The 2011 Human-Robot Interaction Pioneers Workshop was funded by the US National Science Foundation.
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The Human-Robot Interaction (HRI) Pioneers Workshop has become an integral piece of the ACM/IEEE International Conference on Human-Robot Interaction over the past five years. The primary goal of the workshop is to provide young researchers with a forum to share their current research and perspectives with a diverse group of peers and a panel of experts from HRI. This encourages the formation of collaborative relationships across disciplines and geographic boundaries and fosters long-term relationships with among participants.

In order to facilitate this goal, the workshop’s format includes the following sessions: oral presentations from five of the 28 attendees, poster presentations from 23 attendees, a hands-on breakout session, group presentations, and panel presentations with senior researchers. The five oral presentations and an interactive poster session will provide a forum for participants to share their research, enabling them to receive feedback on their work and to gain perspective on the field. The hands-on breakout session will involve small groups working to design an integrative HRI project, encouraging group participation and the cultivation of cross-disciplinary ideas. The panel presentations will feature four senior HRI researchers from both academia and industry who will share insights about the challenges of interdisciplinary research and nature of the HRI community.
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iRobot
USA

Andrea Thomaz
Georgia Tech
USA

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University of Salzburg
Austria
The Interdisciplinary Challenge in HRI Research

The HRI field is inherently interdisciplinary in nature and requires collaboration from many disciplines such as psychology, cognitive science, linguistics, mathematics/statistics, engineering, computer science, and human factors engineering/design. As young researchers in HRI with very limited knowledge and resources, how should we address this challenge and still produce valid and quality research? How should we go about obtaining help and what resources can we utilize? We ask the invited panelists to share their opinion and experience in this subject and provide valuable advice.

Panelists

**Dr. Greg Trafton**  
Section Head for Intelligent Systems  
Naval Research Laboratory  
Washington D.C., USA

**Dr. Peter Kahn**  
Associate Professor  
University of Washington  
Washington State, USA

**Dr. Vanessa Evers**  
Assistant Professor  
University of Amsterdam  
The Netherlands

**Dr. Takayuki Kanda**  
Senior Research Scientist  
ATR Intelligent Robotics and Communication Laboratories  
Japan
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Research Statement

Understanding human activities and internal states basing on audio, video, and physiological information feedbacks.

Biography

- **2010** M.Sc. Specialization Image and sound processing, UPMC, (Université Pierre et Marie Curie), Paris, France.
- **2009** B.S.c. Specialization Automatic systems and signal processing, ENSISA (École Nationale Supérieure d’ingénieurs sud Alsace), Mulhouse, France.
- **2006** B.S.c. Specialization Command and measurements, Benha University, Egypt.
Research Statement

I am especially interested in human perceptions of robots and how these perceptions influence interactions with robots. In particular, I want to explore the factors that lead people to attribute agency to a robot or regard it as lifelike. I have been studying how a robot’s motion can affect such perceptions.

Biography

I am a senior undergraduate at Yale University, and will be starting graduate school next Fall. I am a swing and blues dancer and have a second degree black belt in Tae Kwon Do. I read everything I can get my hands on.
Research Statement

Jenay Beer’s research examines emotionally expressive agents, both robotic and virtual, and the interactions of these agents with older adults. The ability to recognize facial expression changes with age, with older adults commonly misidentifying the human facial expressions of anger, fear, and sadness. Beer’s research suggests that certain age-related differences in emotion recognition apply to expressive agents as well as to human faces.

Biography

Jenay Beer is a fourth year graduate student in the School of Psychology, at the Georgia Institute of Technology. She is currently fulfilling the requirements for a Ph.D. in Engineering Psychology. She is a member of the Human Factors and Aging Laboratory, directed by advisors Arthur D. Fisk and Wendy A. Rogers.
Research Statement

In my research we’ve looked at differences in emotion expression between two robots. One robot can show facial expressions and another robot shows expressions through body posture. We’ve examined if children (8–9 years old) could recognize the emotions and if one of the robots has better recognizable emotions.

Biography

Born in the Netherlands I graduated highschool in 2004. After that I attended the University of Utrecht to studie Psychology. During my bachelor years I also studied Electronical engineering and design for one year. After I succesfuly finished my Psychology bach-elor I enrolled for a masters study called Applied Cognitive Psychology. During this master I did a graduation research in the field of Social Robots, which was my first contact in the field of social robots. The paper I’m presenting here is my master thesis.
Research Statement

Dole is currently studying implicit social cognition in HRI: What attitudes and stereotypes do people have toward robots? Under what conditions might these attitudes and stereotypes be unconsciously and automatically misapplied to people?

Biography

Lorin D. Dole is a PhD student in communication theory and research at Stanford University. He received his BS in psychology from the University of Washington in 2010.
Research Statement

My research lies at the boundary between manipulation planning and human robot interaction, and I am particularly interested in how robots can learn new skills from humans and become better over time at applying these skills. I want robots to be able to extract the relevant information from one particular scenario and generalize it to new scenes and tasks.

Biography

I am a PhD student in the Robotics Institute at Carnegie Mellon. I work on HERB, the Home Exploring Robot Butler, a personal assistant robot sponsored by Intel and the Quality of Life Technology Center, aimed at enabling older adults and people with disabilities to live more independently. My research focuses on the idea of the robot generalizing relevant information in order to truly learn new skills or become better at existing ones. Before coming to Carnegie Mellon, I got my Bachelor’s degree in Computer Science at Jacobs University, an international school in Bremen, Germany. My trip to Bremen was the second time I was outside of Romania, my home country, and living with people from 96 nations while, for example, debating the effects of the Halting Problem on the field of AI, completely shaped me into the person I am today. Besides robots and interesting conversations, I like swing dancing, mountains and board games.
Research Statement

Within the field of human-robot interaction, my interests center on the emergence of a new ontological category through the creation of personified embodied computation. I am particularly interested in how children and adults regard robots socially and morally.

Biography

Heather Gary is a doctoral student in Developmental Psychology at the University of Washington. She received an Ed.M. in Human Development and Psychology from the Harvard Graduate School of Education (2007) and a B.A. in Psychology from Middlebury College (2004). Within the field of human-robot interaction, her interests center on the emergence of a new ontological category through the creation of personified embodied computation. She is particularly interested in how children and adults regard robots socially and morally. She is also interested in human-nature interaction, namely (a) children and adolescents’ moral reasoning about nature, and (b) how human conceptions of and interactions with nature are changing in our increasingly technologically mediated world.
Research Statement

My research goal is to create algorithms that produce or alter humanoid robot motion in order to make it more similar to human motion. This research includes designing algorithms to encode communication into motion, as well as algorithms to improve the quality of humanoid robot motion. The end result of my research will be an algorithm where a robot can observe a potentially bad exemplar of a motion, add the communicative signals of secondary motion, exaggeration, and anticipation in a way that is meaningful to the human partner, optimize the motion for naturalness, and add variance, all while preserving constraints.

Biography

Michael J. Gielniak is a fourth-year Ph.D. candidate in Electrical Engineering at the Georgia Institute of Technology. He holds master’s degrees in Electrical Engineering, Computer Science, and Systems Engineering. From 2000 to 2009, Michael worked at General Motors in software, algorithms, modeling, controls, and R & D. Michael holds two patents and has five patents pending in the area of electrochemical systems.
Research Statement

The overall scientific goal of my PhD-project is to investigate and enhance the interaction between mobile robots and humans in robot based games for elderly. The key idea is that robot based games can facilitate more physical action eventually leading to a better health for the user. More specifically, the research is concerned about developing game algorithms for mobile robot platform and conduct experiment in real world locations, like activity centers or nursing homes.

Biography

My name is Søren Tranberg Hansen and I live in Aarhus, Denmark. I am 35, married and have one a boy who is 3 years old. My academic background is within Computer Science, mainly focusing on robotics and artificial intelligence. I am currently doing an Industrial PhD which is a program funded by the Danish Ministry of Science and calls for PhD research shared between a university and a private company. My PhD is shared between Control and Automation, Aalborg University and Centre of Robot Technology at Danish Technological Institute which is private company working with technology transfer.
Research Statement

I am studying ways to model human behavior while interacting as a member of a human-robot team. Research questions include whether or not current models of human performance while working with human-only teams apply to human performance while working as peers to robots.

Biography

Caroline Harriott graduated from the University of Virginia with a B.A. in computer science in 2009. Shortly after graduating, she began working in Vanderbilt University’s Human-Machine Teaming Lab. She will receive her master’s degree in computer science in May 2011 and continue on in the Ph.D. program.
Research Statement

I have experience in development of human-machine interfaces for a range of applications, including teleoperation for nuclear facilities decommissioning, robotic welding, and industrial robot user interface research and development. My current research is in the area of improving user interfaces for mobile hydraulic equipment. More specifically, my recent work has involved cab vibration reducing control and a study on its effects on operator performance.

Biography

I am a PhD student in Mechanical Engineering, with a focus on human-in-the-loop control. I work in the Intelligent Machine Dynamics Laboratory, led by Dr. Wayne Book. I completed a BS in Mechanical Engineering from the University of Tennessee and a MS in Mechanical Engineering from Georgia Tech. I am an NSF and NDSEG fellow. My hobbies include most any form of outdoor activity, including running, swimming, cycling, golf and skiing.
Research Statement

‘The Naming of Robots’ explores the ways in which robotics research cultures express identity and gender by examining empirical data from robot competitions, integrated with a cultural studies of science approach. I have collected more than 2,000 robot names, which illustrate the ‘habitus’ (Bourdieu) or implicit culture of the robotics research community, which may in turn determine the development of robotics culture generally. I am always interested in asking ‘what’s at stake?’ as Donna Haraway suggests.

Biography

I am a Masters Dissertation student at the University of Sydney in the Digital Cultures Program, working in the area of Human-Robot Interaction. I studied Communications at UTS and the ABC, working as a film editor, multimedia artist and writer before moving into the area of technology for social justice, non-profit and educational purposes. I have been running science and robot workshops for children since 1995, including coaching competition teams in Moonbots, First Lego League and RoboCup Jnr, and I have just relocated to the Silicon Valley area in the US with my family.
Research Statement

Just as robotic soccer competitions motivated development of algorithms for multi-robot coordination and the DARPA Grand Challenge furthered the autonomous capabilities of vehicle navigation, I believe Robot Theater will inspire transformative algorithms for applications in everyday human-robot interaction. This focus extends my previous social robotics work at MIT and now Carnegie Mellon, and includes audience tracking, online learning, artificial personality and behavior generation. In this investigation, we begin to translate aspects of human behavior into rules a machine can understand, eventually deepening its understanding of character, motivation, and, even, relationships with other robotic or human actors on stage.

Biography

Knight is currently conducting her doctoral research at Carnegie Mellon’s Robotics Institute. Her work also includes: robotics and instrumentation at NASA’s Jet Propulsion Laboratory, interactive installations with Syyn Labs, field applications and sensor design at Aldebaran Robotics, and she is an alumnus from the Personal Robots Group at the MIT Media Lab. She earned her bachelor and masters degrees at MIT in Electrical Engineering and Computer Science and has a minor in Mechanical Engineering.
Research Statement

I work on symbolic knowledge processing for robots in human environments. My research focuses on a shared symbolic platform for knowledge representation that allow for on-line modelling of the robot as well as other agents’ state of mind, natural language interpretation, symbolic clustering of concepts, memory models, etc. I work also on the integration of this platform into complete robot architectures for companion robots.

Biography

I’ve studied mechanical engineering in France (Ecole Nationale des Arts et Métiers) and Germany (Karlsruhe TH), followed by a master degree in artificial intelligence applied at educational science (Université Paris 5). I worked then as research engineer at INRIA for a year, on the Cycab robots. After a year of break (for an around-the-world tour), I’ve started in 2008 my PhD thesis in joint supervision between LAAS-CNRS, Toulouse and the Munich University.
Research Statement

Since I was at a research project to evaluate the usability and acceptance of a mobile shopping robot, I was fascinated at this field of research and wanted to know more. And currently my research goal is to develop a Robot-Acceptance-Research-Model and a Robot-Acceptance-Questionnaire to assess user acceptance. Referring to this I evaluate in different studies, which factors are relevant for HRI.

Biography

I am a PhD student at the research group media psychology and media design at the Ilmenau University of Technology and Scholarship holder of the Landesgraduiertenförderung (LGFG). I received my diploma in Applied Media Studies in 2010 from the Ilmenau University of Technology, where I worked during my academic studies as a research student in different projects for the research group media psychology and media design. Currently, my dissertation thesis aims at developing a Robot-Acceptance-Research-Model and a Robot-Acceptance-Questionnaire to assess user acceptance. The question of acceptance with regard to service robots in our society becomes more and more essential, because the field of robotics is extending across various fields of society.
Research Statement

My research interests include spoken dialog systems, human-robot interaction, crowdsourcing for natural language research, and natural language generation. I’m interested in improving human-robot dialogue by better understanding how people use spatial language, both in reference to the environment and to members of a human-robot team. I aim to develop systems that can interpret spatial language from humans fluidly and in turn communicate about space effectively with teammates.

Biography

Matthew Marge is a PhD student in the Language Technologies Institute at Carnegie Mellon University. He received the MSc degree in Artificial Intelligence specializing in Natural Language Engineering from the University of Edinburgh and the BSc degree in Computer Science and Applied Mathematics from Stony Brook University. His doctoral work is funded by the Boeing Company and a National Science Foundation Graduate Research Fellowship. Matthew is a former recipient of a St. Andrew’s Society of the State of New York Scholarship and an Edinburgh-Stanford Link studentship. Some of his hobbies include squash, bowling, and traveling.
Research Statement

I study human-robot interaction within unmanned aerial systems, which are composed of one or more unmanned aerial vehicle and a human team. The focus of my recent work has been with micro unmanned aerial systems to develop individual and team optimal interfaces for the human team role uniquely responsible for acquisition and interpretation of image data from the robot — the Mission Specialist.

Biography

Joshua Peschel received a B.S. in Biological Systems Engineering and a M.S. in Biological & Agricultural Engineering in 2001 and 2004, respectively, from Texas A&M University. He is presently a graduate student at Texas A&M seeking two separate, concurrent doctoral degrees - one in Computer Science & Engineering and the other in Civil Engineering. As a Ph.D. student member of the Center for Robot-Assisted Search and Rescue, working under the direction of Dr. Robin Murphy, his research interests include human-computer interaction, human-robot interaction, and artificial intelligence.
Research Statement

I am interested in non-verbal human-robot interaction in particular bodily communication (rotational and translational movements with the entire body). My questions within this area are; is a human intuitively and bodily prompting a robot, and is a human understanding non-verbal prompts of a mobile non-human robot? Further research interests include prediction of motion, robot navigation, person tracking, mobile robot studies and communication science.

Biography

Annika Peters received her B.S. degree in 2006 and her M.S. degree in 2008 in “Intelligent Systems” from the University of Bielefeld, Germany. She received a research grant from the “Cognitive Interaction Technology” Cluster of Excellence (CITEC) at Bielefeld University in 2009. In the same year she joined the Applied Informatics Group at Bielefeld University and the CITEC Graduate School. She is currently working toward her Ph.D.. Within her Ph.D. project she examines spatial movement concepts in robot-shared environments. Her current research interests include non-verbal human-robot interaction in particular bodily communication (rotational and translational movements with the entire body).
Research Statement

The goal of my research is to leverage the psychology of human-human interaction, which we as people learn instinctively throughout our lives, to create humanoid robotic interfaces that require little to no training to use. This extends to developing new ways to evaluate the success of using nonverbal social cues in robots, investigating specific modes that provide cues such as eye contact, and exploring the connections between reading social cues in animals and reading them in robots. My work emphasizes an interdisciplinary approach, drawing together research from other areas to generate novel methods to understand and solve the problems at hand.

Biography

Irene Rae is a first year graduate student working with Professor Bilge Mutlu at the Human Computer Interaction Lab at the University of Wisconsin–Madison. Her main research interests include the use of nonverbal social cues in human-robot interaction, usability in robots, and robot appearance versus expectation. She completed a B.F.A. in industrial design at the Rochester Institute of Technology and later worked at the IceCube Research Center, an astrophysics project constructing a neutrino observatory at the South Pole, for four and half years.
Research Statement

I’m interested broadly in the fields of AI, mobile robot planning, human-robot interaction, and human-computer interaction. My work focuses on how humans can help physical devices (robots, mobile devices, etc) reduce their sensor uncertainty and overcome physical limitations in order to perform tasks in the environment more effectively. Specifically, I investigate how agents can model humans to determine and plan for appropriate times to ask for help during task planning and execution.

Biography

Stephanie is a 4th year PhD student in Computer Science at Carnegie Mellon University advised by Manuela Veloso and Anind Dey. She received her Bachelors degree in Computer Science with a double major in Human-Computer Interaction in 2007 also from Carnegie Mellon. She is a 2007 NSF Graduate Fellow, National Physical Science Consortium Fellow, Google Anita Borg Scholarship winner, and CRA Outstanding Undergraduate Award winner.
Research Statement

My research interests lie in the field of social human-robot interaction (HRI) with special focus on multimodal interaction and non-verbal expressiveness in humanoid robots. I am currently working on the synthesis and coordination of speech and gesture for the Honda humanoid robot, as well as the evaluation of the impact and effects of such multimodal behaviors on human-robot interaction.

Biography

Since March 2008 I am a PhD student at the Graduate School for Cognition and Robotics (CoR-Lab) and a member of the Artificial Intelligence Group and the Sociable Agents Group at Bielefeld University, Germany. My research is funded by the Honda Research Institute Europe and centers on the synthesis and coordination of speech and gesture for humanoid robots. As an undergraduate student, I studied Computer Science with a minor in Economics at the University of Paderborn, Germany, and the Queensland University of Technology, Brisbane, Australia. I completed my undergraduate studies with the degree Bachelor of Computer Science in November 2004. Subsequently, I studied Interdisciplinary Media Studies at Bielefeld University, Germany, and the American University in Cairo, Egypt, and received the degree Master of Science in May 2007.
Research Statement

Rachel Severson’s research investigates children’s conceptions of natural and technological entities, such as animals and robotic animals, and how their understanding may change as a function of development, culture, and experience. She is particularly interested in (a) which characteristics underlie social and moral regard for an entity, and how this may inform developmental psychology theory; (b) the role of pretense and imagination in children’s animistic attributions; and (c) whether a new ontological category is emerging that moves beyond long-standing canonical categories (e.g., between alive and not alive).

Biography

Rachel L. Severson, Ph.D. is a Fulbright Fellow at the Centre for the Study of Mind in Nature (a Norwegian Centre of Excellence) at University of Oslo during the 2010-2011 academic year. She received a Ph.D. in Developmental Psychology from the University of Washington (2010); her advisor was Peter H. Kahn, Jr. Severson’s publications have appeared in such journals as Neural Networks, Current Directions in Psychological Science, Human-Computer Interaction, Interaction Studies, Journal of Applied Developmental Psychology, and Journal of Environmental Psychology.
Research Statement

I am interested in investigating the possible use of robots for the children who have difficulty in interacting with human, especially children who have been diagnosed of autism. As autonomous and interactive objects, robots can be great intervention tool for those children if appropriate methodology is invented. Through my research, I would like to investigate the various methodologies in HRI setting that can be used for children with autism.

Biography

I studied History of Arts and Classical Studies in College. Now, I just finished first year Master course from Interaction Science Department at Sungkyunkwan University. I have been studying the human robot interaction in intervention and education for children especially for those who have difficulty in social skills.
Research Statement

Geographically distributed collaborators often feel a step behind their collocated teammates. Even with increasingly sophisticated communication technology, they become both motor and sensory impaired and 2-dimensional. As a result, they use the communication channel to discuss work performed independently, rather than to perform that work together. I introduce physically embodied, gesturing avatars into the interaction, and study how they can support more effective, improvisational communication.

Biography

David Sirkin is design researcher and a PhD candidate in Mechanical Engineering at Stanford University. He currently builds gesturing telepresence robots that distant collaborators ‘inhabit’ to improve their expressive abilities. His research explores the non-verbal physical and social aspects of human-robot-human interaction. He received a BS in Computer Science & Engineering from the University of Pennsylvania, and MS degrees in Electrical Engineering & Computer Science, and in Management of Technology from MIT.
Research Statement

I'm interested in assistive robots, particularly for young children who need help getting around safely. I frequently think about how to learn/construct optimal assistive policies, either from demonstration by experts (e.g. physiotherapists) or by reasoning about the end-user. I also wonder about the long-term effects of assistive policies and how a symbiotic robot-child relationship can be nurtured/maintained in the long run.

Biography

Harold is a Khazanah Scholar working towards his Ph.D at the BioART Lab at Imperial College London. A former Regents Scholar at the University of California at Davis, Harold graduated with a double-major in Computer Science and Economics in 2004. After completing a Masters in Software Systems Engineering from the University of Melbourne, Australia, he began research at the Institute of High Performance Computing in Singapore. His main research activities were in the areas of complex networks, computational epidemiology and computational intelligence. His current research is in learning algorithms and robots that assist disabled individuals, particularly young children who need help moving around.
Research Statement

My research goal is to develop a computational model of Social Gaze that is autonomous, consistent and repeatable across different agent identities — Pure Medium, Social Medium and Social Actor

Biography

Howdy! I am a second year PhD Student at Computer Science and Engineering Department at Texas A&M University. My interests are in AI, Human-Robot Interaction. More specifically, I’m interested in social gaze, developing and maintaining engagement and relationships between humans and robots, and application of HRI to search and rescue. My advisor is Dr. Robin Murphy.
Research Statement

I am currently exploring human robot interaction using data driven methods. My testbed is a crowded cafeteria with a wily pioneer robot.

Biography

Pete Trautman is a graduate student in Control and Dynamical Systems at the California Institute of Technology. Prior to coming to Caltech, Pete was a Captain in the United States Air Force, assigned first to the National Air and Space Intelligence Center and later to the Air Force Research Laboratories, both at Wright-Patterson Air Force Base in Dayton, Ohio. He graduated Magna Cum Laude with a degree in Applied Math and Physics in 2000 from Baylor University. He grew up in Alamogordo, New Mexico, near Trinity Site, where the first atomic bomb was detonated.
Research Statement

His recent research discussed and investigated the advantages of an asynchronous display, called image queue, for foraging tasks with emphasis on Urban Search and Rescue. This approach allows operators to search through a large amount of data gathered by autonomous robot teams, and fills the gap for comprehensive and scalable displays to obtain a network-centric perspective for UGVs. With such an approach, larger multi-robot systems gathering huge amounts of data, which then distributed to multiple operators, can be scaled up.

Biography

Huadong Wang is a doctoral student in the School of Information Sciences at the University of Pittsburgh in Pittsburgh, Pennsylvania. He received his M.S. degree in industrial engineering from Tsinghua University in Beijing, People’s Republic of China, in 2007. He also received his B.S. degree in Measurements, Control Technology and Instruments from Tsinghua University in 2004. His research primarily focuses on Human Robotic Interaction, Group Decision Modeling, Information Visualization and Human Factors.
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Robots are artificial agents with capacities of perception and action in the physical world. Recent applications in human robot interaction (HRI) try to utilize these capacities in order to build an intuitive and easy communication between the robot and the human through speech, gestures, and facial expressions. The robot has to adapt its reaction to the human desires and orders but not the contrary.

