EDITORIAL

Epigenetic robotics

Modelling cognitive development in robotic systems

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What is Epigenetic Robotics?

Epigenetic Robotics is a new discipline at the frontier of developmental psychology, neural-, and engineering sciences whose goal is to model the development of cognition in natural and artificial systems. In this effort we see a bi-directional and mutually beneficial exchange of competences between different disciplines: robotics, computer science, neurophysiology, psychology, and artificial intelligence to name a few. Therefore, not only robotics can search for inspiration from results of neuroscience but, perhaps more importantly, it can contribute to neuroscience by suggesting new explanations to experiments and theories.

We see robotics as a new tool, filling the same role that systems theory played for computational motor control in the recent past, contributing to the understanding of the functioning of the brain. Robotics research can be, in our view, a new and powerful tool where models of brain functions are implemented and tested against a real physical environment. Moreover, Epigenetic Robotics includes the study of development which provides the unique possibility of observing the appearance and modification of cognitive structures in a progression from the embryo to the adult form. That is, we have the chance of observing the process of construction of cognition. Intuitively this should provide a deeper insight also into the adult manifestation of cognitive skills.

Interestingly, the study of development relates to the problem of designing artificial systems that adapt to the environment through learning and by

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modification of their initial skills. Development entails also open-ended and continuous adaptation during the physical interaction with the environment or during social interaction with other people.

The reason for endeavouring in building physical artefacts, instead of being content with simulations, is to be found in the complexity of the systems and problems under investigation. Beyond a certain level, it becomes extremely difficult to study realistic interactions between the agent and the environment without including a real body and real people in it. If we are to understand complex problems, then it seems plausible that there are no shortcuts to be easily taken, and that the full interaction has to be considered.

Epigenetic Robotics has also taken other names in different contexts, such as Developmental Robotics, Ontogenetic Robotics, etc. The word "epigenetic" was chosen here in antithesis to "phylogenetic", to distinguish this work from the field of evolutionary approaches and artificial life, and rather stress the aspect of postnatal development. A survey of the field was carried out recently by Lungarella et al. (Lungarella, Metta, Pfeifer, & Sandini, 2003) and constitutes so far the only comprehensive summary of Epigenetic Robotics research.

Papers in this issue

This special issue includes five papers selected among the submission of the 4th International Workshop on Epigenetic Robotics held in Genova, Italy in August 2004.

Kaplan and Hafner discuss joint attention starting from a comprehensive review of what is known from developmental psychology results and drawing then conclusions relevant for Epigenetic Robotics. In particular they frame their review on Tomasello's work (see for example (Tomasello, Carpenter, Call, Behne, & Moll, 2004)) by supporting the view that joint attention is a lot more than simultaneously looking or pointing. The authors stress the aspect of intentionality in joint attention behaviour in contrast to many studies that only analyze the geometric aspects of the interaction. As in Tomasello's proposal, Kaplan and Hafner consider joint attention as the sharing of a goal and intentions being the plan of actions to achieve that goal. Linking intentions to joint attention requires brain structures that can plausibly support such a link. Recent neuroscience results might indeed support such a proposal (Fogassi et al., 2005). Some of these aspects are also discussed in the Metta et al. paper in this same issue (pp. **xxx**).

The authors define joint attention as the "(1) coordinated and collaborative coupling between intentional agents where (2) the goal of each agent is to attend to the same aspect of the environment", then they derive requirements in terms of necessary skills and eventually interpret developmental psychology results in these terms. In particular, they discuss and categorize the current understanding of joint attention and show the prerequisites that must develop before the infants can engage in intentional interactions. It appears clear that our understanding and especially modelling of joint attention is modest as we consider these higher level capabilities.

Indeed, this is a timely review of joint attention research that tries to place itself on both realms by looking at developmental psychology while keeping an eye on existing robotics models. It is interesting to note how the authors aim "… to discuss the potential contribution of artificial models for the understanding of the development of joint attention" perfectly in line with the Epigenetic Robotics approach.

