# The ShanghAI Lectures

人工智能

上海授课

# The ShanghAI Lectures by the University of Zurich
# An experiment in global teaching

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National Competence Center Research in Robotics (NCCR Robotics)
Artificial Intelligence Laboratory
University of Zurich

Today from Media City, Manchester, UK

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**“来自上海的人工智能系列讲座”**

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# Lecture 3

## Towards a theory of intelligence

## 20 October 2011

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# Today's topics

- short recap
- Braitenberg vehicles (for reading)
- the "Swiss Robots"
- prerequisites for a "theory of intelligence"
- intelligent systems: properties and principles (mostly lecture 4)
- Guest lectures by Yukie Nagai and Minor Asada (Osaka University, Japan)

# Short recap

- The classical approach: Cognition as computation
- Successes and failures of the classical approach
- Some problems of the classical approach
- The need for an embodied approach
- The “frame-of-reference” problem



Some problems:
- symbol grounding problem
- frame problem
- homunculus problem

The need for an embodied approach:
previous lecture: Louis Wolpert’s quote: why do plants not have brains?
Also evolutionary argument by Rodney Brooks: (“The embodied turn”)
(see next slide)

# The "embodied turn" Rodney Brooks, MIT

Single-cell entities arose out of the primordial soup roughly 3.5 billion years ago. A billion years passed before photosynthetic plants appeared. After almost another billion and a half years—around 550 million years ago—the first fish and vertebrates came into being, and 100 million years later insects emerged. Let us quote directly from Brooks's argument:

"Then things started moving fast. Reptiles arrived 370 million years ago, followed by dinosaurs at 330 and mammals at 250 million years ago. The first primates appeared 120 million years ago and the immediate predecessors to the great apes a mere 18 million years ago. Man arrived in roughly his present form 2.5 million years ago. He invented agriculture a mere 19,000 years ago, writing less than 5,000 years ago and "expert" knowledge only over the last few hundred years." (Brooks, 1990, p. 5)



Brooks' argument: time from primordial soup to insects - much longer than from insects to humans. We must start to study insects first.

Because of this interest in insects, walking and locomotion in general became important research topics in artificial intelligence and robotics research.

Brooks, R. A. (1990). Elephants don't play chess. In P. Maes, ed. Design autonomous agents: Theory and practice from biology to engineering and back. Cambridge, MA: MIT Press, 3-15.

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# Observation exercise

## Video "Didabots"

**what's happening, what's going on?**

**mind the "frame-of-reference"**



- Didabot video

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# A robot experiment

6x6m arena with Styrofoam cubes

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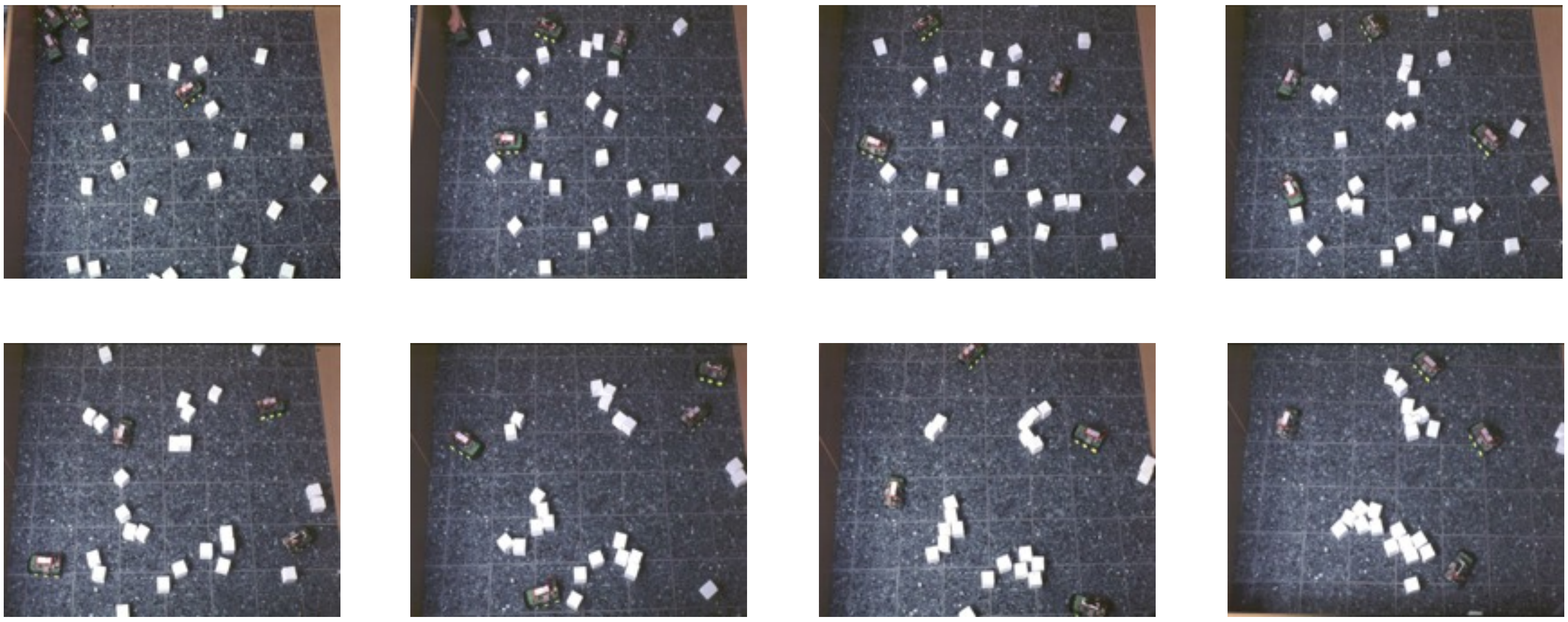
Arena filled with Styrofoam cubes, initially randomly distributed. Put robots in there, they start working.

# Sequence



entire process: ∼20min
frames: 2-3min

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The frames are taken about every two to three minutes; the whole process takes roughly twenty minutes. Although the clusters and exact positions of the cubes vary, the final configurations are all qualitatively similar, i.e. a few clusters, and some cubes distributed along the walls.

# What are the robots doing?

- forming clusters
- moving cubes together
- making free space
- cleaning up

→ the "Swiss Robots"

observer's perspective

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# What are the robots really doing?

## mechanisms underlying their behavior

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# Activities involved in clustering: standard solution

6x6m arena with Styrofoam cubes

Requirements for design the robots?

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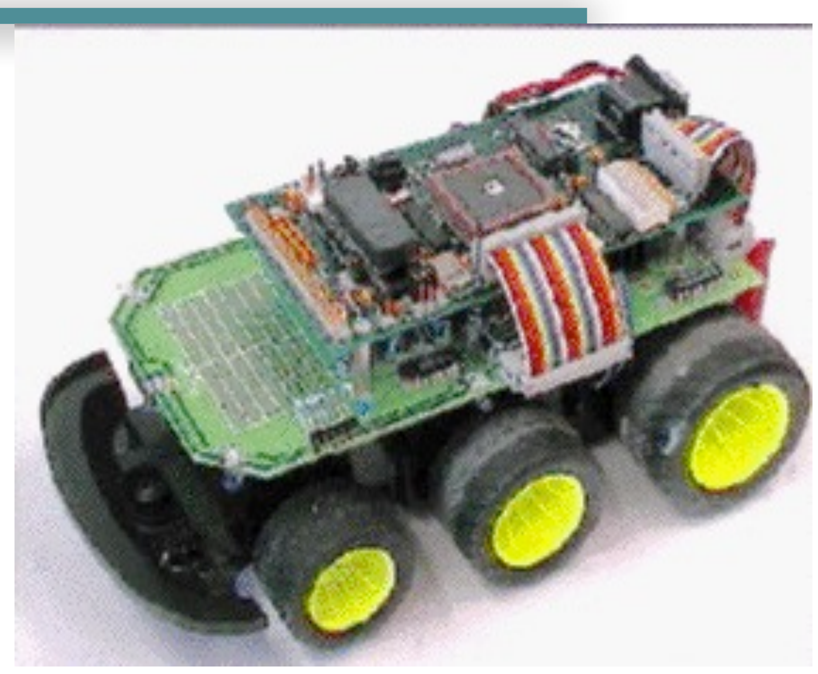
Look for cube, if possible, the nearest one). Pick up cube (somehow). Look for nearest cluster. Go to cluster. Deposit cube. Look for new cube, etc.

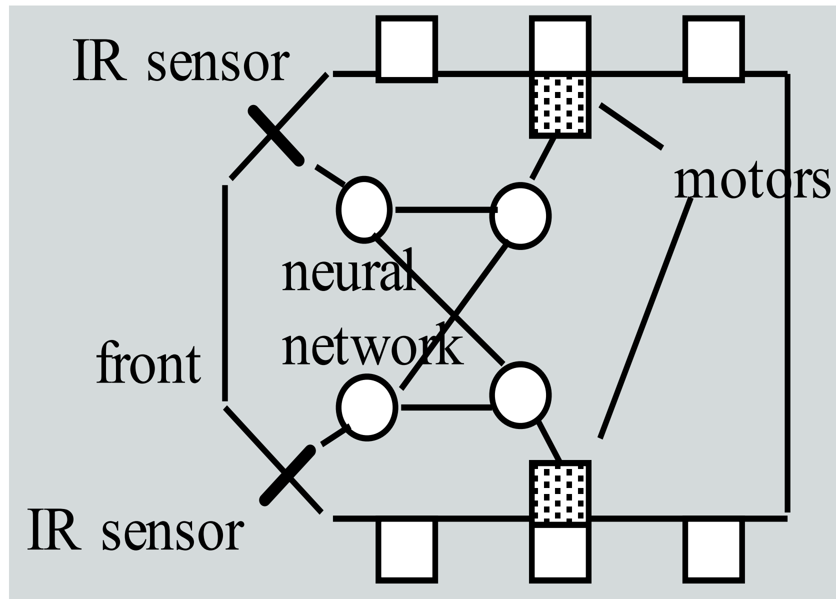
Requires quite sophisticated perceptual skills on the part of the robots (recognizing a cube from different angles and distances, recognizing a cluster). Some elementary motor skills for grasping and dropping. locomotion skills.

