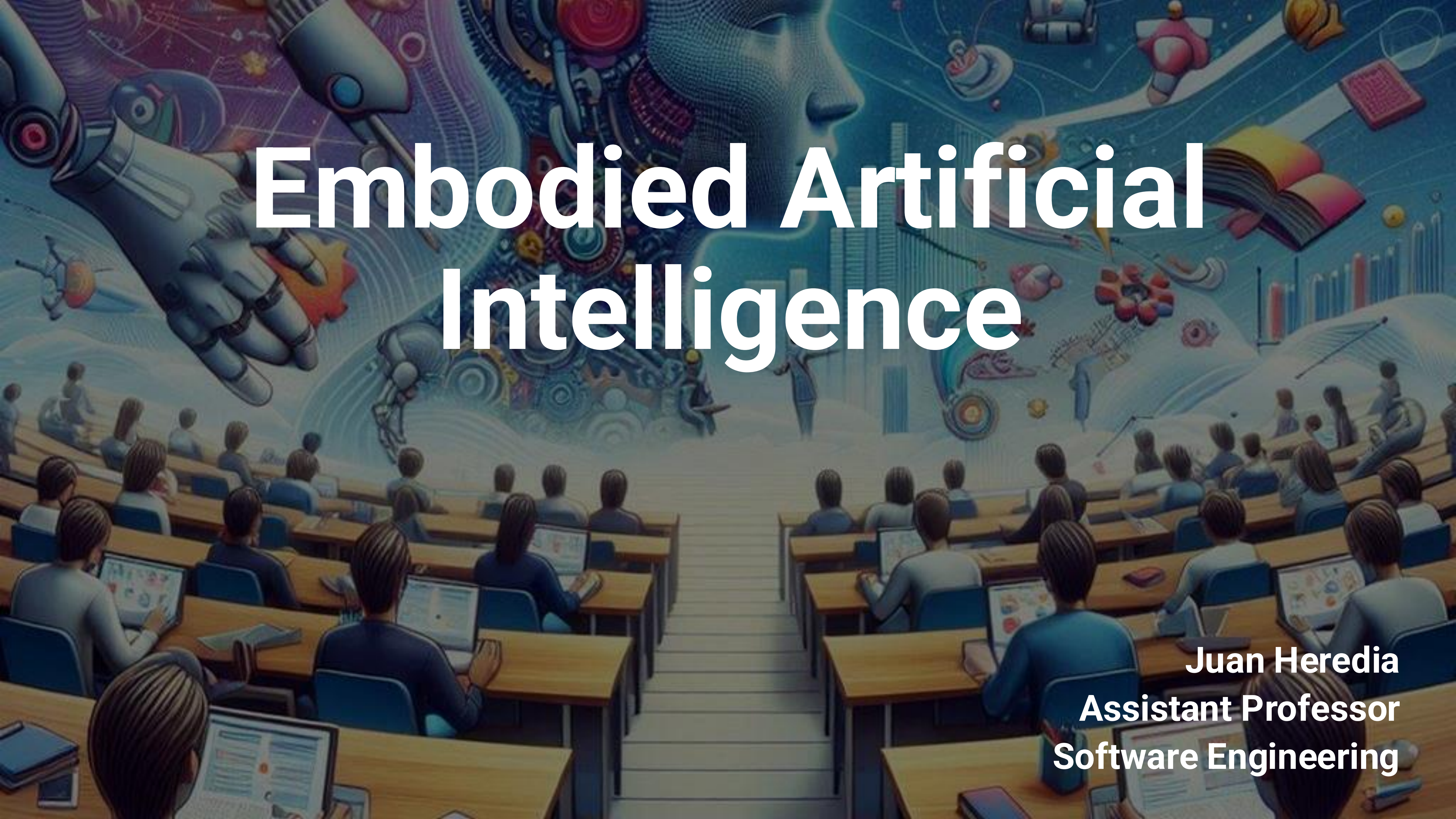


Embodied Artificial Intelligence

Juan Heredia
Assistant Professor
Software Engineering

1 Artificial Intelligence

An embodied perspective

1. Introduction, practical matters (20 min)
2. Project Introduction (10 min)
3. How do you learn? (10 min)
4. Lecture (90 min)
   3.1. Artificial Intelligence
   3.2 Embodied Artificial Intelligence
   3.3 Examples
   3.4 Applications

Research Interests

- Sustainable Robotics:
  - Standardization of energy consumption measurement and metrics for manipulators.
  - Manipulators CO2 footprint.
  - Energy Consumption Modeling for Reliability

- Reuse of data for programming.
  - How to use data to make easier and faster to program a robot?

- Embodied Artificial Intelligence
  - Development or sensorimotor controllers for bioinspired soft robotics.

Practical matters

- Course consists of
  - Lectures (typically uploaded the night before lecture on Itslearning)
  - Practical work (Lego robot design, construction and programming)
- Evaluation based on two group reports and final exam
  - Preliminary report (2-3 pages) in the middle of the course (October)
  - Final report (max. 10 pages) at the end of the course (December)
  - Oral exam (January)
- Who to ask for help
  - AI, approach, methods, theory, project ideas etc. – Juan Heredia (jehm@mmmi.sdu.dk)
  - Lego hardware, robot programming etc. – Casper Hewson (crask21@student.sdu.dk)

Practical matters - Schedule

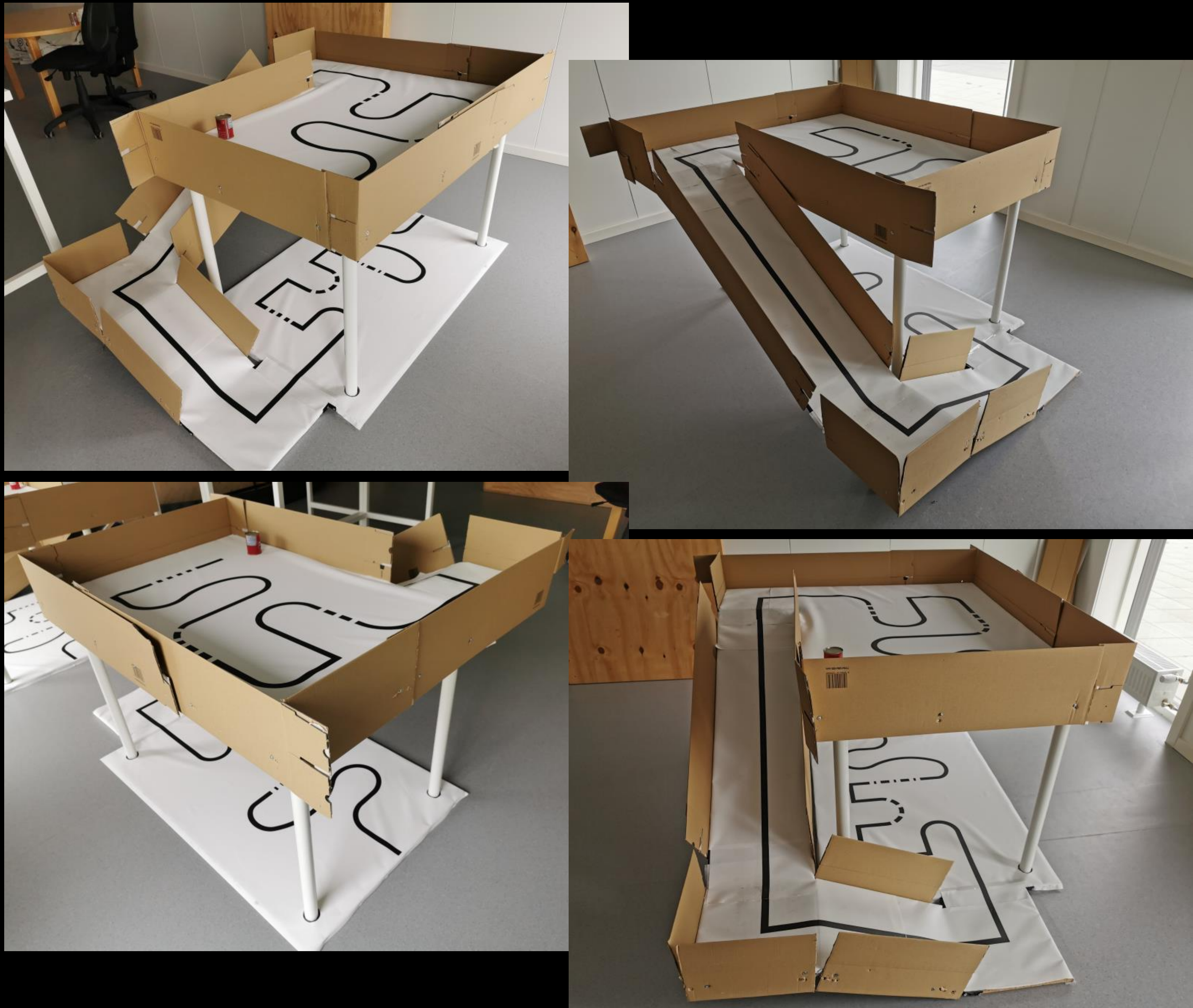
Week	Lectures/ Activities	Date	Deadlines
36	Lecture 1: AI - An embodied perspective	4-Sep	
37	Introduction to Lego Mainstorm	11-Sep	
38	Lecture 2: Behaviour-based robotics - intelligent control for robots	18-Sep	
39	Semester Project Work	25-Sep	Checkpoint 1 :Line Follower
40	Lecture 3: Bioinspiration in Embodied AI - perception and action	2-Oct	
41	Semester Project Work	9-Oct	
42			
43	Semester Project Work	23-Oct	Checkpoint 2: Finding the Can /Preliminar Report
44	Lecture 4: Sensorimotor integration - Perception-action relationship	30-Oct	
45	Semester Project Work	6-Nov	
46	Lecture 5: Adaptation in embodiment - the role of learning in intelligence	13-Nov	Checkpoint 3:Ramp Managemen
47	Semester Project Work	20-Nov	
48			
49	Final Presentation	4-Dec	Checkpoint 4 : Competition
50			
51	Final Report	18-Dec	Checkpoint 5 : Report

2 Project

Design an embodied AI solution for robotic search and rescue

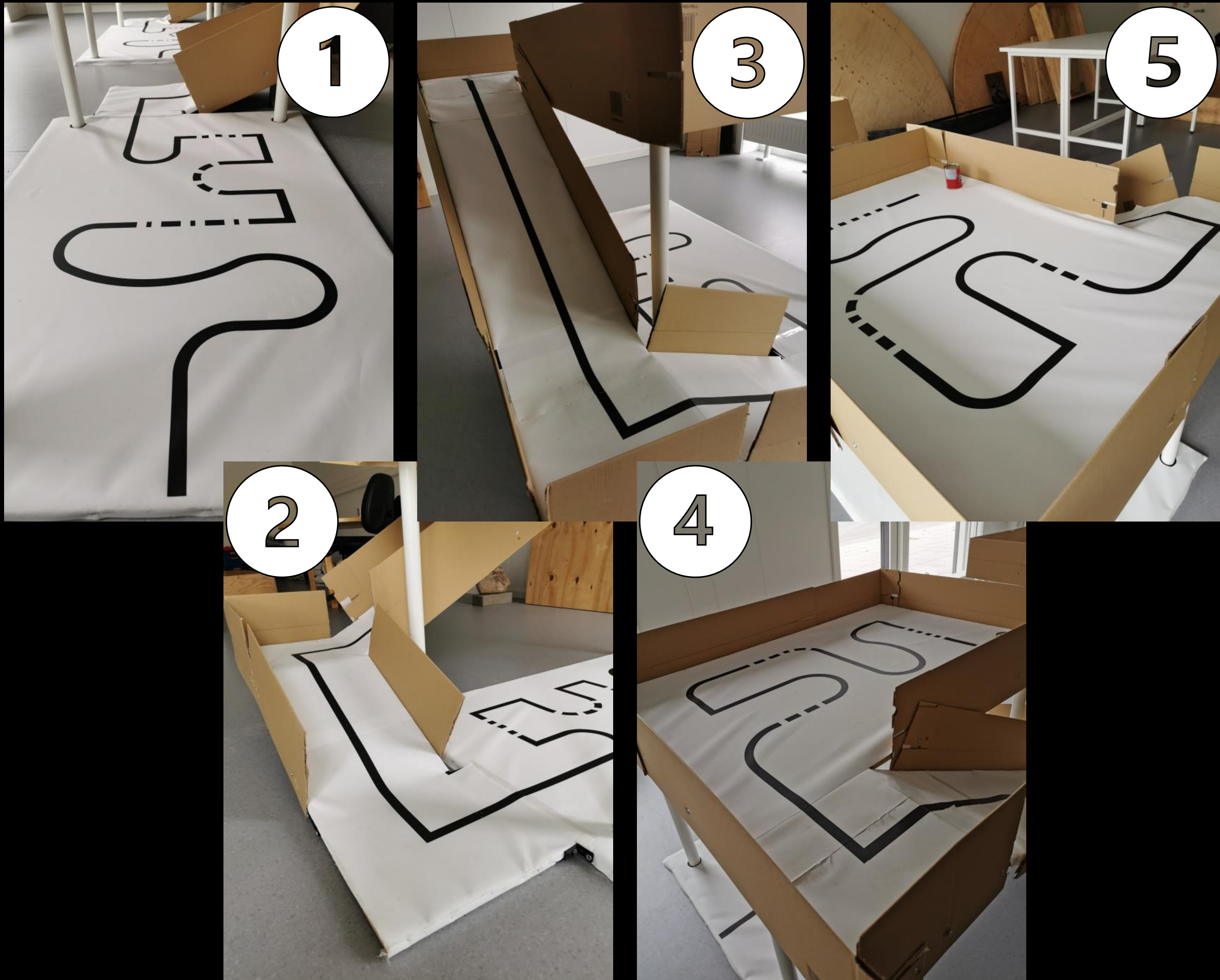
Goal

- Build a robot, using principles of embodied AI, to "rescue" a "survivor" from a building
- The "survivor" is a tomato can on the 1st floor of a robot arena at an approximate location
- Robot starts from a known location on the ground floor
- Robot must find the tomato can, grab it and transport it back down to the starting location
- Sub-goal: Reach and transport the can as fast as possible



Practical details

- Robot can reach 1st floor by following track (black line on white background)
- On 1st floor, robot can use two possible solutions to reach can:
  - Simpler but longer/slower solution
    Robot can get close to the can by following the track, then “find” the can using the ultrasound sensor
  - Complex but shorter/faster solution
    Robot must plan a straight-line path to the location of the can, then “find” the can using the ultrasound sensor
- Robot must grab can and return to starting location



Notes

- You must use a behaviour-based architecture (will be covered Lecture 2) to design the controller
- Design a robust gripper solution to grab the can even when not aligned perfectly
  - Rubber bands may be used to increase the friction of the grip. Robot need not lift the can after grabbing it, just drag it along
- Use the colour sensor(s) to follow the track
  - Readings of colour sensors are affected by ambient light. One way to deal with this is to shield the sensor with tape or something similar, to block ambient light from interfering with emitted light and stabilise the readings.
- Use the ultrasound sensor to “see” the can, and touch sensor to “feel” it
  - Can has round shape, exploit this to robustly detect the can. Scan by moving ultrasound sensor to “see” the can.
- Center of gravity (CoG) of the robot affects the performance on the ramps
  - Heavier parts of the robot affect the CoG more than lighter parts. Keep the CoG as vertically low as possible, as well as keep the CoG as close as possible to the wheel axes that are connected to the motors. This will push the wheels down more and increase grip, which is particularly important when driving up and down the ramps. You may use extra wheels to increase grip.
- Can adds additional weight to the robot
  - This will affect the robot’s kinematics and dynamics when driving down the ramp. The controller must deal with this.
- Robot can drive backwards to starting location, or turn 180° first and then drive back
  - Risk in driving backwards is that the controller must be designed to be direction independent. Risk in turning 180° is that colour sensors will not see the track while turning, and robot has to find the track again.

