# Towards a developmental memory-based and embodied cognitive architecture

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Abstract

A novel memory-based embodied cognitive architecture is introduced – the MBC architecture. It is founded upon neuropsychological theory, and may be applied to investigating the interplay of embodiment, autonomy, and environmental interaction as related to the development of cognition.

## 1. Introduction

Autonomous, adaptive and flexible behaviours are accepted properties of biological agents, and desired properties for artificial agents. The present work aims to move towards the incorporation of these properties in artificial agents. The approach used is based upon the Autonomous Mental Development methodology, where only developmental principles are implemented, allowing the agent to autonomously develop through interaction with its environment (Weng et al. 2001), and also takes some inspiration from the Induction architecture (Holland et al. 1986), which describes a rule-based learning (and cognitive) framework.

This work introduces a novel computational architecture, which enables the exploration of questions relating to the interdependence of embodiment, autonomy and environmental interaction in support of developing behavioural competences. The Memory-Based Cognitive (MBC) architecture takes inspiration from neuropsychological theories of cognition and aims to capture the underlying properties of these theories in order to produce the desired adaptability of behaviour. The explicit nature of memory representations used ensures that the development of functionality of the architecture may be easily interrogated; and the hierarchical nature of the developed memory allows the development of more complex behaviours, eventually leading to what may be described as (albeit simplistic) abstraction capabilities.

## 2. Background

The traditional theories of memory and cognition, based on the modular organisation view of the brain, are increasingly unable to account for recent neuropsychological evidence. This evidence indicates parallel and distributed operation instead of modular organisation, and has given rise to a number of contemporary models.

One such view is the “Network Memory” theory (Fuster 1997) which proposes a wide ranging theory of human cognition which holds memory to be an associative and distributive process. It postulates that memory, perception and cognition share the same substrate: basic neural elements, termed ‘cognits’, encode associative relationships between sensory stimuli and/or motor commands. These cognits, through processes akin to hebbian learning, may also encode associations between different cognits. In this way, and due to the spatial separation of basic sensory and motor cortical regions, two informal and overlapping hierarchies are formed (sensory and motor), the upper echelons of which are proposed to be responsible for high level cognition (Fuster 2004). Not all behaviour needs to be mediated by these upper levels: automatic behaviour may be executed by lower levels of the cortical hierarchies, and sub-cortical regions.

## 3. The MBC architecture

The MBC architecture is based around the ‘cognit’ concept from the Network Memory theory. Whereas the functional principle is analogous, the implementation is explicit rather than neural: associations are represented by ‘rules’ which are Production Rule-inspired constructs. Sensory or motor associations (be they spatial or temporal) therefore require the definition of the agents’ sensory and motor spaces to enable these explicit encodings – thus coupling the architecture with the physical instantiation of the agent. While the spaces must themselves be defined a priori, the subsequent development of associations occurs through a process of imprinting in reaction to environmental interaction.

Hierarchies of these associations may be formed through the agent’s interaction with the environment (Figure 1) – where the created association rules may be described as being more or less removed from the basic sensory and motor spaces. For autonomous development of behaviours, the architecture must incorporate some form of action evaluation (Ziemke

2008): the Value/Credit system implemented in the MBC architecture, whilst explicitly defined, is held as the equivalent of phylogenetically encoded 'information' – following phyletic memory in the Network Memory theory (Fuster 2000).

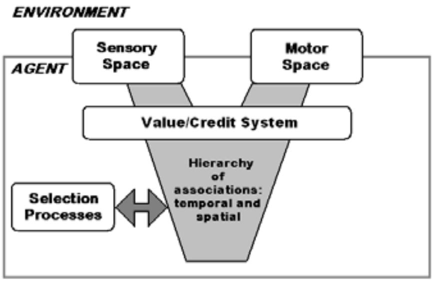


**Figure 1**: Functional overview of the MBC architecture

On this basis, the embodied MBC architecture is capable of developing meaningful behaviour from an empty initial rule-set. Obstacle avoidance has been the first behaviour developed, in order to demonstrate the basic functionality of the architecture (Figure 2). It is postulated that basic sensorimotor contingencies such as these would be prerequisite to more complex emergent behaviours (Prince et al. 2005).

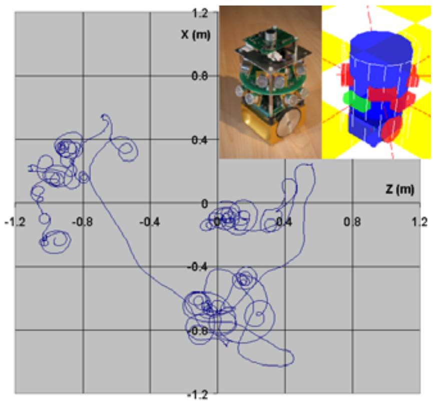


**Figure 2**: A sample run (5000 time-steps) of an initial simulation implementation of the MBC architecture in an enclosed environment. Initial sensor-motor associations are created with random motor actions. Inset: The Miabot Pro, Merlin Robotics ltd., hardware platform used – both real (left) and simulated (right).

## 4. Application and Discussion

One particular application is an exploration of a question in the field of animal cognition: whether stored spatial information, most notably in hippocampal place cells, is represented topologically (Eichenbaum et al. 1999) or in a euclidean manner (or cognitive map - (O'Keefe et al. 1978)). Because of the associative nature of knowledge representation in the MBC architecture, development of behaviours in spatial tasks similar to those observed in animal test subjects would lend support to the topological view of place cells.

The discrete nature of information representation allows a detailed analysis of how this behaviour develops, which is an advantage over equivalent artificial neural network approaches. One drawback of this explicit representation of associations is that the initially rapid integration of new associative elements results a large rule-base, which incurs a high computational cost. In the present experiments, this is managed through the minimisation of the sensory and motor spaces to facilitate analysis, however, in the future, more efficient algorithms may be required. It must be considered though that the proposed MBC architecture emphasises investigation of theoretical questions over optimal real-world performance.

## 5. Conclusion

The design of the novel MBC architecture facilitates adaptive behaviour in unknown environments, and serves as a tool in discussing a number of theoretical issues. Furthermore, it will permit a detailed analysis of the development of behaviours in an environment, to a greater extent than equivalent artificial neural network methodologies.

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