# On Constructing a Communicative Space in HRI

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**Abstract.** Interaction means to share a communicative space with others. Social interactions are reciprocally-oriented activities among currently present partners. An artificial system can be such a partner for humans. In this study, we investigate the effect of disturbance in human-robot interaction. Disturbance in communication is an attention shift of a partner caused by an external factor. In human-human interaction, people would cope with the problem to continue to communicate because they presuppose that the partner might get irritated and thereby shift his/her interactive orientation. Our hypothesis is that people reproduce a social attitude of reattracting the partner's attention by varying their communication channels even toward a robot. We conducted an experiment of hybrid interaction between a human and a robot simulation and analyzed it from a sociological and an engineering perspective. Our qualitative analysis revealed that people established a communicative space with our robot and accepted it as a proactive agent.

**Keywords:** Human-Machine Interaction, Social Robotics, Disturbance in Communication.

## 1 Introduction

Humans are social beings. The interaction partners use alternating demonstrations and utterances, which corporately construct a communicative space. Such immaterial space is *social*. People together establish a binary structured situation which is constructed through their communicative activities in each human-human interaction (HHI) [1]. However we can wonder whether the interaction with artificial partners is also social. Can double sided activity be performed? What can help to clarify human-robot interaction (HRI) and make it easier?

Social activities can be expanded to inanimate and be build up among humans and artifacts. We can evaluate proactive social activities of a robot system by means of its social embeddedness. Dautenhahn et al. [2] have been measuring the degrees of embodiment, situatedness, and social embeddedness in different biological and artificial systems. They give requirements for the design of interaction-aware machines, which have a high social impact.

Many researchers have been attempting to find factors which are influencing the human impression of robots [3]. For example, Goetz et al. [4] suggested

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that matching a task and the robot's behavior to it would improve human-robot cooperation. They designed two types of robots, a playful and a serious one, and compared the people's acceptance of the robots working either on an entertaining or a serious task. People accepted better and interacted longer with the robot which acted in an appropriate manner to the task. Minato et al. [5] defined the familiarity of a robot with respect to its appearance and behavior. They extended the uncanny valley proposed by Mori [6] and described how the above two factors synergistically affect the people's impression of a robot. Their experiments using their android, in which the human response of breaking eye contact was measured, showed that people dealt with the android as a human-like agent. These studies had a major impact on the design of communication robots, however, they focused only on the factors directly relevant to HRI.

Various activities in interactions and elements of communication have been studied. We here also explore factors which could encourage HRI. We propose to concentrate on a foremost counter-intuitive aspect: disturbance in an interaction. In HRI this phenomenon is usually disliked and is regarded as a problem. However the disturbance in interaction can be a positive factor. Focusing on HHI, we notice accompanying effects in disrupted communications. If two people are talking while a television or radio is turned on, different effects can be observed: People continue to communicate with the partner and even intensify their activities toward the other whose attention has been shifted to the additional visual and/or acoustic input. They can deal with the upcoming problems because they presuppose an irritation. People know the strategies to regain the interactive orientation.

We designed a robot simulation embedded with a mechanism of primal visual attention. Although the robot shows only primitive reactions, it can motivate the human partners to hold on the interaction. This enables us to explore the variety of human reactions and to point out the observed social activity, which is highly oriented toward the artificial partner. We suggest that people who are accepting the robot as a situated intentional partner might dislike a distracted robot's attention, try to regain it, and make it re-engage in the interaction actively.

Here we investigate from a sociological perspective how disturbance in HRI affects the behavior of human partners. We wish to add an analytical perspective from the field of sociology to the continously emerging interdisciplinary discourse in the field of robotics (e.g., [7,8]), We believe that a qualitative approach helps to reveal effects induced by disturbance, to discover how people act and react toward a robot, and thereby to contribute to the development of social robots.

In Section 2, we depict sociological communication theory of interaction between humans and the phenomenon of disturbance in communication. Our robot simulation as a communication partner is explained in Section 3. In Sections 4 and 5, we introduce an experiment of HRI using the robot simulation and show the results of the qualitative analysis of people's reactions. The results are discussed from both a sociological and an engineering point of view in Section 6. Finally, the conclusion and further research issues are given in Section 7.