My PhD research concerns studying and understanding the human activities and internal state using captured information by sound, vision and physiological sensors in social human robot interactive contexts.

Vision based approach of the research concerns making the robot (NAO robot) able to well understand and classify the performed gestures by its own normal 2D vision system in parallel with the received information of external motion sensors. I have already developed a new 2D vision methodology that focuses on the kinematics of the gesture by classifying it according to its amplitude to one of two categories as: large or small amplitude gestures. The purpose behind this amplitude classification is to compensate possible speed differences between persons performing gestures. The detection of the gesture’s amplitude could be achieved by a real time optical flow system in which it tracks, through each of the captured frames, the dynamic part of the body. Afterwards, it calculates the Euclidian distance between the centroid coordinates of the tracked dynamic part in the first and last captured frames, and this distance could indicate the amplitude of the performed gesture. After detecting the amplitude of the gesture, proper key frames are extracted and the characteristic vector representing the gap between the final and initial positions of the dynamic part of the body is calculated. The calculated characteristic vectors of gestures are used in the construction of the database and in the classification. For more details and results, please consult this research paper: A.Aly and A.Tapus, “Gesture imitation with a mobile robot in the context of human robot interaction for children with Autism” in the 3rd workshop for young researchers on human friendly robots, Tubingen, Germany, 2010.

Moreover, motion sensors could successfully contribute to the gestures recognition system: first, to create an online recognition system which is difficult to afford in a normal 2D vision system especially in complex environments, and secondly, to avoid any dynamic limitations while performing a gesture (i.e. while nodding with the head “yes”, it is not required, in the normal vision system, that the person moves other part of the body except the head, like the hand or the leg in order to create a successful motion segmentation). Meanwhile, with external motion sensors, these restrictions disappear. However, when working with vulnerable users (e.g., elderly people or children with autism) such devices could appear invasive. Therefore, a compromise between the robot’s 2D vision system and any additional motion capture sensors to be used is under debate according to the HRI application and the context itself.

Another important direction in my research is the verbal communication between the robot and the human, in which the robot has to be able to estimate the human internal state based on some extracted acoustic features such as the pitch, the energy, etc, beside the ability to estimate the gender of the interacting human as a man or a woman. The difficulty of this point, is to construct a successful online gender and internal state detection model for two reasons: first, to get rid of using a database in the recognition process, because it is not easy to construct a big database including all possible human internal states, and secondly, to avoid wrong recognition, consequently wrong action, in case of a new internal state to the database. Subtractive clustering algorithm is used to estimate the number of clusters through the online recognition process by calculating the possible cluster centers of the updated database which assures the assimilation of any new internal state to the database. The challenging point is to be able to collect similar centers together in order to estimate the borders of the clusters, thus their total number. This point states a current ongoing research problem. For more details and results, please consult this research (Under Revision- HRI Late Break Report): A.Aly and A.Tapus, ”Towards an Online Voice-Based Gender and Internal State Combined Detection Model” in the 6th ACM/IEEE international conference on Human Robot Interaction, Switzerland, 2011.

Furthermore, it seems useful to investigate the relationship between the verbal and non verbal communication during human-human interaction, because the way that gestures and speech are aligned to each other seems ambiguous, however they are thought to be produced by the same generative process. Understanding this mechanism of alignment will help the robot to interact in a
more natural way in different HRI scenarios. Therefore, our proposed approach is to construct an audio-video dictionary for many individuals expressing different internal states, and to try to align the performed gesture and/or facial expressions to voice features (e.g., the pitch and the energy). We are currently working on this alignment mechanism and we propose to test it on a 3D artificial agent to see how it could be useful and relevant when being applied to the robot in a specific scenario.

Another important direction in my research is investigating the human internal state using physiological sensors like the electrocardiograph ECG and the galvanic skin response GSR sensors. These sensors could play an important role in clarifying the human internal state in parallel with the other approaches like voice prosody or facial expression based analysis, which will give the robot better chances to interact in a relevant and robust way.

Other directions and ideas will be proposed progressively during this PhD research according to the obtained results through each of the previously discussed points.
I am a senior undergraduate at Yale University. I am currently applying to graduate schools in computer science. My primary interest is in robotics and artificial intelligence, and that is the area I expect to pursue in graduate school. In robotics, I am especially interested in human-robot interaction. I have been working in the Social Robotics Laboratory at Yale since the summer after my freshman year. My particular focus has been on human perceptions of robots and how these perceptions influence interactions with robots.

1. AGENCY AND DANCE

I am currently involved in a project studying aspects of dance and motion that can affect whether human observers attribute agency to a robot and whether they regard it as lifelike. Previous work in the lab using game-playing found that participants attributed agency to the robot when it violated the expected paradigm of play by cheating [1]. In my project, we have moved to the context of dance, enabling us to explore lower-level mechanisms for producing such attributions that may be easier to incorporate into other kinds of human-robot interaction.

A paper on this work, “Effects Related to Synchrony and Repertoire in Perceptions of Robot Dance”, co-authored with Justin Hart, Ashley Douglas, and Brian Scassellati, will appear at this year’s HRI conference.

This project began in 2009 as an experiment that I designed and ran with a Theater Studies major to test several aspects of people’s perceptions of dance. That experiment then became the pilot study for a larger project. We created videos showing the creature-like robot Keepon moving accompanied by music, varying different aspects of the robot’s motion, such as its coordination with the rhythm of the music and with musical phrases. We then showed these videos to participants and asked them to rate the dance quality, lifelikeness, and entertainment value of each video. Since directly asking participants about their perceptions of agency on the part of the robot only tells us about their ideas regarding technology, we used their ratings of the robot’s dance performance on these measures for insight into the question of agency.

We had 200 participants in our online experiment, and our findings suggested that there are two principal factors that affect participants’ perception of lifelikeness and agency on the part of the robot. One is whether the robot moves perfectly on the beat of the music or appears to make “mistakes” in its dance. The other is whether changes in the robot’s performance correspond to changes in the music, as would those of a human dancer anticipating or reacting to the musical change. These findings motivated a second experiment of the same form using new stimuli. In the second study, which had more than 100 participants, we explored these factors in more detail. We found that the robot is perceived as a better dancer when it dances on the beat, which is to be expected, but also that when the robot makes mistakes it is sometimes perceived as dancing as well as when it dances on the beat. Having the robot make mistakes actually produces a greater perception of lifelikeness than having it dance strictly on the beat. We also found that ratings improved when the robot’s repertoire or correspondence to the beat changed with changes in the music. These results suggest that simple techniques, such as the introduction of small “errors” in the robot’s behavior, may significantly affect humans’ attribution of agency to the robot.

Though the direction of my future research will obviously depend a great deal on where I go to graduate school, there are several possibilities for further work on this project that I would like to explore. For example, the “mistakes” that the robot made in our study consisted of moving at a fixed offset from the musical beat. Introducing randomness into the robot’s errors may have a different effect on human viewers’ perceptions, since human dancers rarely err in such a steady, regular way. I also want to explore more involved alterations to the robot’s behavior, such as mimicking the way human dancers often briefly “lose” the beat and then “catch” it again. Another aspect that can be explored within this “mistake-and-recovery” scenario is the influence of social gestures, such as head-shaking after an error. This is a somewhat extreme mechanism for affecting human perceptions, but such a response to error could be useful for human-robot interaction in situations where the error is not intended, but rather the result of mechanical or software failure. Identifying the effects of these factors on attributions of agency in a controlled dance task is also only the first step to applying...
them in other situations, such as in a face-to-face interaction, or on different robot platforms.

2. EMOTION AND TEACHING
I have also been working with Dan Leyzberg on a different project examining how robots can influence the way humans perceive them and what effects this can have on human-robot interactions, this time through emotion-modeling. This work will also appear at HRI, in the paper “Robots That Express Emotion Elicit Better Human Teaching”.

We chose to test these effects by measuring investment in a teaching task. We asked participants to teach the Keepon robot several short dances by demonstration, and measured how many times the participants repeated each dance and how precisely they demonstrated it. The robot was given an accuracy score after each repetition, which was fixed across all conditions. After “seeing” this score, the robot gave a verbal response that varied by condition. In one condition, the robot gave an emotionally appropriate response, in another it gave an apathetic response, and in the third it gave a randomized and often emotionally inappropriate response. We found that people invested more time and effort in teaching when the robot gave an appropriate emotional response.

3. REFERENCES
Can You Recognize Your Robot’s Expression?

Age-Related Differences in Emotion Recognition

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ABSTRACT
Personal and service robots are becoming more commonplace. As these systems become more advanced, their applications may require that they demonstrate some level of social capability, such as facial expression. However, younger and older adults interpret human facial expressions differently [3], and it is possible that age-related differences may exist for robotic agents as well. The purpose of this research was to investigate age-related differences in emotion recognition of a robotic agent (Philips iCat), synthetic human, and human facial expressions. The data suggest that age-related differences in emotion recognition transcend human faces, with older adults demonstrating lower recognition for the iCat emotions of anger, fear, happy, and neutral.

1. INTRODUCTION
Modern technological advancements have lead to an increase in the development and research of socially-based service robots with the capability to assist or entertain humans in a domestic or recreational setting [1]. Development of service robots has the promise of increasing the quality of life for older adults in particular. People are living longer and service robots may help older individuals to perform the activities that they personally need or want help with as they age. Service robots have the potential to keep older adults independent longer, reduce healthcare needs, and provide everyday assistance.

Making better robots is not only about improving technology. It is crucial to understand issues related to the social characteristics of robots that promote optimal human-robot interaction. A better understanding of how older adults interact with technology will directly impact the design of service robots.

Service robots may help with daily tasks, and in some contexts may be required to demonstrate some level of social capability, such as expressing emotion. Facial expressions are one of the most important mediums for communicating emotional state [2], and a critical component in successful social interaction. A human interacting with a social robot will need to interpret its facial expressions. Therefore, the robot will need to display facial expression effectively to depict its intended message correctly.

What if older and younger adults interpret facial expression differently? The ability to recognize facial expressions has been shown to differ with age, with older adults more commonly mislabeling facial expressions compared to younger adults. Age-related differences have been documented for the recognition of human facial expression, where older adults commonly mislabel the emotions of anger, fear, and sadness (for a summary, see [3]). There are many open research questions regarding whether age-related differences in emotion recognition may transcend human faces. Although some research has examined recognition of agent facial expressions [4], little research has investigated the generalizability of age-related differences to a variety of robotic and agent faces. The goals of the present work investigated age-related differences in the recognition of facial expressions displayed by a robotic agent, as compared to human, and synthetic (modified 2D photographs) human faces.

2. METHOD

2.1 Participants
The participants included an equal number of males and females, with 42 younger adults between the ages of 18 to 28 years (M = 19.74, SD = 1.43), and 42 community dwelling older adults between the ages of 65 to 85 years (M = 72.48, SD = 4.69).

2.2 Stimuli

2.2.1 iCat Faces
The Philips iCat robot is equipped with 11 servo motors that control features of the face, including the eyebrows, eyes, eyelids, mouth and head position. For consistency between the characters, the robot was depicted as a 2D agent, capable of creating the same facial expressions with the same level of control. The iCat’s emotions were created in-house and were based upon Ekman and Friesen’s [5] qualitative descriptions of facial expressions.

2.2.2 Synthetic Human Faces
The synthetic faces were taken from a database of digitized grayscale human photographs (i.e., lacking features such as wrinkles, hair and skin textures, color and luminance) created by Wilson and colleagues [6,7]. Goren and Wilson morphed the faces to express emotion according to Ekman and Friesen’s [5] qualitative descriptions of facial expressions. The average female face was used in this study.

2.2.3 Human Faces
The human faces were taken from the Montreal Set of Facial Displays of Emotion (MSFDE) [8]. In this set, each expression was created based on the Facial Action Coding System (FACS) [9]. For this study, photographs of a single female face were used. The same female actor was chosen for each of the emotions and was selected according to visual similarity to the synthetic face. See figure 1 for depictions of each of the characters and emotions.
2.3 Design and Procedure
A mixed 5 Emotion Type (within) x 3 Character Type (within) x 2 Age (grouping variable) factorial design was used. The main dependent variable was the mean proportion of participant responses matching the emotion the character was designed to display. Static pictures of the characters were presented to participants on a computer screen (for up to 20s). Participants responded by selecting an emotion they thought the face depicted. Participants were able to choose from the six basic emotions [5] and neutral. Presentation order of the characters was counterbalanced, and the emotions were randomly permuted. There were a total of 135 trials, with nine blocks (three blocks for each Character Type) of 15 trials per block.

3. RESULTS
To test for age-related differences, a repeated measure ANOVA was conducted for each Character Type. A main effect of age was found for the human faces $F(1, 82) = 4.08, p < .05, \eta^2 = .29$, synthetic face $F(1, 82) = 38.13, p < .001, \eta^2 = .32$, and iCat faces $F(1, 82) = 40.47, p < .001, \eta^2 = .33$. Older adults showed a lower proportion match for each character type. Additionally, a significant Emotion x Age interaction was found for the human faces $F(2.74, 224.28)=32.17, p < .001, \eta^2 = .33$, and iCat faces $F(2.77, 226.96) = 3.22, p < .05, \eta^2 = .01$, suggesting age-related differences differed as a function of emotion type.

Post-hoc independent samples t-tests were conducted. Both the human and synthetic human faces resulted in significant $p < .01$ age-related differences for the emotions anger, fear, sadness, and neutral, with younger adults showing higher proportion match. The iCat faces resulted in significant $p < .01$ age-related differences for the emotions anger, fear, happiness, and neutral, with younger adults showing higher proportion match.

Previous work in emotion recognition [3] has focused almost exclusively on the proportion of participants’ responses that matched the emotion a face was intended to display. However, in this data the patterns of labeling were identified as a crucial component of measuring emotion recognition. Further analysis directly assessed mislabels participants made when identifying emotion. The results indicated that some emotions were commonly mislabeled as another emotion similar in appearance (e.g., facial feature placement for the iCat’s expression fear was similar to surprise) suggesting emotion recognition might be further explained by perceptual discrimination.

4. CONCLUSION
The data provide support that age-related differences in emotion recognition transcend human faces. That is, a similar pattern of age-related differences in emotion recognition of human faces, also apply to synthetic human and robotic characters. In particular, older adults showed lower emotion recognition for the iCat emotions of anger, fear, happiness, and neutral. In an applied setting, designers might believe that certain negative emotions displayed by a robot would be useful for conveying an error or misunderstanding. However, if older adults mislabel certain emotions they may not interpret the robot’s intended message correctly, particularly if it is a negative emotion such as anger.

The analysis of mislabels participants made help provide a better understanding of what emotions were mislabeled as one another, and what facial features may carry vital information used to determine facial expression. The data may provide a road map for roboticists designing the facial expressions of social robots that may interact with both younger and older adults.

5. ACKNOWLEDGMENTS
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6. REFERENCES
Child’s recognition of emotions in robot’s face and body.

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ABSTRACT
Social robots can comfort and support children who have to cope with chronic diseases. In previous studies, an immobile “facial robot”, the iCat, proved to show well-recognized emotional expressions that are important in social interactions. The question is if a mobile robot without such a face, the Nao, can express emotions with its body. First, dynamic body postures were created and validated that express fear, happiness, anger, sadness and surprise. Then, fourteen children had to recognize emotions, expressed by the Nao and by the iCat. For both robots, recognition rates were relatively. Only for the emotion “sad”, the recognition was better for the iCat (95%) compared to the Nao (68%). Providing context, increased the number of correct recognitions. One week later, in a second session, the emotions were significantly better recognized than during the first session for both robots. In sum, we succeeded to design Nao emotions, which were well recognized and learned, and can be important ingredients of the social dialogs with children.

1. INTRODUCTION
With computers and robots stepping out of their industrial environment and into the human society, they can be of surprising help in the healthcare. Relatively “non-interactive” robots can provide substantial support for surgical, rehabilitation and medication delivery purposes, whereas “highly interactive” robots can provide more cognitive, affective and social support [6]. Our research focuses on these, last, socially assistive, robots and their potential to comfort or support children who have to cope with a chronic disease.

The iCat is a robotic research platform created by Philips. With movable eyes, eyelids, eyebrows and lips, the iCat has the ability to show facial expressions and thus show emotions. The six basic emotions were programmed into the iCat and validated by Kessens et al. [5]. The Nao robot is a humanoid robot that doesn’t have moveable facial features like the iCat does, but has the ability to alter its body posture. This can help to express emotions through its body posture. The Nao also has the ability to show different colors in its eyes and this can help to strengthen the emotions being expressed. The colors that will be used are those investigated by Kaya and Epps [4].

This article describes two experiments. In the first one, a set of dynamic emotional behaviors for the Nao will be created and validated, and the second assesses and compares child’s emotion recognition of the iCat and Nao. The question is if the emotions are recognized more accurate with the iCat (facial expression) or with the Nao (body posture). An additional question is if the emotion recognition is better when the emotional expression is presented in a corresponding context for both robots. And a third research question concerns repeated exposures to the robots and the recognition rates of the emotions. Does it get easier to recognize emotions in a second time contact, than after the first session for both robots?

2. EXPERIMENT 1
First, emotional postures for the Nao needed to be created. Four emotional postures, anger, fear, happiness and sadness were based on research by Bianchi-Berthouze and Kleinsmith [2] and one posture, surprise was based on research by Coulsen [3]. For anger, fear and happiness, two postures were created for the Nao, for sad, three postures were created and for surprise one posture was created.

2.1 Methods
A signal-detection task was used to validate the postures. Every emotion had a trial, where the participants had to indicate whether they saw a certain emotion (signal), or a different emotion (noise).

2.2 Results
The hit-rates and false-alarm rates were then calculated (see table 1). D’ was calculated by the Z-score of the hit-rate minus the Z-score of the false alarm-rate and shows the discriminability between the trial emotion (signal) and different emotions (noise). A higher d’, means a higher discriminability between the trial emotion and a noise emotion. Therefore, the posture with the highest d’ was chosen as the posture for that emotion. For anger and sadness, the second posture was chosen and for fear and happiness the first posture was chosen. The surprise posture was altered to make a better recognizable emotion with the help of vocal feedback from the participants.

Table 1

<table>
<thead>
<tr>
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<th>Hits, false alarms, hit rate, false alarm rate and d’.</th>
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<td>Angry2</td>
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<td>Fear1</td>
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<td>Fear2</td>
<td>11</td>
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<tr>
<td>Happy1</td>
<td>14</td>
</tr>
<tr>
<td>Happy2</td>
<td>12</td>
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<tr>
<td>Sad1</td>
<td>11</td>
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<tr>
<td>Sad2</td>
<td>7</td>
</tr>
<tr>
<td>Sad3</td>
<td>3</td>
</tr>
<tr>
<td>Surprise</td>
<td>22</td>
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2.3 Conclusion
With these results the final postures were chosen and for surprised the final posture was altered. The postures are shown in figure 2 and can be seen at the following link:
3. EXPERIMENT 2
With the two robots now both having validated emotional expressions (see figure 1 and 2), the actual experiment was conducted.

![Figure 1. A scared, happy, angry, sad and surprised iCat](image1)

![Figure 2. A scared, happy, angry, sad and surprised Nao](image2)

3.1 Methods
Participants
Fourteen children between 8 and 9 years, were recruited from an elementary school in the Netherlands.

Procedure
The children came to the experiment room, and had two interactions with both robots. A 'context' interaction and a 'no-context' interaction. The orders of the interactions were counterbalanced to reduce order effects. In the context interactions, a story was told by the computer. The robots showed emotions appropriate to the story. In the 'no-context' interaction, the robots showed the emotions without a story. On a questionnaire the children could fill in what emotion they thought the robot had shown.

3.2 RESULTS
Correct recognition rates for the emotions are calculated. For the iCat, fear had a recognition of 88.39%, happy had a rate of 73.21%, angry had 99.11%, sad 94.64% and for surprised, 69.64% was correctly recognized. For the Nao, the percentages of correct recognitions for fear, happy, angry, sad and surprised were 87.5%, 89.28%, 96.43%, 67.86% and 68.75% respectively.

Then, an ANOVA (figure 3) showed that there was no overall significant difference of recognition accuracy between the iCat and Nao emotions F(1, 1118)=1.24, p=0.27.

Emotions expressed in context were significantly better recognized than emotions expressed without a context F(1, 1118) = 29.79, p = .00.

And last, in the second session, emotions were better recognized than in the first session (F(1, 1118) = 18.76, p = .00).

3.3 Conclusion
The main research questions focused on (1) the difference in emotion recognition for the two robots, (2) the effects of context and (3) learning effects.

Only for the sad emotion, the facial expression was significantly better recognized than the body posture, but when looking at the entire set of emotions, no difference was found between facial and body posture expression.

It was expected that emotions in this experiment will be better recognized when they are being expressed in the context condition [1]. The conducted ANOVA shows that this is indeed the case.

The last and final hypothesis stated that in the second session the correct recognition rates would be higher than in the first session. This was based on Nelson’s review [7] which conclude that the skill for emotion recognition increases with multiple experiences. This hypotheses was supported by the results.

Implicit social cognition in HRI?
How robots could be automatically changing the way we see each other

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Abstract— Could attitudes and stereotypes about robots and people be unconsciously and automatically affecting the way people make judgments about both people and robots? We outline a current study and suggest directions for future research.

Keywords- human-robot interaction, implicit social cognition, unconscious, attitude, stereotype, schema, transferral, misattribution, mistake

I. INTRODUCTION

When people are not carefully controlling their reactions to the present situation, thoughts, feelings, and behaviors occur automatically according to learned mental maps called schemas. People have schemas for interacting in settings like family reunions, work, or home; with categories of people, from significant others to racial and ethnic groups; and perhaps even with robotic and non-robotic entities. Sometimes, schemas meant for one type of interaction are used in another, unconsciously and automatically transferring “implicit” attitudes and stereotypes [1] from the activated schema to the unintended target one is interacting with.

In the context of human-robot interaction, this “schema transferral” could cause attitudes and stereotypes about robotic entities to automatically alter people’s reactions to non-robotic entities, or vice versa. For example, researchers have already found hints of cross-cultural implicit attitudes that hold robots to be moderately less pleasant and slightly more threatening than people [2]; under certain conditions, one might misattribute the relative unpleasantness and threat evoked by a robot to a (undeserving) person, or even confuse someone with a robot, with similar effects. The current project investigates the possible existence of these two modes of schema transferral and their influence on judgments toward people and robots. We close with some proposals for future research.

II. ROBOT SCHEMA: A FIRST LOOK

Our study has two goals: 1) to detect the existence of a robot schema; and 2) to determine how and with what effects this schema might be unconsciously transferred and applied to people. The first mode of schema transferral involves the misattribution of attitudes or stereotypes associated with robots to non-robotic entities, while the second involves the mistaking of a non-robotic entity’s social category with that of a robotic entity, leading to use of one’s schema for reacting to the other. In both cases, attitudes and stereotypes toward robots have the potential to unconsciously shape people’s reactions to non-robotic entities in unexpected and potentially undesirable ways.

