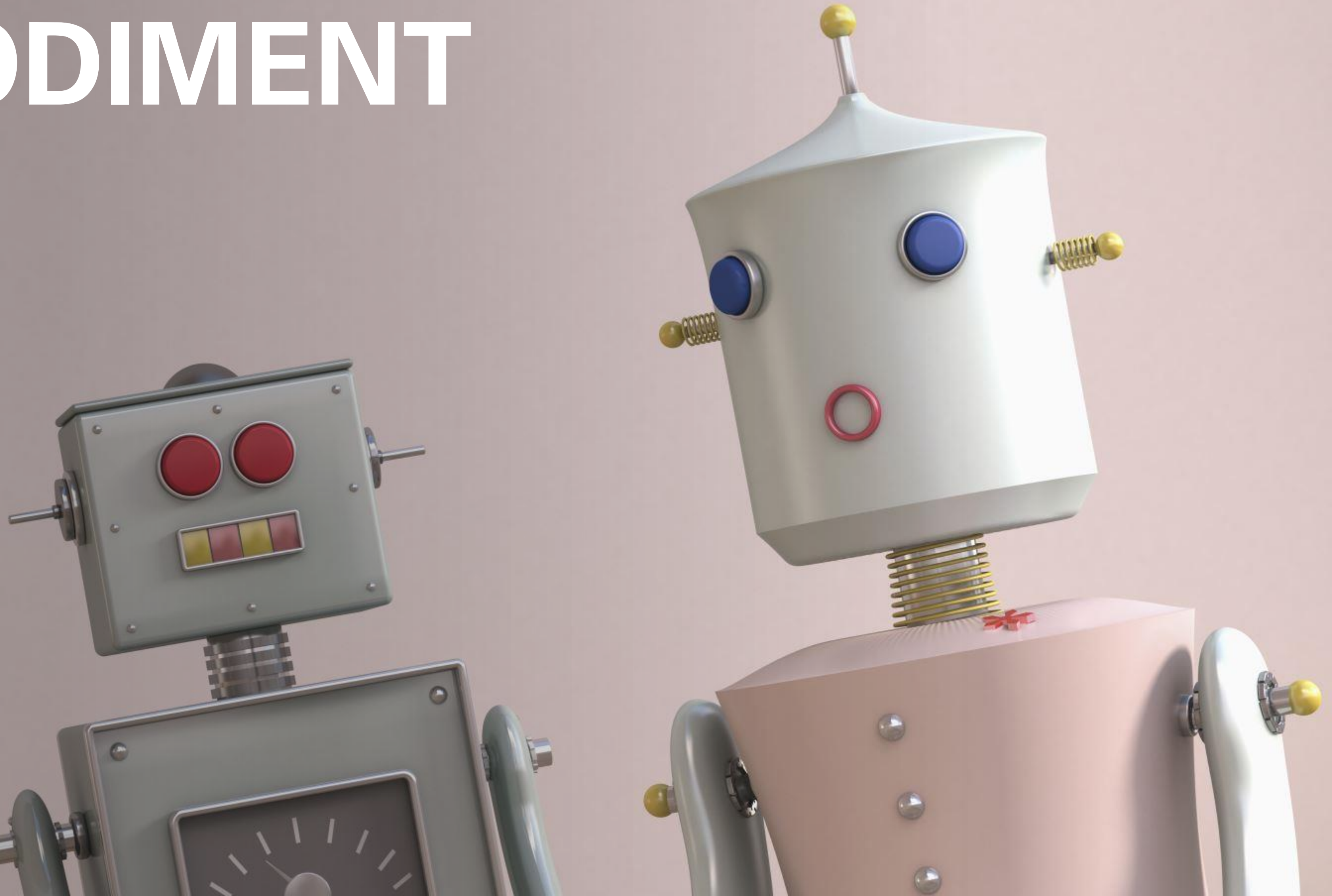
THE QUESTION OF EMBODIMENT



Università di Pisa

DILETTA GOGLIA
COURSE OF ROBOTICS A.Y. 2019/20
ARTIFICIAL INTELLIGENCE CURRICULUM
MASTER PROGRAM IN COMPUTER SCIENCE

OVERVIEW

REPRESENTATION

- Classic AI
- "Weak" embodiment
- *Allopoietic*
- ON-world philosophy

PERCEPTION

- New AI
- "Strong" embodiment
- *Autopoietic*
- IN-world philosophy

Definition

- "Embodiment" refers strictly to the *physical existence* of a body.

