Adaptive **Behavior**

Editorial: Introduction to the Special Issue with Papers from the Fifth International Conference on Development and Learning (ICDL)

In June 2006, 168 researchers from 11 countries converged on the campus of Indiana University Bloomington to participate in the Fifth International Conference on Development and Learning (ICDL 05). Ever since its inaugural meeting at Michigan State University in 2000, ICDL has had a unique thematic focus. The conference brings together empirical scientists working in a broad range of natural and social sciences, such as developmental psychologists and neuroscientists, with researchers who are more focused on theoretical models and engineering, such as neural network or robotic systems. The goal is to identify principles of learning and development that are held in common between natural and artificial systems (Weng et al., 2001). The payoff is twofold: capturing these principles will pave the way to a better understanding of how development unfolds in animals and humans, and it will also lead to new kinds of technological systems that are capable of autonomous development.

Learning and development are traditional core topics for the journal *Adaptive Behavior*. This special issue presents a cross-section of cutting edge topics and approaches exemplified by five papers presented at ICDL 05. Eighteen out of a total of 93 papers that were presented at ICDL 05 received nominations by reviewers and members of the program committee to be included in this special issue. The five papers presented here were among those that received the highest overall rankings. After the conference, incorporating discussion and feedback, these papers were extensively revised and expanded, and they underwent a second round of peer review. The papers cover a range of topics, including reinforcement learning, the development of visual attention, modeling gaze following, the construction of interaction histories for autonomous agents, and the concept of distributed intelligence. Together they provide a snapshot of the breadth and sophistication of this emerging interdisciplinary effort into fundamental principles of autonomous development.

Reinforcement learning, and more specifically temporal difference (TD) learning, has been a strong focus in machine learning as well as in human and animal experimentation. While it has been quite successful as a framework for specific forms of biological learning, relatively little work has been done to investigate its interactions with other components of a cognitive architecture, or in the context of autonomous behavior. William Alexander's article attempts to integrate TD learning with models of attentional shifting in an autonomous agent. The proposed model incorporates effects of learning on the attentional representation of stimuli, and it does so in real time. The results point to a clear performance gain and better match to empirical data when attentional effects are combined with TD learning. This illustrates the importance of building models that integrate different functionalities and operate within a common cognitive architecture.

Matthew Schlesinger, Dima Amso, and Scott Johnson have studied the role of visual attention in infant development and argued that active deployment of attentional resources is crucial for the development of a visual object perception, specifically visual completion. Building on this empirical work, the current article presents a detailed model of the developing visual system in an attempt to use the model to gain insight into

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plausible neural mechanisms that underlie these developmental changes. Three specific neural constraints are investigated, oculomotor noise, horizontal connections in visual cortex, and recurrent parietal processing. The simulations provide insights that can be used to evaluate the potential role of these mechanisms during infant development and thus inform future experimentation. Specifically, the model suggests that increases in parietal processing may underlie experimentally observed developmental changes in visual search. This study provides an example for how empirical research can lead to a detailed model which in turn makes predictions about developmental mechanisms.

As humans direct their gaze to an object, a social partner observing this behavior may use it to direct their own gaze to the same object. Such gaze following is considered a behavior that is important for social interactions and its development in human infants is subject to intensive empirical study. Jochen Triesch, Hector Jasso, and Gedeon Deák describe a computational model of the development of gaze following that involves the emergence of mirror neurons for looking behaviors. In the model, mirror neurons in a premotor area link representations of other agents' visual behavior to intentions to execute corresponding actions. The model predicts the existence of mirror neurons for gaze following and provides a general insight into how mirror neurons might develop across time through a reinforcement learning mechanism.

Applications of information theory to the characterization of robot–environment interactions hold the promise of providing new insights into principles of autonomous development. All developmental processes unfold in time and the study by Assif Mirza, Chrystopher Nehaniv, Kerstin Dautenhahn, and René te Boekhorst represents an attempt to capture the individual history of interactions and behaviors of an autonomous agent within a quantitative framework. A key concept is that of the temporal horizon which defines the limits over which an agent has access to information that guides its ongoing behavior. The authors suggest that a temporally extended history may serve as the basis for guiding actions through individual experience, and may also support temporal projection (prediction) into the future. This interaction history is naturally rooted in embodied sensorimotor activity and social interactions. The authors develop a detailed model for how such an interaction history may be built and updated, based on methods from information theory.

In the final article of this special issue, Alex Pentland offers a fresh perspective on the nature of intelligence. In most traditional accounts, intelligence is attributed to an individual agent or organism. Pentland argues that a large part of intelligence emerges from interactions between individuals in social networks and should thus be attributed to communities of individuals. This view calls into question the prevailing notion of human behavior as caused by individual conscious thought, anchored in rationality and language. Instead, Pentland provides evidence that a large part of human behavior can be explained by simpler processes based on reactive patterns, unconscious social cues, and nonlinguistically mediated attitudes, goals and intentions. There are clear implications of this view of intelligence for our understanding of development.

Each of these articles embodies new approaches to empirical or computational research in autonomous development. Finding principles of development is important not only for understanding the emergence of behavior and cognition, it is also critical for creating the flexible and robust intelligent systems of the future—for such systems, as for animals and humans, development really matters!

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Reference

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