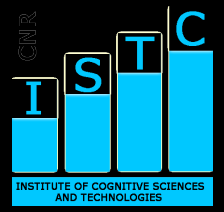

Evolutionary Algorithms, Application Domains and Open Research Directions

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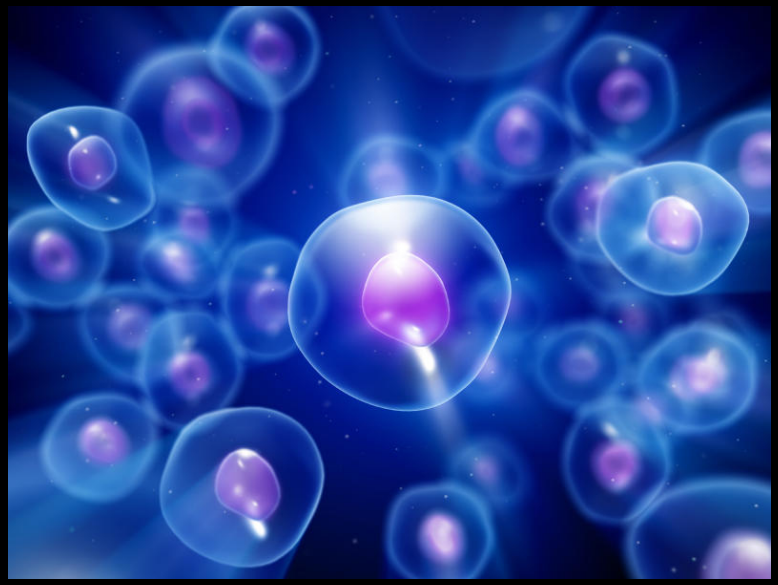
Origin of Life and Natural Evolution



Self-replication

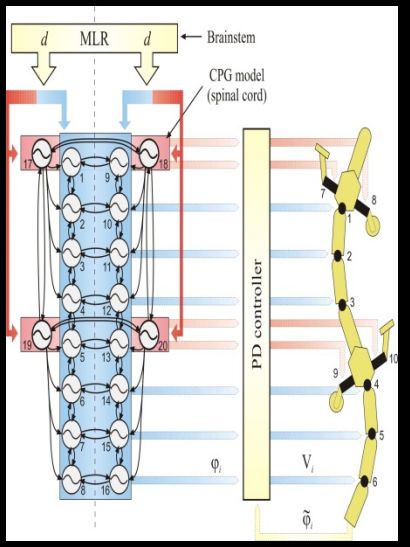
Inherited-variations

Competition for limited resources

An ever expanding set of adaptive capabilities

Bio-Inspired Methods

Velcro



Ijspeert el al. 2007

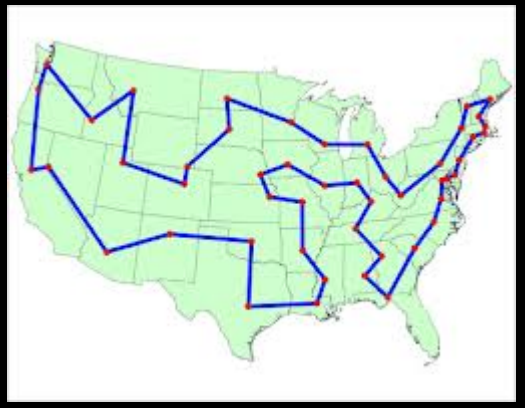
Design artefacts displaying a desired functionality by emulating solutions (e.g. mechanisms displayed by specific animal species) discovered by natural evolution

Artificial Life versus Artificial Evolution

Artificial Life: designing self-replicating physical entities

Artificial Evolution: evolving physical or software entities that are selected on the basis of an user defined selective criterion (fitness) and that are replicated and varied by an external machine (or computer).

Evolving solutions for the traveling salesman problem



Generation n.1

Genotype n.1	1 20 2 8 9 10 13 14 3 4 18 6 7 15 16 17 5 11 12 19	Fitness = 865362 Km	discarded
Genotype n.2	19 1 4 18 6 7 17 5 11 20 2 8 9 10 13 14 3 15 16 12	Fitness = 795806 Km	selected
	.....		
Genotype n.N	1 20 2 8 9 10 13 14 3 4 18 6 7 15 16 17 5 11 12 19	Fitness = 856372 Km	discarded

Generation n.2

Genotype n.1	19 1 4 18 15 7 17 5 11 20 2 8 9 10 13 14 3 6 16 12	Fitness = 808356 Km
Genotype n.2	19 1 4 18 6 7 17 5 11 12 2 8 9 10 13 14 3 15 16 20	Fitness = 764201 Km
	.....	
Genotype n.N	9 10 13 11 12 19 14 3 1 20 2 8 4 18 6 7 15 16 17 5	Fitness = 838354 Km

Evolutionary Algorithms: Pseudo-code

BEGIN

INITIALIZE POPULATION (by randomly selecting the value of genes)

EVALUATE individuals

REPEAT UNTIL (termination condition) IS SATISFIED

    SELECT parents

    VARY offspring (through mutations, recombination etc.)

