Making Friends: Building Social Robots Through Interdisciplinary Collaboration

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Abstract

This paper discusses social robotics as a hybrid knowledge space that encourages interaction and collaboration among many different disciplines: engineering, computer science, the social sciences and humanities, design, the arts, etc. Such collaboration in the design of socio-culturally situated artifacts poses many challenges, occassioned by differences in conceptual frameworks, methods for conducting research, and even daily work practices. By approaching these challenges in a spirit of friendship across the sciences, it is possible to achieve transdisciplinary understanding and reap the benefits of applying different, yet complementary, forms of expertise to social robot design. In this paper, we use insights and lessons learned from our own collaborative experiences to discuss how social as well as technical and design issues are addressed in the construction and evaluation of social robots and how the boundaries between the social, natural, and applied sciences are challenged, redefined, and traversed.

Introduction

Social roboticists aim to create 'natural' and 'compelling' robots that can engage people in social interaction in everyday human environments. To accomplish this aim, they seek to endow robots with various combinations of traits: the capacity to express and perceive emotion, the skill to engage in high-level dialogue, the aptitude to learn and recognize models held by other agents, the development and maintenance of social relationships, the learning and use of social competencies and natural social cues (gaze, gestures, etc.), and the capability to exhibit distinctive personality and character (Fong, Nourbakhsh, & Dautenhahn 2002). While roboticists often cite the limitations of available technologies (e.g., processor speed, actuation technologies, sensory failures, etc.) as the key obstacles to constructing socially interactive robots, the synergistic combination of relevant *social* as well as *technical* capabilities is fundamental to effective social robot design. The success of human-robot interaction depends not just on the robot's technical abilities, but also on its "social robustness" (Nowotny, Scott, & Gibbons 2001)—its incorporation of relevant principles of human social behavior, an awareness of the socio-cultural context of the interaction, and an understanding of the potential direct and personal as well as broader social impacts of the design.

Increasingly, social robotics projects involve not only engineers and computer scientists with technical expertise, but also social scientists proficient in analyzing human social behavior and relations with technology, designers who skillfully construct dynamic interaction systems, and artists with an eye for cultural and social critique (Nourbakhsh *et al.* 2005; Scassellati 2005; Torrey *et al.* 2006; Kozima & Nakagawa 2006; Gockley *et al.* 2005). Depending on the context of application for the robot, an array of other experts can be involved, e.g. medical and healthcare professionals and patients in the case of assistive technologies, or pedagogues, teachers, students, and parents in the case of educational technologies. The design of socially interactive robots can aptly be viewed as a driving force in the creation of a "hybrid science" (Caporael 2000), a knowledge space in which experts from a variety of communities, backgrounds, and perspectives can collaborate in the context of problem-, issue-, or task-based inquiry. Social robots are conducive to and encourage this kind of study because they are exemplary "boundary objects" (Star & Griesemer 1989), artifacts that can be imagined, perceived, and interpreted differently by various disciplinary communities, yet still provide a common focus for inquiry and action.

Attempts at collaboration among practitioners in such a wide variety of fields are understandably accompanied by various challenges and the constant need to re-establish mutual understanding and rapport. In this paper, we describe our own experiences in the collaborative evaluation and design of exploratory and socially assistive robots, and discuss some ways for negotiating disciplinary differences in worldviews, language, methodologies, research tools, and theories in the pursuit of mutually rewarding cooperation. Interdisciplinary collaboration within a hybrid knowledge space such as social robotics exposes the values and assumptions of disciplinary communities that guide and limit their research problems and practices (Forsythe 2001). Practiced as a congenial and egalitarian attempt at creating knowledge at multiple levels of analysis (e.g. the machine, human-robot interaction, society), it can serve to develop alternative theories and methods for designing technologies and understanding how humans interact with them. This is an important step if we consider that the future of social robotics will be

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defined not by the available materials but by the "limits of interpretive courage or foolhardiness allowed by new social structures" (Restivo 2003) that we are in the collaborative process of constructing.

