**Guest Editors’ Introduction**

**Human-Centered Computing at NASA**

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Human-centered computing, also called “human-centered systems,”

- Focuses on creating new computational devices
- Is often contrasted with the traditional approach in computer science that might be dubbed “machine-centered computing”

That statement also accurately and succinctly describes NASA’s working definition of HCC. In the last issue of *Intelligent Systems*, Robert Hoffman and his colleagues presented a framework encompassing the various approaches that constitute the world of HCC. This special issue examines the particular region NASA is exploring within this vast world—the working definition of HCC shaped by NASA’s mission requirements, available resources, and existing investments.

HCC and human-factors engineering

HCC is influenced by emerging views within human-factors engineering in psychology. Historically, NASA efforts have entailed a great deal of human-factors research on topics including vision, fatigue and circadian factors, attention, cognitive modeling, display design and evaluation, virtual environments, workload models and metrics, design of procedures, human–automation interaction, decision making, and group performance. In recent years, new, important research topics have emerged, such as how to make automated systems “team players.” These topics have mandated an interdisciplinary approach and, more recently, have led to a focus on human-centered design. Both the approach and the focus have changed the landscape of human-factors engineering.

David Woods recommends more proactive involvement of human-factors engineers in the design of new systems, along with increased use of field research methods and strong integration of research with design and testing. His recommendations aim to increase the impact of human-centered design considerations, thereby improving overall system performance and reducing the likelihood of disastrous failures. HCC, in addition to extending our knowledge base about human behavior, focuses on creating new computational devices that amplify and extend human capabilities. In HCC, as in computer science generally, design, capability, and understanding are inextricably joined.

While embracing Woods’ vision about human-factors engineers’ role in design, HCC practitioners must keep in mind the research side of the research–design merger. HCC aims to deliver real systems, but enthusiasm for your own design con-
cepts or intimidation by implementation schedules sometimes drives out research-oriented concerns. For example, introducing new technologies into complex sociotechnical workplaces invariably changes the nature of the cognitive work of both individuals and teams. In the usual procurement process, after providing a deliverable to the sponsor, the system developers go away. HCC methodology mandates a second wave of empirical effort to ensure usability and usefulness in the envisioned workplace. Unless that happens, HCC might no longer be so clearly “contrasted with the traditional approach in computer science that might be dubbed ‘machine-centered computing.’”

**HCC and computer science**

Advances in computer science theory and practice have also uniquely shaped HCC. A core research challenge of HCC is to extend the scope of computer science and software engineering to include distributed systems of human agents and software agents. In particular, design and analysis methods must be extended to cope with the flexibility and adaptability required by present and future NASA missions. Computer science advances have been confined mainly to computational systems’ internal workings. Many difficult challenges that HCC poses deal with interactions between a computational system and its external environment.

In HCC’s concern with these external interactions, it is related to the software engineering subdiscipline known as requirements modeling. By drawing on a knowledge base from the behavioral, cognitive, and social sciences and integrating this knowledge with computational modeling systems, HCC places primary emphasis on exploring and questioning requirements. The refusal to oversimplify requirements engineering is mainly what gives HCC the look and feel of a research activity, despite its firm commitment to the design and implementation of actual systems.

When we build new systems for complex sociotechnical workplaces, we are actually building new tasks and jobs. This might incur grave risks. Gaps in our understanding of the real requirements have serious practical impacts, such as:

- Weak definitions of mission design alternatives
- Imprecise reasoning about tradeoffs among performance, cost, and safety
- Vague and unrealistic assumptions about operations concepts
- Unwillingness to change legacy systems because of unknown impacts
- Fragilities and user-hostile features that force local kludges and work-arounds

HCC as an emerging paradigm envisioned by Woods, Hoffman and his colleagues, and many others, including NASA researchers, is explicitly oriented toward developing a methodology that avoids these risks.

