

# Adaptive Robotics

## Behaviour and Cognition as Complex Adaptive Systems

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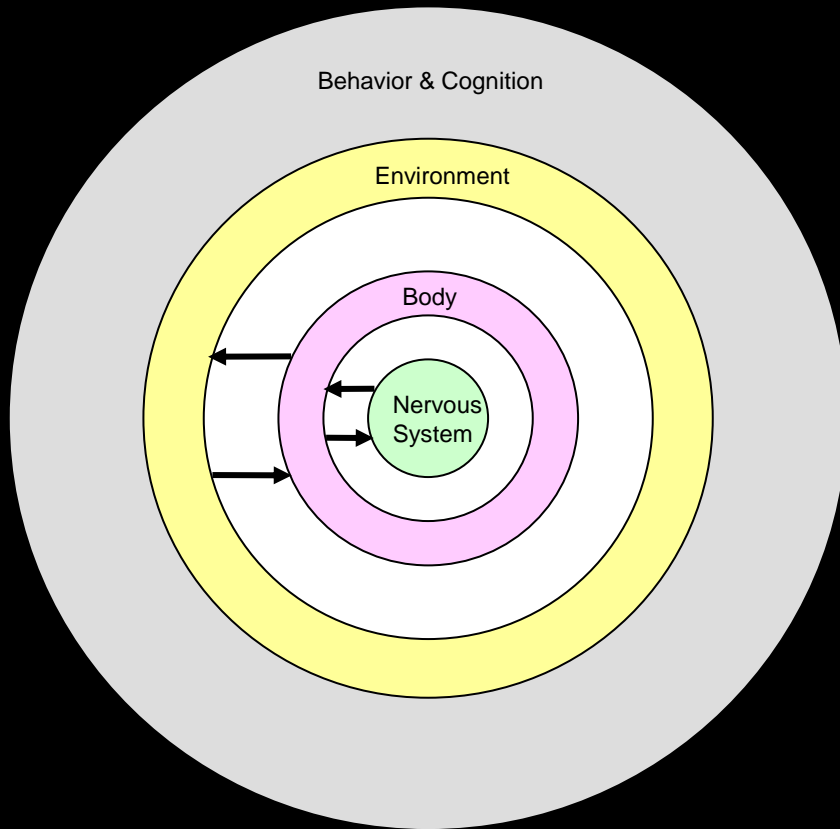
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# Outline

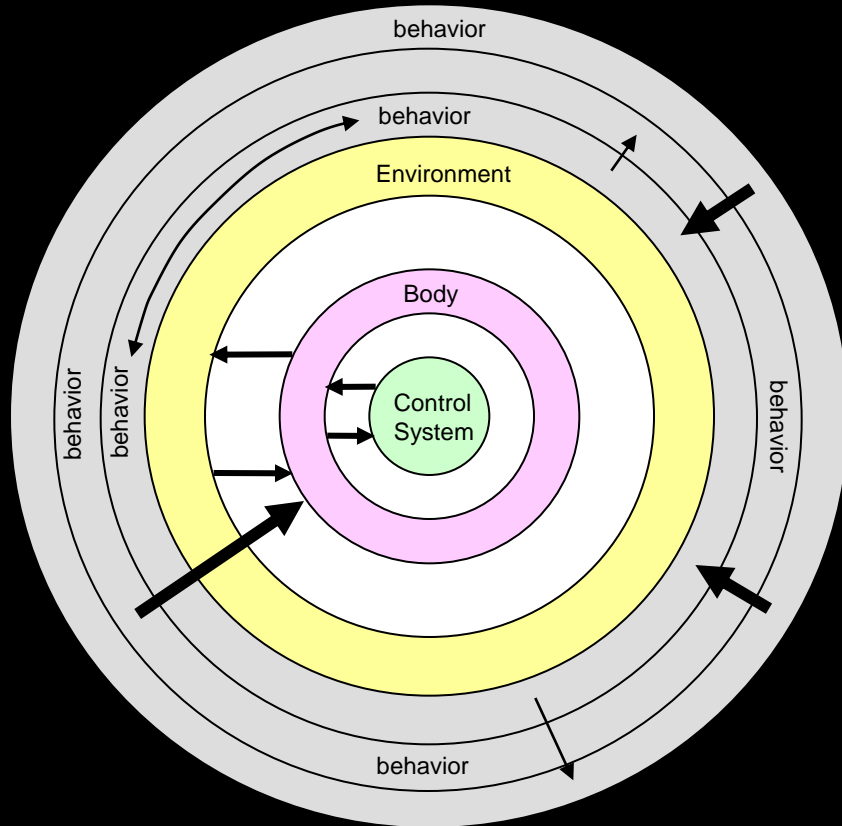
1. Behaviour and Cognition as Complex Adaptive Systems
2. Adaptive Approaches to Robotics
3. Example 1: Evolution of communication
4. Example 2: Language and Action Integration

# Behavior and Cognition as Dynamical Systems



**Behaviour and cognition are dynamical processes that extend over time and result from a large number of robot/environmental interactions occurring at a fast time rate between the robot's control system, body, and the environment.**

# Behavior and Cognition as Complex Multi-Level and Multi-Scale Dynamical Systems



**(i) The interactions between lower-level processes (that extend for a limited time duration) give rise to higher-level processes (that extend for longer time spans)**

**(ii) higher-level processes later affect the lower-level processes from which they originate**

# Implications of the Complex Dynamical System Nature of Behavior and Cognition

**Emergence:** Possibility to exploit properties that emerge from the interactions which leads to **compact** and **integrated** solutions

**Adaptability:** Possibility to progressively improve and expand agents' behavioral and cognitive skills through progressive variations and behaviour re-use.

