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Introduction: The Fifth International Workshop on Epigenetic Robotics

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1. Introduction

The international workshop on Epigenetic Robotics has established itself as a forum for multi-disciplinary research, ranging from developmental psychology to neural sciences (in its widest sense) and robotics including computational studies. With contributions and audience increasingly spreading across disciplines, the two-fold aim of research in epigenetic robotics is also becoming increasingly clear. On the one hand, the proposed systems and models start showing the characteristics of human development, and in doing so, gain in robustness and flexibility; and on the other hand, these systems also establish themselves as an alternative route to understanding the brain, cognitive functions, and social development.

This year, in an effort to further encourage submissions by the psychology community, we introduced a dual-track (abstract, short-paper) submission system. Short-papers could be accepted either as long papers (to be extended up to 8 pages), short papers (4 pages) or posters. Forty short papers and 10 abstracts were submitted. Each contribution received three reviews which resulted in a technical program with 10 long papers, 8 short papers, 5 posters (from short paper submissions) and 8 posters (from abstract submissions). The workshop will also feature five invited talks that reflect the distribution of topics addressed since the inception of this series of workshops: robotics and dynamical systems (**Masahiro Fujita**), motor learning (**Eugene Goldfield**), imitation (TBA), cognitive development (**Annette Karmiloff-Smith**), and social interaction (**Brian Scassellati**).

2. Regular contributions

2.1 Long papers

So-called epigenetic systems/models often show only one step of development: such systems will typically acquire *one* motor skill, or will emerge *one* cognitive function. Yet human development is characterized by what **Prince, Helder and Hollich** call *on-going emergence*, i.e., the continuous development and integration of new skills. They propose six concrete criteria for a system to exhibit on-going emergence: (1) continuous skill acquisition, (2) incorporation of new skills with existing skills, (3) autonomous development of values and goals, (4) bootstrapping of initial skills, (5) stability of skills, and (6) reproducibility. On-going emergence is exactly what **Demiris and Dearden** try to address with HAMMER, a hierarchical architecture that implements a principled way for combining knowledge through exploration and knowledge from others. They describe a developmental pathway whereby the system can develop hierarchies of increasingly complex inverse models, and combine both learning through self exploration and learning from others. Predictive control plays a critical role in the simulation theory of mind advocated by those authors. It does so as well in **Balkenius and Johansson**'s model of gaze control for the development of visual attention. The authors describe a model of gaze control that includes mechanisms for predictive control using a forward model and event driven expectations of target behavior. They show the model to roughly undergo stages similar to those of human infants if the influence of the predictive systems is gradually increased. Once a visual target is identified, being able to reach for it is critical. From a control point of view, however, learning to reach is saddled with the so-called 'curse of dimensionality'. **Sun and Scassellati** demonstrate that sensory information from a vestibular system can be used to replace a portion of the kinematic chain involved in learning to reach. This replacement has two benefits: (a) it can result in a decrease of the dimensionality of the learning problem, and (b) the errors that are necessarily introduced by this replacement strategy lead to curved reaching trajectories similar to those observed in human reaches. Having the capability to reach objects it sees, a system can now engage in haptic exploration of objects in its environment. This is the focus of **Torres-Jara, Natale and Fitzpatrick**'s contribution. They adopt a bottom-up approach to adapting and learning about the environment. Rather than providing the system with abilities that would enable the robot to accomplish specific tasks, they provide it with a generic ability: tapping. The repetitive, redundant, cross-modal nature of tapping gives the robot an opportunity to reliably identify when the sound of contact with the object occurs, and to collect samples of that sound. The authors demonstrate the utility of this exploratory procedure for a simple object recognition scenario. Now, how would a robot understand whether it is touching an object or itself? That's the question **Edsinger-Gonzales** tries to answer. His robot learns to disciminate between ego and exo forces purely on the basis of its proprioceptive sense of force, through a series of semi-autonomous developmental stages.

Two papers round up this series of motor-related papers. In the first one, **Konczak** continues on last year's keynote with a review of two reflexive motor patterns in humans: Primitive reflexes and motor primitives. He argues that an understanding (and modelling?) of the human motor system that encompasses both primitive reflexes and motor primitives as well as the interaction with supraspinal motor centers is critical to the design of epigenetic robots. Indeed, understanding the mechanisms (change in connectivity? internal clock mechanism?) by which the *primitive* motor system is being integrated with later maturing supraspinal motor centers to give rise to complex motor behaviors should be most beneficial for robots to acquire complex motor skills in a bottom-up approach. In the second paper, **Veskos and Demiris** revisit a study published by Berthouze and Lungarella in a previous edition of the workshop on swinging and the degrees of freedom problem. Using a different formalism of central pattern generators, the authors successfully apply the same principle of entrainment to acquiring two motor skills: swinging and walking.

Finally, two papers deal with much higher cognitive tasks but still within the context of the system's sensory inputs. **Lacerda et al.** attempt to interpret the infant's first steps in the acquisition of the ambient language as a consequence of the infant's general capacity to represent sensory input and the infant's interaction with other actors in its immediate ecological environment. The authors argue that their Ecological Theory of Language Acquisition (ETLA), which they presented last year, offers a productive alternative to traditional descriptive views of the language acquisition process by presenting an operative model of how early linguistic function may emerge through interaction. Finally, **Blanchard and Cañamero** discuss a perception-action architecture for *imprinting* – the establishment of strong attachment links between robot and caregiver. Imprinting allows adaptation as a result of reward-based learning in the context of a history of affective interactions between the robot and the human. This certainly is an ability an epigenetic robot will need in order to proceed further in its social development.