- *Embodiment has been perceived as one of the fundamental issues in the pursuit of artificial intelligence, a perspective that has only been mainstream in recent years.*

- Italian translation: "personificazione", "incarnazione".

This gives immediately the idea of anthropomorphic / zoomorphic body.

- Common (and wrong) use of the term.

Frequently used to refer to the association of certain attributes to an artificial agent (i.e. vision ability, certain behaviours, …) but this *do not* constitute embodiment.

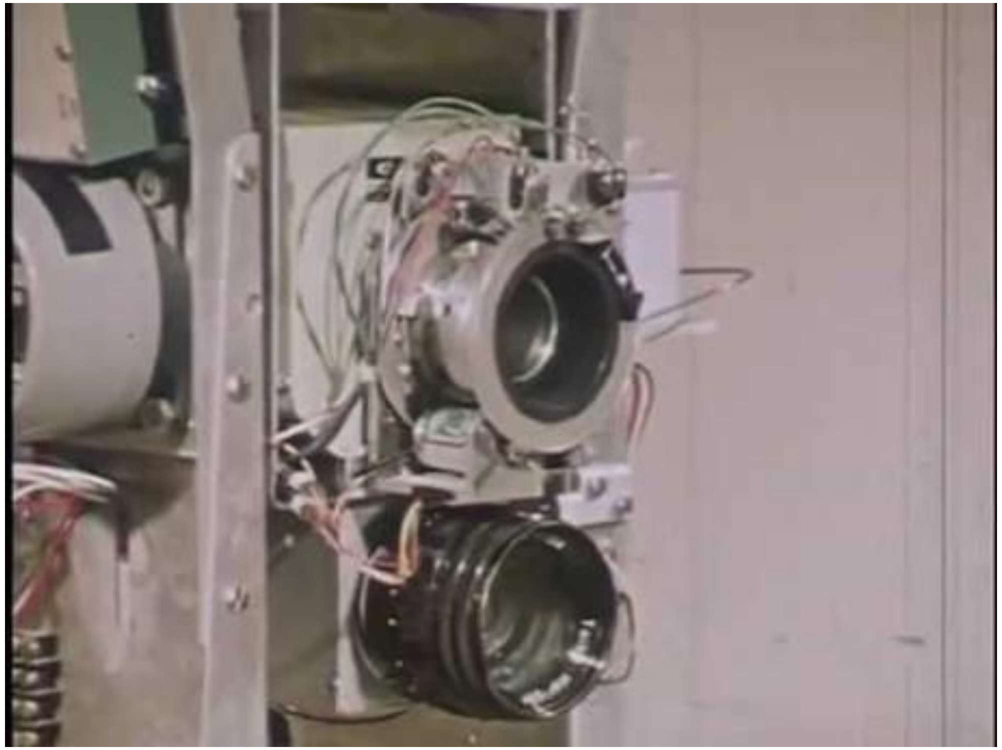
Classical AI for Robot Control

- Problems arose when Classical AI control paradigms are applied to the control of autonomous mobile robots.
- **Robots cannot simply provide the sensors and actuators for an artificial brain**
- Main issues:
  - Problems with real-time performance and stability.
  - Too computationally expensive and time consuming to generate real-time behavior.
  - Perception complexity problem: noise and errors in the perceived environment result in decisions based on incorrect perceptions.
  - As the environment increases in complexity, correct perception becomes even more difficult.
  - "Shakey" example (next slide)

Classical AI for Robot Control (II)

- Brooks, "Elephants Don't Play Chess":
  - *The symbol system hypothesis upon which classical AI is base is fundamentally flawed, and as such imposes severe limitations.*
  - *[...] implicitly includes a number of unfounded leaps of faith when called upon to provide a plausible path to the digital equivalent of human level intelligence.*
- **Inability Classical AI systems to handle unconstrained interaction with the real world**

  → this leads to search for new control architectures for autonomous agents.



Evolution of Robot Control

- Aim: achieve robust control for autonomous robots existing in a physical world.
- Understanding **system-environment interaction** is fundamental.
- Issues in real-time processing are crucial: if a robot cannot cope, it crashes into something.