# Embodiment and Situatedness

**Embodiment:** Suitability of the body to exploit the interaction with the environment



[Collins, 2000']

**Situatedness:** Suitability of the control system to exploit the interaction with the environment

coordinated motion

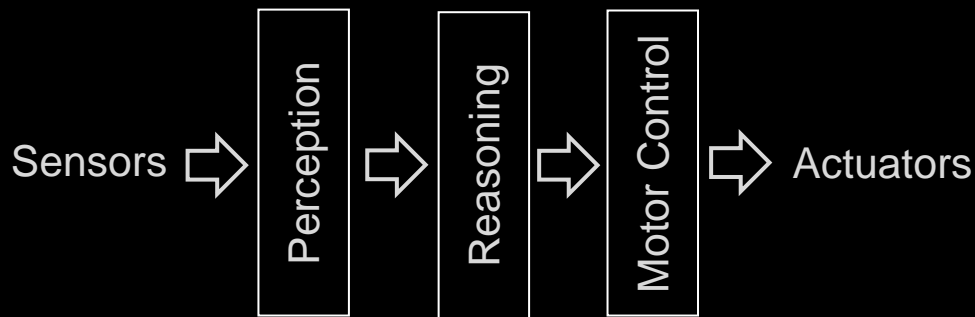
[Baldassarre, Trianni, Nolfi 2006']



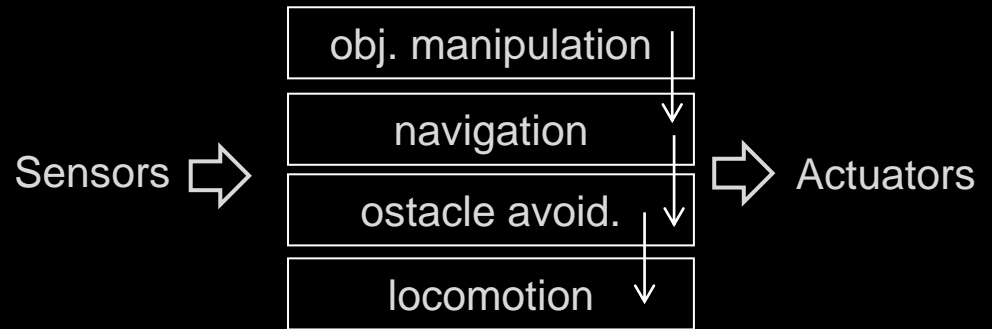
[Tuci, Ferrauto, Nolfi 2010']

In embodied and situated systems, the characteristics of the agents are strongly integrated with the characteristics of the environment and of the task

# Design Methods



deliberative architecture



behavior-based architecture

**Problem 1:** These design methods based on a set of relatively independent layers/modules playing different functionalities tend to minimize the effect of the interactions

**Problem 2:** The effect of the interaction can be minimized but not eliminated. The human designer therefore needs to face the problem caused by unexpected emerging properties that can hardly be predicted or deduced by the characteristics of the interacting elements