In misattribution studies, a prime stimulus is first presented subliminally or outside of a subject’s awareness, followed by a target stimulus. Because the prime is not clearly perceived, it cannot be identified as the source of the thoughts or emotions that it evokes. Instead, the thoughts or emotions are misattributed to the consciously perceived target stimulus. Misattribution effects are most easily measured in cases where the target provides ambiguous or no information at all to the subject. For example, Payne et al. [3] primed non-readers of Chinese with pleasant or unpleasant images and then asked them to rate Chinese ideograms as pleasant, unpleasant, or neutral. Ideograms preceded by pleasant images were more likely to be rated pleasant than ones preceded by neutral images, and even more so than those preceded by negative images; the effect was even replicated when subjects were not instructed to try and resist them, demonstrating the uncontrollability of the primes’ implicit effects. Devine [4] primed high- and low-prejudice White subjects with words related to stereotypes about African Americans and then asked subjects to rate the hostility of a race-ambiguous person they read about. In both the high- and low-prejudice groups, subjects exposed mostly to words that were stereotype-consistent rated the ambiguous character as more hostile than subjects exposed to fewer stereotype-consistent words. Similarly, we expect that implicit reactions evoked by a robot will automatically influence reactions to an ambiguous person.

Confusing a person with a robot might have consequences similar to those of misattribution. When a person mistakes someone for someone else, the people who are confused are likely to have the same social category relative to the person making the mistake (e.g., subordinate), or a similar salient role or physical attribute (e.g., attractive). Fiske, Haslam, and Fiske [5] found this pattern behind self-reports of misnaming, misacting (e.g., driving to the wrong person’s house), and misremembering with whom one has done something. While these subjects’ errors were self-reportable,
presumably because the remembered errors either self-corrected (as in the driving example), or because they caused an embarrassing reaction (as misnaming often does), many day-to-day errors may go unnoticed. Nothing in our study signals when one has made an error (we collect responses via questionnaire), so we do not expect our subjects to notice mistakes they make. By combining the critical aspects of priming and shared attributes from studies on misattribution and social mistakes, our study should be able to elicit and detect both modes of schema transferral.

A. Study Design

Participants are recruited for an alleged memory and judgment experiment and shown one of three video clips. In two treatment conditions, subjects are first primed with either a segment showing Willow Garage’s PR2 robot [6] folding a shirt, or a person folding a shirt in the exact same way and in the same location. Later in the clip subjects see a different target person who folds a shirt in the same location, but in a different way. In these treatment conditions, the prime and target share the role attribute of “shirt folder.” In a control condition, subjects first see a PR2 plugging an electric cord into a wall instead of folding a shirt, but then see the same target folding a shirt as subjects in the treatment conditions. To distract them from the otherwise curious sight of two different actors performing virtually the same action in the same setting, subjects are told that they will later be asked to recall the exact steps taken by the target person to fold his shirt. The target folds his shirt differently than the primes so that subjects can only recall him, not the primes, in recounting the target’s shirt-folding steps. If subjects recalled the PR2 prime — our implicit cue — in order to recount the steps, then any implicit effects it causes would be reduced [1]. To further increase the study’s believability, each clip is embedded within a custom infomercial that informs viewers about humanoid robots’ increasing prevalence in society and future participation alongside humans in day-to-day tasks. After they recall the target’s shirt-folding steps, subjects read an ambiguous biography of the target and evaluate him on several dimensions.

Differences in how the three groups evaluate the target will provide indirect measures of a robot schema’s presence and its effects when transferred, either by misattribution alone or by misattribution and category mistake together. When contrasted with the control condition, the treatment condition in which the PR2 and target human have different roles should measure only the effect of misattribution. But in the treatment condition where the PR2 and target human have different roles should measure only the effect of misattribution. And in the treatment condition where the PR2 and target human share the role attribute of “shirt folder,” subjects’ evaluations could be influenced by a category mistake in addition to misattribution. Therefore, a contrast between the last-mentioned condition and the human prime condition will detect the influence of some combination of misattribution and category mistake. By contrasting the two conditions with PR2 primes, we will be able to measure the relative strength of schema transferral via misattribution alone, versus both misattribution and category mistake.

We plan to ask for subjects’ evaluations on a few key dimensions already investigated in social psychology and human-robot interaction: competence and warmth; status as a social and moral entity; and authority. Competence and warmth are constructs identified by Fiske, Cuddy, and Glick [7] as “universal dimensions of social judgment” that reliably predict interpersonal and intergroup cognition. Kahn et al. [8] used the other three dimensions to evaluate subjects’ judgments about ATR’s Robovie [9] after participants engaged with it in 15-minute didactic interactions. We predict that on dimensions of warmth and competence, schema transferral will lead people to treat others whose jobs, for example, are shared with robots more coldly, yet regard them as more competent. More concerning is the possibility that attributions on the other three dimensions are reduced — especially status as a social or moral entity. In that case, robots’ increasing prevalence may truly change what it means to us to be human.

III. Conclusion

If we want to fully understand the impact that robots’ proliferation throughout society will have, we should seriously consider implicit social cognition as a source of change. Schema transferral, driven by misattribution and category mistakes, shapes cognition and behavior automatically and unconsciously. Because it happens without our awareness, we are not able to consciously control its effects, making it all the more important that we understand what those effects are. The study described here is but a first step toward uncovering evidence of schema transferral in the context of human-robot interaction, and there are many questions left to ask: What other attitudes and stereotypes exist toward robots? Which ones are most likely to affect our reactions to other people, and which are most powerful? Finally, what social categories or attributes are most likely to facilitate schema transferral when shared with a robot? We encourage the HRI community to join us in exploring these and related ideas.

REFERENCES

Learning to Provide Better Examples for Our Robots

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1. INTRODUCTION

Good coaches can put themselves in the shoes of their trainees, and provide them with useful examples. Simply watching a professional squash player during a game often does not provide mere beginners with enough information for them to improve their skills: their muscles are not as well formed and they are missing some of the elementary skills to build upon. When a squash expert is asked to coach a beginner, however, he will probably learn the beginner’s limitations over time, and end up providing different, more suitable examples than originally.

We have reasons to expect that the same holds for robots: for example, humans are utter experts in manipulation tasks, while robots are novices with different kinematics and much less impressive basic capabilities for the teacher to build on. Therefore, when humans teach robots certain manipulation tasks, they might have to come up with a strategy for the robot to use that is different from the strategy they would apply themselves. For example, if the robot’s hands are shaped differently (e.g. HERB, at Intel Labs Pittsburgh, shown in Figure 1), then it will not necessarily be able to open a fridge door the same way a human does. When the human is asked to teach the robot, they will likely not be aware of this at first, but when observing how the robot fails, they will strive to come up with a new way to approach the problem that is easier for the robot.

In our current work, we are exploring how humans adapt to the capabilities of the robot when teaching them such manipulation skills, and what interface is the most effective for this kind of adaptive teaching. We are looking at two types of interfaces: human tracking followed by mapping movement to the robot’s kinematics, and direct control (in which the human can directly move or teleoperate the robot). Our future goal is to create a framework for learning by demonstration in which the expert is not automatically regarded as ideal, but is allowed time to provide exemplars that are directly applicable to the robot.

2. PREVIOUS WORK

Today’s robots are still novices in a multitude of domains in which the average human is an expert by comparison. Learning from demonstration is thus a popular field because it strives towards transferring skills from humans to robots in a natural, effective and general way. There are two main teaching interfaces: the robot can track the human and map the example to its own action range (Atkeson[1], Schaal[7]), or the human can exert direct control of the robot. This can be achieved either by physically moving it (Hersch[4]), or by teleoperating, e.g. via joystick (Chernova[2], Grollmann[3]) or via a graphical interface, like the one proposed at HRI Pioneers 2010(Koening[6]). The advantage of the direct control type is that it is trivially mappable to the robot, filtering out unsuccessful examples automatically. However, it can also be a lot less intuitive for the human, thus preventing them from achieving the intended example.

In a psychology study, Hinds[5] showed that it can be hard for experts to assess the capabilities of novices. If we extrapolate this to humans teaching robots, we can infer that the first exemplar a human might provide when demonstrating a task can very well be outside the robot’s capabilities. Atkeson[1] found that in some cases, imitating the human directly is not feasible – unaware of what works for the robot, the human gives an example that is not well applicable. Another example is shown in Figure 2, when the expert is asked to demonstrate picking up the bottle, he chooses a trajectory that ends with a grasp from the top of the target object. However, HERB is not able to grasp in the same manner, thus the reaching trajectory not directly applicable: the robot can imitate it, yet at the end fail to accomplish its goal. This mismatch between expert and novice can happen in this case either because HERB was not yet taught how to grasp bottles from the top, or because HERB’s hand is not adequate for that particular grasp.
Figure 2: The expert demonstrating how to reach for a bottle. Since HERB cannot grasp the bottle in the same way, the example is not particularly useful.

3. PILOT STUDY

Setup: In a pilot user study meant to evaluate a direct interface, 5 subjects were given 3 minutes to command a robot to successfully grasp an object in the absence of clutter. They could control it by planar motions of the end-effector using the iPhone as a joystick (a direct control interface) and hitting a grasp button when close enough to the target. The users could visualize the robot in a simulated environment (Figure 3).

Findings: The task has proven to be very challenging, with only one out of the 5 users successful. All users had problems with joint limits. Furthermore, the successful trajectory was unsatisfactory because it was very unsmooth (due to joint limits and planar hand motion). We expect that incorporating clutter into the scene (a situation in which the robot actually require assistance due to limited planning capabilities) would make successful demonstration even harder to attain. This indicates that the tracking interface (as opposed to the direct control one used in this study) has the potential to be more suitable for teaching, despite the difficulty in mapping the motion, provided the expert is given time to adapt and ensure that the examples are applicable to the robot.

4. PROPOSED EXPERIMENT

We propose an experiment targeted at the following questions:

1. When it comes to teaching manipulation skills to a robot, does a human adapt over time to the limitations and constraints of the robot and the interface? In other words, does it take less time to successfully demonstrate how to accomplish a subsequent tasks than it does to accomplish the first one?

2. What type of demonstration interface is most effective for teaching manipulation skills?

Interfaces: A first interface is a tracking one, in which a human demonstrates a trajectory to HERB, after which he/she observes the robot imitating the trajectory in a duplicate environment. The second interface is at the middle ground between tracking and direct control: the robot imitates the human’s arm in real-time, which can be viewed as teleoperation. In case of failure, the human can reset the robot to the original configuration and attempt another demonstration. The third interface is direct control – the human moves the robot arm (with HERB in gravity compensation mode to allow for easy interaction). Again, the human can reset the robot.

Setup: Each subject is given basic information about an interface and 5 similar tasks for grasping a target object in a cluttered environment. We expect to see that the subsequent tasks become easier. We define a successful demonstration as one that yields a trajectory that the robot can re-execute without colliding and that results in a successful grasp. The teachers are told to stop when they are satisfied with the trajectory that robot executes, in terms of success and quality.

Measurable quantities:
- time required to get the first successful trajectory and the end trajectory (that the teacher is satisfied with), for each interface and task
- the cost of both trajectories, for each task (length and smoothness, defined as sum squared velocities)

Survey: The subjects will be asked to rate: 1) how fit the interface is for teaching, 2) how well they could get the robot to follow the movement they intended (ease of use), 3) the difficulty of each of the tasks and 4) how different the trajectory they originally had in mind is from the final trajectory (change in strategy) for each task.

5. DISCUSSION

We hope to find that humans do in fact adapt to the robot’s capabilities (including the teaching interface), and to get an idea for what interface is more suitable for this sort of teaching. Ultimately, we want to show that learning from experience is facilitated by good examples that are adapted to the robot. We look forward to discussing this experimental setup at the HRI Pioneers Workshop, and developing new ideas about learning from adapted demonstration.

6. REFERENCES


The New Ontological Category Hypothesis in Human-Robot Interaction

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ABSTRACT
This paper discusses converging evidence to support the hypothesis that personified robots and other embodied personified computational systems may represent a new ontological category, where ontology refers to basic categories of being, and ways of distinguishing them.

Keywords
Ontology, category membership, personified robot

1. INTRODUCTION
Are personified robots animate or inanimate? They are animate in the sense that they can move and speak. They are inanimate in the sense that they are technological artifacts. The answer, then, to the question of whether personified robots are animate could be “yes, no, and both.” If so, it points to a hypothesis that Kahn and colleagues proposed and have been addressing since 2002 [4, 5, 6, 7].

Ontology refers to basic categories of being, and ways of distinguishing them. The hypothesis is that a new ontological category (a) is emerging through the creation of personified robots and (b) will continue to emerge as other embodied personified computational systems (e.g., “smart” cars and homes of the future) become increasingly pervasive.

2. EVIDENCE FOR THE NEW ONTOLOGICAL CATEGORY HYPOTHESIS
Initial evidence to support the New Ontological Category (NOC) Hypothesis comes from research in developmental psychology. Findings show that young children consistently classify canonical living and nonliving entities as distinct from one another, understanding by age five that living and nonliving things differ in terms of biological, psychological, and perceptual properties [e.g., 2,3]. Preschoolers understand that living things, including people, animals, and plants, are both similar to one another and distinct from nonliving things, and use causal explanations that invoke “life” to explain phenomena that pertain only to living things [3].

Unlike canonical living and nonliving entities, robots present a somewhat perplexing case. Research suggests that biology (e.g., whether an entity is alive or eats) is not a necessary precondition for children to attribute psychological states such as cognition and emotion to robots [3]. For example, Jipson and Gelman [3] found that 4-year-olds rarely attributed biological properties, but did attribute psychological and perceptual properties, to the robotic dog I-Cybie. Bernstein and Crowley [1] found that children who had more prior experience with robots were less likely to judge a robot as alive, but more likely to judge it as intelligent in a unique way, distinct from human or animal intelligence. Children with little prior experience believed the robot was alive and had intellectual and psychological properties. One possibility is that as children gain experience interacting with robotic others, their judgments about entities within the new ontological category will become more nuanced. Taken together, these studies show that patterns of attribution to robots do not mirror patterns of attribution to canonical entities.

The above body of research, however, has had three major limitations. First, the studies involved children viewing images or video clips of a robot, and not interacting directly with an actual robot. Second, the studies did not emphasize social and moral relationships with actual robot. Third, the studies did not report children’s reasoning about their evaluative category judgments.

Toward addressing the limitations, Kahn and colleagues employed a structural developmental methodology in three studies that sought to assess social and moral relationships with and conceptions of the robot dog AIBO [5, 6, 7]. In the first study, researchers systematically coded content from 3,119 Internet discussion forum postings by 182 AIBO owners, all presumably adults [5]. The purpose of the study was to establish an initial framework for understanding mature conceptions of AIBO’s biological, mental, social, and moral status. In that study, 48% referred to AIBO in life-like terms (e.g. “He seems ALIVE to me”), 68% referred to AIBO’s mental states (e.g. “He has woken in the night very sad and distressed”), 59% referred to AIBO as a social other (e.g. “I do view him as a companion”), and 12% spoke of AIBO as a moral other (e.g. “I actually felt sad and guilty for causing him pain!”).

Using this established framework for investigating attributions of category membership to AIBO, Kahn and colleagues conducted two additional studies focused on children’s social and moral relationships with AIBO. In both studies, children were given the opportunity to interact with AIBO prior to being...
interviewed about the interaction. The first study assessed 80 preschoolers, aged 3–5 years [6]. The second study assessed 72 children, aged 7–15 years [7]. Comparing across studies, 38% of preschoolers, 23% of 7–9-year-olds, and 33% of 10–12-year-olds, agreed that AIBO was alive, whereas only 5% of 13–15-year-olds agreed. Examination of justifications for “alive/not alive” responses revealed nuanced reasoning. For example, one child stated: “He [AIBO] is alive, for a robot.” So, while the majority of children did not conceive of AIBO as biological, reasoning suggests a more nuanced position than yes or no. Equally important, across both studies most participants attributed psychological states, including thoughts and feelings, to AIBO. The majority of participants in both studies attributed sociality to AIBO (e.g. AIBO can be a friend). Thus, the three AIBO studies provide converging evidence that children and adults can and often do establish meaningful and robust social conceptualizations of and relationships with a robotic other that they recognize as a technology.

Kahn and colleagues subsequently conducted a study using ATR’s humanoid robot Robovie [4]. In that study the researchers were interested both in the categorical attributions participants would make to Robovie, and in whether or not children would conceive of Robovie as an entity worthy of social and moral regard (i.e. whether Robovie is entitled to welfare and justice). In the study, 90 children and adolescents, 30 in each of the 9-, 12-, and 15-year old age groups, engaged in a 15-minute structured interaction with Robovie, followed by a 50-minute semi-structured interview. The interaction culminated with an experimenter interrupting a game of “I Spy” to put Robovie in the closet, against Robovie’s verbal objection. The majority of participants engaged in nuanced social interactions with Robovie (e.g., followed Robovie’s directions while learning about a coral reef aquarium; engaged Robovie in dialogue about relevant topics). In terms of judgments and reasoning about the interaction, children and adolescents believed that Robovie had mental states and was a social other. Some children even believed that Robovie was deserving of moral regard (i.e. entitled to welfare and fairness).

Results also showed that many children were unwilling to commit to Robovie as living or not living, and spoke in various ways of Robovie being “in between” living and not living or simply not fitting either category. For example one participant said, “He’s like half living, half not.” And another participant reasoned, “He just seemed like really life like so it’s hard to say it. He’s not human but he has the characteristics and the potential.” In trying to understand the feeling state of Robovie, one participant reasoned, “I mean cause robots I’ve heard everybody say aren’t living things and I’ve pretty much agreed with them but meeting Robovie has really changed my opinion on that because he seemed more living and I know if you covered his mouth he wouldn’t die or pass out or anything but he seemed more living than like a regular robot and like he did have feelings.”

3. CONCLUSION

For the most part, people are not confused about how to categorize most entities in the world. We do not, for example, talk to a brick wall and expect it to talk back, nor do we attribute to it mental capabilities or think of it as a possible friend. But robots appear different.

The findings outlined in this paper provide support for the NOC hypothesis. In brief, there is emerging evidence to suggest that there is a constellation of attributes that children and adults ascribe to personified robots – including those that involve mental states, sociality, and in some ways even moral regard – which do not appear to mirror reasoning about such canonical living entities as humans, non-human animals, or artifacts.

4. ACKNOWLEDGMENTS

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5. REFERENCES


Adaptation of Task-Aware, Communicative Variance for Motion Control in Social Humanoid Robotic Applications

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ABSTRACT
Motion is an underused channel of communication in robots that can be harnessed to increase the transparency and observability of system state information. My research goals are to (1) develop a real-time, context dependent, dynamic, and autonomous control algorithm for social robots that generates more natural, life-like, or believable motion from minimal input information; (2) prove that motion can communicate internal and external state parameters; (3) demonstrate how to appropriately exploit redundancy to add motion variability and communicative signals to primary motion without interfering with the robot tasks; (4) prove or disprove spatiotemporal correspondence of task-space coordinates of an articulated body (i.e. motor coordination) as a metric for human-like robot motion for humanoid robots, and (5) measure the impact of human-like motion generating algorithms on human-social robot interaction.

The end result of my research will be a algorithm where a robot can observe a potentially bad exemplar of a motion, add the communicative signals of secondary motion, exaggeration, and anticipation in a way that is meaningful to the human partner, optimize the motion for naturalness, and add variance all while preserving constraints.

1. INTRODUCTION

The human body is a powerful representational tool, optimized for communicating spatial reference, demonstration, disambiguating speech, inquiring for feedback, influencing others’ behavior, and directing attention. Non-verbal communication constitutes approximately 60% of human interaction and meaningful motion accompanies 75% of discourse [9]. Since humans naturally assign internal states to inanimate objects [1, 4, 16] and nonverbal behavior cannot be regulated to convey no impression [5], motion must be carefully constructed to communicate the intended impression.

Evidence and experience have shown that effectiveness of interaction increases when a machine is endowed with human-like traits [19, 14]. Display of appropriate non-verbal communication behaviors results in increased perception of agent realism [3].

Human communication is multimodal, involving multiple simultaneous feedback channels. Multimodality increases attribution of social communicative mechanisms to the agent, such as social responses, communicative intent, and internal states [14, 3]. To achieve more robust interaction, motion can be exploited and social robots can increase the signal-to-noise ratio of communication signals expressed during collaborations with human partners by utilizing behaviors and motions that are socially relevant to the people with whom they interact and increasing the transparency and observability of their own state information.

Conveying information using familiar output modes, forms, and interfaces in interaction may be the key to widespread acceptance of robots beyond the domains of education and entertainment [2, 20, 17]. If robots become future collaborators, service workers, guides, instructors, and personal helpers then costs are lower and less training is necessary when meaningful interaction can begin immediately because robot communication is embedded in a familiar, user-friendly format, in all aspects, including its motion [18, 6].

2. RESEARCH

My research goals are to (1) develop a real-time, context dependent, dynamic, and autonomous control algorithm for social robots that generates more natural, life-like, or believable motion from minimal input information; (2) prove that motion can communicate internal and external state parameters; (3) demonstrate how to appropriately exploit redundancy to add motion variability and communicative signals to primary motion without interfering with the robot tasks; (4) prove or disprove spatiotemporal correspondence of task-space coordinates of an articulated body (i.e. motor coordination) as a metric for human-like robot motion for humanoid robots, and (5) measure the impact of natural-motion algorithms on human-social robot interaction.

2.1 Add Communicative Motion

My work to understand what information can be communicated in motion and develop autonomous techniques to encode desired signals into motion is inspired by principles of animation made famous by Johnston, Thomas, and Lasseter [15, 12].

2.1.1 Anticipation

Anticipation is the idea that someone watching motion can discern future motion from current and past motion.
In cooperative tasks and interaction between two agents, anticipation of world states and earlier knowledge of collaboration partners’ actions enable better teammate timing, which implies that robot motion must clearly and transparently communicate state information and expectations to partners [11, 10].

My unpublished algorithm demonstrates a novel method for adding communicative anticipatory motion to gestures. A series of ongoing studies have preliminarily shown that when anticipatory communicative motion is added to gestures, humans correctly recognize and label these motions earlier than for the original motions lacking anticipatory communication. These results will be published in 2011.

2.1.2 Exaggeration

Exaggeration is useful when the robot needs to draw attention to a particular body part using its motion. Trajectories that sweep larger ranges of Cartesian space are said to be exaggerated, as compared to direct motions that minimize the body parts’ travel through Euclidean space. A preliminary algorithm has been developed and user studies to evaluate the algorithm will begin in January 2011.

2.1.3 Secondary Motion

Secondary motion is a phenomenon that produces consistency in the motion of all the body parts of the social robot. Ongoing studies to test my hypothesis that secondary response to a primary action can communicate internal (e.g., passivity, motor temperature) and external (e.g., mass, friction) state parameters will be published in 2011. Three algorithms that I developed to create secondary motion are published in [7].

