Interaction Dynamics: The Interface of Humans and Smart Machines

By JOHN BAILLIEUL, Fellow IEEE

NAOMI EHRICH LEONARD, Fellow IEEE

KRISTI A. MORGANSEN, Senior Member IEEE

A
n essentially new domain of research involving the social and psychological aspects of humans interacting with smart machines has emerged over the past few years. Major funding agencies worldwide have become involved in supporting research that addresses various aspects of this interaction, and a corresponding body of published literature is now rapidly emerging. As new results are reported at scientific meetings and in scholarly journals, the interest of the popular press has been aroused. The public is being informed that “computer scientists [are] debating whether there should be limits on research that might lead to loss of human control over computer-based systems that carry a growing share of society’s workload” [1].

While the scientific debate is providing science fiction writers with fresh sources of material for the well-worked theme of “artificial intelligence systems run amok,” it is also pointing to an important change in the way scientific research into topics related to joint cognitive systems involving humans and machines is carried out. In many of the projects currently under way, the research teams involve a nontraditionally diverse mixture of disciplines. The projects have given birth to a network of scholars in which philosophy, psychology, biology, mathematics, engineering, and computer science are now linked. It is an exciting time as researchers from widely varied domains of study work to understand each other’s language and thought modalities.

A common focus of much of the current research on human–machine interactions is decision making. Models of decision dynamics from those based on the simplest organisms (such as E. coli foraging strategies—as described by Montague [2]) to those that have the most significant consequences (such as decisions regarding the use of lethal force—as discussed by Arkin [3]) are being developed, analyzed, and debated.

In broad terms, this Special Issue on Interaction Dynamics: The Interface of Humans and Smart Machines treats two interrelated topics:
1) communication and trust between humans and robots and 2) decision dynamics. The first of these topics is increasingly of interest as robots are becoming more and more autonomous. In many ways, the second topic has grown naturally from the foundations of classical decision theory [4]–[6]. The major new element of the research being reported in the Special Issue is the emphasis on empirical studies of human decision making and how this decision making depends on such factors as social context and interactions, speed versus accuracy tradeoffs, and natural tendencies to place great or small emphasis on attention to detail in tasks involving search and exploration. In the future, autonomous machine agents will possess expanded decision-making capacity, and a deeper understanding of decision-making styles will be needed to prepare both our intelligent machines and their human operators for effective operation in human–robot teams. The Special Issue contains 12 papers, the first six of which deal to varying degrees with communication and trust between humans and robots, and the second six of which focus on decision dynamics.

The first paper, “Moral decision making in autonomous systems: Enforcement, moral emotions, dignity, trust, and deception,” by Arkin et al. examines ethical issues that inevitably arise as a consequence of fielding robotic systems that operate with much higher levels of autonomy than in the past. The paper argues that questions regarding ethical behavior by machines must be addressed as new generations of robotic warriors are about to be deployed.

The second paper, “Autonomy spectrum and performance perception issues in swarm supervisory control” by Coppin and Legras, reports research on the changing roles of human operators of unmanned systems as those systems operate with increased autonomy. The authors introduce the notion of an autonomy spectrum for a multiple uninhabited air vehicle (UAV) system that permits visualization and analysis of how the different levels of autonomy depend on the nature of the tasks being undertaken.

The third and fourth papers deal with interface technologies that enable human operators to communicate with robotic agents. In “A sketch interface for robust and natural robot control” by Shah et al., a probabilistic multistroke sketch recognition interface for commanding mobile robots is developed. The use of the interface in commanding behaviors of experimental robots is described, and the results of a set of 64 experiments in which 16 operators controlled a single mobile robot in an indoor search-and-identify mission are reported. The paper “Human-oriented control for haptic teleoperation” by Hirche and Buss, discusses recent control design successes in the area of haptic teleoperation. Recent work on dissipativity-based modeling is reported for subsystems of a teleoperation system, and a novel approach to guarantee stability of the closed-loop system with communication unreliabilities is presented. The paper also discusses human-oriented evaluation and design aspects of teleoperation systems.

The final two papers in the first set address scenarios where humans and automata assist one another. In “Building and verifying a predictive model of interruption resumption” by Trafton et al., the use of assistance to recall narrative position in storytelling after an interruption is explored. A model of whether the storyteller remembered the position in the story was built based on human–assisted human experiments then utilized with robot-assisted human pairings where the robot was tasked with determining whether to remind the storyteller of narrative location. The human–robot experiments performed well in this context, and the results predicting both quantitative and qualitative phenomena point to a bright future of effective human–robot interaction.

