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Alberto Acerbi , Davide Marocco & Paul Vogt

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EDITORIAL
Social learning in embodied agents

1. Introduction

Social learning refers to the process in which agents learn, during their lifetime, new skills by interacting with other agents (for definitions and review of social learning in ethology see Zentall and Galef 1988; Heyes and Galef 1996). In the last decades, a large body of experimental studies (see for example Tomasello, Kruger and Ratner 1993) as well as analytical models (see for example Boyd and Richerson 1985) highlighted the significance of social-learning dynamics in the development of the behavioural repertoire of human beings. At the same time, researchers in animal behaviour have shown how social learning is widespread also in other species from primates (Whiten 2000) to rats (Laland and Plotkin 1990), birds (Sherry and Galef 1984), and fish (Dugtakin 1996), just to cite some influential studies.

More recently, research in artificial life, adaptive behaviour, evolutionary robotics, and, more generally, embodied dynamical systems started to focus explicitly on the features and outcomes of social-learning dynamics (see for example chapters in Dautenhahn and Nehaniv 2002; Nehaniv and Dautenhahn 2007). When considering behaviour as a complex outcome resulting from the interactions between different levels such as body, nervous system, and physical and social environment (Nolfi 2006), an embodied approach to behaviour seems particularly promising for the study of social learning phenomena, as they typically depend on several hierarchical relationships. Indeed, empirical observations, laboratory experiments and 'traditional' analytical modelling often experience difficulties in managing that complexity.

The aims of this special issue are two-fold. Although a consistent number of successful social-learning models have been realised in the last years, the field is still fragmented. With this special issue, we try to point out the shared results and the common open issues in order to contribute to the definition of the specificity of the embodied approach to social learning, as well as its connections with other approaches, inside and outside artificial life. Moreover, it will be an opportunity to review the recent advances on a fast developing field that can be relevant for many readers of *Connection Science*.

2. The contributions

In selecting the papers for this special issue, we tried to take an open view to different approaches and to stress the plurality of perspectives that an embodied approach to social learning permits.

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Hence, the contributions collected here vary in their degree of embodiment (from real robotics systems like in the contribution of *Pini and Tuci* to social network structures of abstract agents in the paper of *Gong, Minett and Wang*) as well as their methodologies (even though most papers are simulations or robotics experiments, the contribution of *Pereira, Smith and Yu* describes experiments of interactions between mothers and toddlers, while the contributions of *Thomaz and Breazeal* as well as *Otero, Saunders, Dautenhahn and Nehaniv* describe experiments on human–robot interaction). Finally, the contributions deal with different forms of social learning, from high level forms that characterise human dynamics (such as the contributions of *Kwisthout, Vogt, Haselager and Dijkstra* and *Wellens, Loetzsch and Steels*) to simple, animal-like forms of social transmission of information (like in the paper of *Thenius, Schmickl and Crailsheim*).

Social scaffolding (Vygotsky 1978) is the term that relates to how social interactions can provide guidance towards learning from one another. The first three papers show the importance of social scaffolds in human–human and human–robot interaction studies. In order to understand how we can build artificial embodied agents capable of social learning at a high level, it is instructive to look closely at the way humans learn socially. In their contribution, *Pereira* et al. sophisticatedly investigate the dynamics of turn-taking and joint coordination of bodily movements in mother–child interaction and their role in providing social scaffolds for the child's social learning of word meanings. They show that when turn-taking is better coordinated, learning tends to becomes better. The way such findings can be used in developing artificial systems capable of social learning is extensively discussed and could provide useful data to modellers on how to incorporate empirical findings on human interaction.

In their contribution, *Thomaz and Breazeal* describe part of their ongoing work regarding human–robot interaction between their robot Leo and student-subjects. In particular, they investigate how human social scaffolding can contribute to the robot's learning abilities. Even though their robot can learn by itself, its performance improves considerably from the guidance provided by the human. The authors show that the more guidance relevant to the learning task is given, the better the robot can learn. This contribution, thus, not only shows the importance of social learning, but also that there are individual differences in the way guidance is given by humans and that it is important to understand how humans interact with robots in order to improve human–robot interaction systems that can learn.

