Metaphor and the Semantics of Embedded Action

by
William A. Stubblefield
Department of Mathematics and Computer Science
Dartmouth College
6211 Sudikoff Laboratory
Hanover, NH 03755-3510
sfield@cs.dartmouth.edu
&
George F. Luger
Department of Computer Science
University of New Mexico
Albuquerque, New Mexico 87131
luger@cs.unm.edu

Recent years have seen a growing challenge to "traditional" representational approaches to Artificial Intelligence (Dreyfus and Dreyfus 1986; Johnson 1987; Searle 1980; Varela and others 1991; Winograd and Flores 1986). All of these challenges differ in their particulars, but all of them seem to share a view of intelligence as *embedded action*. Under this view, an intelligent agent must be embedded in its world through a biological embodiment and a rich sensory apparatus. This enables it to sense and respond to changes in the world. The agent is also primarily an actor: rather than planning and reasoning about abstract mental models, it acts in the world, senses the results and adapts. The embedded action model of intelligence implies:

- A growing recognition of the importance of embodiment. While the physical symbol system hypothesis (Newell and Simon 1976) asserts that the medium in which we realize intelligence is unimportant, the alternative view argues that a biological embodiment is an essential foundation for mind. Embodiment, by providing a rich sensory apparatus, needs and motivations, and a subjective experience of phenomena, integrates an intelligent organism with its environment in ways not possible with conventional computer architectures.

- A rejection of the primacy of mental representations and referential semantics. Representational AI gives mental representations a central role in controlling intelligent behavior, and assigns a meaning to those representations through reference to objects in an objective external world. Embedded actors interact with the external world in a purposeful fashion, although representations of the world are not an essential intermediary for this interaction. When an agent does form representations, their meaning does not depend upon reference to an "objective" reality; instead, the process of constructing representations determines the perceived structure of the world.

- A purpose for consciousness. Traditional models of intelligence ignore consciousness. Recent trends in cognitive science have argued that consciousness has a function in intelligence, through regulating our focus of attention and coordinating mental activity (Dennett 1991).

Even embedded actors, however, form symbols, and these symbols have meaning. Humans and, it is increasingly recognized, many animals use language, communicate in a cultural context, create signs, texts and other representational artifacts, and use representations to shape individual and group behavior. How can we reconcile this with the view of intelligence as embedded action? If we reject referential semantics, then how do representations come to have meaning?

Metaphor and analogy a promising source of answers to these questions (Helman 1988; Lakoff and Johnson 1980; Lakoff and Turner 1989; Vosniadou and Ortony 1989). The meaning of any symbol results from a vast web of metaphoric connections to other symbols. These metaphors are ultimately grounded in our physical being, through metaphors with such fundamental aspects of our physical embodiment as "inside and outside," "self and other," or "up and down." Intelligent agents construct their web of metaphors through an iterative process of proposing new metaphors and analogies, acting on these conjectures, and reifying those that lead to successful actions.

SCAVENGER is a computer program that was designed to test this hypothesis. Since current technologies do not allow us to give a computer program a sufficient sensory apparatus to "embed" it in a physical world, SCAVENGER "lives" in a world of computer programs.

SCAVENGER is an analogy based software reuse advisor for a library of class and method definitions written in the Common LISP Object System (CLOS). Given a *target* specification for a set of LISP classes and methods a user would like to implement, SCAVENGER searches its library for *sources* that can best be used to implement the target specification. SCAVENGER constructs analogies between library functions and targets, planning and executing experiments (acting in its world) to test these analogies. In the course of its experience, SCAVENGER stores successful patterns of analogy in an indexing system, using these patterns to improve future performance.

One of the most interesting aspects of the SCAVENGER program is its treatment of semantics. When solving a target problem, SCAVENGER considers multiple candidate analogies. Each of these analogies leads to a different interpretation of the semantic structure of the target problem. SCAVENGER searches a space of these interpretations for those that best satisfy certain heuristic criteria. Only then does it empirically validate its conjectures. The interpretation of the problem specification comes from analogies with known LISP functions, not through reference to an "external" world. The world (the LISP interpreter) does not provide a direct semantic model for the target: it only serves to validate the metaphoric interpretation.

The SCAVENGER experiments illuminate a number of issues, including

- The structure of analogical inference and semantics.
- The management and evaluation of multiple semantic interpretations.
- The use of limited, noisy information to validate analogies
- The mechanism by which experience establishes the relevance and meaning of objects in a world of embedded action.

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