*Editorial Introduction to the Special Articles in the Fall Issue*

# Human-Centered Cognitive Orthoses: Artificial Intelligence for, Rather Than Instead of, the People

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■ *This issue of AI Magazine includes six articles on cognitive orthoses, which we broadly conceive as technological approaches that amplify or enhance individual or team cognition across a wide range of goals and activities. The articles are grouped by how they relate to orthoses-enhanced sociotechnical team intelligence at three different cognitive levels—sensorimotor physical, professional learning, and networked knowledge.*

Human-centered design aims to create technology that fits the capabilities and needs of people, including their practices and learning processes. A human-centered approach can be contrasted with a technology-centered design process in which how people interact with a system comes last, proceeding from automating functions to developing an interface, and then teaching people to use the interface. Human-centered design begins by characterizing the interests, capabilities, and limitations of individuals (or groups) with respect to the underlying activity the new design will address. This often involves an earlier partnership between the designer and end users who together iteratively experiment with and improve prototypes. In this manner, the design may be refined and adapted to changes in work or life practices and exploit new opportunities the technology itself enables.

When we think about prosthetic devices, we typically picture devices that substitute for missing limbs (for example, prosthetic legs) or sensory capabilities (for example, cochlear implants) to restore or extend an individual's capabilities. But

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orthotic devices like eyeglasses can improve or enhance individual capability without acting as a replacement. By extension, one can view tools like power screwdrivers as going beyond normal capability but relying on people to hold and direct them. Correspondingly, cognitive orthoses constitute the class of technological systems that improve, leverage, and extend the user's cognition while operating in tandem with it. This special issue covers some recent advances in the different kinds of "orthoses" that support cognitive activities and how these different technologies demonstrate human-centered design through development of a joint human–machine system.

In summary, in formulating this special issue we broadly conceived cognitive orthoses as technological approaches that amplify or enhance individual or team cognition across a wide range of goals and activities. The six articles in this volume are grouped by how they relate to orthoses-enhanced sociotechnical team intelligence at three different cognitive levels—sensorimotor physical, professional learning, and networked knowledge.

Many advances of the human species have begun by enhancing an individual's physical capabilities. Whether the tool is a simple one, such as a spear, or more sophisticated, such as a jet plane, the interface is critical to the operation and the basic design principles apply. Wearable robotics (also called powered orthoses) designed to restore or extended a person's physical capabilities require integration into a biological system, a system that does not have a digital input or output port or rigid attachment points. Standard computer interfaces, such as keyboards, mice, and joysticks, are impractical for wearable robots, especially those designed for rehabilitation or mobility assistance. The article by Jose L. Contreras-Vidal, Atilla Kilicarslan, He (Helen) Huang, and Robert G. Grossman, Human-Centered Design of Wearable Neuroprostheses and Exoskeletons, discusses state-of-the-art techniques for brain–machine interfaces that assist people in walking. Traditional physical rehabilitation depends on repetitive motions of the patient. Learning and healing has been found to be more effective using a robot that works in tandem with the patient. The article by Domen Novak and Robert Riener, Control Strategies and Artificial Intelligence in Rehabilitation Robotics, presents the latest techniques for creating a human-machine system in the rehabilitation setting.

Applications to education and learning have been an AI research theme since the early 1970s. Janet L. Kolodner's article, Cognitive Prosthetics for Fostering Learning: A View from the Learning Sciences, challenges AI researchers to reconsider the roles intelligent technologies might play in the variety of practical settings in which learning is possible. She gives examples of formal and informal learning environments that enable learners to engage in aspects of professional work, in which the learning more generally can be viewed as promoting a productive, healthy, and engaged life. Of particular interest are environments (including tools and platforms) that people inhabit over long periods. The present-day notion of a learning system as a technologically-infused environment is very different from the original concept of tutoring dialogues and automated instructors; it adapts early research to make technology fit what people are doing and how they learn in particular settings.

Following the perspective of the learning sciences, the article by Santosh Mathan and Nick Yeung — Extending the Diagnostic Capabilities of Artificial Intelligence–Based Instructional Systems — explores the evolution of AI orthoses in tutoring. Automated teaching systems have matured from those that mimicked the rote instructional style of a lecture hall or a procedures training station, evolved to include adaptation to individual learning styles, biases and skill sets (for both learning and for skills in the particular task). With the addition of psychophysiologic measures and cognitive state estimation, however, the intelligent automated tutors can now approach the capabilities of human instructors in one-on-one training to readily recognize student thought process errors early enough to avoid


**2016 AAAI Spring Symposium Series**

**March 23-25**

The Association for the Advancement of Artificial Intelligence's 2016 Spring Symposium Series will be held Monday - Wednesday, March 21-23, 2016, at Stanford University, in cooperation with the Stanford Computer Science Department. The titles of the six symposia are as follows:

AI and the Mitigation of Human Error: Anomalies, Team Metrics and Thermodynamics (organized by Ranjeev Mittu, Gavin Taylor, Don Sofge, and W. F. Lawless)

Challenges and Opportunities in Multiagent Learning for the Real World (organized by Christopher Amato, Miao Liu, Frans Oliehoek, Karl Tuyls, Jonathan P. How, and Peter Stone)

Enabling Computing Research in Socially Intelligent Human-Robot Interaction: A Community-Driven Modular Research Platform (organized by Maja Mataric , Mark Yim, and Ross Mead)

Ethical and Moral Considerations in Non-Human Agents (organized by Bipin Indurkhya and Georgi Stojanov)

Intelligent Systems for Supporting Distributed Human Teamwork (organized by Ofra Amir, Krzysztof Gajos, Ya'akov (Kobi) Gal, Barbara Grosz, Jonathan Grudin), Robert Kraut, Gary Olson, and Peter Stone)