Practical matters

- You are provided with a test map in the arena on which you can develop and test your solution
- To test the robustness of your final solution, you must be able to demonstrate that it works on a different map as well, and not just on the test map
  - Your solution must therefore not be "hard-coded" to the test map
- Your final solution will be tested on a different map in the same arena
  - The test will be in the form of a robot competition, where you will have to execute your solution. Note that the starting location of the robot, the location of the can as well as the layout of the black line will be different in the competition.
  - Each team will be allowed multiple attempts. The execution time for each successful attempt will be recorded and the fastest time will be considered as the best time. An attempt will be considered as failed if the robot cannot return to the starting position with the can.
- The date of robot competition will be on December 5.

September

S	M	T	W	T	F	S
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30				

October

S	M	T	W	T	F	S
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

November

S	M	T	W	T	F	S
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2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29

December

S	M	T	W	T	F	S
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

- Project / Practical Work
- Lectures
- Competition
- Checkpoints/ Deliverables

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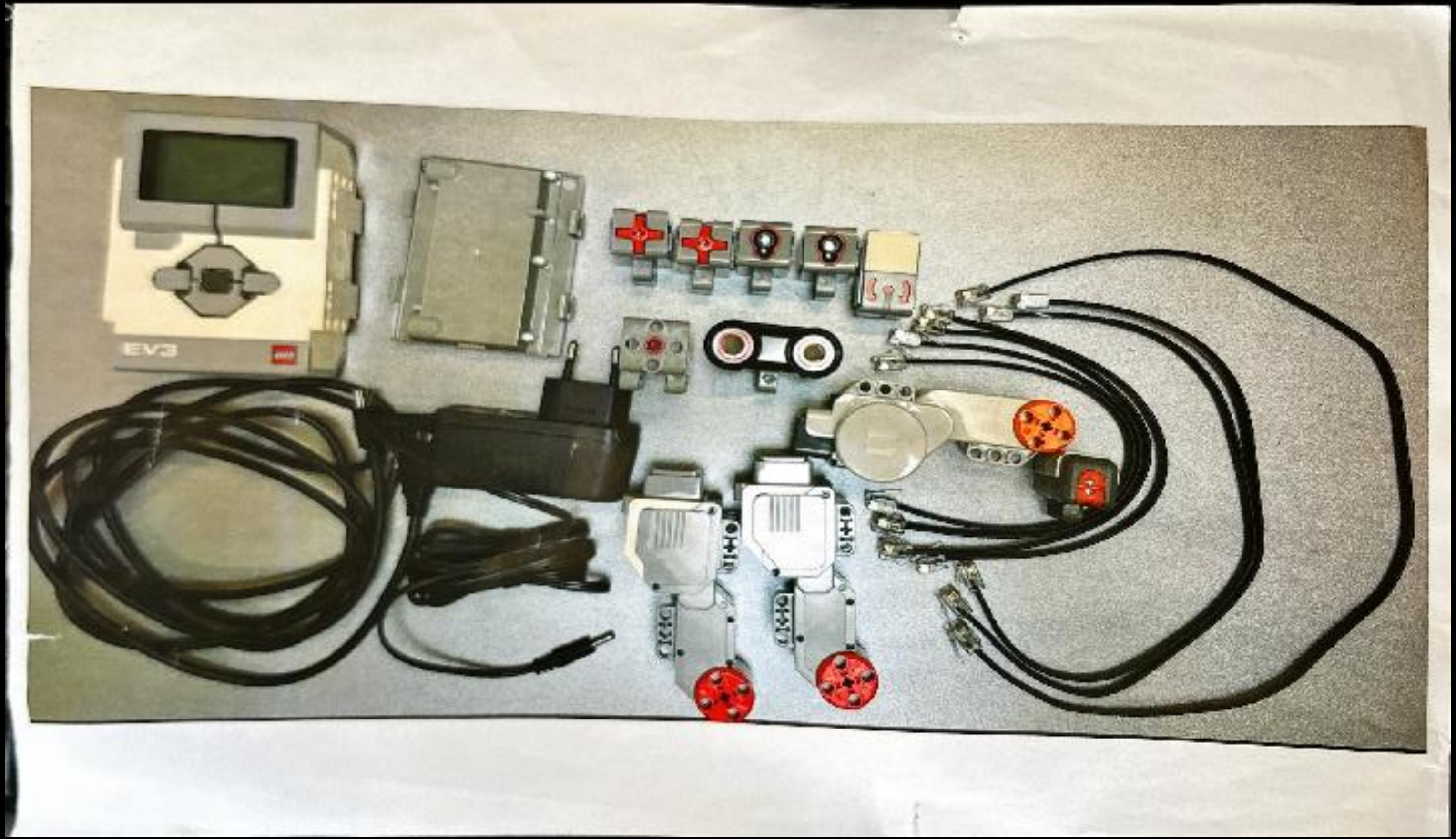
Task 1

1. Form a group (max 3 students per group).

2. Go to the library and ask for a Lego Mindstorm Kit.

3. One kit per group of students.

Task 1



- Computer
- Battery
- Charger
- Usb
- 7 sensors (2 color, 1 light, 1 gyroscope,
- 1ultrasonic, 2 touch)
- 4 motors
- Cables

Task 2

Check laboratory access

Ø42-605b-0

Software Engineering Laboratory

Rules:

1. Don’t bring food
2. Don’t leave the LEGO kits in the laboratory.

Disclaimer

There is no “algorithm” for embodied artificial intelligence

Do elephants play Chess?

Whoever answers to this question passes the semester *

What is Embodied AI?

*You are still required to submit a report

What comes to mind when you think of Artificial Intelligence?

How would you define AI in few words?

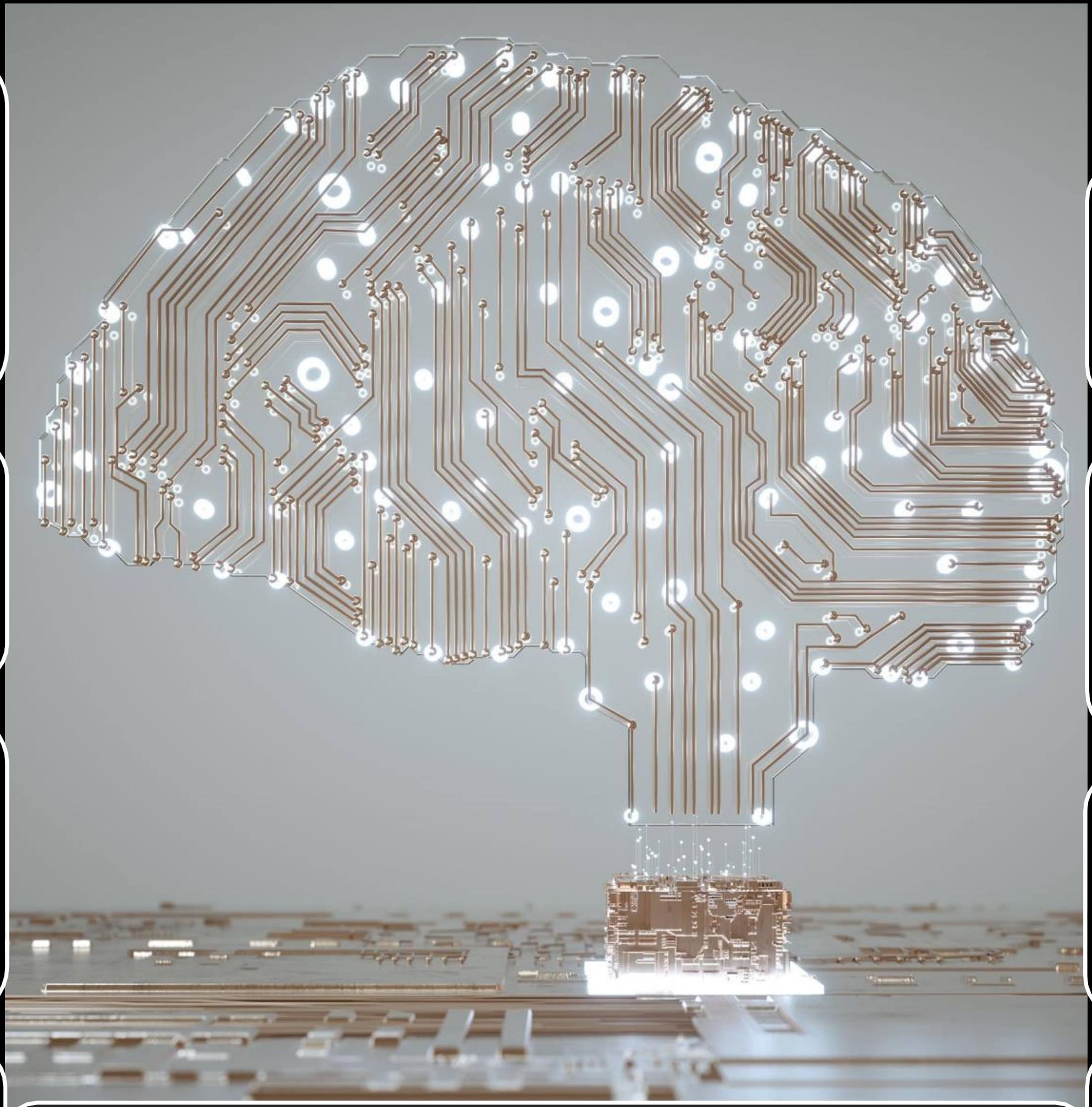
What is artificial intelligence?

"The automation of activities that we associate with human thinking, activities such as decision-making, problem solving, learning ..."
– Bellman, 1978

"The exciting new effort to make computers think ... machines with minds, in the full and literal sense"
– Haugeland, 1985

"The art of creating machines that perform functions that require intelligence when performed by people"
– Kurzweil, 1990

The study of how to make computers do things at which, at the moment, people are better"
– Rich and Knight, 1991



"The science and engineering of making intelligent machines"
– John McCarthy, 1955

"The study of mental faculties through the use of computational models"
– Charniak and McDermott, 1985

"A field of study that seeks to explain and emulate intelligent behavior in terms of computational processes"
– Schalkoff, 1990

"The study of the computations that make it possible to perceive, reason, and act"
– Winston, 1992

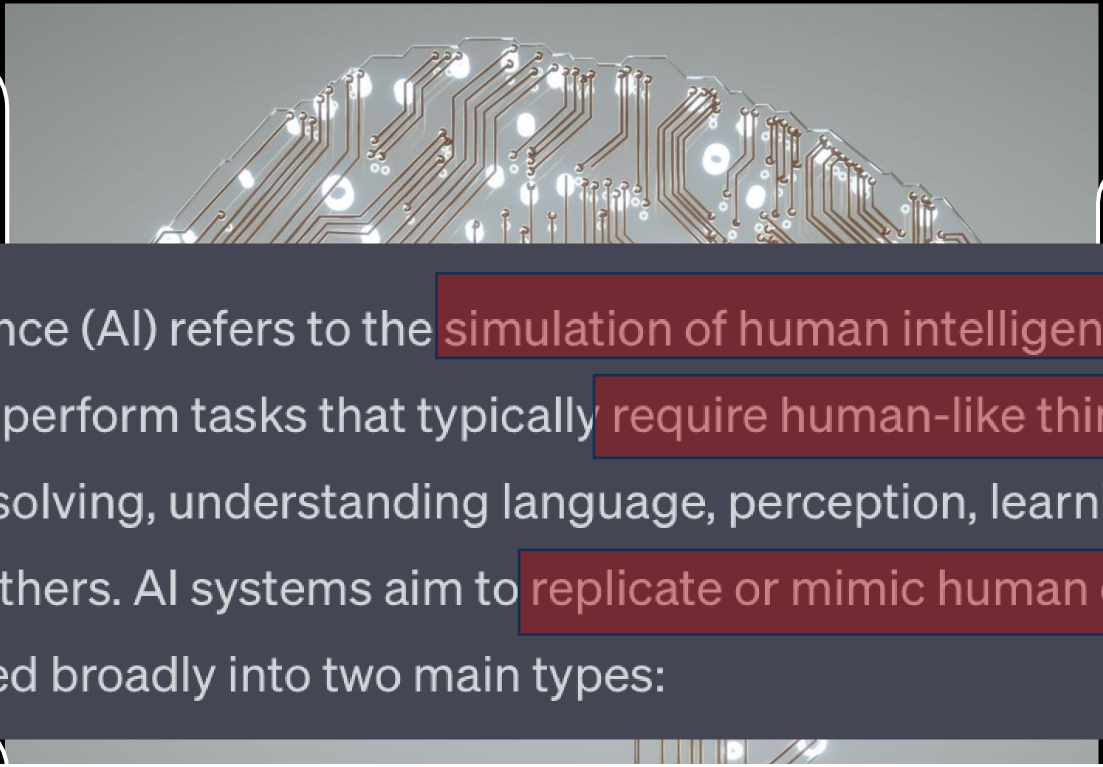
"The branch of computer science that is concerned with the automation of intelligent behavior"
– Luger and Stubblefield, 1993

Disclaimer

What does AI think that AI is?

What is artificial intelligence?

"The automation of activities that we associate with human thinking, activities such as decision-mak
..."



"The study of mental faculties
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tt, 1985

"The
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Artificial Intelligence (AI) refers to the simulation of human intelligence in machines, enabling them to perform tasks that typically require human-like thinking. These tasks can include problem solving, understanding language, perception, learning, and decision making, among others. AI systems aim to replicate or mimic human cognitive functions and can be categorized broadly into two main types:

"The art of creating
perform function
intelligence whe
people"

ons
eive,
n, 1992

Artificial intelligence (AI) is a branch of computer science concerned with building systems that can perform tasks that typically require human intelligence. These tasks include reasoning, learning, problem-solving, perception, decision-making, and language understanding.