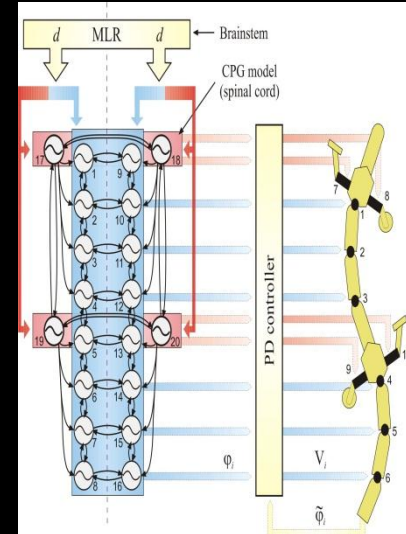
# Bio-Inspired Methods



Franceschini et al. 1992



Ijspeert et al. 2007



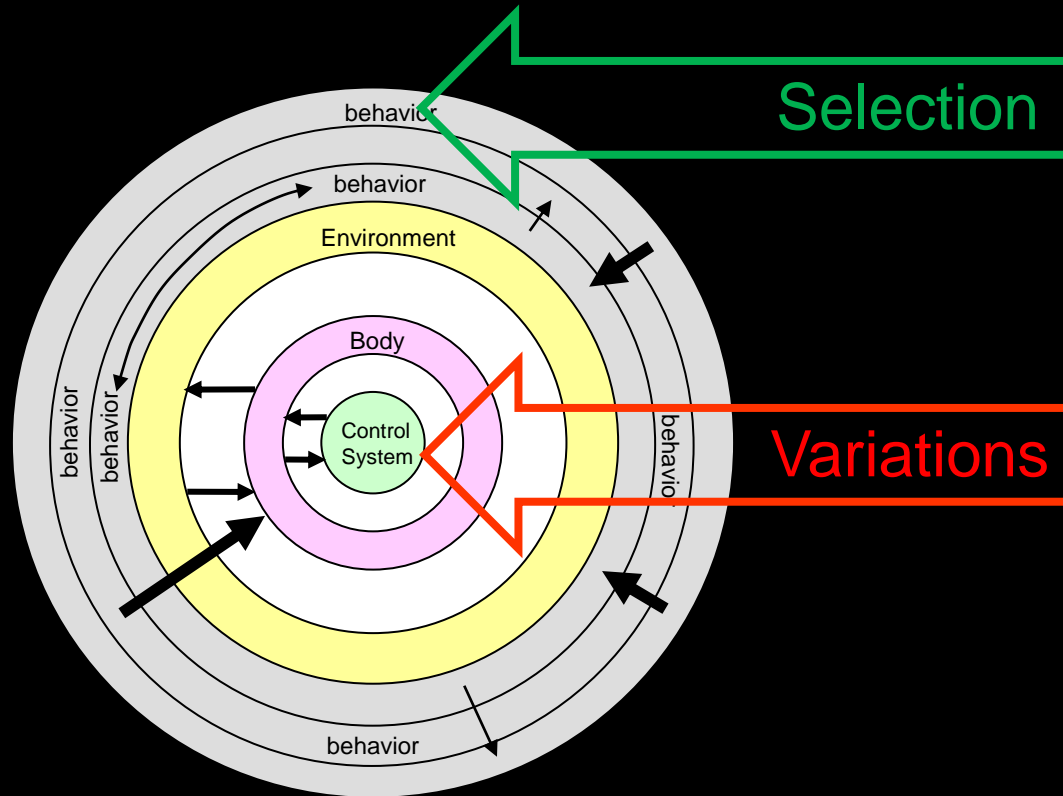
This method allows to capitalize on embodied and situated solutions discovered by natural evolution but can be applied only to domains/solutions for which we have a detailed understanding



# Adaptive Methods

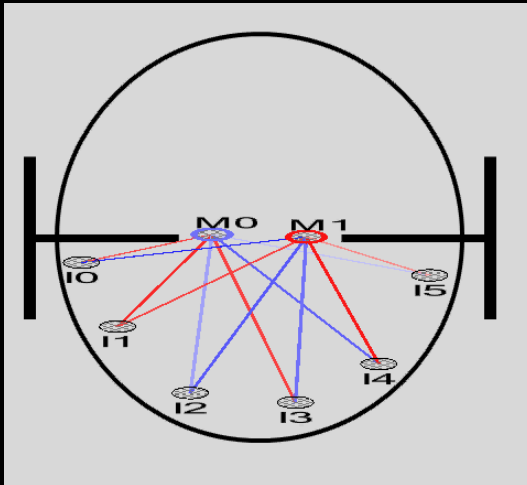
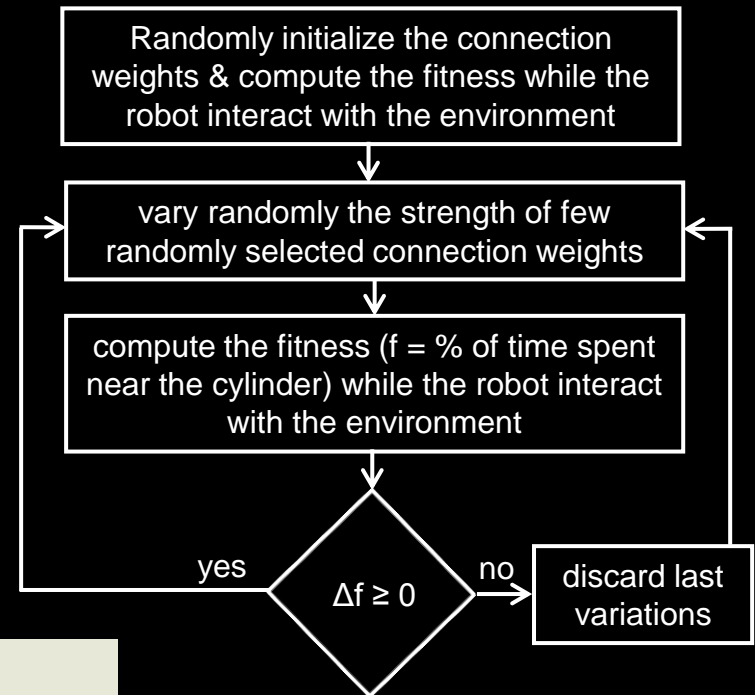
Allowing the robots themselves to develop their skills autonomously while they are situated in their environment through a phylogenetic and/or ontogenetic adaptive processes homologous to natural evolution and/or learning