In the next paper by Fitzpatrick, Arsenio and Torres-Jara, we find an interesting work on a humanoid robotic platform where the multimodal aspects of perception are explored. This paper represents the leading edge of Epigenetic Robotics research by providing a fully-fledged implementation of the model in a robot while making links to developmental psychology research. In particular, it seems that the message of Gergely (Gergely, 2003) who was an invited speaker at the previous year's Epigenetic Robotics workshop was well received by the community and, in fact, also the paper by (Prince & Hollich, 2005) in a twin special issue on the same topic addresses the issue of timing and the exploitation of temporal aspects in multimodal signals. Furthermore, the paper by Striano et al., (pp. **xxx**) in this same issue investigates aspects of the sensitivity to interpersonal timing during dyadic interactions.

Fitzpatrick et al. propose computational methods for analyzing audio, video, and proprioceptive data as recorded by the robot sensorial system. In a series of experiments the authors touch the aspect of perceiving periodicity in visual, auditory, tactile and proprioceptive signals with the consequent segmentation of the object from the a possibly cluttered background. More importantly they also demonstrate various algorithms to match multimodal periodic events. The common theme here is the exploitation of redundant information, this being either because of periodicity or because of the temporal coincidence of various modalities.

The paper then shows yet another method to exploit redundant information which looks at cast shadows as a measure of 3D distance from a surface. Clearly humans seem to exploit all these cues opportunistically and this proof of principle by Fitzpatrick et al. shows that this might indeed be the case. Although we can get a working model in a robot, relating it to the actual brain functions is difficult. Fitzpatrick et al. cautiously say: "we cannot say whether those theories are true or false, but we can certainly say if they are productive". Nonetheless, productive theories are in general useful to improve and support the scientific understanding.

Metta et al. (pp. **xxx**) present another contribution to modelling cognitive skills which includes both sides of the Epigenetic Robotics research, namely, biological explanation and inspiration, and computational/robotics implementation. In this paper the authors strive to provide a biologically compatible explanation of the mirror neuron system by stressing a plausible developmental origin. Moreover, they propose a model which takes into account the interaction of different neural population in determining the activation of the mirror system.

Experiments are carried out to validate the model with two different experimental setups. In the first one, human grasping is analyzed by a machine learning classifier. The paper presents results supporting the idea that motor information is fundamental while learning to recognize other agents' actions. In the second experiment, a complete robotic implementation is presented showing that a robot acting in the environment and equipped with some basic visual routines can learn objects' affordances and factor this knowledge in when recognizing people's actions. A discussion on temporal delays and causation is also included to explain the sequence of learning events that constitutes the proposed theory of the development of the mirror system.

The paper by Striano, Henning, and Vaish moves us to developmental psychology proper. They analyzed the sensitivity of infants of 12 months of age to contingency and selective looking. It is interesting again to note the emphasis on "time" as the intermodal property par excellence which can be at the foundations of learning. In particular Striano et al. examine the behaviour of 12-month-olds after the interaction with two strangers, one of which is non-contingent. In the test phase they measured the gazing behaviour of the infants when presented with a novel toy. Infants looked more at the contingent stranger as in search of explanations and words about the new toy.

They conclude by saying that "all else being equal, timing plays a role in selective looking by 12-month-olds". This influence of timing links beautifully to both the already mentioned Tomasello's work and to the Fitzpatrick et al. paper. Time being amodal becomes the cue that selects relevant information in a cluttered environment. Clearly, the detection of synchronous events allows the brain to relate different sources and signals and consequently allows mapping one into each other thus segmenting and partitioning out the flow of information into coherent entities such as objects and people.

In another paper by Striano, Henning, and Stahl (pp. xxx) the interaction between caregiver and infant is analyzed subject to various temporal delays. The rationale of this set of experiments is that it is possible to separate contingency from pure time delay and, also, to dissociate these two effects on the infants. For all these experiments a closed-circuit double video system was employed which allowed manipulating the delays between caregiver and infant. Three and six month old children participated to this study. In fact, it was then possible to note the variation in attention (gazing) due to the temporal delay with respect to a control situation and the unaffected emotional content of the interaction (smiling).

This paper, as the previous one, stresses once more the importance of the analysis of "time" for adaptive systems, being these humans or humanoid robots.

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