# Behavior and Cognition as a Complex Adaptive System in Robotics

**Stefano Nolfi**

Institute of Cognitive Sciences and Technologies
National Research Council (CNR)
Via S. Martino della Battaglia, 44, Rome, Italy
stefano.nolfi@istc.cnr.it

Recent advances in different disciplines, ranging from cognitive sciences and robotics, biology and neurosciences, to social sciences and philosophy are clarifying that intelligence resides in the circular relationship between the brain of an individual organism, its body, and the environment (including the social environment).

In this paper we will focus our attention on the evidences collected in robotic research with particular reference to results obtained in experiments in which the robots develop their skill autonomously while they interact with the external environment through an adaptive process. In particular we will demonstrate how the behavioural and cognitive skills developed by the robots can be properly characterized as complex adaptive systems which: (a) arise from fine-grained non-linear interactions between the brain of the robots, their body, and the environment, (b) display a multi-level and a multi-scale organization in which properties at different levels of organization and extending at different time scales affect and are affected by lower- and higher-level properties.

The complex system nature of behaviour and cognition has important consequences both from a modelling and an engineering point of view. From the point of view of developing effective robotic artefacts it implies the need to rely on "design for emergence" techniques, i.e. techniques which allow to develop systems displaying behavioural and cognitive skills which are emergent (i.e. which are not produced by dedicated control mechanisms but which rather emerge from the interactions between lower level elements). We refer in particular to adaptive techniques in which the rules that regulate the fine-grained interaction between the robot's control system, body, and environment are varied randomly and in which variations are retained or discarded on the basis of whether they lead to behavioural or cognitive skills that are useful with respect to the functionalities requested to the robot.

From the point of view of modelling biological system, it implies the need to conceptualize behaviour and cognition as the result of dynamical processes which are quantitative in state and time and which unfold while the organism interacts with the environment. Moreover, it implies the need to study how living organisms change, phylogenetically and ontogenetically as they adapt to their environment.

Viewing behaviour and cognition as a complex adaptive system represents a new conceptual framework that can have profound consequences on cognitive science. In particular, as we will demonstrate in this article, it might allow us to more clearly understand the relation between behavioural and cognitive processes and to better clarify the importance and the implications of embodiment and situatedness.