2.2 Increase Naturalness

My metric that can be used to optimize motion in order to make it more humanlike will be presented at HRI ’11. I present a set of user studies to prove that robot motion optimized with respect to spatiotemporal correspondence is (1) more often recognized as a common human motion, (2) more accurately labeled as the originally intended motion, and (3) mimicked more accurately than non-optimized motion [8].

2.3 Add Variance & Maintain Constraints

Highly dynamic and unpredictable environments require flexibility in motion, which suggests that motion variance is a design requirement for robots. Repetitive motions are not realistic, and therefore, a systematic, formalized technique is required to generate varied trajectories in real-time.

Work has been submitted for publication that demonstrates a technique to take a single exemplar of a motion and combine it with operational space control [13] to preserve world constraints in order to produce varied robot motions that satisfy constraints.

3. CONCLUSION

My work raises awareness of the challenges presented in the rapidly developing field of motion control for social robots. The HRI’11 Pioneers Workshop will give me an opportunity to showcase the work that I have accomplished in the field of generating human-like motion for social robots. The timing of the workshop is excellent because as a fourth-year Ph.D. near graduation, I would like to share my work with the research community and talk with any potential future employers who may be interested in my work.

4. REFERENCES


Robot Games for Elderly

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Abstract—I currently investigate how physical games based on a mobile robot can be used as a persuasive tool for promoting physical activity in a rehabilitation scenario for elderly with mobility problems. Based on a mobile robot we have developed two simple games. Each game has been investigated in two field studies - one in a nursing home and one in a rehabilitation center for elderly. The goal of the first field study, was to investigate seniors acceptance of the robot game and to obtain knowledge about their play patterns and get ideas about future improvements. The goal of the second field study was to investigate whether is was possible for the robot to adapt the challenge of the game to the skills of the player.

I. INTRODUCTION

Based on the demographic development in most western countries, it has been predicted that the number of people with mental and/or physical disabilities will increase while the amount of people to take care of them will decrease [15], [1]. Digital games hold a significant promise for enhancing the lives of seniors, potentially improving their mental and physical wellbeing, enhancing their social connectedness, and generally offering an enjoyable way of spending time [6]. It has been shown that mental and physical health can be improved through a small amount of physical exercises [13], [4], and e.g. Nintendo Wii has been suggested as way to increase physical activity among elderly [2], [9]. Computer games are gradually moving from the pure virtual domain into the physical world with the introduction of products like Nintendo Wii, Microsoft Kinect, Sony’s EyeToy, but to our knowledge, motivating users to move physically by playing a game with a mobile robot is a new approach. The physical and tangible nature of autonomous robots, catalyzes interaction and encourages humans to anthropomorphize them [5] even when their physical aspect is obviously different from that of a human being. The idea of attributing agency to objects in our environment is almost innate in humans, especially for objects that move [10] which has long been recognized in the computer game industry. Although the complexity of computer games has developed rapidly the last 50 years, electronic games do not necessarily have to be complex to be successful, i.e. a game like Tetris keeps being a popular game. Successful games are often characterized using the concept Flow, as proposed by Cskszentmihly [3] which only occur when there is an appropriate balance between challenge and skill. In this paper, I will first describe the implementation of two robot games and then briefly summarize the results of the corresponding field studies.

II. IMPLEMENTATION OF THE GAMES

The games were based on a robot platform from FESTO equipped with a head having red diodes (LEDs) which enabled it to express different emotions. The robot was meter high, and had mounted an URG-04LX line scan laser placed above ground level, scanning 35 degrees in front of the robot. To detect persons, the robot relied on the scans from the laser range finder using the leg detection algorithm presented in [14].

In the first game, the participants should try to get and maintain the attention of the robot while moving around physically. When the robot detected a player it would follow the interacting person within a specific range (1.3 meters). Once the robot followed a player, another participant should try to 'steal' the robot's attention from the current. We chose to use this relative simple game setup as it has shown to be very robust when operating in open-ended environments [11].

The second game was based on a simplified pursuit and evasion scenario with a single pursuer (the human player) and a evader (a mobile robot). The player should try to hand over a ball to the robot, while the robot should try to avoid receiving the ball. The robot would continuously register the players position and orientation of the body by inferring 2D laser range measurements as explained in [12]. To incorporate the ability to learn from experiences and adapt challenge to skill we used Case Based Reasoning (CBR) which has been proven successful in related problems in [8], [7].

III. BRIEF SUMMARY OF RESULTS

Traditionally, training of elderly with mobility problems is often performed by occupational therapists who instruct a number of people (5-10) at the same time. Training is often based on exercises where the participants sit on a chair and do different movements with their arms and legs while listening to music (See 1). It is often difficult for the therapists to motivate the elderly to train hard and long enough, making it interesting to try robot games as a new tool.

The goal of the first field study, was to investigate seniors acceptance of the robot game and to obtain knowledge about their play patterns and get ideas about future improvements. One of the findings was that the elderly did not mind participating in the game. Out of 26 invited, 23 accepted playing actively while 3 observed the others play. A general observation was that the elderly would act towards the robot as if it was a living agent talking to it as if it was a dog or a young man. Another observation was that the elderly
would tend to walk more freely when playing the game by e.g. walking backwards which exercise the players postural control. A third observation was that although the elderly initially got engaged in playing the game and tried to play several times, they also thought the game quickly became boring. They expressed that the robot should be able to do more like singing or being capable of playing more challenging games. A technical finding from the study, was that the robot was able to detect people using assistive tools crutches, walkers or wheelchairs.

The second study was based on a simple ball game, and the goal was to investigate user acceptance and how the robot would adjust the difficulty of the game to the individual player. One of the findings from the second study was the play style of each individual player would vary so much, that the adaptation of the game challenge did not make much sense. E.g. some players would deliberately not complete the game although they could, just to ‘tease’ the robot. Others would only approach the robot from the back, making it incapable of detecting the behavior patterns of the person and thereby adapt the challenge.

IV. DISCUSSION AND CONCLUSION

So far, only a few real world evaluations on robot games have been conducted. Nevertheless, I estimate that robot games are on the stage where computer games were 50 years ago having the same potential. On the Pioneer Conference, I would like to discuss how I could enhance the game seen from a technical point of view and how new interesting experiments could be setup evaluating the user experience and the potential physiological benefits of robot games.

REFERENCES


Predicting Human Performance in Peer-based Human-Robot Teams

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ABSTRACT
Human behavior can be predicted through computational modeling using Human Performance Moderator Functions (HPMFs). HPMFs have been validated for application to humans and human-human teams, but in order to predict the behavior of humans in human-robot peer-based teams, current HPMFs must be proven applicable to human-robot teams or redefined. My research models human-human and human-robot teams performing the same set of tasks using a current model of an HPMF, validates the models with empirical user evaluations, and analyzes the performance predictions. Ultimately, the resulting performance functions may be used to allocate human-robot teams or to modify the robot response to humans as the human performance degrades.

Categories and Subject Descriptors
I.2 [Artificial Intelligence]: Robotics.

General Terms
Experimentation, Human Factors, Verification.

Keywords
Human performance moderator functions, IMPRINT Pro, human-robot peer-based teams

1. INTRODUCTION
As robotic technology develops, the possibility of humans and robots acting as partners for peer-based tasks increases [1]. Individual human performance can impact the overall performance of human teams [2]. Therefore, human performance will impact the task performance of human-robot teams (HRTs). With increased capabilities and responsibilities, the robotic team members will need to understand how the human’s performance capabilities are affecting the task at hand. Future robots should be able to adapt their behavior, as humans do in human teams, to mitigate and accommodate changes in the performance of their human partners. In order to develop such robotic capabilities, it is necessary to understand if and how existing human performance moderator functions apply to human-robot teams. Developing such understanding necessitates modeling human performance moderator functions for such teams, conducting evaluations to gather the associated empirical results, and understanding how the empirical results relate to the modeled performance moderator functions.

2. BACKGROUND
HPMFs are equations derived from empirical results that predict human performance due to specific performance factors such as fatigue, mental workload or temperature. Over 500 HPMFs [3] are known to exist. It is well known that a number of interactions exist across human performance functions, thus it can be very difficult to model and evaluate human performance. Our current research is focused on understanding a subset of the known human performance moderator functions. We have chosen to initially focus our research on workload and future work will integrate a number of other functions.

HPMFs have been evaluated for various domains such as aviation [4] and nuclear power plants [5]. These domains represent fairly well defined and controlled domains than the potential dynamic and highly uncertain domains in which human-robot teams will be deployed, for example, first response to Chemical, Biological, Radiological, Nuclear, and Explosive (CBRNE) incidents or military missions [6]. Rather than blindly applying existing results to HRTs, it is necessary to understand the applicability of these functions to HRTs.

A significant amount of research in the human-robot interaction domain has focused on measuring human performance [7, 8], but little research has focused on modeling the human performance moderator functions for purposes of impacting the interaction between peer-based teams of humans and robots. In addition to the body of research focused on providing empirical HRI results, research has also focused on developing appropriate metrics for assessing human-robot interaction (HRI) [9] and predicting robot operator capacity [10, 11].

3. METHOD
3.1 Human-Performance Modeling
Human performance modeling simulates human behavior under a variety of conditions and tasks. The models require inputs related to human performance and result in the likely actions based on the current scenario. HPMFs can be incorporated into Human Performance Models (HPMs) in order to improve the model fidelity [12]. Our human performance models are created using...
the IMPRINT Pro [13, 14] software and involve creating task network models with HPMF values attached to each task. For each evaluation, we create a HPM for the human-human team performing a set of tasks and the human-robot team.

3.2 Experimental Validation
After creating the two HPMs, the empirical evaluation focuses on real human-human and human-robot teams completing the tasks. The models are validated by the evaluation and HPMF data compared with model predictions. Conclusions can be drawn whether the models accurately predicted human performance in a human-human team, human-robot team and whether performance in the two scenarios was different due to the partner.

4. CURRENT RESULTS
Our research group has performed one evaluation, focused on workload in a medical triage scenario [15, 16]. Results have indicated that current HPMFs for workload are applicable to human-robot teams as long as differences in timing related to differences between a human partner vs. a robot partner are accounted for. Further experiments will be performed to confirm or refute this conclusion and investigate the applicability of other HPMFs such as vigilance or stress.

5. CONTRIBUTIONS
This research is intended to inform team planning with human-robot peer-based teams. When forming teams from a larger group of both robots and humans, it is necessary to have a way to predict which team will perform better, how much can be expected of a human’s behaviors and interaction with the human as the human’s performance degrades. Human performance modeling can inform these decisions and when combined with HPMFs specific to human-robot peer-based teams, the prediction will become more accurate.

6. ACKNOWLEDGMENTS
This research is supported by AFOSR award FA9550-09-1-0108.

REFERENCES
Modeling and Compensation for Biodynamic Feedthrough in an Advanced Backhoe Operator Interface: Research Summary

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ABSTRACT

Biodynamic feedthrough can occur in many types of human-controlled machines where the operator is also a passenger. The motion of the controlled machine excites motion of the human operator’s body, causing motion of the operator’s hand, creating undesirable input. Backhoes are one example of a machine that is susceptible to significant performance degradation from biodynamic feedthrough. It is a recognized problem in various types of backhoe user interfaces. The main goals of this research are to investigate and model the system dynamics, including the human operator and biodynamic feedthrough, to develop compensation for biodynamic feedthrough based on those models, and to experimentally validate the performance of the biodynamic feedthrough compensation; this research summary briefly describes each of these steps.

Keywords

human-machine interfaces, mobile hydraulic machinery, active vibration control

1. INTRODUCTION

Biodynamic feedthrough can cause significant performance degradation in backhoe and excavator operation, resulting in unwanted oscillations and even instability. This undesirable addition to the operator input is highly correlated with the output and acts as feedback loop. This research seeks to mitigate this problem.

![Figure 1: Operator input devices](image)

This research utilizes a previously developed backhoe testbed with an advanced user interface, using coordinated position control with haptic feedback. In contrast to the conventional 2-joystick control scheme, it uses the SensAble Omni six degree-of-freedom (DOF) haptic display device for the operator input (Figure 1). The testbed is described in [5] and [1].

This work is part of a larger group effort to improve user interfaces for mobile hydraulic machinery and is affiliated with the NSF Center for Compact and Efficient Fluid Power. Many approaches to biodynamic feedthrough compensation were considered. A controller-based approach was selected, using the working implement itself for cab vibration compensation; this minimizes cost and additional hardware. This approach necessitates the development of a controller which not only drives the backhoe arm position to the commanded reference, but also minimizes cab vibration.

![Figure 2: Single degree-of-freedom approximation](image)

As an initial step, in order to make this complex problem more manageable, the system was limited to a single fore-aft degree of freedom with actuation of only the boom joint. As shown in Figure 2, fore-aft motion of the human hand excites approximately fore-aft motion of the backhoe arm and tractor/backhoe structure, with small angle approximation.

2. BACKGROUND

Biodynamic feedthrough is a widely studied problem in high-performance aircraft; however, it has received less attention in other areas. The US Air Force supported a notable study on biodynamic feedthrough, which focused on biomechanical modeling of the pilot [4]. Other biodynamic feedthrough studies have been performed on 1-DOF motion platforms and a few excavator simulations. There are several publications on this research, including those focusing on the following topics: system modeling [3], overview and compensation methods [2], and others recently submitted.
3. SYSTEM MODELING AND CONTROLLER DESIGN

Lumped parameter models were developed for each of the main dynamic components of the system, based on a hybrid of first principles and system identification. Those subsystem models were combined as shown in Figure 3 to form a full control system model including biodynamic feedthrough.

![Figure 3: Basic biodynamic feedthrough block diagram](image)

The controller has two conflicting goals, to track the desired reference and to minimize cab vibration. There is a tradeoff between cylinder tracking performance and vibration reduction.

Two main types of cylinder position controllers were tested, a PID controller and a state feedback linear quadratic regulator (LQR) controller. Passive compensation methods were added to the PID controller, while active compensation was added to the LQR controller. The following controller types were tested: (1) PID with no vibration compensation, (2) PID plus notch filter, (3) PID plus input shaping compensation, (4) LQR with no vibration compensation, (5) LQR with active vibration compensation. The two types of controllers were not tuned to be equivalent; therefore, the experiments have two distinct baseline controllers without vibration compensation.

4. EXPERIMENTS

Two separate sets of experiments were performed, all limited to a single degree of freedom.

4.1 Vibration Compensation Testing

The first set of experiments tested the controllers' performance with two types of software inputs, without the additional variability introduced by human subjects. The two inputs were a slowly varying large amplitude S-curve and a faster varying smaller amplitude swept sine.

With the swept sine input, the input shaper produces a 96% reduction in cab vibration as compared to the PID controller without vibration compensation. With the state feedback control, the active vibration compensation provides a 49% reduction in cab vibration.

4.2 Human Operator Pilot Study

The second experiment was a pilot human operator study with eight subjects. The full-scale human operator study and data analysis are ongoing. A tracking-pursuit experiment was used, with the reference and output signals displayed on a monitor. The reference signal and presentation of controllers were randomized. Experiments were performed with each controller at two workstations, one on the tractor (with biodynamic feedthrough) and one off the tractor (without biodynamic feedthrough). After each controller test, operators provided ratings in terms of accuracy, smoothness, speed of response, and overall controllability.

While the pilot study did not include a sufficient number of participants to obtain statistical significance, the following trends were observed.

- Operators' tracking performance was significantly degraded when using the workstation on the tractor, with biodynamic feedthrough, as compared to performance off the tractor.
- Both the input shaping and active vibration compensation do reduce cab vibration.
- Operators on the tractor perform better with the input shaping compensation and the active vibration compensation.
- In general, operators rate the vibration compensating controllers higher when using the on-tractor workstation.

5. CONCLUSIONS AND FUTURE WORK

These results indicate that the proposed methods can improve operator performance with biodynamic feedthrough. Larger scale human operator studies are in progress. Necessary next steps for industry application include expanding the solution to multiple degrees of freedom and investigating robustness, as well as developing an improved input device.

6. REFERENCES

The Naming of Robots

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ABSTRACT
Naming a robot categorizes it, creates expectations and triggers social response. An analysis of robot naming practices in research robot competitions shows widespread conventions of naming with more than $2/3$rd of all robots reflecting biomorphic or lifelike non-mechanistic attributes. This will evoke ‘mindless’ or anthropoic social response. My preliminary research findings are that robot naming in different competitions either replicates human gender stereotypes or is evidence of prosthesis (or projection), the extension of self into the robot. Even robot names that avoid anthropomorphism, gender or animism are subject to version control strategies, highlighting the difficulties that we face with regard to robot identity. To address these issues, the human robot interaction field may need to adopt an expanded vocabulary.

Categories and Subject Descriptors
H.1.2 [User/Machine Systems]

General Terms
Human Factors

Keywords
Human-Robot Interaction, Cultural Studies, Gender, Identity, Naming, Anthropomorphism, Biomorphism.

1. INTRODUCTION
The robot, whether humanoid or not, has become a model (in)organism [13], standing for human. Whether the robot is a prosthetic extension [3][4][8][9][10], mirror [1][3] or an ‘other’ social actor [4][8][9][11], our relationship with robots is part of a broader culture. Cultural studies, with its emphasis on questions of power, gender and identity is always asking ‘what’s at stake?’ [6]. My current research uses cultural studies methodology, content and discourse analysis, to examine the field of robot competitions, focusing on naming practices, which are primary indicators of gender, class and identity [5][11]. It is well known that robotics is a highly gendered field, but the broader issue of identity is going to be of extreme significance as the number of robots in use in the world grows exponentially.

2. THE NAMING OF ROBOTS
2.1 Method
The source of my robot name data is published or online information from robot competitions. There are more than 100 competitions across the world each year, primarily for university students and researchers. I have collected more than 2000 unique names to date, from a range of competition types, from combat robots to chatbots, navigation, entertainment and soccer robots.

Robot names have been coded as either male, female, lifelike or machinelike. Only English names were coded and as I was limited to public data, not all major competitions could be included. Teams of robots, primarily in soccer and dance competitions, did not tend to have individual names, however, it is surprising just how many individual robots were named, particularly in competitions where human interaction is not part of the design.

2.2 Results
My preliminary results have focused on names from two competitions that represent quite different robots. The AIGV competition has been running since 1993 with results published continuously in the same format. The AIGV or Annual Independent Ground Vehicle competition is based in the USA but attracts competitors from around the world. The robots involved are small vehicles. Initially no robots were named, but over a 5-year period naming became the convention and since 1998 all robots have had a name.

The Chatterbox Challenge, while for social agents or disembodied ‘bots’ is a very useful comparison. While the records are not as extensive, the Chatterbox competition does provide records of 10 consecutive years of a global competition in which human interaction is the primary purpose. My initial thesis was that chatbots would be primarily human with female bias and that the vehicular robots would be largely unnamed or machinic with a male bias.

In fact, the results showed that both sets of robots were far more likely to have a male or animal/pet name and the names chosen also expressed certain common characteristics. For example, a majority of male names expressed mastery or dominance whereas more than half of female names were diminutives. For every Athena, there was an Amber. For every Johnny5, there was an Overlord, Zeus, Thor PRO, Harvinator, Kratos and a Warrior.

Overall, there was a surprising bias towards male and animal/pet names in both the chatbots and the vehicles, moving away from the female or the machine. This suggests either a prosthetic relationship or the robot as a social actor in a gendered field.

<table>
<thead>
<tr>
<th>Competition</th>
<th>Chatterbox</th>
<th>AIGV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>44 (30%)</td>
<td>109 (30%)</td>
</tr>
<tr>
<td>Female</td>
<td>37 (26%)</td>
<td>28 (8%)</td>
</tr>
<tr>
<td>Unknown</td>
<td>35 (25%)</td>
<td>129 (35%)</td>
</tr>
<tr>
<td>Other</td>
<td>27 (19%)</td>
<td>98 (27%)</td>
</tr>
<tr>
<td>Total Unique Names</td>
<td>143</td>
<td>364</td>
</tr>
</tbody>
</table>
2.3 Conclusions
My preliminary conclusions are that robot names provide a window into human robot interaction in the earliest stages of robot evolution and therefore more study is warranted. Robots are named for a wide variety of reasons, some functional and some whimsical. By evaluating a large number of names, aggregate trends can be identified, which will aid further investigation and indicate areas in which the emerging robotics field is creating new cultural forms not just reflecting the dominant cultures.

2.3.1 Gender
It is well known that robotics, like much of STEM, has been a highly gendered field, so research into gender interactions is relevant for the improving gender equity in this field. And as robots are model (in)organisms, understanding gender interactions will have broader applications.

2.3.2 Identity
The version control strategies resorted to in robot names highlight the many ways in which a robot identity is formed or fixed, and how fluid a robot identity actually is, which has great social, legal and economic implications.

2.3.3 Vocabulary
Many HRI researchers have indicated the need for an expanded vocabulary, with common reference points [2][7][9][12][14]. For example in the naming of robots, I have used biomorphic to describe the giving of lifelike attributes in the construction of a robot, which might be human traits (anthropomorphic), animal traits (zoomorphic) or simply a behaviour or appearance which is known to be ‘lifelike’. The evocation of response should, in my view, be a separate quality as it depends on the audience and context. I have used the terms ‘ethopoeic’, and ‘mindless’ in conjunction with conscious ‘anthropomorphism’. As this field grows in complexity, the need for more subtlety in the scales becomes evident.

3. FUTURE DIRECTIONS
The robot name database that I have developed could become an open collection in the future. I am also in the preliminary stages of developing a website of robot images that allows for interactive robot naming (as an art project) due to feedback from the test surveys during the development of the robot naming research proposal, in which most participants found robot naming to be entertaining and yet somewhat confronting.

4. ACKNOWLEDGMENTS
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5. REFERENCES
Devilishly Charming Robots and Charismatic Machines

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ABSTRACT
Charismatic machines play an important and growing roll in our rapidly transforming technological society. To address this challenge, I propose using Robot Theater as a new investigation space for developing the intelligence and interaction capabilities of the next generation of socially engaging machines, which will need to navigate interactions with groups of humans. In this paper I describe my current and previous research in the area of Human Robot Interaction, leading into a Robot Standup Comic with audience tracking that I demoed at TEDWomen 2010, then, I present my technical goals moving forward for live robot performance and collaborations with the arts.

Categories and Subject Descriptors
H.5.M [Information Systems]: Information Interfaces and Presentation (e.g. HCI), J.5 [Computer Applications] Computer applications in the Fine and Performing Arts

General Terms
Performance, Design, Human Factors

Keywords
Robot Theater, Human Robot Interaction, Entertainment, Sensors, Behavior Systems, Social Robots

1. INTRODUCTION
Just as robotic soccer competitions motivated development of algorithms for multi-robot coordination and the DARPA Grand Challenge furthered the autonomous capabilities of vehicle navigation, I believe Robot Theater will inspire transformative algorithms for applications in everyday human-robot interaction.