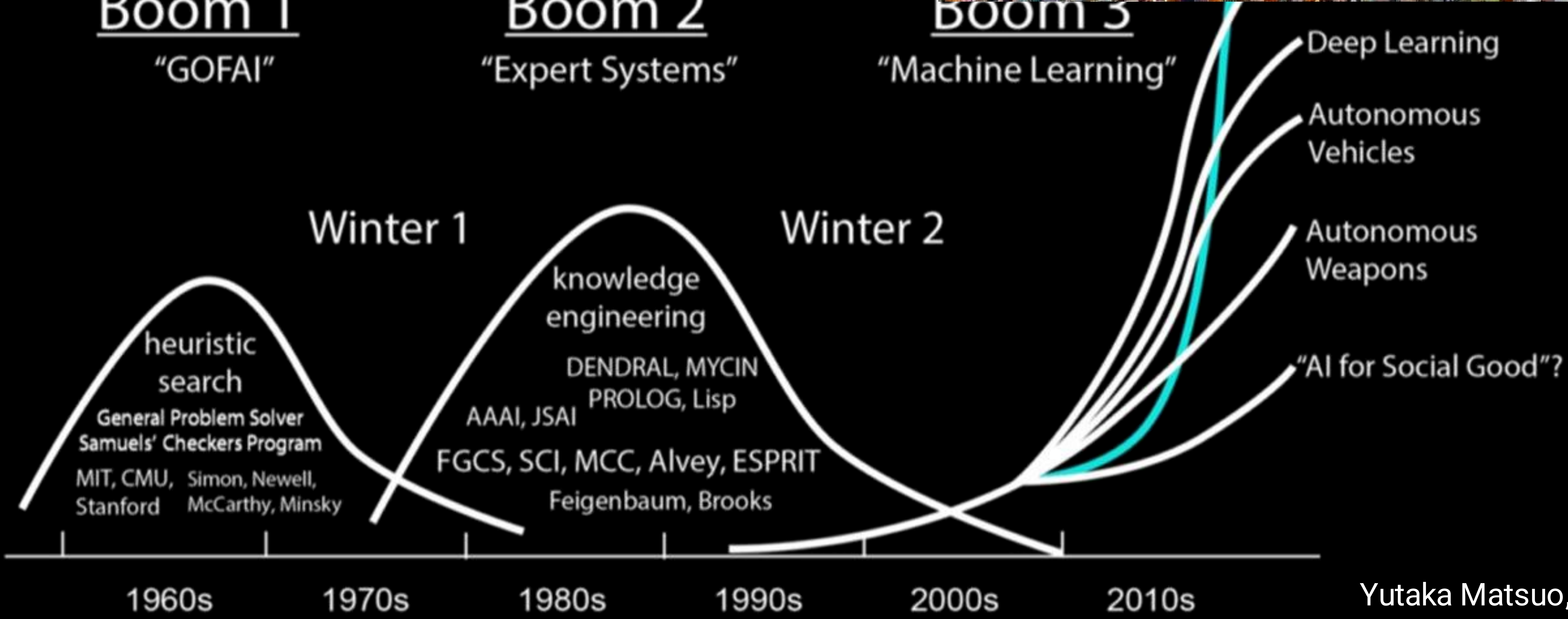
At its core, AI combines **algorithms, data, and computational models** to simulate aspects of human cognition and behavior. AI can be classified in several ways:

The study of how
computers do th
the moment, peo
– Rich and Knight, 1991

– John McCarthy, 1955

ience
havior"
– Luger and Stubblefield, 1993

The promise of AI



Yutaka Matsuo, 2015

Fundamental AI paradigms

AI paradigms establish fundamental assumptions and approaches

- “Classical” or Good Old-Fashioned AI (GOFAI)
  computing with symbols

- Connectionist (Machine Learning, Transfomers, Deep Learning, etc.)
  distributed computational units (neural networks)

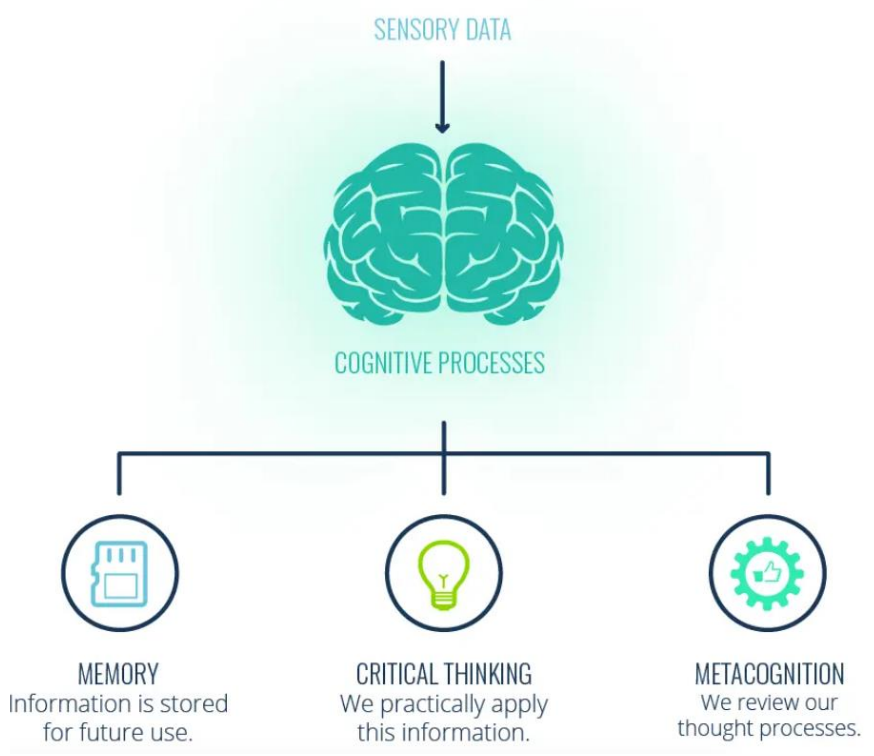
- Embodied AI
  focus on the “system” rather than just the robot

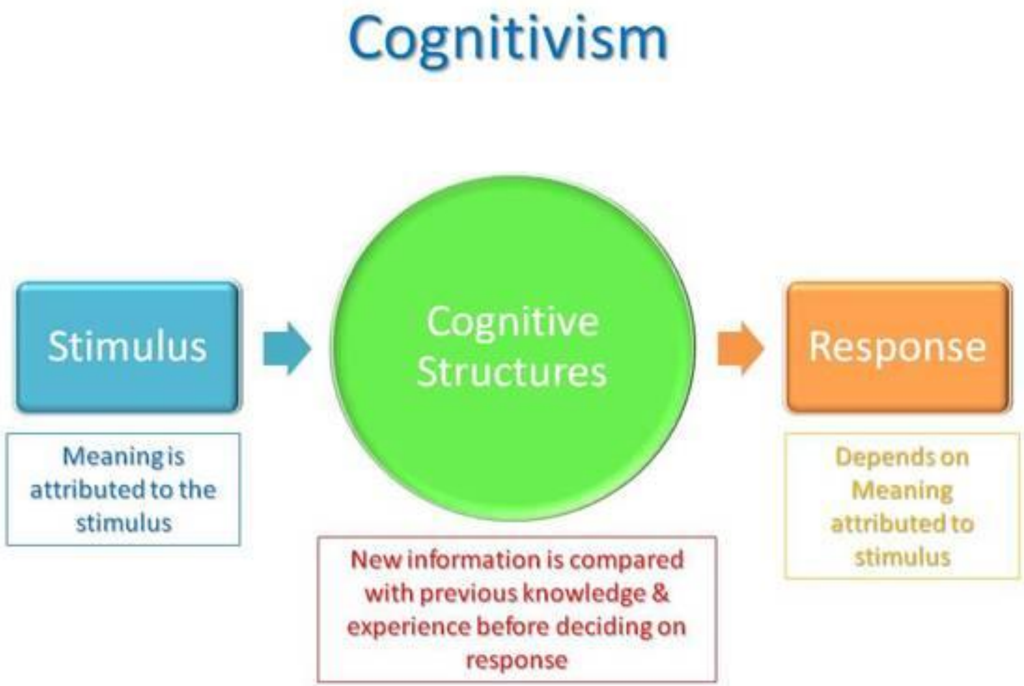
  - Behaviour-based AI
    focused only on robot

Physiology 1.0

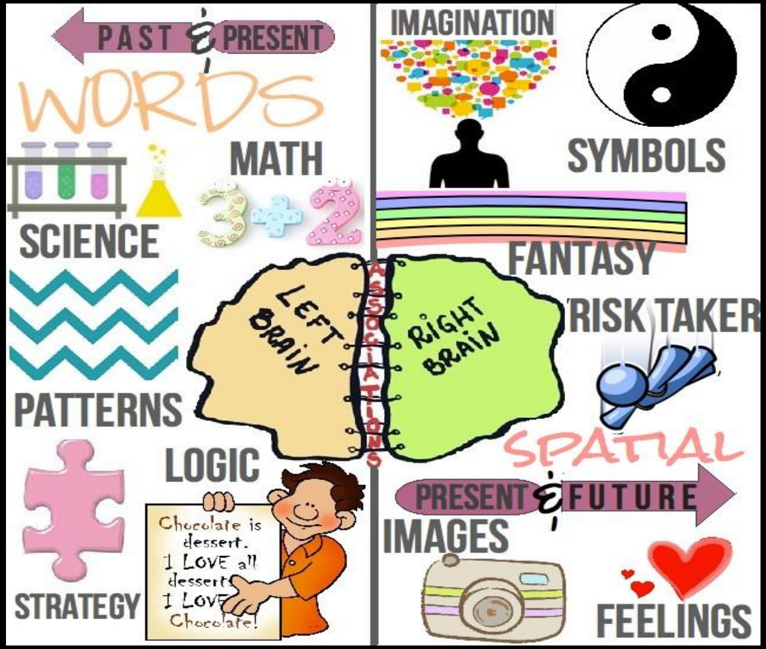
What is Cognitivism?

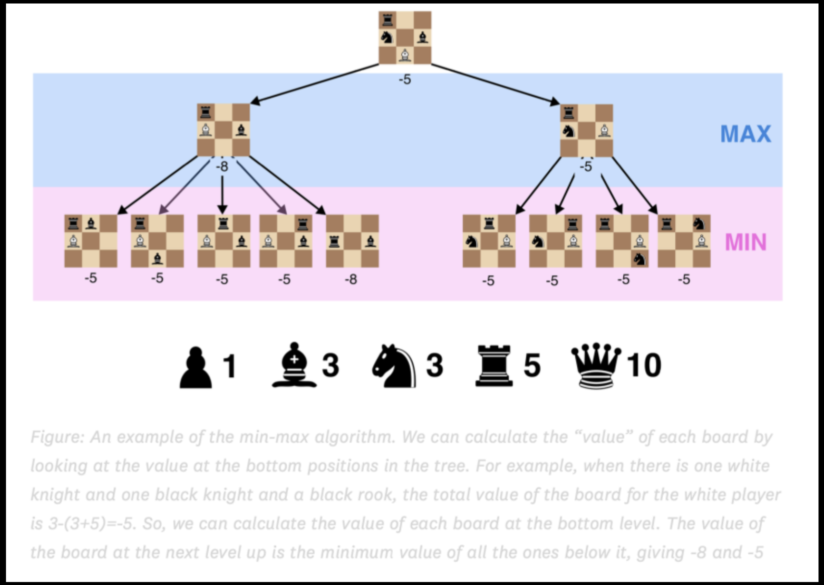
Cognitivism is a theoretical framework for understanding the mind, how it process and retrieves information.





Good old-fashioned AI (GOFAI)

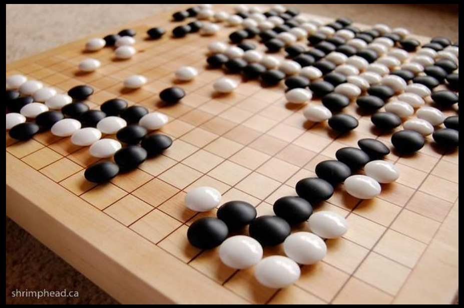


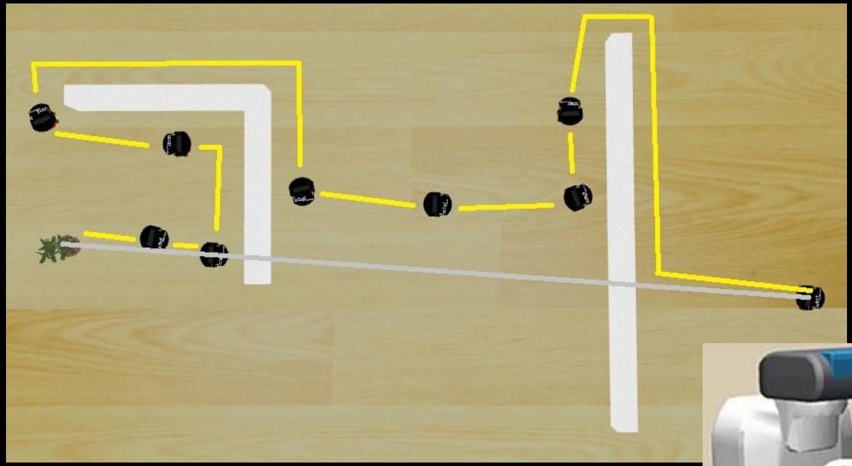


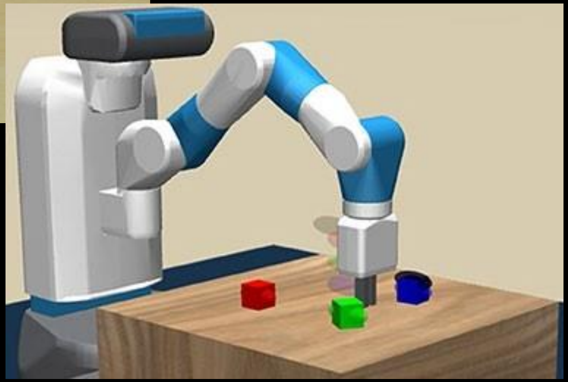
- Assumes cognition as being computation
- What matters for intelligence is the abstract algorithm or program
- The GOFAI approach therefore implies that not only can intelligence run on wet, biological brains, but it can also run on computers (!)

