The Development of Symbol Manipulation Capabilities in Children

Symbolic representations come in many different flavors: language, mathematics, logic, decision making, and others. The development of symbol manipulation capabilities in children such as productive language use is preceded by the establishment of a variety of both verbal and non-verbal communication routines with their caregivers. Such routines are grounded in multi-modal interaction practices that are temporally coordinated and contingent with the interlocutor’s feedback. E.g. Nomikou and Rohlfing [1] found that when speaking with their three month old infants, mothers vocalize in a tight temporal relationship with action over a considerable part of the overall interaction time, thereby making the vocal signal both perceptible and tangible to the infants. In later practices, adults use combination of pointing, showing and words to describe an action or an object and highlight its specific features [2]. The child acquires the symbolic meaning of these words and actions by a frequent observation of the parents and reception of their feedback in response to their own actions [3].

We present here two experiments that make use of the same embodied robotic approach to model different aspects of relations between symbolic and motor knowledge.

Experiment 1: Toward the Grounding of Abstract Words

Development of Symbolic and Linguistic Skills through the Grounding in Sensorimotor Experiences

We propose a model based on Artificial Neural Networks (ANNs) for symbol manipulation that provides a useful tool for investigating and testing embodied theories of language learning [4]. Experiments, taking inspiration from the model proposed by Cangelosi and Riga [5], have been developed on a software environment for the iCub robot.

Cognitive robots have been successfully used for learning concrete concepts.

**AIM:** to extend the symbol grounding mechanism to abstract words for a humanoid robotic platform.

**MODEL:** The training of the robot consists of three incremental stages (fig.2):

1. **Basic Grounding** (BG) stage: the robot learns to perform a set of basic action primitives and their corresponding names (e.g. “GRASP”, “STOP”, “SMILE”);
2. **Higher-order Grounding** 1 (HG1) stage: the robot, via linguistic description, acquires higher-order words combining basic action primitives (e.g. “KEEP” [is] “GRASP” [and] “STOP”);
3. **Higher-order Grounding** 2 (HG2) stage: the robot learns high-level behaviors through the combination of action primitives and higher-order words (e.g. “ACCEPT” [is] “KEEP” [and] “SMILE” [and] “STOP”).

**RESULTS:** Results show that the iCub is able to gradually acquire abstract representations via combinations of directly grounded concrete words.

![Figure 2: Representation of the procedure that implements the grounding transfer mechanism.](image)

![Figure 3: Root Mean Square Error after the Basic Grounding training stage.](image)

![Figure 4: Execution of action primitives on the iCub: initial position (a), “MOVE_ARM_AWAY” (b), “CLOSE_HAND” (c), “OPEN_HAND” (d) and “MOVE_ARM_TOWARD” (e).](image)

Conclusions

The above studies demonstrate the potential of cognitive robotics models for understanding the development of abstract symbol representations. The simulations described in Experiment 1 show that higher-order symbolic representations and behaviors can be indirectly-grounded in basic action primitives directly-grounded in sensorimotor experience. Currently, this model is being extended to test other embodied cognition theories of language learning such as the Action-sentence Compatibility Effect [6]. The experiment 2 shows that interactions between symbolic and motor representations can be shaped by the environmental biases. This work will serve as a basis to understand the role of gesture in learning to count.

References