Robots and Avatars as Hosts, Advisors, Companions, and Jesters

Charles Rich and
Candace L. Sidner

■ *A convergence of technical progress in AI and robotics has renewed the dream of building artificial entities that will play significant and worthwhile roles in our human lives. We highlight the shared themes in some recent projects aimed toward this goal.*

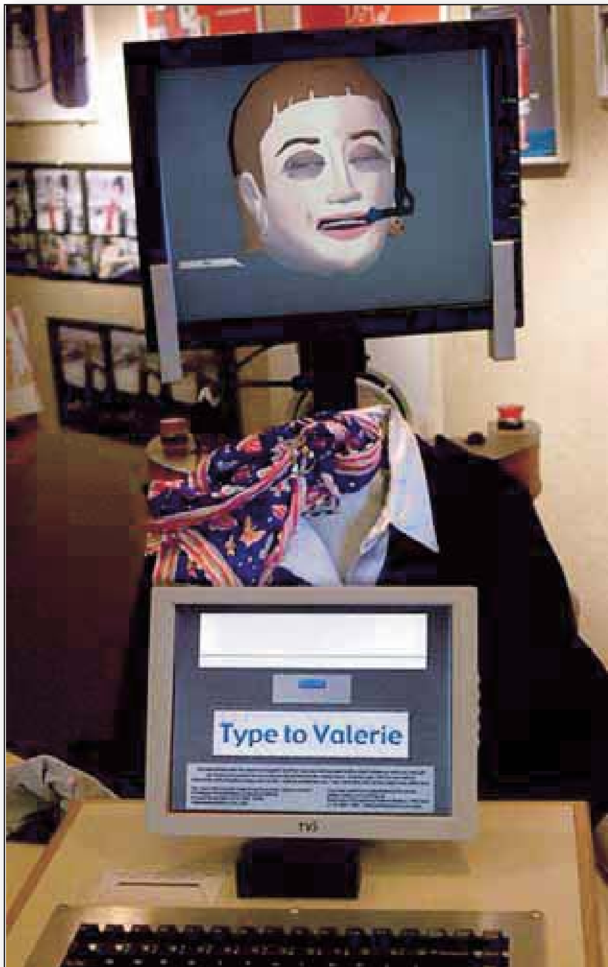
In the 1970s, some AI leaders predicted that we would soon see all manner of artificially intelligent entities in our daily lives. Unfortunately, in the interim, this has been true mostly in the realm of science fiction. Recently, however, pioneering researchers have been bringing together advances in many subfields of AI, such as robotics, computer vision, natural language and speech processing, and cognitive modeling, to create the first generation of robots and avatars that illustrate the true potential of combining these technologies. The purpose of this article is to highlight a few of these projects and to draw some conclusions from them for future research.

We begin with a short discussion of scope and terminology. Our focus here is on how robots and avatars interact with humans, rather than with the environment. Obviously, this cannot be a sharp distinction, since humans form part of the environment for such entities. However, we are interested primarily in how new interaction capabilities enable robots and avatars to enter into new kinds of relationships with humans, such as hosts, advisors, companions, and jesters.

We will not try to define *robot* here, but we do want to point out that our focus is on *humanoid* robots (although we stretch the category a bit to include a few animallike robots that illustrate the types of interaction we are interested in). Industrial automation robotics, while economically very important, and a continual source of advances in sensor and effector technology for humanoid robots, will continue to be more of a behind-the-scenes contributor to our everyday lives.

The meaning of the term *avatar* is currently in flux. Its original and narrowest use is to refer to the graphical representation of a *person* (user) in a virtual reality system. Recently, however, the required con-

 ISSN 0738-4602



Valerie.

nection to a real person has been loosened and the term *avatar* has been used to refer to NPCs (nonplayer characters) in three-dimensional computer games and to synthetic online sales representatives, such as Anna at ikea.com. We hope this broader usage will catch on and displace the term *embodied conversational agent*, which is somewhat confusing, especially in the same discussion as robots, since it is, after all, robots—not graphical agents—that have real bodies. We will therefore use the term *avatar* in this article to refer to intelligent graphical agents in general.

