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Editorial

Epigenetic robotics: modelling cognitive development in robotic systems

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1. Introduction

According to Zlatev and Balkenius (2001), the goal of Epigenetic robotics is to understand, and model, the role of development in the emergence of increasingly complex cognitive structures from physical and social interaction. As such, Epigenetic Robotics is an interdisciplinary effort, combining developmental psychology, neuroscience, and robotics. This still recent field is being driven by two main, somewhat parallel, motivations: (a) to understand the brain by constructing embodied systems – the so-called synthetic approach, and (b) to build better systems by learning from human studies. While this two-pronged approach has led to promising results (see (Lungarella, Metta, Pfeifer, & Sandini, 2003) for a comprehensive review), these editors believe that the field will benefit from a more rigorous coupling between both components. Proposed models should provide a useful explanatory component and contribute to the validation and further development of theoretical foundations. The plausibility of a model should be demonstrated by providing possible explanations for the data available and by being accurate in a wide range of developmentally valid constraints (Berthouze & Ziemke, 2003). It is with this focus in mind that the four papers of this special issue were selected.

2. Papers in this issue

Attention, the process whereby a person or system decides where to look, or what to imitate, is a key component of development. As such, it has been the focus of quite a few contributions in the field of epigenetic robotics. In this issue, **Björne and Balkenius** aim to propose a cognitive model of how normal and autistic children deal with forced attention shifts. To test their model, they considered the study of Akshoomoff and Courchesne (1992) and Courchesne et al. (1994) in which both normal and autistic children were

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tested on a task involving mixed visual and auditory stimuli with forced attention shifts. Taking the stance that a model of autistic disorders should have its basis in a model of normal cognitive development, Björne and Balkenius constructed a general cognitive model from components developed to model various other cognitive tasks (e.g., task-switching experiments, visual search in real-time video sequences, emotional conditioning). By using non task-specific components, the authors could focus on the mechanisms of development, rather than on its consequences. The three components used were: a contextQ system that learns associations between stimuli and response based on reinforcement, a context module that controls in what context each stimulus-response association should be used, and an automation system that learns to produce stimulus-triggered contextual shifts. The authors show the model to successfully replicate human data, with differences between normal and autistic children accounted for by the variation of a single parameter describing the influence of the automation system on the context.

Keeping in the realm of the cognitive modeling of key developmental mechanisms, **Prince and Hollich** propose a formal perceptual-level model of synchrony detection, a form of contingency detection. As discussed by Gergely and Watson (1999) (see also (Gergely, 2003), in a previous special issue on Epigenetic Robotics), contingency detection (a generalized form of synchrony detection) has been linked to a vast array of critical cognitive developments (word learning, object interaction skills, emotional self-awareness and control to name just a few). Nadel (2004) for example, showed that contingency facilitates early reciprocal imitation, a mechanism hypothesized to help the development of a sense of agency. What we lack, however, is a formal model of synchrony detection. To measure synchrony in audio-visual information, Prince and Hollich used an algorithm by Hershey and Movellan (2000) – where synchrony is defined as Gaussian mutual information – and extended it to estimate the degree of synchrony. The model was tested against five tasks of increasing complexity – from integrating punctuate visual movements of an object and synchronous audio presentations of a word, to audio source separation using the continuous visual movements of an oscilloscope as a substitute for facial speech movements – and compared with data from infant studies (Pickens et al., 1994, Gogate and Bahrick, 1998; Hollich, Newman, and Jusczyk, 2004). Although experimental results showed some notable differences between system and infant performance (in particular on the most complex task), the model detected audio-visual synchrony at levels similar to those of infants, thus suggesting that a perceptually-based model could ground a developmental model of synchrony detection. The authors conclude with a number of possible future directions, which will certainly stimulate the development of contingency-aware epigenetic robots.

The next contribution deals with another critical component of development, imitation. The recent discovery of mirror neurons in the monkey has received considerable attention from robotics to neuroscience. Roboticists have quickly adopted mirror neurons as a do-it-all tool to construct imitating systems. Yet, a number of open questions remain, one of which being: where do mirror neurons come from? This is precisely the focus of **Borenstein and Ruppin**'s contribution. Instead of designing a mirror neuron system, they developed evolutionary agents that demonstrate imitative learning, without explicitly specifying a particular mechanism for imitation. Adaptation was achieved using a modified version of Floreano and Urzelai's (2000) adaptation method. The examination of the agents' emerging characteristics – structure and dynamics of the resulting neuro-controllers – showed that the agents had developed a neural "mirror" device analogous to that observed in biological systems: certain neurons were active for both observation and execution of a specific action, and were not active in any other scenario. Although the complexity of the scenario is limited by computational considerations, the study does suggest a universal and fundamental link between the ability to replicate the actions of others and the capacity to represent and match others' actions. It is interesting that this result is supported by recent brain imaging studies showing that in humans such principle is present to a larger extent than in the monkey (e.g., general movement versus goal-directed movements).

Finally, **Dominey and Boucher** conclude this special issue by dealing with another critical issue in epigenetic robotics, namely, that of demonstrating the "successive emergence of behaviors in a developmental progression of increasing processing power and complexity". Language acquisition provides an excellent case-scenario because generative linguists have argued for the need of a "highly pre-specified" grammar (e.g., Chomsky, 1995) while various infants studies have suggested perceptual-level mechanisms to explain meaning acquisition (e.g., Mandler, 1999). The authors adopt a construction based approach and propose a biologically and developmentally plausible framework based on three main processes: (a) extraction of meaning from the environment using perceptual primitives. In particular, the authors exploit contact information, movements and spatial relationships, an idea which has recently received some attention in the Epigenetic Robotics community (e.g., Metta & Fitzpatrick, 2003); (b) learning mapping between grammatical structure and meaning: words are associated with individual components of event descriptions, and grammatical structure is associated with functional roles within scene events; (c) identifying-discriminating between different grammatical structures of input sentences, a step which requires a minimum baseline of semantic knowledge. The authors present experimental results showing the system successfully progresses from words to sentences. Finally, they discuss the extension of this construction framework to spatial relations and attention. Similarly to Björne and Balkenius's contribution, the focus is to show that non task-specific components can be re-used and provide the basis for the emergence of new behavioral functionality, a step which we hope will receive more and more attention from our community.

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Luc Berthouze, Neuroscience Research Institute, AIST, Japan.
Yiannis Demiris, Intelligent and Interactive Systems, Imperial College, UK.
Luciano Fadiga, Department of Biomedical Sciences, University of Ferrara, Italy.
Paul Fitzpatrick, Computer Science and Artificial Intelligence Laboratory, MIT, USA.
Philippe Gaussier, Université de Cergy-Pontoise and ENSEA, France.
Hideki Kozima, National Institute of Information and Communications Technology, Japan.
Valerie Kuhlmeier, Department of Psychology, Queen's University, Canada.
Max Lungarella, Department of Mechano-Informatics, Tokyo University, Japan.
Giorgio Metta, DIST, University of Genova, Italy.
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Matthew Schlesinger, Department of Psychology, Southern Illinois University, USA.
Gert Westermann, Department of Psychology, Oxford Brookes University, UK.
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