Storytelling is a central facet of being human. It is common to spend much of our free time watching movies, sharing gossip and reading the newspaper. If robots are to integrate into everyday life, charisma will play a key role in their acceptance. Their embodied presence and ability to touch and move around in the physical world allow us to communicate with them in novel ways, which are more naturally human [5]. Robot Theater can provide a valuable stepping-stone to creating impactful robotic characters [2].

Various forays have been made into the topic of robotic performance, including ([1][3][6][7]). The key addition in this project is the integration of intelligent audience sensing, which allows conscious and subconscious human behaviors to motivate live performance generation. In this process, we transform the theater into a valuable arena for interaction research.

Because of this unique approach, the work extends and begins to answer Breazeal’s call to action in [1]: “The script places constraints on dialog and interaction, and it defines concise test scenarios. The stage constrains the environment, especially if it is equipped with special sensing, communication or computational infrastructure. More importantly, the intelligent stage, with its embedded computing and sensing systems, is a resource that autonomous robotic performers could use to bolster their own ability to perceive and interact with people within the environment”

2. PREVIOUS WORK
My current interests in Robot Theater are a natural extension of the social robotics projects that I had the opportunity to create at MIT and now Carnegie Mellon. These past and current investigations have laid the groundwork for my current goals in audience tracking, online learning, artificial personality and behavior generation.

As a sophomore at MIT in 2003, I worked with three other roboticists to create Cyberflora, an interactive robotic flower installation at the Smithsonian Cooper-Hewitt Design Museum. I was responsible for the mechanical design for one of the flowers, on-site integration, and troubleshooting repairs over the six-month period that it was on display. Being exposed to the installation and its visitors, I became intrigued with the ability of sensors to imbue machines with interaction intelligence.

For my Master’s Thesis beginning 2007, I researched, built and programmed the Sensate Bear, as part of the Huggable Project at the MIT Media Lab. It had full body capacitive touch sensors and my goal was to encode certain human social behaviors into patterns that a machine could understand. I conducted user studies to develop a taxonomy of how humans physically interact with a robotic teddy bear through touch. The resulting pattern recognition algorithms could be termed an API (Application Programming Interface) for human social gestures. The study gave me insight into how humans communicated with the bear, but also provided interesting examples overlapping with how we communicate with each other. For example, gestural meaning usually corresponded to the robot physiology (a pat on the head was often affirming good behavior or successful inferences, particular regions were expected to be ticklish) and an individual touch gesture had similar time-based behaviors and migration patterns for ‘pet’, ‘poke’, ‘hold’, and ‘tickle’ as we would be likely to see with a pet or small child.

Now, as a new PhD student at CMU, I am working on a Standup Comedian robot, based on the Nao platform, that caters its jokes, animation level, and interactivity to individual audiences using online learning techniques. In August 2010, I created a series called ‘Postcards from New York’ and displayed the robot publicly to strangers in Washington Square Park, NYC. Viewers found the performance highly engaging, especially enjoying sequences with a high level of animation, but were sensitive to sound quality and the apparent intelligence of its prop manipulation. In this project, as with the Sensate Bear, I have begun to reverse engineer constrained aspects of human social behavior in terms that a machine can understand and replicate, putting robot users at the center of future application designs and
advancing the state of the art in human-robot interaction. We had further chance to present the system at the PopTech conference in Camden Maine, October 2010, also demoing the first performance with sensor-based audience tracking and live joke sequencings at TEDWomen in Washington DC, December 2010 [4].

3. TECHNICAL GOALS

3.1 Online Learning
Online learning provides the ability for a robot to incorporate new data, as it arrives, into its model of the world. For example, in field robotics, a robot might look to noisy sensor data to decide where the obstacles are in its path, reassessing its estimates at different time steps based on aggregated sensor history and current state. By continuously updating inferred state (are viewers and/or interaction-partners paying attention, laughing, wandering away) and direct feedback modes (literall communication of desires), the robot can cater its higher-level decisions (e.g. the next activity) to particular groups.

3.2 Audience Tracking
Online-learning goes hand and hand with audience-tracking capabilities, i.e., using sensors to understand the human response. This tracking will ultimately involve an exploration of a variety of technologies, which might be local to the robot, mounted on an intelligent stage, installed in the auditorium chairs or handed out to audience members, such as button-based input devices or even biometric sensing bracelets. Innovation made here can be easily reapplied to a robot interacting in group settings, as the robot learns to parse aggregate response and social context. I have begun early investigations into this domain with a single robot performing standup comedy in an auditorium setting. We model audience state by generalizing audio-visual features such as total volume (due to laughter, applause) and colored paddles (indicating like/dislike) to estimate what attributes an audience enjoys, as demoed at TEDWomen.

3.3 Generating Robot Expression
If audience tracking involves reverse engineering the social behaviors of an audience, generating robot expression involves reverse engineering human psychology and storytelling. Expression could include tone of voice, timing, movement, LED illumination, facial expression, pose, overall animation level and interactivity. We hope to learn from the existing literature in drama research and practice to develop techniques relevant to society on a much wider scale [2]. For example, methods for more expressive voice-to-speech technologies might have an integrated track for emotion, allowing those with speech disabilities to more naturally communicate. To do so, we will create a taxonomy of non-verbal robot communication, as the touch gesture library I developed for my Master’s Thesis [5]. In this case, the audience would act as a collective user study to evaluate the robot-sourced expressions.

3.4 Anthropomorphic Physical Design
The stage will allow us to evaluate the influence of physical configurations on perceived character within a constrained and repeatable environment [1]. By using robot designs that have different degrees of human-like physiology, we could undertake a deeper analysis of the “uncanny valley,” a theory about the humanness of a robot’s design, evaluating how to imbue the robot with convincing expression and personality. Recognition of relatable physiology can both smooth and confuse communication, depending on the coherency of the robots behaviors. I suspect that anthropomorphic movement and social intelligence might have just as much or more influence on interaction as a literal human form.

3.5 Control Software for Behavior Creation
If we know what performance parameters we want to control, we can create software that abstracts expression based on the taxonomies developed, simplifying the creation of new movements and performances, extending the work done in [3]. Smooth control software will also enable collaborations with human performers and potentially enhance the information-flow and shared intelligence those in the dramatic arts might be able to convey relevant to the creation of charismatic robots.

4. CONCLUSION
In our case, the metaphor of robotic theater has already served to develop algorithm concepts that apply directly to everyday robotics research. For example, I plan to adapt my robot standup comic software to a tour-guide robot that will individualize the sequence, style and content of its tours based on self-supervised audience tracking as part of an autonomous robots initiative here at CMU. It will incorporate online sequencing of content and some forms of spontaneous interaction.

In follow-up projects, I intend to partner with and learn from those in the arts community. By adding a model of performance attributes to the overall system, we could begin to evaluate the success of the robot's delivery. Parameters might include: tone of voice, accent, costuming, props, gestures, timing, LED illumination and pose. In this process, we are beginning to translate human behavior into rules a machine can understand. Ultimately, I hope to extend these learnings to full theatrical performances, deepening the understanding of character, motivation, and, even, relationships with other robotic or human actors on stage. The work has only just begun.

5. REFERENCES
Anchoring interaction through grounded knowledge

[Extended Abstract]

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ABSTRACT

This work presents how extraction, representation and use of symbolic knowledge from real-world perception and human-robot verbal and non-verbal interaction can actually enable a grounded and shared model of the world. This model is used for later high-level tasks like dialogue understanding, symbolic task planning or reactive supervision. We show how the anchoring process itself fundamentally relies on both the situated and embodied nature of human-robot interactions. We present an implementation, including a specialized symbolic knowledge representation system based on Description Logics, and experiments on several robotic platforms that demonstrate these cognitive capabilities.

Keywords
human-robot interaction, symbolic knowledge anchoring, ontologies, natural language processing

1. GROUNDING HUMAN INTERACTION

A messy table, covered with cardboard boxes, books, video tapes... Thomas is moving and packs everything with the help of Jido, its robot.

"– Jido, give me this", says Thomas, looking at a video tape. The robot smoothly grasps the tape, and hands it to the human.

While this kind of interaction should hopefully sound quite familiar in a foreseeable future, our robots are not yet quite up to the task. Neither regarding natural language understanding nor plan-making and manipulation.

To be combined together, those abilities require first an unambiguous and shared representation of concepts (objects, agents, actions...) underlying the interaction.

Our work focus on these questions: what are the prerequisites for such a human sentence — “Jido, give me this” — to be understood by the robot, correctly interpreted in the spatial context of the interaction, and ultimately transformed into an action?

Numerous work in the field of grounded speech interaction can be mentioned [5, 3] that propose situated language processors and demonstrate working integrations on simple robots.

Likewise, several teams have been working on symbol grounding for robots in real-world environments (computation of geometric relationships from an on-line reconstructed 3D model of the environment and a symbolic framework based on ontologies) [2, 1].

Besides proposing a new integration model for natural language processing with symbolic knowledge repositories, our work extend these previous contribution by focusing on more realistic human-robot interactions: open speech ; complex, dynamic, partially unknown human environments ; fully embodied (with arms, head, ability to move,...) autonomous robots that can perform manipulation. Another original contribution in the human-robots interaction field is the explicit modeling of each agents' beliefs: each agent is endowed with its own, independent knowledge model in the robot’s architecture, containing their beliefs of the world (built from the robot perspective, i.e. the robot’s beliefs about the beliefs of the agents). We show how leveraging visual and spatial perspective taking in conjunction with a sound symbolic knowledge representation system enables resolution of natural language interactions and active supervision of the robot.

Lastly, the tools (all open-source) and architecture we present have been deployed and tested on three distinct
robotic platforms (including both humanoid robot and service robots), demonstrating the versatility and hardware-agnosticity of our developments.

2. APPROACH

![Figure 2: Generic model of cognitive abilities interactions for grounding](image)

Our work introduce three distinct cognitive functions integrated into a full cognitive architecture:

1) **Physical environment modeling and spatial reasoning** are in charge of rebuilding a coherent physical model of the world (figure 3). Once available, the geometric model is used to compute several spatial properties of the scene that actually convert the original sensory data into symbolic beliefs. This includes relative locations of objects, visibility state, gestures like pointing, etc. Assuming that other agents are as well represented in the model, the same computations can be applied to analyze the scene from each agents’ perspectives.

2) **Knowledge representation and management**: the robot builds and keeps up-to-date a logically sound symbolic model of its beliefs on the world, as well as models for each cognitive agent the robot interact with. Each of these models are individually consistent, but they do not have to be necessarily globally consistent (for instance, a specific object can be visible for some agent and non-visible for another one). Our ontology-based ORO platform enables continuous storage, querying and reasoning over the pool of facts known by the robot.

Finally 3) **dialogue input processing**, including natural language parsing capabilities, disambiguation routines and interactive concept anchoring. Orders, questions, statements (new information) are recognized and separately processed.

3. EXPERIMENTS

Several experiments have been conducted on three different robots.

1. The **Odd One out** uses the ORO knowledge base to anchor perception into the robot’s knowledge through interaction with the user: the robot picks an unknown object from the table, shows it to the user, and asks about its name and type until a concept already known is given. Once all objects are learned, the robot tells which objects do not belong to a typical breakfast table (i.e. objects that are neither food or tableware).

![Figure 3: Using a dynamic 3D model for situation assessment](image)

2. The **Spy Game** experiment is based on the traditional children game “I Spy”. The idea is to discover the object or concept one of the participants is thinking of by asking questions such as: “Is it green? Is it a machine? Is it on your left?”, etc. The robot exploits its knowledge about the world while categorizing and describing objects through useful discriminants that will allow to find out the answer as fast as possible [4].

3. The **Moving to London** scenario takes places in the living-room, where the robot is observing two humans packing and moving around household objects. The humans and the robot interact through underspecified statements and orders (entered through keyboard) that lead to manipulation tasks and symbolic reasoning (figure 1).

Acknowledgments

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4. REFERENCES


Shopping Robots in Home Improvement Stores: 
Evaluation of Usability and User Acceptance of a Mobile Shopping Robot

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Abstract - This paper presents the results of formative and summative studies of a mobile shopping robot for home improvement stores. The robot was evaluated on its usability and user acceptance.

Shopping robot; usability; user acceptance

I. INTRODUCTION

During the last years, shopping robots are on the upturn. In the last two years several teams have presented new prototypes. One of them is the team [1] with the service robot platform SCITOS A5:

SCITOS A5 is used under the name TOOMAS (see Figure 1) as a mobile shopping robot for shopping assistance. Clients can search for articles in a database and let the robot guide them to the article location. To implement such a system, on the one hand marketability regarding technological and usability criteria must be ensured, on the other hand a highly realistic implementation in the application context has to be carried out.

So the motivation was to evaluate these aspects to provide development-related results to the partners from toom BauMarkt GmbH and the Robotics Research Lab. The social science perspective – and the user's perspective (perceived utility, usability and joy of use) were considered, because of its relevance. Theoretical models explaining technology acceptance such as the Unified Theory of Acceptance and Use of Technology (UTAUT from [2]), show, that these aspects can be frequently understood as major factors influencing user acceptance of a technological system. Accordingly, they constitute relevant determinants of robot use, because systems that are not accepted will most likely not be used. Toward this, the usability and acceptance of human-robot interaction were evaluated in two studies presented in this paper.

II. EVALUATION PROJECT

A. Evaluation object

TOOMAS, is a joint development of the Neuroinformatics and Cognitive Robotics Lab at the Ilmenau University of Technology with the company MetraLabs GmbH Ilmenau [1]. He was designed to facilitate clients’ orientation within the store and to support them in finding sought-after articles in a short time frame. Thereby TOOMAS operates completely autonomously [1].

B. Evaluation targets

First, the robot’s usability was tested in order to know as to what extent the requirements for a user-friendly human-robot interaction were fulfilled. Usability criteria from the ISO 9241-11 were used as evaluation criteria [3]: effectiveness, efficiency and satisfaction. The following research questions were derived:

∞ Q1: Does the human-robot interaction meet the needs and requirements of the users? Is purchasing with robot assistance effective, efficient and satisfactory?
∞ Q2: How can human-robot interaction be improved?

Secondly, customer’s acceptance was analyzed. On the basis of UTAUT by [2], intention to use regarding the robot was added as acceptance criteria. The following research question was formulated:

∞ Q3: Is the shopping robot accepted by the customers as a shopping assistant, are they willing to use the robot as a shopping assistant in the future?

III. FORMATIVE EVALUATION OF HUMAN-ROBOT INTERACTION FOR THE MOBILE SHOPPING ROBOT

The formative evaluation was implemented to advance successful human-robot interaction and to eliminate constraints and problems in relation to the robot.

a) Method

Field trials were conducted in a home improvement store of toom BauMarkt GmbH in Erfurt in Germany in December 2006. Subjects (n=39) were recruited in the entrance area of the store (72% men, 28% women). During usability tests, system usage was observed to protocol problems. After testing the shopping robot, users were interviewed on system evaluation.

b) Results

Orientation problems (e.g. robot cut the curve too closely and hit objects) and problems with voice output (e.g. robot sometimes quitted in the middle of the sentence) were observed. The results about these technical dysfunctions were handed to the developer team who optimized the system.

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In reference to the integrated voice output, the study showed that enunciation was very comfortable for customers. With the help of a five-point Likert scale, the enunciation was mainly rated as uncomplicated (M=1.4; SD=0.9) and articulated (M=4.8; SD=0.7). Speech tempo (M=3.0; SD=0.2) and speech volume (M=3.0; SD=0.4) were seen as normal and matched the environment.

Considering adaptation of the robot’s Movement and Mobility to user requirements was revealed that 59% of subjects rated driving speed as comfortable, 33% as too slow and 7% as too fast.

IV. SUMMATIVE EVALUATION OF MOBILE SHOPPING ROBOT

In 2009, at the end of the pilot phase, a field evaluation of robot usability was to be carried out. On the one hand, focus was on summative evaluation of effectiveness, efficiency and customer satisfaction. On the other hand, customer acceptance of shopping robots in a home improvement store was of interest, as acceptance is a key determinant for future use.

A. Sub-study 1: Summative Evaluation of Usability

a) Method

In February 2009, field trials with a quasi-experimental design were conducted in a home improvement store of toom BauMarkt GmbH in Bergheim, Germany. A total of n=94 customers (57% men, 43% women) took part in the study. Those were recruited in the entrance area of the store. Participants were arbitrarily subdivided into experimental group (shopping with robot, n=47) and control group (shopping without robot; n=47).

b) Results

With regard to effectiveness, no significant difference between retrieving an article with or without robot assistance was revealed (McNemar χ²=1.0; df=1; p=1.0; n=47 measurement pairs).

Considering efficiency, search duration showed a significant difference. Searching without robot was faster (M=135.4 seconds, SD=85.8) than searching with robot assistance (M=180.3 seconds, SD=82.8; t=2.8; df=46; p=.003; n=94). Effect size was medium (d=0.4).

In case of customer satisfaction, no direct added value of TOOMAS was shown. There was no significant difference and a very weak effect between shopping with robot (M=4.1; SD=1.0) and without (M=4.1; SD=0.9; t=.3; df=46; p=.74; n=94; d=.05).

B. Sub-study 2: User acceptance

a) Method

Field trials were conducted at the same time and location like sub-study 1. N = 188 subjects were recruited.

b) Results

Descriptive data showed that future Intention to Use the robot was rather high (M=3.9; SD=1.2; n=188). This could be due to positive rating of acceptance determinants.

Participants believed that they found articles faster by using TOOMAS than searching on their own (Performance Expectancy). They also rated the robot as understandable and easy to operate (Effort Expectancy). Further customers stated that they would have asked expert staff if they would have experienced problems with the shopping assistant, but they declined the need of computer skills to handle the system (Facilitating Conditions). Social influence in sense of acquaintances talking about the robot was negated.

Regression analysis revealed in the third iteration a model with significant correlation (r=0.7; SE=0.8; df=3; F=70.7; p<.0001) and corrected explained variance of $R^2_{\text{corrected}}=0.57$ ($R^2=0.58$). Future Intention to Use was mostly influenced by Attitude toward Using Technology. Further relevant factors are Performance Expectancy and Effort Expectancy.

V. DISCUSSION

TOOMAS designed in the presented cooperation project is a mobile shopping robot. Development in course of the whole project was always connected to a concrete or precise praxis implementation plan. Therefore, ongoing systematic evaluations in field trials in a home improvement store were conducted:

The formative study focused on evaluating usability of human-robot interaction showed, that the robot usability was assessed as positive and the needs and requirements of the users were fulfilled. Only orientation problems and sometimes problems with voice output had to be optimized.

In the summative study shopping with TOOMAS was compared to shopping without robot assistance concerning usability. All in all, effectiveness, efficiency and satisfaction were positively rated by customers. However, values did not exceed those in regard to conventional shopping. Conventional shopping was faster and did not lead to worse results.

Further, user acceptance was surveyed and evaluated as relatively positive.

Future studies with TOOMAS focus on optimizing of human-robot interaction to increase the user acceptance. Therefore, different aspects of acceptance, like social behavior (social accepted navigation) and a perceived personality (extrovert and therefore eye contact) of a mobile service robot are important factors for a better comfortable and intuitive human-robot interaction and to that effect a higher acceptance.

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1. RESEARCH INTERESTS
My research interests lie in the domain of spoken dialogue systems for human-robot interaction. As part of the TeamTalk project at Carnegie Mellon, I work on improving how multimodal robots can better interpret spatial language and their environment [6, 8]. Our project’s domain requires that people and robots work together on a “treasure hunting” task. I rely on the principle of grounding for my research efforts. In my doctoral research, I am exploring spatial language in human-robot dialogue across presentation formats (2-dimensional schematics, 3-dimensional virtual environments, real-world environments). This past summer, as a research intern at iRobot Corporation, I designed and developed an experiment that compared heads-up, hands-free operation of ground robots (namely the iRobot 510 PackBot) to traditional controller-based teleoperation. Heads-up, hands-free operation incorporates gesture recognition and person following technologies.

2. ADAPTIVE HUMAN-ROBOT DIALOGUE AND SPATIAL REASONING
In past research, I investigated the cognitive and social aspects of robotics at the Carnegie Mellon University Human-Computer Interaction Institute. I studied how robots might adapt to the existing knowledge of novices and experts via dialogue interaction. Pearl, an interactive robot from the CMU Robotics Institute, was used in our experiments. We investigated whether, given a topic of conversation such as cooking, Pearl should use technical terms with experts but longer explanations of those terms with novices. When we compared responses of novices and experts, we found that novice cooks appreciated Pearl and performed best when it gave detailed explanations of the tools rather than the tool names alone [9]. By contrast, expert cooks found Pearl patronizing when it gave them detailed explanations of the tools.

As an intern at the Naval Research Laboratory (NRL), I developed a scenario for disambiguating dialogue in a human-robot team [3]. In this scenario, two people are directing a mobile robot to retrieve an item from a dangerous area. In order to improve the ability of the robot to disambiguate dialogue spoken by the team members, I worked with graduate students to integrate several functionalities into the robot, including gesture recognition, sound localization, and natural language understanding.

Also while at NRL, I researched how to improve a mobile robot’s ability to take the spatial perspective of other members of an environment [4]. Our robot, StealthBot, is designed to simulate a person’s strategy when trying to covertly approach a moving target. My contribution was to add an evaluation of whether a direct line of sight existed between the StealthBot and the moving target, considering the objects in the room. I also wrote the cognitive modeling software that changed the StealthBot’s behavior based on this evaluation using the ACT-R cognitive architecture. This led to an emergent behavior of “peeking,” i.e., starting to move from a hidden place, discovering it had become visible, and immediately moving to a hidden place.

3. SPATIAL LANGUAGE FOR DIALOGUE
Currently, I am working on the TeamTalk project, which investigates how robots can better collaborate with people using speech and dialogue with the goal of finding “treasures” in real-world and virtual environments. TeamTalk operates aboard real-world robots (P2DX Pioneers and Segway Robot Mobile Platform “RMP” robots). The Virtual TeamTalk system, built using the USARSim simulator, provides us a vehicle to rapidly test our spoken dialogue system locally without the need to manage actual robots [1]. The system uses the RavenClaw/Olympus Dialogue Architecture [2].

I am currently exploring spatial language use in human-robot dialogue. We want to find out how spatial perspective-taking, both in reference to members of a human-robot team and to objects in the environment, can be incorporated into the current TeamTalk platform.

Our exploration of spatial perspective-taking in human-robot dialogue has led to a series of experiments to assess how people give spatial language instructions (i.e., route instructions) in reference to members of a human-robot team. Our series of experiments explored how people used spatial language with robots in a variety of presentation formats (2-dimensional schematics, 3-dimensional virtual environments,
and real-world environments) [8]. Results showed that people generally preferred giving spatial language instructions that were absolute in nature (i.e., using exact distances). In general, we concluded human-robot dialogue systems must be prepared to interpret both absolute instructions (e.g., “Move forward two feet”) and landmark-based instructions (e.g., “Move to the box”).

These experiments also permitted us to collect a corpus of hundreds of verbal route instructions. From this data we expect to train a spatial language understanding system, which will translate route instructions to movement plans. I expect to first develop a system that can permit team members to refer to locations relative to team members in a scenario. Afterwards, I plan to extend the component to reference objects in the environment of the human-robot dialogue scenario. This will require developing a basic ontology of the environment that will be shared by humans and robots in the scenario. We will focus on using TeamTalk’s virtual system for developing and testing this component.