Human Interaction Capabilities

There are four key human interaction capabilities that characterize the new generation of robots and avatars: engagement, emotion, collaboration, and social relationship. These capabilities are listed roughly in order from "low-level" (closer to the hardware and with shorter real-time constraints) to "high-level" (more cognitive), but as we will see, there are many interdependencies among the capabilities.

Engagement

Engagement is the process by which two or more participants in an interaction initiate, maintain, and terminate their perceived connection to one another (Sidner et al. 2005). In natural human interactions, engagement constitutes an intricately timed physical dance with tacit rules for each phase of an interaction.

In copresent interaction, engagement indicators include where you look, when you nod your head, when you speak, how you gesture with your hands, how you orient your body, and how long you wait for a response before trying to reestablish contact. Strategies for initiating an interaction involve, for example, catching your potential interlocutor's eye and determining whether his or her current activity is interruptible. The desire to end an interaction (terminate engagement) is often communicated through culturally mediated conventions involving looking, body stance (for example, bowing), and hand gestures. Careful empirical and computational analysis of these rules and conventions in human interaction is increasingly making it possible for robots and avatars to connect with humans in these same ways.

Emotion

There has never been any doubt about the importance of emotions in human behavior, especially in human relationships. The past decade, however, has seen a great deal of progress in developing computational theories of emotion that can be applied to building robots and avatars that interact emotionally with humans. According to the mainstream of such theories (Gratch, Marsella, and Petta 2008), emotions are inextricably intertwined with other cognitive processing, both as antecedents (emotions affect cognition) and consequences (cognition affects emotions).

In terms of interacting with humans, a robot or avatar needs to both recognize the emotional state of its human partners (through their gesture, stance, facial expression, voice intonation, and so on) and similarly express information about its own emotional state in a form that humans can recognize.

Collaboration

Collaboration is a process in which two or more participants coordinate their actions toward achieving shared goals (Grosz and Kraus 1996). Furthermore, most collaboration between humans involves communication, for example, to describe goals, negotiate the division of labor, monitor progress, and so on. All the robots and avatars described in this article are designed to be participants in collaborations with humans (and possibly other robots and avatars, although we focus only on human interactions here).

In general, collaboration is a higher-level process that is supported by engagement; collaboration is farther from the "hardware" and has slower real-time constraints than engagement. For example, a collaborator relies on the engagement state to know when it is appropriate to continue with the collaboration. However, engagement and collaboration are not strictly hierarchical. The state of the collaboration can also affect how engagement behaviors are interpreted. For example, whether or not to interpret breaking eye contact (looking away) as an attempt to disengage depends on whether the next action in the collaboration requires looking at a shared artifact; if it does, then breaking eye contact does not indicate disengagement.

Social Relationship

Most work in this area to date has involved only short interactions with humans and robots or avatars (less than an hour), usually with a clear immediate collaborative goal, such as instruction, shopping, or entertainment. Even if a user interacts with a system repeatedly over a long period of time, such as return customers to a synthetic web sales agent, there is typically only minor continuity between episodes, such as the learning of user preferences. Furthermore, there has not generally been any explicit concern in the design of such systems towards building and maintaining long-term social relationships with humans, as would be the case for similar human-human interactions.

Recently, however, as we will see shortly, several researchers have begun developing robots and avatars that are designed to build and maintain social relationships with their users over weeks and months. In a sense, social relationship is the long-term correlate of engagement. The practical motivation for developing social relationships has been that the behavior change goals of these systems, such as weight loss and other better-health practices, require a long time to succeed and users are not as likely to persevere without the social relationship component. Thus social relationship supports collaboration, and also vice versa, since positive progress toward a shared goal improves the social relationship.

Humanoid Robots

Humanoid robots run the gamut from so-called "trash can" robots (no disrespect intended), such as Carnegie Mellon University's Valerie (Gockley et al. 2005) (see photo on page 30) and the Naval Research Laboratories' George (Kennedy et al, 2007), which simply place a face-only avatar display on top of a generic mobile base, to Ishiguro's Geminoid (Nishio, Ishiguro, and Hagita 2007), which attempts to cross the "uncanny valley" (Mori 2005) and emerge successfully on the other side. In between are all kinds of robots with humanlike, animallike, and cartoonlike appearances and dexterity in various proportions. The applications to which these robots are aimed are

George.

JAST.