    EVALUATE individuals

END

1. The selection process should be probabilistic

2. The amount of variations introduced through genetic operators should not be either too high either too low

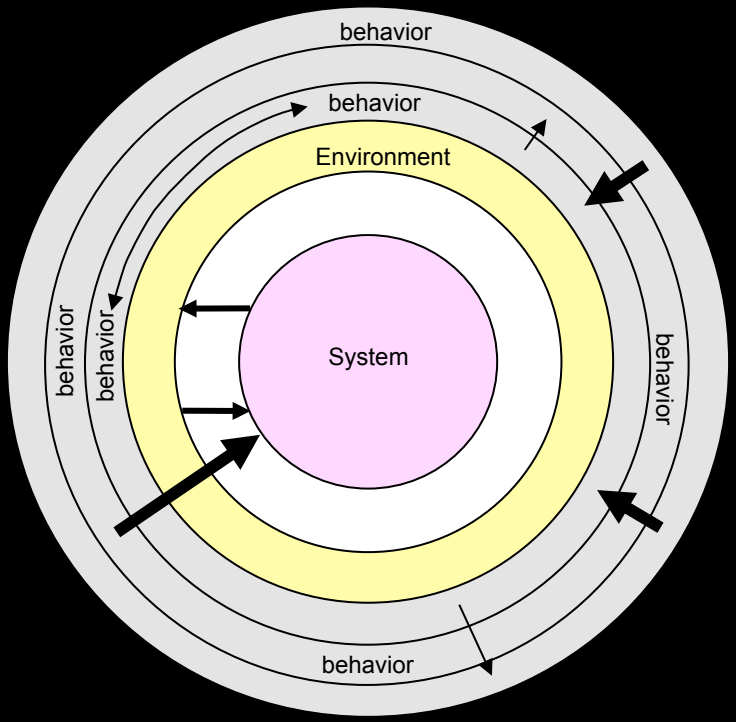
Evolving Embodied Systems

Embodied systems = Artefacts that are situated in an external world with which they interact directly without human intervention

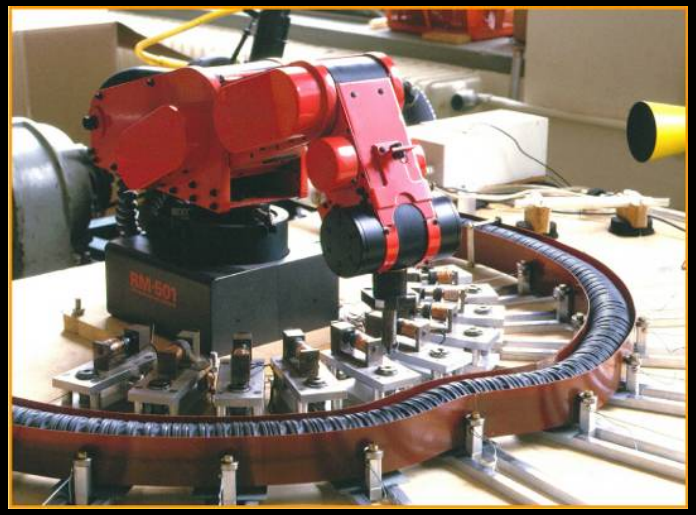
Embodied systems are hard to synthesize through standard design techniques

Embodied systems display functionalities and/or behaviors that do not depends from the characteristics of the system only but that rather emerge from the dynamical interaction between the system and the environment

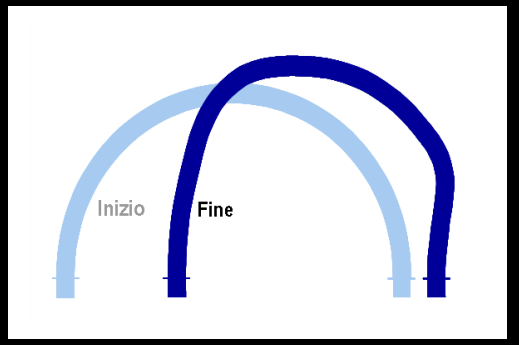
Synthesizing Embodied Systems



Evolving Shapes: Pipe Joints



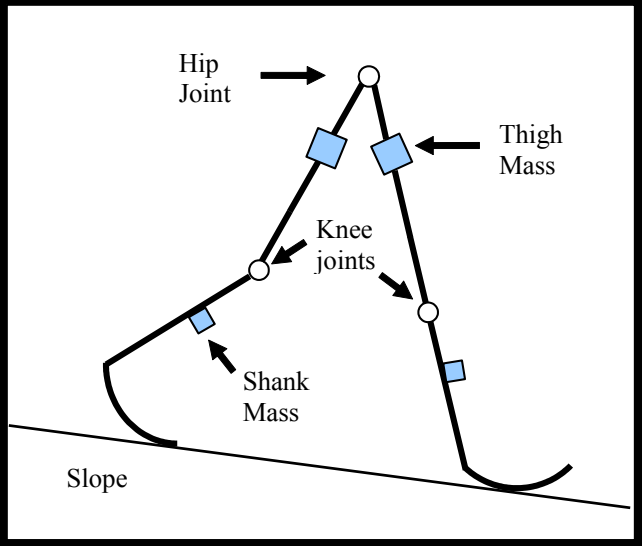
Ingo Rechenberg, 1985



Evolved Antenna

Antenna characterized by a wide radiation pattern mounted on the tree satellites that were lunched in 2006 by NASA to take measurements of Earth Magnetosphere

Evolving passive bipedal walking machines



[McGeer, 1996]

[Collins, 2000']

The walking behavior emerge providing that the length, mass, and size of the body segments ext. are carefully adapted to the task.