Clash of cultures: Challenges in interdisciplinary collaboration

The multiplicity of conceptual frameworks, methodological preferences, and daily scientific practices of the technical and social disciplines can become a source of tension in the search for understanding, partial consensus, and collaboration among the various disciplinary cultures[1] contributing to social robot design (Forsythe 2001; Smith 2005). The practice of social robotics entails constant renegotiation of conceptual and practical boundaries: between the natural, applied, and social sciences; between functional and "relational" (Turkle 2005) artifacts; between humans and machines; and between the socio-cultural neutrality of science and social responsibility. By taking note of the misunderstandings, debates, and concessions among the various contributing experts, we can track the development of common meanings and complementary practices among the various disciplinary cultures that comprise the field of social robotics.

I say tomato (to-may-tou), you say tomato (to-mah-tou)

Confusion about terminology is probably the most common cause of misunderstanding among disciplines. Scientific jargon carries epistemic baggage and travels with difficulty; the meaning of a term can vary depending on the particular methodological, theoretical, and social commitments and practices of the disciplinary context in which it is used, while scholars with different disciplinary backgrounds can have opposing opinions on the appropriate usage of certain concepts. As an example from our own collaborative experience, a decision about the appropriate way to refer to people whose interactions with the robot we were analyzing was cause for heated discussion. Team members variously suggested, opposed, and championed calling people 'users,' 'participants,' 'subjects,' 'interaction partners,' or even 'resources' used by the robot. A similar controversy sprung around the different uses of the term 'distributed,' one referring to "distributed cognition" and another to "distributed sensors." Another familiar example is the increasingly popular term "affordance," which has different connotations in the design and psychology literatures.[2]

While these language-related differences may be the easiest to pinpoint and resolve, the process needs to be extended to the more subtle underlying assumptions and values of the different fields. For example, referring to people as 'resources' for the robot implies a robo-centric (rather than user-centic or interaction-focused) design approach; it can also be seen as robbing humans of 'agency' (not to be mistaken for what computer scientists call an 'agent'). Calling a person a 'user,' on the other hand, implies that they are merely interacting in a mode that was pre-determined by the designer rather than co-creating an emergent sociality through the process of interaction. The interdisciplinary participants of the August 2006 Graduate Student Invitational Research Workshop on Human-Robot Interaction in Carmel, CA, which included engineers, designers, and computer and social scientists, realized that the list of terms that are not 'universally' agreed upon is virtually endless. A particular understanding and use of language is based on years of enculturation and socialization in a disciplinary community, and collaboration between individuals with different cultural understandings necessitates not only negotiation among but also awareness of the validity of differing perspectives.

The value of numbers

The social, natural, and applied sciences have marked differences in their modes of inquiry, particularly relating to the use of quantitative and/or qualitative approaches to problem definition, methodology selection, choices of relevant data, and the theoretical basis of robot design. Social robotics, with roots in computer science and engineering, exhibits a "quantitative bias" (Forsythe 2001): evaluations of human-robot interaction are generally expressed in terms of easily quantifiable measures (turns to task completion, the number of mistakes made or people spoken to, the length of interaction, etc.), and researchers tend to appropriate experimental methodologies and related statistical analyses from psychology that are more familiar and 'scientific' (Restivo 2002). Roboticists commonly refer to the results of qualitative ethnographic techniques and other contextual, interpretive studies as "anecdotal," thereby challenging their validity; while such methods are making inroads into the field, they are still marginal. The contextual nature of social interaction, however, precludes reliance on quantitative measures of human-robot social interaction alone, as they lead to the systematic exclusion of social phenomena that are not easily amenable to quantification. This quantitative bias may also dissuade scholars interested in qualitative studies of social interaction from participating in social robotics.