**HCC and NASA**

A mission system consists of the people, facilities, procedures, software, and other technologies required to conduct a NASA mission. Mission systems design must balance the risks of innovation against the costs of conservatism. NASA’s traditional approach is heavily weighted toward continuity of current-generation operations with those of prior missions. HCC aims to advance key technologies that will enable NASA to envision and evaluate a broader range of new mission system designs. The goal is to dramatically increase the range of visionary mission options.

NASA’s HCC research endeavors to improve the design of mission systems for science and exploration. HCC’s practical impacts will include launch and range operations, vehicle processing, and Space Transportation System and International Space Station orbital and ground operations, as well as surface, orbital, and remote planetary exploration operations. HCC is also concerned with advanced air–ground integration concepts in civil aviation.

The four articles in this special issue illustrate four aspects of NASA’s HCC research program: sociotechnical systems, multimodal interfaces, human–system modeling, and decision systems.

**Sociotechnical systems**

To achieve its technical ambitions, HCC must deploy the combined strengths of behavioral, social, and computer science. Behavioral and social sciences contribute essential methods for analyzing teams and organizations. Computer science contributes powerful theoretical and modeling approaches for describing dynamic hybrid systems. Combining all these methods lets us analyze existing sociotechnical systems and design new ones.

Sociotechnical systems are obviously more difficult to understand than are their software components alone. We find some of the same challenges as in conventional software engineering—interactions among schedule pressure, uncertainty, and dynamically changing situations and priorities. However, we also find other challenges that arise from interactions among software, teams, and the risky environments of aerospace operations.

In “Ethnography, Customers, and Negotiated Interactions at the Airport,” Roxana Wales, John O’Neill, and Zara Mirmalek discuss the combined use of behavioral, social, and computational methods to analyze an existing sociotechnical system—the commercial airline passenger system. They use ethnographic methods to build systematic, though informal, models of internal work processes, decision making, software design, and resource allocation as factors in airline passenger delays. They work at the boundaries of these informal models to identify external interactions across the system, exposing additional systematic influences that were invisible under the organizational model of routine air travel, with delays as an exception. They provide several practical suggestions for system-level improvements. “Negotiated interactions”—once described—present opportunities to develop new technology and services. Developing the systems to support an effective system design requires a new model of the airline passenger system and new kinds of user interfaces and intelligent systems.

This work demonstrates a core paradox of HCC, driven by the intimate connection of research methods and design goals: Meticulous description of work practice yields ideas for radical design changes. What seems at first an obsession with the status quo turns into a recipe for transformation.

**Multimodal interfaces**

Within sociotechnical systems, multimodal interfaces play a central role in acquir-
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ing, transmitting, and rendering information in visual, speech, nonspeech audio, and tactile formats. Methods and formal models for designing suites of such interfaces are in their infancy. NASA is exploring a wide range of interface concepts, including concept maps and speech recognition.

Multimodal interfaces must enable decision makers to integrate and interpret high-bandwidth, heterogeneous data for biomedical support, remote science, predictive control, intelligent-vehicle health maintenance, onboard-system management, and procedure execution.

In “Designing Human–Centered Distributed Information Systems,” Jajie Zhang, Vimla Patel, Kathy Johnson, Jane Malin, and Jack Smith consider information management and interface design in a distributed biomedical support system. They move beyond conventional human–computer interaction to a broad consideration of ontologies for interface programming. Interfaces must be described in terms of

- Levels of abstraction and flexible movement among levels
- Multiple representations and expert coordination of multiple representations
- Fast, error-free communication in safety-critical situations, including predictive and preparatory aspects of communication

Zhang and his colleagues’ perspective and methods extend our understanding of interface-programming methods from relatively static GUIs to team interfaces that reflect mixed-initiative models of content, activity, and dialog.

Mission-critical displays must fit with the cognitive characteristics of decision makers. This will ensure the reliability of time-pressured decision systems. Conventional display design focuses only at the level of representations, which are usually relatively independent of tasks, users, and functions. HCC focuses attention not just at the level of representations but also at the levels of roles, users, and tasks. This multilevel approach is important for designing information systems that support multiple types of users. Each particular user interface must be analyzed in relation to a larger system, as well as in relation to a set of tasks and procedures.

