Collected Essays on Human-Centered Computing, 2001-2011

Introduction

The notion of Human-Centered Computing (HCC) was introduced as a named program at the NASA-Ames Research Center. As shaped by Kenneth M. Ford, then the Associate Center Director at Ames, the NASA HCC program had a new vision for Artificial Intelligence (AI; see Ford, 2009). The Turing Test criterion for AI seeks to develop machine capabilities to imitate (or substitute for) the human. This is in contrast to HCC, which, in our perspective, has the goal of creating technologies that amplify and extend human perceptual, cognitive, and collaborative capabilities (Ford and Hayes, 1998; Hayes and Ford, 1995; Hoffman, Hayes, and Ford, 2001).

What Is Human-Centered Computing?

The term HCC is sometimes used as an umbrella, encompassing a range of research themes such as interaction design and intelligent systems, human-computer interaction, and so forth. Some identify HCC with social networking. Some uses of HCC terms and concepts come without any apparent commitment to HCC as an overarching conceptual framework for intelligent systems, other than a general interest in the development of complex human-machine systems that pay close attention to human and social factors. In this use of the HCC term, the field of HCC is simply the sum of its parts, so HCC can be described by an enumeration of the topics and sub-fields that make it up. For us, however, the phrase "human-centered" in such terms as "human-centered design," "human-centered systems," and "human-centered computing" implies a specific theoretical—and ethical—commitment for the design and development of technologies that augment human capabilities and expertise (e.g., Cooley, 1987; Winograd, 2006).

In a memorable encapsulation of a few of these themes, Ford, Glymour, and Hayes (1997) argued that the accumulated tools of human history could all profitably be regarded as orthoses—not in the sense that they compensate for the specific disabilities of any given individual, but rather because they enable us to overcome the biological limitations shared by all of us. With reading and writing, anyone can transcend the finite capacity of human memory; with a power screwdriver, anyone can drive the hardest screw; with a calculator, anyone can get the numbers right; with an aircraft, anyone can fly to Paris; and with IBM's *Watson*, anyone can beat the world Jeopardy champion. Eyeglasses, a familiar instance of an "ocular orthosis," provide a particularly useful example of three basic HCC principles:

- ***Transparency.*** Eyeglasses leverage and extend our ability to see, but in no way model our eyes: They don't look or act like them and wouldn't pass a Turing test for being an eye. Moreover, eyeglasses are designed in ways that help us forget we have them on—we don't want to "use" them, we want to see *through* them.
- ***Unity.*** Since our goal is not making smart eyeglasses but rather augmenting vision, the minimum unit of design includes the device, the person, and the environment. This mode of analysis necessarily blurs the line between humans and technology.
- ***Fit.*** Your eyeglasses won't fit me; neither will mine do you much good. Prostheses must fit the human and technological components together in ways that synergistically exploit their mutual strengths and mitigate their respective limitations. This implies a requirement for rich knowledge not only of technology, but also of how humans function.

Orthoses or prostheses are useful *only* to the extent that they "fit"—in fact, the "goodness of fit" will determine system performance more than any other specific characteristic. This is true whether one considers eyeglasses, wooden legs, or cognitive orthoses. One can identify two broad categories of fit—*species fit* and *individual fit*. In some cases, a particular aspect of human function can afford a consistent fit across most of a population of interest. In many other instances, however, an *individual fit* is desirable, and in these cases relevant differences amongst individuals must be accommodated (Ford, 2008).

One important difference between eyeglasses and the kinds of sophisticated machine-based assistance usually envisioned in HCC is the active, adaptive nature of the assistance. This quality is often characterized in the AI literature by the word "autonomy." Autonomy, however, sounds like just the *wrong* word for characterizing systems that are designed to assist, rather than replace, people. Though we are certainly interested in making machines more active, adaptive, and functional, the point of increasing these proficiencies is not merely to make the machines more independent when independence is required, but also to make them more capable of sophisticated *interdependent* joint activity with people. In addition to being able to hand off their tasks to machines, people need to be able to work coactively with them, participating in joint activity in a fluid and coordinated manner (Bradshaw et al., in press; Bradshaw, Feltovich, and Johnson, 2011; Johnson et al., 2011; Klein et al., 2004).