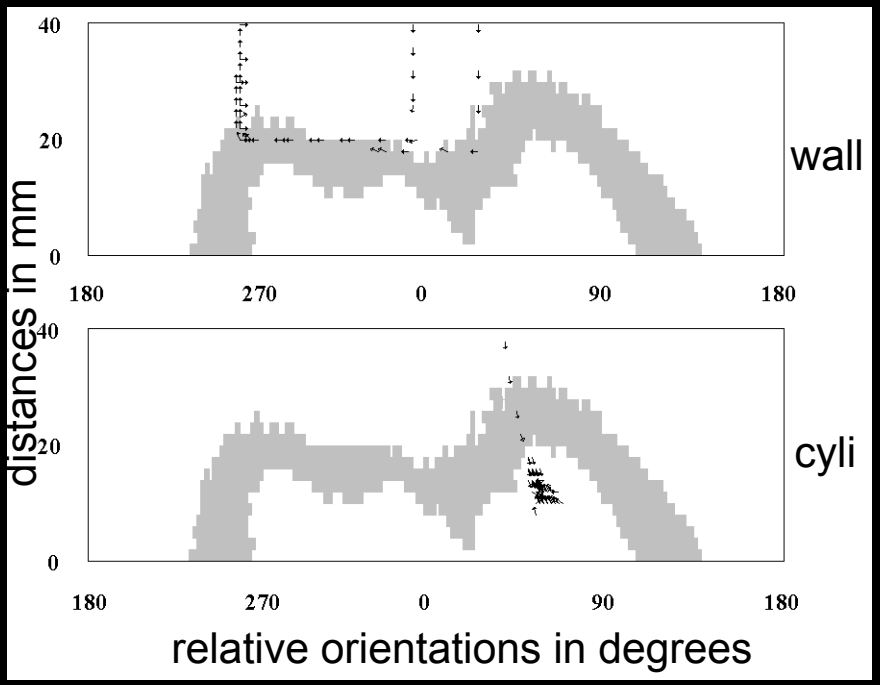
Evolving actuated bipedal walking machines

Geijtenbeek, van de Panne, van der Stappen (2013)

