Evolutionary Robotics: Looking forward

Stefano Nolfi
Institute of Cognitive Sciences and Technologies, CNR
Viale Marx, 15, 00137 Rome, Italy
e-mail: s.nolfi@istc.cnr.it

Introduction

Evolutionary robotics (Cliff et al. 1993; Nolfi and Floreano, 2000) is the study and application of autonomous robots developed through a self-organizational method based on artificial evolution. This approach stresses the importance of the study of systems that: (1) have a body and are situated in a physical environment, and (2) autonomously develop their own skills in close interaction with the environment.

Over the last ten years, or more, *Evolutionary Robotics* has attracted the interest of a large community of researchers with different research interests and backgrounds, ranging from AI and robotics, to biology and cognitive science, to the study of social behavior.

Continuous progress in evolutionary robotics has led to a substantial maturation of the field and a clearer understanding of its potential and of its current limitations. The contributions of this special issue cover many of the most interesting research directions currently investigated in the field. For other important topics, not covered or only partially covered in this special issue, the reader might consult: co-evolution of morphology and control (Pollack et al., 2001; Bongard & Pfeifer, 2003), evolution and learning (Nolfi & Floreano, 1999; Floreano & Urzelai, 2001; Tuci et al., 2003), integration of sensory-motor information over time (Nolfi and Marocco, 2001; Nolfi, 2002; Ziemke & Thieme, 2002; Beer, 2003), homeostasis (Di Paolo, 2000), evolution of collective behaviors (Baldassarre et al., 2003, 2004; Quinn et al., 2003), emergence of communication and language (Quinn, 2001; Marocco et al., 2003).

The papers in this issue

Bianco and Nolfi discuss how current evolutionary robotics methods can be extended to lead to a truly open-ended evolutionary process leading to a large variety of qualitatively different solutions and to the development of novelties, that is new traits that tend to be retained for long evolutionary periods and to constitute important building blocks for further evolutionary stages. More specifically, the authors discuss three factors that might promote open-ended evolution: (1) implicit and general selection criteria, (2) favourable organization of the evolving individuals, and (3) varying social and environmental conditions. After a review of the most relevant contributions in the field, the authors describe a new experimental framework that might potentially lead to an open-ended evolutionary process. The preliminary experiments described in the paper involve a population of autonomous elementary robotic units that are left free to interact and to self-assemble. The possibility of self-assembling and propagating their genotype into the body of assembled units leads to a spontaneous evolutionary process without the need for an explicit selection criterion.

Hulse, Wischmann & Pasemann present a new approach based on the evolution of neuro-modules (i.e. dynamical recurrent neural networks) that are combined together in order to form the control system of the corresponding robots. Neural modules are combined through a form of incremental evolutionary process in which: (1) a first neural module is evolved for the ability to perform behaviour *A*, (2) an additional neural module is evolved for the ability to perform behaviour *B*, and (3) the connectivity between the new neural modules and pre-existing neural modules is evolved for the ability to perform behaviours *A* and *B*. The authors then show how this approach has been successfully applied to the evolution of robots able to solve different problems and can be generalized to co-evolution of morphology and control and co-evolution of distributed control architectures.

Miglino & Walker used the evolutionary robotic approach to study how natural organisms are able to exploit abstract geometrical relationships between landmarks to reach a target location. More specifically, by evolving robots for the ability of pecking for a seed concealed at the midpoint between two landmarks (a problem studied experimentally with Clark’s Nutrackers --- a species of crow), the authors show how the problem can be solved through a simple form of sensory-motor coordination and without the need of any internal representation. Although the obtained results do not falsify the assumption that natural organisms use “cognitive maps” and “place cells” to detect geometrical relationships, they demonstrate that these problems admit~~s~~ other qualitatively different solutions.

Iizuka & Ikegami provide a new interesting perspective on perception and categorization. They demonstrate how evolved robots use the possibility of autonomously switching the impact of sensory neurons on or off to solve categorization problems. More specifically, authors demonstrate how robots selected for the ability of approaching or avoiding light blinking at different time rates show an ability to couple their internal dynamic (that determines the rate with which sensory information is switched on and off) with the dynamic of the blinking light.

Tuci, Trianni & Dorigo’s contribution addresses the problem of integrating sensory information over time. In particular the authors show how robots provided with continuous time recurrent neural networks are able to: (1) act so to bring fourth the perceptual experience necessary to discriminate between two types of environments and, (2) integrate relevant sensory information in time. Moreover the authors show how evolved robots generalize their discrimination ability to new environmental circumstances never experienced before.