- Brooks:
  - *Real world autonomous systems or embodied systems must be studied in dealing with the problems posed by classical approaches". [3][4][5]*

- Only by direct interaction a robot can gain an environmental "understanding".

[3] Brooks, R. "A Robust Layered Control System for a Mobile Robot", IEEE Jour. Rob. And Autom., 2(1) 1986
[4] Brooks, R. A., "Elephants Don't Play Chess", Robotics and Autonomous Sys. (6) P3-15, 1990
[5] Brooks, R.A., "Integrated Systems Based on Behaviors", SIGART Bulletin, Vol. 2, No. 4, August 1991, pp. 46--50.

New AI

- A recently coined term, used in discussing **embodied cognitive systems** and, in particular, mobile robots.
- A new methodology for studying intelligence and understanding the mind to provide a framework for alternative approaches to the classical AI. [6]
- Main characteristic: investigation of system-environment interaction.

- Brooks:
    - *Nouvelle AI is based on the physical grounding hypothesis. It provides a different methodology for building intelligent systems than that pursued for the last thirty years.*
    - *Nouvelle AI relies on the emergence of more global behavior from the interaction of smaller behavioral units.*
    - **The world is its own best model.**

[6] Pfeifer, R., and Scheier, C. Understanding intelligence, MIT Press. (in press) 1999

TWO APPROACHES

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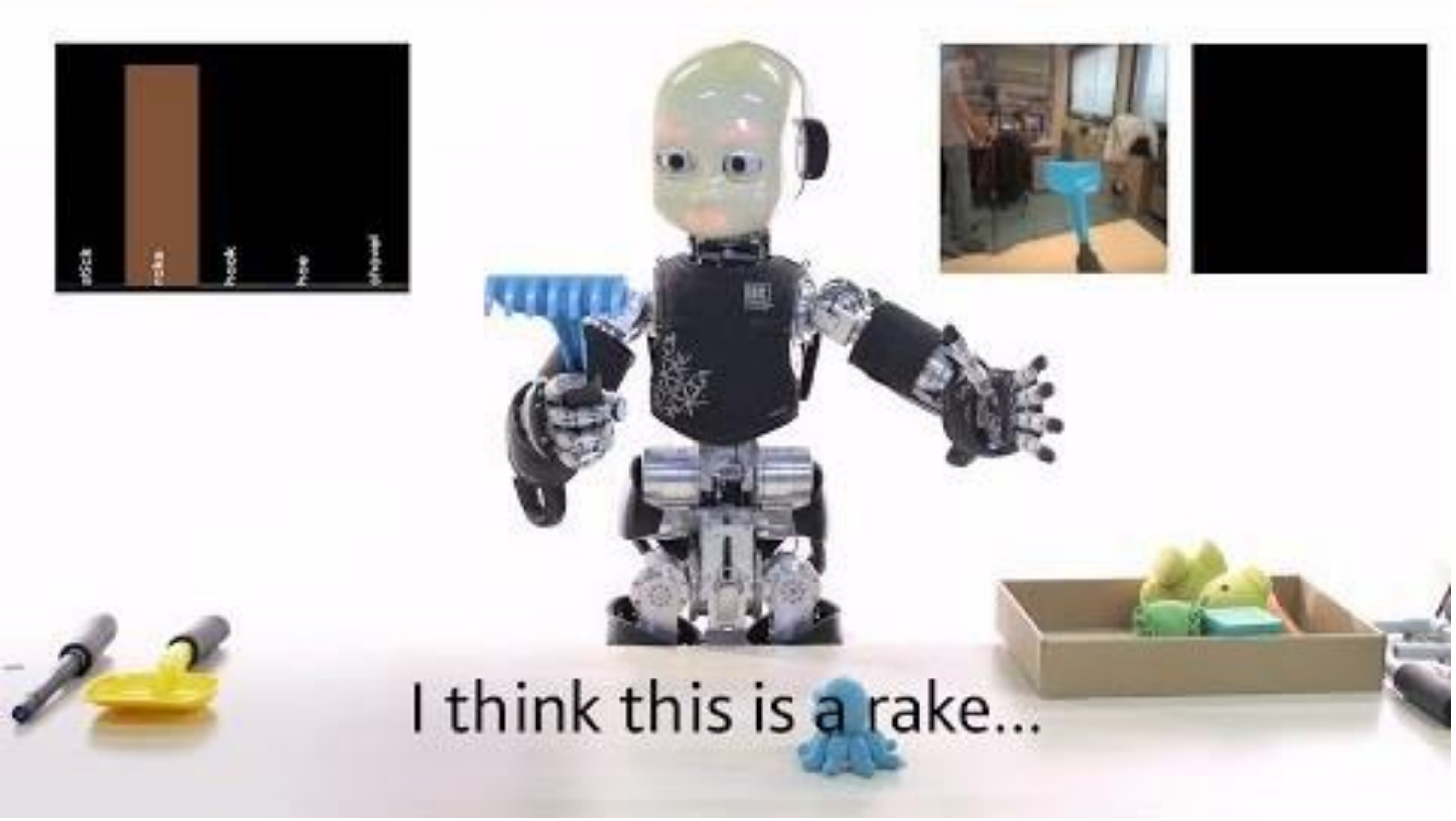
Classical vs New AI