## 2 Sociological Aspects of Communication

### 2.1 Involvement in Social Interaction

Every contact which takes place between humans, who are addressing others, is social. Sociological systems theory denominates communications among partners in attendance as *interacting systems* [9]. One criteria for communication is the reciprocal percipience, whereas the presence or media mediated utterances of both partners is a prerequisite to be acquired [10]. The reciprocity of awareness of the coparticipants means that both are sharing contextual perceptions which enable them to construct a common sense and to build a situated common ground. These operations open an intersubjective space of social actions and expressions. Participating in an interaction system means to be engaged in the reciprocal course of action with interactive practices and to shape it with reciprocal addressed behavior [11].

Sequences of contributions of speech and actions like mimic, gesture, and body movements are aligned with the partner in each interaction [12, 13]. All elements of the dialog are organized as reciprocal turns which are successively arranged in a turn-taking set. Each participant of an interaction is oriented toward the partner by considering his/her individual situated involvement. This phenomenon includes a sensitivity to the coparticipant and his/her situatedness. Sacks et al. [14] named the context-aware possibility of referencing to partners' actions and utterances in HHI *recipient design.* Garfinkel [15] takes constructivist arguments into account when he describes interactions as situated in a specific context, which is constructed by each interaction partner employing his/her own category systems, commonsense knowledge, and practical reasoning to the actual experience. Though the interaction partners achieve mutual understanding. As a consequence of this individual construction of the specific social situation, humans are able to act within their circumstances and to interprete others. However communications consist of mutual constructions of the situation. Von Glasersfeld [16, 17] takes into account that our reality is built upon experiences and the utilization of feasible strategies. Every individual is constructing such a space within his/her mind by using the perceived world and relating it to former and actual experiences. This argument of constructivist theory and the findings about social interaction characteristics inspire the idea of a constructed communicative space.

### 2.2 Dealing with Disturbances

Communications are fragile and their alternating follow-up is often disrupted by surrounding factors. What happens in case of addressing someone who has lost concentration and is occupied with processing information derived from a third person's perspective? This shift of the attention will be recognized by the partner and cause some reaction. Spontaneously appearing reasons might effectuate severe irritations that can lead to discontinuity in the dialog processing and the interaction might be terminated. By lifelong practice humans learn to deal with such disturbances. They can defy the problem, and thus an originally negative cause leads to positive effects.

In HHI the problem of focusing the attention in a communication has been investigated intensively. Social interactions can be studied in everyday life, and such analysis revealed that humans moreover often implement disturbances in communications themselves. Goodwin and colleagues [10, 12] analyzed multiple face-to-face interactions of humans in different contexts. They discovered that the ideal turn-taking in *talk-in-interaction*s is often disturbed by the co-participants themselves [10]. Such strategic elements are used in order to evaluate whether the partner's co-orientation is still focused on the ongoing interaction [12].

Those techniques are applied to organize the exchange of speech and gaze, and, if inconvenience is discovered, *repairing mechanisms* are initiated [18]. For example, the speaker often stops him-/herself and restarts the sentence with identical words. Such explicitly evoked breaks in the verbal flow ensure about the interaction partner's concentration on the mutual topic. As a positive effect, those disturbances affirm the interaction and the dialog can be continued.

## 3 A Communication Robot with Primal Visual Attention

In order to study the effect of disturbance in HRI, we developed a robot simulation of which attention can be naturally distracted by a visual disturbance.

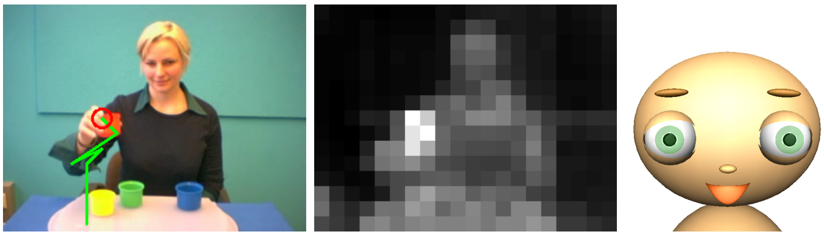
### 3.1 Robot Simulation

Fig. 1 (c) shows a robot simulation used in our experiment, which was originally developed by Ogino et al. [19]. The robot has only the face with an infant-like appearance, thus being considered adequate to examine the nature of HRI.