# Fundamental property 1: Variation and selection operate at the lowest and highest levels of organization



Selection operates on a process that result from the agent/environmental interaction

# Finding and Remaining Close to a Target Object



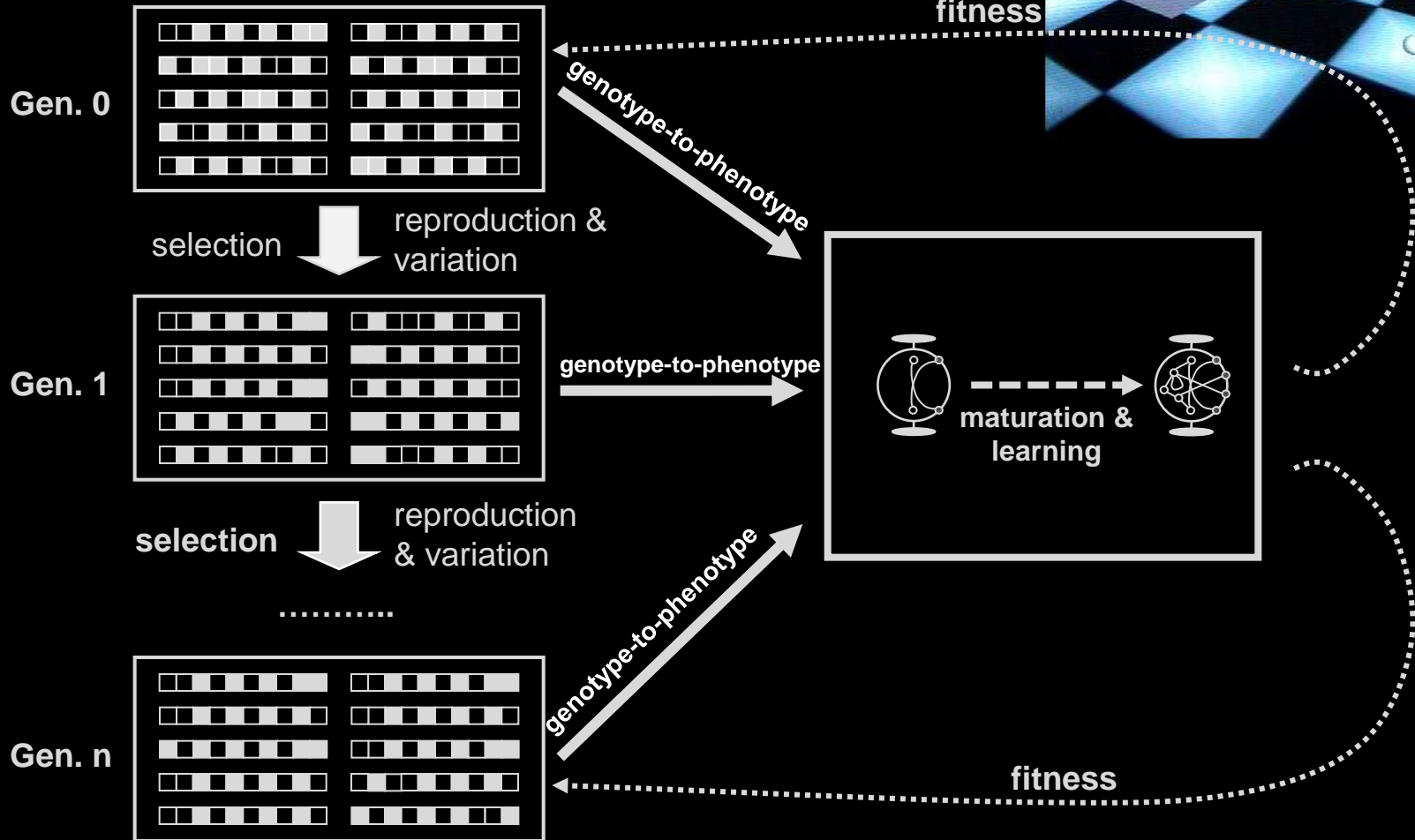
## Fundamental property 2: Evolution operates on a population of individuals

To speed-up the adaptive process (parallel search, recombination)