# The Swiss robots

6x6m arena with Styrofoam cubes

Didabot
simple robot
for didactial
purposes





# What are the robots really doing?

behavioral rule:

**sensory stimulation on left: turn right**

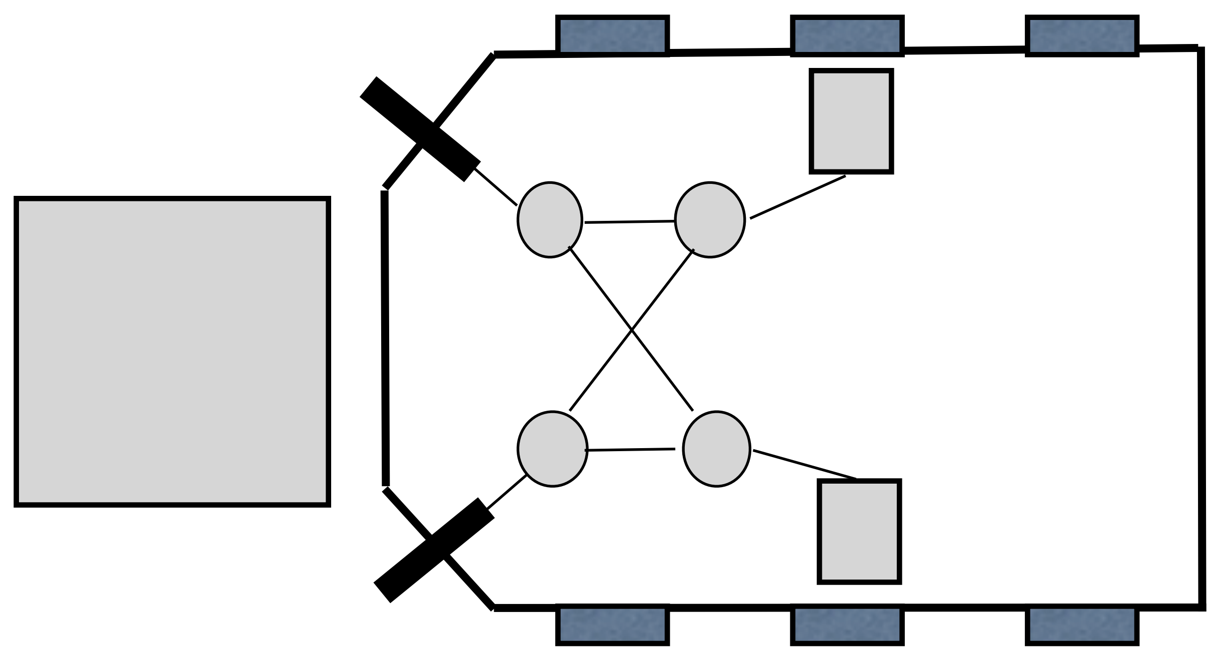
**sensory stimulation on right: turn left**

(obstacle avoidance)

→

**situated perspective (from the agent's point of view)**

# Cluster formation



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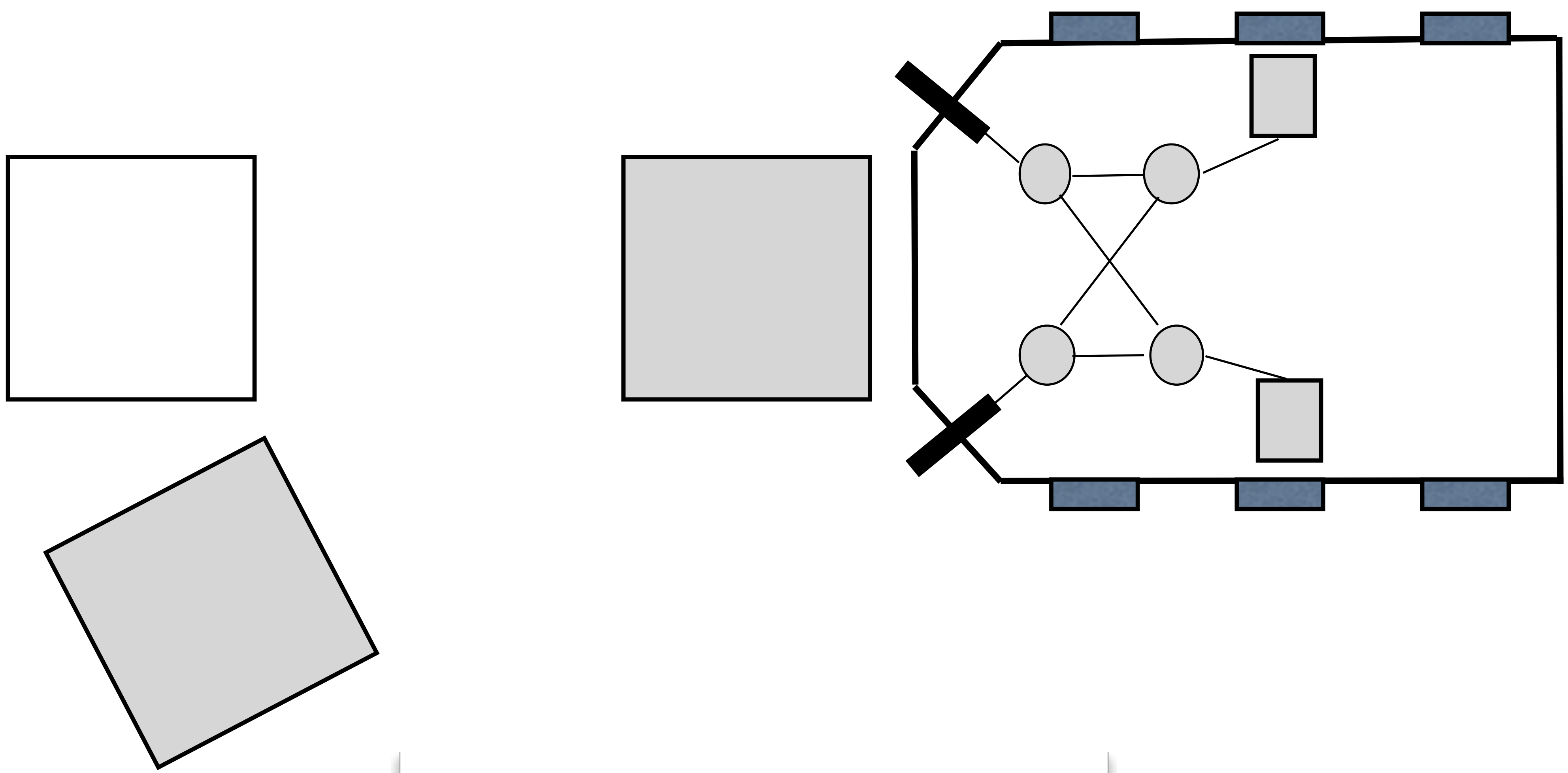
Encountering a cube head-on by chance —> no stimulation of the sensors. What happens?
How far will it push the cube?

# Cluster formation



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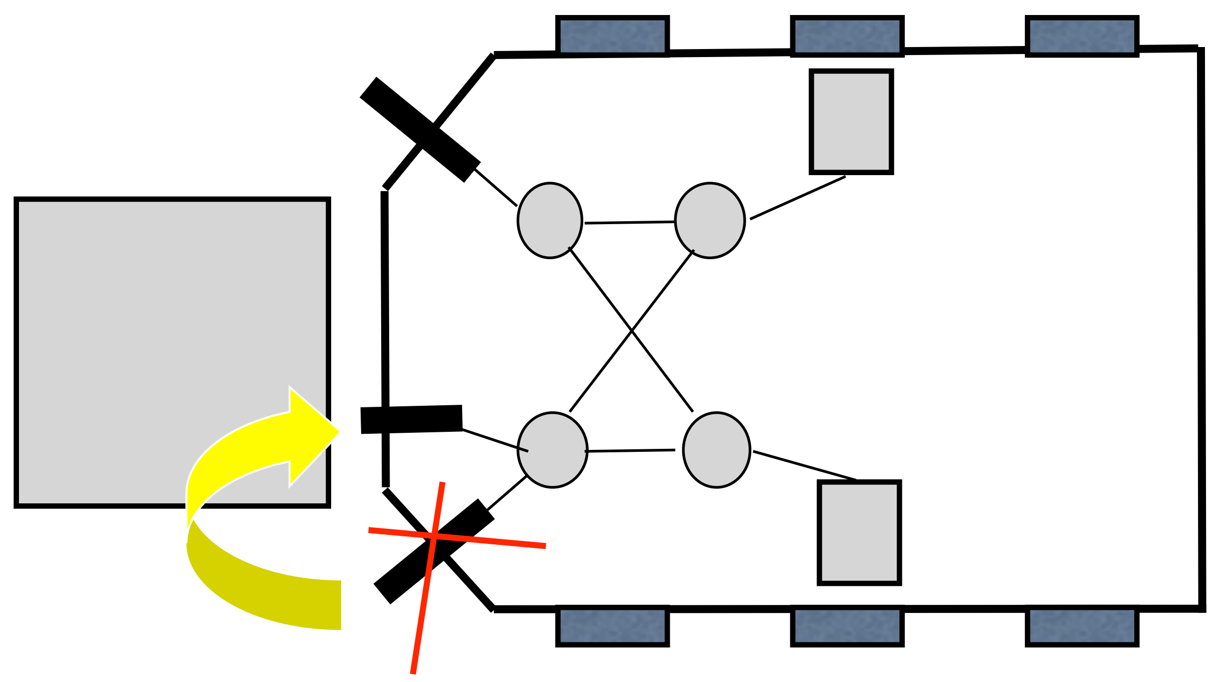
until it encounters an object with one of its sensors – here the one on the left; it will then turn right, leaving two cubes together.

