

A Computational Model of Graded Cueing: Robots Encouraging Behavior Change

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Abstract. This work presents a model of the occupational therapy technique of *graded cueing* for teaching and practicing desirable health and social behaviors adapted for use in socially assistive human-machine interaction. Graded cueing is represented as a probabilistic model of first prompt choice based on the perceived user ability level. The model is used to increase imitation proficiency of children with autism spectrum disorders through a “Copy Cat” imitation game.

1 Introduction

Socially assistive robots have the potential to augment therapy and rehabilitation by providing personalized care at any time and for as long as is needed. Studies are beginning to show how robots can invoke behavior change in humans over long-term interactions (e.g., [9]). In this work, we model the occupational therapy technique of *graded cueing* to provide a general framework for teaching and practicing desirable health and social behaviors over many human-machine interactions. The potential benefit of our approach to long-term interaction is the ability to adapt to and affect the user’s behavior over time.

Graded cueing is a process of behavior shaping that uses increasingly specific cues, or prompts, to help improve people’s skills at everyday tasks during recuperative therapy [2]. It is used in treatments for individuals who have lost skills, such as through a brain injury, or need to learn new skills, such as social skills of individuals with autism spectrum disorders (ASD). In graded cueing, the therapist asks the patient to perform a task, then prompts the patient with increasing specificity based on how much the patient struggles with the task. The goal is to increase both patient task performance and autonomy in performing the task, through minimal therapist intervention.

Our graded cueing framework is instantiated in a “Copy Cat” imitation game played between a NAO robot and a child with ASD. Our work is motivated by the evidence that children with ASD are often behind in their development of imitative behavior [11], and that practicing through repeated interactions with a therapist can improve imitation abilities [13]. Our model approximates those effect with a socially assistive robot in order to use technology to broaden access to ASD therapy.

2 Related Work

Our approach uses a probabilistic graphical model of graded cueing capable of adapting a socially assistive robot's behavior along with the changes of the user's performance over time. Probabilistic graphical models have been shown to be effective tools for representation in human-centric domains such as assistive technologies [7], including nurse robots [15] and autonomous wheelchairs [14]. Research has also addressed learning of parameters over these models through human interaction [15, 1, 10], allowing for their use in human-robot interaction (HRI) domains.

Robots are good candidates for ASD therapy because of their apparent appeal to some children with ASD, and their ability to provide predictable, concrete feedback. Larson found that children with ASD prefer concrete feedback such as lights, colors, and sounds, which can be measured and quantified [12]. Ingersoll reported that multi-modal feedback is more effective than any single feedback alone [8]. Thus, the NAO robot in our study uses lights, colors, and sounds as feedback modalities to indicate to the children how well they are imitating. The NAO has previously been used in a study where a child with ASD imitates a robot, but the focus was modeling human motion rather than affecting child imitation behavior [6]. Although our initial study utilizes the NAO for interaction with the children, the framework is not dependent on a specific platform or user population.

Various robots have previously been used to shape child behavior [16, 3, 5]. Robins et al. [16] found that four children with ASD imitated a doll-like robotic toy, often without any initial prompting; they attributed this to the robot's "simpler" physical appearance. Duquette et al. [3] found that a humanoid robot elicited more shared attention between two children with ASD than a human mediator. Ferrari et al. [5] presented the IROMEC robot as a social mediator in interactive play between a child with ASD and a parent, teacher or therapist. Our work extends previous work by Feil-Seifer and Matarić, which introduced the use of graded cueing applied to socially assistive robots interacting with children with ASD [4]. There, graded cueing was implemented as a finite state machine in the context of a Simon Says imitation game of arm postures.

3 Methods

Tasks amenable to graded cueing are characterized by their ability to be broken down into discrete steps. The simplest tasks consist of a single step, while more complex tasks may require a long series of steps. For each step of the task, there is a series of increasingly specific prompts that provide the therapy patient assistance with that particular step. The prompts are meant to be tailored to the patient's specific abilities in the given task, so that the process is neither frustrating nor patronizing. In computational terms, the therapist seeks to minimize the number and specificity of prompts while maximizing patient progress.