In our experiment, the robot interacted with a human partner by changing its gaze direction as well as facial expression in response to visual input. The gaze direction was controlled so that communication partners could perceive that the robot was looking at a likely interesting location in the environment. The explanation of the attention mechanism is given in the next section. Facial expression was also used to facilitate the interaction. The robot, for example, showed pleased expression by rising the eyebrows and opening the mouth when it could stably look at a static target.

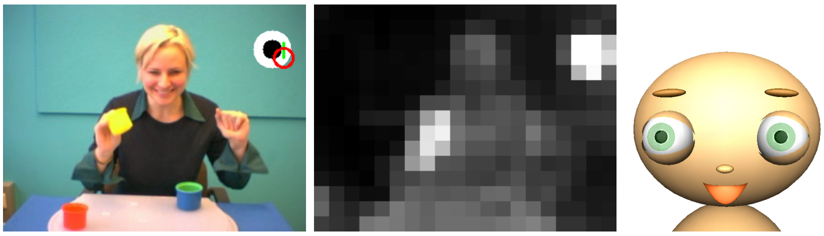
### 3.2 Mechanism of Primal Visual Attention

As the mechanism for the robot's vision, we adopted the model of saliency-based visual attention proposed by Itti et al. [20,21]. The model based on the neuronal mechanism of primates enables the robot to imitate the primary attention of primates, who can rapidly detect and gaze at salient locations in their views. A salient location is here defined as a spot which locally stands out from the surroundings with respect to its primitive visual features: color, intensity, orientation, flicker, and motion [21]. For example, a human face can be detected



(a) Input image. (b) Saliency map. (c) Robot's face simulation.

**Fig. 1.** A scene without disturbance. The robot is gazing at the red cup held by the human partner because of its outstanding color and motion.



(a) Input image. (b) Saliency map. (c) Robot's face simulation.

**Fig. 2.** A scene with disturbance, a black and white circle. The robot is looking at the disturbance because of its highly contrasted intensity and motion, although the human partner tries to attract its attention by showing the yellow cup and shaking her left hand.

as salient because of its intrinsic features, i.e., the skin color and the compound form, as well as of the motion even though no face model is applied to. The saliency model therefore enables the robot to detect likely important locations in the interaction without any top-down knowledge about the situation or the communication partners. The effectiveness of the model has been demonstrated in the studies of social robot learning and social robot interaction (e.g., [22,23]).

Fig. 1 (a) shows an example of the visual input captured in the experiment. The human partner was picking up and showing a red cup to the robot in a blue background. Fig. 1 (b) gives the corresponding saliency map, in which the degree of saliency is represented by the brightness of the pixels. The map was generated by calculating the difference between each pixel and the surrounding ones, which highlighted the prominent pixels in the image. Refer to [20, 21] for more detailed mechanism. In our HRI experiment, the robot gazed at the most salient location in each image frame. In the scene shown in Fig. 1 (a), the red cup held in the right hand of the human partner had been attended to for a while because of its outstanding color and motion. The current position of the attended location and its trajectory are denoted by a red circle with green lines.

The robot shown in Fig. 1 (c) was captured when it was gazing at the red cup. The robot's eyes were controlled so that human partners could perceive that it was responding to their action and was looking at an interesting location for it. Note that, in our experiment, human partners could only see the simulation of the robot's face, but not the input image or the saliency map.

### 3.3 Disturbance in Robot's Vision

To distract the visual attention of the robot during the interaction, we created a salient object superimposed in the input image. Fig. 2 shows a scene captured while a disturbing object was put at the upper-right corner of the image. The object was designed as a white circle with a smaller black circle, which vibrated randomly. Because of the highly contrasted intensity and the motion, it attracted mostly, but not certainly, the robot's attention. In Fig. 2, the robot gazed at the disturbing object although the human partner tried to attract its attention by showing the yellow cup and shaking her left hand. Note that the disturbing object was presented only in the robot's vision, not in the real environment, and therefore human partners could not discover anything at the location where the robot was looking. The initial position of the disturbance had been fixed at the upper-left or upper-right corner of the image.