The work in “The impact of human–automation collaboration in decentralized multiple unmanned vehicle control” by Cummings et al. is the thematic converse of the previous paper. Automated mission planners for assisting operators of networked automata are considered in scenarios in which both routine and unplanned events occur. The work shows that performance can be improved quite significantly for unanticipated events through the use of human oversight, but for cases of rapid and/or precise calculations, human aid was not a significant improving factor in performance. These results clearly demonstrate the relative efficacy of variable levels of autonomy.

The second set of papers focusing on decision dynamics begins with “A dynamical queue approach to intelligent task management for human operators” by Savla and Frazzoli. In this work, effective workload management is studied based on dynamic queueing in which service time depends on server utilization history. This type of service dynamic is based on empirical data of human performance in relationship to mental arousal. Analytical designs for maximally stabilizing task release control policies are presented, and these address the deterministic workload case as well as the case of randomly varying workloads. The results are backed by initial human operator data and corroborate workload assignment methods used in common practice.

This paper is followed by “Accuracy and decision time for sequential decision aggregation” by Dandach et al., which addresses collective decision making based on aggregation of independent decisions using threshold-based methods. In the scenarios considered here, group decisions based on different aggregation rules are compared. The results indicate that the fastest group decision tends to agree with the first decision made by an individual in the group and that majority rule decisions provide exponential improvement over fastest time decisions in terms of accuracy.
The paper “Towards human–robot teams: Model-based analysis of human decision making in two-alternative forced choice tasks” by Stewart et al. develops an analytic predictive capability using a Markov model of decision making in human groups. Steady-state probability distributions of decision sequences are derived, and analysis yields testable results on the sensitivity of individual performance to parameters such as the strength and path of the social feedback. The paper discusses possible applications to human–robot team and network design.

The final paper, “Decision making for rapid information acquisition in the reconnaissance of random fields” by Baronov and Baillieul, describes new sensor-enabled motion control techniques that can be used for rapid robotic reconnaissance of unknown spatially varying scalar fields. There are both theoretical and experimental components of this research. The theory provides the foundation for developing efficient reconnaissance strategies that explicitly account for the tradeoff between speed and accuracy. Contact is made with classical concepts in information theory, and the reconnaissance algorithms can be thought of as providing heuristics for the steepest ascent of an information gradient. The paper concludes by describing a computer game that has been designed to simulate reconnaissance of unknown fields. Players carry out reconnaissance missions in which the goal is to quickly generate contour maps of an unknown field. The game records each player’s performance in acquiring information about both the topology and geometry of fields that have been randomly generated.

When the guest editors began discussing the possibility of assembling a cohesive set of papers for this Special Issue, it was of some concern that much of the research we wanted to cover had not yet achieved the level of maturity that readers expect to see in the PROCEEDINGS OF THE IEEE. The past several years have witnessed remarkable progress, and it is our hope that the work that is herein reported will be of use to a rapidly growing research community. We conclude by expressing gratitude to Dr. Sharon Heise and Dr. Fariba Fahroo of the U.S. Air Force Office of Scientific Research for their support and vision in creating several large-scale research efforts dealing with human behavior in mixed teams of humans and semiautonomous machine agents.
Motivated by this work, he has been led to other challenges in the design of decentralized control algorithms for networks of mobile sensor networks, collective animal behavior, and decision dynamics in mixed teams of humans and robots.

**Kristi A. Morgansen** (Senior Member, IEEE) received the B.S. (summa cum laude) and M.S. degrees in mechanical engineering from Boston University, Boston, MA, in 1993 and 1994, respectively, and the S.M. degree in applied mathematics and the Ph.D. degree in engineering sciences from Harvard University, Cambridge, MA, in 1996 and 1999, respectively. After receiving the Ph.D. degree, she was first a Postdoctoral Scholar and then a Senior Research Fellow in Control and Dynamical Systems and Mechanical Engineering at the California Institute of Technology, Pasadena. In August 2002, she joined the faculty of the Department of Aeronautics and Astronautics, University of Washington, Seattle, where she is currently an Associate Professor with tenure. From 2002 to 2007, she held the chaired position of Clare Boothe Luce Assistant Professor of Engineering at the University of Washington. Her research interests include nonlinear control and dynamics with current interests in cooperative control, collective motion, and collective decision making. Applications include mobile sensor networks, collective animal behavior, and decision dynamics in mixed teams of humans and robots.

Prof. Morgansen received a National Science Foundation (NSF) CAREER Award in 2003 and the 2010 Hugo Schuck Award for Best Paper in the Theory Category in the 2009 American Control Conference.