4. HEADS-UP, HANDS-FREE OPERATION OF GROUND ROBOTS

Traditional robot teleoperation requires an operator’s full attention in order to achieve task goals. As part of a research team at iRobot, I collaborated on the development of a heads-up and hands-free way of controlling ground robots through person following and gesture control, so that operators can better concentrate on their surroundings and accomplish their mission faster [7]. We designed and conducted a quantitative study of whether heads-up, hands-free operation is better than teleoperation at close distances in a highly mobile task, namely building clearance. In a study of 30 participants, we found that when using these modes of interaction, operators performed missions faster, had better situational awareness, and had a lower cognitive load than they did when they teleoperated the robot. We concluded that heads-up, hands-free operation is an effective alternative to teleoperation.

Today, thousands of unmanned ground vehicles (UGVs) are in use in Iraq and Afghanistan, and many hundreds of others are used in law enforcement and rescue operations. At present, however, all marketed UGVs are teleoperated. The operator typically controls the robot using one of a varied set of operator control units (OCUs) like game controllers, tablets, or laptops. Teleoperation demands the full concentration of an operator for maximum effectiveness. An operator’s situational awareness is so hampered, in fact, that another soldier is typically assigned to guard the UGV operator. The goal of this research is to transform the way in which we interact with UGVs so that an operator’s hands are free and head is up: heads-up, hands-free operation. In this study, we chose one instance of this that uses person following and gesture control to achieve heads-up, hands-free operation. We found through a controlled laboratory experiment that users’ time on task is lower, their cognitive load is lower, and their situational awareness is higher than teleoperation.

Heads-up, hands-free human-robot interaction in mobile scenarios can be achieved using a combination of person tracking and following, gesture recognition, and speech recognition and synthesis [5]. A heads-up, hands-free robot’s influence on the operator in mobile scenarios, where the operator and robot are together, has not been studied nor compared to traditional teleoperation.

Understanding how real-world operators will use heads-up, hands-free interfaces prompted us to conduct a formal study that involved recruiting potential users of this robot (military personnel) to perform a common highly mobile task with the robot, building clearance. To better understand how heads-up, hands-free robots affect operators’ cognitive load, time on task, and situational awareness, we designed the task to be representative of situations encountered with this class of robot. This task required participants to explore and inspect an unknown area together with the robot. We chose a variant of building clearance since this is a common operation encountered in combat situations.

Future work will involve testing the inclusion of a video feed to heads-up, hands-free operation, and an evaluation of the impact of experience on operation. We also plan to investigate how multiple people can be followed and operate the hands-free robot.

5. REFERENCES

Mission Specialist Human-Robot Interaction in Micro Unmanned Aerial Systems

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1. INTRODUCTION

Micro unmanned aerial systems (mUAS) have experienced significant technological advancement and permeation into a myriad of modern domains [3], especially military and various search and rescue operations [1,7,10,13]. Several factors can be attributed to this trend in mUAS operational integration, including human safety, clandestine capabilities, remote access, and high spatial resolution information retrieval.

All mUAS operations involve a human-robot team [2,6,11], defined here as the human personnel primarily responsible for mUAS flight, navigation, and acquisition of mission-related information and will exclude consumers of information without direct control over the payload or platform (referred to as “knowledge workers” in [12]). These human team members, whose roles may overlap, can be either co-located with the unmanned aerial vehicle (UAV) or at a remote location, and, depending on the type of UAV and mission, can vary in number.

Peschel and Murphy [14] have identified three human team member roles that trend from the collective UAS research literature: Flight Operations Director, Pilot and Navigator, and Mission Specialist. They characterize the Mission Specialist role as the individual charged to collect reconnaissance data, with specific responsibilities that include viewing the real-time video output from the UAV camera, directing the Pilot for reconnaissance, and adjusting the UAV camera settings for optimal image capture.

Research and development to improve the human-computer interaction experience of UAS interfaces has historically focused on larger UAS flight and navigation [16,17]; however, a similar approach to support the acquisition of data and other mission-related information remains historically less well developed [4], particularly for small and micro UAVs, as does an understanding of the human-computer interaction aspects of the Mission Specialist as the human team member responsible for such acquisition [8].

Understanding human-computer interfaces currently available to the Mission Specialist role is a first step before understanding how a human fulfills the Mission Specialist role through human-computer interaction and is critical for investigating general human-robot interaction in mUAS, reducing the human-robot crewing ratio, and improving the individual role and team performance. To this end, the focus of our ongoing research is what is the appropriate human-computer interface for the Mission Specialist human team member in a mUAS that maximizes human-robot team performance?

2. CURRENT FINDINGS

In this section, a summary of three findings from Peschel and Murphy [14] is provided for Mission Specialist interface technologies across all classifications of UAS. It was observed that smaller UAS missions are very similar to larger UAS missions, in that image and data collection were primary responsibilities for the Mission Specialist role.

Finding 1: Pilots and Mission Specialists have distinctly different interfaces in all categories of UAS except for small and micro UAVs, where Mission Specialists either share the Pilot-oriented display or have a mirrored replica. Larger UAS tend to have interface technologies that separate the Pilot and Mission Specialist roles. In smaller UAS, the Mission Specialist role tends to use the Pilot interface or a mirrored version. This lack of separation violates good human-computer interaction principles and suggests that the Mission Specialist role may be suboptimal, in terms of role performance, thus work is called for to create Mission Specialist-oriented interfaces for mUAS.

Finding 2: Mission Specialists in larger UAS tend to have more sophisticated software-based interfaces to collect and interact with images and video, while in smaller UAS they
are generally limited to hardware-based interfaces. In larger UAS, the interaction technology available for the Mission Specialist role tends to include aerial imagery, software menus, real-time video, and synthetic overlays. The interaction technology available in small and micro UAS tends to take the form of a joystick and simple designated pushbutton system for camera angling, zoom, and image capture. This finding suggests that Mission Specialist interfaces in mUAS should be developed that are more software-oriented, with the appropriate mobile hardware that can support mission activities, such as multitouch and pen-based computing.

Finding 3: The Mission Specialist role in smaller UAS has more overlap with the Pilot role, both in spatial proximity and in coordinating functions, than with larger UAS. Overlaps in the available interaction technology may present limitations for individual crew roles. It is important to consider this as a design constraint and an opportunity for creating a dedicated Mission Specialist interface for smaller UAS; this remains an open research question.

3. ONGOING WORK

Ongoing efforts of this work address two additional research sub-questions i) which aspects of human-computer interaction support the creation of a shared user interface for the Mission Specialist role in a mUAS, and ii) how does geographically distributing the Mission Specialist role in a mUAS through a shared user interface related to individual role and overall human-robot team performance?

This work is expected to contribute i) a formal human-robot interaction analysis and specification of the Mission Specialist role, ii) a set of human-computer interaction guidelines for, and an implementation of, a shared Mission Specialist interface that significantly increases individual and team performance, and iii) an example of the use of the shared roles model for identifying vulnerabilities in human-robot interaction with mUAS.

4. REFERENCES

Small movements as communicational cues in HRI

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Abstract—In this short paper full body movements as communicational actions (such as steps), which are intuitively used to incite someone’s reaction, will be examined. Those movements are referred to as prompts. An observational study was conducted to examine those prompts in a narrow spatial configuration in a “make each other room” scenario. The observed small communicational movements are presented in this paper.

I. INTRODUCTION

Although speech plays a major role in human-robot communication, there are also various non-verbal cues, which play an important role. In particular, in situations in which interaction partner’s spatially make each other room, for example, if someone is blocking the other one’s way. Humans prompt each other with communicational movements, such as a step towards a blocking person inciting the other one to step back. Human-robot interaction (HRI) should be intuitive, not only with experienced users but also with bystanders, which are unfamiliar with the robot’s verbal commands. Furthermore, the interpretation of those communicational actions could be helpful in situations in which the noisy background makes verbal interaction difficult. The idea in this paper is to investigate if and how humans prompt a robot intuitively in order to pass by the robot in a narrow space. Having scenarios in mind in which a future robot should help in shops, homes, and offices, a robot needs to detect, and react to non-verbal human cues. Any of these environments have narrow passages or spaces in which a robot could block the way of a human accidentally. An observational study was conducted, in which participants had the task to guide a robot through an office environment, including a very small room. At one point the participants manoeuvred themselves into a situation in which the robot blocked the way out of the room: the participant navigated the robot between themselves and the door frame in order to show implicitly created here, was a situation in which the robot blocked the way out of the room: the participant navigated the robot between themselves and the door frame in order to show the printer and other items in the printer room, see Figure 1. I assume that human small communicational movements can be also found in that particular situation.

II. RELATED WORK

The assumption relates to the research Hüttenrauch et al. conducted [1]. They observed small motions as communicative cues of participants in a HRI study. Participants had to show several items to a mobile robot. In their analysis they divided the study into showing, validating, and follow me episodes. Between those episodes they found transition episodes in which small motions of the participant such as small changes of distance and changes of posture for several seconds could be found. They called those findings small spatial adaptations, which indicate a transition to a new episode. Small spatial adaptations in the form of a step help humans, to predict the partners movements and intention. In our daily life, humans infer intentions from other human movements [2], e.g. crossing streets together, moving through a crowd of people, and making room for each other. This comes to perfection in team sports [3]. It is immediately evident that bodily communication is a natural means of communication in human-human interaction. Its presence and role in HRI has mostly been investigated regarding non-verbal and verbal prompts performed by a stationary robot towards a human user.

Work in this direction was reported by Althaus et al., who made a robot approach and ultimately join a group of people by indicating its intention through its movements [4]. In addition, Breazeal et al. reported that implicit and non-verbal communication on the part of the robot, such as head nodding, makes human-robot teamwork more robust to errors and therefore more efficient. The human user receives more feedback and predicts the robot’s behaviour more easily [5].

In 2009, Koo et al. published work on the recognition of human intentions which underlay the ongoing performed actions (i.e. approaching a robot, departing from a robot in fairly open space) [6]. On the contrary, this paper aims to investigate small movements as communicative actions that precede these actions.

III. OBSERVATIONAL HRI STUDY

Participants were instructed to guide a service robot around an office environment and show a meeting room, an office and a printer room, and items in the room. A instruction sheet explained the task, the items to show, and spoken commands. The commands for guiding the robot around were: follow me, turn right, - left, move backward, - forward and all commands with equivalent meaning. The first room was a narrow printer room (1.5m²) in which the human and the robot just fit in together to have a look at the printer. The scenario of interest, implicitly created here, was a situation in which the robot blocked the way out of the room: the participant navigated the robot between themselves and the door frame in order to show the printer and other items in the printer room, see Figure 1. In order to proceed to another room they had to negotiate the joint space with the robot. As the participants had only been instructed that they could talk to the robot, it is interesting to examine, what intuitively happened shortly after they stopped showing and the participants tried to leave the room.
The robot used in the study is a technical looking, Pioneer P3-DX\(^1\), with two laser range finders (covering 360°), an extra laptop and an aluminium bar construction with the video camera on top. Its measures are 130 cm (h) x 45 cm (w) x 50 cm (d). Within the study the robot navigated autonomously while speech recognition was provided by a wizard operator who interpreted spoken commands and utterances. A laptop with a wireless connection to the robot allowed the wizard operator to stay outside of a room that the subject entered together with the robot, avoiding interference with the interaction. The participants were not informed of the underlying question on non-verbal communication. They were of course debriefed later on. Hence, any type of non-verbal prompts displayed by the participant would be spontaneous. In addition to the robot’s camera, the interaction was also recorded by an external camera.

IV. EXPLORATIVE RESULTS

32 participants took part and manoeuvred themselves into the respective “blocking-robot” situation.

The work of Hüttenerauch et al. mentioned earlier is the background to this analysis. We assume those small movements can be observed in our study between a showing episode and a leaving episode. Figure 1 depicts a model timeline of the “blocking-robot” scenario and the respective scenario. Within the video analysis of the scenario I found that a transition episode between the showing episode and leaving episode also existed. Furthermore, small movements of the participants within this episode are described. All movements within the transition episode were analysed using ELAN\(^2\). They were directed towards the robot (and the room’s exit). They were not directed towards the items in the room as this was the case in the showing episode. Movements to the robot were either directed to its front or left or right, meaning that the participant took steps covering 5 cm - 50 cm towards the robot. There are three types of movements with the entire body:  

a) a step towards the robot, which occurred in 43.75%,  
b) a step to the participant’s left (25%),  
c) a step to the participant’s right (12.50%).

The other two patterns are repetitions of the three above:  

d) swaying/moving to the left and right (9.38%)  
e) swaying/moving back and forth (9.38%).

V. DISCUSSION AND CONCLUSION

Single steps towards the robot and sequences of small steps towards the robot and steps to the right and left towards the robot and back are described. I assume that these movements are communicational and can not only be used as cues for a transition from a showing episode to another leaving episode. I also like to generalise this further. Humans prompt the robot spontaneously to make the robot move out of the way. The movements described above are an explorative start to analyse bodily communication from humans towards robots. The results describe, how human movements as communicational cues look like in one scenario: a robot blocks the way out of a room. Naturally, the question arises which movement is communicational and which is not. A video study will be done to make sure those movements or repetitions of movements convey the communicational aspect the scenario was created for.

How much prior knowledge a robotic system needs to interpret and to react to those particular communicational movements has to be tested. It might need the knowledge that it is in an interaction episode of some kind, which can end, and another episode can start. In a next step a detection system for those prompts is built and tested, depending on the prior knowledge it is given, against any other movement within the study described above. The spatial concept of “making room for each other” is a very basic one. Hence, it is interesting and supportive for the hypothesis (that humans prompt a robot to make room) to examine a group of people interacting with a robot and evaluate prompts in different types of narrow spatial configurations.

ACKNOWLEDGMENT

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ABSTRACT
In this paper, I briefly describe my three current research projects: understanding how people interpret social signals in robots, investigating the role of gaze in the initiation of human-robot encounters, and examining the effect of pet ownership on human-robot social interactions. Each of these projects is designed to help construct a framework for understanding the use of social cues in human-robot interaction (HRI). My work emphasizes an interdisciplinary approach, drawing together research from other areas to generate novel methods to understand and solve the problems at hand. Additionally, the continuation of this work will lead to a standardized model for testing the interpretation of social cues, which will be invaluable for the entire field of HRI.

Categories and Subject Descriptors

General Terms
Design, Human Factors

Keywords
human-robot interaction, design, gaze, social cues.

1. INTRODUCTION
The goal of my research is to leverage the psychology of human-human interaction, which we as people learn instinctively throughout our lives, to create humanoid, robotic interfaces like Wakamaru [2] (see Figure 1) that require little to no training to use. This archetype drastically reduces the barrier to entry for using computers, allowing people to acclimate more easily and to take advantage of our technological advances in a way that integrates seamlessly with their lives.

The impact of this research is readily apparent, as computers and technology have become ubiquitous. Every interface that we interact with has its own learning curve, requiring an overall investment in time and energy that quickly becomes staggering when considered in aggregate. Facilitating the production of more intuitive interfaces has the potential to drastically change the landscape of high-tech industry and technology’s role in our lives. In particular, robots are becoming more and more common, assistive robots used in hospitals, products like the Roomba used in households, and instructional robots like the Nao used in classrooms. As this trend continues, work is urgently needed to understand how they interact with humans, allowing us to maximize the utility of these robots in our everyday lives.

There is a vast body of literature elaborating on human relationships in these environments that has been produced by the field of psychology, but relatively little work has been done so far to explore which of these resources and models correspond to responses in human-computer and human-robot interactions. I have been taking baby steps in this direction by working on three different projects, and I am excited to tackle the challenging questions that have already arisen as I’ve moved forward.

Due to the complex nature of human-robotic interaction, an interdisciplinary approach and perspective is a great asset. This applies to both the generation of new ideas and increasing our understanding of how HRI dovetails with research and development in other areas. In addition to my previous educational background in design, I am structuring my graduate education around the inclusion of multiple disciplines. Along with courses in computer science are also classes in statistics, psychology, and engineering, all of which are complementary to fully understanding research in human-robot interaction.

2. CURRENT RESEARCH
2.1 Understanding How People Interpret Social Signals in Robots

Figure 1. Wakamaru, an example of a humanoid, robotic interface
The first project that I’m engaged in seeks to create new models that describe and break down each aspect of human-robot interaction and use these models to determine if a connection or correlation exists between detecting and interpreting social cues in humans and the ability to do the same with robots. In order to do this, we are using the PONS test [1]—a psychology test developed to evaluate a person’s ability to notice and understand social cues—as a base point for creating a standardized system of measuring social cue detection and interpretation between humans and robots. Such a system would provide an objective measure that would be invaluable to all research in the field of HRI involved with the conveyance of meaning through multimodal channels such as gesture, tone, and expression.

Once a framework has been created, it will be possible to choose specific areas to focus on, ranging from what behaviors are required to express specific roles and emotions to how each individual movement expresses or affects a user’s reactions. In addition, by replicating particular mannerisms in a robot, we are able to determine which cues are successful in communicating non-verbally to users, and we are able to investigate what messages these signals send. This information can then be translated to a broad spectrum of applications and can be used to transparently provide feedback and access to system features, allowing us to augment the user’s experience without the need for explicit instruction.

2.2 Role of Gaze in the Initiation of Human-Robot Encounter

In our second project, we are looking at how gaze plays a role in the amount of time it takes someone to engage with a robot in a social or instructional situation. In order to do this, we have built a model that subsections behaviors into a progression of five stages that lead up to the start of a verbal or gestural encounter based on previous psychology research. We have been conducting tests in both stationary and passing situations to recreate environments in the lab that robots may naturally be utilized in, allowing us to measure the effects of the changes in gaze condition on the timing of addressing the robot. This research might help to clarify the best gaze techniques for engaging and encouraging users to interact with robots and to increase the comfort level of those seeking assistance.

2.3 Pet Ownership and its Effect on Human-Robot Social Interaction

Lastly, we are working on exploring the connection between pet ownership and a person’s abilities to read social cues in robots. In order to do this, we are first conducting a web study to manipulate the amount of scripted animal behavior training subjects are exposed to, and measuring how it changes their ability to understand the cues being given by robots in a social situation. Achieving a better understanding of the way in which these factors correlate and whether or not it is attributable to focused education (e.g., obedience training) can help us to refine our research and to learn how people perceive and understand anthropomorphic interfaces.

3. FUTURE WORK

My vision for research in the next five years is the completion of several models of behavior that compare the relation between human-human and human-robotic interactions. Beyond this, I would like to examine the effectiveness of applying these models to situations and scenarios where robots play a key role in providing service, assistance, and in improving quality of life. This will allow me to demonstrate real world use cases and quantifiably express the importance of incorporating these discoveries into industry.

In preparation for delving more deeply into the projects at hand and future HRI research, I am receiving ample guidance from Dr. Mutlu in understanding human-subjects testing and research techniques; additionally, I have been supplementing my education with classes in statistical methods. Furthermore, the University of Wisconsin–Madison is the perfect place to conduct this research because of the Computer Sciences department’s strong interest in HCI, and its dedication to creating an HCI group. Finally, the university’s top ten computer sciences, engineering, and psychology departments are rich resources for the support and development of further interdisciplinary work and projects.

4. CONCLUSION

I am interested in creating models for human-robot social interactions because it can be generalized to the entire field of HRI. In order to do this, I will be working toward creating these models based off of previous psychology research and demonstrating their effectiveness in specific scenarios in the next five years. The creation of standardized and broadly applicable frameworks that demonstrably provide structure will provide information about where specific investigations fit in the overall picture. This will be invaluable to future research in HRI and to the adoption rate of discoveries into industry, thus improving the ability of robots to be accepted and successfully integrated into our society.

5. REFERENCES


Hello? Is Someone in this Office Available to Help Me?
Proactively Seeking Help from Spatially-Situated Humans

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ABSTRACT

Robots are increasingly autonomous in our environments, but they still must overcome limited sensing, reasoning, and actuating capabilities while completing services for humans. While some work has focused on robots that proactively request help from humans to reduce their limitations, the work often assumes that humans are always available to help. In this work, we propose a model for task-embedded robot navigation that includes the people who can help the robot and benefit from the robot’s services - those who are assigned static locations in the environment, in particular offices. These occupants have different challenges compared to traditional helpers such as teleoperators in that they are not always available to help and they are spatially-situated and therefore physically cannot help in every location.

Categories and Subject Descriptors
H.4 [Information Systems Applications]: Miscellaneous

General Terms
Experimentation

Keywords
Human-Robot Interaction, Asking for Help, Planning

1. INTRODUCTION

Robots are becoming increasingly autonomous in their ability to perform services for us in our environments. They can give visitors directions in malls [11] and tours in museums [12], and act as companions for individual users [9]. Despite these great strides, robots are still not ubiquitous as they have sensing and actuation limitations that can affect their task performance. For example, many robots have difficulty recognizing speech in loud or busy environments, recognizing objects or obstacles to avoid while navigating, and may not have the physical ability to manipulate objects in the environment.

To overcome these limitations, some work has focused on reasoning about the robot’s current state and proactively requesting help from humans to correct predictions (e.g., in speech) and direct the robot’s action if necessary during tasks. However, this work has been limited to asking for only one kind of help at a time. Additionally, whether the human helper is a supervisor that typically assigned the robot its task and therefore have high incentive for it to perform [1, 6] or a passer-by willing to help a robot even when they are not receiving services from it [14], there is an assumption that humans are almost always available to help the robot and can help the robot anywhere in its environment.

We instead focus on asking for many types of help from the actual occupants of the environment and beneficiaries of the robots’ services as the robot performs tasks for them (e.g., [9]). We argue that robots that ask for help from occupants combine the benefits of asking passers-by with supervisors in the following ways, discussed next.

2. SPATIALLY-SITUATED OCCUPANTS

We define occupants of buildings as having predefined spatially-situated work spaces and conducting long-term work which requires that they be present over a period of time. While they have similarities to both supervisors and bystanders, they also have constraints which violate the assumptions of this previous work. In particular, they are spatially-situated in the environment and no single occupant can help the robot at every location in the environment. As a result, the robot will need to navigate to an occupant’s office to request help. Additionally, they may not be available to help at their location, and the robot will need to learn and model this availability through long-term interaction.

2.1 Distributed Help

The idea of human computation (e.g., [13]) and crowdsourcing on websites like Amazon.com’s Mechanical Turk [8] have been used to gather help from a distributed set of people. In robot domains, bystanders and passers-by in busy environments have helped robots complete tasks in locations as varied as offices [2], conferences [7], and even on the street [14]. Because the number of people in these areas is so high, there is a very limited possibility that any particular person will be asked for help too frequently or will be asked to spend a lot of time with the robot.

Because there are many occupants in a building, the work to help the robot is distributed among them, significantly reducing the burden of help especially in the office environment in which occupants are busy and may not be able to
answer frequently. It is unclear whether occupants are even willing to help the robot at all given that they have other work to do. Our work will address the following questions:

- Are office occupants willing and available to help a robot perform its tasks?
- Are they willing to provide some types of help more than others (e.g., are they unwilling to help with tasks that require them to leave their office)?
- Are there available occupants distributed around the environment or only in one area of the building?