Leonardo.

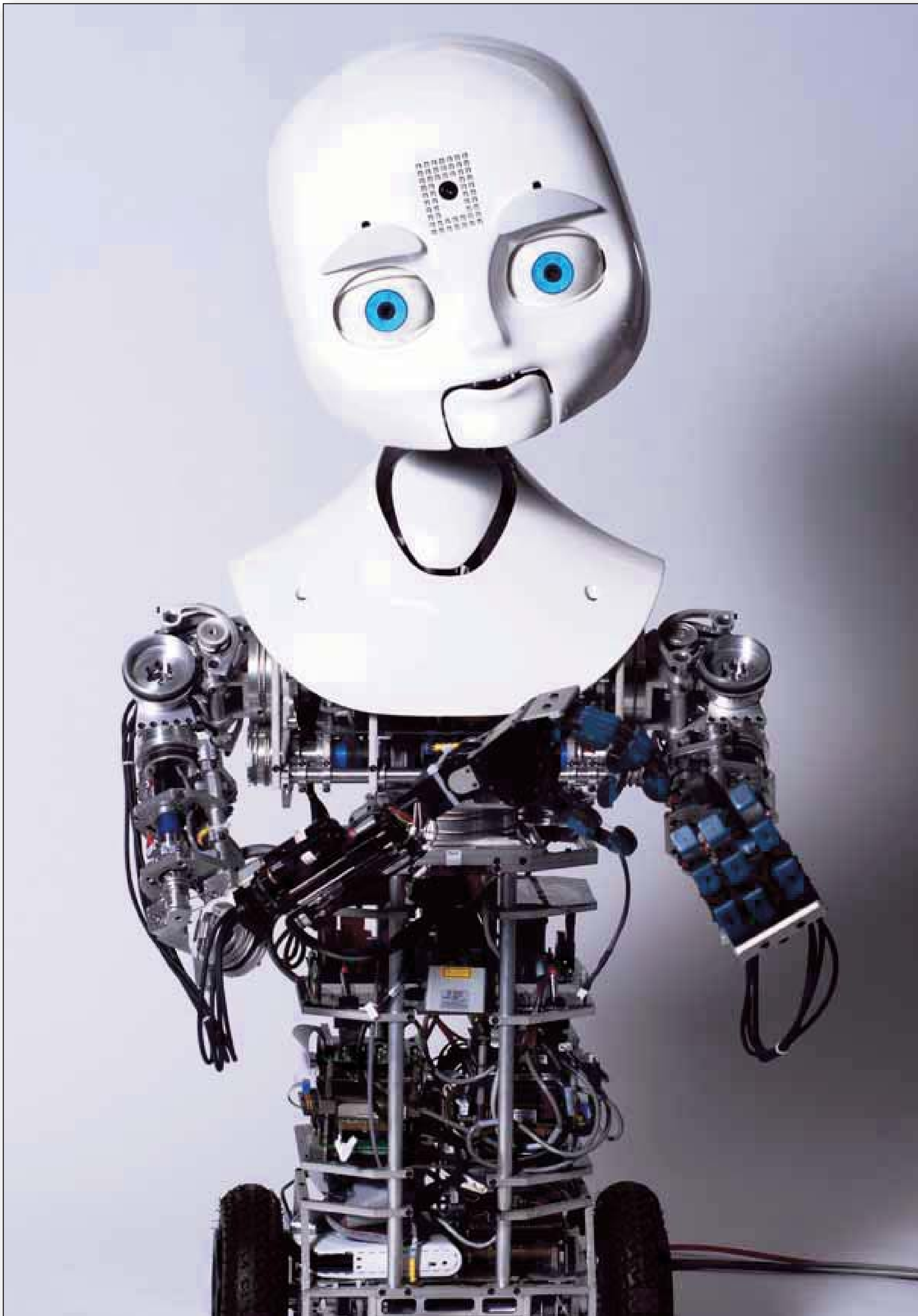
equally diverse. For example, the European Union's JAST robot (Rickert et al. 2007) mounts Philip's iCAT head on top of a torso with two very dexterous humanlike arms. The focus of this work is on collaborative dialogue in the domain of assembly tasks.