# Change of morphology

**What happens if everything stays the same except that the position of one of the sensors is changed as shown in the figure?**



# “Swiss Robots” summary

- frame-of-reference
- self-organization and emergence
- embodiment: interdependence morphology — behavior
- exploitation of ecological niche:
  “cheap design” (see later)

Video “Didabots heap building”

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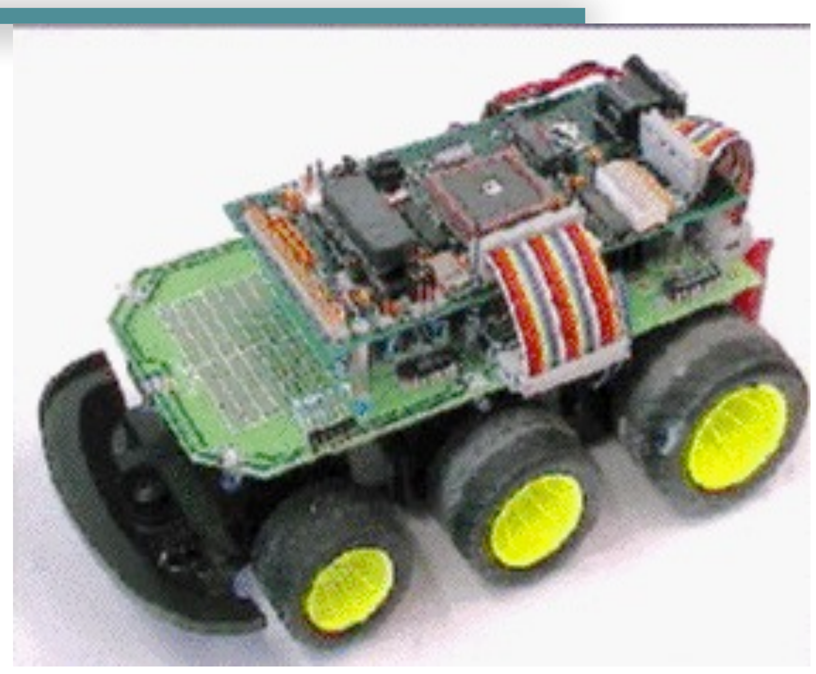
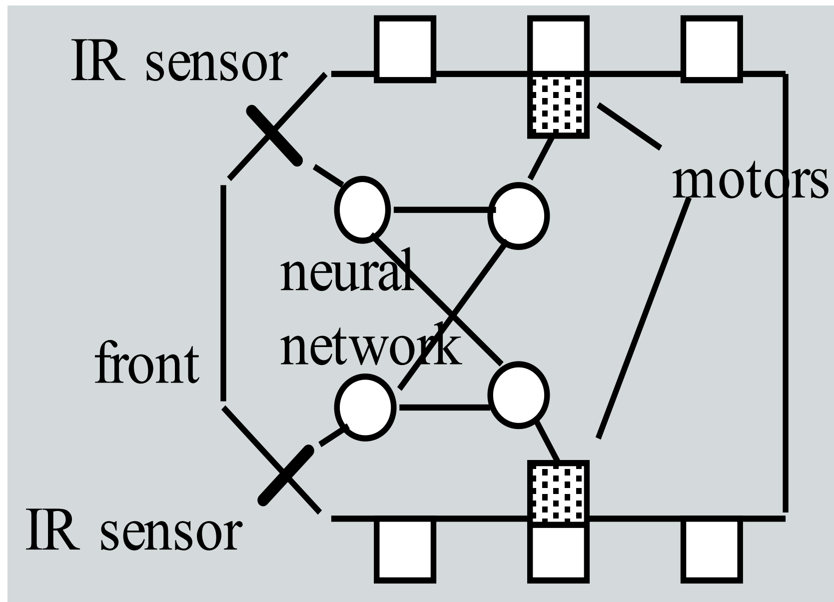
# Daniel Dennett
# (philosophy of mind)

6x6m arena with Styrofoam cubes

Didabot
simple robot
for didactial
purposes



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These robots are cleaning up, but that’s not what they think they are doing (joke — can they think?)

# Change of number of robots

**What happens if instead of four to five, only one robot is used?**

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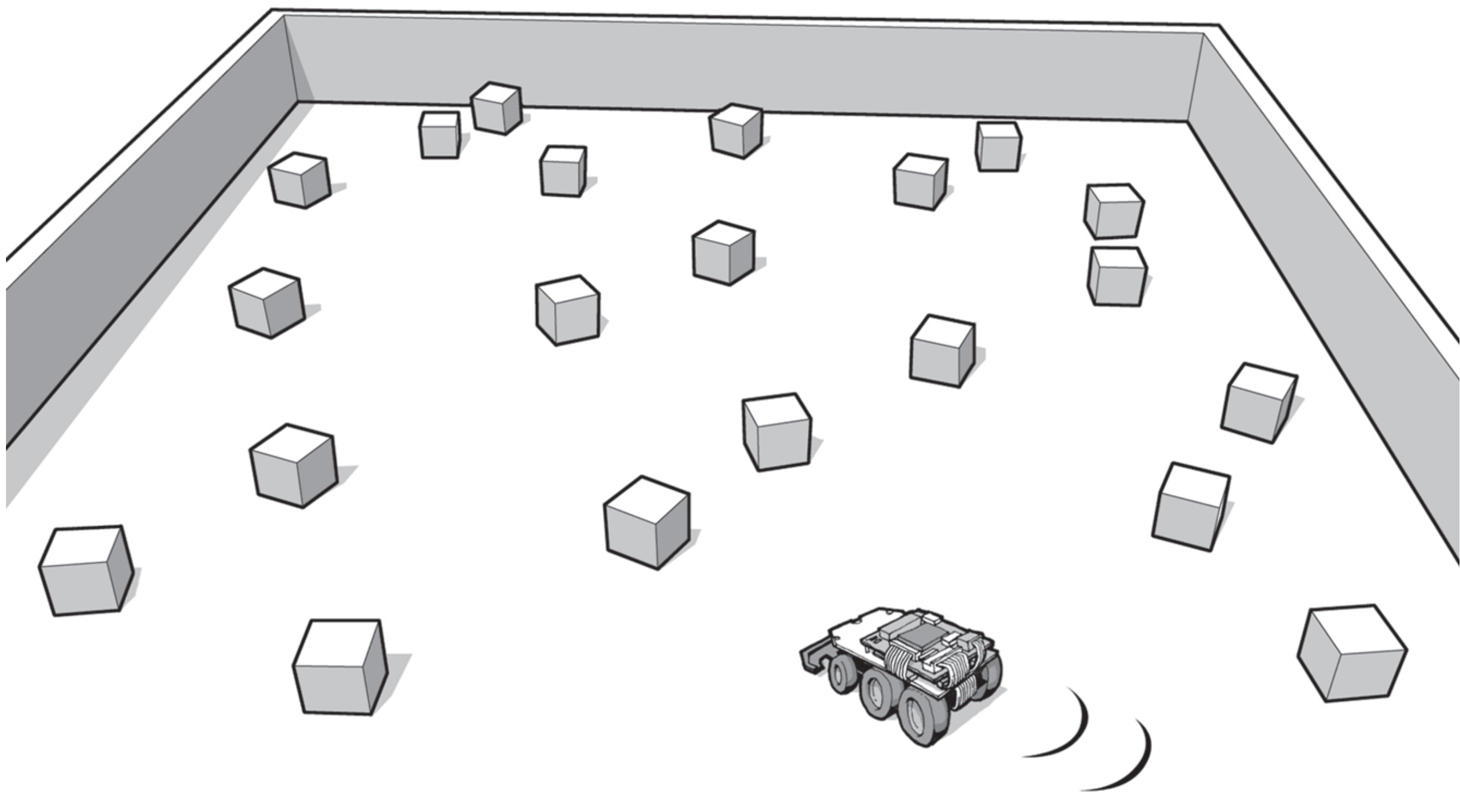
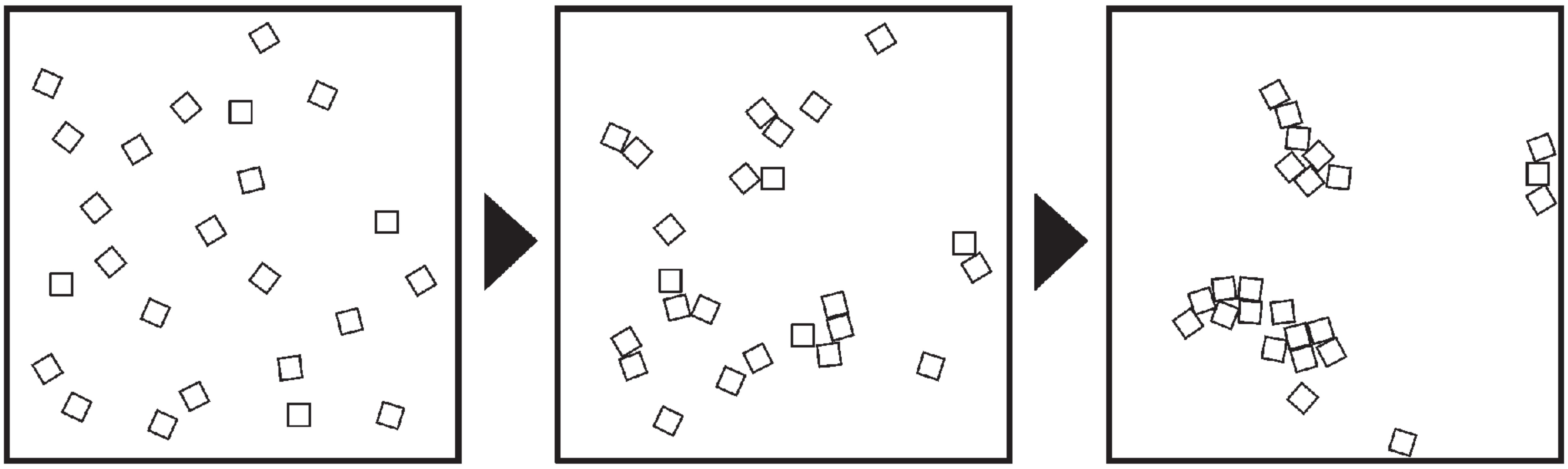
# The "Swiss Robots"



"building clusters"

Figure 3.1 from "How the body …"



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# The "Swiss Robots": cluster formation — morphology change