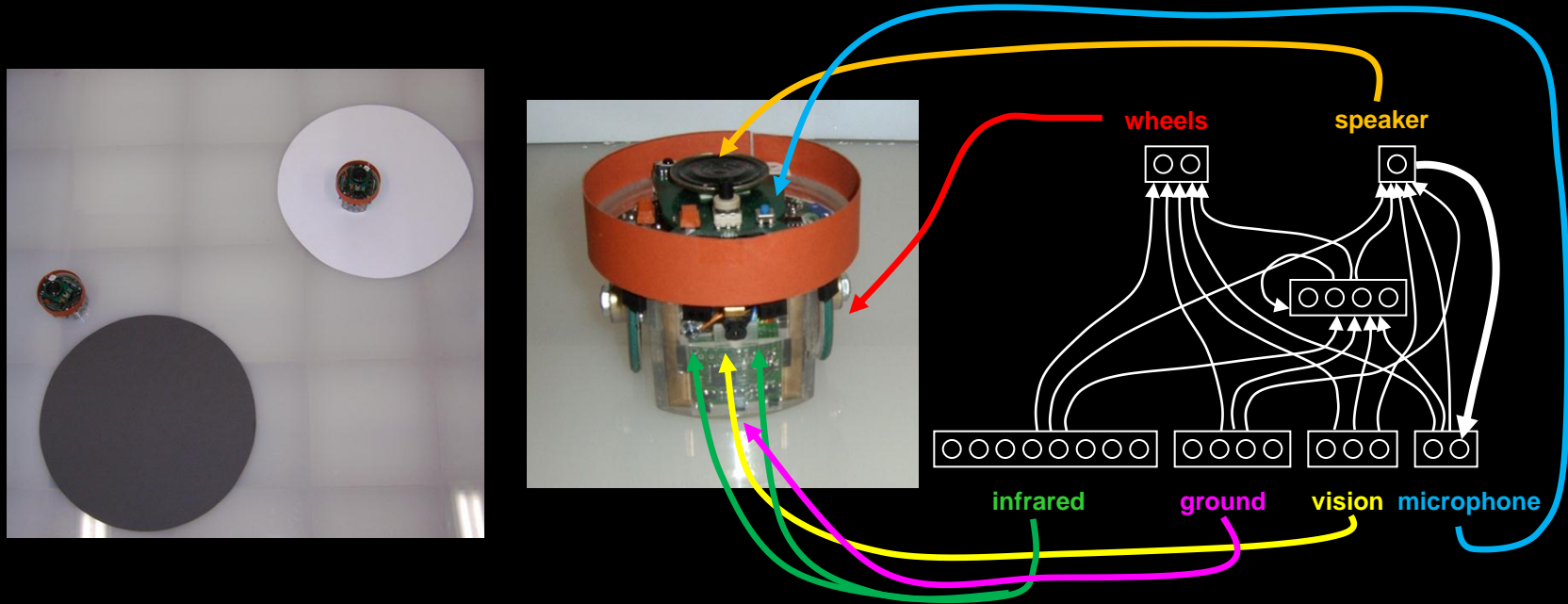
To increase the robustness of the adaptive process

