Development of imitation in a humanoid robot

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The Problem: It is believed that one of the distinguishing skills of *homo sapiens sapiens* is that of learning from imitation while it is less clear whether other primates are capable of true imitation. Imitation encompasses a set of different competences such as recognizing other people's actions, recognizing the goal of a particular action and the objects and / or subjects involved. This project attempts to implement a similar set of abilities in a humanoid robot following a biologically motivated perspective.

Motivation and biological basis: Our inspiration comes from one of the most fascinating discovery of the neurophysiology of the last decade: that is *mirror neurons*. This is a class of neurons found in the monkey's frontal cortex (area F5). A particular mirror neuron is activated both when the monkey executes an action and when it observes the same action performed by somebody else: hence the name *mirror*. The importance of the discovery lies in the possibility to relate mirror neurons to gesture recognition, language, and learning by imitation. Grossly simplifying, it is believed (see also [1]) that mirror neurons evolved from a phylogenetically older system used by the brain to control the interaction between hand and graspable objects. We suggest that a similar process, during ontogenesis, might also explain how the brain develops to endow a "mirror representation". During a first stage the understanding of object properties is connected to the growing motor repertoire (e.g. precision grip, full palm grasp, etc). This leads to a pragmatic description of objects in the spirit of the Gibsonian concept of affordances. Successively, in a second stage, the understanding is extended to include the observation of somebody else's actions: i.e. how a foreign manipulator acts onto a particular known object. Also, we hope that by building a biologically plausible model of this process we can advance the understanding of how similar processes are "implemented" in the brain.

Previous Work: The neurophysiology of the mirror neurons has been mainly investigated by Rizzolatti et al. [2] and Arbib et al. [5]. More recent results provided evidences for the existence of a mirror system in humans [4]. In robotics there has been a lot of interest about the problem of learning by imitation [3]. Indeed, it is appealing to imagine a robot that learns a new and possibly complicated task simply by observing a human demonstrating it. Some researchers explicitly proposed mirror neurons as the basis of their implementation (for example [6]) although the goal was that of providing the implementation *per se* rather than that of getting a biologically plausible model. The process of learning or developing the mirror system was not explicitly considered. Oztop and Arbib [1] proposed a very detailed model of the functioning of mirror neurons but their results were mostly obtained in a simulated environment rather than on a real robot.

Approach: Our approach is based on real manipulation where we expect the robot to interact freely with humans and objects, and to learn during continuous interaction with the environment. The experimental setup is the humanoid robot COG (see figure 1). We employed poking and prodding [7] as a first and simpler step towards full-blown manipulation. The robot interacts with a small set of objects with different physical properties with respect to pushing. For example, objects can roll along a preferred direction and move a long way (think of a toy car) or simply slide along when pushed and come to a quick stop (think of a stuffed animal). In a first set of experiments we showed how the robot was able to learn (statistically) about this limited set of objects and poke them appropriately if they were presented again. Also, we demonstrated goal-directed mimicry behavior. In the latter, the robot poked an object so to imitate the "type of poking" previously executed by a human. These experiments were developed on top of a general attentional mechanism, tracking, and reaching skills.

Impact: Of course, if fully successful the project might have an impact on how robots are currently programmed (i.e. thousands of lines of code). The mirror neurons, however, are only a part of the story because the robot should be able not only to imitate but also to adapt imitation to the ongoing task as well as to extend it to similar situations. On the other hand, the humanoid robot might become a testbed for cognitive theories of imitation and learning. Whether this will be feasible depends on how close the model will take into account the existing biological evidence, the level of detail, etc.

Future Work: Clearly, this is work in progress; the next step will be that of improving the individual components of the architecture to get better performance when more objects and actions are allowed.

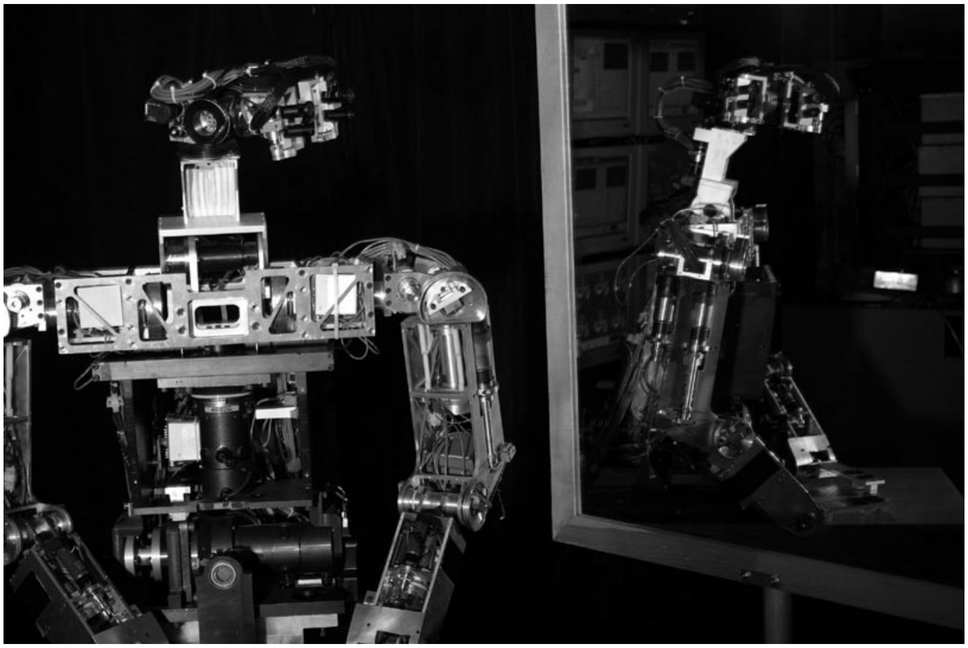

Figure 1: The experimental setup - COG

Possible extensions of this work might include better manipulation (e.g. grasping rather than poking) and the automatic acquisition of new tasks thus effectively extending the robot's repertoire automatically.

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References:

[1] Oztop E. and Arbib M.A. Schema design and implementation of the grasp-related mirror neuron system. *Biological Cybernetics*, 87:116–140, 2002.

[2] Rizzolatti G., Fadiga L., Gallese V., and Fogassi L. Premotor cortex and the recognition of motor actions. *Cognitive Brain Research*, pages 131–141, 1996.

[3] Miyamoto H., Schaal S., Gomi H., Koike Y., Osu R., Nakano E., Wada Y., and Kawato M. A kendame learning robot based on bi-directional theory. *Neural Networks*, 9:1281–1302, 2000.

[4] Fadiga L., Fogassi L., Gallese V., and Rizzolatti G. Visuomotor neurons: ambiguity of the discharge of motor perception? *International Journal of Psychophysiology*, 35:165–177, 2000.

[5] Arbib M.A., Billard A., Iacoboni M., and Oztop E. Synthetic brain imaging: grasping, mirror neurons and imitation. *Neural Networks*, pages 975–997, 2000.

[6] Mataric M.J. Getting humanoids to move and imitate. *IEEE Intelligent Systems*, pages 18–24, 2000.

[7] Fitzpatrick P. and Metta G. Towards manipulation-driven vision. In *IEEE/RJS International Conference of Intelligent Robots and Systems (IROS)*, October 2002.