- Top-Down approach: high-level reasoning capabilities but lacks real world robustness.
- Decomposition of intelligence into information processing modules, whose combinations provide overall system behavior.
- None of the modules themselves generate the behavior of the total system. Indeed it is necessary to combine them together to get any behavior from the system.

- Bottom-Up approach via reactive architectures leds to emergent ("intelligent") behaviour.
- Simple control architectures: complex behaviours *do not* need complex control structures.
- Decomposition of intelligence into individual behavior generating modules, whose coexistence and co-operation let more complex behaviors emerge.
- Each module itself generates behavior.

Not opposite approaches, but complementary (Brooks)

Emergent (intelligent) behavior



- Situated agent
- Behaviour-based
- Modular
- Reactive
- NO world model

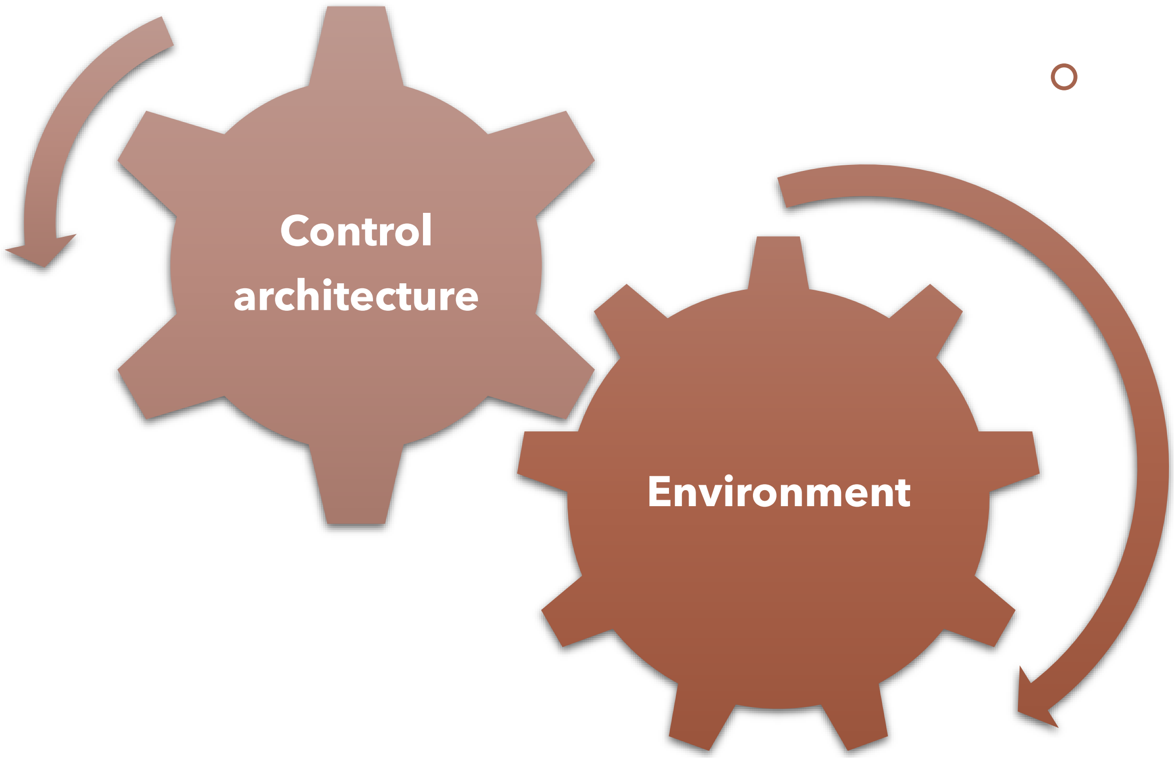
- *Embodiment and intelligence are inextricably linked.*

(Damasio, "A. Descartes' Error: Emotion, Reason, and the Human Brain." New York: G.P. Putnam's Sons, 1994.)