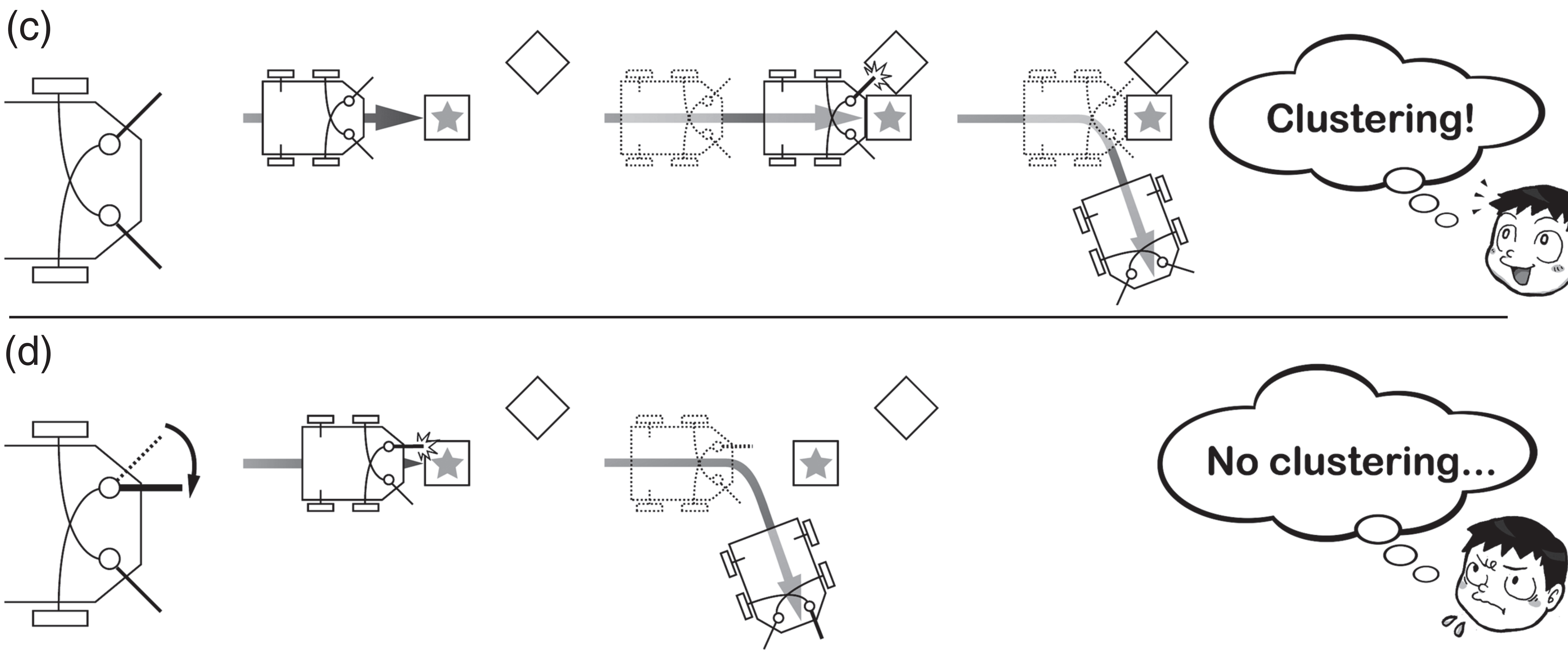


Figure 3.1 from "How the body …"

# Today's topics

- short recap
- Braitenberg vehicles (for reading)
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- **prerequisites for a "theory of intelligence"**
- **intelligent systems: properties and principles (mostly lecture 4)**
- **Guest lectures by Yukie Nagai and Minor Asada (Osaka University, Japan)**

# Prerequisites for a “theory of intelligence”

- form of theory
- frame-of-reference
- synthetic methodology
- time perspectives
- emergence

# Form of theory

- philosophy of science, not one answer, subjective, preferences
- verbal: low precision
- mathematical: rigorious (will use dynamical systems)
- algorithmic: GOFAI
- intelligence: not only "understanding", but also "building" → synthetic methodology

design principles:
joining engineering and science

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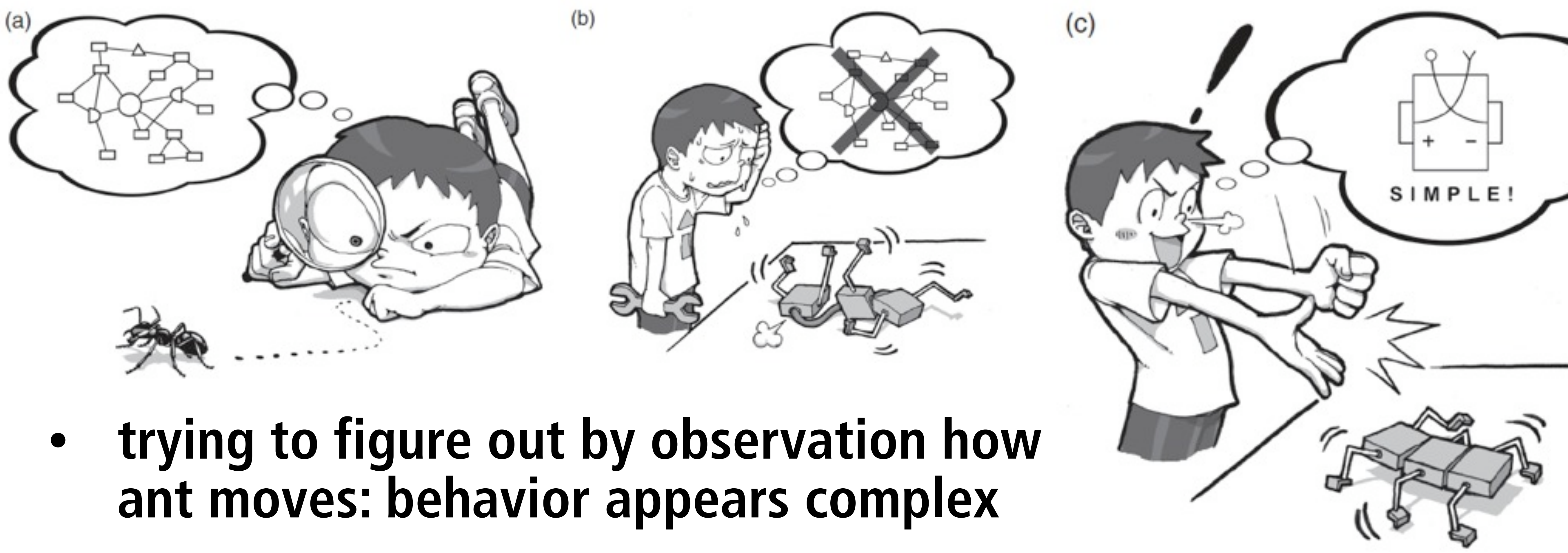
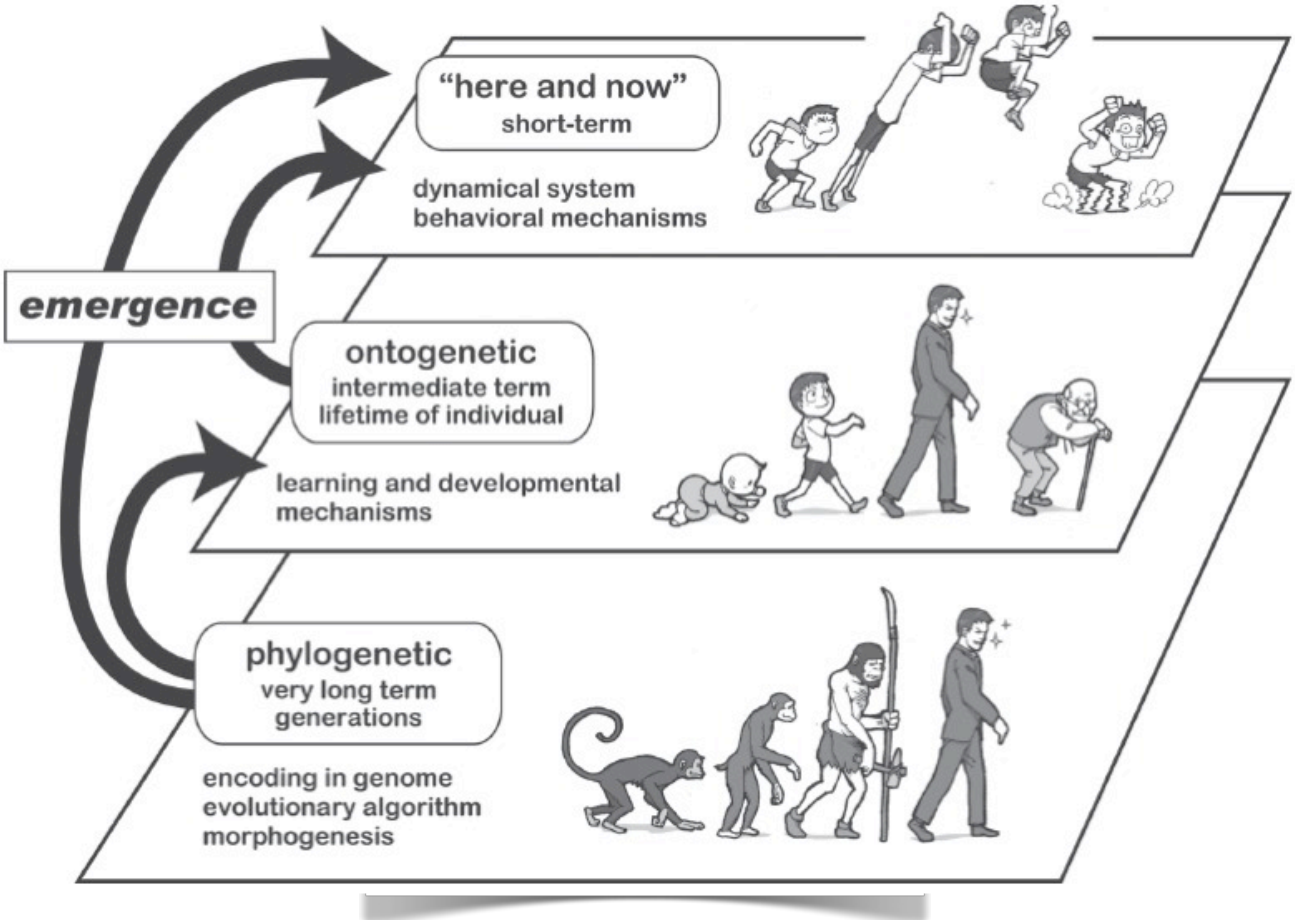
# Synthetic methodology and frame-of-reference




- trying to figure out by observation how ant moves: behavior appears complex
- first design fails
- complex behavior from simple behavioral architecture

# Time perspectives



# Time perspectives in understanding and design

state-oriented
**"hand design"**

"here and now" perspective

learning and development
**initial conditions, learning and developmental processes**

"ontogenetic" perspective

evolutionary
**evolutionary algorithms, morphogenesis**

"phylogenetic" perspective

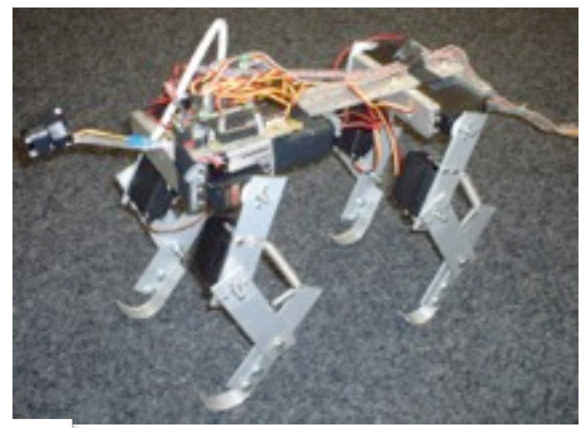
Understanding: **all three perspectives requires**
Design: **level of designer commitments, relation to autonomy**