Along with quantitative models and measures, qualitative analytical skills and situated contextual analyses of social behavior are legitimate, valid, and in the case of social robotics, *useful* and *necessary* frameworks for thinking about the world. Reliance on quantitative metrics and controlled experiments alone has limited utility for understanding social interactions in contexts where the task bound-

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[1] Scientific disciplines have varying "epistemic cultures"—arrangements, mechanisms, categories, and processes that make up "how we know what we know" (Knorr-Cetina 1999). These are observable in comparisons of the empirical methods, research instruments, daily practices, social organizations, and socio-cultural values and assumptions of various scientific disciplines.

[2] In psychology, affordances are certain latent "action possibilities" presented to an actor by its environment, and existing independently of its recognition of those possibilities (Gibson 1979). In design, it is the user's perception of an artifact's affordances that makes all the difference, so affordances are considered to be dependent not only on the actor's physical capabilities, but on their goals, plans, values, beliefs, and past experiences (Norman 2002; 1999).

aries and success criteria are not clearly defined. For example, with the robot Tank, we initially evaluated aspects of the robot's design through frequency and duration of what the robot perceived to be 'interactions.' Through observational analysis of video of people actually interacting with the robot (Michalowski, Sabanovic, & Simmons 2006; Sabanovic, Michalowski, & Simmons 2006), we found not only that we were missing very important qualities of the interaction (such as the tendency of people to interact in groups, taking turns between users), but that the robot's very perception of the state of an interaction was rarely in line with the human evaluation.

No social robot is an island

Another aspect of the quantitative bias of social robotics is expressed through the computational and technological metaphors of human cognition and behavior that are at the basis of robotics and artificial intelligence. These metaphors typically depict the mind as a rational, logical, neutral, and detached input-output device inside the skull (Caporael 2006). When approached from this perspective, robots are designed as stand-alone entities with particular inherent social capabilities that can be regurgitated at the appropriate time in the course of an interaction. Social interpretations of intelligence, on the other hand, focus on the embodied, mobile, socially embedded relationship between human actors and their dynamic environment. Within this framework, the computational model "in which '*the* [single given] environment' is conceived in terms of a set of autonomously determinate features, can be seen as crucially confining, or, indeed, disabling" (Smith 2005). Social interactivity in robots needs to be understood as the ability of agents to participate in a dynamic sequence of actions between individuals or groups, and to modify their actions according to those of their interaction partner(s), rather than as an inherent capability of the agent—there is no socially interactive robot by itself (Okada, Sakamoto, & Suzuki 2000). For example, the prevalent serial model of interaction, treating communication as a ping-pong-like transaction of information, has difficulty accounting for the rhythmic *co-action* and simultaneous coordination/adapation between two interactors. The meaning of the interaction, and of the robot's behaviors in it, emerges from the robot's situatedness in the interaction.

Looks do count

In creating socially assistive robots for research, roboticists often spend time developing functionality to the exclusion of appearance and aesthetics. Yet collaboration with the design discipline is important not only for aesthetic purposes; it is crucial that questions of form, functionality, and appearance are appropriately addressed for the scientific inquiry through such artifacts to be valid and productive. There is perhaps a widespread faith that, in a controlled experiment in which a single variable is manipulated, any observed difference between conditions can be used to make general statements about the variable under study. In a domain as complex as human social interaction, however, the potential for confounding factors to appear is great, and the design of a robot's appearance is as important as the design of the experiment. For example, early in the design of GRACE's pink-hat-finding task (Michalowski *et al.* 2007), a roboticist suggested a touch-screen interface that would allow people to enter a set of directions (in the manner of writing a sequential program) for GRACE to find the hat. A designer on the team saw that this would detract from the goals of the project, which was to encourage and observe as many social interactions with people as possible, and proposed a much simpler interface in which arrows were selected to point GRACE in a general direction. The roboticist can thus use an artifact that is more comfortably used in the interaction under study, and the designer has the opportunity to develop and test ideas about interactive, embodied technologies.