# Evolutionary Robotics

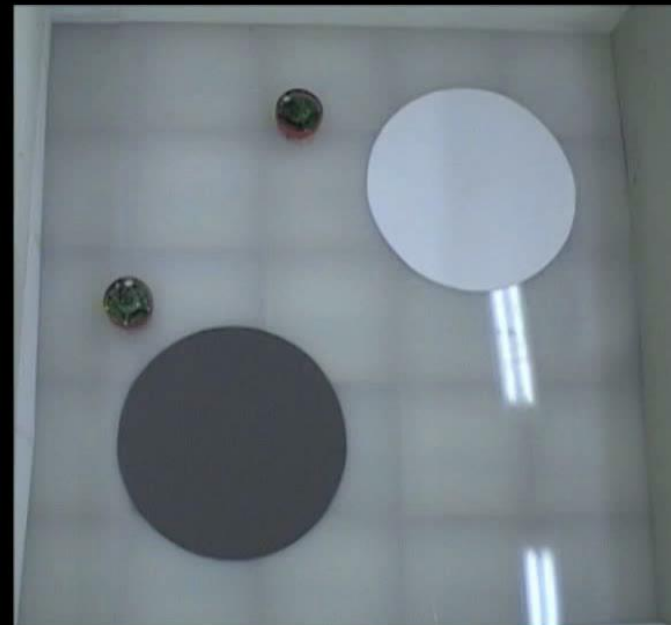
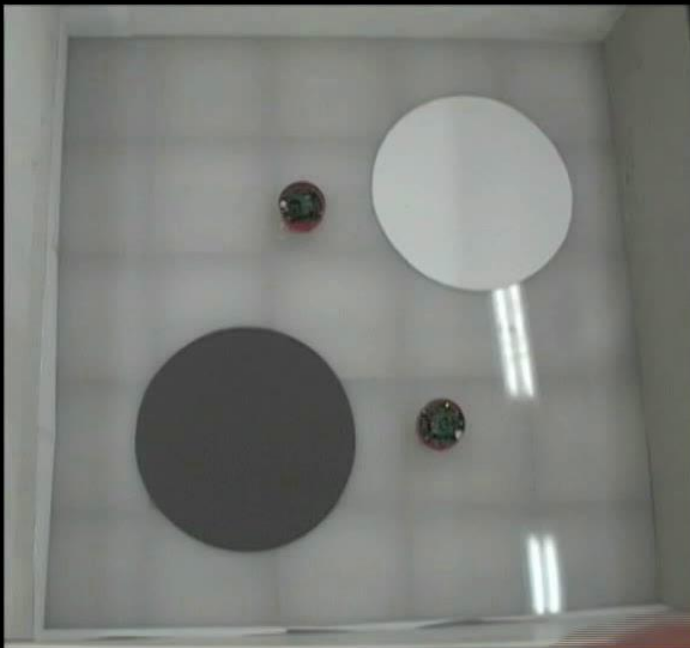
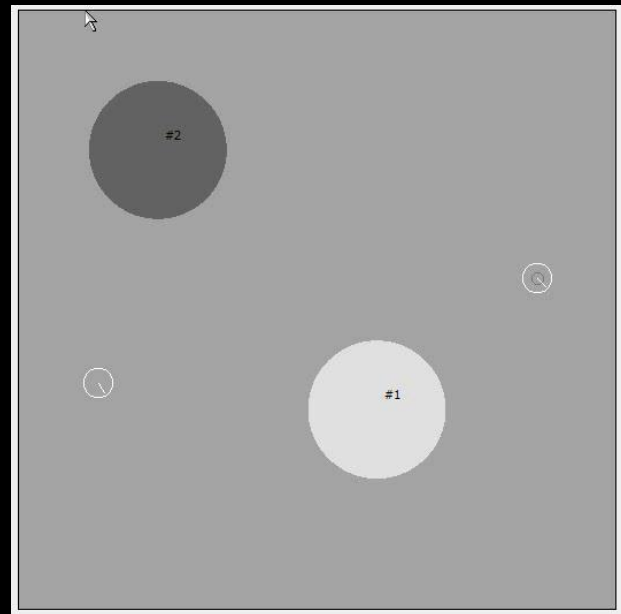
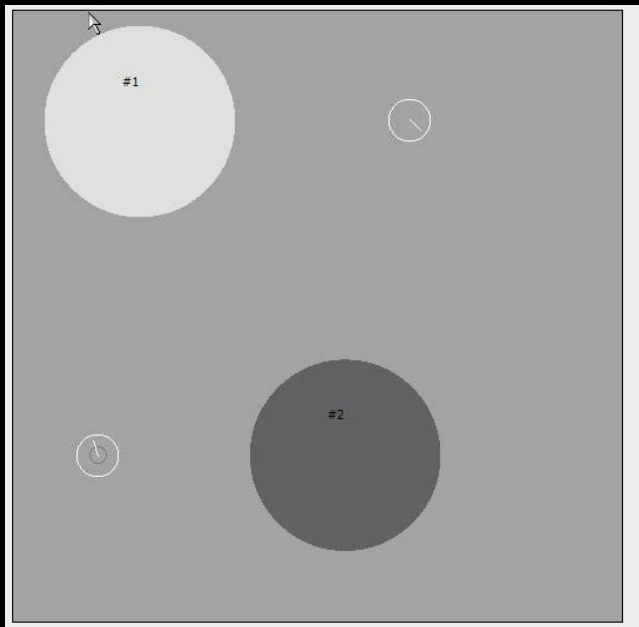
[Bongard & Pfeifer, 2001']



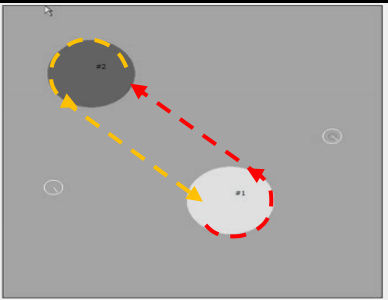
# Evolution of cooperative/communicative behaviour



The group is reward with 1 point every time the robots are concurrently located in the two areas for the first time or after a switch