2.2 Short papers

Building on their previous work on homeostatic behaviors, **Andry, Gaussier, and Nadel** propose a neural architecture for sequence learning, an important component for an imitating system. In their architecture, demonstration and reproduction stages are fused, with learning occuring when the system is not in an equilibrium.

Vitay proposes a computational model for a system to learn to count objects. An interesting particularity of his model is that this ability is realized from the merging, via a common reward signal, of two independent computational models: a model for switching spatial visual attention, and a model for learning the ordinal sequence of phonetical numbers.

Olsson, Nehaniv, and Polani continue with their research on the issue of how many sensory systems adapt to the environment. This year, they have a robot learn how correlations over time in the sensors are related to the actuators' activities. With this approach, a robot can develop from unknown sensors and actuators to being able to perceive motion.

Van Dartel and Postma investigate whether symbol manipulation, the hallmark of traditional cognitive science, can be achieved by robots with the ability to simulate perception and behaviour internally. As a case-study they investigate how and why internal simulation in a Situated Tower of London task improves performance in the Tower of London task, and compare system and human performance.

In an interesting attempt towards achieving ongoing emergence, **Clowes and Morse** look at language as a way to not only speed up the acquisition of normal behaviours, but also to further enable successful operation at tasks beyond the original capabilities of the agent. Investigating the Vygotskian idea that language plays a role in intimately structuring the learning environment, allowing the construction of more complex cognitive activities, the authors describe experiments with evolved agents that use self-directed speech and show that they achieve high fitness more rapidly than agents that don't.

Huang and Weng describe a reinforcement-based model for a robot to develop its covert perceptual capability (the selection of an action by a value system). The method is tested in a non-trivial vision-based navigation task.

Finally, in a contribution that nicely complements that of Prince et al., **Metta, Vernon, and Sandini** outline an agenda for the RobotCub project which could very well be an agenda for our entire community.

2.3 Posters

Understanding the development of joint attention is a crucial issue for research in epigenetic robotics. Prior studies in developmental psychology argue that skills underlying joint attention do not emerge until 9 month of age. **Stahl and Striano** present a longitudinal experimental study with sixteen infants from 7 to 10 months of age. Their results seem to indicate that such skills gradually unfold before 9 months of age. These findings that go in favor of a gradual development give encouraging support for robotic models that try to reenact the developmental trajectory towards joint attention. To achieve joint attention between machines using artificial vision systems, segmentation stability is often a key issue. **Baillie and Nottale** describe a way to measure the stability of a segmentation algorithm and present experimental results obtained with several algorithms under various forms of image distortion.

How can robots and computational models help understanding developmental disorders like autism? **Björne and Balkenius** have worked for a few years on a computational theory of autism. This year, they investigate the role of context in motor impairments for children with autism. They present a speculative view arguing that an inability to take contextual factors into account could explain some characteristic motor impairment in autism. From another perspective, **Miyamoto, Lee, Fujii and Okada** investigate how robots can facilitate interaction with autistic children. They present results of a longitudinal study with five children interacting with a speaking robot in two situations. They discuss in particular the cases of two children who showed developmental change in interacting with the robot.

How does an infant develop the animate/inanimate distinction? What underlie the feeling of animacy? **Kuwamura, Yamamoto and Hashimoto** discuss the relationship between movement and animacy with a psychophysical experiment where dynamical systems are designed using an interactive evolution method. Their results suggest that oscillations and stroke movements are key perceptual factors underlying the feeling of animacy.

Bredeche and Hugues investigate the issue of open development from an evolutionary robotics perspective. They suggest to define stages of increasing complexity in order to evolve increasingly complex controllers. For this purpose, they define an environment generator that automatically produces environments of adapted complexity. They present preliminary experimental results showing the efficiency of this approach compared to standard fitness criteria.

By sharing environmental sounds, humans and robots can share information on the environment. Unfortunately, it is difficult for humans and robots to communicate such sounds. **Hattori et al.** suggest to acquire a multi-modal mapping from sound to motion (the motion performed by the object that produced the sound) by learning from temporal contingencies. The robot can then imitate the motion using its body.

Aryananda placed her humanoid head robot with two basic in-built behaviors (tracking of faces and bright objects, mimicking of phoneme sequences) in an open-ended environment and tried to find out what the robot could see, and what it could hear. Results show that there was enough "interesting" information for the robot to start unsupervised lexical acquisition for example.

Mirza, Nehaniv, te Boekhorst, and Dautenhahn show that information theoretical methods can be used for a robot to characterize its interactions and interaction history. In particular, the authors show that fractal dimension of the sensory-motor phase plot is a useful measure.

Prepin, Gaussier, Revel, and Nadel briefly outline the basic principles of a formal approach – the Cognitive System Formalism – to represent, analyze and compare cognitive systems of developmental robotics and psychology.

Finally, **Oka and Ozaki** describe RobotPHONE, a simple robotic platform designed for educational purposes. By using a software SDK, students can experiment with associative learning systems and build easily simple epigenetic systems.

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