# Emergence

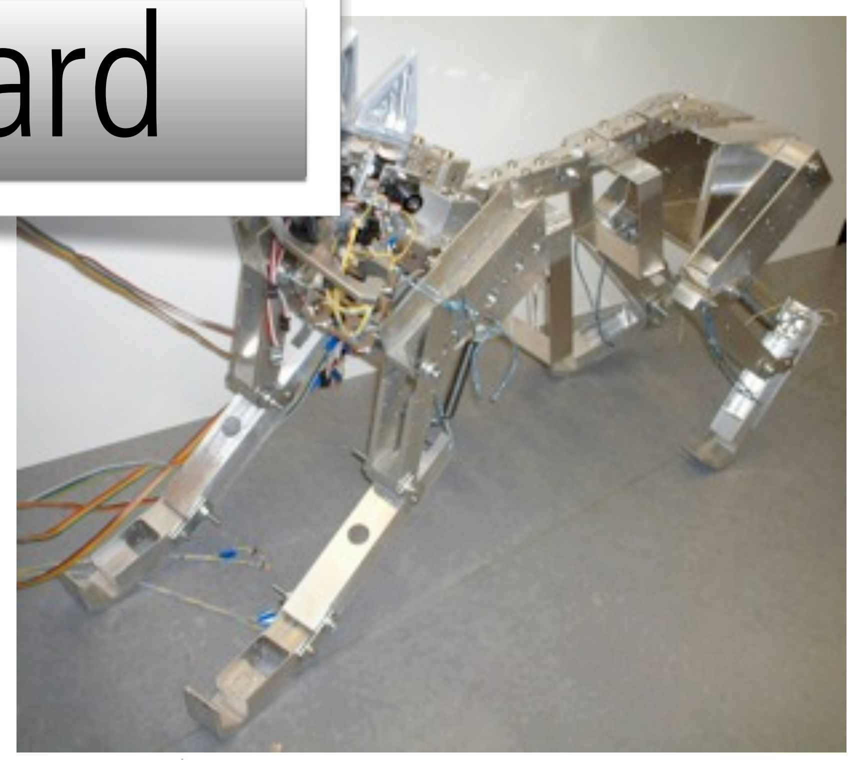
- collective behavior: global patterns from local interactions (e.g. “Swiss Robots”, bird flocks, clapping) (see chapter 7)
- behavior of individual: emergent from interaction with environment
- from time scales (see later)

# Emergence of behavior: the quadruped “Puppy”

**rapid locomotion in biological systems**



Video “Puppy” standard



Design and construction:
Fumiya Iida, AI Lab, UZH and ETH-Z

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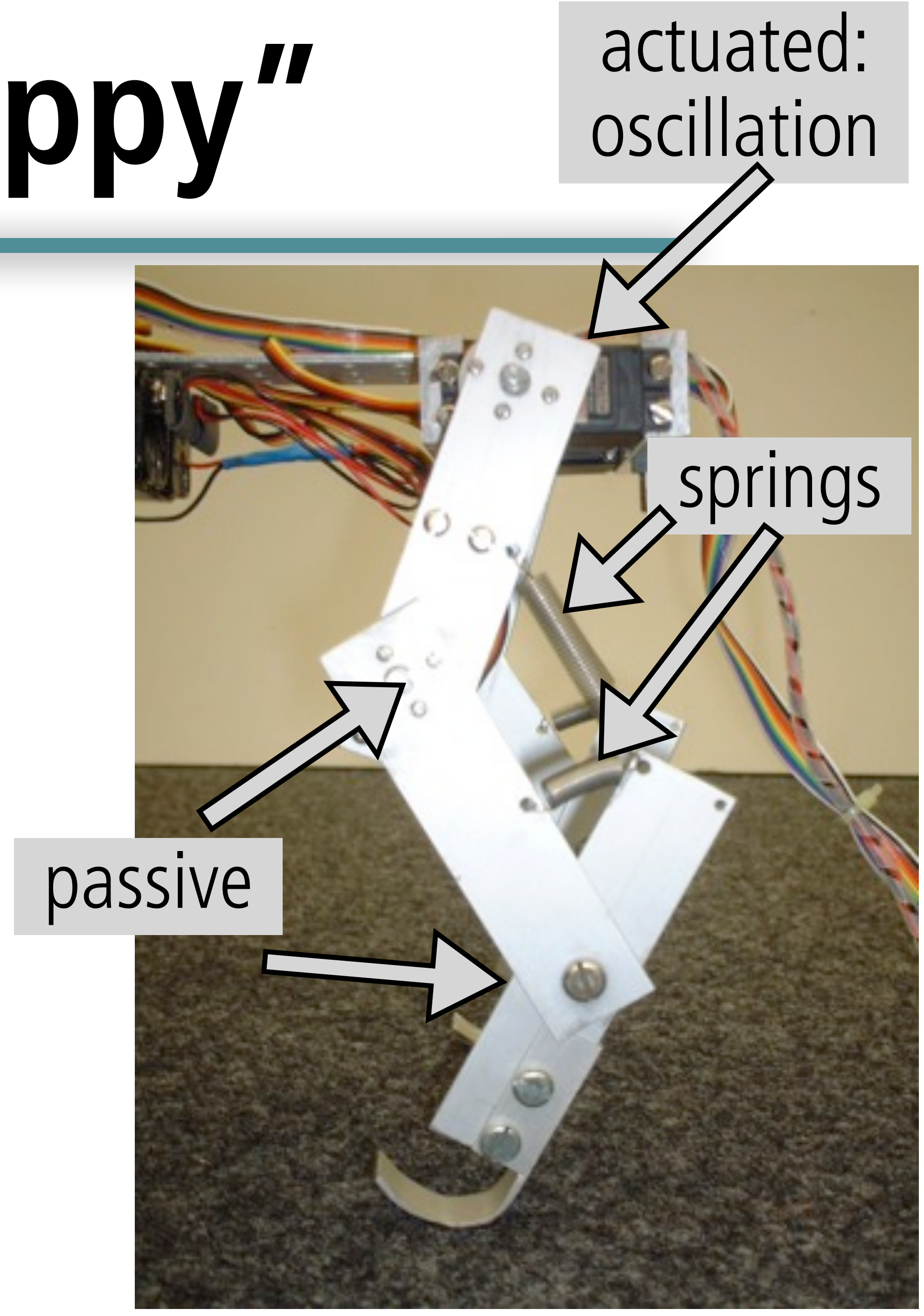
# Emergence of behavior: the quadruped "Puppy"

- **simple control (oscillations of "hip" joints)**
- **spring-like material properties ("under-actuated" system)**
- **self-stabilization, no sensors**
- **"outsourcing" of functionality**

→ morphological computation

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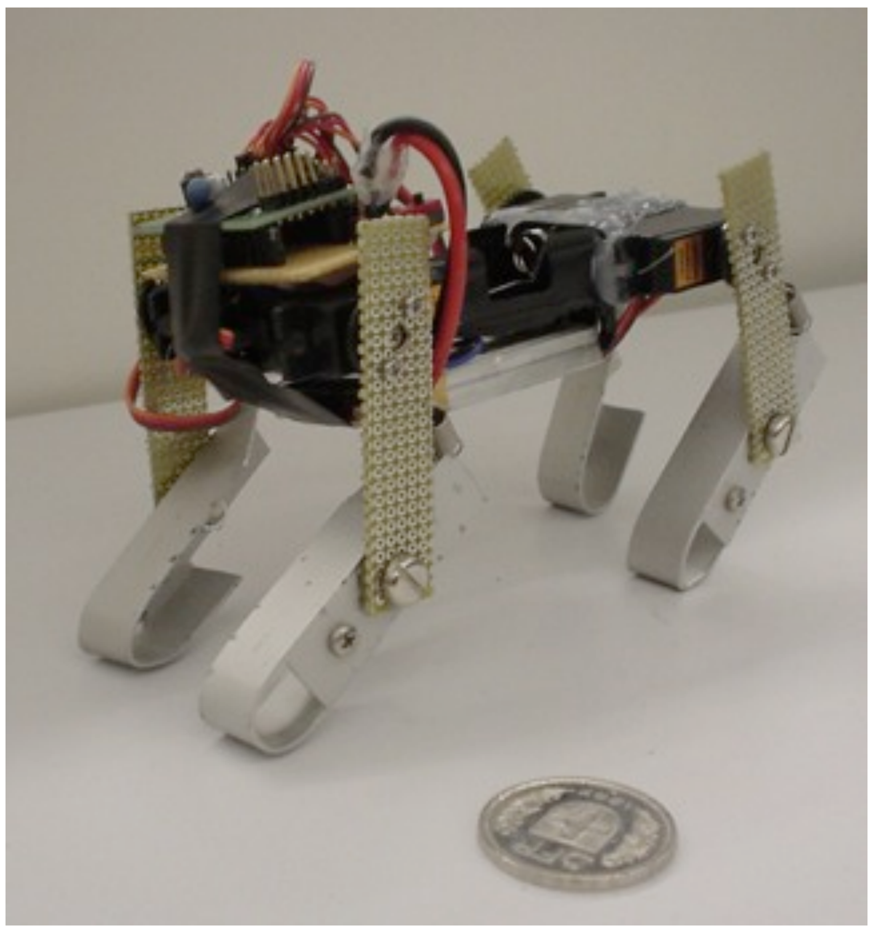
In this example, only the "shoulder" or "hip" joint is actuated, the others are passive but connected through springs.

The concept of morphological computation is about outsourcing functionality to morphological and material characteristics of the organism, e.g. elastic damped springs, arrangement of arrays of light sensors, passively deformable tissue, etc. Many examples will be given during the lectures.

# “Puppy” video



Video “Mini-dog”

**Design and construction: Fumiya Iida, ETH-Z (formerly AI Lab, University of Zurich)**

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# Emergence of behavior in "Puppy"

- control: oscillation
- only "hip joints" driven, other joints passive
- trajectories of passive joints: not programmed into robot (but they do the right thing)

→ exploitation of passive dynamics

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joints self-organize into proper trajectory (without being directly controlled). The fact that the joint is not directly controlled doesn't imply that it's not doing the right thing.