Observational Studies through Social Media and Other Human-Generated Content (organized by Elad Yom-Tov, Munmun De Choudhury, and Emre Kiciman)

Well-Being Computation: AI Meets Health and Happiness Science (organized by Takashi Kido and Keiki Takadama)

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entraining poor strategies, adapt the curriculum and alter tutoring styles dynamically. This approach can reduce impacts due to instructor skill variations and biases. Building on the 1990s work of Anderson and colleagues on the Adaptive Control of Thought – Rational (ACT-R) framework, the authors discuss the development of cognitive tutors that incorporate real-time cognitive state estimation through psychophysiologic sensing to dynamically adapt to the requirements of the learner. These AI-based cognitive tutors include parameters such as cognitive workload in the adaptive algorithm. This allows these truly student-centered tutors to become orthoses that teach more quickly, accurately and consistently than even the most experienced human instructors.

The AI methods used by search engines today, though often taken for granted, have radically changed how many scientists and engineers, shoppers, hobbyists, cooks, and others explore ideas and work. How does the notion of *fit* to user interests and behaviors apply when a radically new kind of tool becomes available? Daniel M. Russell's article, What Do You Need to Know to Use a Search Engine? Why We Still Need to Teach Research Skills, discusses search engines from the perspective of research activities and provides many tips for how to use search tools effectively. Search engines change the very nature of what it means for a person to know something. As cognitive amplifiers, these orthoses change what we can do and hence the nature of our ambitions, projects, and methods. Russell cautions us that some inquiries require knowledge on the part of the investigator to work through to a successful answer. And we need to be aware that the underlying information content, user interfaces, and capabilities of search engines are continually changing — arguably, no interesting AI system would remain static and unchanging, but rather it will adapt as new information continually flows into the core. This means that how search engines amplify our work and how we use them requires ongoing learning. Russell's article asks how people learn to use complicated and ever-changing AI systems.

Besides individuals, cognitive orthoses can apply to teams and communities. What does it mean to amplify the cognitive work of a group? Jim Spohrer and Guruduth Banavar's article, Cognition as a Service: An Industry Perspective, explains how the notion of cognition as a service leveraging big data can make professionals and their teams more productive and increase the output of industries, organizations, and nations. The article broadly relates the concepts of cognitive computing, cognitive systems, cognition as a service, and human-centered smart service systems. Smart service systems are sociotechnical configurations of people and technologies designed to deliver commercial and research services, such as a "cognitive assistant" design tool for manufacturing engineers. By viewing knowledge from a social perspective, in which a system integrates with a community of practice, this research seeks transformational change in improving and creating service systems. From this perspective, service systems are a kind of cognitive prosthesis that augments and scales expertise in a networked manner that promotes reimagining work practices for entire professions, industries, and geographic regions.

Together these articles reveal how artificial intelligence implementations — viewed not as standalone systems or individual "brains," but as orthotic devices that fit how people think, learn, and work and that amplify human cognition — have become part of our everyday lives and potentially would move the intellectual capability of individuals and society to a new level of organization and capability.

**Peter Neuhaus** is a senior research scientist at the Florida Institute for Human and Machine Cognition (IHMC). He received his B.S. from MIT and his M.S. and Ph.D. from the University of California Berkeley. In 2003, he joined IHMC. His work focuses on wearable robotic systems and legged robots. His work on wearable robotic devices centers on lower extremity exoskeleton devices with application for mobility assistance for people with paralysis and paresis, gait rehabilitation, strength and endurance enhancement, and smart exercise devices. He has developed a series of mobility assistance exoskeletons, including the IHMC Mina exoskeleton, which has demonstrated assisting two persons with paraplegia in walking mobility. After that, he completed the X1 exoskeleton with NASA Johnson Space Center, which offers strength enhancement for able-bodied people in addition to mobility assistance.

**Anil Raj** is a research scientist (M.D., 1990, and B.A., biomedical sciences, 1987, both from the University of Michigan) at the Florida Institute for Human and Machine Cognition (IHMC) who focuses on augmentic solutions for improving human-machine interactions for able-bodied and disabled individuals. Since joining IHMC in 1996, Raj has been involved with the development of human-centered interfaces and the development of automated systems for tracking, analyzing, and manipulating human response characteristics in dynamic task environments. He has developed methods for integrating heterogeneous software agents with human-centered interfaces and adjustable autonomy. He currently works on machine-learning systems for modeling brain function when using multisensory interfaces, investigating novel approaches to comparative effectiveness research, developing sensorimotor substitution approaches for augmenting situation awareness and mobility, and nutritional approaches to cognitive and physical performance enhancement.

**William J. Clancey** is a cognitive scientist (computer science Ph.D., Stanford University 1979; mathematical sciences BA, Rice University 1974) at the Florida Institute for Human and Machine Cognition; previously on assignment to NASA Ames Research Center, chief scientist for human-centered computing, Intelligent Systems Division (1998–2013). A founding member of the Institute for Research on Learning (1987–1997), he was lead inventor of Brahms, a work system design tool that simulates interactions between human practices and automated systems. He and his colleagues have developed applications of Brahms for medicine, aeronautics, robotics, and spaceflight systems. A real-time, distributed version of Brahms was used to develop OCAMS, which automates routine file transfers to the International Space Station. Clancey is a Fellow of the Association for Psychological Science, Association for Advancement of Artificial Intelligence, and the American College of Medical Informatics. He has written seven books including *Working on Mars: Voyages of Scientific Discovery with the Mars Exploration Rovers,* which received the AIAA 2014 Gardner-Lasser Aerospace History Literature Award.