Evolving robots

Fitness = time spent close to cylinders

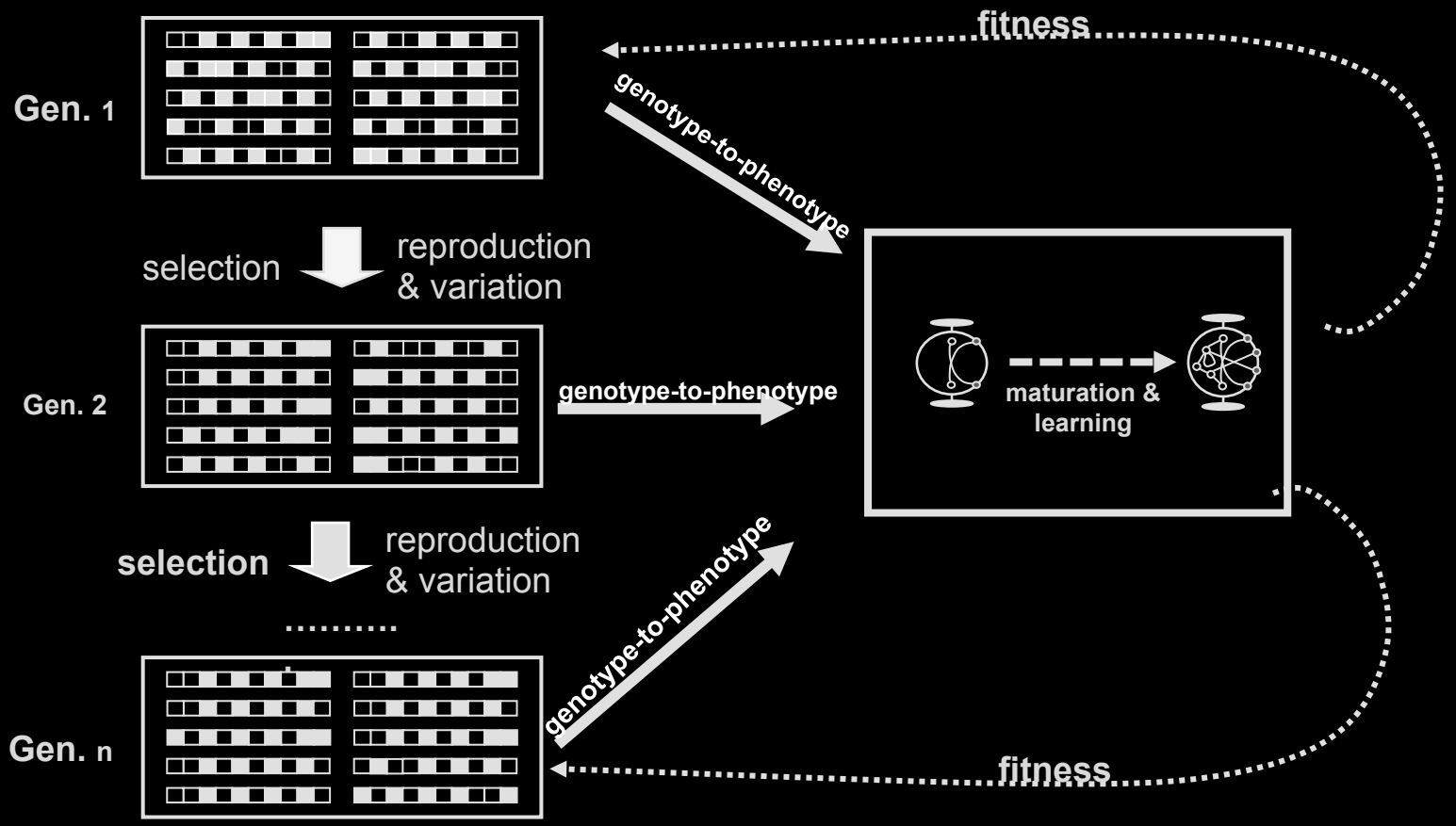
6 infrared sensors, 2 motorized wheels



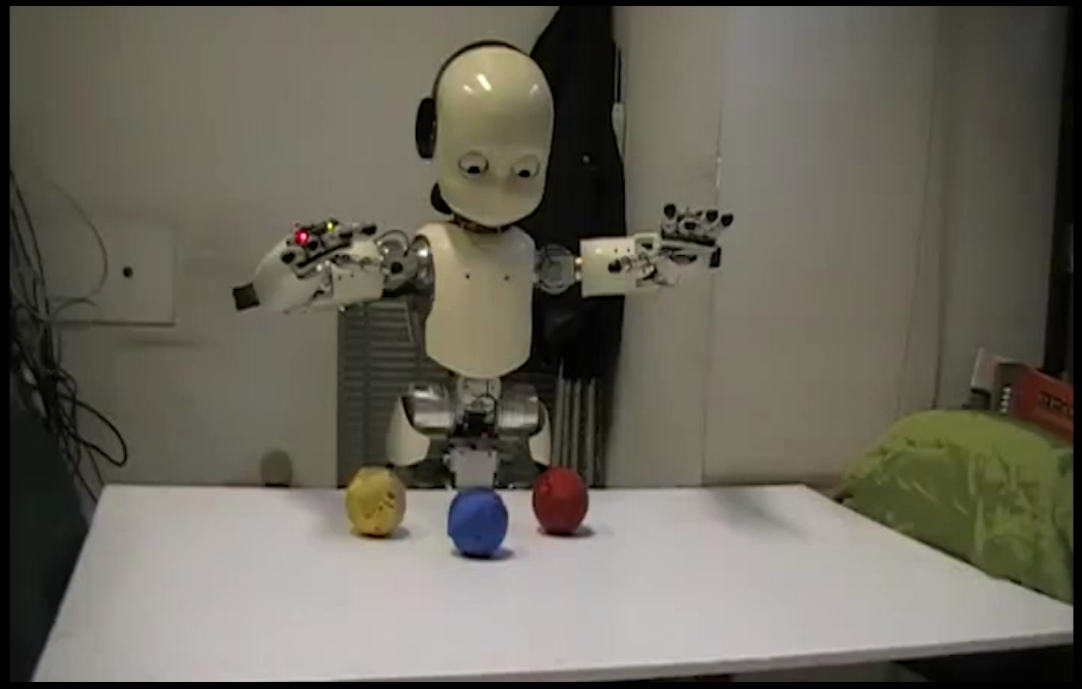
By tuning how much the robot turns left/right and forward/ backward depending on how the infrared sensors are activated lead to a behavioral attractor close to cylindrical but not close to wall objects.

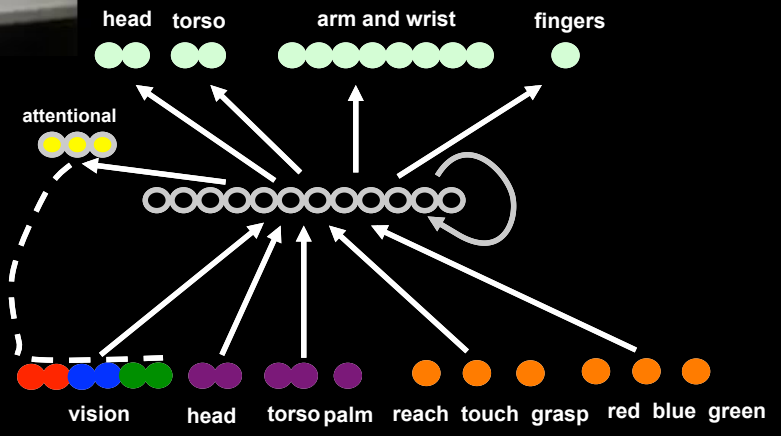
[Nolfi, 1996]