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- **Guest lectures by Yukie Nagai and Minor Asada (Osaka University, Japan)**

# Intelligent systems: properties and principles

"How the body …", chapter 4

- **complete agents: embodied, situated, autonomous, self-sufficient**
- **real worlds vs. virtual worlds (see lecture 2)**
- **dynamical systems**
- **properties of complete agents**
- **agent design principles**

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The Japanese psychologist Masanao Toda introduced the so-called "Fungus Eaters", creatures that were sent to a distant planet to collect uranium ore. Because it was so distant, it could not be directly controlled, it had to be autonomous. It had to learn about the environment from its own perspective, i.e. it had to be situation. Because there was nobody to replace the batteries or to repair it, it had to be self-sufficient. Finally, because it had to survive on the real planet and collect ore, it obviously had to be embodied.

Real worlds vs. virtual worlds have been discussed in lecture 2

Agents can be viewed as complex dynamical systems, because they are physical systems. This implies that we can apply the concepts and the terminology of the field, which provides a highly productive and intuitive metaphor for talking about intelligent systems.

Complete agents have a number of properties, see p. 95 of "How the body …".

For agent design principles, see chapter 4.

# Design principles for intelligent systems

Principle 1: Three constituents principle

Principle 2: Complete agent principle

Principle 3: Parallel, loosely coupled processes

Principle 4: Sensory-motor coordination/ information self-structuring

Principle 5: Cheap design

Principle 6: Redundancy

Principle 7: Ecological balance

# Assignments for next week

- Read chapter 4 of “How the body …”
- Read materials for self-study (Braitenberg vehicles)

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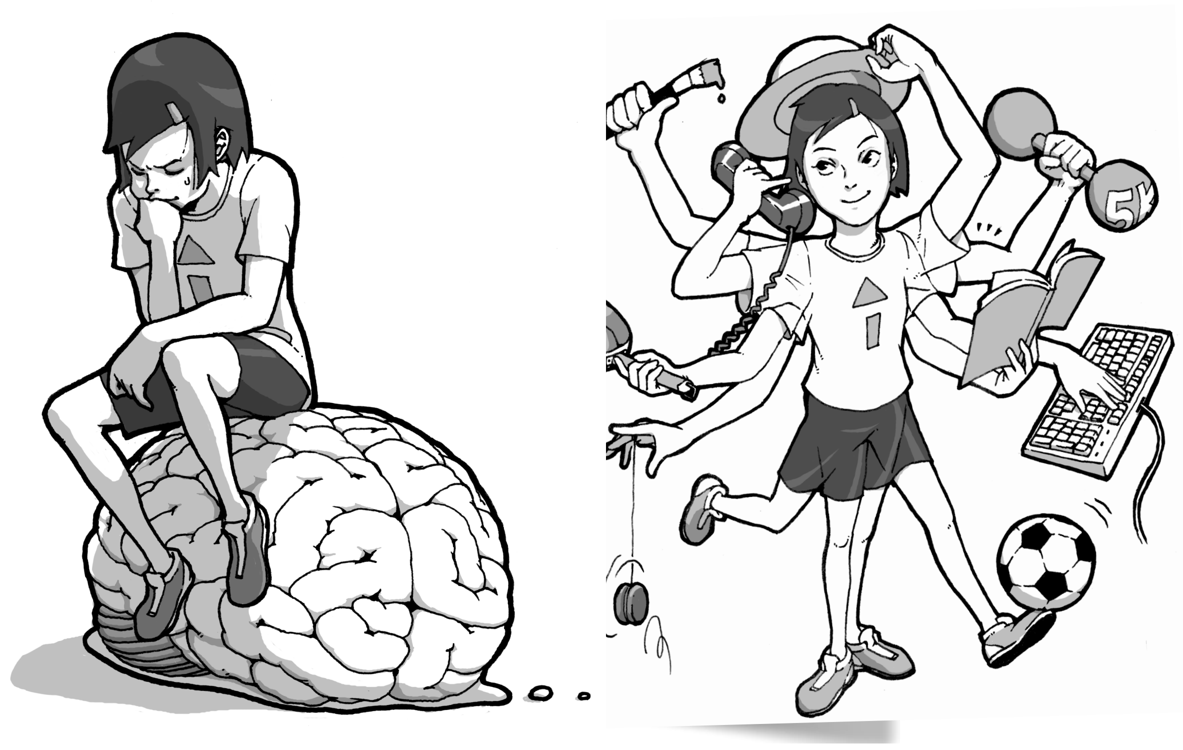
# End of lecture 3

**Thank you for your attention!**

**stay tuned for guest lectures**

**by Dr. Yukie Nagai and Prof. Minoru Asada**



# Guest speaker


from Osaka University
Graduate School of Engineering

**Dr. Yukie Nagai**
**(A topic related to developmental robotics)**

**Today, 10.00 CET (9.00 GMT)**

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Dr. Yukie Nagai has done fundamental work in the area of developmental and social robotics.

# Guest speaker

from Osaka University
Graduate School of Engineering

**Prof. Minoru Asada**
**(A topic related to developmental robotics)**

**Today, 10.30 CET (9.30 GMT)**

University of Zurich



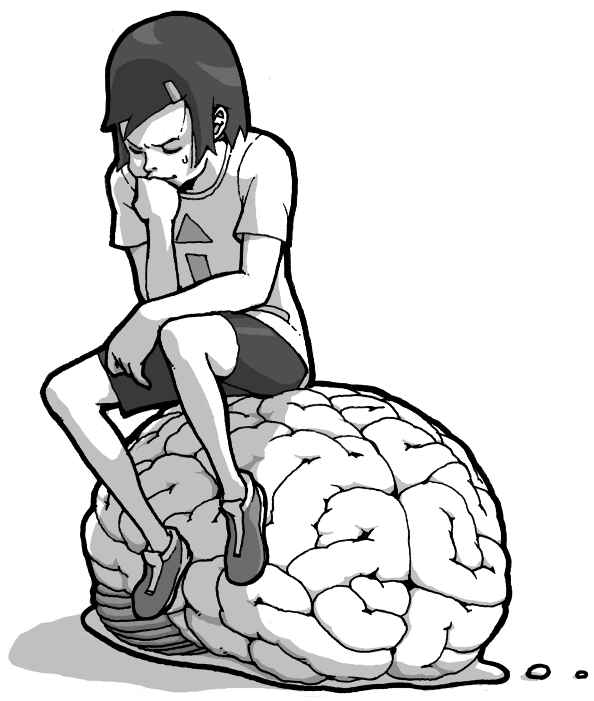
Prof. Asada is one of the pioneers of developmental robotics and one of the “fathers” of the Robocup movement, the world wide robot soccer competition.

# End of lecture 3

**Thank you for your attention!**

**stay tuned for lecture 4**

**“Design principles for intelligent systems,Part I”**



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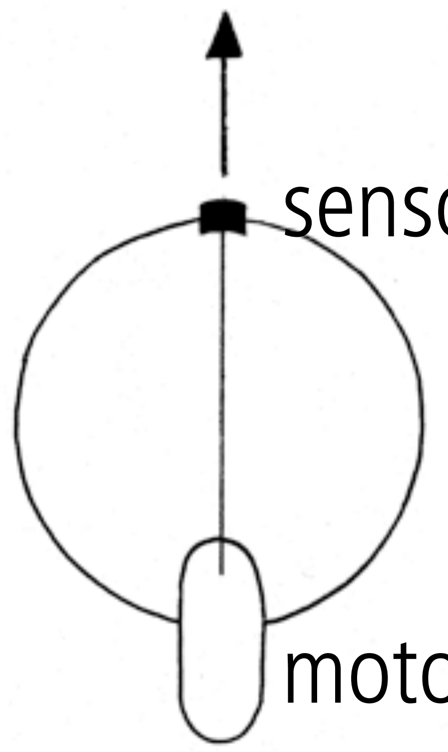
# Materials for self-study

# Braitenberg vehicle 1




- Vehicle 1

**quality: e.g. temperature**

**medium: water**

**wire: the higher the temperature the faster the motor**

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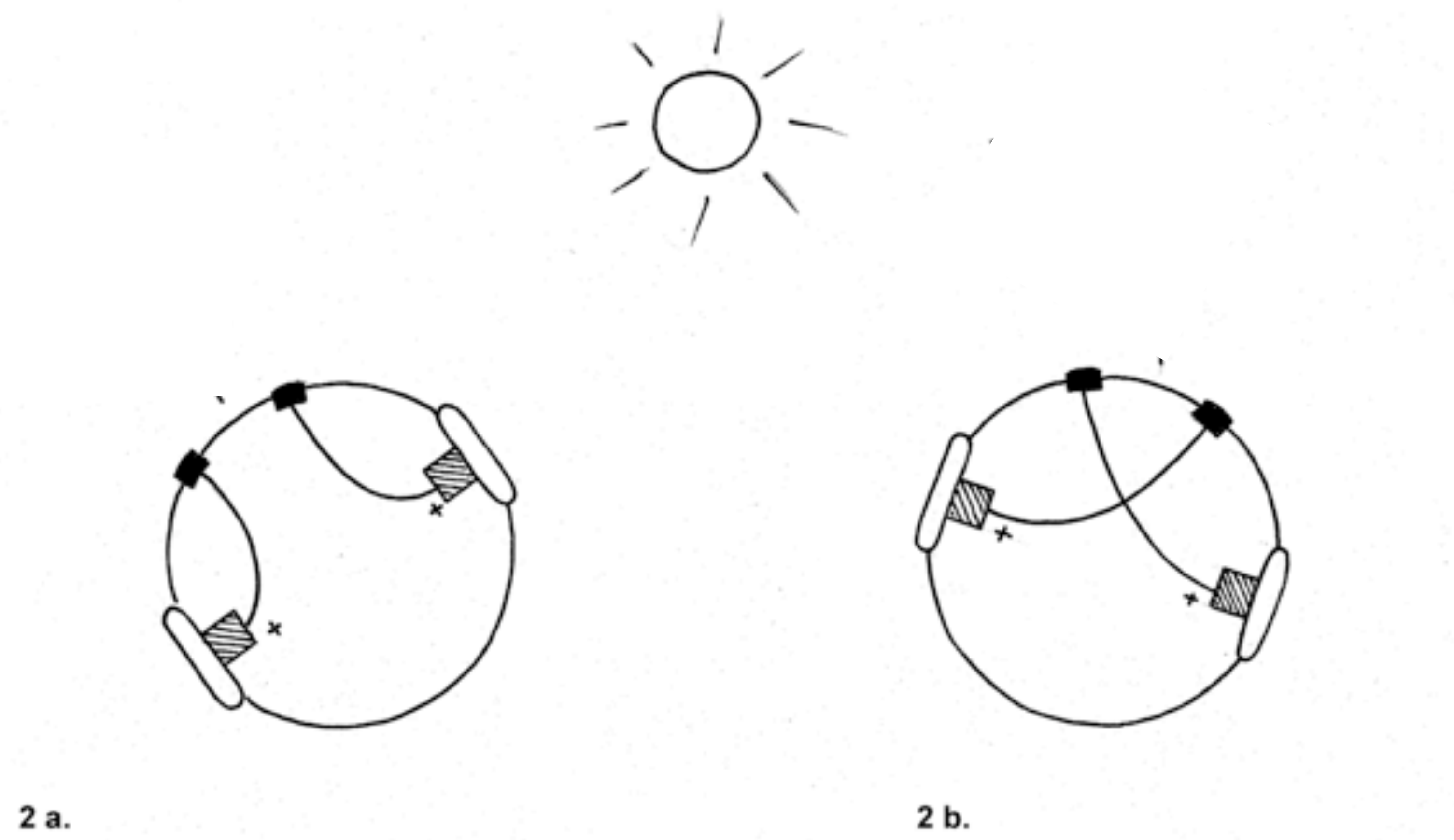
If the vehicle functions in the water and the quality is temperature, how will the vehicle behave?