System-Environment interaction

- When integrated properly, their cooperation can result in new control architectures utilising certain environmental properties to their benefit.

- However, that part of human intelligence that we are inspired by as a model, could derive from the evloutive process and here things get more difficult.
- Brooks: *This part of intelligence is where evolution has concentrated its time is much harder.*



Embodiment in Robotics: a brief review

BROOKS:

- Term "being-in-the-world" to refer to the implementation of the **subsumption** architecture of autonomous mobile robots. [8]
- **Embodiment is vital** to the development of artificial intelligence [5][9]
- Combat the difficulty in developing purely internal symbolic representational models of reality utilised in classical AI approaches

CLARK:

- Term "blueprints", a detailed plan in discussing "**embodied cognition**" in relation to the developmental process in infants, according to which "mind, body and world act as equal partners" [13].
- **Embodiment is crucial** to intelligent systems.

LAKOFF:

- Our ability to understand and reason abstractly **relies on our bodily experience** and that "high level" intelligence depends crucially on embodiment. [10] [11]
- Against the use of internal symbolic representations: "an embodied agent can dwell in the world in such a way as to avoid the…task of formalising everything" because its "body enables [it] to by-pass this formal analysis" [12].

[3] Brooks, R. "A Robust Layered Control System for a Mobile Robot", IEEE Jour. Rob. And Autom., 2(1) 1986
[5] Brooks, R.A., "Integrated Systems Based on Behaviors", SIGART Bulletin, Vol. 2, No. 4, August 1991, pp. 46--50.
[7] Damasio, A. Descartes' Error: Emotion, Reason, and the Human Brain. New York: G.P. Putnam's Sons, 1994.
[8] Dreyfus, H.L, Being-In-The-World : A Commentary on Heidegger's Being and Time, MIT Press, 1991
[9] Brooks, R. A., "Intelligence Without Representation", Artificial Intelligence Journal (47), P139-159, 1991
[10] Lakoff, G., Women, Fire, and Dangerous Things. University of Chicago Press, 1987
[11] Lakoff G. and Johnson. M., Metaphors We Live By. Univ. of Chicago Press, 1980.
[12] Dreyfus, H. What Computers Can't Do, Harper, 1979.
[13] Clark, A., Being There: Putting Brain, Body, and World Together Again, MIT Press. 1997

ALife

- Embodied cognition is unique for all natural systems: individual experiences are collected during a system's lifetime.
- The "Artificial Life" or "Alife" community has approached an alternative perspective**: the notion of a robot "surviving".**
- Intelligent systems must have some learning from experience in order to function in complex nondeterministic environments. The system must be able to update and add to its knowledge set in order to "survive".
- Alife definition by Langton: *"the study of artificial systems that exhibit behavio[u]rs characteristic of natural living systems. It complements the traditional biological sciences concerned with the analysis of living organisms by attempting to synthesize life-like behavio[u]rs within computer and other artificial media."* [27]

[27] Langton, C.G.. "Artificial Life." In C. G. Langton, editor. Artificial Life, Volume VI of SFI Studies in the Sciences of Complexity, pages 1-47, Addison-Wesley, CA, 1989

WEAK VS STRONG

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Weak and Strong ALife:

Olson, E.T., " *The ontological basis of strong artificial life*" , Artificial Life 3, P29-39, 1997

Weak ALife: the use of computers to *simulate* life

Strong Alife: "computer programmers can go beyond mere modelling and *literally create living things*".

A very philosophical perspective and lacks foundation in real world concepts and applications.

The real challenge: physically embodied artificially "alive" entities.