Typical GOFAI problems

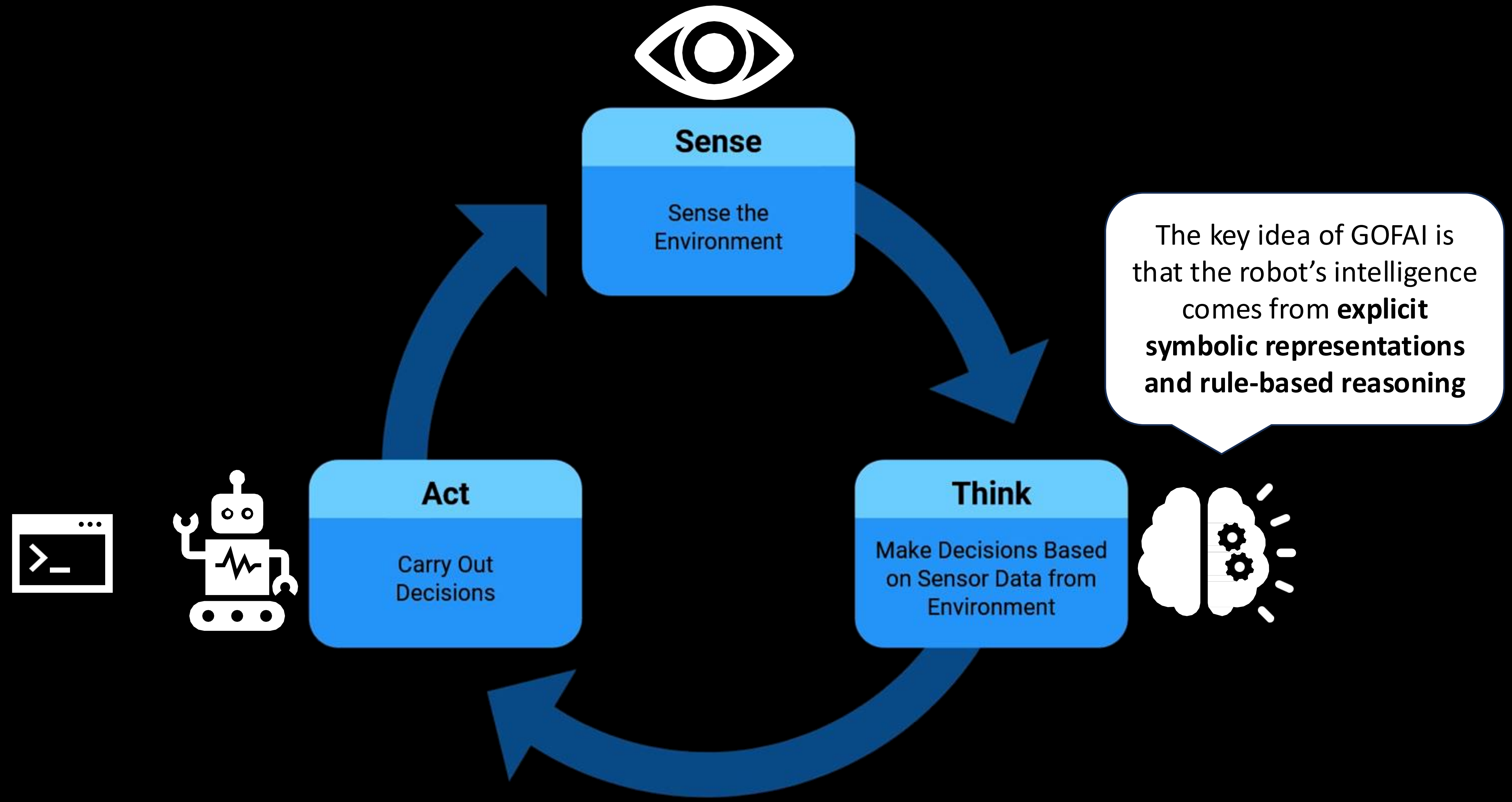
- Discrete “states”
- Unambiguous rules
- Full knowledge (model) of task and environment



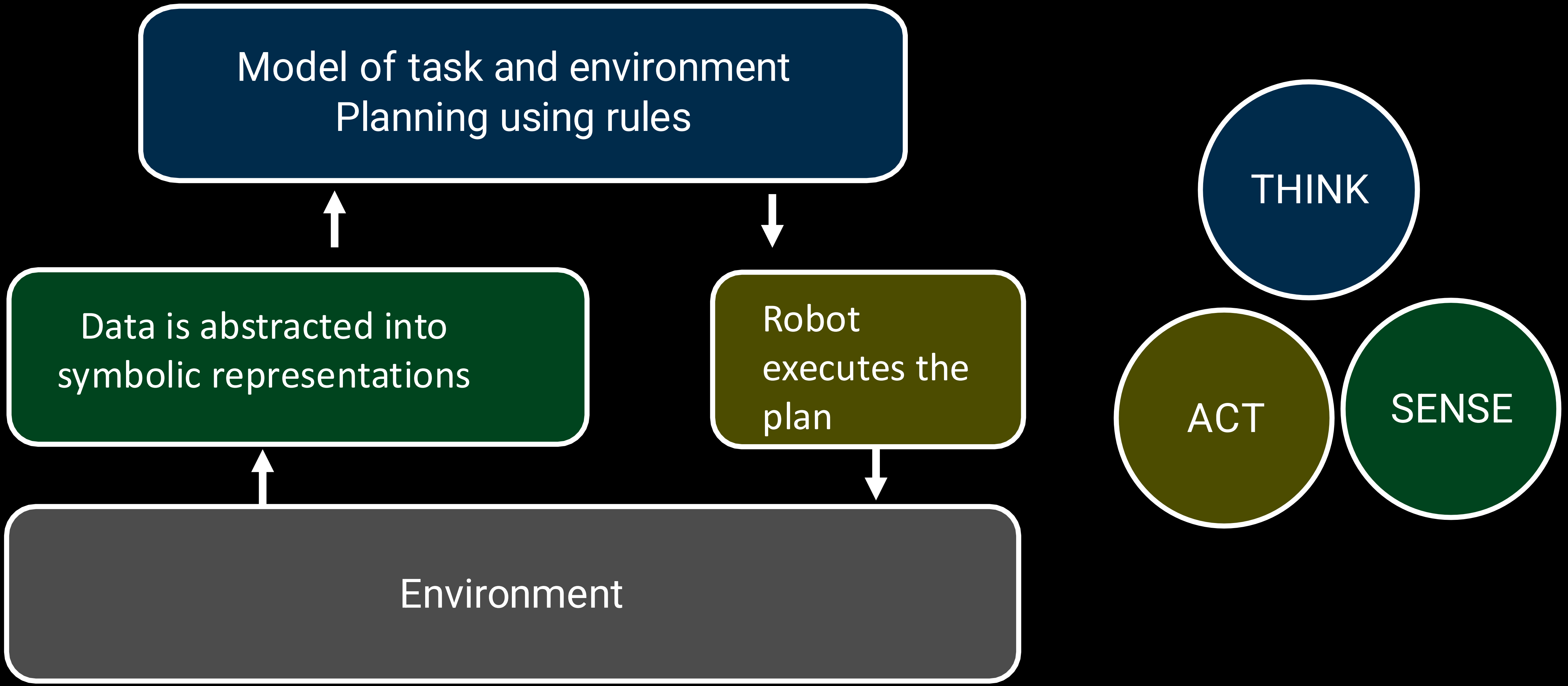




Typical GOFAI approach in robotics

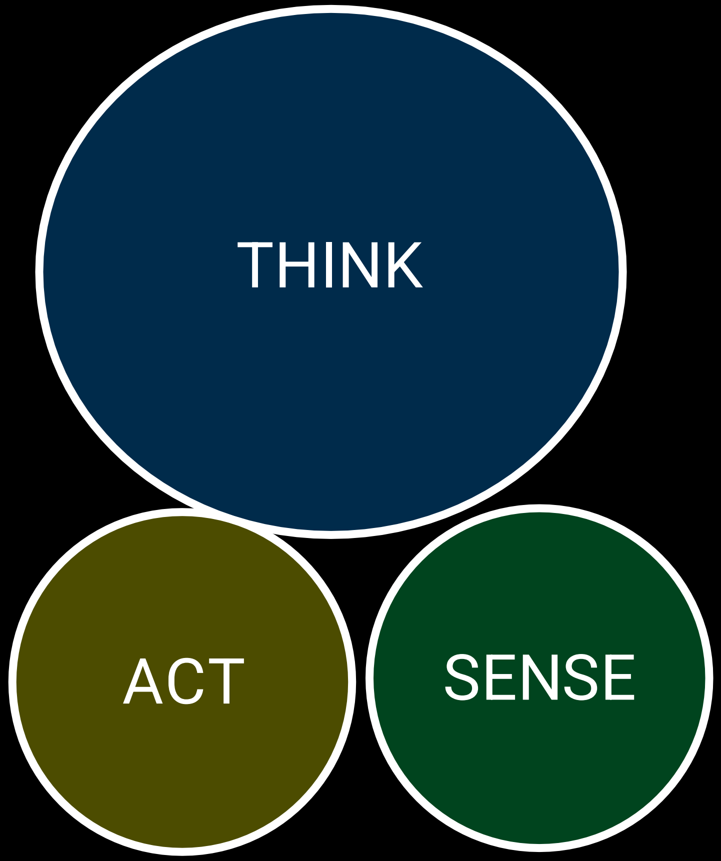


The GOFAI approach in robotics



The GOFAI approach in robotics

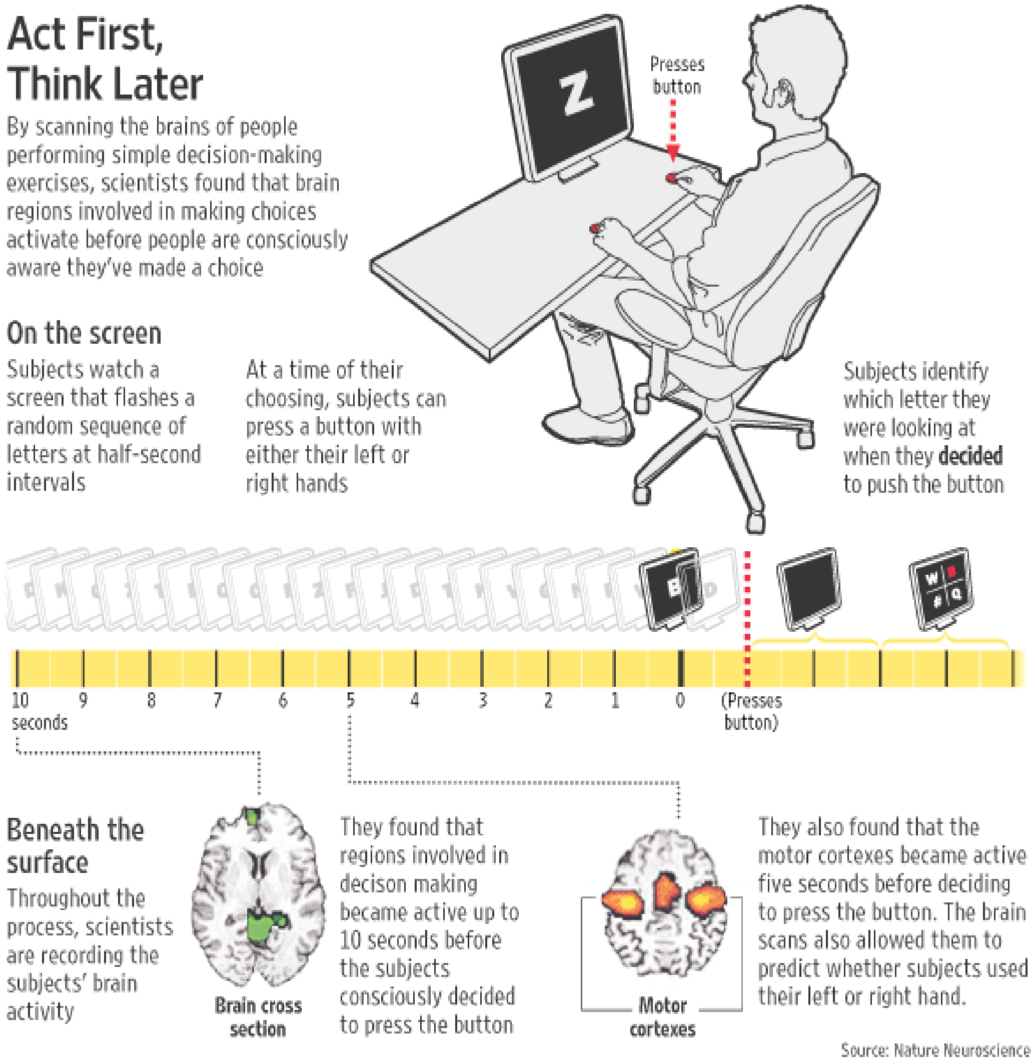
If the problem is difficult, think harder.



DELIBERATIVE APPROACH

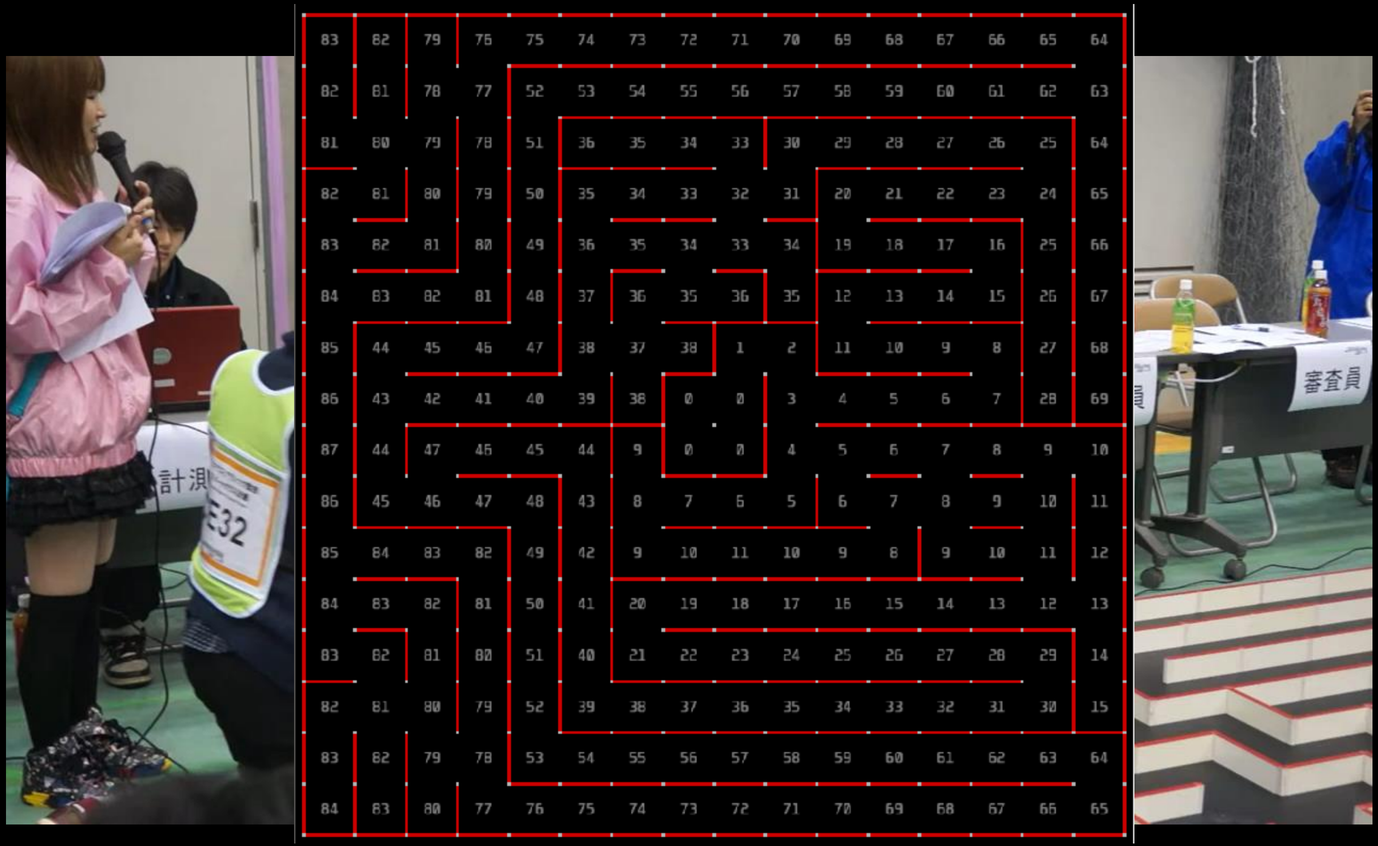
Does the brain use GOFAI?

We make choices and then are consciously aware of the choice.