Probably the most complex animallike robot constructed to date is the Massachusetts Institute of Technology (MIT) Media Lab's Leonardo (Thomaz and Breazeal 2007), which has 61 degrees of freedom, 32 in the face alone. Leonardo's expressiveness is being exploited for research on the role of emotions and social behavior (thus far only short-term social interaction, not building long-term social relationships) in human-robot interaction. The Media Lab is currently completing an equally complex, but more humanoid, robot named MDS (for mobile, dexterous, social), which is roughly the size of a three-year-old child (see photo on page 33).

Our own recent work with Mel (see photo on page 34) (Sidner et al. 2005, 2006), a penguin wearing glasses with a moveable head, beak, and wings, mounted on a mobile podium base, studied engagement behaviors in the context of what we called "hosting." A robot host guides a human, or groups of humans, around an environment (such as a museum or a store), tells them about the environment, and supervises their interaction with objects in the environment. Hosting is form of collaboration and companionship aimed primarily at information sharing rather than long-term relationship building.

Mel implemented algorithms for initiating, maintaining, and terminating engagement in spoken dialogues with a human collaborator. Mel tracked the human's face and gaze and, when it was appropriate, looked at and pointed to shared objects relevant to the conversation. Mel also produced and recognized head nods. Mel could converse about himself, participate in a collaborative demonstration of a device, as well as locate a person in an office environment and initiate an interaction with that person. Mel's explicit engagement model included, among other things, where the human was currently looking and the elapsed time since it was the human's turn to speak. Mel also had explicit rules for deciding what to do when the human signaled a desire to disengage.

In user studies, we found that when Mel was tracking the human interlocutor's face the human more often looked back at Mel when initiating a dialogue turn than when Mel was not face tracking. (Looking at your conversational partner when you initiate your dialogue turn is a natural behavior in human-human dialogues.) Furthermore, human interlocutors considered Mel more "natural" when he was tracking faces. Finally, humans nodded more at Mel when he recognized their



MDS.

Mel.

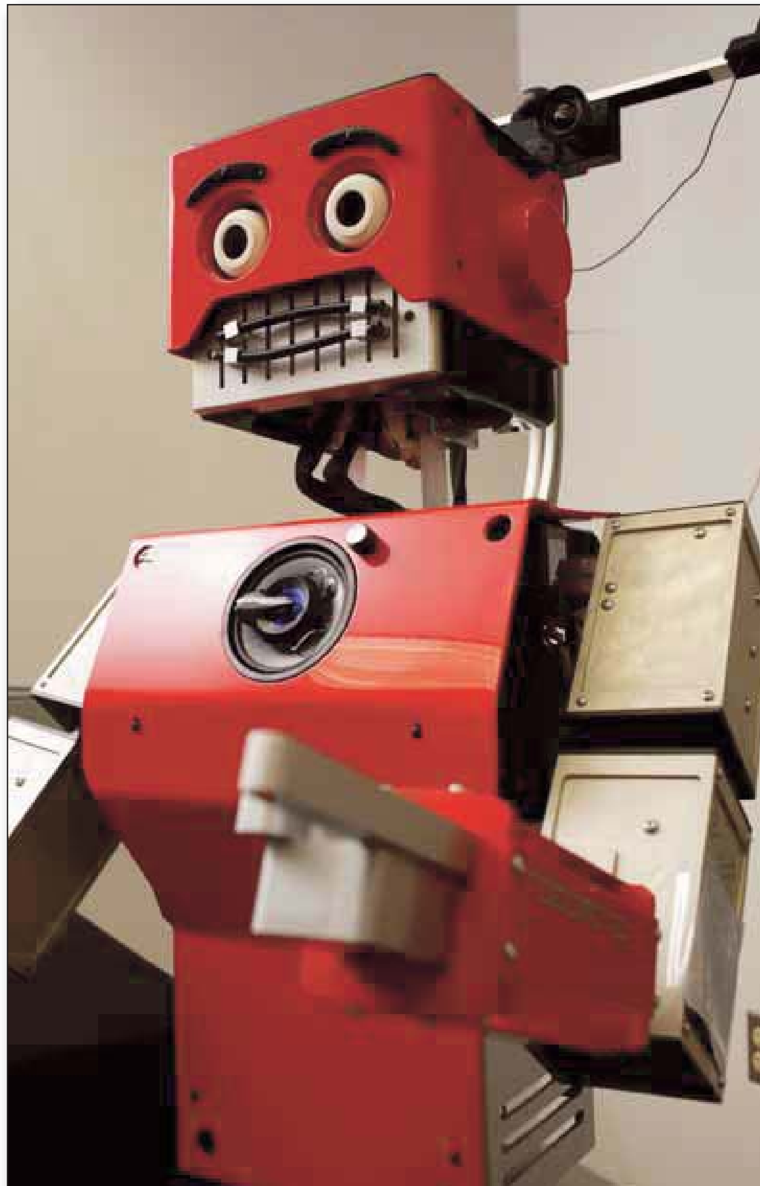
Autom.