How Did This All Get Started?

The Federal High Performance Computing program was established in the mid-1990s, based on a report by the National Science and Technology Council that identified human-centered systems as an important program component (Computer Science and Telecommunications Board, 1994). Stemming from that was an NSF workshop on "Human-Centered Systems" held in Arlington Virginia in February 1997 (Flanagan et al., 1997). This workshop was motivated by the same general issues that had also motivated human factors and cognitive engineering:

> Human-centered systems have vast potential to... increase the effectiveness of computer technology... by making computers easier to use... In an era of unprecedented technological change and growth, basic scientific research is crucial to design appropriate interventions into complex human social systems and to analyze and evaluate the effects of such interventions. To be human-centered, a [computer] system should be based on an analysis of the human tasks that the system is aiding, monitored for performance in terms of human benefits, built to take account of human skills, and adaptable easily to changing human needs (Flanagan et al., 1997, p. 12).

"Human-centered systems" was not seen as a community of practice, but rather as a rallying point for an inter-discipline. This was reflected in the merging of three programs of the US National Science Foundation (Human-Computer Interaction, Universal Access, and Digital Society and Technology) into a cluster called Human-Centered Computing (Sears et al., 2008). The interdisciplinary nature of HCC is also reflected in the Statement of Goals of the IEEE Computer Society's Task Force on Human-Centered Computing (2009):

> The field... has emerged from the convergence of multiple disciplines and research areas that are concerned both with understanding human beings and with the design of computational devices and interfaces. Researchers and designers of human-centered computing include individuals from computer science, sociology, psychology, cognitive science, engineering, graphic design, and industrial design. (p. 1)

In retrospect, HCC has a number of historical antecedents. Detailed reviews of this history appear in Hoffman, Bannon, and Sebe (2010) and Hoffman and Militello (2008). Roots can be traced to the notion of "sociotechnical systems" developed at the Tavistock Institute in the 1950s, to DARPA-funded work in the 1960s (e.g., Licklider, 1960; Engelbart, 1962), and to European work analysis (DeKeyser, 1997; Floyd et al., 1989). In the 1980s and 1990s, sentiments about the consequences of deficient design of information technology were expressed by many scientists in fields of computer science, psychology, and human factors (e.g., Billings, 1996; Goguen, 1997; Landauer, 1995; Winograd and Flores, 1986). Beginning in the 1980s and continuing for a decade or so, a flurry of catchphrases were introduced, such as "Human-Centered Design," "User-Centered Design," "Contextual Design," and literally dozens more (see Hoffman et al., 2002). The impetus came from both academic groups and private industry.

What Are These Essays About?

In 1999 when Hoffman joined the Institute for Human and Machine Cognition, he was charged by its Director, Kenneth M. Ford, to "lay out the principles of HCC." At the time, Hoffman was one of the applied cognitive psychologists who had turned their attention to the study of domain experts (versus the academic study of the college freshman) and a confident practitioner of knowledge elicitation for expert systems. But he was broadening his focus to general cognitive task analysis methodology and its applications. He was not sure what these principles might be, or what it would mean for there to be such a thing as a "principle."

Bradshaw, on the other hand, with his background in both cognitive and computer science, had turned his attention early on from building knowledge acquisition tools for domain experts to the task of developing policy-governed multi-agent systems capable of participating in mixed human-automation teams (Bradshaw, 1997; in press). Though he was a latecomer as a Department Co-Editor on these HCC essays, the hallway leading between his office and that of Pat Hayes at IHMC had, for years, been a conduit for frequent sharing of ideas and outlooks.

Some 45 essays later, we have begun to achieve some clarity about the "principles of HCC." Both the evolution of HCC and its current theoretical and research foundations are laid out in the essays that are compiled into this volume. We hope that this may be the first of other such compilations. Already, we are told, this column has surpassed the longevity record of any other essay series that has previously appeared in IEEE journals.

The first section of the book includes some of the earliest essays, which focused on the question of what HCC is, and especially what its principles might be. As the diverse meanings and interpretations of HCC emerged, as we mentioned just above, we began to question what was meant by "principle" and began to look at broader systems-level issues.