# Braitenberg vehicle 2

quality: light intensity

medium: flat ground

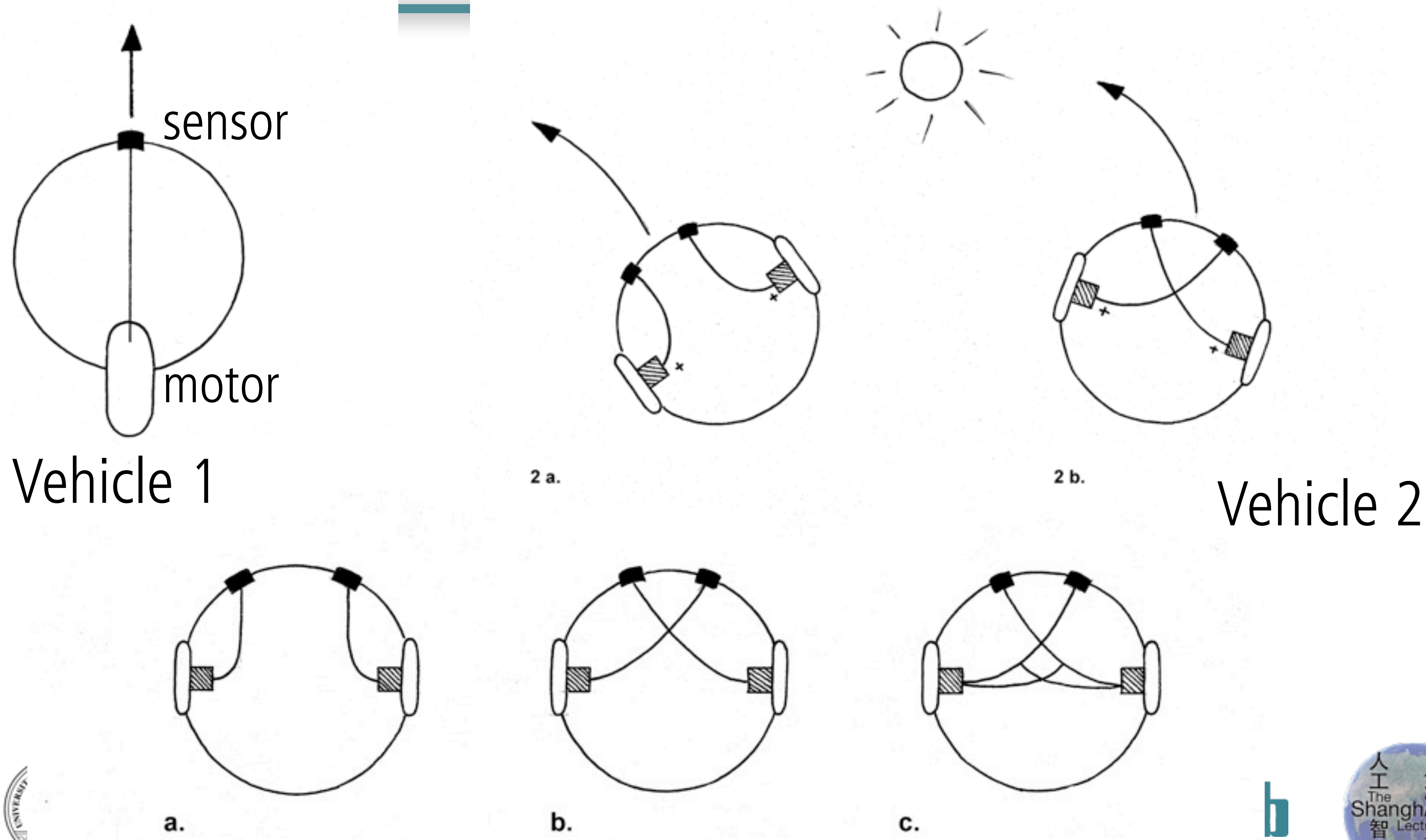
wires: brighter
—> faster






In the arrangement shown in the slides, what will the vehicles do?

# Braitenberg vehicles






Please read about the Braitenberg vehicles:
Braitenberg, V. (1986). Vehicles: Experiments in synthetic psychology. MIT Press.
or
Chapter 6 in “Understanding intelligence”.

Braitenberg vehicles represent a series of agents of increasing complexity. Although some are purely reactive, others include learning mechanisms, and thus have their own history.

In the simplest vehicles, it is quite obvious what they do. As matters get slightly more involved, predicting their behavior turns out to be very difficult, even in purely reactive systems, because the mechanisms generating the vehicles' behavior interact in interesting ways. Even if we have complete knowledge of the vehicle's insides, it still proves difficult to control it. Its interaction with itsenvironment adds complexity, which leads to some degree of unpredictability, even if the driving mechanisms are entirely deterministic -- in physics, there are always fluctuations. Let us examine the Braitenberg vehicles one by one. As always, we pay attention to the frame-of-reference problem. In examining this series of vehicles, it is always a good idea to imagine how they move around under various conditions. This process of imagination is best complemented with computer simulations or with experiments on real robots.

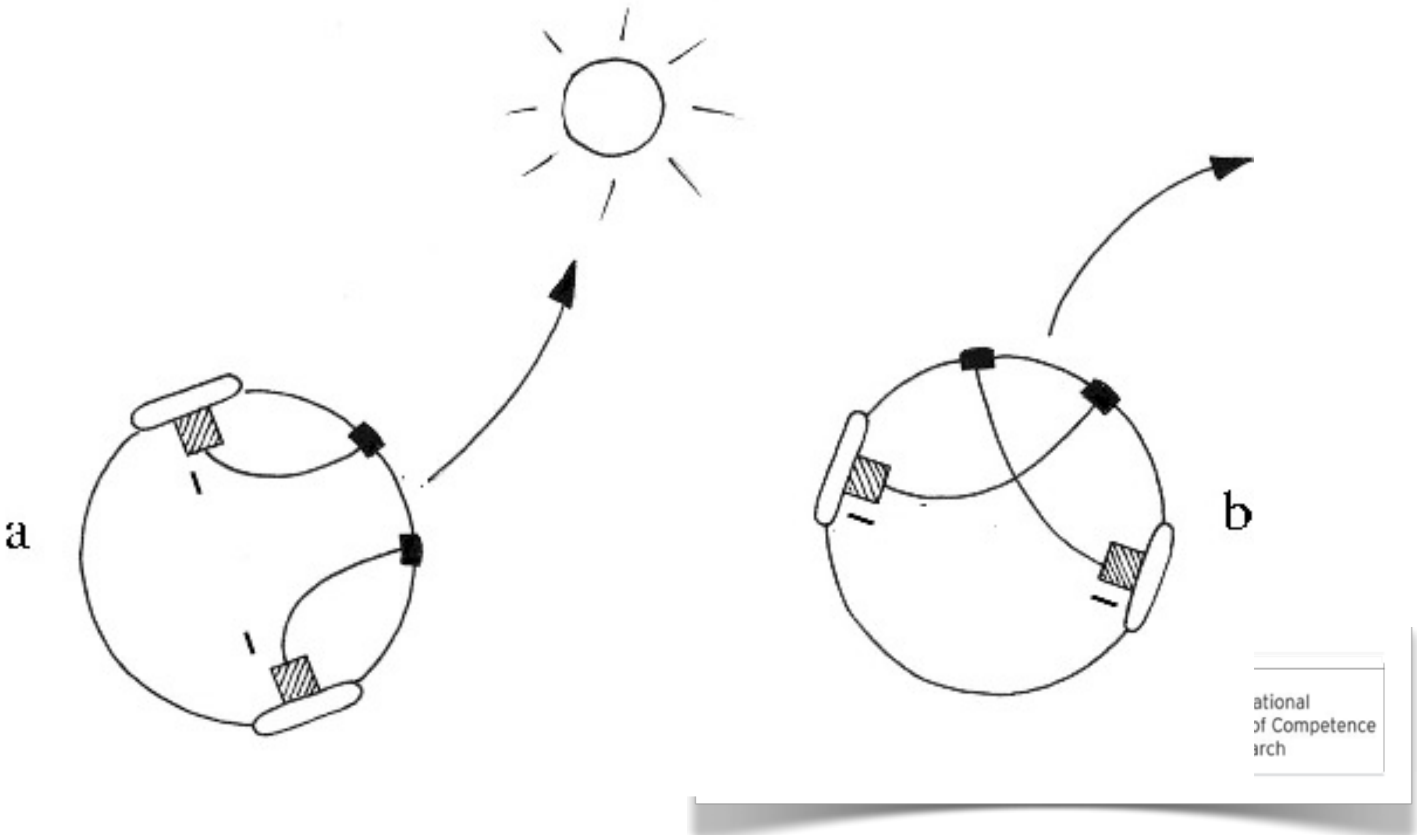
Vehicle 1
The first Braitenberg vehicle has one sensor, for one particular quality, and one motor. The sensor and the motor are connected very simply: The more there is of the quality to which the sensor is tuned, the faster the motor goes. If this quality is temperature, it will move fast in hot regions and slow down in cold regions. An observer might get the impression that such a vehicle likes cold and tries to avoid heat. The precise nature of thisquality does not matter; it can be concentration of chemicals, temperature, light, noise level, or any other of a number of qualities. The vehicle always moves in the direction in which it happens to be
pointing.