## 4 Method for HRI Experiment

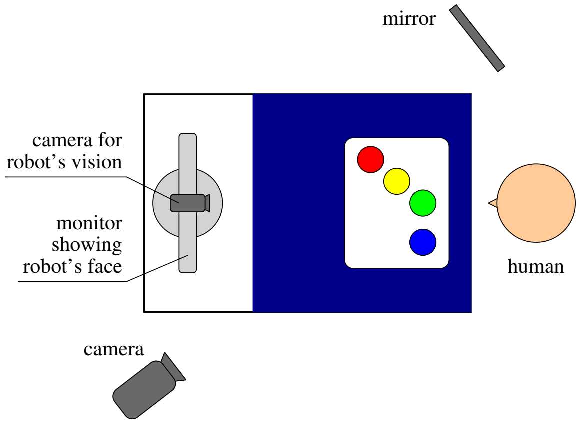
We conducted a HRI experiment using our robot simulation. By controlling the disturbance in the robot's vision, we investigated its effect on the following behavior of human partners.

### 4.1 Participants

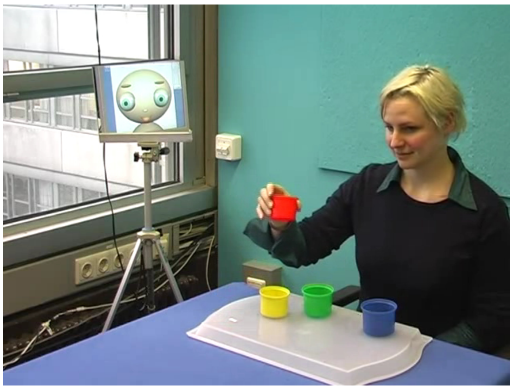
Twenty-two university students (sixteen males and six females) participated in the experiment as communication partners. Sixteen of them major in computer science and thus are familiar with robotic systems, while the others studying sociology or linguistics are not. All of them saw our robot for the first time in this experiment.

### 4.2 Setting

Fig. 3 (a) illustrates the experimental setup, and (b) shows a sample scene of the experiment. A human partner was seated at a table facing the robot simulation displayed on a computer monitor. The window for the simulation was enlarged to fill the screen so that the partners could get the impression of the embodied robot with a monitor head. A FireWire camera for the robot's vision was placed on the monitor. No other sensors or actuators, e.g., microphone or speaker, were used, meaning the robot could respond only visually but not by other modalities. Another camera beside the monitor videotaped the interaction between the robot reflected on a mirror and a partner, which was used for the later analysis.




(a) Top-view of the experimental environment.



(b) A scene of the videotaped HRI, in which the robot is reflected on the mirror.

**Fig. 3.** Experimental setup for HRI

### 4.3 Procedure

The human partners were asked to teach some tasks, e.g., stacking cups, serving tee, and sweeping on the table, to the robot by using prepared objects. They were allowed to choose the objects and to decide what to and how to teach with them. Nothing about the usage of their gesture or speech was instructed. That is, they could use all their communication channels if they wanted although they were told of the robot's capability, i.e., it could perceive and respond only visually, beforehand. The mechanism of the robot's visual attention was not explained to them.

The interaction with the robot went on for five to more than thirty minutes depending on the partner. Over the interaction, the disturbing object was presented in the robot's vision three to thirty times at a maximum. The timing to insert and to remove the disturbance was decided by an experimenter responding to the partner's reaction. In other words, the partner's efforts to reattract the robot's attention did not directly but indirectly effected it although they could not realize that the experimenter was controlling the disturbance.

### 4.4 Sociological Analysis

Qualitative sociological methodology helps to identify concrete human behavior and social interaction in a contextual setting [24]. It seeks to describe the underlying social patterns which occur as concrete phenomena in the real world. The resource for this method is data taken from everyday phenomena like dialogs. Here communication patterns can be studied and framed. In this experiment we make use of ethnomethodological conversation analysis to investigate the video data of the HRI.

Conversation analysis is a qualitative method to evaluate the speech and action processes of individuals in a continuous interaction situation [10]. This close grained analytical technique starts with describing prominent elements from the empirical data. With the categorization of action patterns, the interaction structure can be revealed.

The goal of the sociological reasoning in our HRI experiment is to evaluate the interactive potential of irritation. The disturbance of the robot becomes part of the interaction system, meaning it causes irritation in the human partners that leads to a change in their behavior.