2.2 Incentives

Because a robot would know the office locations, it could provide services or incentives to the occupants to encourage occupants to help it. Like supervisors who must help the robot for tasks to be completed, if occupants want to continue to receive incentives from the robot (e.g., mail delivery), they must also agree to help the robot at some times. In this work, we assume that the robot will ask for help more often than it will provide incentives (e.g., it will require help navigating to deliver mail to other occupants more often than any occupant will receive mail themselves). We will answer the following questions relating to incentives:

- Are office occupants report that they are motivated to answer questions with incentives?
- Do they actually answer more frequently when offered an incentive?

2.3 Long-Term Interaction

Because supervision occurs over time, there are additional opportunities for robots to take advantage of the long-term interactions. Models of humans have been proposed to take into account the expertise of the human to determine the type of question that the robot should ask [3, 6], to ground or familiarize the helper with the robot’s current state to increase the likelihood of accurate responses [4, 10], and to model the helper’s interruptibility or availability to answer questions [5, 11].

We assume that the occupant would not be supervising a robot while conducting their work and often may not be available to help the robot if it needs it. Unlike bystanders who may only have to answer a particular robot’s questions once, an office occupant will be asked questions more often allowing the robot to learn who is often available at certain times to avoid interruptions as well as keep track of the frequency of questions to avoid asking a single person too often. We address the following questions:

- Is there a novelty effect associated with willingness to help the robot and does willingness to help decrease over time?
- Can the availability of occupants be modeled to take into account who will be able to help?
- Does occupant availability change through the day?

2.4 Navigation

Finally, due to the lack of constant supervision, the robot must navigate to the spatially-situated occupants to determine their availability and to ask them for help if needed. Current navigational models take into account the uncertainty in the path and the path distance but not who is available to help the robot along a path. Intuitively, a robot should choose short paths that also have humans available to help it if necessary. We will answer the following question:

- Can a robot use availability information from its long-term interactions to determine its best path?

3. REFERENCES


ABSTRACT
The generation of communicative, speech-accompanying robot gesture together with an evaluation of the effects of such multimodal behaviour is still largely unexplored. The main objective of my research is to shed light onto human perception and understanding of gestural machine behaviors and how these can be used to design more natural communication in social robots. My approach is twofold: Firstly, the technical challenges encountered when implementing a speech-gesture generation model on a robotic platform have to be tackled. The aim is to enable the Honda humanoid robot to flexibly produce synthetic speech and expressive hand gesture from conceptual representations and planning, while not being limited to a predefined repertoire of motor action. Secondly, the achieved flexibility in robot gesture will be exploited for controlled experiments. These will center around how humans perceive various gestural patterns performed by the humanoid robot as they interact in a situational context.

Keywords
Multimodal Interaction and Conversational Skills, Non-verbal Cues and Expressiveness, Social Human-Robot Interaction

1. MOTIVATION
One of the crucial steps in the attempt to build communicative social robots is to endow them with expressive non-verbal behaviors. One such behavior is gesture, frequently used by human speakers to emphasize, supplement, or even complement what they express in speech [2]. Forming an important feature of social interaction, human listeners have been shown to be well attentive to a speaker’s gestures. For example, pointing to objects for reference or giving spatial directions conveys information that can hardly be encoded by speech alone. Accordingly, humanoid robot companions that are intended to engage in natural and fluent human-robot interaction must be able to produce speech-accompanying, non-verbal behaviors from conceptual information. Hand and arm gestures, which represent an integral part of human communication, are ideal candidates in extending the communicative capabilities of social robots. This, in turn, poses a number of research challenges. Essentially, a motor control architecture is required to generate arbitrary, expressive hand-arm movements which should further be coordinated with other interaction modalities such as speech.

The aim of my research is to systematically address the challenges described above using the Honda humanoid robot as a research platform. The first objective is to enable the robot to flexibly produce synthetic speech and expressive gesture from conceptual representations and planning at run-time, while not being limited to a predefined repertoire of motor action in this. The second objective is to exploit the achieved flexibility in robot gesture for controlled experiments by evaluating what humans perceive from a humanoid robot performing gestures in different situational contexts. In the following, the two major objectives of my research are described in more detail.

2. RESEARCH OBJECTIVES

2.1 Part I: Implementation of a Robot Control Architecture
The generation of communicative co-verbal gestures for artificial humanoid bodies demands a high degree of control and flexibility concerning shape and time properties of the gesture, while ensuring a natural appearance of the movement. Ideally, if such non-verbal behaviors are to be realized, they have to be derived from conceptual, to-be-communicated information. Since the challenge of multi-modal behavior realization has already been tackled in various ways within the domain of virtual conversational agents, my approach exploits the experiences gained from the development of a speech and gesture production model used for embodied virtual agents. In particular, we build on the Articulated Communicator Engine (ACE), which is one of the most sophisticated multi-modal schedulers and behavior realizers by replacing the use of lexicons of canned behaviors with an on-the-spot production of flexibly planned behavior representations [1]. Having implemented an interface that couples ACE with the perceptuo-motor system of the Honda robot, the robot control architecture (outlined in Fig. 1) is now used as the underlying action generation framework for the humanoid robot. It combines conceptual representation and planning with motor control primitives for speech and arm movements of a physical robot body. Details of the implementation can be found in [3] and [4].

2.2 Part II: Evaluation of Robot Gesture Using the Implemented Framework
Having implemented and tested the proposed robot control architecture, the technical framework will be assessed and evaluated in an exhaustive human-robot interaction study to be conducted in the next few months. For this purpose, a
suitable scenario for gesture-based human-robot interaction is to be designed and benchmarks for evaluation are to be identified. To learn about the effect of communicative robot gesture on human interaction partners, a proposed scenario will comprise a joint task to be performed by human subjects in collaboration with the humanoid robot. In a given task, the robot will refer to various objects by utilizing several multi-modal utterances, based on which the human participants are expected to perceive, interpret and perform an according action.

2.2.1 Study Scenario
The proposed study scenario will be set in a kitchen environment. Together with the robot, participants will partake in the emptying of clean items from a dishwasher. The task of the participant will be to remove the objects from the dishwasher and to arrange them in a kitchen cupboard. For this, the robot will present the participants with a set of verbal instructions and corresponding gestures in order to explain exactly where each item should be placed (Fig. 2).

Figure 2: Scenario for evaluation study.

2.2.2 Objects
The kitchen objects used for this joint task will comprise a total of eight ‘unique’ objects whose storage placement is not known a priori (unlike plates, e.g., which are usually piled on top of each other). Examples include tray, spatula, jug, and vase.

2.2.3 Conditions
The study will comprise three different conditions:
- Speech and gesture, semantically matching (e.g., robot says “put it up there” and points up)
- Speech and gesture, semantically non-matching (e.g., robot says “put it up there” but points down)
- Speech only

2.2.4 Gestures
To indicate the designated placement of each item, in the ‘with gesture’ conditions the robot will use three different types of gestures along with speech:
- Iconic gestures, e.g. to illustrate shape/size of objects
- Deictic gestures to indicate positions
- Miming gestures, e.g. hand movement using a spatula

2.2.5 Participants
There will be a total of 60 participants in this study, with 20 per condition (10 male, 10 female), none of whom have prior interaction experience with humanoid robots.

2.2.6 Evaluation
The evaluation of the study will be based on three criteria:
- Subject’s reaction time after instruction
- Subject’s performance time
- Final position of objects

In addition, upon completion of the task, participants will be asked to fill out a questionnaire in which they will rate the robot’s appearance, naturalness, believability, friendliness and other factors.

3. CONCLUSION
The generation together with the evaluation of the effects of robot gesture is identified as being largely unexplored. The implementation of a robot control architecture for “conceptual motorics” realized on the Honda humanoid robot, together with an exhaustive evaluation study to be conducted with 60 human interaction partners in the near future, will thus enable new insights into human perception and understanding of gestural machine behaviors. Ultimately, this will not only shed light on human behavior, but will also allow us to design and build better artificial communicators.

4. REFERENCES
Thinking “As” or Thinking “As If”

The Role of Pretense in Children’s and Young Adults’ Attributions to a Robot Dinosaur

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Abstract—This study investigated children’s (7 and 10 years) and young adults’ attributions to a personified robot dinosaur, Pleo, and whether their attributions were based on pretense. Results indicated children, more so than adults, attributed aliveness, perceptual capabilities, psychological states, sociality, and moral standing, but not biological characteristics, to the robot. At the same time, participants tended not to pretend when making attributions to the robot.

Keywords—pretense; children; personified robots; Pleo; attributions

I. INTRODUCTION

An emerging body of research suggests that children conceive of personified robots as animate, social, and moral entities [1-5]. Do these attributions reflect children’s actual (thinking as) or pretend (thinking as if) beliefs [6]? Pretend play is a hallmark of childhood; children regularly endow objects with imagined personas and capabilities. Thus it seems possible that children engage in pretend when making attributions to robots. Clark [7] argued that people are acting as if the robot is a social actor. Yet there are good reasons to consider that children are not pretending [6]. This study sought to provide empirical evidence to begin to address this question.

II. METHOD

A. Participants

Participants included twenty-six 7-year-olds (M = 7.6 years; 14 males and 12 females), twenty-six 10-year-olds (M = 10.6 years; 13 males and 13 females), and 26 undergraduate students (M = 19.3 years; 13 males and 13 females).

B. Equipment

The personified robot used in this study was Pleo, a robotic dinosaur. Pleo has a repertoire of interactive behaviors, including eating, playing tug-o-war, sitting, curling up when held, and responding to petting and scratching. Pleo’s technical specifications can be found at www.pleoworld.com.

C. Procedure

Each participant was individually tested during a 1-hour session. The procedure was comprised of a 10-minute interaction period followed by a 30-minute interview. The entire procedure was audio and video recorded and the interviews were transcribed for analysis. During the interaction period, the researcher initiated five interactions with Pleo: petting, feeding, playing tug-o-war, sitting in lap, and holding. Two additional interactions served as stimuli to later assess participants’ attributions of moral standing: holding by the tail and hitting.

The interview was comprised of 12 multi-part questions. The characteristics under investigation included aliveness (living thing; life), biological properties (grow; die), perceptual capabilities (see; feel touch), psychological states (emotions; thought), sociality (friendship; feel left out), and morality (holding by tail; hitting). The questions were structured as follows: (a) Does Pleo have X? (b) If yes, Do you have to pretend Pleo has X? If no, Could you pretend Pleo has X? Participants were asked the same set of questions for four comparison entities: dog, stuffed animal, tree, and computer.

D. Coding and Reliability

A coding manual was developed from a random selection of half of the interview data and then applied to the entire data set. A second individual trained in the use of the coding manual independently recoded 30% of the interviews. Cohen’s kappa revealed inter-coder reliability to be $\kappa=0.98$ ($p<.001$).

III. RESULTS

The percentage of participants’ affirmative attributions to the robot are reported in Table 1. A repeated measure ANOVA indicated developmental differences across the 12 questions ($F(2)=8.931$, $p<.001$). In particular, adults were significantly less likely to affirm characteristics to the robot than either 7-year-olds ($p=.002$) or 10-year-olds ($p=.001$).

This pattern bore out in further analyses that assessed differences at the individual characteristic level. A 2 (sex: male, female) x 3 (age: 7 years, 10 years, adult) ANOVA and post-hoc comparisons (Tukey’s HSD, adjusted $\alpha=0.0167$) revealed significant age differences on five characteristics: living thing, 7 years > adults ($p=.015$); emotions, 7 and 10 years > adults ($p=.015$); think, 10 years > adults ($p=.001$); friend, 7 and 10 years > adults ($p<.001$ and $p=.004$, respectively); and permisibility of hitting, 7 and 10 years < adults ($p=.002$ and $p=.005$, respectively). In summary, where age differences were found, children more often made attributions to the robot than adults.

¹ This work was completed in partial fulfillment of a doctoral degree from the Department of Psychology, University of Washington, Seattle, USA.
TABLE I. PERCENTAGE OF PARTICIPANTS BY AGE GROUP AFFIRMING CHARACTERISTICS FOR THE ROBOT

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>7 years</th>
<th>10 years</th>
<th>Adults</th>
</tr>
</thead>
<tbody>
<tr>
<td>Living Thing</td>
<td>38.46</td>
<td>19.23</td>
<td>7.69</td>
</tr>
<tr>
<td>Life</td>
<td>53.85</td>
<td>42.3</td>
<td>15.38</td>
</tr>
<tr>
<td>Grow</td>
<td>7.69</td>
<td>3.85</td>
<td>0</td>
</tr>
<tr>
<td>Die</td>
<td>0</td>
<td>11.54</td>
<td>7.69</td>
</tr>
<tr>
<td>See</td>
<td>69.23</td>
<td>65.38</td>
<td>42.31</td>
</tr>
<tr>
<td>Feel Touch</td>
<td>92.31</td>
<td>88.46</td>
<td>76.92</td>
</tr>
<tr>
<td>Emotions</td>
<td>76.92</td>
<td>73.08</td>
<td>34.62</td>
</tr>
<tr>
<td>Think</td>
<td>30.77</td>
<td>61.54</td>
<td>15.38</td>
</tr>
<tr>
<td>Friend</td>
<td>100</td>
<td>92.31</td>
<td>61.54</td>
</tr>
<tr>
<td>Left Out</td>
<td>56</td>
<td>61.54</td>
<td>30.77</td>
</tr>
<tr>
<td>Not Alright to Hold by Tail</td>
<td>50</td>
<td>42.31</td>
<td>23.87</td>
</tr>
<tr>
<td>Not Alright to Hit</td>
<td>65.38</td>
<td>61.54</td>
<td>19.23</td>
</tr>
</tbody>
</table>

Were participants’ affirmative attributions based on pretense? Results indicated pretense accounted for a significant proportion of 7-year-olds’ judgments that the robot could see (21%; t(25) = -2.132, p < .043), but not for any other characteristic. For 10-year-olds, pretense did not account for a significant proportion of their affirmative responses for any characteristic. Finally, for adults, results indicated pretense accounted for a significant proportion of their judgments that the robot could be a friend (35%; t(25) = -3.638, p < .001), but not for any other characteristic.

The next step was to test for age differences in engagement in pretense. A random effects logistic regression model revealed no significant differences emerged between 7-year-olds and 10-year-olds (z = 1.258, p = .20). However, adults were significantly more likely than 7-year-olds, and by implication 10-year-olds, to pretend when making positive attributions to the robot (z = -2.576, p < .01).

To test if adults’ engagement in pretense on the friendship question accounted for the overall difference found between adults and children, the friend question was removed and the random effects logistic regression was re-run. Results indicated no significant differences between adults and the children’s age groups (z = -1.049, p = .294). In other words, adults were no more or less likely to pretend than children when making attributions to the robot once the friend question was removed from the overall analysis.

The final set of analyses assessed differences in engagement in pretense between the robot and the four comparison entities (dog, stuffed animal, tree, computer). Omnibus tests of differences in children’s engagement in pretense indicated differences across entities on some characteristics, yet these differences did not persist in post-hoc direct comparisons. Omnibus tests of differences indicated no significant differences between entities in adults’ use of pretense on any of the characteristics. Notably, adults engaged in pretense most frequently on the questions of whether the entity could be a friend, and this did not differ significantly across entities.

IV. DISCUSSION

Results indicated, to varying degrees, children attributed aliveness, perceptual capabilities, psychological states, sociality, and moral standing, but not biological characteristics, to the robot. Adults were significantly less likely than children to make attributions to the robot.

The pivotal question in this study was whether participants’ attributions to the robot were based on pretense. The answer from this study appears to be ‘no.’ Three forms of evidence support this interpretation. First, pretense accounted for a significant proportion of attributions to the robot only twice out of a possible 36 instances (3 age groups x 12 characteristics). Second, while adults were significantly more likely than children to pretend when making attributions to the robot, this was accounted for by adults pretending a lot on the friend question. Finally, children’s engagement in pretense was modest and not significantly more or less from their pretense when making attributions to the other four entities. The same was true for adults. Adults consistently high level of pretense on the friend question across entities suggests there is something about that the friend question, rather than something about the entity, that leads to more pretending. Taken together these results suggest that, by and large, children’s and adults’ attributions to the robot were based on their actual, as opposed to pretend, beliefs.

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Can robots give attachment experience for the children with Autism Spectrum Disorder?

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ABSTRACT
In this project, we use a robot to intervene children with Autistic Spectrum Disorder (ASD). This study explores the possible use of robots in teaching children with autism caregiving skills and to give attachment experience. The combination of picture and in-person modeling prompts have been used to train children. While experiment is in progress, most of the children show interest in robot and gaze the robot more often. This study suggests the possible use of a robot in teaching some critical social skills to children with Autistic Spectrum Disorder.

Categories and Subject Descriptors
J.4[Computer Applications]: Social and Behavioral Sciences – Psychology

General Terms
Performance, Experimentation, Human Factors.

Keywords
Autism, Robot, Animal Robot, Attachment, Caregiving behavior, Modeling, Social development

1. INTRODUCTION
Nowadays, one of the main interests of researchers in the field of Human Robot interaction (HRI) is use of socially interactive robot in practical setting. Increasing interactivity between humans and robots has become a significant issue among researchers in the fields of HRI. They study strategies for using robots to assist people who have difficulty in interpersonal communication[1]. This study also explores the possible use of social robots for children with ASD.

2. CHARACTERISTICS OF CHILDREN WITH ASD
ASD and PDD are terms that refer to a wide range of neurobehavioral disorders [2, 3]. They often occur in males and females at ratio of 4 to 1. According to a recent statistical report, the prevalence rate of autistic spectrum disorder is 22.0/10000 and this rate is increasing every [4]. Children with ASD and PDD exhibit impairments in various behavioral areas including: socialization, verbal and nonverbal communication, and repetitive behaviors and restricted interest [2, 3, 5]. These impairments leave children with ASD with a lack of social interaction skills that include impairments in nonverbal behaviors such as making eye contact, facial expressions, body movements and gestures.; difficulty in building social relationships, and lack of emotional responsiveness toward others [3].

3. CAREGIVING BEHAVIOR
Attachment theory usually refers to the importance of the relationship between infants and parents. As infants and parents bond, according to Bowlby, they desire to maintain proximity with one another. The person who provides the attachment is also responsible for the development of recipient. The caregiving bond works in same way as attachment bond. The caregiving behavior is reactive to the attachment experience and is preceded by the dependent’s attachment behaviors [6, 7]. The ultimate goal of the attachment behavioral system is to protect the young and maintain proximity with the caregiver. In the other words, the goal of the caregiving system is proximity and security [8]. The caregiving behaviors used in this experiment were selected based on these two set goals of proximity and security. The attachment experience is reciprocal. As children with ASD demonstrates the difficulties in interaction with humans, in this study a robot was used as care-receiver.

4. METHOD
4.1 Prompts and Imitation
Normally developing children learn caregiving behaviors by observing a parent’s behavior. However, children with ASD learn ordinary behaviors passively through intensive imitation training. Therefore, this study used prompts. Prompt is defined as an artificial stimulus that helps a learner to display appropriate behaviors at a right circumstance [9]. In this study, we provided three different kinds of prompts: photographs, modeling and verbal instruction.

4.2 Research Design and Procedure
The research was conducted over five weeks and consisted of three stages: free play, intervention and evaluation. In the first week, each child had a free play session with the robot for five minutes. Once the child entered into the room, the instructor introduced the robot briefly and asked the child to play with the robot. Then each child played with the robot freely for five
minutes. The second stage ran over three weeks. The instructor taught four connected caregiving behaviors using prompts. This process took 8-10 minutes depending on the child’s attention ability and learning process. The third stage was one week long. During this stage, children were ordered to perform the caregiving behaviors only by verbal instruction.

5. DISCUSSION
The results proposed the possible use of robots in developing social skills of children with ASD and PDD. Robots are especially useful tool for educating those children because of their unique features. Robots are autonomous and show response toward its user yet, it is still safe to use. Robots behaviors are consistent and predictable as it repeats the same move every time. ASD children tend to feel more comfortable in simple, consistent and predictable situations. Moreover, robots have simple appearances. Children with ASD tend to have difficulty in perceiving emotions and interacting with other people from the complex facial expressions [10]. We developed our own research paradigm since the study was exploratory. Future studies need to develop a suitable methodology and extend a research period. Also a larger number of children will be encouraged in future studies although this kind of research has a sever difficulty of involving a large number of participants. Lastly, observation of children’s behavior outside of the room is necessary. The best option would be to observe children’s behavior on a daily basis. In future studies, we plan to have more participants in different setting.

6. ACKNOWLEDGMENTS
This study was supported by a grant from the World-Class University program (R31-2008-000-10062-0) of the Korean Ministry of Education, Science and Technology via the National Research Foundation.

7. REFERENCES
1. GESTURE AND ROBOTIC AVATARS
Most of us live in a world of words. Yet we communicate with each other in ways that draw upon a cultural language of behavior that frequently takes place outside of our conscious awareness [1]. This language includes behaviors such as gesture and movement, posture, physical proximity and body orientation, eye gaze, facial expressions and even non-verbal vocalizations. We draw upon these actions every day, without even thinking about it, to ease our abilities to think improvisationally and to speak expressively.

Until very recently, video has been the only way to convey such non-verbal information between each other at a distance. But video chat does not provide the full breadth of rich, gestural content that we exchange in our collocated interactions, because the images typically only display one’s head and shoulders. And while conferences capture a greater range of behaviors, distant collaborators become literally and figuratively two-dimensional. That is, they cannot move around the physical space where their partners are located, so their presence may readily be forgotten. They cannot reach through their screens to touch people or objects within that space, so their ability to collaborate is compromised.

We have been developing physically embodied, remotely actuated, robotic avatars for use during distributed collaboration. These hybrids draw upon the advantages of both live video, which communicates facial expressions and vocal characteristics, and robotics, which manifest an embodied, physical presence. The devices allow team members who cannot be physically present to extend themselves into the group’s workspace. Remote participants control robotic components that represent their heads, necks and arms—using motion-sensitive interfaces—so that they can look around, gesture expressively and point at shared artifacts. They can therefore be considered physical avatars, personifications that represent particular individuals in another place.

2. STUDIES IN EXPRESSION AND ROLE
We are employing these avatars in two related studies that explore the role of avatar-enabled non-verbal communication in distributed design activities. The first study focuses on the basics of how people interpret actions presented by a remote participant who is communicating by robotic avatar during a conversation. The second study shifts focus to how people infer the personalities and roles of remote and local participants whom they observe interacting in a team setting.

Figure 1. As the remote collaborator leans forward to look closer, his robot avatar gestures in concert. Study participants reported that complementary onscreen and physical actions were more understandable and had greater impact on them than the facial expression or robotic motion alone.

