Modeling the development of human body representations

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Abstract

In this paper, we describe the setup in which we use the iCub robot to model the development of a body schema in infants through a self-touch behavior. Based on this scenario, we discuss several conceptual questions regarding the utility and limitations of robots as models of biological phenomena. In particular, we discuss (i) the role of the morphology, including the type and quantity of sensory receptors; (ii) the choice of abstraction levels and the constraints imposed by a robotic model; (iii) the issue of finding correspondences on the level of internal mechanisms as well as whole behaviors. In this regard, the strengths and weaknesses of a robotic model are summarized.

1 Introduction

In order to achieve a variety of goals, humans and animals seamlessly command their highly complex bodies in space, and concurrently integrate multimodal sensory information. In pursuance of this, it seems that a model or representation of the body and the surrounding space is necessary. In this regard, the concepts of *Body Schema ('BS')* and *PeriPersonal Space Representation ('PPSR')* have been proposed (e.g. [1]). These representations are intimately coupled and play a crucial role in building up perception and motion in nearby space. However, despite a growing number of studies, a coherent understanding of the key mechanisms is missing [2]. Furthermore, computational models are scarce and address at the most isolated subsystems. Even less is known about the development of BS and PPSR. One possible mechanism that can lead to learning its own body is self-stimulation or *self-touch* [3].

Robots may provide a path toward more complete and operational models of BS and PPSR development (cf. [4] for a review, and [5] for one example). Taking inspiration from the self-touch hypothesis, we use the iCub humanoid robot in order to model the self-explorative behavior and subsequent learning of body representations. In this article, we will analyze the conceptual implications of this endeavour (the implementation has started only recently and no results will be reported here) and contribute to the the discussion whether robots can make good models of biological behavior (e.g., [6, 7]).

2 Body representations and self-touch in biology vs. robotics: seeking the common ground

Up to now, a first implementation of the self-touch behavior has been validated in simulation, and recently tested on the iCub (Fig. 1). This behavior is the first necessary step in our modeling effort, but still, it raises a number of issues, which will be detailed below.