AUTOPOIETIC VS ALLOPOIETIC

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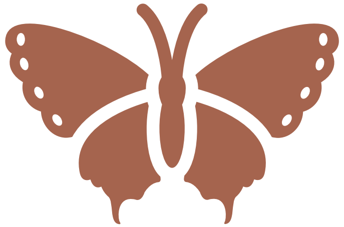
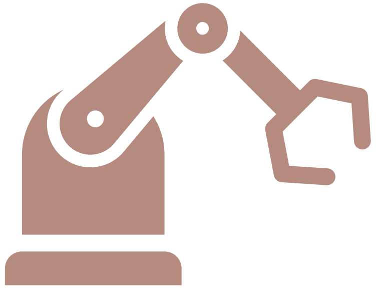
Autopoietic vs Allopoietic systems

Maturana and Varela [30] : **animal systems VS mechanical systems**.
Fundamental distinction between true embodiment and an artificial intelligence perspective of embodiment.



Autopoiesis means selfcreating, selfmaking, or selfproducing. Animal systems adapt to their environment and are therefore termed autopoietic systems.



Mechanical systems on the other hand can only adapt at a behavioural level and are termed allopoietic.

[30] Maturana, H.R., Varela, F.J., "Autopoiesis and cognition – The realization of the living", D. Reidel Publishing, Dordrecht, Holland, 1980.

Embodiment: a complete definiton

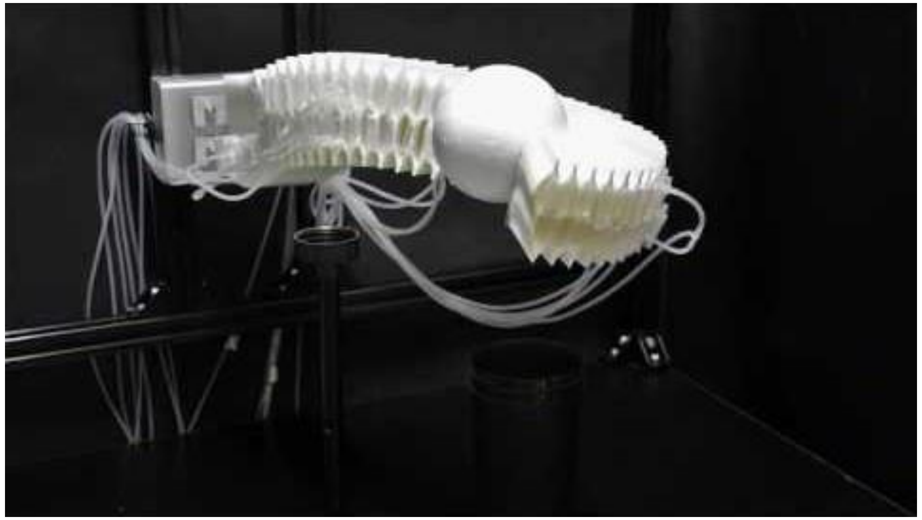
- Dautenhahn and Christaller [29]: a control paradigm on a physical robot is NOT sufficient for fulfilling the embodiment criteria. This results in a robot *not being aware* of whether it is acting in a simulated or physical body.
  - *[…] development of a conception of the body, which is generally discussed as the acquisition of a body image or body schema, is necessary for embodied action and cognition.*

- They propose that the use of **evolvable robots** with an adaptation of both body and control mechanisms to its environment could provide an ideal solution.

[29] Dautenhahn, K., Christaller, T., "Remembering, rehearsal and empathy – Towards a social and embodied cognitive psychology for artifacts", Proc. AISB-95 Workshop "Reaching for Mind: Foundations of Cognitive Science", 1995

Towards Soft Robots…

- Sharkey and Zeimke: notion of **evolvable hardware**.
- *The designer of a robot is constrained by such issues as the physical and chemical properties of the materials used, by the limitations of existing design techniques and methodologies. The introduction of evolvable hardware could help overcome the inherent global limitations of the robot […] by facilitating adaptation and learning capabilities at a hardware level rather than only at a software level.*



- This **adaptability** is often taken for granted in biological systems and likewise ignored when dealing with such issues as robustness, survivability, and fault tolerance in robotic systems.
- Underline the lack of **evolvable capabilities** in allopoietic systems as being directly related to its non-autonomy. Biological autopoietic systems instead are fully autonomous.

IN-WORLD VS ON-WORLD

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IN-World vs ON-World

The question is whether there is a difference between the performance of a controller with actuators and preceptors (a robot ON its environment) and the behaviour of an agent being a part of its environment (a robot IN its environment).