## 5 Results of People's Responses to Robot's Disturbance

The human partners were showing different strategies concerning eye-contact in the interaction. Some of them mostly concentrated on their own actions and thus inspected the robot's gaze immediately after having fulfilled a task. Others checked the robot's attention during the activity. When they recognized extraordinary changes in the robot's gaze behavior, all of them got irritated and swerved their task. By ascertaining a differentiated set of actions in case of disturbance, we searched for specific features in the human behavior. Here we focused on aspects that occurred during the interactions affected by the disturbance.

### 5.1 Categorization of People's Frequent Responses

Analyzing the individual performances, we found a set of main strategies over all human participants in the experiment. People were directed toward the robot and attended to evaluate the cause of its behavior. Summing these observations, we propose a map shown in Fig. 4, which is locating categories of the people's responses caused by the robot's disturbance. We have five categories scaled on two axes: the physical and psychological distance to the robot and the implied change in the subjects' activity, strong enough to recover the relationship in the ongoing HRI.

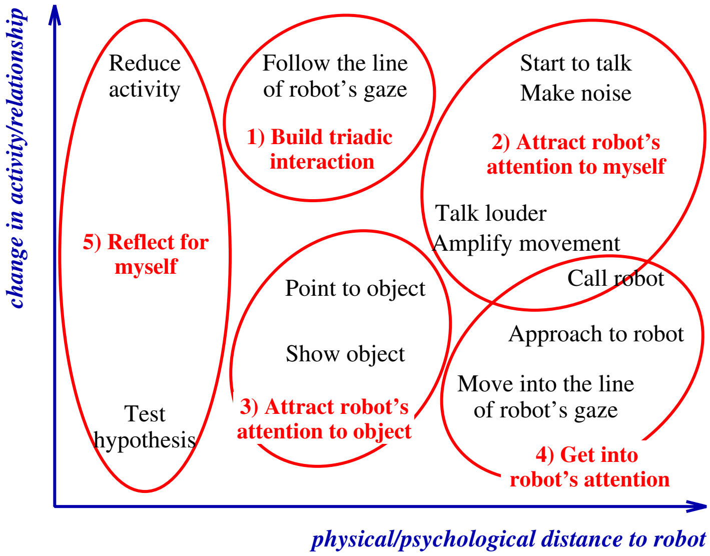


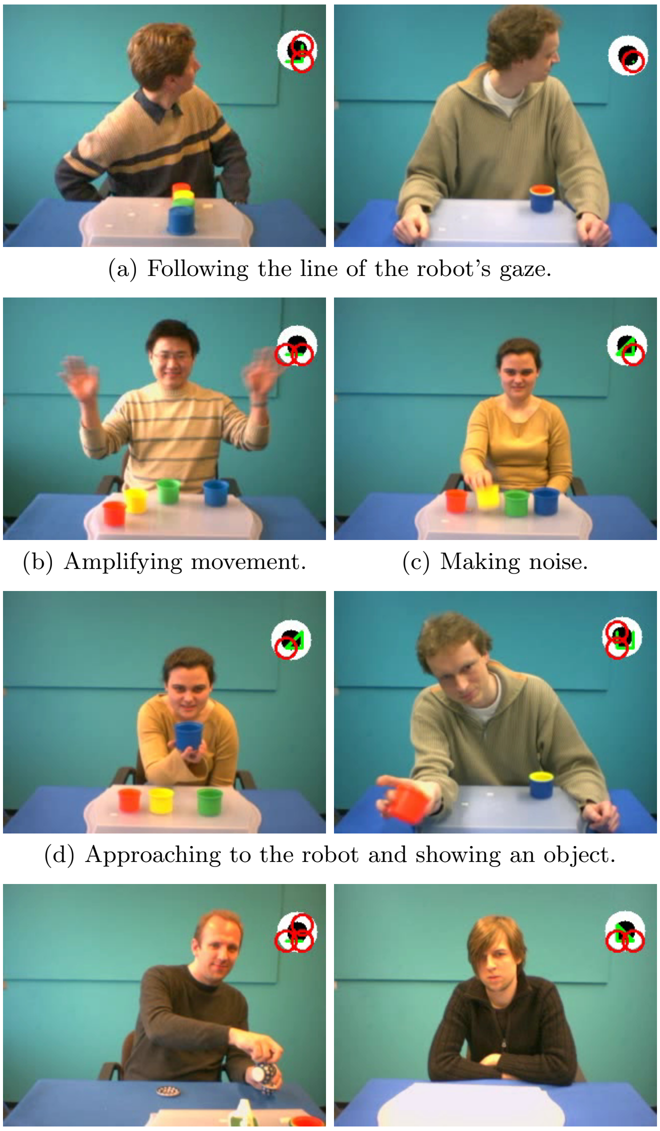

**Fig. 4.** People's responses to the robot's disturbance. Five categories are created on a two-dimensional map with reference to the physical/psychological distance to the robot and the change in the activity/relationship.

**(1) Building triadic interaction:** While interacting with the robot, some participants followed the line of the robot's gaze and tried to achieve joint attention when the robot had been disturbed (see Fig. 5 (a)). At the same time, they often commented verbally on the expected direction of the robot's gaze, although there would not be anything to discover. This reaction shows situated involvement. That is, a human partner follows the robot's action and attributes a participant's role to it. This phenomenon marks the evolvement of a triadic interaction, which includes the surrounding context.

**(2) Attracting the robot's attention to oneself:** The next category represents a huge variety in the reactive intensity. The human partners began exaggerating their already performed actions. They enlarged their gestures and movement (see Fig. 5 (b)). Others called the robot, just started to talk to the robot or made noise, even though they already had tested the robot would not react to acoustic signals (see Fig. 5 (c)). They seemed to try to attract the robot's attention to themselves.

**(3) Attracting the robot's attention to an object:** The third category assembles strategies that could possibly attire the robot's attention back to the object, i.e., getting closer to the robot while demonstrating the object (see Fig. 5 (d)). The object had been shaken or closely presented to the robot. Some people also pointed to the object to re-attract the robot's gaze.

**(4) Getting into the robot's attention:** Reaching closer to the robot builds the fourth category of action. Here we sum movements like a physical approach



(a) Following the line of the robot's gaze.

(b) Amplifying movement.

