Convergence Divergence Zone Framework: extracting sensory-motor contingencies.

Abstract

Brains present the generic ability to associate co-occurring sensory-motor stimuli and to generate prediction of one based on the other. At the cortical level, early areas (e.g primary visual cortex, auditory cortex, somatic sensory cortex) are receiving input from specifics sensors of the body while other areas (motor cortex) generate motor commands when stimulated. Together with the remaining amodal areas, they are connected in a dense network composed of pathways that are both feedforward (from the sensory cortices) and feedback (from higher level areas to sensory-motor levels). The so called Convergence Divergence Zone (CDZ) theory proposes that the cortex acts as a hierarchy of convergence zones which have the role of merging modality specific stimuli into amodal concepts (Damasio, 1989; Meyer & Damasio, 2009). It is mainly based on the numerous evidences of interaction among sensory-motor modalities provided by illusions (e.g Mc Gurk effect (McGurk & MacDonald, 1976), rubber hand illusion (Botvinick & Cohen, 1998)) and numerous neurophysiological data. Although the CDZ theory proposes an interesting model of the cortex as a whole, very few computational studies have tried to implement it as such and they focused mainly on the interaction with the hippocampus for long term storage of memory traces (Moll & Miikkulainen, 1997). Moreover, while the CDZ explains global properties of the cortical network, it does not provide any clear insight about the computations done locally ; it just assumes that a given area that should be able to associate several modalities together into an amodal code that be used to reproduce the original input or to propagate the information upward. The CDZ framework relies on the idea that sensory-motor contingencies are extracted by a hierarchy of multimodal cortical units. Being bidirectional, this hierarchy allows both for compression of the raw sensory streams (convergence) and for retrieval of this raw information from another modality or an amodal code (divergence). In this research, we present a variation of the MultiModal Convergence Map algorithm (Lallee & Dominey, 2013), able to cope with the requirements of the CDZ computational unit. We also propose formalism as well as an open-source implementation of the CDZ framework in the form of an implemented C++ library which allows developing cortical models for robots. We demonstrate the model application on real world processing using the iCub humanoid robot which provides the most extensive set of sensory motor modalities to be explored. We demonstrate how the model can be used in order to generate perceptual categorization, learning of body schemas and production of acquired reflexes.

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