[…] the robot being "ON" its environment where it is not considered as part of its own environment per se, and the robot being "IN" its environment where it functions directly with its environment in a dynamic, adaptive and interactive way, and very much in real-time.

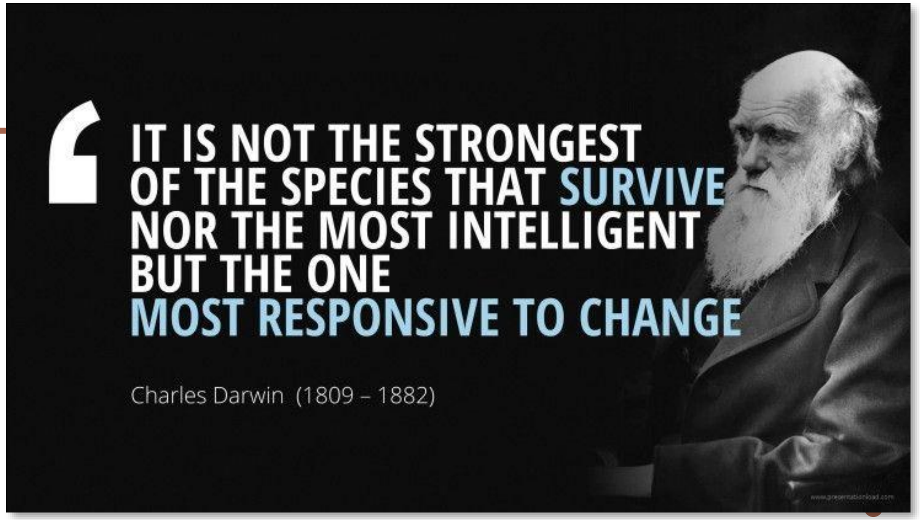
ON-World corresponds to an **allopoietic** interpretation of embodiment in robotics.

IN-World seeks to approximate the notion of **autopoietic** embodiment.

Bioinspired Robots

- Strong embodiment involves the robot **being** a more integrated **part** of the environment within which it exists.
- The robot has to **understand** the world within which it is embodied.
- Sharkey and Zeimke refer to strong embodiment as implying “that the robot is integrated and connected to the world in the same way as an animal”. The issue is to analyse exactly how an animal interacts with its environment and how it is also inherently constitutes an element of the environment for others.
- The fundamental difference between an **allopoietic** and **autopoietic** entity defines the level of possible embodiment, either **strong** for animals or **weak** for robotic entities.
- Based on the current technologies for the design and realisation of a robotic entity, strong embodiment analogous to the autopoietic features of animal systems is not yet available.

Adapt… to survive.



- Sharkey and Zeimke:
- IN-World, in contrast to ON-World, does not require the robot to have all possible maps and internal representations of the world in conjunction with a "complete set" of perceptor to perceive the world, but rather, provides it with some degree of mobility and **adaptability** in order to interact with and influence its environment. This integration of the agent into the environment allows greater real world **autonomy**; otherwise it is merely situated in its internal static representation of the real world, and as such is inherently flawed.
- The ability of a system to adapt to, learn from and develop with its environment, which constitutes its **interaction** with its environment, is directly related to whether that system will "survive" in that environment.

COMPLETE VIEW

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Weak embodiment: simply placing a computer with wheels in the real world. It cannot have expectations that can only arise within a dynamic interactive scenario. The degree with which the agent can anticipate causal realities is very much restricted.

Strong embodiment: cohesive integration with the environment, promoting learning and adaptation, requiring the agent to have the ability to coordinate its actuator and sensor to interactively explore its environment, and to have an understanding of the physical laws, to reduce internal representation loading by inferences.