Evolving robots: Algorithms



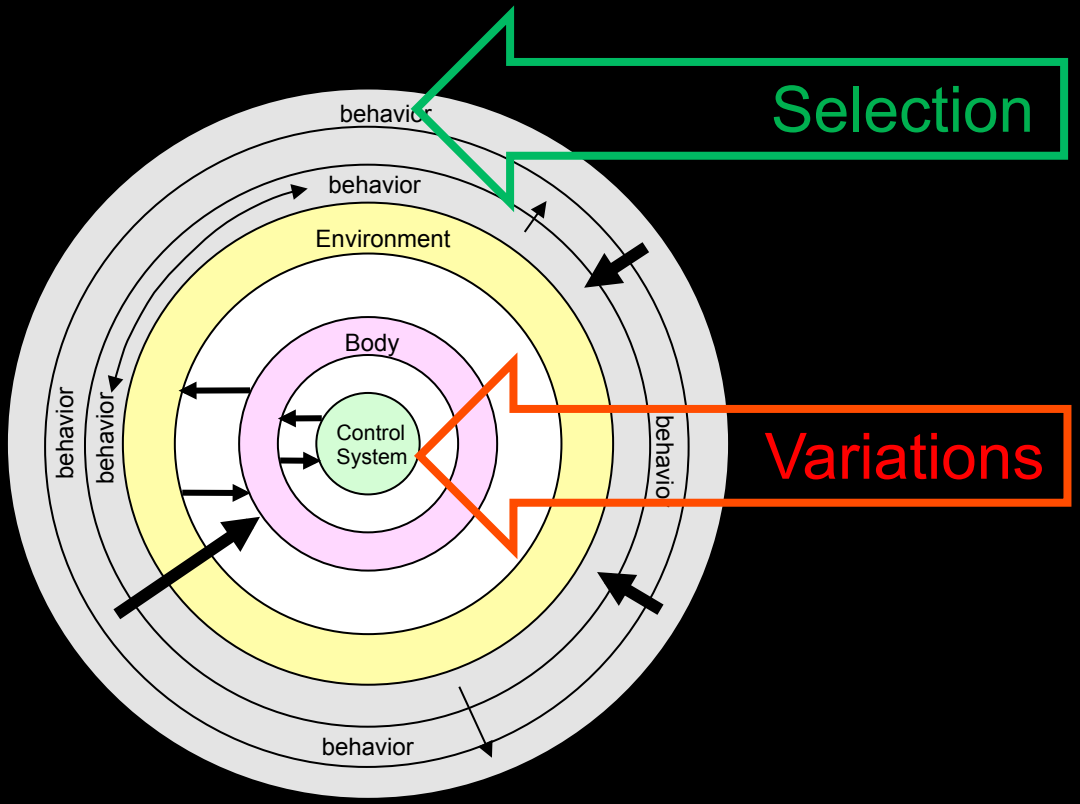
Evolution of manipulation skills in an humanoid robot





Ferrauto and Nolfi (2013)

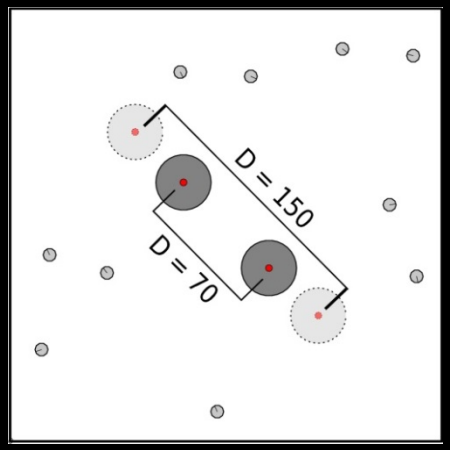
Evolution enable the discovery and exploitation of emergent properties

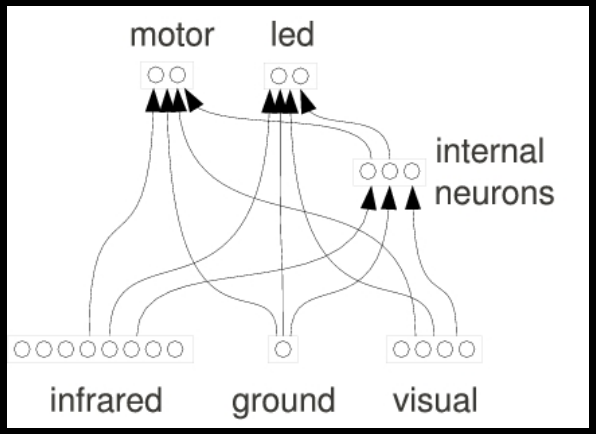


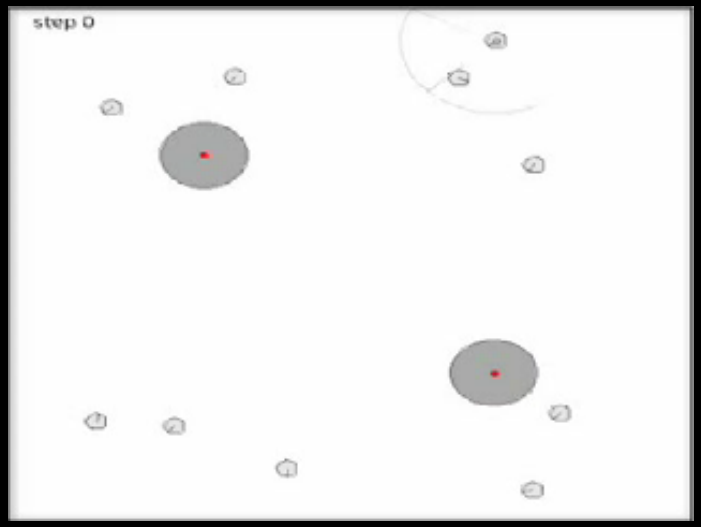
The variation process operates on the characteristic of the robot

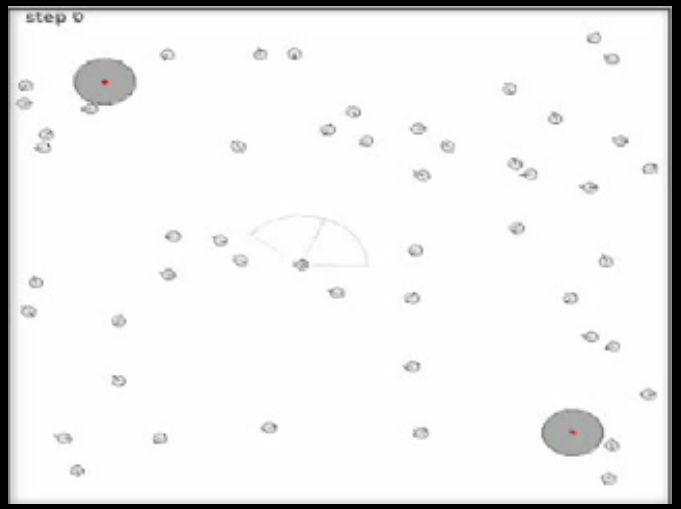
Selection operates on a properties that result from the robot/ environmental interaction

