

# The Mechanics of Embodiment

**Ken McRae (kenm@uwo.ca)**

Department of Psychology, University of Western Ontario  
London, Ontario, Canada N6A 5C2

**Martin H. Fischer (m.h.fischer@dundee.ac.uk)**

School of Psychology, University of Dundee  
DD1 4HN Scotland UK

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## Overview and Motivation

Embodied cognition is a theoretical stance which postulates that sensory and motor experiences are key parts of the representation of our knowledge. This view has challenged the longstanding assumption that knowledge is represented abstractly in an amodal conceptual network.

There now exist a large number of interesting and intriguing demonstrations of embodied cognition. Examples include changes in perceptual experience or motor behaviour as a result of semantic processing. These demonstrations have received a great deal of attention in the literature, and have spurred many researchers to take an embodied approach in their own work.

There are also a number of theoretical accounts of how embodied cognition might work. One influential proposal is “perceptual symbols system” theory, according to which the retrieval of conceptual meaning involves a partial re-enactment of experiences during concept acquisition. However, to a large extent, embodied theories are still developing, particularly in terms of computational implementations, as well as specification with regard to moment-by-moment on-line processing.

Given the established empirical foundation, and the relatively underspecified theories to date, many researchers are extremely interested in embodied cognition but are clamouring for more mechanistic implementations. This symposium aims to address this specific need for more detailed explorations of the specific processing mechanisms involved in embodied cognition. Four speakers from varying backgrounds and approaches will describe how they think the human mind is embodied, and what they view as the critical current and next steps toward mechanistic theories of embodiment.

## Toward Implementing Embodiment

Lawrence Barsalou (Emory University, Atlanta, Georgia, USA) and Ken McRae (University of Western Ontario, London, Canada) will address issues concerning the construction of embodied computational models. One general set of issues concerns the computational architecture, aside from whether it takes the form of neural networks, Bayesian approaches, production systems, classic AI architectures, or another form. To implement a truly

embodied system, multiple modalities are essential. In particular, intelligent action coupled with perception epitomizes embodied approaches, beyond basic response production. Other modalities are also essential from the embodied perspective, including affect and motivation, as well as abstract thought. Another architectural issue concerns the hierarchical structure of feature areas, the hierarchical structure of association areas, and the connectivity patterns among them (Simmons & Barsalou, 2003). Also important are the unique areas associated with bottom-up activation versus top-down simulation, along with shared areas. Finally, issues associated with the architecture’s development and plasticity are important, including genetic and experiential contributions, and how epigenesis is realized (Elman et al., 1996).

A second set of critical issues surrounds specific forms of functionality to implement in the architecture. Barsalou (2003) argues that selective attention and categorical memory integration are essential for creating a symbolic system. Once these functions are present, symbolic capabilities can be built upon them, including type-token propositions, predication, categorical inference, conceptual relations, argument binding, productivity, and conceptual combination. Another key aspect is the implementation of space and time. Perception, cognition, and action must be coupled in space and time, and simulations of non-present situations must be implemented in space and time, perhaps using overlapping systems.

Because situated action in the environment is fundamental for all organisms, implementing embodied cognition that supports intelligent activity in a few critical situations may be a good place to start (Robbins & Aydede, 2008). By focusing on a complete embodied approach to achieving goals in specific situations, modelers must not only implement specific capabilities, such as goal setting, planning, perception, action, cognition, affect, reward, and learning, but implement interfaces that allow all these processes to interact effectively.

These are lofty goals indeed, and the remaining talks will describe current projects that are working toward them.

## Computational Explorations of Perceptual Symbol Systems Theory

The second speaker is **Giovanni Pezzulo** (National Research Council, Rome, Italy) who has worked extensively

on computational models of embodied cognition. He will present an overview of his computational work and describe the precise mechanisms and processes involved in the emergence of embodied cognitive performance.

Pezzulo will present a computational architecture that acquires a “perceptual symbol system” through its autonomous interaction with the environment, and assembles perceptual symbols to form simulators for perceptual and abstract categories.

He will discuss the design of the architecture, which includes a combination of schema-based and dynamical systems principles, with the aim of suggesting a few basic mechanistic principles from which embodied theories of cognition can be implemented and tested.

Pezzulo will also discuss more generally the functioning of the perceptual-symbol-system-based architecture in prediction, categorization, and abstraction tasks, with the aim to assess the possible roles of perceptual symbols systems in producing embodied cognitive processing.

It is worth noting that, in addition to their use as “proofs of concept” for an embodied theory of cognition such as perceptual symbol systems, the importance of computational models also lies in the possibility to investigate elements that are left unspecified in the initial theoretical formulations, or that are challenging to study by means of experimental methods only. Therefore, Pezzulo will discuss the specific predictions and implications of our computational architecture for the perceptual symbol systems theory, and in particular the (tentative) answers it gives to challenging questions such as: *How are simulators formed from perceptual symbols? Which features are stored in simulators, and which are not? How are the most relevant simulators selected depending on the organism's goals and the current environmental context?*

### **Cognitive Modeling with the Open Source Humanoid Robot iCub**

The third speaker is Angelo Cangelosi (University of Plymouth, UK) who leads a large-scale EU project on language and action learning ([www.italkproject.org](http://www.italkproject.org)) and the Marie Curie doctoral network on developmental robotics ([www.robotdoc.org](http://www.robotdoc.org)). Approaching embodiment from an engineering and cognitive modeling perspective, his talk will describe the current state of development of efforts to implement human cognition in a physical agent with sensory and motor capabilities. He will describe in detail two current cognitive robotics models based on the humanoid robot iCub: one study on stimulus response compatibility effects and one on language acquisition. In addition, he will present the open source humanoid robotic platform iCub, and the associated computer simulator.

### **A Theoretical Framework for Embodied Cognition**

The final speaker, Michael J. Spivey (University of California, Merced, USA), is a cognitive scientist who uses

eye-tracking, reach-tracking, and neural network simulations to explore the close-knit relationship between sensorimotor processes and high-level cognition (Spivey, 2007). In Spivey's talk, he will discuss how the mountains of evidence for embodied cognition are now being acknowledged by classical cognitive scientists, albeit warily (Mahon & Caramazza, 2009). However, the next step, of how these many varied findings can impact traditional mainstream theories of cognition, is still not well articulated in the field. Rather than treating sensorimotor properties as “something extra” that gets facilitated after certain concepts become active, those sensorimotor properties may be part and parcel of the very conceptual representations themselves. What is needed at this stage is a push toward explicit computational models that implement sensorimotor grounding as intrinsic to cognitive processes. With such models, theoretical descriptions can be fleshed out as explicit mechanisms, idiosyncratic patterns across experiments may be explained, and quantitative predictions for new experiments can be put forward. Spivey will discuss some examples of such nascent modeling efforts.

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