The Model. This work aims to contribute a general framework for graded cueing, based on a probabilistic model of prompt choice. The model consists of N states, one for each level of the user’s task ability. Higher levels of ability are associated with increased prompt specificity. For example, specificity level 4 would be the best action for ability level 4. An $N+1$ state (P_0) represents the success state. The goal of our model is to select the *first* prompt to give to the user depending on the user’s ability level. From that initial prompt, any subsequent prompt required is the next most specific prompt. An example of this model for four levels of prompt specificity is shown in Figure 2. During execution, the robot uses the child’s responses to maintain a distribution over the ability level, and then to select appropriate actions based on a policy calculated over the model. To compensate for few available data points that are typical of HRI contexts, the probabilistic model must be able to adapt quickly to the changing user state. To achieve this rapid adaptation, we use a Bayesian approach, wherein the model maintains a distribution over the states, updates based on the responses, and selects actions by sampling from the distribution.

The Application. The above-described probabilistic representation of graded cueing is implemented in a “Copy Cat” imitation game played between a NAO robot and a child with ASD. In the game, the robot poses its arms and asks the child to copy its pose. If the child successfully copies the robot’s pose, the robot gives positive verbal feedback, nods, and flashes its eyes green. If the child does not successfully copy the robot’s pose, the robot gives a starting prompt as determined by the model. During the first interaction, the starting prompt specificity is P_1 , but for each subsequent round of interactions over the entire study, the starting prompt is determined by the model. From there, if the child requires further prompting, the robot moves up within four levels of prompt specificity in this particular implementation, corresponding to the following five states:

- P0.** no prompts are given (success)
- P1.** words (“Are you sure?”)
- P2.** words + gesture (“Look again at your left arm.” + arm movement)
- P3.** specific words + gesture (“Bend your right arm.” + arm movement)
- P4.** specific words + specific gesture (“You look like this.” + imitation of child)

Fig. 1. The five states that dictate the actions of the robot based on the perceived imitation ability of the child. The verbal prompts were designed by an ASD therapist.

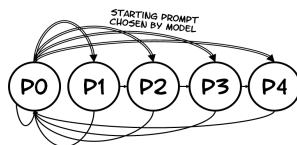


Fig. 2. The graded cueing implementation of the model. The double lines represent the starting prompt chosen by the model.

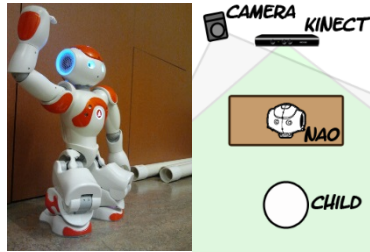


Fig. 3. The NAO during the imitation game (left) and the experimental setup (right)

The Pilot Study. A pilot study is being conducted to validate the described model with children with ASD at a local elementary school. The expected sample size is 12 participants, drawn from an ASD-only class of students between the ages of 7 and 10. The participants are split into two groups: one receives graded cueing feedback from the robot, the other (control group) receives constant feedback, P4, from the robot in each round. The constant-P4 condition represents a lack of cueing, which is expected to result in a lack of generalization of the imitation skills learned by the child despite descriptive feedback. The study is being conducted over 2.5 weeks, with each child receiving two fifteen-minute interactive play sessions with the robot per week.

The experimental setup, shown in Figure 3, above, consists of the NAO robot placed on a table in front of the seated child so that it is approximately at the child's eye-level. Behind the robot, a Microsoft Kinect is used for sensing the child's pose. A teacher or aide may also be in the room for comfort or safety. The teacher or aide does not interact with the child during the experiment, but may assist the child during setup or after the experiment. The relevant outcome measure of the study is the increase in the child's imitation ability. This measure will be evaluated both within and between sessions. No statistical significance is necessarily expected given the small size of the pilot study, but trends in the outcome measure are expected. Specifically, we expect an increase in the average correctness of the child's pose, measured as a decrease of the child's deviation from the robot's pose, a decrease in the level of prompt specificity the child needs for successful imitation of the robot, and a decrease in the number of prompts the child needs for successful imitation of the robot.

4 Future Work

At the time of this submission, the pilot study of the effectiveness of the presented model is near completion. Improvements of the model will be based on the insights gained from the study results.

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