All for one and one for all: Mutually rewarding exchange among disciplines

Knowledge production in hybrid sciences such as social robotics cannot be an individual endeavor; rather, participating scholars must strive for "collective comprehensiveness through overlapping patterns of unique narrowness" (Campbell 1969). Despite the difference in disciplinary cultures, a common interest in systematizing the fundamental principles of social interaction and evaluating the emerging relationships between humans and robots brings social scientists and roboticists together in projects that explore sociality in novel ways. Rather than maintaining oppositional identities and disciplinary boundaries, collaborative modes of inquiry emphasize the complementarity of skills among researchers with diverging social and technical expertise and common goals. The goals and interests of the disciplines overlap enough to enable collaboration, but are different enough to avoid replicating each others' efforts. The discipline-traversing potential of social, assistive, and epigenetic robotics and human-robot interaction is apparent in work by researchers that defy disciplinary confinement and opt for collaborative problem-oriented approaches in an effort to move beyond existing knowledge structures.[3]

One strength of interdisciplinary projects is in the depth of the complementary analytical and practical skills that scholars bring to the project: social scientists bring detailed expertise in analyzing and describing social interaction, and roboticists apply their skills in making artifacts that work in the real world, that behave consistently, and that can provide a record of what they have sensed and done with respect to their environment. Benefits from interdisciplinary projects can, furthermore, be shared through all the participating fields. In our collaborative work, we have found that one of the valuable roles that social scientists can play in social robotics projects (particularly those that are already established) is in the rigorous, systematic, and contextually appropriate evaluation of the resulting systems. In the other direction, social roboticists can help construct machines that can serve as research tools for social scientists to use in an-

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[3] See work by Brian Scassellati (Scassellati 2002; 2005), Michio Okada (Suzuki *et al.* 2004), Kerstin Dautenhahn (Dautenhahn & Nehaniv 2002; Nehaniv & Dautenhahn 2007), and Hideki Kozima (Kozima & Nakagawa 2006).

alyzing the interactions and relationships people have with each other and with techno-scientific artifacts. In this section, we will describe some of the collaborative methods of inquiry that have enabled us to traverse the technical, social, and design disciplines as we evaluated existing robot platforms and embarked on the construction of a new social robot based on lessons learned from our previous work.

It's a jungle out there

Even though social robots are expected to participate in real-world social interactions with humans in an autonomous and 'natural' manner, the majority of evaluations of robots are done in a laboratory by the very people who have built them. Evaluations performed in this manner often end up merely re-confirming the initial design assumptions and principles with which the robot was constructed; they do not provide insights into the aspects of human-robot interaction that emerge in the less structured real-world social settings in which they are meant to function. In order to challenge initial design assumptions and discover interaction principles relevant to a robot's performance in various contexts, it is necessary to study human-robot interactions as situated activities outside the laboratory, "in the wild" (Hutchins 1995).

Roboticists often combine certain results and theories from psychology (and less commonly sociology, anthropology, or design) with models of human-robot interaction based on their own everyday social experiences, failing to take into account the discrepancies between the conscious models of events constructed by humans after the fact and behavior observed in the context of interaction (Forsythe 2001). Such approaches do not necessarily seek to faithfully emulate human social cognition, but aim to make robots engaging and believable, at least in short and confined interactions. Critiques of these examples of "shallow" sociality (Dautenhahn 1999) often assign the responsibility for these deficiencies squarely within the robotics community and overlook the difficulty of performing transdisciplinary translations of abstract, interpretive, and qualitative social science research into rules that can be implemented in building and programming a robot. Faced with the complexity of detailed descriptions and theoretical interpretations of social interaction, roboticists often embrace simple, general and decontextualized operationalizations of interaction criteria,[4] discrete lists of attributes,[5] and quantifiable experimental methods that readily map onto rules that can be applied to the design of robotic systems. The systematic observation and analysis of robots in real-world environments, such as those discussed below, can provide opportunities for creating more contextually appropriate models of interaction and should be used to 'deepen' the social responsiveness and interactivity of existing robotic platforms.

Figure 1: A frame from video of the robot GRACE at AAAI 2005.