Evolving Collective Systems









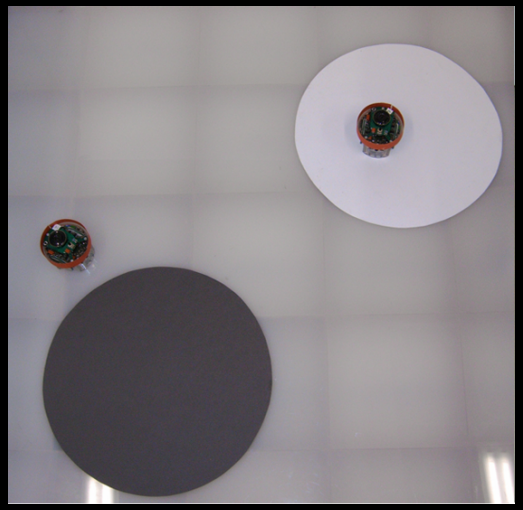
Sperati, Trianni & Nolfi, 2011

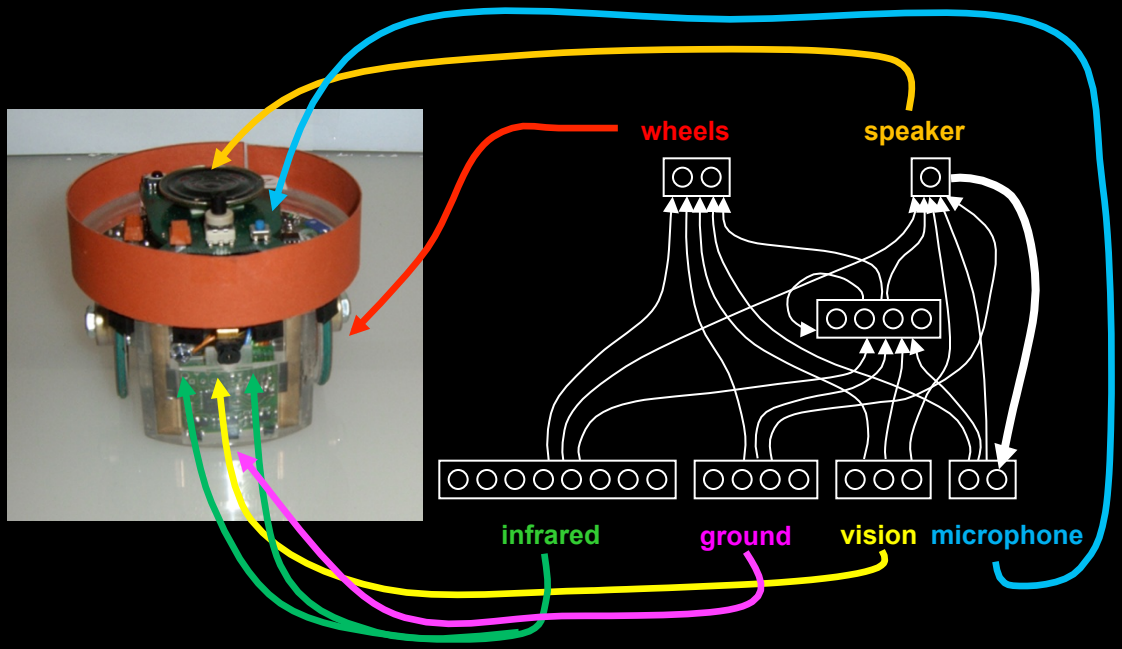
Open challenge: Open-ended evolution

How can evolving individuals keep expanding their behavioral repertoire by keep discovering new skills and by integrating the new acquired capabilities with their pre-existing skills ?

How can we set-up an evolutionary process analogous to natural evolution can lead to an open ended evolutionary process characterized by a never-ending innovation phase, and in some cases, to a progressive complexification of evolving individuals ?

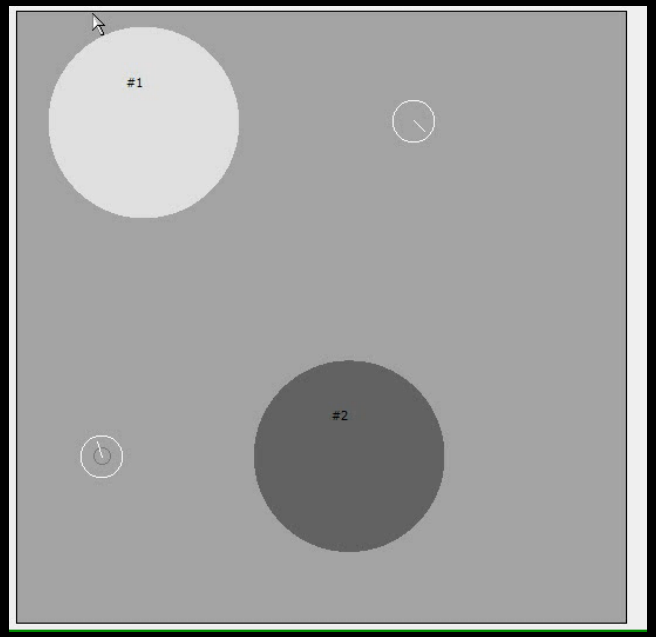
Evolution of behavioral and communication skills in groups of cooperating robots