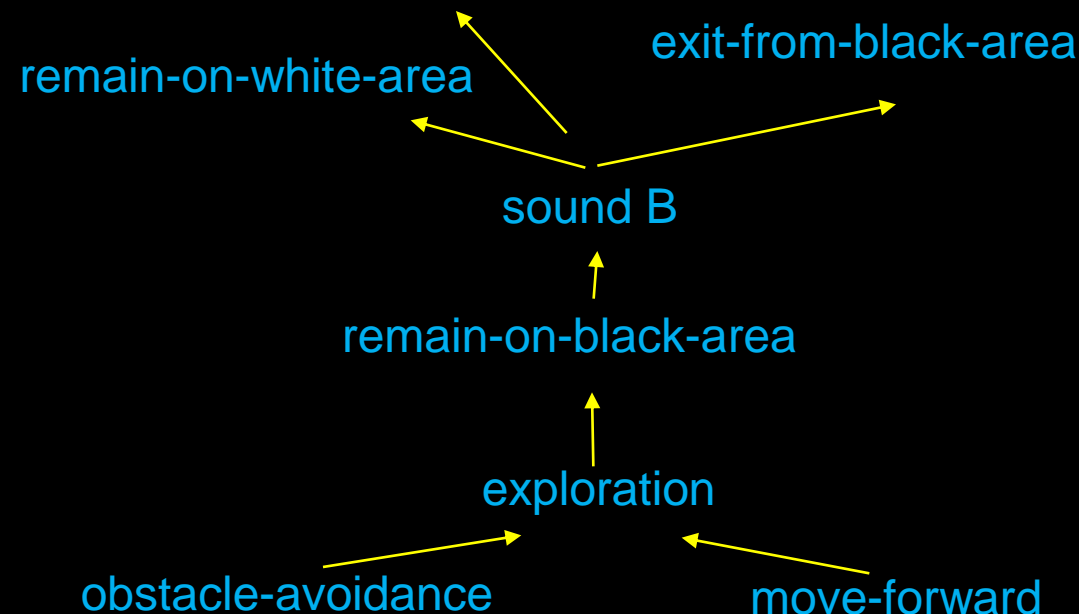


# Summary of Main Evolutionary Progresses



remain-on-black-area:  
look-robot-and-follow-border

exit-from-white-area  
toward the other robot



Infrared-off -> move-forward

Infrared-on -> avoid-obstacles

ground-black -> remain on the black  
area look-robot-and-follow-border

ground-not-black -> sound A

ground-black -> sound B

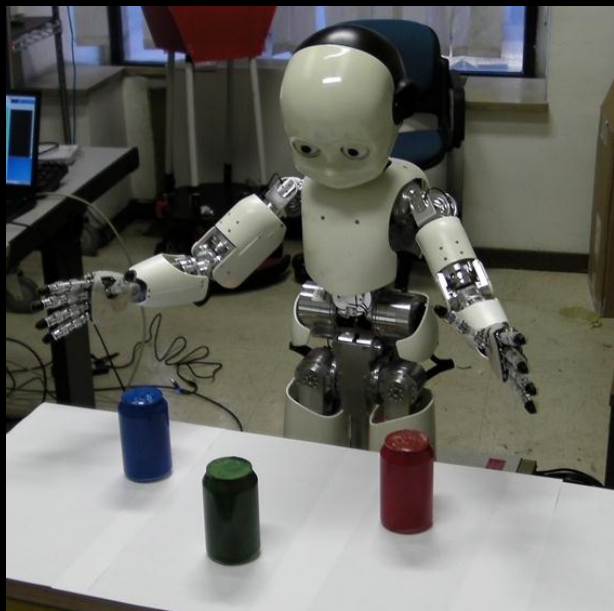
Sound-B & ground-black -> exit  
from black area

Sound-A & ground-white -> remain  
on white area follow border

Sound-B & ground-white & see-robot -> exit from white area toward  
the other robot