The second section includes essays that focused on issues of teams and collaboration. The taxonomy of types of kludges and workarounds and the topic of design anti-patterns still present opportunities for empirical research that could lead to metrics for evaluating usability and human-centeredness. We still see considerable potential here.

We are seeing indications that the distinction between requirements and "desirements" is coming to be recognized as having value for our understanding of procurement processes. A comment often made is that "users" have difficulty specifying their requirements, and that, as designs are prototyped, the requirements described by the user keep morphing or "creeping" the bane of project management. The word "requirements" here refers to descriptions that enable the software engineer to proceed with the programming. It is important to recognize that requirements creep is inevitable, not a thing to be avoided or managed away. Rather than bemoaning this fact, users and software engineers need to work collaboratively, with users specifying their desirements and with designers bearing some responsibility for creative design, rather than simply "building to the requirements." The issue of responsibility in design is crucial with respect to the ultimate goal of building human-centered technologies.

IEEE Intelligent Systems originated in the heyday of expert systems, and the field of Expertise Studies is where we all cut our teeth in the 1980s. HCC remains directly related to expertise, since the goal of amplifying and extending human abilities is to achieve and exercise expertise. The macrocgnition-microcognition distinction discussed in a 2003 essay has proven valuable as a means for people to frame their inquiries and goals. The theory of sensemaking is gaining traction as a way of understanding human reasoning, often characterized in contrast with the "heuristics and biases" approach that focuses on human fallibilities. Finally, the notion of *perceptual re-learning of meaningful patterns that exist across multiple dynamic data types*—while a mouthful—is a significant extension of traditional notions of perceptual learning. It is crucial in most domains of expertise and certainly the critical activity in such domains as cybersecurity.

HCC seeks to escape the traditions of measurement and performance evaluation that place the worker as John Henry racing the steam hammer. Measurements of such things as hit rate, errors, efficiency, and so on are certainly useful and necessary for some purposes, but do not do well at capturing more meaningful levels of human-automation interaction. The distinction between measures and metrics is crucial, but generally overlooked. Metrics do not emerge from measures, or from the conceptual measureables that are the subject of measurement. Rather, metrics come from policy. The HCC Department's essays that pertain to measurement are an invitation to push measurement to more meaningful, system levels of analysis.

This topic of measurement relates directly to issues of procurement, and the final set of essays in this collection address this topic. These discuss barriers to human-centeredness as well as schemes such as the "Practitioner's Cycles" for injecting human-centered considerations into procurement. This is more than "human-system integration," which seems to simply be a new phrase to express some basic considerations that have a long standing in human factors (e.g., safety, manpower, training, safety). Human-centeredness is about making the work meaningful, about being *in* the problem rather than fighting the technology, and about human desires to achieve and grow.

In some of the essays we were deliberately tilting at windmills. With some sense of accomplishment—and astonishment—we see that some sails were actually moved.

The ten challenges for team players outlined in 2004 are still crucial considerations in work design and management for any sort of collective, whether humans and more humans, or humans and software agents and robots (Klein et al., 2004). Related to the increasing development and application of robotic technologies, the notion of task allocation has given way to a notion of human-machine interdependence (Johnson et al., 2011). This crucial concept merits further exploration and application.

Stay tuned—we're not done yet.

References

C.E. Billings, *Aviation Automation: The Search for a Human-Centered Approach*, Erlbaum, 2006.

J.M. Bradshaw, ed., *Software Agents*, The AAAI Press/The MIT Press, 1997.

J.M. Bradshaw, P.J. Feltovich, and M. Johnson, "Human-Agent Interaction," *Handbook of Human-Machine Interaction*, G. Boy, ed., Ashgate, 2011, pp. 283–302.

J.M. Bradshaw et al., "Sol: An Agent-Based Framework for Cyber Situation Awareness," *Kuenstliche Intelligenz*, in press, due May 2012.

Computer Science and Telecommunications Board, *Realizing the Information Future: The Internet and Beyond*, National Research Council, 1994.