If we introduce friction into the vehicle's environment, its behavior gets interesting, because friction is always a bit asymmetric. The vehicle eventually deviates from its straight course, and in the long run, is seen to move in a complicated trajectory, curing one way or another without apparent (to the observer!) good reason. Perturbations other than friction that will force the vehicle from its straight course are, for example in water, streams, waves, fish, and other obstacles.

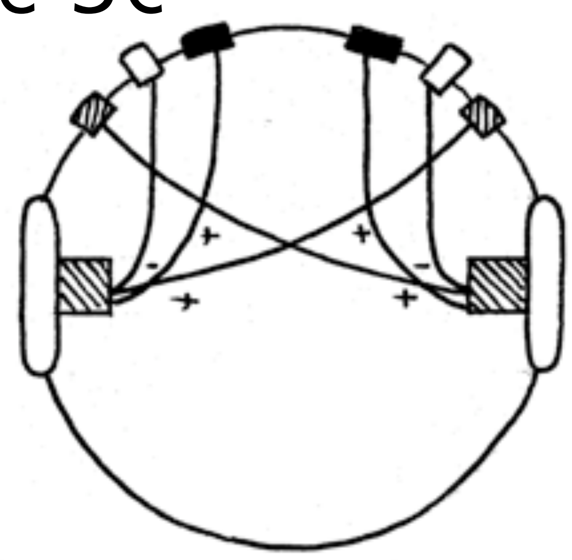
Vehicle 2
Vehicle 2 is very similar to vehicle 1, except that it has two sensors, one on each side, and two motors, right and left. There are three possibilities for connecting the sensors to the motors. If both sensors are connected in the same way to the motors, it is essentially the same as vehicle 1. Assuming that we have light sensors, in which the sensors are tuned to a light source. Because the right sensor of vehicle 2a is closer to the light source than the left, it gets more stimulation and thus the right motor turns faster than the left. As outside observers, we might characterize the vehicles as follows:
Vehicle (a) is a coward, whereas vehicle (b)is aggressive:
Vehicle (a) avoids the source, whereas (b) moves towards it and will hit it, possibly even destroying it. The ``brains'' of these vehicles are very simple. They consist merely of two neurons connecting the sensors to the motors. Note,however, the seemingly complex interactions among these vehicles can emerge.

# Braitenberg vehicles

Vehicle 3



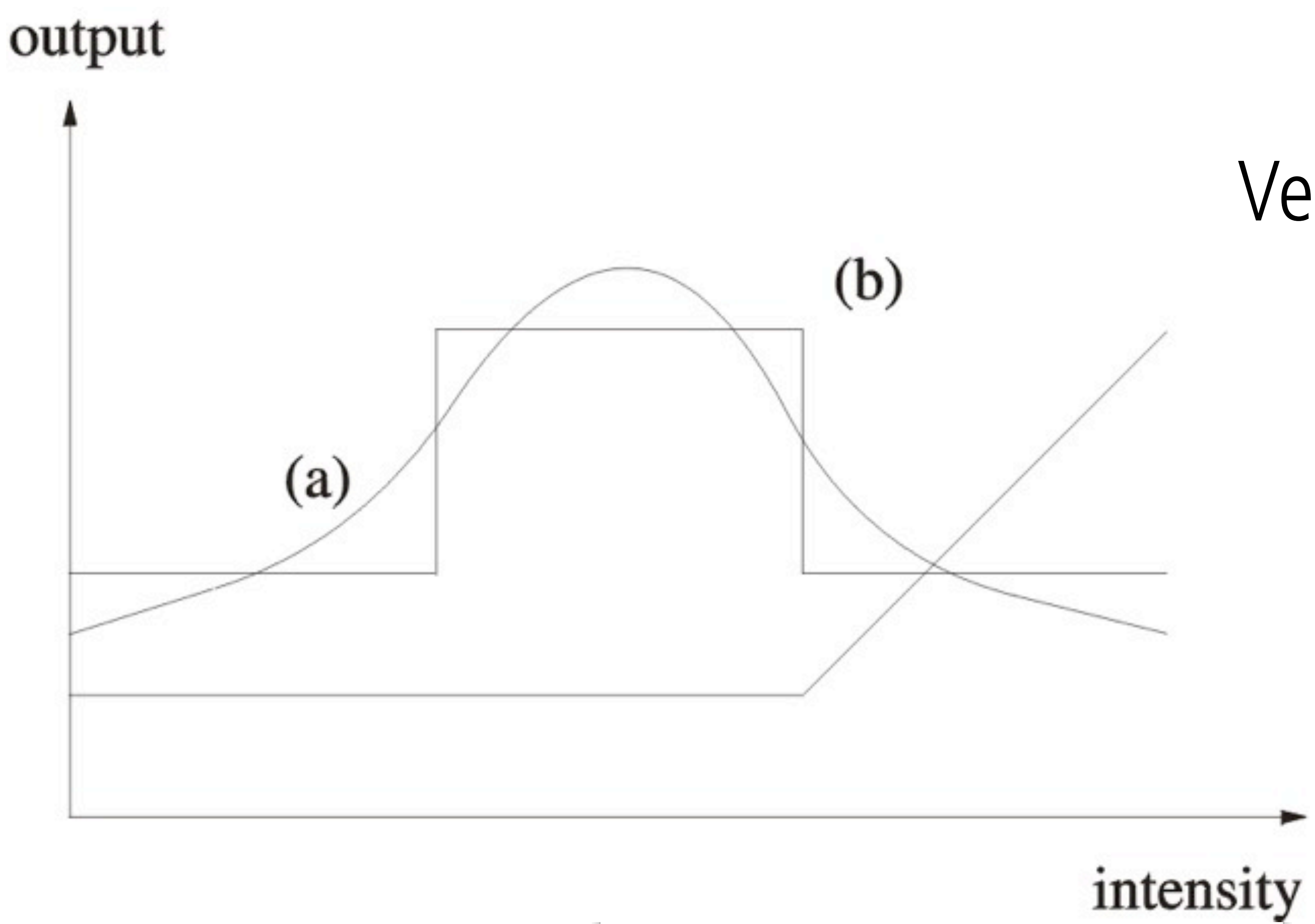

multisensorial
vehicle 3c



Vehicle 3
The first two Braitenberg vehicles have only excitation: the more stimulation at the sensors, the more the motors are powered. Let usnow introduce inhibition: the more stimulation, the less power is delivered to the motors. This principle is incorporated in Braitenberg vehicle 3.

The behaviors involved are fairly obvious. Vehicle 3a ends up facing, say, a light source, whereas vehicle 3b turns away from it but also remains near the source, unless there is a disturbance, like another source. Additional sensors can also be introduced, and each stimulus can be connected either to the motor on the same or the opposite side, and can be excitatory or inhibitory (see figure 6.6). Stimuli to which the sensors are attuned could be light, oxygen concentration, temperature, concentration of organic molecules (food), or similar things. The vehicle has a tendency to stay longer in certain areas than in others because when its sensors are activated by the presence of a stimulus, its motor and thus its movement are inhibited. We cannot help admitting that the vehicle appears to have a set of ``values'' and that it incorporates them in some way that we would want to call ``knowledge.'' ``Knowledge'' in this context does not mean ``stored representations;'' that is, it is not--as in the classical AI view--stored in an explicit form to be manipulated by the agent (the vehicle) itself. Rather, it is attributed to the vehicle as a whole by an outside observer. Attributing ``knowledge'' to an agent is a way of describing its behavior--it has nothing to do with the agent's internal structure.

# Braitenberg vehicles




Vehicle 4



Vehicle 4 has non-linear collections from sensors to motors. For example, up to s certain light intensity, the vehicle is still, and if the light intensity then further increases, the vehicle starts to move (as if it were waking up). Still, it is a purely reactive system: it does not have its own history; that is, it does not change over time. Nevertheless, it looks very much like an autonomous agent. If it has many sensors and they are connected in complex ways to the motors, it would in fact be very difficult to control the agent's behavior.

Vehicle 5
We can now add arbitrary complexity by introducing threshold devices. In chapter 5 we called these ``devices'' nodes or model neurons. The kinds of nodes suggested here are of the linear threshold variety, but they could also be of the sigmoid type. They can either be interposed between sensors and motors or connected to each other in various ways. A vehicle possessing these devices is of Braitenberg type 5. These kinds of models are also called artificial neural networks and will be further discussed in lecture 5.

# Braitenberg vehicles: Vehicles 6 and beyond

- **Vehicles 6: evolution**
- **Vehicles 7 to 14: increasing the internal neural connections**

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Vehicle 6:Evolution

Suppose we put a number of vehicles that we have built on a table containing light sources, sounds, smells, and so forth and let them move around. We pick out one vehicle, the model, make a copy of it, and put both the model and the copy back on the table. We pick out another, and repeat the process indefinitely. Of course, we do not choose vehicles that have fallen on the floor, because they are obviously incapable of coping with this particular environment. We produce vehicles at a pace that roughly matches the rate at which vehicles fall off the table.

If we play this game in a hurry, we are likely to make mistakes now and then. A well-tested vehicle might still fall off the table.

Particularly shrewd variations might also be introduced unwittingly into the pattern of connections with the result that our copy survives, whereas the original may turn out to be unfit for survival after all. If the imperfect copying results simply from sloppiness, the chances that something interesting will emerge because of the mistakes in copying are small. However, a ``better'' sort of error would involve creating new combinations of partial mechanisms, and structures such as IR sensors, cameras, motors, or wheels, each of which has not been disrupted in its own well-tested functionality. Such errors have a much greater chance of transcending the intelligence of the original plan. If these ``lucky'' incidents live forever, they will have many descendants, because they and their descendants will frequently be chosen for copying simply because they stay on the table all the time.

This is, of course, a model of Darwinian evolution. It reminds usof the metaphor of the blind watchmaker, created by Richard Dawkins (1988) to describe evolution. Vehicles created in such a

scenario are said to be Braitenberg type 6. We may, by accident, create vehicles whose behavior is extraordinary without understanding why they behave as they do, because building something that works is typically much easier than analysis: Braitenberg called this the ``law of uphill analysis and downhill invention.'' Indeed in evolutionary approaches you can quite often get the agents to do what they should do, but it is usually hard to understand why they do what they do. (Evolutionary methods are discussed in detail in chapter 8.)

Other Vehicles

We discuss the remaining vehicles, vehicle 7 to 14, only briefly, because for our purposes, the simple vehicles are more interesting: They illustrate the sensory-motor couplings and how they lead to remarkable behavior. The later ones, especially vehicles 7 and above, have a cognitivistic flavor and are therefore bound to run into the problems the classical approac to AI.

# End of materials for self-study