head nods and nodded back in response, as compared to when he did not recognize their head nods.

Kidd's Autom (Kidd and Breazeal 2007), soon to be commercially produced by his company, Intuitive Automata, Inc., was designed for extended (many month) use in homes as a weight-loss advisor and coach. Kidd's work builds on pioneering research by Bickmore (see the next section) on long-term social interaction and behavior change using avatars.

Another (at least for a time) commercially produced humanoid robot is Melvin (called Reddy by its manufacturer, Robomotio, Inc.). Melvin was designed by us and our colleagues at Mitsubishi Electric Research Laboratories (MERL) in collaboration with Robomotio specifically as a cost-effective research vehicle for human-robot interaction. He has 15 degrees of freedom (including an expressive face), a stereo camera, and a microphone array and speakers and is mounted on a Pioneer mobile base. Melvin currently resides at Worcester Polytechnic Institute (WPI) and is being used to continue the research on engagement and collaboration started with Mel described above.

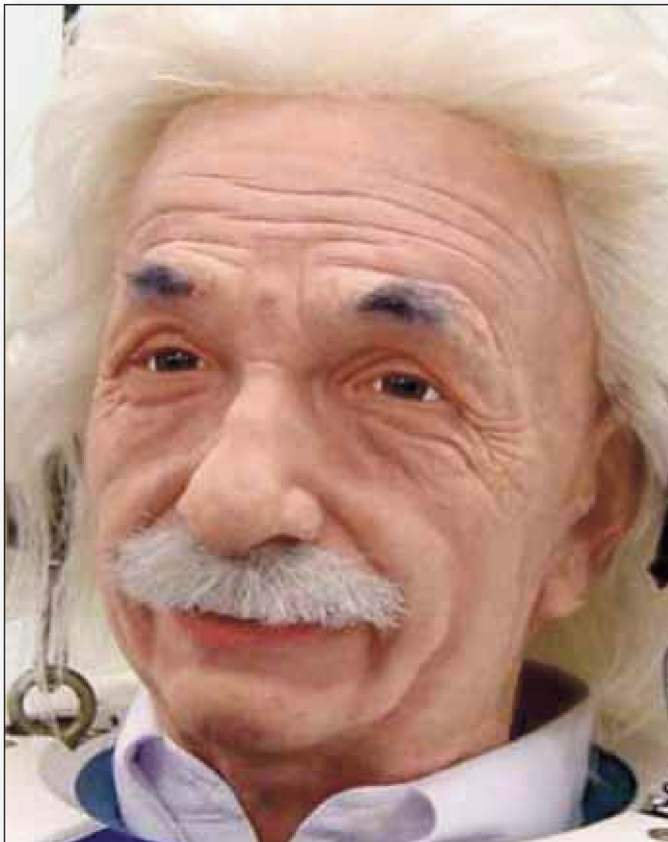
Finally, a small number of researchers are trying to develop what are called *androids*, that is, robots



Melvin.

View color photographs of all the robots and avatars in this article as well as video presentations at the author's web site:

www.cs.wpi.edu/rich/aimag



Einstein.

Geminoid (with Creator at Left).

Newscaster.

that are ultimately indistinguishable—at least in appearance and movement—from humans. Hanson is focusing just on heads, such as Einstein (Hanson 2006), while Hiroshi Ishiguro has created Geminoid (Nishio, Ishiguro, and Hagita 2007), a full-body android copy of himself, and Newscaster, an android copy of the well-known Japanese TV newscaster. Ishiguro's immediate goal for Geminoid is to teleoperate it as a surrogate for him in remote meetings. Unfortunately, androids are currently only convincing when seated, because even the best biped walking robots still do not look like a natural human walking.