Within the field of human–robot interaction, and with the aim of understanding an appropriate way of designing a fruitful teaching–learning dynamic between humans and robots, *Otero* et al. present two exploratory human–robot teaching scenarios in which the role of human teacher is studied both from the robot and human point of view. In the first experiment, by examining different ways of teaching a robot, the authors show that the way in which the teaching process is carried out, and especially the way in which the robot's task is decomposed by the teacher, has a critical effect on the effectiveness of robot learning, while the second experiment addresses the same issue from the human viewpoint and studies the human teacher's spontaneous levels of event segmentation.

Work on language evolution represented 'historically' – and continues to be – one of the more developed fields in the study of social learning in simulative and robotics literature (see chapters in Cangelosi and Parisi 2002). In their contribution, *Gong, Minett and Wang* present a computational model of language evolution in which the language is acquired by the agents through social learning. In the three experiments presented, the authors aim to study the effect of social structure on language emergence and maintenance. In these experiments, the authors manipulate agents' individual probability to participate in social interactions to study the role of 'popular' agents in language evolution, the relationship between mutual understanding and social hierarchy, and the effect of inter-community communications.

Kwisthout et al. investigate the relationships between joint attentional mechanisms and the performances in language games played by the agents. The results of these simulations show

how, by adding constructs that mimic the three stages of joint attention identified in children's early development (checking attention, following attention, and directing attention), it is possible to observe an increasing improvement of performances and how this improvement has the same ordering as that of the emergence of these mechanisms in infants' development. Essentially, this again shows the importance of social scaffolding in learning.

Complementary to the contribution of *Kwisthout* et al. is that of *Wellens* et al.. In a related language game model, they discuss the difficulties arising in categorisation, meaning formation, and language emergence as the result of dealing with robotic agents, and propose a novel model of categorisation and learning word meanings that can deal with those difficulties. This contribution shows that social scaffolding is not the only important aspect of social learning, as argued in many other contributions, but that the cognitive capacity to categorise and name objects in a flexible manner is crucial to adapt to the dynamics of languages and the social environment in which they are used.

Thenius et al. describe, in their contribution, a multi agent model of the foraging of honeybees' colonies, and they show how cohorts of foragers can exploit the information provided by other cohorts of the same colony to detect changes in quality in other food sources they have never visited. This contribution emphasises how social learning can be, at least in some cases, considered as an emergent outcome of processes that are not, by themselves, oriented to an explicit exchange of information, but that social learning can be interpreted as a property of systems that have some peculiar characteristics, rather than a mechanism that resides 'in the heads' of the agents involved in social learning (on this point see also Marocco and Acerbi 2007). Moreover, this work represents one of the rare attempts to parameterise models with empirical data taken from observations of real animals.

The final contribution comes from the field of evolutionary robotics. In this work, *Pini and Tuci* present a series of simulations in which they evolve neural controllers for autonomous robots to study how phototaxis behaviour can be socially transmitted from a model to a learner, only by allowing the learner to physically follow the model while the model is performing its own behaviour. An interesting aspect of the work resides in the fact that the same neural controllers are shown to perform both individual learning of positive and negative phototaxis, and social learning. So, like the previous contribution, the authors present social learning not as a cognitive machinery 'in the head' of the learner, but as a dynamical process between to the individual capabilities of the learner and the physical interaction with the model.

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Alberto Acerbi[a], Davide Marocco[b] and Paul Vogt[c]
[a]Max Planck Institute for Evolutionary Anthropology, Leipzig, Germany;
[b]School of Computing, Communication, and Electronics, University of Plymouth, Plymouth, UK;
[c]ILK, Tilburg University, Tilburg, The Netherlands
Email: alberto.acerbi@eva.mpg.de