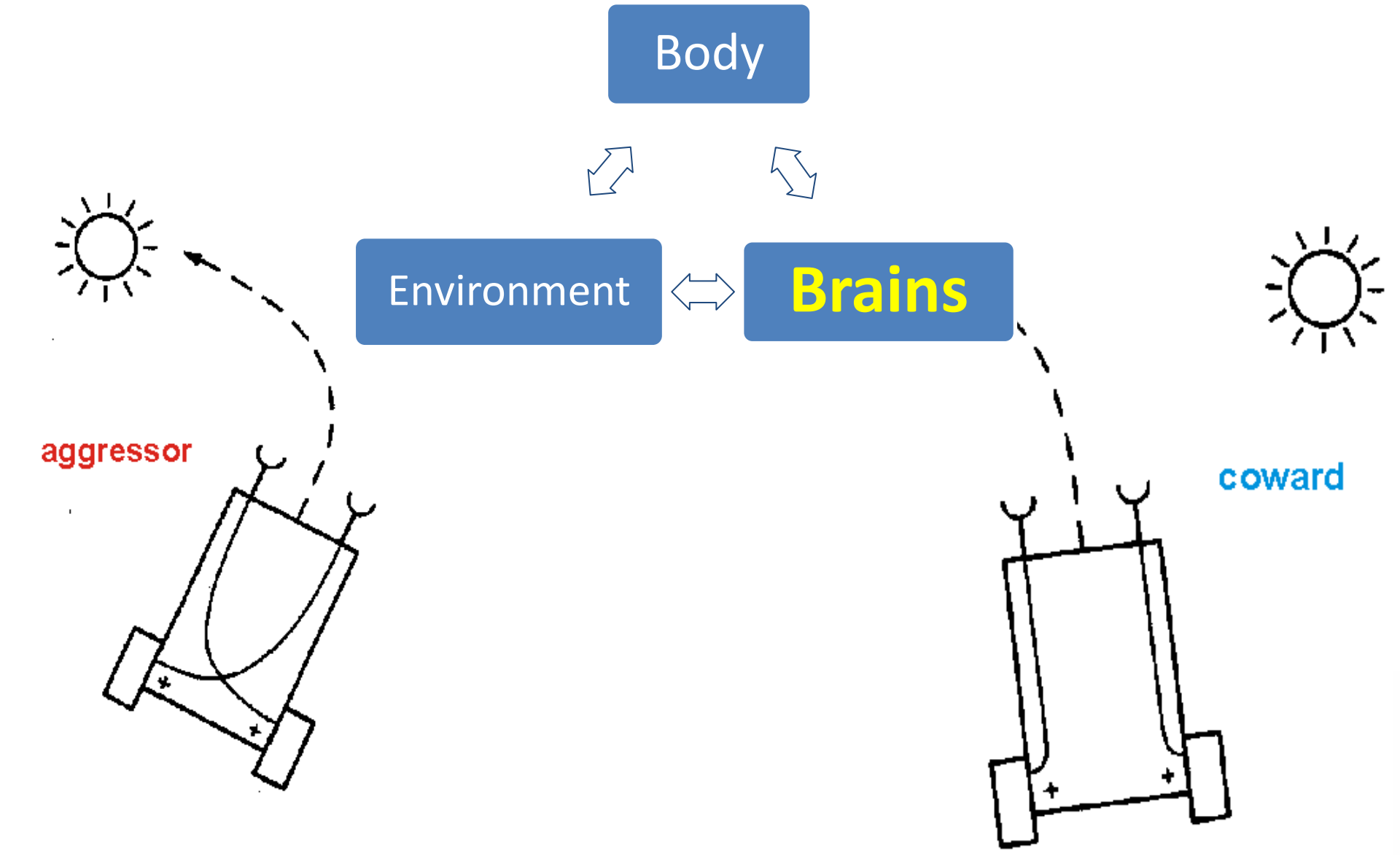
Embodiment can solve the engineering problem in some contexts





Brown et al., 2010 PNAS

Don’t forget, brains matter



Learning Outcomes

- Defining intelligence in way that allows comparisons between humans, animals and machines is hard.
- If we take human-centric definitions then we can widen gap between humans and other animals.
- If we take biological definitions then they are very inclusive.

- But we can still study where intelligent behaviour ‘comes from’.
- Behaviour emerges from the interactions between brains, bodies and the environment.

Reading List

General module reading

- Chapter 1 Understanding Intelligence – Pfeifer and Scheier
- Chapter 1 Cognition, Evolution, and Behavior – Shettleworth
- Towards a bottom-up perspective on animal and human cognition – de Waal and Ferrari
- Animal cognition - Gould

Lecture 1 reading

- A new approach to robotics – Brooks

- Vehicles - Braitenberg
- Plant intelligence - Trewavas
- Slime mold cognition - Reid