Body-Representations for Sensorimotor Coordination and Tool-Use

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Knowing the dimensions of the different parts of our body, their characteristics and their location in space is necessary for controlling our motor actions in an efficient way. Although a clear understanding of how such body representations are stored in our brain is still missing, it is reasonable to think that they undergo a continuous process of adaptation. They need to match not only growing corporal dimensions during development, but also temporary changes in the characteristics of the body, such as the morphological changes affected by the usage of tools [1]. Therefore, it is crucial to include the notion of plasticity in the concept of a body schema.

We investigate the formation of internal body representations through self-exploration in the humanoid robot Nao. As a preliminary experiment, we address the development of visuo-motor coordination [3]. Visuo-motor coordination seems to rely on processes that map spatial vision onto patterns of muscular contraction. In infants, such a skill improves over time starting from early stages of development, suggesting that there is a gradual formation of internal body representations modulated by physical interactions.

In this context, we propose a biologically inspired model for coding internal representations of sensorimotor experience that can be fed with data coming from different motor and sensory modalities. The model is inspired by the self-organising properties of areas in the human brain, whose topologies are structured by the information produced through the interaction of the individual with the external world. In our experiment, body representations consist of mappings between different modalities, formed through the physical interaction of the robot with its surrounding. In particular, Dynamic Self-Organising Maps (DSOMs) proposed by Rougier et al. [2] are adopted for modelling sensory and motor modalities. DSOMs allow on-line and continuous learning on both static and dynamic data distributions. Thus, a Hebbian paradigm was used for mapping the DSOMs. In a preliminary experiment the learning of visuo-motor coordination was studied; for this, two DSOMs were used for coding the proprioceptive information coming from the joint encoders of the arm and of the neck of a Nao robot simulated in the Webots environment. During random arm movement generation, arm and head postures were used for updating the corresponding DSOMs in an online fashion. The DSOMs were associated through Hebbian learning whenever the hand of the robot was visible in the visual input. Head movements were generated as outputs of the proposed model. We observed the robot gradually improve its visuo-motor coordination skills over time, starting from a random configuration where no knowledge about how to visually follow its arm movements was present. In addition, the capability of the proposed model to adapt to unexpected changes was tested. At a certain stage during the developmental timeline, a damage in the system was simulated by adding a perturbation to the motor command used for training the model, resulting in a translation of the original data distribution. Consequently, the performance of the visuo-motor coordination was affected by an initial degradation, followed by a new improvement as the model adapted to the new mapping.

Future experiments will include forming more complex body representations including additional sensory and motor maps in the model. In particular, we will test the adaptive capabilities of the model in the context of tool-use.

[1] Farnè A, Iriki A, Làdavas E (2005) Shaping multisensory action-space with tools: evidence from patients with cross-modal extinction. Neuropsychologia 43 (2):238-248
[2] Rougier N, Boniface Y (2011) Dynamic self-organising map, Neuro-comput. 74(11): 1840-1847
[3] Schillaci, G., Hafner, V.V., Lara, B. (2014), Online Learning of Visuo-Motor Coordination in a Humanoid Robot. A Biologically Inspired Model, 4th International Conference on Development and Learning and on Epigenetic Robotics (ICDL-EpiRob 2014), Genova, Italy.

Questions to the invited speakers (and to the audience in general):

- what are the mechanisms for online adaptation of body schema (on different time scales)?
- do we have conscious access to body schema?
- can body schemas be transferred, e.g. for imitation?
- how can we scale up the complexity of behaviours, from low-level sensorimotor schemes to higher cognitive processes?
- how far up can the tools and framework of embodied cognitive robotics shed light on the understanding of human cognition?

Our personal definition of the concept of body schema:

Body schema is a sensorimotor mapping learned by an agent throughout its experiencing the world. This schema is an adaptive model which copes with changes in the agent's body. It is necessary for building up the cognitive capabilities of an agent.