1. Overview

One new trend in robotics is the embodiment of higher order cognitive capabilities in humanoids (Fig.1).

This innovative approach aims to overcome current limitations in robots design. Given its multidisciplinary character, it requires competencies from many fields, ranging from computer science to robotics, cognitive science, development psychology and neuroscience.

The aim of this study is to establish how different behavioural and cognitive capabilities lead to the development of higher order skills such as language acquisition in humanoids.

2. Theoretical Background

Language capabilities are one of the most powerful tools of an agent for understanding situations and interacting with the environment.

Different approaches proposed in the field of language learning mainly focus on the idea that language is an independent and autonomous capability of agents (amodal symbol systems).

Nevertheless, according to the results of psychological experiments the development of linguistic skills requires different cognitive processes working together (perceptual symbol systems).

These robotic experiments focus on the acquisition of abstract concepts through the physical interaction with the environment, in order to investigate the relations between symbol manipulation and sensorimotor knowledge.

3. Open Questions and Proposed Architecture

AIM: To address the following open questions:

- How can robots use sensorimotor categories to indirectly ground abstract concepts?

- How can the symbol grounding mechanism be extended to generate and ground abstract categories?

SOFTWARE ARCHITECTURE (Fig.3): We propose a model based on Artificial Neural Networks (ANNs) for symbol manipulation. It provides a useful tool for investigating and testing embodied theories of language learning. Through the YARP middleware it is possible to exchange information between the user code and the simulated robot.

The execution of action primitives has been implemented using the Action Primitives Library of the iCub software repository.

4. Neurorobotics Model and Results

MODEL: The training of the network consists of three incremental stages (Fig.4):

- (i) Basic Grounding Stage: for the learning of a set of basic action primitives (e.g. “GRASP”, “STOP”, “SMILE”).

- (ii) Higher-order Grounding 1 Stage: for the acquisition of higher-order words by combining basic action primitives (e.g. “KEEP” [is] “GRASP” [and] “STOP”).

- (iii) Higher-order Grounding 2 Stage: for the learning of high-level behaviours through the combination of action primitives and higher-order words (e.g. “ACCEPT” [is] “KEEP” [and] “SMILE” [and] “STOP”).

RESULTS: The iCub is able to gradually acquire abstract representations via combinations of directly grounded concrete words.

5. Conclusion and Future Work

Simulations results show that higher-order symbolic representations can be indirectly grounded in action primitives directly grounded in sensorimotor experience. Future work will extend the proposed model in order to include in the network architecture both perceptual and sensorimotor inputs and to encode in output the motor responses of the robot. This approach aims to prove that the grounding of abstract words can be obtained as a consequence of sensorimotor experiences.