(c) Making noise.

(d) Approaching to the robot and showing an object.

(e) Moving into the line of the robot's gaze.

(f) Reducing his activity and testing his hypothesis.

**Fig. 5.** Sample scenes of the people's responses caused by the disturbance

of the partners to the robot. Some of them even spatially moved into the line of the robot's gaze (see Fig. 5 (e)). As a consequence, they became more present to the robot and decreased the psychological distance to it.

**(5) Reflecting to oneself:** The fifth category assembles the biggest and smallest change in the human activity compared to their former way of action toward the robot. Some of them tested their hypothesis on the robot's functions by increasing and others by reducing the intensity of their activity (see Fig. 5 (f)). This included the sequential variation of their former applied action patterns toward the robot.

In this experiment, humans performed social actions toward the robot. Depending on the complexity of the interaction and its direction, we consider three groups of observed behavior: a triadic interaction (category 1), a dyadic one (categories 2 to 4), and other (category 5), in which people did not direct interactive utterances but rather went along with inner reflections.

### 5.2 Diversity of People's Responses

As expected, people interacting with the robot, which was attracted by an emerging disturbance, showed an immediate change in their behavior when they realized the interaction had been affected. Some reactions like little smiles and very brief frowns came up slightly and were presumably unconscious. Therefore only the most common reactions of the human partners have been listed and classified.

We observed the tendency to repair the situated disorder. Our findings prove that human action is likely to be varied in case the expected results are not relieved. The concrete reactions demonstrate a renewed conceptualization of the situation and the modification of the human hypothesis on the robot's functions, which reminds of recipient design in HHI, which also allows to flexibly change the expectations. All of these strategies tend to refresh and repair the irritated flow of communication. After the appearance of a disturbance, the completion of the primordial task often has been abandoned. In these cases the communicative process was reestablished and the interaction was mostly even intensified.

## 6 Discussions

### 6.1 Constructing Communicative Spaces in Interactions

Each interaction in this HRI experiment opened a new communicative space. Both the robot and the human partner contributed to it. In oder to evaluate the impact of situatedness and social dynamics, individual differences should be taken into account. The usage of action, speech, and interpretation as well as their relevance to the interactions became evident. The human partners used social repairing mechanisms known in sociological conversation analysis. One effect of the disturbance is the encouragement of gestures and utterances. The robot's distraction motivated the partners to reveal strategies to regain its attention and to recover a turn-taking process. This phenomenon can also be observed in participants in HHI. People use the turn-taking to exchange the information efficiently and also apply repair mechanisms to vanquish distractions.