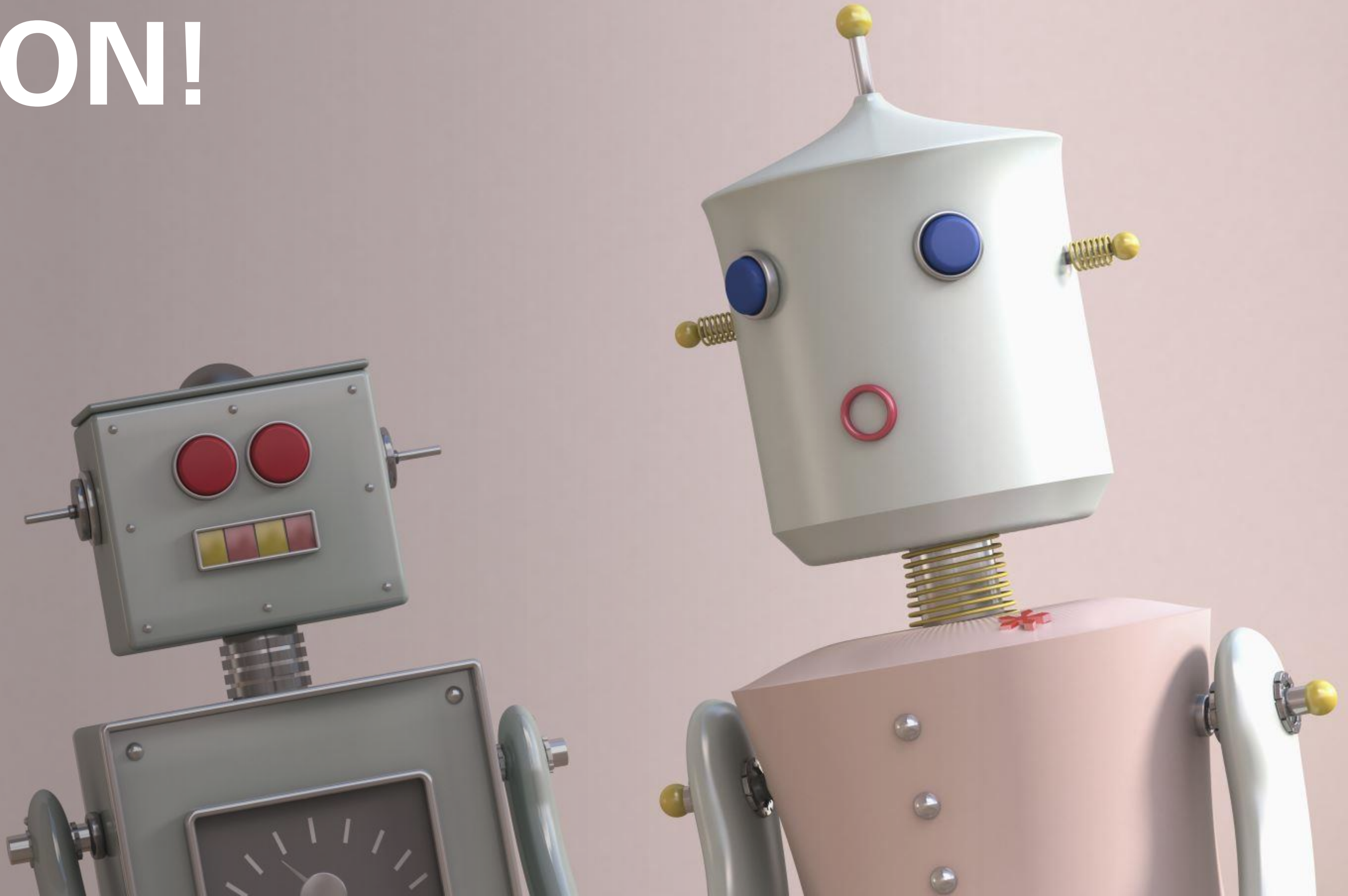
Research and future perspectives

- Weak embodiment is the first stage in control methodology that situates a physical robot in the real world and have it function autonomously by allowing sensory input to situate the "body" in its internal map. However, this type of embodiment still only places the body in static abstractions of the world and not in the dynamic real world itself.
- Weak embodiment therefore characterises the research to date on the embodiment of existing artificial intelligence techniques via mobile robots, but as argued here, has not as yet achieved a cohesive and integrated system-environment interaction. Weak embodiment is simply the "hooking" of internal representations via a body to the real world.

Conclusions

- Embodiment is an inherent property of an agent that exhibits intelligent behaviour leading to the now established hypothesis that, in order to achieve cognitive capabilities or a degree of intelligence in an agent, a notion of **embodiment is required** where there is cohesive interaction between the environment and the body
- Existing and current work into the field of social intelligence and particularly social robotics seeks to develop a stronger notion of embodiment via the use of an intentional architecture (the Social Robot Architecture), social analogies such as identity, character and roles, and a high level agent communication language towards realising a robot system that exists IN its world.

THANKS FOR YOUR ATTENTION!



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