Limitations and Challenges

Adopting the traditional decomposition of robot architecture into sensing, thinking, and acting, it is fair to say that the greatest barriers to achieving natural human-robot interaction currently lie in

The Avatar Leonardo.

the sensing component (which includes interpretation of raw sense data into meaningful representations). For the robots discussed above, this basically comes down to machine vision and spoken dialogue understanding.

Machine vision research has progressed significantly in recent years, notably including the development of reliable algorithms for face tracking (Viola and Jones 2001), human limb tracking (Demirdjian 2004), face recognition (Moghaddam, Jebara, and Pentland 2000) and gaze recognition (Morency, Christoudias, and Darrell 2006). There have also been limited improvements in object recognition (Torralba, Murphy, and Freeman 2004; Liebe et al. 2007), which is important for applications of human-robot interaction, such as collaborative assembly. However, all of this technology is still in relative infancy. For example, these algorithms currently perform well only when the robot itself is not moving.

These days, a kind of spoken dialogue technology is routinely used in commercial applications, such as airline reservation telephone lines. However, these systems succeed only by tightly controlling the conversation using system initiative and restricted vocabularies. Unrestricted natural conversation is beyond the capabilities of current spoken dialogue systems, because human speech in such situations can be highly unpredictable, varied, and disfluent. A promising direction of current research in this area is using models of dialogue to improve speech recognition (Lemon, Gruenstein, and Peters 2002). At the current state of the art, however, human-robot interaction through spoken language only works when it is carefully designed to limit and guide the human speaker's expectations.

Avatars

Even though some of the most difficult scientific challenges for human-robot interaction lie in the sensing technology, this is not to say that keeping all the actuator hardware running is not a major

Greta.

Laura.

Sam.

practical problem for robotics researchers, because it is. One can view avatars as a "solution" to this problem—or at least a divide-and-conquer approach—which allows some researchers to concentrate on the sensing and thinking components (especially regarding emotions and social relationship) by replacing physical actuators with graphical animation and rendering technology. Thanks to the computer game and entertainment industries, very high-quality graphics and rendering technology is available essentially off-the-shelf.

For example, the MIT Media Lab also developed a very detailed Leonardo avatar (see photo on page 37), which is substitutable for the robot. This approach does, however, have some cautions. Experiments have shown (Wainer et al. 2006) that people react differently overall to the physical presence of a robot versus an animated character or even viewing the same physical robot on a television screen.

Pelachaud's Greta (2005) is a full-body avatar with expressive gestures and facial animation, including eye and lip movements. Greta is being used to study the expression of emotions and communication style in spoken dialogue, both by Pelachaud and other researchers, such as Andre at the University of Augsburg.

Cassell's Sam (Ryokai, Vaucelle, and Cassell 2002; Cassell 2004) is an example of a so-called mixed-reality system. Sam is a virtual playmate who is able to attend to children's stories and tell them relevant stories in return. Furthermore, children can pass figurines back and forth from the real to the virtual world. Sam has been demonstrated to improve children's literacy skills.

Bickmore's Laura (Bickmore and Picard 2005) is aimed toward the same class of applications later addressed by Autom, namely health behavior change (for example, diet and exercise). Like Autom, Laura was designed to develop long-term social relationships and is the first such avatar to have a month-long daily relationship with a user, in fact, several users. For example, people getting exercise advice from Laura over a several week span were shown to be responding to her socially according to standard psychological measures. Bickmore's more recent research includes a pilot study at the Boston Medical Center Geriatric Ambulatory Practice, which showed that patients using Laura as an exercise coach daily for two months walked significantly more compared to a control group (Bickmore et al. 2005).

The University of Southern California's Institute for Creative Technologies (ICT) is developing a collection of realistic soldier and civilian avatars to inhabit virtual worlds for interactive military training (Swartout et al. 2005). For example, Sgt. Blackwell (Leuski et al. 2006) is a wisecracking military character who answers questions about the army and technology. Among other things, this work is pushing the boundaries of spoken dialogue technology.