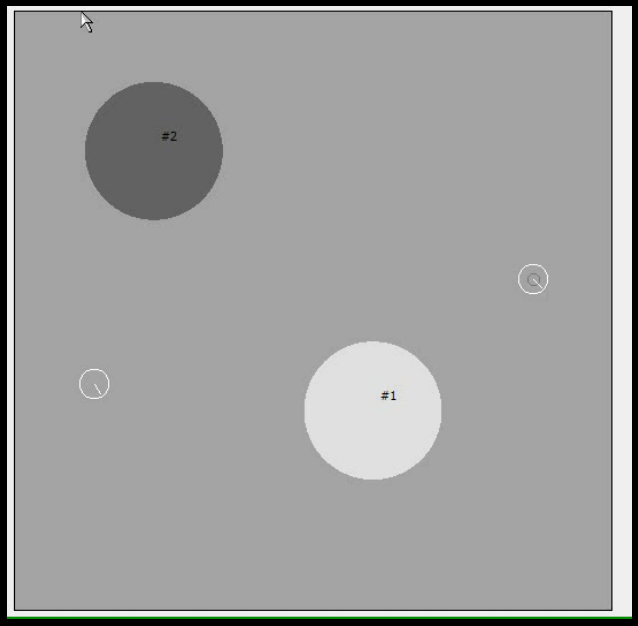


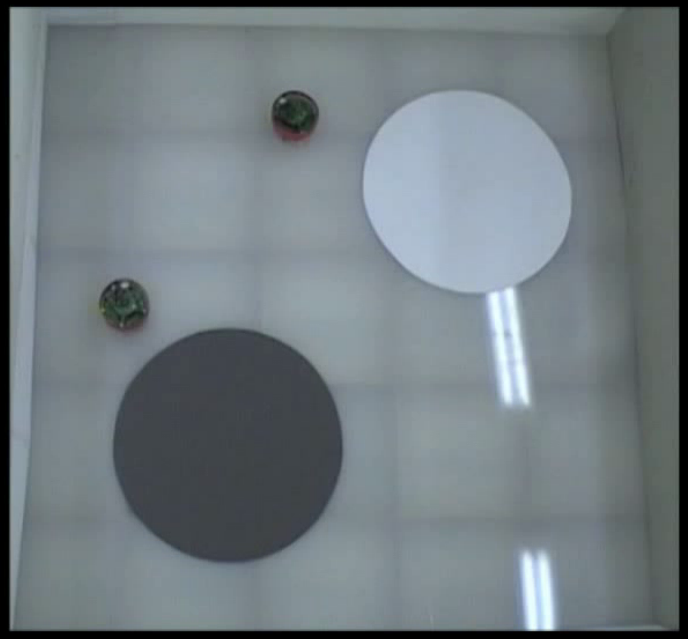


Fitness Function: **The group is reward with 1 point every time the robots are concurrently located in the two areas for the first time or after a switch**