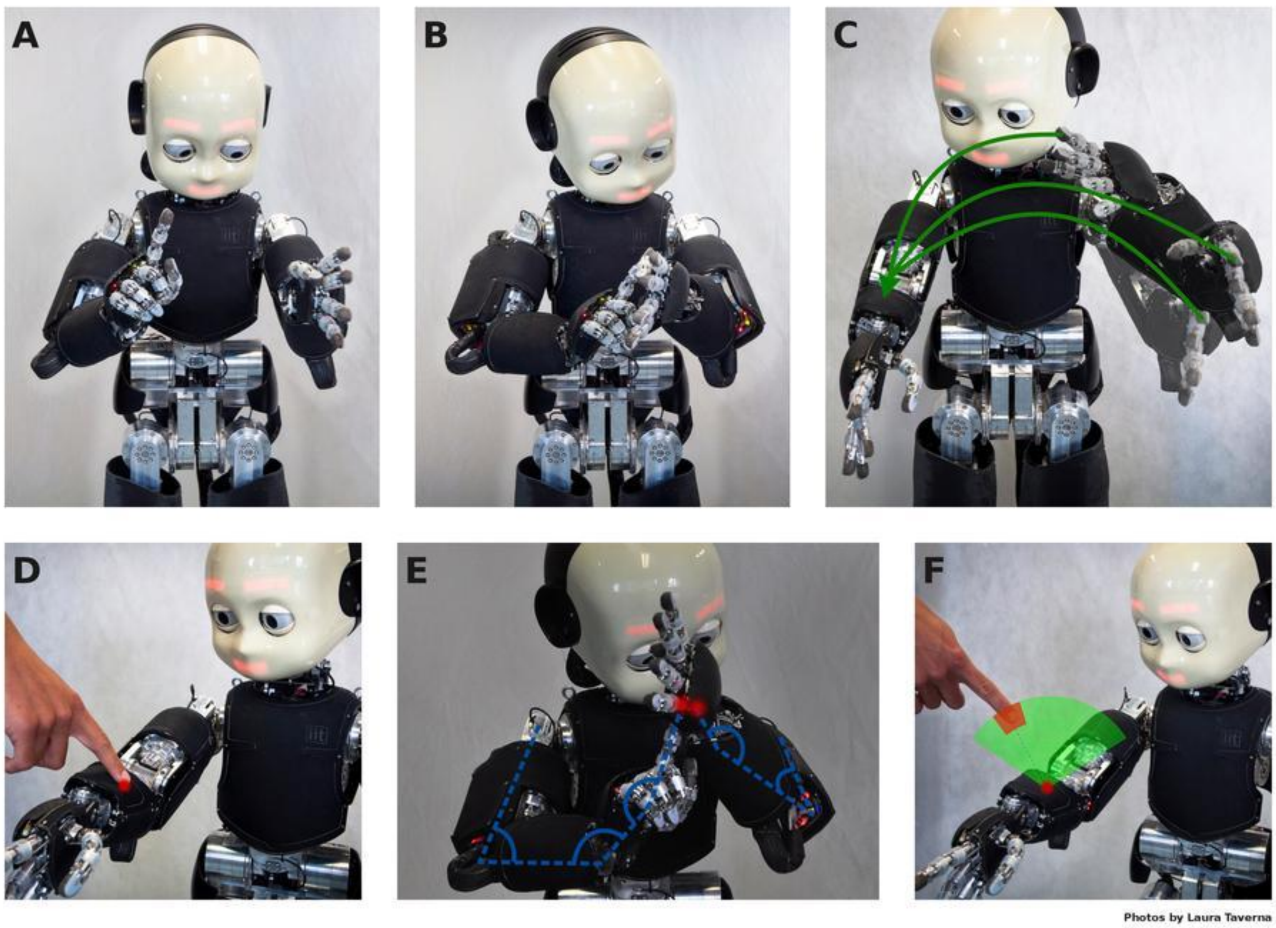

Figure 1: Self-touch behavior running on the iCub. **(A-B)** The robot receives stimulation on its skin and has to reach the stimulus with its index finger. **(C)** This behavior can be triggered from different initial configurations. **(D)** If touched by an external person or object, stimulation in the respective skin part is received. **(E)** Self-touch (or "double-touch") gives rise to tactile stimulation in two different regions (touching and touched) and occurs in specific kinematic configurations only. **(F)** After learning the association between the visual (as represented by optic flow, for example) and tactile modality, an approaching object leads to activation of respective tactile receptive fields prior to actual contact.

2.1 Levels of abstraction and a quest for correspondence

The implication of the embodied cognition stance (e.g. [8]) is that the body morphology as well as the motor and sensory apparatus matter for cognition. The iCub humanoid robot has an anthropomorphic morphology and a similar set of sensory modalities that humans have. Yet, at the same time, they are obviously not quite the same.

For example, BS and PPSR in humans rely heavily upon the information coming from the somatosensory system. It is a heterogeneous sensory complex whose receptors are densely distributed in the body and deliver local information about the environment ("sense of touch") and the internal configuration of the body (proprioception). There are roughly 5 million receptors in the skin only. On the iCub, on the other hand, we have 2000 tactile receptors that deliver only pressure information. In addition, we have access to joint angle information. The implication for our modeling effort thus is that we have to either make the assumption that the information types we are missing (e.g., temperature, pain, muscle stretch) are not important for a BS/PPSR, or, when examining the empirical data, we would have to try to look for subsystems that process only the information we have access to. Alternatively, these sensory modalities would have to be added or emulated on the robot.

Interestingly, apart from the level of internal mechanisms, we feel that considerable power of robotic models lies in the possibility of establishing correspondence on a behavioral level. In the first step of our scenario, we are seeking a comparison with recent behavioral studies on infants, where the precision of self-touch behavior (removal of stimulus from the body) is examined [9]. An almost identical experiment can be instantiated on the robot and the performance could be compared. Of course, no direct conclusions about the correspondence of internal mechanisms can be drawn, yet, a very quantitative initial benchmark is provided.

2.2 Strengths and weaknesses of a robotic model

The implementation of a model of human behavior on a robot surely adds a layer of complexity and specific constraints to the overall architecture. At the same time, it also brings a number of advantages. Hereafter, specific pros and cons are highlighted.

CONS:

• The design of the iCub has been guided by many other (technical) constraints than those that relate solely to mimicking a human infant as close as possible. There are major differences in the body morphology, actuation, as well as its sensorization.

• The "hardware-software" boundaries in biological systems are much more blurred than in a robot. Often, in a robot, there is a single, centralized representation that commands the hardware. Important "control" or "self-organizing" properties such as low-level reflexes and spinal control are typically absent in a robot. Thus, there is a strong tendency toward fewer and more high-level abstraction layers.

• Even a seemingly basic behavior, like self-touch, can turn out to be extremely difficult to achieve on a robot. Often, as a result of non-biological constraints.

• Robots are typically extremely fragile and long-term experiments are difficult.

PROS:

• Robots - as physical models - allow for modeling complete sensorimotor loops that have to prove themselves in the real world. All the components that are necessary thus need to be in place. Correspondence can then be established on different levels - internal mechanism or behavior.

• Synthetic models offer the possibility to exploit other validation criteria than comparing with the phenomenon that is modeled. This "alternative validation criterion" [10] is purely behavioral - a walking machine, for instance, needs to first walk, before we can start comparing with biology. It is an indirect and preliminary check, yet, it is crucial in the initial stages.

• When using a robot, one can have access to all internal as well as external variables. In addition, the conditions - even the body and the brain of the agent - can often be systematically manipulated.

3 Conclusions

Robots still have to prove themselves as useful tools in synthetic modeling. There are many difficulties, but, at the same time, great potential. In addition, they have one important advantage: in well-chosen problems, the robots often become useful artifacts and lead to the development of applications - demonstrating the full power of synthetic methodology.

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