**Human–system modeling**

Understanding the requirements for specific interface designs necessitates the development of human–system models that enable analysis and simulation of key mission activities. A main technical challenge here is to create approximate models of human performance that can be integrated with other system engineering models. As in any type of modeling, model development must be cost effective, and models must be usable at variable and controllable abstraction levels.

Systems’ life-cycle costs are determined largely by early decisions. Model-based design methods must envision and quantify operational scenarios during these early design phases. Life-cycle costs and risks can be mitigated when early system models include human behavior. Without credible human behavior models, it is too easy to push aside safety, performance, and integration issues with the claim that they will be discovered and dealt with during “training.”

Human–system modeling has advanced significantly during the past two decades. The software engineering of modeling frameworks is vastly better today than it was in the early 1980s. As a result, human–system modeling frameworks can now “talk to” other modeling frameworks used during systems design. The objective is to improve early design by letting designers use cost-effective models of human behavior, procedural tasks, human–automation interaction, time budgets for individual agents, and consistency checks on synchronous and asynchronous (for example, document-mediated) communication.


The commitment to HCC as a software engineering methodology implies that HCC should be integrated with other advanced software engineering methodologies. Unlike many earlier human–modeling frameworks, Brahms has a sound semantic foundation, essentially compatible with process-algebraic semantics.

**Decision systems**

At each NASA mission system’s core are one or more decision systems that monitor life support systems, acquire and manage science and engineering data, control trajectories, and generally enforce performance and safety boundaries. Decision systems comprise teams of experts and machines, communicating over a network of multimodal interfaces. The cost-effective design and implementation of such systems presents a serious challenge to NASA and to HCC.

In “Intelligent Control of Life Support for Space Missions,” Debra Schreckenghost, Carroll Thronesbery, Peter Bonasso, David Kortenkamp, and Cheryl Martin describe how they built a decision system for advanced life support. They highlight the challenges of designing intelligent systems for flexible responses to unpredictable events. The nature of current and planned NASA missions precludes detailed planning and rehearsal of every activity. Communication delays and reliance on intelligent aiding systems require shared frameworks for communication and decision making among crew and software agents. Practical success here will be demonstrated by prototype systems that avoid the recurrent failures that Woods and others have documented.
Schreckenghost and her colleagues test the potential of agent-based tools and multimodal interface technologies to enhance the design, development, and deployment of high-performance human–automation systems in a realistic NASA mission environment. Indeed, NASA conducts all system-level tests of HCC decision systems with the research and mission personnel responsible for mission design and operations. This tight integration of research and operations is a defining characteristic of the HCC paradigm. This has two immediate benefits: Research and development challenges are calibrated against the ground truth of real mission operations, and early products of research and development become available for implementation as rapidly as possible. The goal is to design, prototype, and evaluate more-capable automated mission systems for ground and remote operations. A key challenge that Schreckenghost and her colleagues address is the modeling and representation of the vast knowledge required in NASA mission operations. Success in this effort will also benefit other projects at the Johnson Space Center, the Kennedy Space Center, and the Jet Propulsion Laboratory.

NASA HCC is responding to the challenges that Woods laid out by merging theory and models from computer science with knowledge and methodology from behavioral and social science. This conceptual and methodological integration, which Herbert Simon largely anticipated, is then put into practice via a “forward deployment” strategy that places highly trained researchers directly on the front lines of mission design and implementation. The result is a powerful, agile approach to the design of sociotechnical systems. This approach does not wait for organizational change—it causes change.

References


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The exploding popularity of mobile Internet access, third-generation wireless communication, and wearable and handheld devices have made pervasive computing a reality. New mobile computing architectures, algorithms, environments, support services, hardware, and applications are coming online faster than ever. To help you keep pace, the IEEE Computer Society and IEEE Communications Society are proud to announce IEEE Pervasive Computing.

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