De Greef & Nolfi, 2010

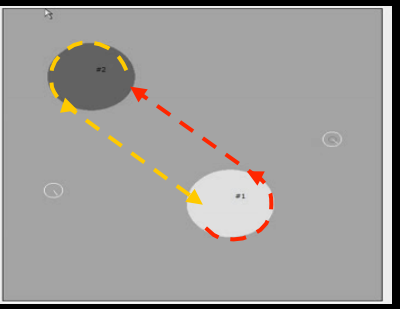






De Greef & Nolfi, 2010

Summary of the main evolutionary progresses



navigate-to-white

look-robot-and-follow-border

navigate-to-black

exit-from-white-area
toward the other robot

remain-on-white-area

exit-from-black-area

signal A/B

remain-on-black-area

find-areas

obstacle-avoidance

move-forward

Infrared-off -> move-forward

Infrared-on -> avoid-obstacles

move-f. & avoid-ob. -> find areas

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

ground-white/black -> signal A/B

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

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

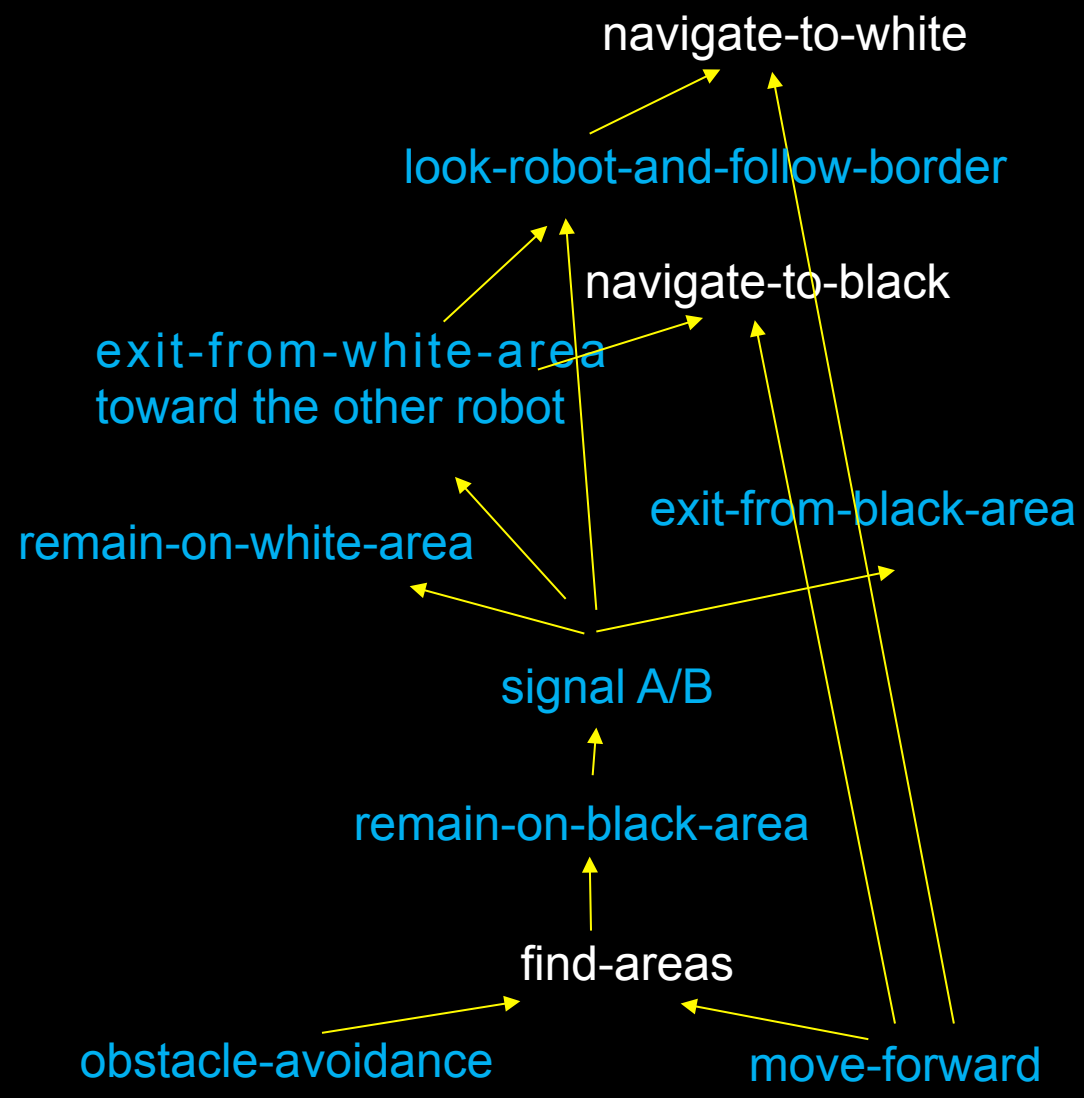
Sound-B & ground-white & see-robot -> exit from white area toward the other robot

exit from white & move-f -> navigate-to-black

look-r.-follow-b. & & move-f -> navigate-to-white

De Greef & Nolfi, 2010.

Multi-level formation, innovations, incrementality & complexification



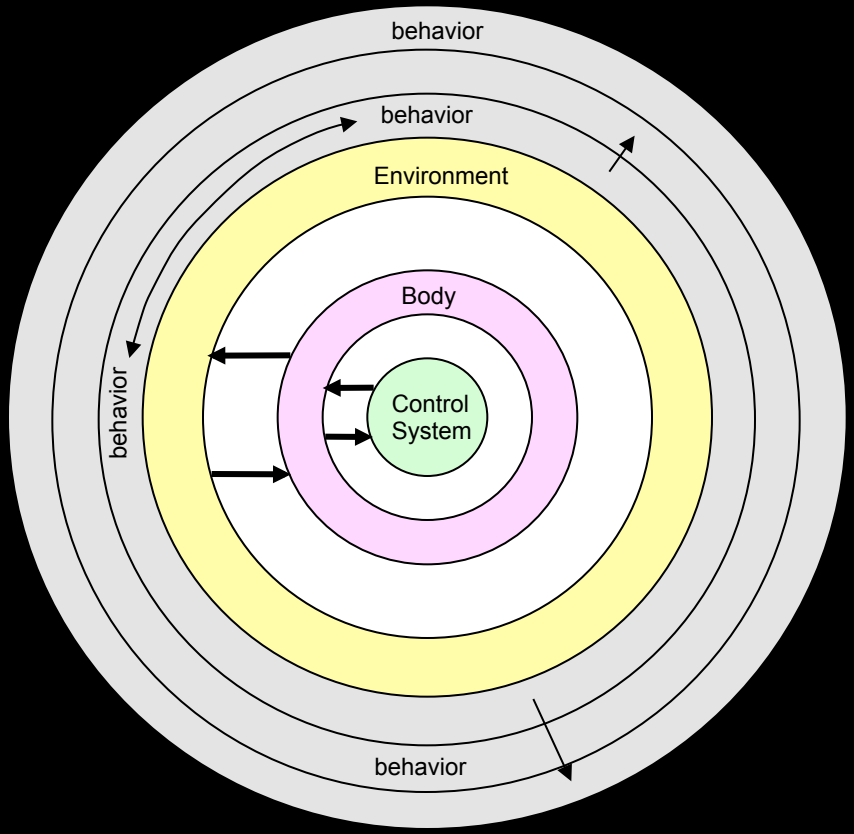
New higher-level capacities emerge through the interactions between pre-existing skills or through new traits combined with skill re-use

Innovations are enabled by the new adaptive opportunities created by the effects of agents' behaviors and by the possibility to re-use existing capacity

Established skills (assuming new functions) tend to be preserved thus leading to an incremental process and to a complexification of agents skills

De Greef & Nolfi, 2010.

Behavior as a Complex Multi-Level and Multi-Scale Dynamical Systems



(i) The robot/environmental interactions and the interactions between lower-level behaviors (that extend for a limited time duration) give rise to higher-level behaviors (that extend for longer time spans)

(ii) New behaviors and new levels of organization might emerge from the same set of interacting elements