

Challenges in Building Robots That Imitate People

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X.1 Introduction

Humans (and some other animals) acquire new skills socially through direct tutelage, observational conditioning, goal emulation, imitation, and other methods (Galef, 1988; Hauser, 1996). These social learning skills provide a powerful mechanism for an observer to acquire behaviors and knowledge from a skilled individual (the model). In particular, imitation is an extremely powerful mechanism for social learning which has received a great deal of interest from researchers in the fields of animal behavior and child development.

Similarly, social interaction can be a powerful way for transferring important skills, tasks, and information to a robot. A socially competent robot could take advantage of the same sorts of social learning and teaching scenarios that humans readily use. From an engineering perspective, a robot that could imitate the actions of a human would provide a simple and effective means for the human to specify a task to the robot and for the robot to acquire new skills without any additional programming. From a computer science perspective, imitation provides a means for biasing interaction and constraining the search space for learning. From a developmental psychology perspective, building systems that learn through imitation allows us to investigate a minimal set of competencies necessary for social learning. We can further speculate that constructing an artificial system may provide useful information about the nature of imitative skills in humans (or other animals).

Initial studies of social learning in robotics focused on allowing one robot to follow a second robot using simple perception (proximity and infrared sensors) through mazes (Hayes & Demiris, 1994) or an unknown landscape (Dautenhahn, 1995). Other work in social learning for autonomous robots addressed learning inter-personal communication protocols between similar robots (Steels, 1996), and between robots with similar morphology but which differ in scale (Billard & Dautenhahn, 1998). Robotics research has also focused on how sequences of known behaviors can be chained together based on input from a model. Mataric, Williamson, Demiris & Mohan (1998) used a simulated humanoid to learn a sequence of gestures from a set of joint angles recorded from a human performing those same gestures, and Gaussier, Moga, Banquet, and Quoy (1998) used a neural network architecture to allow a robot to sequence motor primitives in order to follow the trajectory of a teacher robot. One research program has addressed how perceptual states can be categorized by matching against models of known behaviors; Demiris and Hayes (1999) implemented an architecture for the imitation of movement on a simulated humanoid by predictively matching observed sequences to known behaviors. Finally, a variety of research programs have aimed at training robots to perform single tasks by observing a human demonstrator. Schaal (1997) used a robot arm to learn a pendulum balancing task from constrained visual feedback, and Kuniyoshi, Inaba, and Inoue (1994) discussed a methodology for allowing a robot in a highly constrained environment to replicate a block stacking task performed by a human but in a different part of the workspace.

Traditionally in robot social learning, the model is indifferent to the attempts of the observer to imitate it. In general, learning in adversarial or indifferent conditions is a very difficult problem that requires the observer to decide who to imitate, what to imitate, how to imitate, and when imitation is successful. To make the problem tractable in an indifferent environment, researchers have vastly simplified one or more aspects of the environment and the behaviors of the observer and the model. Many have simplified the problem by using only simple perceptions which are matched to relevant aspects of the task, such as Kuniyoshi, Inaba, and Inoue's (1994) use of white objects on a black background without any distractors or Mataric, Williamson, Demiris, and Mohan's (1998) placement of reflective markers on the human's joints and use of multiple calibrated infrared cameras. Others have assumed the presence of a single model which is always detectable in the scene and which is always performing the task that the observer is programmed to learn, such as Gaussier, Moga, Banquet, and Quoy (1998), and Schaal (1997). Many have simplified the problem of action selection by having limited observable behaviors and limited responses (such as Steels (1996) and Demiris and Hayes (1999)), by assuming that it is always an appropriate time and place to imitate (such as Dautenhahn (1995)), and by fixing the mapping between observed behaviors and response actions (such as Billard & Dautenhahn (1998)). Few have addressed the issue of evaluating the success of an imitative response; most systems use a single, fixed success criteria which can only be used to learn a strictly specified task with no hope for error recovery (although see Nehaniv and Dautenhahn (1998) for one treatment of evaluation and body mapping).