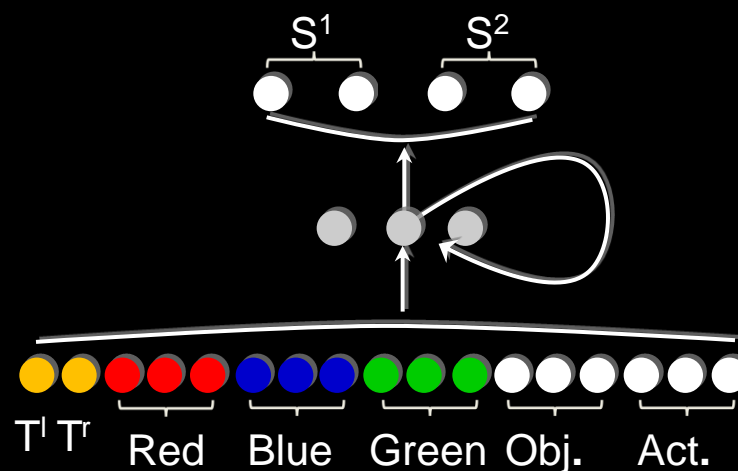


# Linguistic Compositionality and Behaviour Generalization



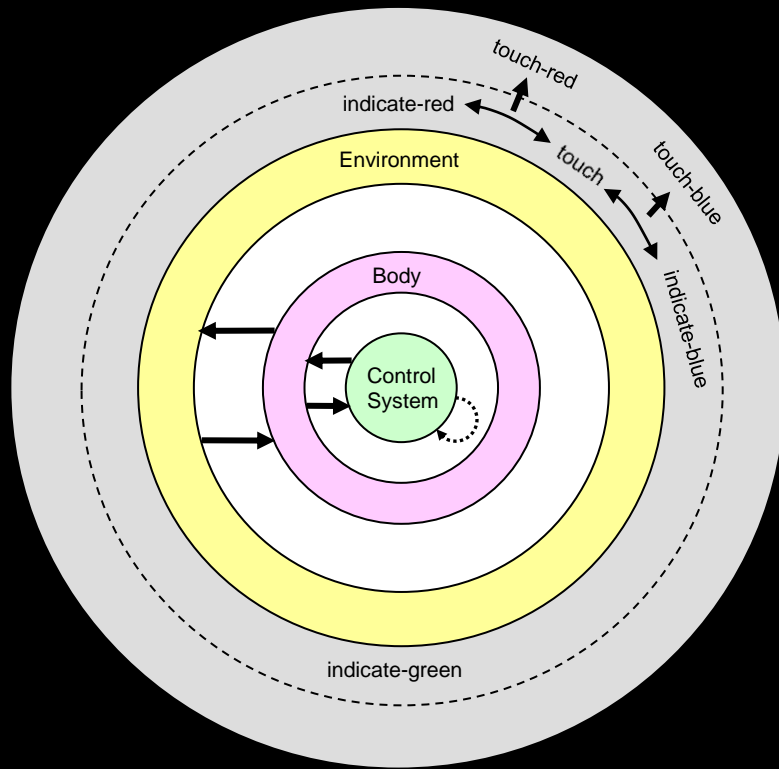
**INDICATE BLUE object**

	BLUE	RED	GREEN
IGNORE	YES	YES	YES
TOUCH	YES	YES	NO
MOVE	NO	YES	YES



# Compositionality and Behaviors Re-use

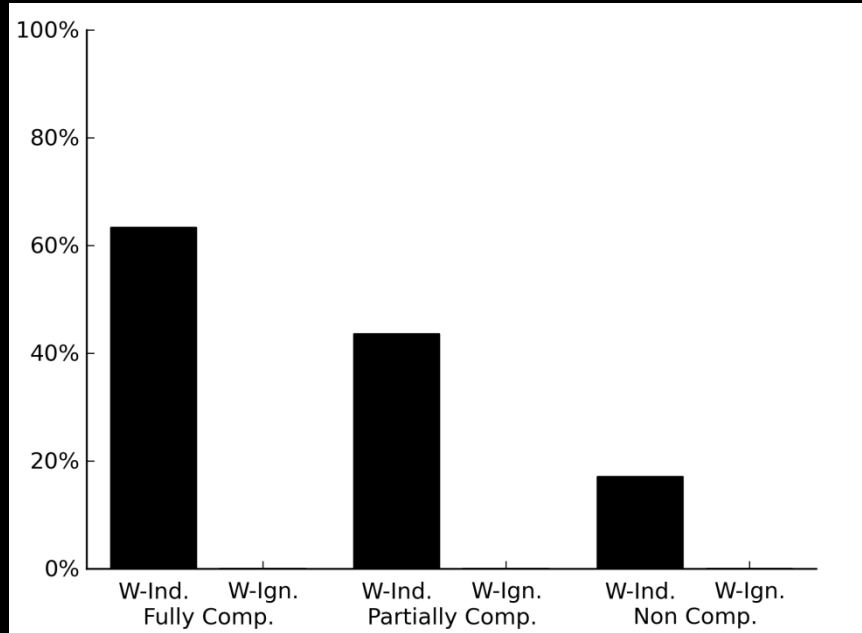
Fully compositional individuals are observed much more frequently in the WITH-INDICATE than in the WITH-IGNORE experimental condition



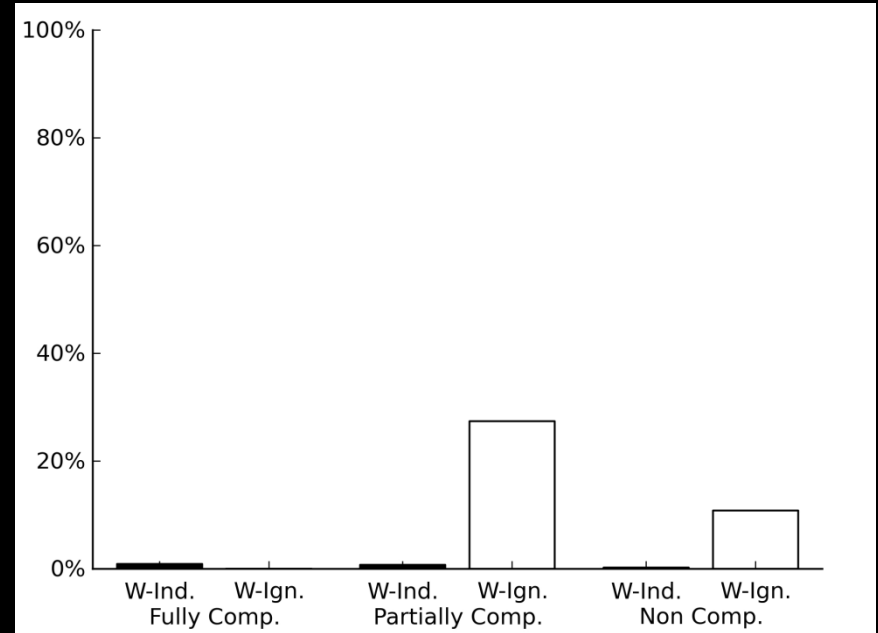
Robots trained to produce related skills tend to do so by exploiting behavior re-use

Behavior re-use is one of the ingredients that enable compositionality and behavior generalization

# Compositionality and Behaviors Re-use



ACTION TRANSITION TESTS



OBJECT TRANSITION TESTS

# Conclusions

We explained in which sense embodied and situated agents should be characterized by complex adaptive systems

We illustrated the implications of such type of organization

We showed how system of this sort can be synthesized

# Acknowledgements

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laral.istc.cnr.it

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<http://www.italkproject.org/>



[www.ecagents.org](http://www.ecagents.org)



[www.swarmanoid.org](http://www.swarmanoid.org)

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