

Guest Editorial: Biologically Inspired Human–Robot Interactions—Developing More Natural Ways to Communicate with our Machines

As robots become more common in our daily activities, improving human–robot interactions (HRI) and human–computer interfaces (HCI) is becoming increasingly important. Despite considerable progress in this relatively new field, very few researchers have paid sufficient attention to how the brain, cognition, and underlying biological mechanisms are crucial for the success of such interactions.

This Special Issue of the IEEE TRANSACTIONS IN AUTONOMOUS MENTAL DEVELOPMENT (TAMD) brings together fields of study, such as cognitive architectures, computational neuroscience, developmental psychology, machine psychology, and socially affective robotics, to advance the field of human–robot interaction. The issue contains five papers that investigate recognizing intent, imitation, social cooperation, and developing language or gestures.

- 1) S. Heath, R. Schulz, D. Ball, and J. Wiles, "Long Summer Days: Grounded Learning of Words for the Uneven Cycles of Real World Events."
- 2) F. Chersi, "Learning Through Imitation: A Biological Approach to Robotics."
- 3) R. Kelley, A. Tavakkoli, C. King, A. Ambardekar, M. Nicolescu, and M. Nicolescu, "Context-Based Bayesian Intent Recognition."
- 4) D. E. Asher, A. Zaldivar, B. Barton, A. A. Brewer, and J. L. Krichmar, "Reciprocity and Retaliation in Social Games With Adaptive Agents."
- 5) S. Lallée, U. Pattacini, S. Lemaignan, A. Lenz, C. Melhuish, L. Natale, S. Skachek, K. Hamann, J. Steinwender, E. A. Sisbot, G. Metta, J. Guitton, R. Alami, M. Warnier, T. Pipe, F. Warneken, and P. Ford Dominey, "Towards a Platform-Independent Cooperative Human Robot Interaction System: III. An Architecture for Learning and Executing Actions and Shared Plans."

The common theme is to look at biology for inspiration to create better ways to communicate with robots and machines.

Developing language and grounding a vocabulary to places and times is an exciting and open area of research in HRI and in cognitive science. Because robots are situated in the environment, they need to solve the grounding problem to communicate information to other robots or people [1]. Thus, robots provide an interesting research platform to investigate these issues [2]–[5]. In "Long summer days: Grounded Learning of Words for the Uneven Cycles of Real World Events" by Heath *et al.*,

the authors use their iRat robots and the RatSLAM mapping system to develop concepts, such as morning, afternoon, dawn, and dusk. Their work builds upon prior work with the Lingodroids system [6]. In this framework, their robots demonstrate the ability to build their own maps, and evolve their own geoperational spatial language, which includes learning spatial concepts and words to learn temporal intervals. Time and space are fundamental to human language and embodied cognition. The Lingodroid framework addresses fundamental issues about time and timing that are not typically addressed in robot–human communication.

Recognizing intent is another key issue in HRI and HCI and is deeply rooted in neuroscience and psychology. The discovery of the mirror neuron system in the primate premotor cortex has led to wide range of research on recognizing gestures and imitation. Intent also has implications with respect to the Theory of Mind, a psychological concept in which we (e.g., humans) have an internal model of what another person might be thinking in a given situation. In "Learning through imitation: a biological approach to robotics," F. Chersi develops a model of the mirror neuron system using spiking neuron models with spike timing dependent plasticity (STDP) and implemented this model on a humanoid robot. In response to a human demonstrator, Chersi's architecture is able to extract the position of their hand and the object the person is grasping, reconstruct their posture and gesture and acquire necessary information about the task. The recognition and execution of motor sequences utilize a circuit of active mirror neurons chains. In "Context-Based Bayesian Intent Recognition," Kelley *et al.* introduce a framework that uses contextual information in the form of object affordances and object state to improve the performance of an underlying intent recognition system. Their system represents objects and their affordances using a directed graph that is automatically extracted from a large corpus of natural language text. They tested their approach in two different settings: a surveillance setting with a Pioneer 2DX mobile robot, and a household setting with the humanoid Nao robot. In both settings, the robots were able to effectively observe the agents within their fields of view and correctly infer the intentions of the agents that they observed.

Adaptation and cooperation are hallmarks of biological systems. Biological systems have the ability to adapt to the context of the environment and to social situations. Many cognitive robot designs have been inspired by biology's adaptive mechanisms [7]–[9]. Two papers in this special issue have developed HRI systems that investigate the neurobiological underpinnings of social interaction and the learning required for cooperation,

as well as developing working systems for HRI. In “Reciprocity and Retaliation in Social Games with Adaptive Agents,” Asher *et al.* employed economic game theory to probe subjects willingness to cooperate when playing competitive games against robots. A model of dopaminergic and serotonergic neuromodulation drove their robot’s behavior and allowed the robot to adapt to its opponents’ strategies. Subjects typically adopted a conservative strategy against the robot, but became retaliatory when the robot acted more aggressive due to lesions of its simulated serotonergic system. This study and others show how the physical embodiment of a robot can evoke strong responses in human participants [10], [11]. Lallée *et al.* present a cooperative human–robot interaction system that has been specifically developed for portability between different humanoid platforms in “Towards a Platform-Independent Cooperative Human Robot Interaction System.” Children are able to cooperate in novel situations, based upon social–cognitive capacities such as representing other people’s intentions, visual perspective taking, and imitation. In an integrated system capable of running on several robotic platforms to study human–robot interactions, they implement the fundamental skills, which enable young children to learn to engage in cooperative activities. Building on previous work on action perception and execution [12]–[14], their system demonstrates shared plan learning and the exchange of acquired knowledge between the iCub and the BERT2 robot platforms.

Biologically inspired human–robot interactions is a broad and exciting area of research, as can be seen by the contributions to this special issue of TAMD. These papers cover a wide range of topics and concepts that are of interest to cognitive psychology: affordance, cooperation, intent, knowledge of space and time, language, skill development, social engagement, and theory of mind. Moreover, the roles of many different brain areas (i.e., the hippocampus, neuromodulatory systems, mirror neuron systems, and parietal cortex) in the context of HRI are addressed in this set of papers. The systems developed by the contributing authors employ a variety of computational techniques (neural networks, Bayesian networks, hidden Markov models) and robots (both humanoid and mobile platforms). Finally, each paper presents a working system that has been deployed on a physical robot. These biologically inspired systems could have a strong impact on society and the widespread use of robots and intelligent machines. Robots that share many of the attributes of the human it is interacting with would not only result in a more sophisticated robot, but they may also allow the human to respond more naturally, and be more willing to cooperate with them. We hope that readers of this Special Issue will be inspired to contribute to this dynamic area of research and engineering in the near future.

FREDERICK C. HARRIS JR., *Guest Editor*
Department of Computer Science and Engineering
University of Nevada
Reno, NV 89557 USA

JEFFREY L. KRICHMAR, *Guest Editor*
Department of Cognitive Sciences
University of California
Irvine, CA 92697 USA

HAVA T. SIEGELMANN, *Guest Editor*
Department of Computer Science
University of Massachusetts Amherst
Amherst, MA 01003 USA

HIROAKI WAGATSUMA, *Guest Editor*
Department of Brain Science and Engineering
Kyushu Institute of Technology
Kitakyushu, 808-0196 Japan

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