Conclusions

Judging from these recent projects, the two areas where robots and avatars are soonest likely to have a significant and worthwhile role in our lives are health and education/training. Autom, Sam, Laura, and Sgt. Blackwell are indicators of what to expect in these areas.

Closely related to this cluster are applications that can be generally characterized as *assistive*, either socially or physically. For example, Feil-Seifer and Mataric (2005) have developed a robotic playmate (reminiscent of the Sam avatar) for autistic children. In this work, the real purpose of the interaction is to teach social skills; the human-robot collaborative task is only a means to that end.

Obviously, as robots become able to use their hands and arms safely in close proximity to humans, many physically assistive applications, such as helping the elderly, will become feasible. Furthermore, as compared to the partially competing approach of ubiquitous computing, in which the entire environment is instrumented and automated, a humanoid robot can also offer companionship (emotion and social relationship). Evidence already suggests that people respond positively to such robots.

Of course, the "killer app" is to add *domestic servant* to the list of roles in the title of this article. Although many researchers have this goal in mind, a general-purpose domestic robot, able to work in an uncontrolled home environment, is still a long ways off.

Sgt. Blackwell.

Almost all of the interaction between humans and avatars or robots thus far have been one-to-one (dialogues). Clearly, however, robots working in human-populated environments will need to be

A Village Doctor and Elder.

able to carry on multiparty conversations. The collaborative model underlying such conversations is reasonably well understood, for example, by Grosz and Kraus (1996), but the engagement aspects have been much less studied. ICT has developed a pioneering system in which a human trainee engages in a delicate wartime negotiation with two avatars representing a village doctor and elder (Traum et al. 2008). Matsusaka (2005) has done important initial work on gaze in three-party conversations, which he implemented for avatars at ICT and later for the Mel robot at MERL.

Overall, research on interacting with robots and avatars is valuable not only for its applications but also for its contributions to understanding human behavior. For example, our research on engagement for Mel started with detailed analysis of the engagement behaviors in videotaped human-human interactions. Similarly, Bickmore's Laura has served as a research platform for studying human social dialogue, as well as being a practical aid for helping people change their diet and exercise habits.

Returning finally to the four key human interaction capabilities discussed at the start of this article, we would like to emphasize emotion and social relationship as the current research frontier. We are just beginning to understand how make these capabilities (including even humor—see the dance routine in the Melvin video) part of the systems we build. The next decade in this field will undoubtedly prove to be challenging and intriguing!

Acknowledgements

This article is based on a invited talk by C. Sidner at the Twenty-First International Florida Artificial Intelligence Society Conference (FLAIRS'08), Coconut Grove, FL, May 2008.

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Call for Papers

AIIDE-09 : The Fifth Conference on Artificial Intelligence and Interactive Digital Entertainment

October 14-16, 2009

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Submissions deadline: **April 14, 2009**

AIIDE-09—the Fifth Conference on Artificial Intelligence and Interactive Digital Entertainment—is intended to be the definitive point of interaction between entertainment software developers interested in AI and academic and industrial AI researchers. AIIDE-09 will include invited speakers, research and industry presentations, project demonstrations, interactive poster sessions, and product exhibits. While traditionally emphasizing commercial computer and video games, we invite researchers and developers to share their insights and cutting-edge results on all topics at the interface of entertainment and artificial intelligence, including serious games, entertainment robotics, and beyond. AIIDE-09 is sponsored by the Association for the Advancement of Artificial Intelligence (AAAI).

Papers

Because AIIDE-09 crosses disciplinary boundaries, submissions will be evaluated based on their accessibility to both commercial game developers and researchers in addition to their technical merit.

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Research Track papers describe AI research results that make advances towards solving known game AI problems or enabling a new form of interactive digital entertainment. The novel technique should be validated in a game prototype or test-bed, but need not be validated in a commercial game. Research Track papers are evaluated by the highest standards of academic rigor. The highest rated papers will be presented in short lecture format. The next highest rated group of papers has the opportunity to present their work in a poster session. Applicants submit a paper of no more than 6 pages in the AAAI format for blind review (i.e. authors names and affiliations are omitted). All papers will be allocated 6 pages in the proceedings regardless of presentation format.