Parisi’s contribution stresses the potential advantages of modelling behaviour as a property that emerges not only from the interaction of the organism with the external environment but also with organisms’ internal physical structure (a rather unexplored aspect in Cognitive Science and Evolutionary Robotics research). The paper discusses the differences between the two types of interactions and describes some simple experiments of the latter category: robots which evolve a biological clock that allows them to modify their behaviour between day and night, robots which evolve a pain signal associated with some damage in their body, and robots which can be hungry and/or thirsty and respond adaptively or maladaptively to conflicts between these two motivations.

Ziemke, Bergfeldt, Buasson, Susi, and Svensson’s contribution also focuses on a rather unexplored research area: the study of how robots might be able to adapt their environment to their own needs. More generally, the paper claims that it is time for Evolutionary Robotics to look at the issue of “Cognitive Congeniality” from an evolutionary perspective: that is, how the capability of animals to modify their environment affects the evolution of cognition. After a theoretical discussion of the topic and of the related literature, the authors present~~s~~ some preliminary experiments in which evolving robots modify the position of some landmarks in their environment.

References

Baldassarre G., Nolfi S. & Parisi D. (2003). Evolving mobile robots able to display collective behaviour. *Artificial Life*, 9: 255-267.

Baldassarre G., Parisi D. & Nolfi S. (2004). Coordination and behavior integration in cooperating simulated robots. In S. Schaal, A. Ijspeert, A. Billard, S. Vijayakumar, J. Hallam and J-A.

Meyer (Eds.), *From Animals to Animats 8: Proceedings of the VIII International Conference on Simulation of Adaptive Behavior*. Cambridge, MA: The MIT Press.

Beer R.D. (2003). The dynamics of active categorical perception in an evolved model agent. *Adaptive Behavior*, 11(4):209-243.

Bongard J.C. & Pfeifer R. (2003). Evolving complete agents using artificial ontogeny. In F. Hara & R. Pfeifer, (Eds.), *Morpho-functional Machines: The New Species (Designing Embodied Intelligence).* Berlin: Springer-Verlag.

Cliff D., Harvey I. & Husbands P. (1993) Explorations in evolutionary robotics. *Adaptive Behavior*, 2:73-110.

Di Paolo E.A. (2000). Homeostatic adaptation to inversion in the visual field and other sensorimotor disruptions. In J-A Meyer, A. Berthoz, D. Floreano, H.L. Roitblat & S.W. Wilson (Eds.), *From Animals to Animats 6. Proceedings of the VI International Conference on Simulation of Adaptive Behavior,* Cambridge, MA: MIT Press.

Floreano D. & Urzelai J. (2001) Evolution of Plastic Control Networks. *Autonomous Robots*, 11: 311-317.

Marocco D., Cangelosi A. & Nolfi S. (2003), The emergence of communication in evolutionary robots. *Philosophical Transactions of the Royal Society London - A,* 361: 2397-2421.

Nolfi S. (2002). Evolving robots able to self-localize in the environment: The importance of viewing cognition as the result of processes occurring at different time scales. *Connection Science* (14) 3:231-244.

Nolfi S. & Floreano D. (1999). Learning and Evolution. *Autonomous Robots,* 7(1): 89-113.

Nolfi S. & Floreano D. (2000) *Evolutionary Robotics*. Cambridge, MA: MIT Press.

Nolfi S. & Marocco D. (2001). Evolving robots able to integrate sensory-motor information over time. *Theory in Biosciences*, 120:287-310.

Tuci E., Quinn M. & Harvey I. (2003). An evolutionary ecological approach to the study of learning behaviour using a robot based model, *Adaptive Behavior* 10:201-222.

Pollack J.B., Lipson H., Hornby G. & Funes P. (2001). Three generations of automatically designed robots. *Artificial Life*, 7:215-223.

Quinn M. (2001). Evolving communication without dedicated communication channels. In J. Kelemen & P. Sosik (Eds.) *Advances in Artificial Life: Sixth European Conference on Artificial Life (ECAL 2001)*. Springer Verlag.

Quinn M., Smith L., Mayley G. & Husbands P. (2003). Evolving controllers for a homogeneous system of physical robots: Structured cooperation with minimal sensors. *Philosophical Transactions of the Royal Society of London, Series A: Mathematical, Physical and Engineering Sciences* 361:2321-2344.

Ziemke & Thieme (2002). Neuromodulation of reactive sensorimotor mappings as a short-term memory mechanism in delayed response tasks. *Adaptive Behavior*, 10(3/4):185-199.