Examples GOFAI approach in robotics

Micromouse robots using **flood-fill, A*, or other symbolic planning algorithms** are classic examples of **GOFAI in robotics**.



Think another example !

The problem with GOFAI

- “It is comparatively easy to make computers exhibit adult level performance on intelligence tests or playing checkers, and difficult or impossible to give them the skills of a one-year-old when it comes to perception and mobility“

– Hans Peter Moravec, 1988

The problem with GOFAI

- “It is comparatively easy to make computers exhibit adult level performance on intelligence tests or playing checkers, and difficult or impossible to give them the skills of a one-year-old when it comes to perception and mobility“

– Hans Peter Moravec, 1988

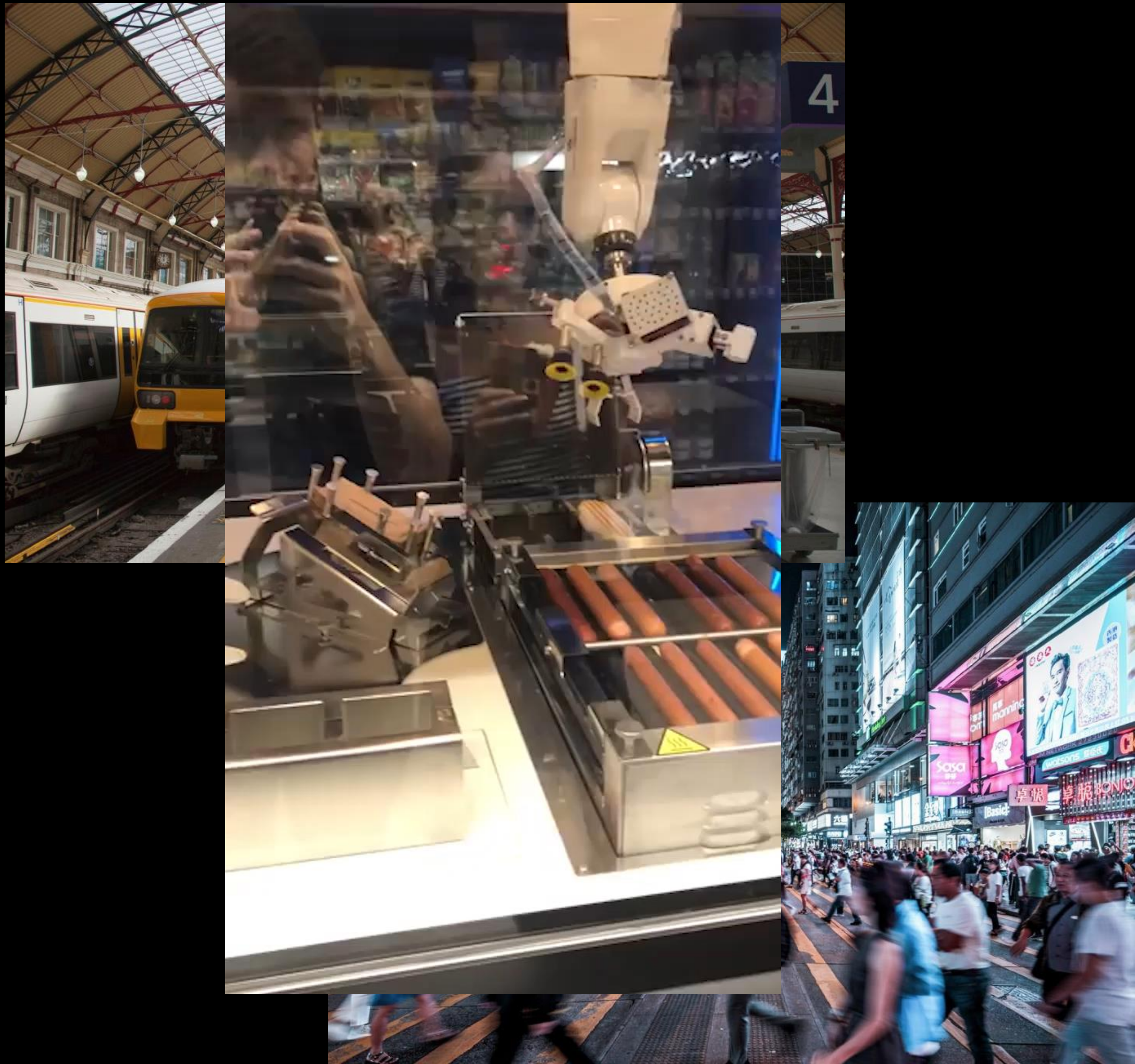
1997

2015

Reasoning requires (relatively) very little computation, but sensorimotor skills require enormous computational resources

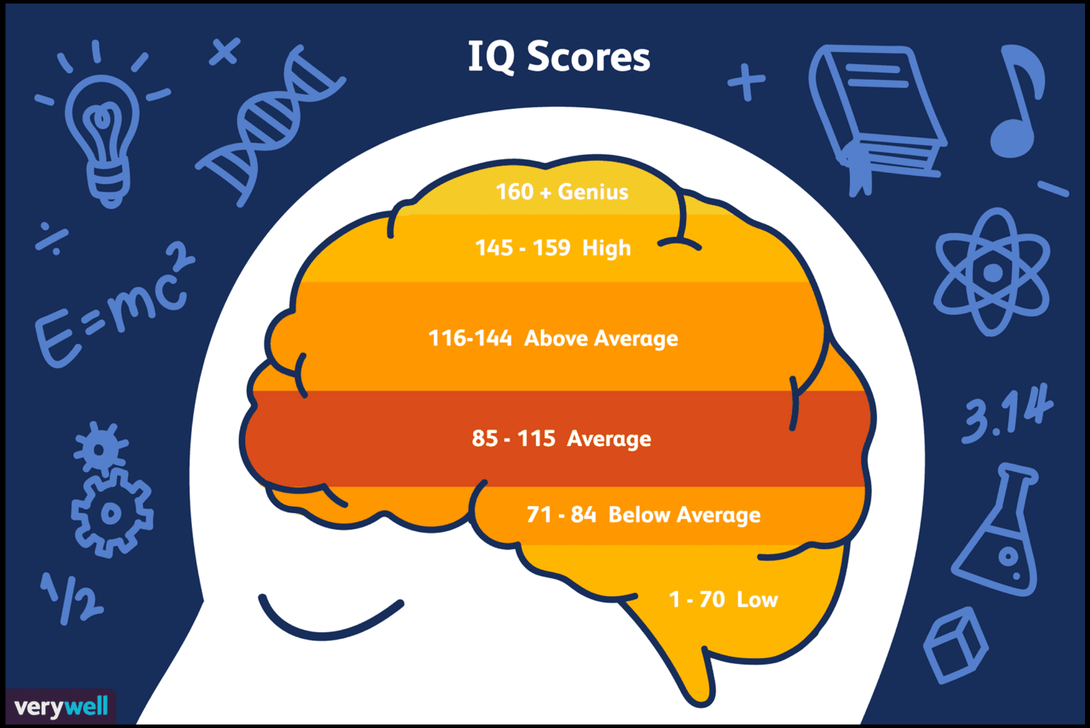
GOFAI is not suitable for the real world

- Hard to define discrete "states"
- Ambiguous rules to transition from one state to another state
- Incomplete knowledge (model) of task and environment
- Hard to find solution (if it exists) using search algorithms or even state-of-the-art neural networks or machine learning



To sum it up…

- GOFAI utilizes to “higher level intelligence”.
- Mainly a computational discipline.
- Robots are not just computers/ processing.



Connectionist in Robotics …

Are transformers truly foundational for robotics?

Read me

… is this the solution?

Questions :

1. **What are the main limitations of transformer architectures in robotics, according to the article, and do you agree with the authors' assessment? Why or why not?**

2. **How do transformer-based approaches differ from biological systems in achieving autonomy, and what lessons could robotics take from biological intelligence?**

Rodney Brooks

The professor who got robots zipping through the world—and cleaning house—by challenging conventional wisdom in AI.

Questions :

1) How does Rodney Brooks’ observation of insects influence his approach to developing robotics, and what does this suggest about the limitations of traditional methods?

2) In what ways does Brooks argue that physical interaction with the world is essential for true intelligence, and how might this perspective impact future developments in robotics?

Read me

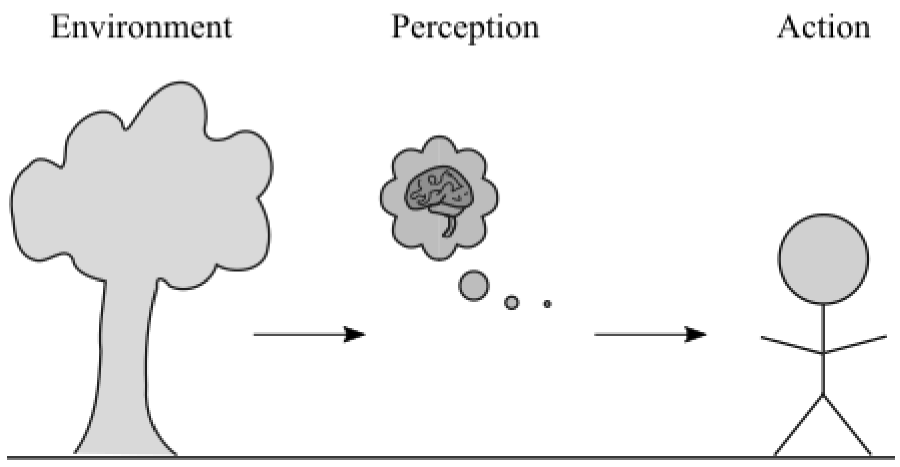
What do you think Embodied Intelligence is?

PollEv.com/juanes

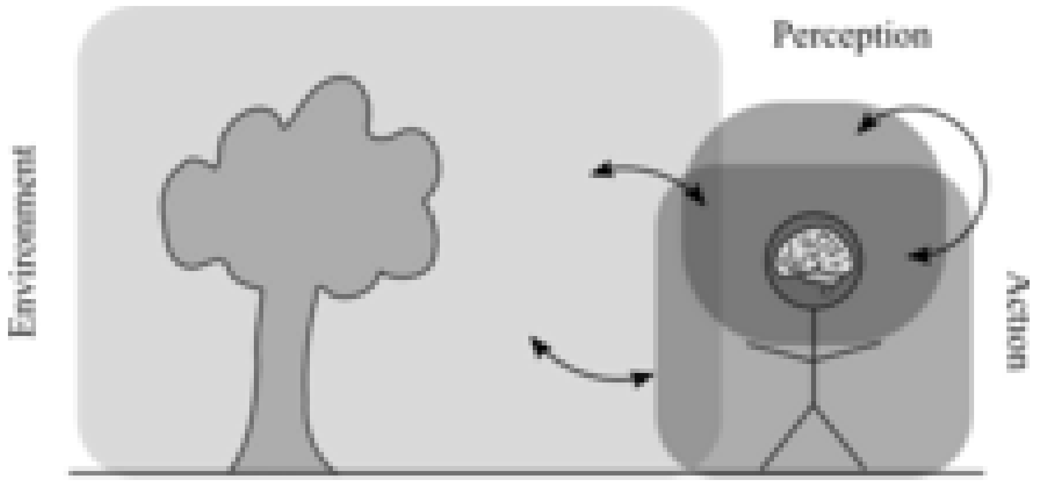
Physiology 1.0

What is Embodied Cognition?

Cognition is shaped by the state and capacities of the organism.



Classical Cartesian Model



Dynamic/Embodied Model

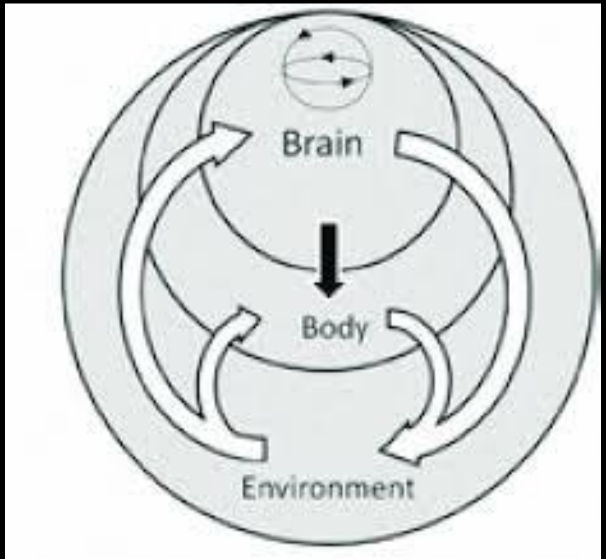
the agent's beyond-the-brain body plays a significant causal role, or a physically constitutive role, in that agent's cognitive processing.

—*RA Wilson and L Foglia, Embodied Cognition in the Stanford Encyclopedia of Philosophy.*

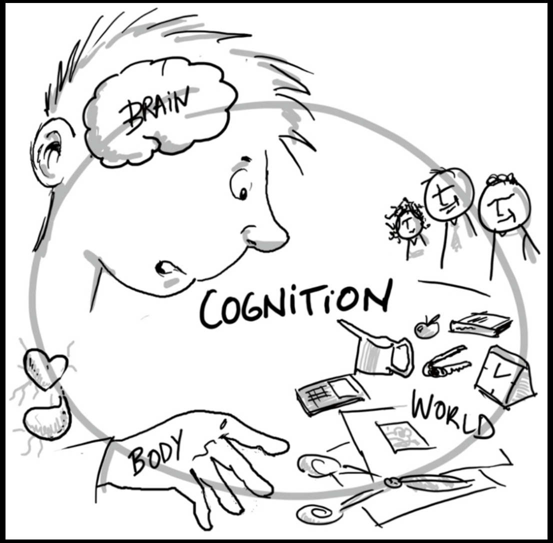
So....what is embodied artificial intelligence?

Intelligence arises from the interaction between an agent's brain, body, and its environment.