We could also find differences in the proactive engagement of the humans. Their interaction strategies seem to vary corresponding to their familiarity with robot systems. As people applied recipient design, they introduce background knowledge and projections derived from the expectations to the actual interaction. If the participants take their background knowledge into account, we need to find which specific knowledge they bring in. In our experiment, for example, people studying computer science showed a systematic behavior to test what could have caused the mistake in the interaction. Our evaluation demands further investigations concerning the variety of the interactive behavior influenced by the background knowledge of humans.

Although we did not develop an embodied robot, our robot simulation has been treated as an interaction partner, which is sharing the same spatial situation. This observation corresponds to the discussion given by Kidd and Breazeal [25]. They compared interactions with either a physically present robot or its presentation on a screen, and could not find a significant difference in the participants' responses. However they presented a real robot, not simulation, in both cases. These findings allow us to summarize that although embodiment is important, it is not the only factor which influences the success of an HRI.

### 6.2 Potential of Robot's Primal Visual Attention in HRI

In developing our communication robot, we introduced the primal attention mechanism based on saliency for the robot's vision. A more common approach to the design of social robots is to apply specific capabilities to detect human features, e.g., a face, a body, and skin color, to their vision systems. Such mechanisms usually function well under well-defined conditions, however, they often face problems in unexpected situations and even in presupposed ones. A reason is that applying top-down knowledge develops the frame problem. In contrast, our robot was not embedded with any task-specific or situation-specific capabilities but instead used a fully bottom-up model to interact with humans. The qualitative analysis of the videotaped input image shown in Fig. 1 (a) revealed that the robot had been looking at likely important locations in the interactions. The robot, for example, gazed at an object when a human partner was handling it, and sometimes shifted its attention to the partner's face, which looked as if the robot tried to check the ongoing interaction. We will further analyze how valuable locations can be attended to by the model.

The attention behavior of the robot also gave the impression of a proactive and infant-like agent to the partners. When the robot was distracted by a visual disturbance, some human partners tried to follow the line of its gaze in order to achieve joint attention (see Fig. 5 (a)). Joint attention [26] is a basis of triadic interaction, which expands the communicative space between the robot and a human partner to the third party. Compared to the former studies (e.g., [27, 28, 29]), in which a robot was able to only follow the human gaze, our robot could take the initiative of joint attention. It indicates that our robot was allowed to proactively explore the communicative space, which is considered as an important capability for a social robot. Another valuable finding is that the human partners modified their task-demonstrating actions when they realized the robot's distracted attention. They, for example, exaggerated actions by

(a) iCat, a desktop robot developed by Philips Research.

(b) BARTHOC, an anthropomorphic robot.

**Fig. 6.** Examples of embodied communication robots

making the movement larger and closely showing objects, which are also observed in parental actions toward infants [30]. The phenomena are moreover suggested to help robots as well as infants to learn the actions [31, 23]. Nagai and Rohlfing [23] have showed that the same attention mechanism as used for our robot can take advantage of parental infant-directed action in robot's action learning. We intend to further investigate how the robot's attention behavior influences the action demonstration of human partners.

## 7 Conclusion and Future Issues

In designing communicative robots, we can profit from knowledge of HHI. Therefore the focus of this experiment has been a common issue in human communication, i.e., the disturbance. We confronted human partners with a communication robot which was not always attentive but diverted, and collected their reactions to it. The results can be a outlined positive: even if the robot was equipped only with a simple attention mechanism, it enabled the partners to treat it as a social partner. They used additional communication channels and increased their utterances to restore the dialog. The effects caused by disturbance reinforced some human partners to help the robot to presume the meaning and the intention of their actions.

For investigating the impact of embodiment, we propose a direct comparison with other robots. Fig. 6 presents two examples: the pet-like iCat and the anthropomorphic BARTHOC. Both robot systems could be equipped with the same attention mechanism and comparative studies could be driven. We suppose a direct comparison would reveal multiple effects.

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