Camera, robots, interaction

The robot GRACE's participation in the Open Interaction Event at AAAI 2005 (fig. 1) (Michalowski *et al.* 2007) gave us our first opportunity to observe and analyze how one of our robots operated outside of the laboratory in which it was designed, with a group of people that were not familiar with the robot through everyday exposure, and with minimal scaffolding by the robot design crew. In order to observe and analyze the unstructured interactions between GRACE and participants through the conference, we videotaped GRACE's experiences with the conference-going crowd. Afterwards, we performed fine-grained behavioral video analysis of the resulting human-robot interactions. Such an analysis is usually conducted on a frame-by-frame basis and entails formulating a coding schema for labeling a set of behaviors or activities for people and robots involved in a recorded interaction. Statistical analysis of the resulting labeling provides quantitative descriptions of the interaction that can be used to support or generate qualitative analyses. In our work, we have aligned logged data about the robot's perceptions and actions with coded video to allow for direct comparison between the system's operation and the evaluation of an expert in behavioral analysis.

Such analysis of robots interacting in real-world environments can be used to analyze how humans react to and interact with a robot; how humans interact with each other while interacting with the robot; which aspects of the robot's and humans' actions lead to breakdowns in the interaction; and how the robot succeeds and fails to engage humans in interaction. Observational analysis can be used to understand situated interaction between people and robots, to reveal factors that surpassed or challenged the initial design assumptions about social interaction, to suggest changes in the robot's design, and to relate findings to more general applications in social robotics. These analyses can provide detailed quantitative and qualitative data that can be used to improve socially situated/embedded robot interactions through iterative design processes. This method also allows us to translate between the quantitative expectations of roboticists and the qualitative aspects of human social interaction.

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[4] For example, the comfortable interpersonal distances in Hall's proxemics (Hall 1974).

[5] For example, Laurel's breakdown of human-computer interaction into "action, character, thought, language, melody, spectacle" (Laurel 1991).

Figure 2: Tank the Roboceptionist and a frame from video of interaction.

Fine-grained behavioral analysis of video-taped human-robot interactions can show us how interaction emerges in particular contexts, as well as how small variations in the social and physical environment can change the nature of the human-robot interaction. In our analysis of the robot GRACE's interactions with conference participants at AAAI 2005, we found that the social and physical context in which the robot was performing had a significant effect on people's interactions with it, despite the robot's behaviors remaining the same (Michalowski *et al.* 2007). Interactivity was not merely inherent in the robot as an isolated artifact—it emerged from an interaction between environmental effects, both predicted and unpredictable, and the robot's sensory and behavioral capabilities. The robot was interacting with people in two different physical rooms during the conference, but we found that the resulting interactions were more strongly shaped by the types of events that were occurring in the spaces; that is, the quantifiable aspects of interaction such as gaze, gesturing, and talking were dependent on the types of social events during which interaction took place. With GRACE, and later with Tank the Roboceptionist (fig. 2), we were able to quantitatively show the importance of qualitative variables such as the context of interaction, the interpersonal interaction and scaffolding among participants for successful and engaging interaction with the robot, and the rhythmic properties of interaction (Sabanovic, Michalowski, & Simmons 2006). In both cases, the "conscious model" of interaction that was built into the robots was shown to be inadequate for supporting the variety of interactive behaviors attempted by humans. Through these studies, we were able to show the need for a more adaptive robot that is "socially embedded" (Dautenhahn, Ogden, & Quick 2002) or "structurally coupled" with, and adaptable to changes in, the spatial and social environment. In our current project, Roillo (described in the next section), we are trying to build a robot that has these characteristics.