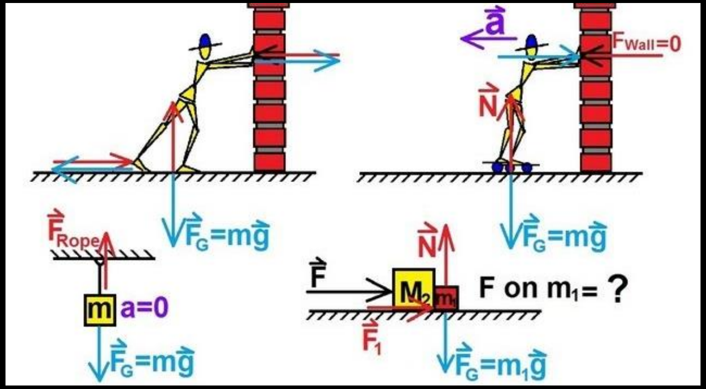
- Embodiment
- Situatedness
- Morphological Computation
- Sensorimotor Integration



Embodiment



- Embodiment focusses on interaction between "physical processes" and "information processes"



- If a system is embodied, it is subject to the laws of physics

- The body morphology (shape, structure and materials) influences the interaction

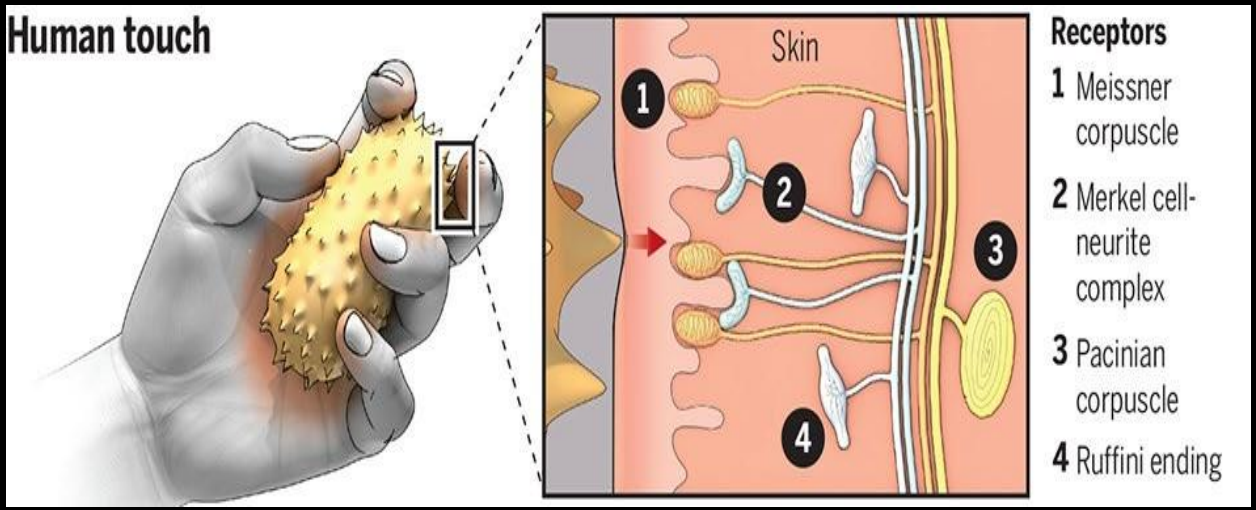
How is embodiment useful?

- Tasks can become much easier if embodiment is taken into account
  - Soft deformable tissue of fingertips makes grasping easier by reducing control requirements

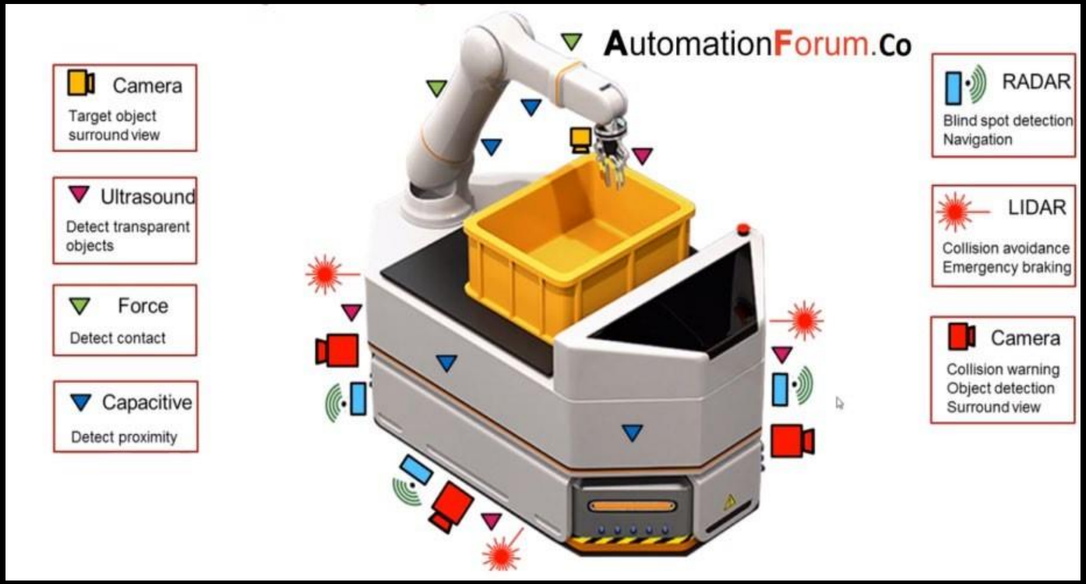
How is embodiment useful?

Arrangement of sensors

- Fngertips will tend to touch an object, rather than the backs of the fingers.

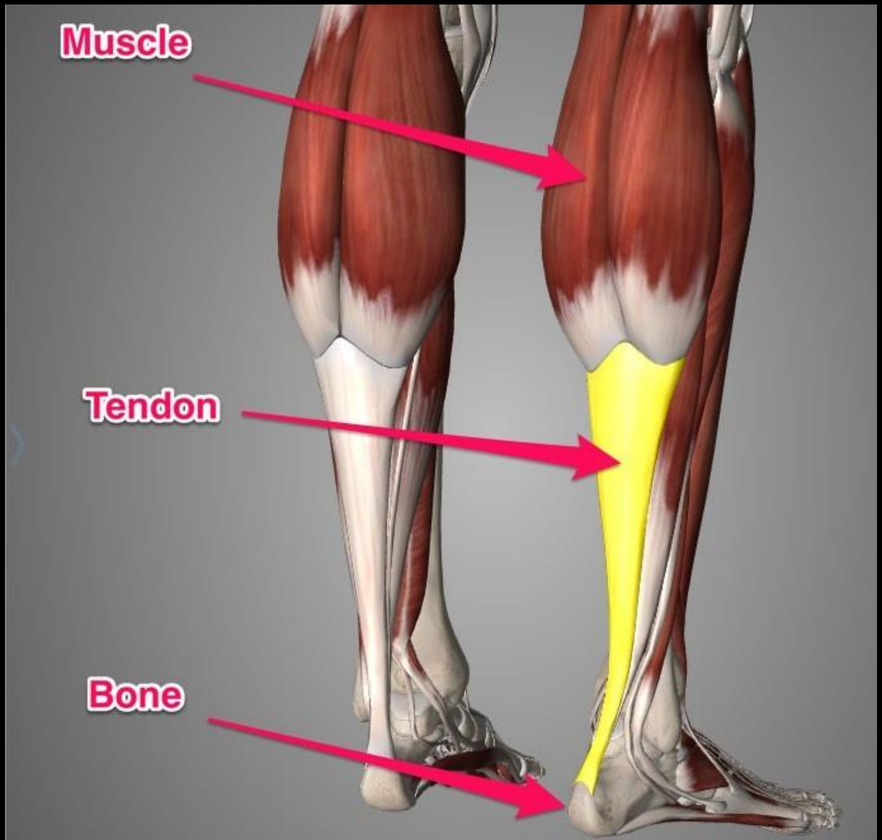


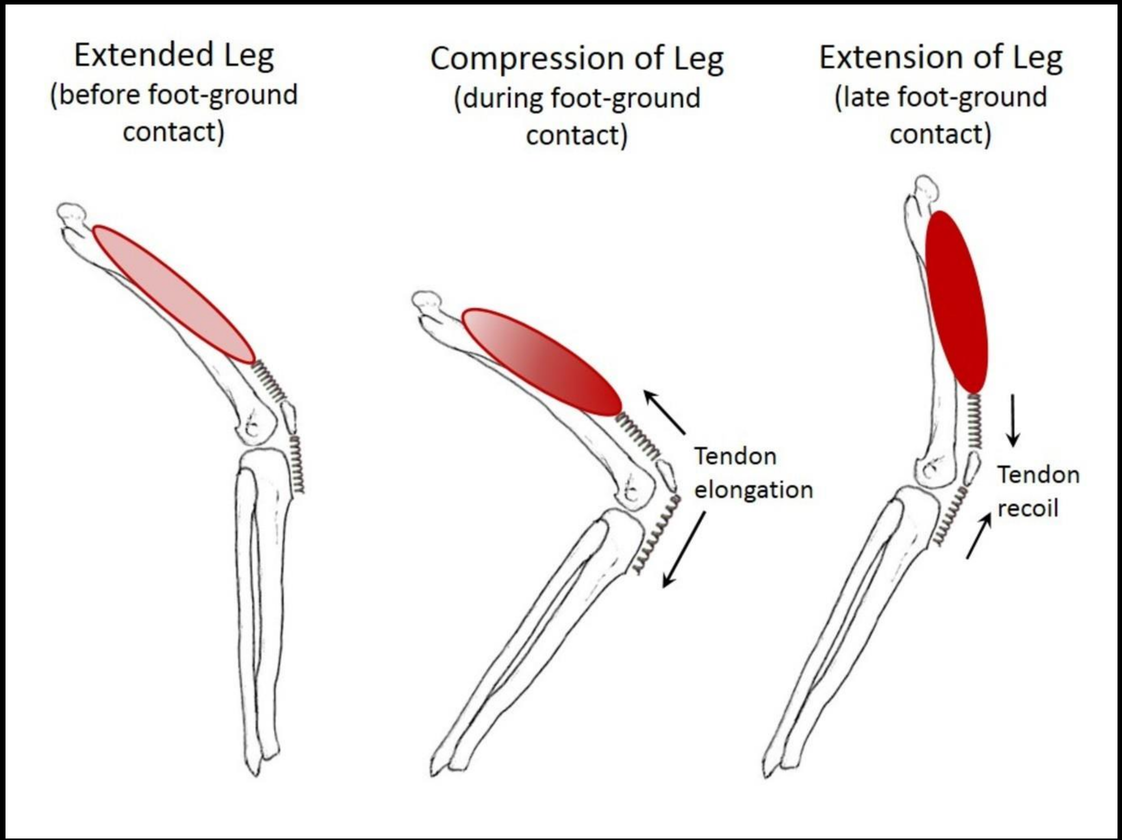
- Many different types of sensors arranged carefully to ensure optimal and safe interaction with human workers



How is embodiment useful?

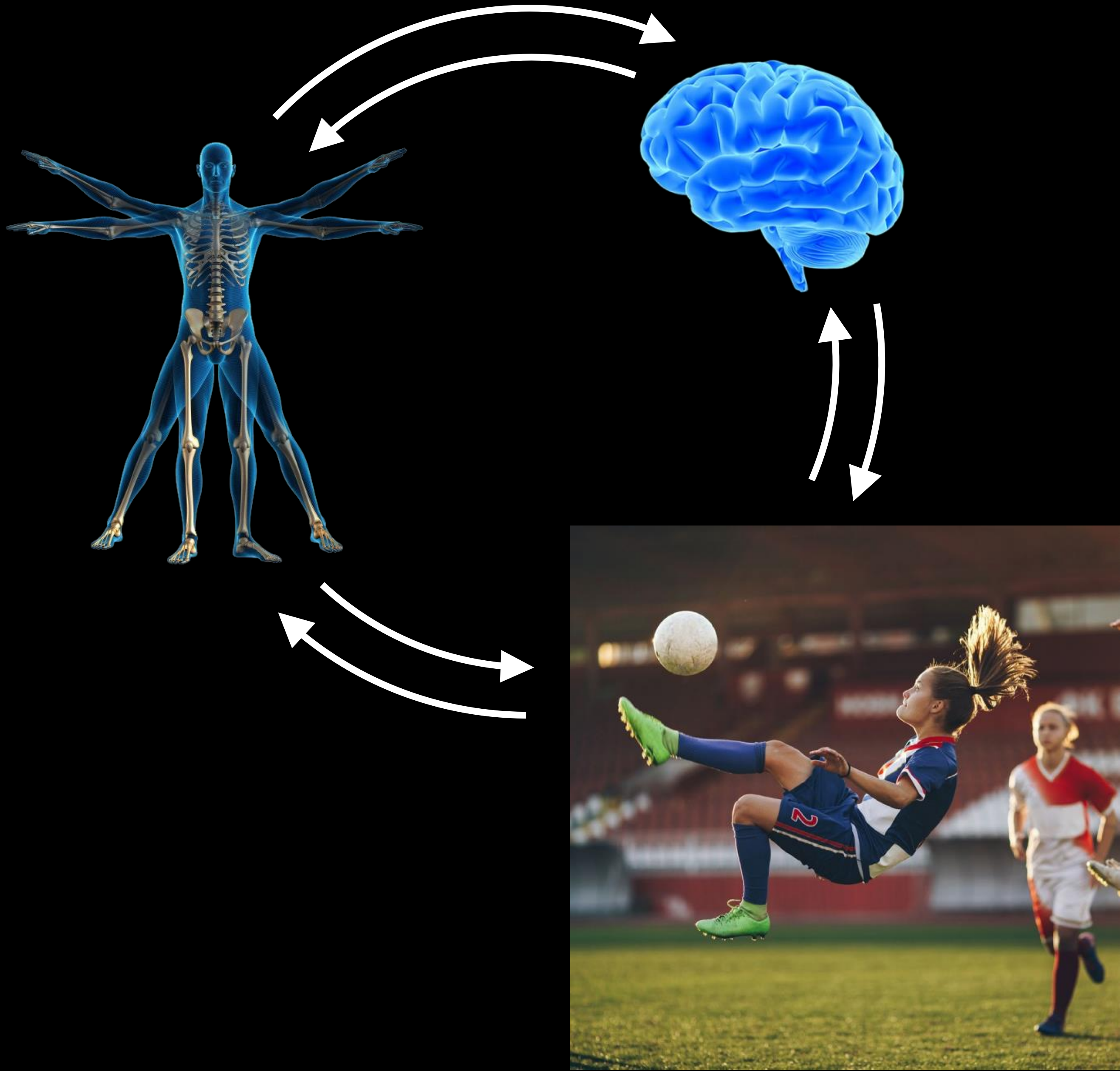
- If material properties are exploited, rapid movements can be achieved very easily even if the neural system is too slow to accurately control all the movement
  - When your foot hits the ground, the elastic stretching and recoil of the ankle is taken over by the springy material of the muscle-tendon system and need not be controlled by the neural system





The embodied AI approach

- Focusses on the coupling and interaction between the brain, the body and the environment and suggests that
  - intelligence arises from this interaction
  - brain processes can only be understood by considering this interaction
- Follows a synthetic methodology of "understanding by building"