2.1 Study 1: Interpreting Avatar Action
We created video prototypes combining onscreen and robotic actions that we wanted to explore, and crowdsourced study participants to interpret them using Amazon’s Mechanical Turk. A video prototype is a brief movie clip that demonstrates how an interactive technology would perform [3], and provides many benefits over live, in-person trials. It permits us: to tune the robot’s motions to be as subtle or obvious, coarse or refined as we intend; to reproduce precise timings between the remote collaborator’s onscreen gestures and the robot’s motions; to repeat the exact same scenario(s) to expose to our study participants, for as many times as the study requires (which was more than a hundred in our case, and the setup and breakdown of a lab study can be laborious and fraught with intermittent breakdowns); or to gain access to an audience that is more diverse in background—including age, culture, experience with conferencing technologies—than would be possible by recruiting only local participants.

We showed participants nine gestures in three different forms: facial expressions alone, robotic motion alone, and combined expression and robotic motion (shown in Fig. 1). For the latter condition, we moved the avatar in concert with the onscreen action. We found that participants were more correct in their interpretations of the expression-plus-motion condition than they were for either of the other two conditions. Participants were also more confident in their interpretations, and felt that the intended message had a greater impact upon them.

However, their abilities to interpret meanings varied not only from one condition to another, but also from one gesture to another. That is, certain forms of body language were more readily understandable than others. For example, nodding one’s head is an outwardly communicative action, and participants recognized it...
readily. But gazing off to the side while confused or immersed in thought is a less intentional action; it reflects a more thoughtful, internal state, and participants had difficulty recognizing it.

2.2 Study 2: Role in a Team Setting
For our follow-up study, we also employed video prototypes. We created an interactive design session scenario between three colleagues, one of whom participated remotely through an avatar, and showed it to study participants. We adapted the Relational Messaging Scale [3] as a measure of the social relations between the colleagues, and asked participants about their perceptions of the interaction. The scale describes the balance between two main indicators, dominance and affiliation, through a number of narrower concepts that are more readily observable.

We recorded four different versions of the design session, depicting the same scene, dialogue, participants and overall sequence of action (shown in Fig. 2). The storyline had the remote collaborator asking his local teammates for help redesigning a remote control that they had recently designed together. We changed only two characteristics of the participants between versions, which we chose because of their relevance to the relational scale. The first was whether the remote collaborator’s physical avatar moved along with his actions, or remained idle for the duration of the session. The second was the degree to which either the remote collaborator, or the local teammate, took a dominant role in leading the session.

The addition of robotic motion over the idle condition led study participants to rate the remote collaborator as more involved and less dominant than in the case where his avatar could not move. This makes sense, as the ability to enact body language influences one’s own sense of involvement in a conversation. Participants also rated the local teammate as more equal to her partner when he could perform such gestures.

Participants rated the remote collaborator as more involved and composed when he took a leadership role in the discussion, compared to when he took a follower role. But they also rated the local teammate as more composed and equal for the same scenario: when the remote collaborator led the discussion. These responses, along with the preceding finding of greater teammate equality during avatar motion, suggest that the addition of physical gestures serves as a moderating influence on the perception of both participants. One interpretation of this finding is that use of an avatar that does not move—which can be considered similar to current forms of video chat—introduces a sense of inequality between the partners; and this inequality can be ameliorated by re-introducing the non-verbal cues that embodied physical motion enables.

3. CONCLUSION
Taken together, the two studies suggest that gesture and motion in embodied telepresence setups influence our ability to understand the meaning, as well as perceive the social role, of distant collaborators. We are currently developing a more robust, field-ready version of the robotic avatar, as well as running these studies with in-person participants.

4. ACKNOWLEDGMENTS
Thanks to colleagues Dr. Wendy Ju, Eric Kent, Rebecca Currano and Samson Phan, who are core members of the research team.

5. REFERENCES
Involving Young Children in the Development of a Safe, Smart Paediatric Wheelchair

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ABSTRACT
Independent mobility is crucial for a growing child and its loss can severely impact cognitive, emotional and social development. Unfortunately, powered wheelchair provision for young children has been difficult due to safety concerns. But powered mobility need not be unsafe. Risks can be reduced through the use of robotic technology (e.g., obstacle avoidance) and we present a prototype safe smart paediatric wheelchair: the Assistive Robot Transport for Youngsters (ARTY). A core aspect of our work is that we aim to bring ARTY to the field and we discuss the challenges faced when trying to involve children in the development/testing of medical technology. We discuss one preliminary experiment designed as a “Hide-and-Seek” game as a short case study.

1. INTRODUCTION
In the UK alone, there are more than 50,000 disabled children who require mobility assistance [7]. Power mobility advocates consider mobility as “an essential component of a child’s early intervention program” [2, 10]. However, powered wheelchair provision for young children remains a contentious issue. Nicholson and Bonsall’s 2002 survey of 193 wheelchair services [11], showed that 51% of the respondents did not supply wheelchairs to children under 5 years. The top two reasons cited were safety of the child (36%) and safety of others (34%).

Safety is clearly an important factor, but for these children to lose independent mobility is a crucial set-back at a critical age. Mobility loss spawns a vicious cycle: the lack of mobility inhibits cognitive, emotional and social development, which in turn further limits personal independence [1, 9, 12]. Ultimately, this results in a severe long-term deterioration in a child’s quality of life.

In our research, we aim to break this cycle by providing a key enabling technology: a safe, paediatric wheelchair we call the Assistive Robot Transport for Youngsters (ARTY) shown in Fig. 1. Contrary to traditional assumptions, powered mobility need not be unsafe (for the child or others). Rather, risks can be mitigated through the use of robotic technology and shared control systems [5, 13]. Delivered to end-users, safe powered mobility has the potential to improve social, emotional and intellectual behaviour [3] and drastically change lives. As such, a core aspect of our work is to bring ARTY into the field at an early design stage. Prior work has mostly focused on developing wheelchairs that work in tightly-controlled environments, but to be a relevant technology, assistive robots should be tested in real-world environments by end-users [6].

2. ASSISTIVE ROBOT TRANSPORT FOR YOUNGSTERS (ARTY)
In brief, ARTY is a children’s powered wheelchair augmented with sensors (both IR and sonar-based) and a tablet PC as the main computational platform for localisation, obstacle avoidance, path-planning and intention prediction. Thanks to its modular design, ARTY accepts a wide range of input devices, and can provide therapists and researchers with badly-needed quantitative data.

Figure 1: J, a 4-year old boy, using the Assistive Robot Transport for Youngsters (ARTY).
3. HRI GAMES WITH ARTY

Conducting studies with young children is not without its challenges. Unlike adult subjects, who tend to follow given instructions, children may wantonly disregard direction and have notoriously short attention spans. Furthermore, disabled young children have additional needs, e.g., the CALL Centre smart wheelchair [4] was not “a single entity” but multiple variants had to be designed (one for each user).

We posit that studies and/or rehabilitation exercises designed as games (e.g., in [4, 8]) are a promising way forward. In these experiments, the “fun-factor” – a design variable not usually considered in other settings – plays a more prominent role. For a preliminary experiment with the objective of gathering data on search patterns, we designed a “Hide-and-Seek” game to motivate children to look for hidden items (toys).

3.1 A Short Case Study: J

Our participant was J, a healthy four-year-old boy. Two earlier attempts with A and H, two girls aged three and two respectively, were not successful: A got bored after a single run of looking for the toy and H refused to sit in the wheelchair (she appeared intimidated by the many people in the experimental area – a busy research lab).

Based on the experienced gained from the previous attempts, we limited the number of people present to five (three experimenters, J and his father). We interviewed J’s father beforehand to find out what J’s favourite toys were (“Battlestrikers”) and about J’s general personality (“outgoing and active”). To make ARTY more attractive, we placed similar toys on ARTY’s tray and changed the tablet’s desktop image to match. To accommodate J’s attention span, we planned side-activities to engage him when he was not using the wheelchair, e.g., playing with a Nao robot and the iCub humanoid. Local obstacle avoidance was used to prevent possible injuries from collisions.

We observed J rapidly learnt how to use the wheelchair – within a few minutes, he was able to navigate independently in both the practice and test zones. J played the “Hide-and-Seek” game twice. Both times, he was able to find the toy without difficulty. However, compared to adult participants (data gathered in prior experiments), J explored the territory in a less organised manner (Fig 2); he went-over the same part of the route several times and looked in the same box twice.

4. CONCLUSIONS

Our research goal is to bring safe, smart mobility to disabled children in real-world settings and we believe ARTY will play a significant role in making this a reality. We are currently working with medical professionals (doctors, therapists and researchers) at local children’s hospital where we have performed a live demonstration. Future planned visits will help us better understand the needs of disabled children and caregivers, allowing us to further tailor ARTY and design better experiments. In the longer term, we expect that ARTY will allow young disabled children to move, play, explore and learn; activities that should be a part of every young child’s life.

5. REFERENCES

A Survey of Social Gaze

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ABSTRACT
Based on a synthesis of eight major studies using six robots involving social gaze in robotics, this research proposes a novel behavioral definition as a mapping \( G = E(C) \) from the perception of a social context \( C \) to a set of head, eye, and body patterns called gaze acts \( G \) that expresses the engagement \( E \). This definition places social gaze within the behavior-based programming framework for robots and agents, providing a guide for principled future implementations. The research also identifies five social contexts, or functions, of social gaze (Establishing agency, Communicating social attention, Regulating the interaction process, Manifesting interaction content and Projecting mental state) along with six discrete gaze acts for social gaze functions (Fixation, Short glance, Aversion, Concurrence, Confusion, and Scan) that have been employed by various robots or in simulation for these contexts. The research contributes to a computational understanding of social gaze that bridges psychological, cognitive, and robotics communities.

1. INTRODUCTION
In the psychology, gaze is recognized as a key component of social interaction between two agents [4]. Gaze is determined (in order of importance) by the direction of the eyes, the orientation of the head, and the orientation of the body [4]. The human-robot interaction community has begun exploring social gaze but implementations have largely been ad hoc [7, 6] or ignore how gaze would actually be programmed [9, 11, 10, 13, 14]. What is lacking is a computational model of gaze for social interaction, which can succinctly describe the phenomena in terms of inputs, outputs, and transformations independently of the natural and robotic sciences perspectives.

This research defines social gaze as the pattern of head, eye, and body orientation that express the level of engagement in the current social context. This definition supports computation because it assumes that there is a mapping \( G = E(C) \) from the perception of a social context \( C \) to a set of head, eye, and body patterns called gaze acts \( G \) that expresses the engagement \( E \). In behavioral robotics terms following [1], the social context would serve as the releaser or affordance for a gaze act signifying a specific social engagement behavior. The perception of social context would be either external or internal. With this more computationally-oriented definition of social gaze, the literature can be examined in terms of what gaze acts by a robot have been shown to work for which social contexts.

2. RELATED WORK
Fourteen studies have addressed a model or some aspect of social gaze [3, 6, 2, 12, 5, 9, 10, 14, 11, 13, 15, 4, 8, 7] either in general or for robots. [5] provides a computational model of how visual attention and gaze is used for conversation. [3] work on conversational agents is the earliest discussion of gaze for agent-human interaction. [6] explored gaze at an object and at a person, concentrating on determining how precisely the robot had to look at an object or face. [14, 13] shared the same topic with [6] but differed in that their gaze behavior implementation was more tightly coupled to language. [12] in 2004 posed Mel, the first overall model of engagement that included gaze for social attention, regulating interaction, establishing agency, and manifesting interaction content and projecting mental state. [2] also addressed all five contexts of gaze as part of their study on human-robot teamwork. Mutlu led three different studies, one in 2006 [9] and two in 2009 [10, 11] exploring social attention, projecting the mental state through gaze leakage and regulating the interaction process by using footing signals to establish the various roles of the conversational partners.

3. FIVE SOCIAL CONTEXTS OF SOCIAL GAZE
Based on the major studies in Section 2, social gaze in intelligent agents serves at least five distinct functions, listed below and shown in Figure 1.

Establishing agency, where gaze reinforces humanlike presence and general aliveness.

Communicating social attention, where the robot shows interest in the human usually by making “eye contact” [6, 9, 14, 12].

Regulating the interaction process, where gaze signals conversational participation and manages turn taking [12, 10, 5, 3].

Manifesting interaction content, where gaze cues goal achievement such as looking at an object to confirm it is the one
4. SIX GAZE ACTS

Six gaze acts used across the eight major studies and is summarised in Figure 1.

*Fixation.* A gaze persisting for a minimum of 1.40 sec [10] on a target (person, object, or location in space). If the person or object is moving, the fixation tracks and maintains gaze with the target.

*Short glance.* A fixation persisting less than 0.77 sec [10] to 1 sec [12].

*Aversion.* A gaze away from a person, usually on the order of lengthy unspecified time [5] with no specified direction.

*Concurrence.* A repetitive vertical movement greater than 10° or horizontal movement greater than 25° of the head, which interrupts fixation [5].

*Confusion.* A series of an unspecified number of rapid shifts back and forth to signify confusion, which can be accompanied with a roll of the head as amplification.

*Scan.* An unspecified number of short glances to a series of random points in space.

5. CONCLUSIONS

Based on the survey of the relevant literature, social gaze can be expressed as a mapping of \( G = E(C) \) from the perception of a social context \( C \) to a set of head, eye, and body patterns called gaze acts \( G \) that expresses the engagement \( E \) consistent with behavioral robotics programming. These findings are expected to provide a more precise vocabulary for discussing social gaze and to clarify and simplify programming social gaze.

6. ACKNOWLEDGMENTS

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7. REFERENCES


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**Figure 1:** Social contexts and Gaze acts used in each of the Eight major studies.

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that should be acted upon [6, 9, 13, 14, 12, 2, 13].

*Projecting mental state,* which for the purposes of this research will include expressing confusion, emotions, or intent [12, 11, 5, 8, 2].

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**Table:**

<table>
<thead>
<tr>
<th>SOCIAL CONTEXT</th>
<th>Gaze Acts</th>
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<td>Fixation</td>
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<tr>
<td>Short glance</td>
<td>X</td>
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<tr>
<td>Aversion</td>
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<td>Concurrence</td>
<td>X</td>
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<tr>
<td>Confusion</td>
<td>X</td>
</tr>
<tr>
<td>Scan</td>
<td>X</td>
</tr>
</tbody>
</table>

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**Notes:**

- Fixation persists for a minimum of 1.40 sec on a target (person, object, or location in space).
- Short glance is a fixation persisting less than 0.77 sec to 1 sec.
- Aversion is a gaze away from a person, usually on the order of lengthy unspecified time with no specified direction.
- Concurrence is a repetitive vertical movement greater than 10° or horizontal movement greater than 25° of the head, which interrupts fixation.
- Confusion is a series of an unspecified number of rapid shifts back and forth to signify confusion, accompanied with a roll of the head as amplification.
- Scan is an unspecified number of short glances to a series of random points in space.
1. INTRODUCTION

Human Robotic Interaction (HRI) is a burgeoning field with great potential and wide applicability. Much current research has been aimed at placing robots in various assistive roles: as a caretaker in hospitals, as a courier in retail settings, and as a tour guide in museums, to name just a few. The prevailing design paradigm for HRI software is based on the scientist’s instincts about how humans behave, intuition about how humans will respond to robots, and heuristics gleaned from psychological experiments.

Unfortunately, these anecdotal approaches leave HRI in a precarious position. For instance, heuristics can often generate desired behavior, but they provide no methods that can predict if or when failure will occur. This is unacceptable for robots working near humans, as failure can lead to injury.

Furthermore, heuristic approaches do not provide insight about how robots “should” behave around humans. Instead, these methods are built around the observations of a team of researchers, whose bias influences design. For instance, humans move around each other in quite clever ways. They unobtrusively weave themselves into, through, and out of crowds in a safe manner (see Figures 1, 2). How can one capture this behavior by mere observation?

More rigorous engineering disciplines, such as machine learning, provide insight about how to guarantee performance in automation applications and about how to mimic the behavior of complicated systems. However, most research in this field has veered away from the challenging problems of HRI; by and large, the complexity of human behavior outstrips the state of the art in machine learning.

This is where our research is having an impact—at bridging the gap between the anecdotal procedures of HRI (which provide invaluable data about human machine interaction) and the principled methodologies of machine learning (which provides rigorous analysis tools for this data).

2. FORMULATION AND RESULTS

As a case study in the synthesis of these two fields, we have been exploring a basic functionality of many service robots: navigating through crowds of humans in a natural and safe manner (Figure 1). Specifically, the goal of my thesis is to demonstrate a robot successfully navigating through the crowds of the Caltech student cafeteria at lunchtime. In the course of executing this experiment, the following three questions have become especially salient:

1. What does “successful” robotic navigation in human crowds even mean? In traditional robotic tasks (i.e., without a human presence), navigation is almost always well defined. However, in human environments, taking the shortest path between goal points is not necessarily ideal.

One of our initial discoveries was an equivalence between robotic navigation in human crowds and human crowd forecasting models (it is useful here to employ weather forecasting as an analogy—we are trying to predict the value of certain key quantities of crowds).

The importance of this discovery was that we now had a quantitative way to evaluate how “successful” our robot was performing in human crowds. Indeed, the success of our human crowd forecasting models correlates directly with the success of our robot navigation. But this result of course begs the following question:

2. How do we design a human crowd forecast model? As it turns out, modeling just a few prominent crowd fea-
tures (Figure 2) can be incredibly productive: goal oriented behavior (moving towards a food station), joint collision avoidance (people avoiding contact with solid objects), and movement dynamics (humans can only change direction so fast) all dramatically increase the reliability of the forecast.

Figure 2: A seemingly erratic trajectory (sequence of dots). Modeling goals (green), collision avoidance (red), and movement dynamics (blue) all increase forecast fidelity.

Additionally, modeling joint collision avoidance has an important side effect: the robot can now anticipate the cooperative intentions of nearby humans. This approach leads to more efficient robot paths; at the same time, the robot appears more natural since it is anticipating and cooperating with the humans.

3. Our final question: how do we get the humans to play fair? In many early robot-in-crowd experiments, the robot failed because humans sabotaged the robot: they jumped on the robot, kicked the robot, etc (Figure 3).

Figure 3: How can we prevent people from treating service robots as toys?

My research also aims to address the question of how to properly acclimate humans to a long term robotic presence. This ranges from simply remote controlling the robot in cafeteria lunchtime crowds (to familiarize people with the robot), to decorating the robot to look like the cartoon character Wall-E (Figure 4). In future studies, we plan to treat this problem in a rigorous manner, by building statistical models about how humans respond to specific robotic designs.

Thus far, results have been highly encouraging. In a paper presented at the International Conference on Intelligent Robots and Systems ([1]), we demonstrated the necessity of modeling human-robot interaction for navigation in human crowds. In particular, our algorithms were able to reproduce the navigation decisions made by humans. Furthermore, we showed that unless you model the full human-robot system, navigation failure is inevitable.

We have also begun human-robot experiments in the lunchtime crowds in the student cafeteria. Specifically, I have completed and passed the Institutional Review Board (human experiment consent), installed a person tracking system over the pizza station to collect data about human trajectories, built the computer-robot network infrastructure, and designed the human crowd models.

Figure 4: Human friendly design improves treatment of robot; how do we drive design using data?

In conclusion: if we truly want to realize the vision of social and assistive robotics—automated service machines seamlessly integrated into the daily routine of human beings—we need to better understand the basic functionalities of robots in the presence of people. In the course of this experiment, we have demonstrated an important preliminary step towards achieving the long term goal of fully integrated service robots. Extending this framework to other tasks will prove fruitful as well.

3. REFERENCES

Abstract of Current Research
Synchronous vs. Asynchronous Control in Multi-robot Search
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Categories and Subject Descriptors
1.2.9 [Artificial Intelligence]: Robotics – operator interfaces.

General Terms
Human Factors, Experimentation, Performance, Algorithms

Keywords
Human-robot interaction, metrics, evaluation, multi-robot system

1. INTRODUCTION
Many applications such as interplanetary construction, search and rescue in dangerous environments, or cooperating uninhabited aerial vehicles have been proposed for multi-robot systems (MrS) [1, 2]. Controlling these robot teams has been a primary concern of many HRI researchers [3, 4]. The problem addressed in this paper is the design of an asynchronous, scalable, and comprehensive display, to enable operators to detect relevant targets in environments that are being explored by large teams of UGVs.

We coin this type of asynchronous display image queue (Figure 1) and compare it to the traditional synchronous method of providing streaming video for each robot (figure 2). The goal of the image queue interface is to best utilize the advantages of an asynchronous display and to maximize the amount of time human operators can spend on tasks which human’s performs better than robots, such as victim identification and navigating robots out of dangerous areas [5]. The demands on operators for these tasks increase when the number of robots increases. Hence, another requirement for the interface is to provide the potential for scaling to larger numbers of robots and operators.

Figure 1. GUI for the image queue condition.

The image queue interface focuses on two tasks: (1) viewing imagery and (2) localizing victims. It consists of a filmstrip viewer designed to reduce redundancy by only showing highly relevant images from the video stream. Images with larger unviewed areas receive higher utility scores, which the visual coverage is computed by referencing the image in the map. Figure 3 presents an overview of the steps involved in this process. Tests of this system show that an operator can view 70% of the area covered by viewing the 10 highest utility frames and 90% within the first 100 frames.

Figure 2. GUI for the streaming video condition.

Figure 3. An illustration of the system architecture for the image queue.

2. METHODS
The experiment reported in this paper was conducted using the USARSim robotic simulation with 12 simulated Pioneer P3-AT
robots performing Urban Search and Rescue (USAR) foraging tasks. USARSim is a high-fidelity simulation of USAR robots and environments developed as a research tool for the study of human-robot interaction (HRI) and multi-robot coordination [6].

The experiment followed a two condition repeated measures designs comparing the synchronous with the asynchronous display. 32 paid participants were recruited to perform a victim search task controlling 12 robots in teams using either the streaming video or image queue display with a counterbalanced design. At the conclusion of each real task session, participants were asked to complete the NASA-TLX workload survey [7].

3. RESULTS AND DISCUSSION

Data were analyzed using a repeated measure ANOVA. Overall, in both conditions participants were successful in searching through the environment. However, there is no significant difference between conditions for victim found (F₁, 28 = .733, p = .387) and area explored (F₁, 28 = 2.147, p = .154).

When comparing the marking result with the ground truth, a mark made further than 2 meters away from any victim or multiple marks for one victim were counted as false positives. Victims that were present in the video feed but not marked were counted as false negatives. There were significantly fewer false positives (F₁, 28 = 13.032, p = .001) as well as fewer false negatives (F₁, 28 = 5.526, p = .026) for the image queue condition (Figure 4). The full scale NASA-TLX workload measure also revealed a significant advantage (F₁, 28 = 7.347, p = .001) favoring the image queue condition.

The overall significance of the image queue interface goes further than the mere reduction of errors and workload. It allows the design of a system that treats target detection tasks as notifications for a call center. At this point we can well imagine the difficulty of two operators supervising 24 UVs with live videos (Figure 5). As further work we intend to directly address scalability with an image queue-call center approach and investigate its effects on even larger teams with multiple operators. Evidently, an asynchronous display method will face particular challenges when dealing with dynamic environments and targets and will require more sophisticated techniques.

4. REFERENCES


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