Designing in step

Evaluations such as those described above can provide valuable suggestions for manipulating a robot's interaction design. Unfortunately, it can be difficult to apply these suggestions to an existing robot because its design has already been entrenched through funds, time, and labor spent. Another way to use the results of these analyses is to apply them in the construction of new artifacts. While interdisciplinary collaboration can revitalize existing projects and obtain new results from existing systems, its potential can be most fully realized when it is used early in the project; indeed, when the project itself is born of a discussion between members of different disciplines in order to investigate mutual interests. We have begun such a project, and it would not have been possible without equal contribution from multiple fields. Our collaborative practices follow an iterative process that starts in theory, moves through design (in various media, such as rendering, animation, hardware prototyping, and puppeteering), culminates in evaluation in situated interaction and feeds back to theory and redesign.

Figure 3: A rendering of Roillo, and Keepon dancing with children.

Roillo (fig. 3) (Michalowski, Sabanovic, & Michel 2006) is a small, stationary, nonverbal robot that interacts with children in playrooms through dance and other rhythmic activities. Roillo's interactive repertoire draws on four decades of social science research and theory in rhythmicity and interaction synchrony. The rhythmic organization of social interaction is an expression of the oscillatory neurobiological language of the central nervous system through learned cultural patterns (Chapple 1982). Rhythmic entrainment is involved in establishing rapport and engagement between interactors as well as in providing a foundation for the mutual coordination of social interaction. The project's focus on rhythmic synchrony between a robot and children binds the contributing disciplines: social rhythmicity is a fundamental, but under-researched, aspect of human-human and human-robot interaction; it is generalizable and applicable to a range of different platforms and technologies; it is a critical yet very labor-intensive subject to study; and the rhythmic characteristics of interaction are involved in the expression, diagnosis, and therapy of various physical and psychological disorders such as autism.

One of our goals, from a social science perspective, is to use the robot to critically study, for the first time in a controlled manner, rhythmic interaction as an emergent phenomena between interaction partners. Arguably, a major barrier to the rapid development of research and theory in the social sciences is the lack of a genealogy of research technologies that can be manipulated and modified to produce new phenomena and related research results (Collins

1994). Social robots such as Roillo can serve as such a technology: they can be autonomous or remote-controlled, they can reliably repeat certain behaviors consistently, and they can be used to both develop and test models of human social interaction and human development. At the same time, from an engineering standpoint, such a robot has the potential to establish interaction rhythm and synchrony as important components of effective socially interactive robotic systems. From a therapeutic perspective, a robot like Roillo has the potential to serve as a way of testing and developing consistent methods in movement-based interventions. Finally, from a clinical standpoint, it can serve as a tool for doctors and parents to record and observe responses to consistent stimuli and to craft individualized care for children with special needs. Our early work in this area has been promising: a pilot observation of our control architecture for the perception and generation of rhythmic behaviors (in dance-centered interactions between children and the robot Keepon, fig. 3) has suggested that there is indeed an effect of the robot's subtle rhythmicity on the qualities of children's interaction with it (Michalowski, Sabanovic, & Kozima 2007). Rather than being hierarchically subsumed under the leadership of one discipline which appropriates techniques and ideas from different fields, the project rests on the deep involvement of computer scientists, engineers, social scientists, movement therapists, and clinicians who all have access to and a voice in every stage of the research process.

Conclusion

By inhabiting the same space, working on common problems, and developing a shared language and understanding of social robotics (as roboticists, designers, and social scientists), we as partners in collaborative design and research are continuously traversing and deconstructing disciplinary boundaries through our everyday practices. At the same time, our research continues to change through dialogue, debate, and cross-pollination. From the social scientist's viewpoint, the critical aspects of our work on social robotics have been informed by a deeper understanding of the technical limitations of technology and the issues and practices involved in building and programming robots. At the same time, our robotics research has become informed by methodological and theoretical contributions from the social sciences. A commitment from all sides to friendship, respect, and open-minded inquiry, as well as a willingness to value differing backgrounds, ideas, and perspectives (Downey & Lucena 2005), enables practitioners from very different epistemic communities to "'muddle through' together toward mutual understanding and even practical ends—uneasily, to be sure, but abetted by the same combination of laughter, dedication, forbearance born of sustained proximity, and *mutual* critique that characterizes the best friendships in the personal domain." (Fortun 2005)

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