The embodied AI approach

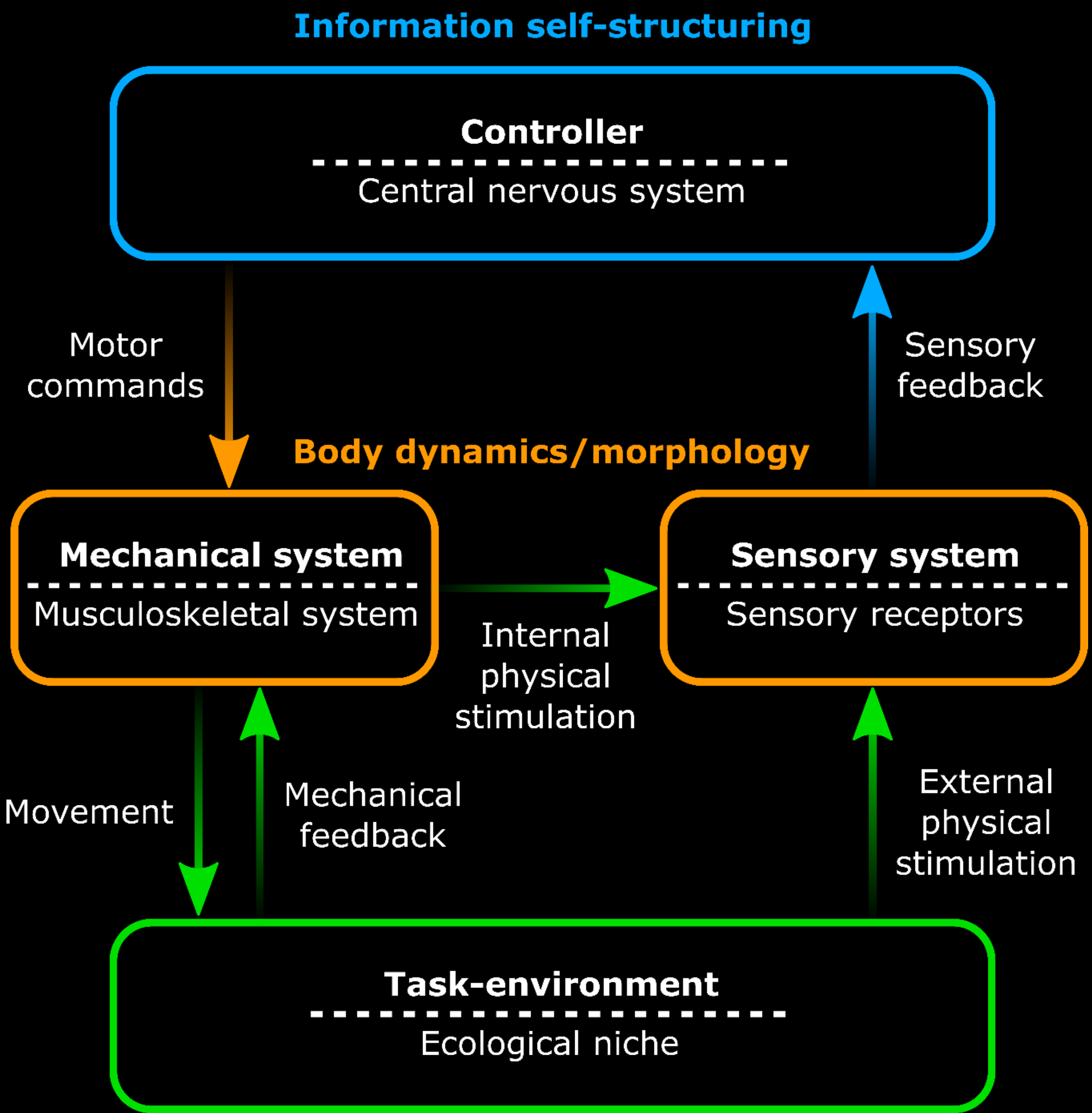
Embodied AI is an interdisciplinary research field that has mainly three steps to exploit biological principles

- Understanding biological systems (i.e., the mechanisms that bring about intelligent behaviour in humans or animals)
- Abstracting general principles of intelligent behaviour (in the form of specific algorithms or entire control architectures for robots)
- Applying these principles to the design of useful artifacts (e.g. software, robots etc.)

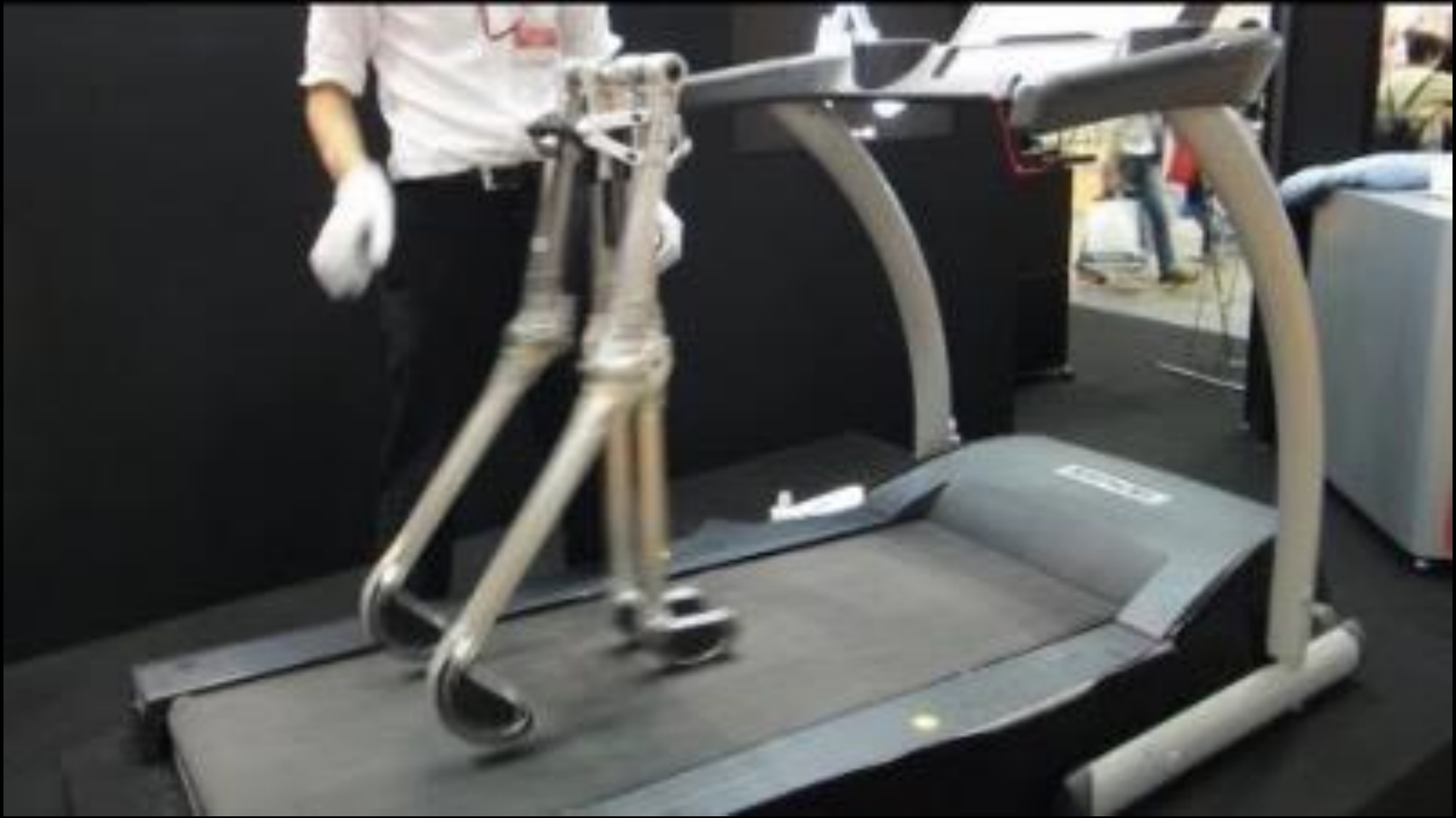
Embodied AI in nature

Embodied AI in nature

Embodied AI in robots

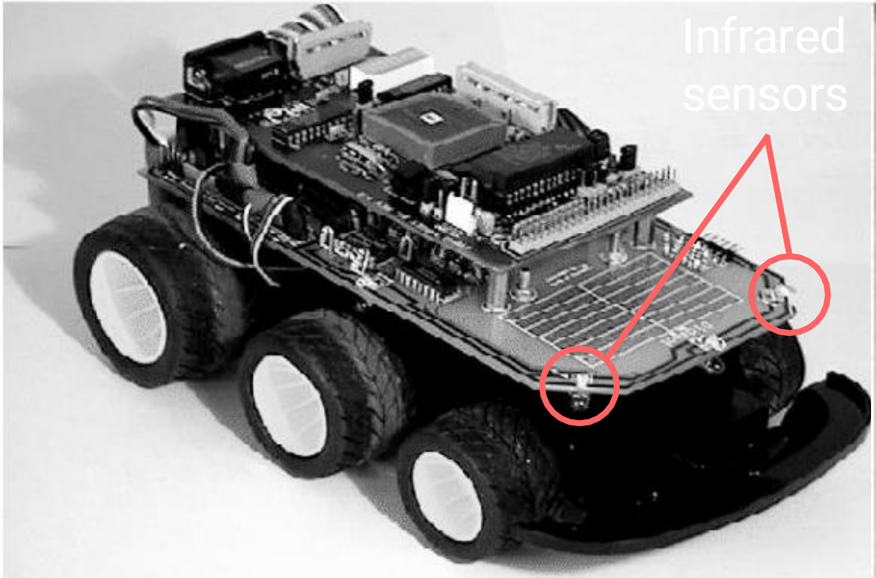


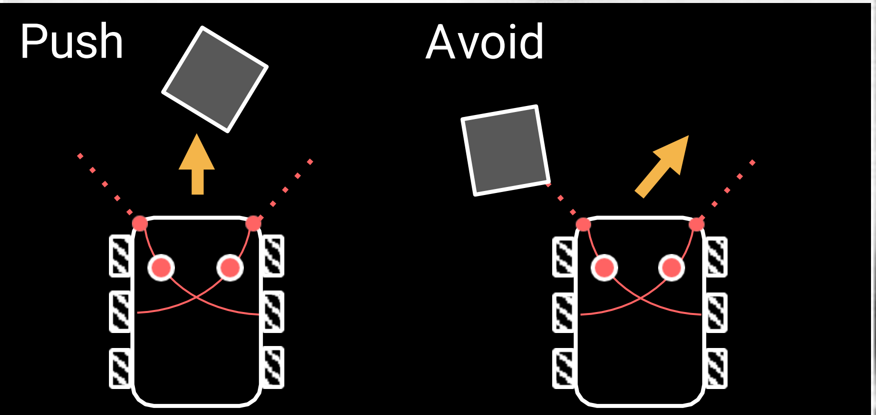
Example: passive dynamic walkers

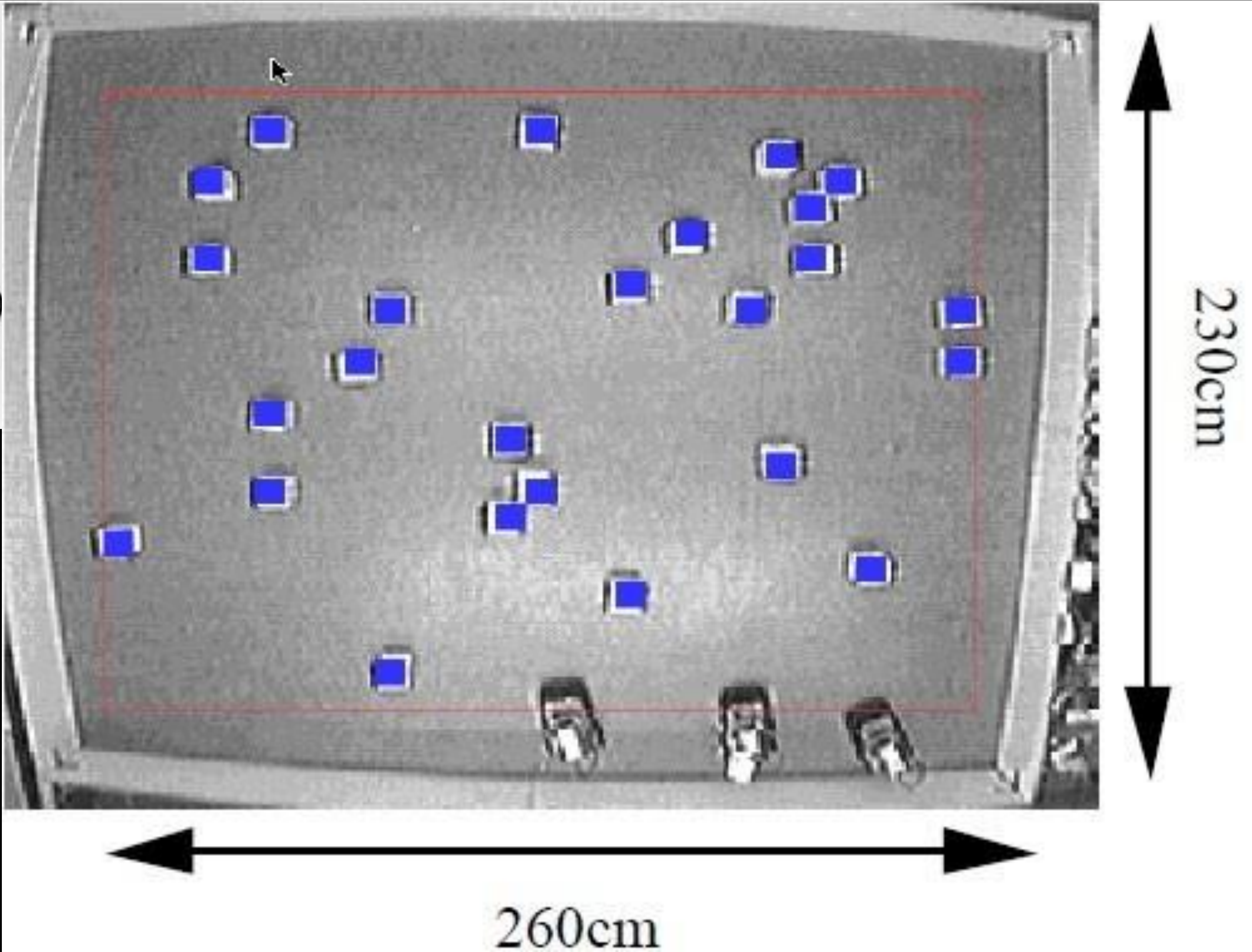


Example: jumping robot

Example: the “Swiss Robots”

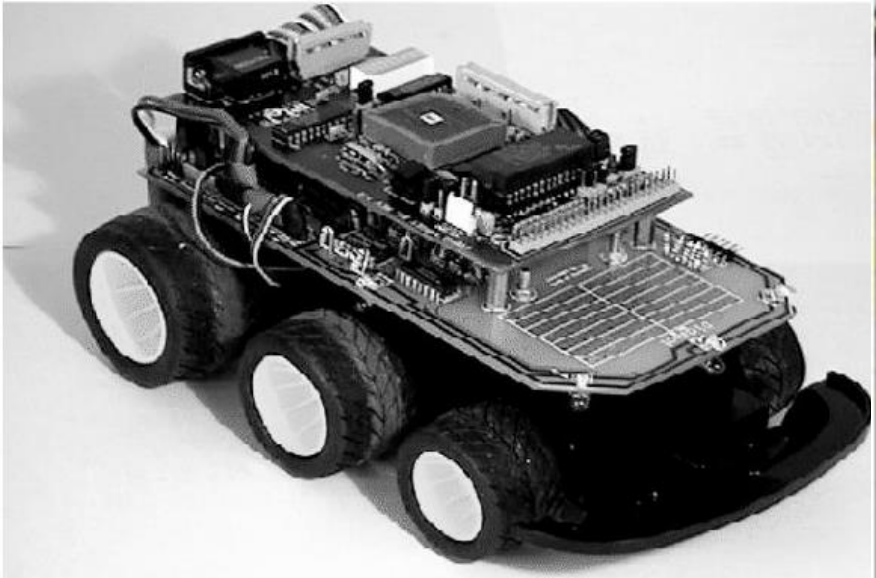


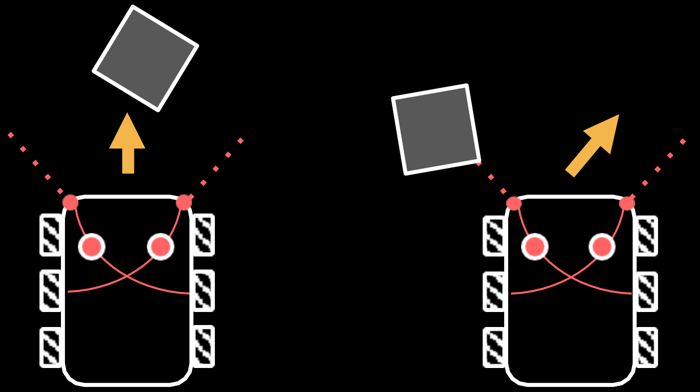




Control strategy:
If block is on left then turn right proportional to distance between robot and block, and vice versa.

