A Developmental Roadmap for Learning by Imitation in Robots

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There is a growing research effort for designing ``robot companions'' able to interact with people in a friendly way, over extended periods of time. This is a challenging endeavour for two main reasons: (i) the need to work in highly unpredictable and uncertain environments, designed for people instead of robots and (ii) the variety of the tasks to execute and the interaction with (non-technical) people over long periods of time. These problems are addressed in this thesis using the paradigms of imitation and artificial development.

With the metaphor of imitation, one could ``program'' a humanoid-type robot to solve a certain task simply by demonstration and have the robot imitating the task later on, avoiding the user having to write sophisticated computer programs.

Although imitation is a learning mechanism massively used by human infants, it is not an easy problem. Inspired after developmental psychology, we present a developmental pathway for the robot to progressively acquire the skills necessary to imitate observed actions: (i) explore its own sensory-motor capabilities, (ii) understand its surrounding environment, (iii) become aware of people acting in the environment.

The first developmental level is devoted to sensory-motor coordination, during which the robot learns how to control its own body. Sensory-motor maps allow the robot to predict the sensory consequences of a certain action (forward model) as well as to determine the motor action necessary to produce a given effect in the world (inverse model). We present a variety of sensory-motor maps that are learned during periods of auto-observation.

In the second developmental level, the robot is attracted toward objects. It learns how to grasp them and explore their properties, based on the sensory-motor maps learned previously. In addition, the robot learns how to recognize grasp actions performed by others, an approach based on the recent findings of the mirror neurons in the pre-motor cortex of macaque monkeys.

In the last stage of development, the robot engages (to some extent) in social interaction. Its attention is drawn toward people and the robot learns how to imitate the tasks performed by a demonstrator. For that purpose, it solves the view-point transformation problem to account for the different coordinate frames of the demonstrator and its own body, chooses among different metrics giving different imitation behaviours and solves the body correspondence problem.

Experiments have been conducted with Baltazar, an anthropomorphic robot combining a binocular head and an articulated arm and hand.

Keywords: imitation learning, artificial development, humanoid robotics, human-robot interaction, vision, machine learning