M. Cooley, *Architect or Bee? The Human Price of Technology*, Chatto and Windus, 1987.

V. De Keyser, "'Shallow' versus 'In-Depth' Work Analysis in Human-Centered Design," *Human-Centered Systems: Information, Interactivity and Intelligence*, J. Flanagan et al., eds., Report, National Science Foundation, 1997, pp. 261–266.

D.C. Engelbart, "Augmenting Human Intellect: A Conceptual Framework," Stanford Research Institute, 1962.

J. Flanagan et al., eds., "Human-Centered Systems: Information, Interactivity and Intelligence," Report, National Science Foundation, 1997.

C. Floyd et al., "Out of Scandinavia: Alternative Approaches to Software Design and System Development," *Human-Computer Interaction,* vol. 4, no. 4, 1989, pp. 253–350.

K.M. Ford, "Toward Cognitive Prostheses," Robert S. Englemore Memorial Award Lecture, *23rd AAAI Conf. Artificial Intelligence* (AAAI 08), Association for the Advancement of Artificial Intelligence, 2008.

K.M. Ford, *Personal Communication*, Florida Institute for Human and Machine Cognition, 2009.

K.M. Ford, C. Glymour, and P.J. Hayes, "Cognitive Prostheses," *AI Magazine*, vol. 18, no. 3, Fall 1997, p. 104.

K.M. Ford and P.J. Hayes, "On Computational Wings: Rethinking the Goals of Artificial Intelligence," *Scientific American*, Special Issue on Intelligence, Winter 1998, pp.78–83.

J. Goguen, "Towards a Social, Ethical Theory of Information," *Social Science Research: Technical Systems and Cooperative Work: Beyond the Great Divide*, G. Bowker et al., eds., Erlbaum, 1997, pp. 27–56.

P.J. Hayes and K.M. Ford, "Turing Test Considered Harmful," *Proc. Int'l Joint Conf. on Artificial Intelligence* (IJCAI 95), Morgan Kaufman, 1995, pp. 972–997.

R.R. Hoffman, L.J. Bannon, and N. Sebe, "Human-Centered Computing," *Encyclopedia of Software Engineering*, P.A. Laplante, ed., Taylor & Francis, 2010, pp. 395–403.

R.R. Hoffman et al., "A Rose by Any Other Name… Would Probably Be Given an Acronym," *IEEE Intelligent Systems*, vol. 17, no. 4, July/Aug. 2002, pp. 72–80.

R.R. Hoffman, P.J. Hayes, and K.M. Ford, "Human-Centered Computing: Thinking In and Out of the Box," *IEEE Intelligent Systems*, vol. 16, no. 5, Sep./Oct. 2001, pp. 76–78.

R.R. Hoffman and L. Militello, *Perspectives on Cognitive Task Analysis*: *Historical Origins and Modern Communities of Practice*, CRC Press/Taylor and Francis, 2008.

M. Johnson et al., "Beyond Cooperative Robotics: The Central Role of Interdependence in Coactive Design," *IEEE Intelligent Systems*, vol. 26, no. 3, May/June 2011, pp. 81–88.

IEEE Computer Society, "Task Force on Human-Centered Computing," 2009; http://www.human-centered-computing.org/.

G. Klein et al., "Ten Challenges for Making Automation a "Team Player" in Joint Human-Agent Activity," *IEEE Intelligent Systems,* vol. 19, no. 6, Nov./Dec. 2004, pp. 91–95.

T.K. Landauer, *The Trouble with Computers,* MIT Press, 1995.

J.C.R. Licklider, "Man-Computer Symbiosis," *IRE Transactions on Human Factors in Electronics*, vol. HFE-1, Mar. 1960, pp. 4-11.

A. Sears et al., "Human-Centered Computing: Defining a Research Agenda," *International Journal of Human-Computer Interaction*, vol. 24, no. 1, 2008, pp. 2–16.

T. Winograd, "Shifting Viewpoints: Artificial Intelligence and Human-Computer Interaction," *Artificial Intelligence*, vol. 170, pp. 1256–1258.

T. Winograd and F. Flores, *Understanding Computers and Cognition*, Ablex, 1986.