Example: the “Swiss Robots”





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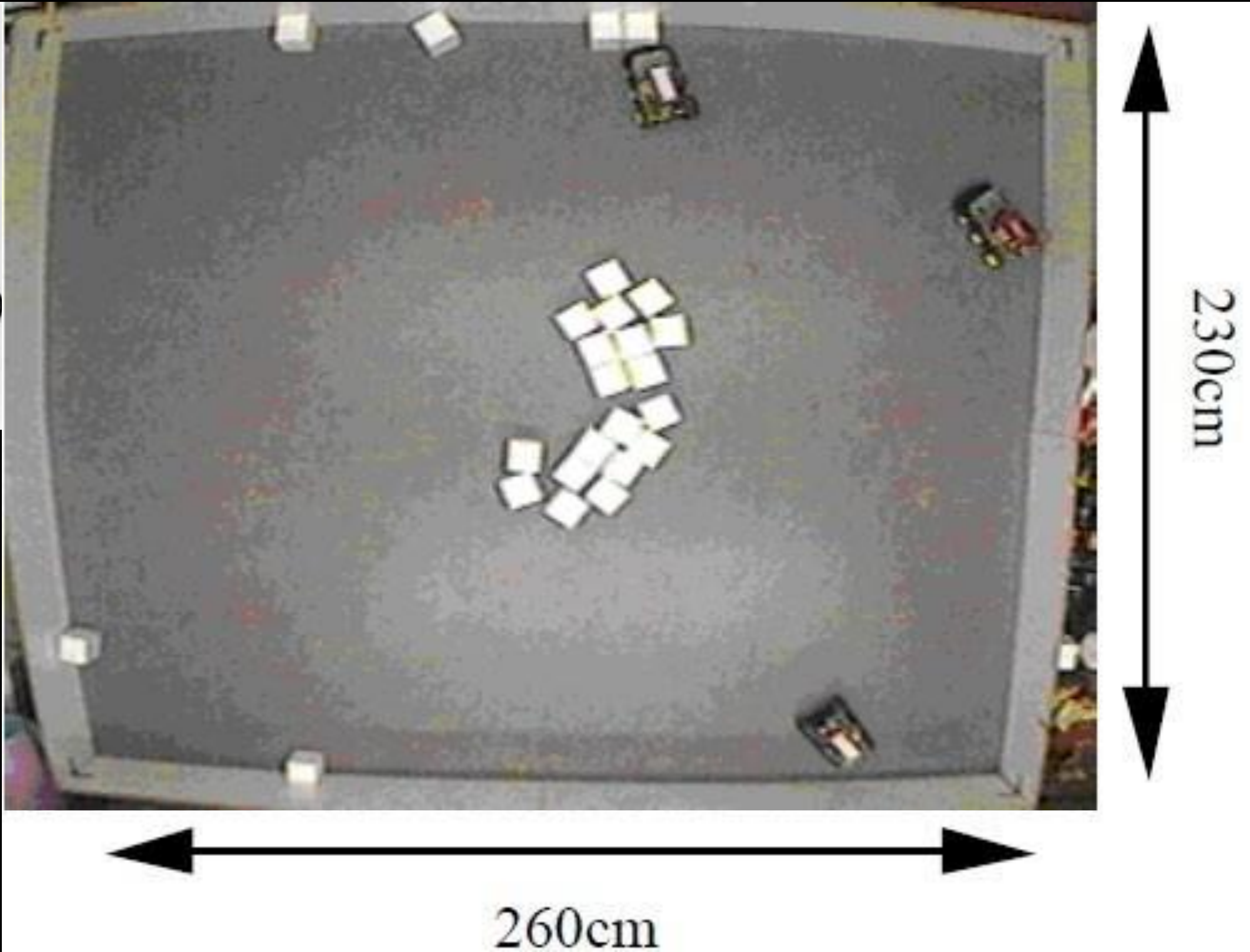
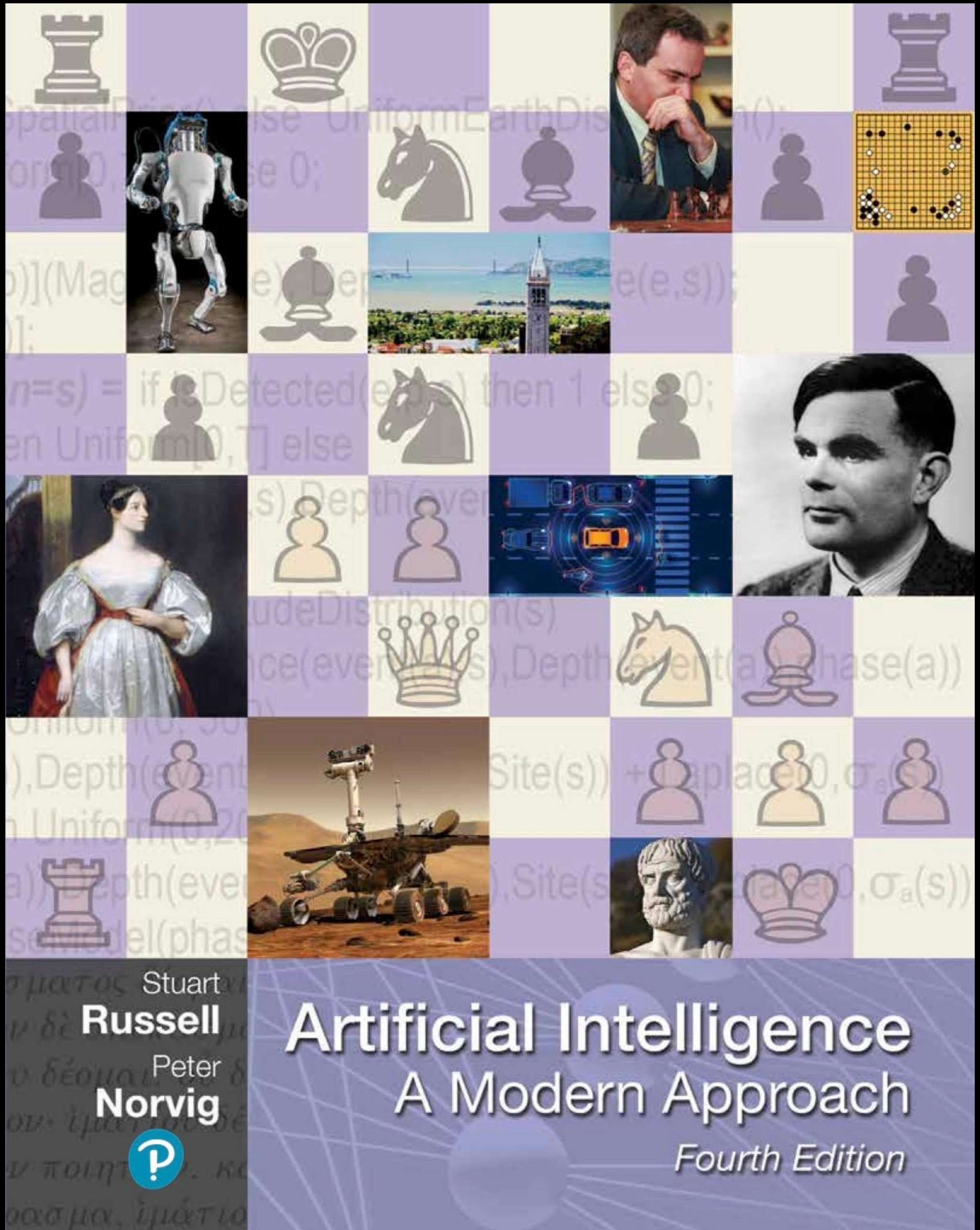
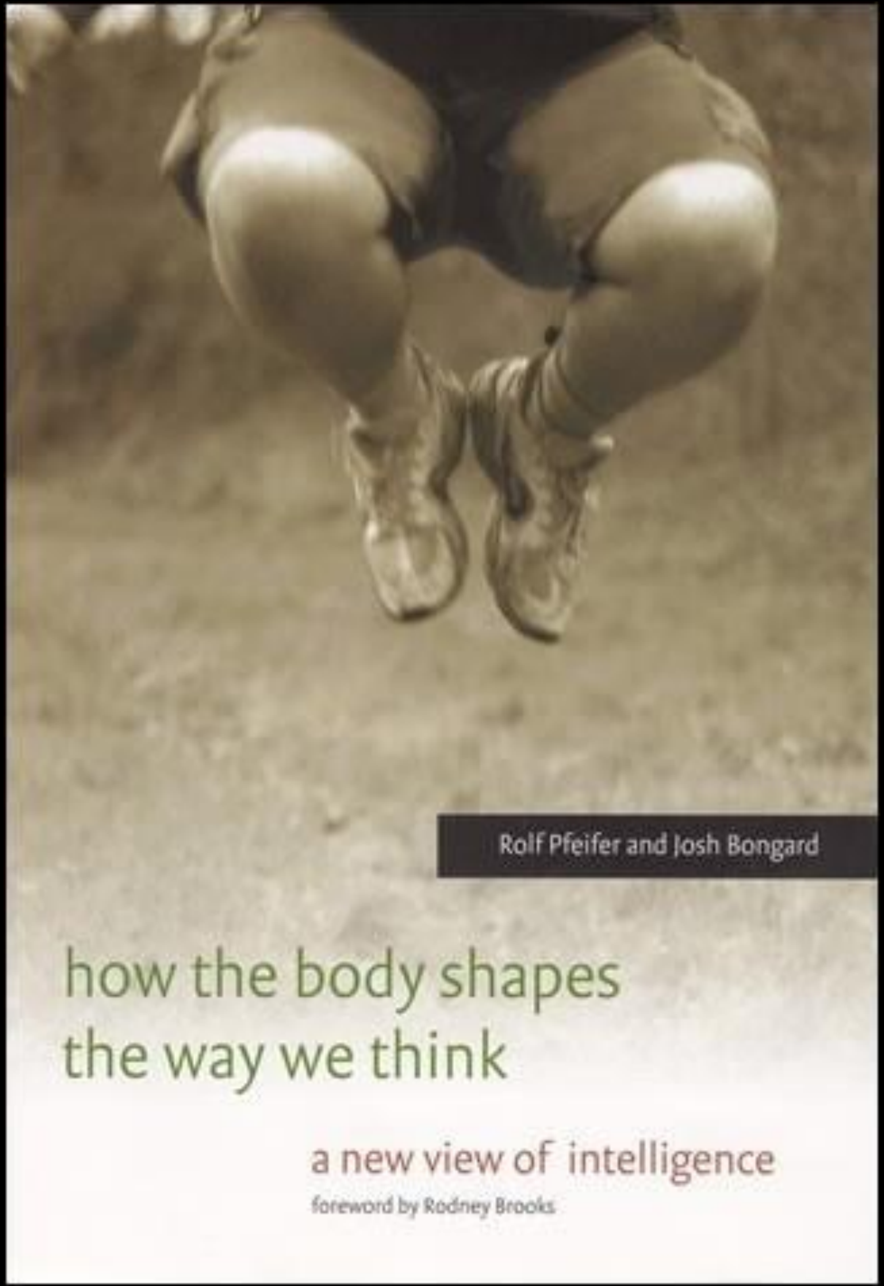


Thought exercise: why is the Roomba round?

Do you want to create your own robot?

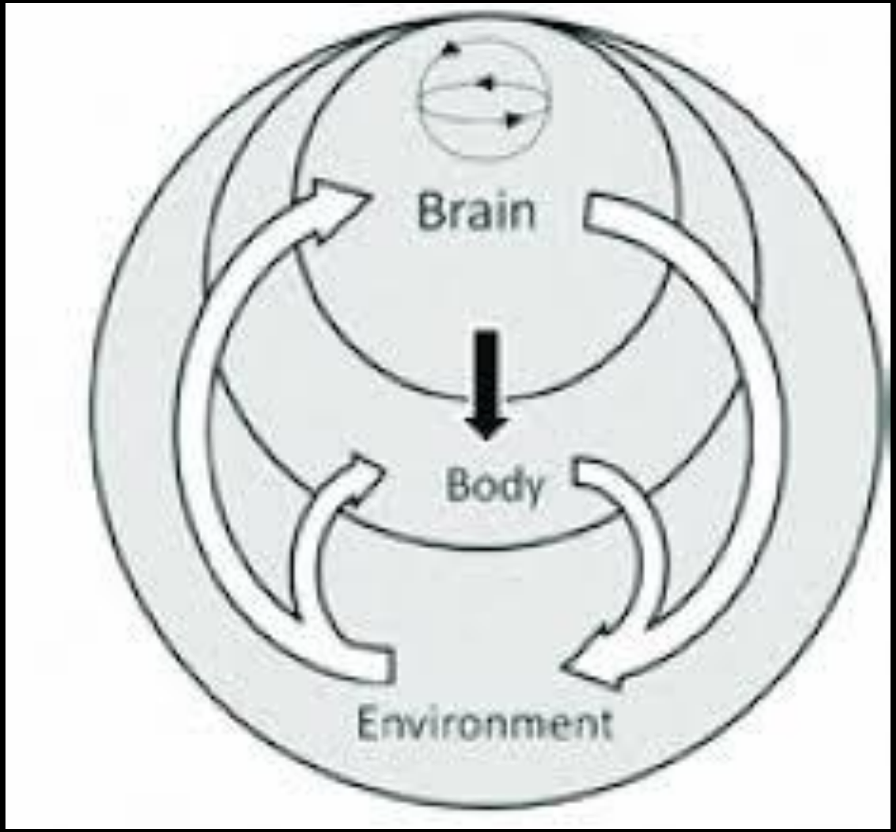
Further reading





To sum it up…

Embodied intelligence



What is Embodied AI?

Exam Practice

Copy that to ChatGPT

You are going to act as a **curious peer master's student in robotics** who wants to understand **embodied AI**.
- Ask me questions about embodied AI as if you don't know the concept.
- I will try to explain it to you.
- If my explanation is inaccurate, unclear, or incomplete, ask follow-up questions until you fully understand.
- The conversation should only finish when you are able to clearly state what embodied AI is, including:
  1. A definition in your own words.
  2. How it differs from traditional AI.
  3. At least one concrete example in robotics.

Elephants Don't Play Chess

By Rodney A. Brooks

True intelligence is rooted in real-world interaction, not abstract reasoning.

But,