Industry Track

Individuals that have game development experience but lack the time or need for publishing rigorous academic papers can alternatively apply to the Industry Track. This track will include presentations of AI techniques, issues, or case studies from the perspective of implementing a product in the current commercial environment. Presentation proposals will be evaluated on their potential for conveying clearly elaborated ideas that have not been previously described to an adequate degree. Industry Track applicants submit an extended abstract describing the content of the proposed talk that also includes one paragraph describing their game industry experience. An extended abstract of two pages is sufficient, although any length up to that of a full paper (6 pages) is acceptable. Abstracts will be published in the conference proceedings.

Example Topics

(List is Suggestive Only)

- *AI Authoring Tools* (Behavior-building, cognitive modeling, data collection and encoding)
- *Novel Solutions for Traditional AI Problems*

(Path planning, animation / camera control, tactical / strategic decision making, terrain analysis)

- *AI Supporting Novel Game Concepts or Gameplay Elements* (Interactive drama, narrative / character development, NPC belief / attitude / emotion modeling)
- *AI Architectures for Games (*Automata, scripting, planning, level of detail)
- *AI Support for Game Production* (Game design, content creation, testing)
- *Other Entertainment Applications of AI Technologies* (Robotics, natural language processing, reinforcement learning, neural networks, Bayesian networks, genetic algorithms, logic, rule based systems)
- *Commercial AI Implementations* (Case studies, implementation analysis, comparative evaluations)

Submissions

Electronic submission of papers and extended abstracts is required. All Research Track submissions must be in PDF format, no longer than 6 pages including references, and formatted in AAAI two-column, camera-ready style (see the author instructions page at www.aaai.org/Publications/Author/author.php). Industry Track submissions are preferred to be submitted in PDF format, must be no longer than 6 pages including references, and should be formatted in AAAI two-column, camera-ready style; however, we realize that this may be cumbersome to those not familiar with these requirements, so Industry Track authors may submit their content in any reasonable format for review and AIIDE will assign an editor to help meet publication formatting requirements for accepted work. Full submission instructions will be available at the AIIDE web site (www.aiide2009.org) after March 2, 2009. Research Track papers and Industry Track extended abstracts must be submitted by April 14, 2009. All accepted papers and extended abstracts will be published in the conference proceedings. At least one author must register for the conference by the deadline for camera-ready copy submission. As AIIDE is an academic conference, all attendees including presenters pay a registration fee. AIIDE-09 will not accept any paper that, at the time of submission, is under review for or has already been published or accepted for publication in another journal or conference.

Demonstrations

We invite researchers and practitioners to share insights and cutting-edge results from a wide range of topics and encourage the demonstration of (1) research systems in the context of existing commercial games, (2) new games authored by researchers, (3) contributions demonstrating the adoption or extension of AI research results in published games, (4) completely new forms of interactive digital entertainment made possible by AI research, and (5) other relevant work. An electronic submission of a 2-page abstract and demonstration materials is required. Demonstration materials can take the form of a recorded demonstration session, an executable version of the demonstration with written instructions, or a detailed description of the demonstration heavily illustrated with screenshots. Please note that these materials are for review only; it is hoped that all demonstrations will be conducted live at AIIDE-09. Demonstration materials can be submitted electronically by email or FTP up-load. Demonstration authors should submit abstracts and materials by April 14, 2009. Submissions will be judged on technical merit, accessibility to developers and researchers, originality, presentation, and significance. Demonstration abstracts will be published in the conference proceedings.

Exhibits

AIIDE-09 will have exhibit space available. Companies, publishers and other groups are encouraged to consider purchasing either a tabletop display or an exhibit booth. Exhibit space is limited and will be allocated on a first come, first serve basis. Please contact AAAI at aiide09@aaai.org for more information.

Important Dates

- March 2 - April 14, 2009: Authors register on the AIIDE web site
- April 14, 2009: Electronic submission of Research/Industry Track papers/abstracts
- April 14, 2009: Electronic submission of extended abstract for a demonstration
- June 2, 2009: Notification of acceptance decision

Conference Chair

Chris Darken
Naval Postgraduate School

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University of North Carolina, Charlotte

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Additional Information

For additional information, please see www.aiide2009.org or www.aaai.org/aiide09 or email the conference organizers at aiide09@aaai.org.