Solutions and Open Challenges for the Symbol Grounding Problem

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ABSTRACT

This article discusses the current progress and solutions to the symbol grounding problem and specifically identifies which aspects of the problem have been addressed and issues and scientific challenges that still require investigation. In particular, the paper suggests that of the various aspects of the symbol grounding problem, the transition from indexical representations to symbol-symbol relationships requires the most research. This analysis initiated a debate and solicited commentaries from experts in the field to gather consensus on progress and achievements and identify the challenges still open in the symbol grounding problem.

Keywords: Cognitive Robotics, Developmental Robotics, Embodiment, Symbol Grounding, Symbol Relationships

MAIN TEXT

The grounding of symbols, i.e. the process by which symbols (such as words) are linked to the agent’s own semantic representation of the world, is an issue of crucial importance to the field of cognitive science, raging from philosophy and semiotics, to artificial intelligence, and to cognitive robotics. For example, in cognitive and developmental robotics, in the last decades there has been a tremendous increase in new models of the evolution of communication and the developmental acquisition of language. These models directly regard the issue of symbol grounding, since robotic agents are trained to use symbols that often refer to entities and states in the robot’s own world.

In the literature on artificial intelligence, cognitive science and philosophy, there has been extensive discussion on the symbol grounding problem. Different views on the importance of the symbol grounding have been proposed. On one extreme, we find the so called “symbolic” approaches that practically ignore the cognitive significance of such an issue (Fodor, 1983; Chomsky, 1965). This is the case of classical GOFAI (Good Old Fashion Artificial Intelligence) approaches, based on symbolic methods such as logic, where the meaning or a linguistic symbol (word) is simply represented by another symbol (meaning), without having to deal of how meanings have formed and have been associated to words. On the other hand, new “embodied” approaches to cogni-
tion acknowledge the importance of grounding symbols through the agent’s interaction with the environment. However, even in this field, there have been suggestions that the problem has practically been solved (Steels, 2008), thus appearing to suggest that the symbol grounding problem is not important anymore.

In this target article, I am going to suggest a different analysis of the current progress on symbol grounding, indentify specifically which aspects of the problem have been already addressed, and which other issues still require investigation. This analysis will initiate a debate and solicit commentaries from experts in the field, to gather consensus on actual progress, achievements and open challenges in the symbol grounding problem.

To assess better the current state of the art on the Symbol Ground Problem, I will use the definition and discussion of the problem originally given by Stevan Harnad in his seminal 1990 article “The Symbol Grounding Problem”. Here Harnad explains that the symbol grounding problem refers to the capability of natural and artificial cognitive agents to acquire an *intrinsic link* (*autonomous*, we would say in nowadays robotics terminology) between internal symbolic representations and some referents in the external word or internal states. In addition, Harnad explicitly proposes a definition of a symbol that requires the existence of logical links (e.g. syntactic) between the symbols themselves. It is thanks to these inter-symbol links, its associated symbol manipulation processes, and the symbol grounding transfer mechanism (Cangelosi & Riga, 2006) that a symbolic system like human language can exist. The symbol-symbol link is the main property that differentiates a real symbol from an *index*, as in Peirce’s semiotics. These symbolic (e.g. syntactic) links also support the phenomena of productivity and generativity in language, and contribute to the grounding of abstract concepts and symbols (Barsalou, 1999).

Finally, an important component of the symbol grounding problem is the social and cultural dimension, that is, the role of social interaction in the sharing of symbols (the external/social symbol grounding problem, as in Cangelosi, 2006; Vogt, 1997; Vogt & Divina, 2007).

To summarise, we can say that there are three sub-problems in the development of a grounded symbol system:

(i) How can a cognitive agent autonomously *link symbols to referents* in the world such as objects, events and internal and external states;

(ii) How can an agent autonomously create a set of *symbol-symbol relationships* and the associated transition from an indexical system to a proper symbol system;

(iii) How can a society of agents autonomously develop a *shared set of symbols*.

When we look at the current cognitive agent models of language learning (Cangelosi & Parisi, 2002; Wagner et al., 2003; Lyon et al., 2007), I believe that much progress has been achieved in the first and third sub-problems (individual and social grounding of symbols), whilst I believe that for the second sub-problem (autonomous creating of symbol-symbol relationships) much still needs to be done. I therefore agree with Steels (2008) that much has been done on the robotic and cognitive modelling of the symbol grounding problem, but only when we consider the two sub-problems (i) and (iii), “we now understand enough to create experiments in which groups of agents self-organize symbolic systems that are grounded in their interactions with the world and others” (Steels, 2008, p. 240).

For example, when we consider the well known “Talking Heads” model of the emergence of communication in robotic agents (Steels, 1999; Kaplan & Steels, 2002), we have a demonstration that each individual robot can autonomously create categorical representations of the world (a white board with a variable combination of coloured shapes). Using the technique of discrimination trees, each agent creates categories defined by specific patterns of boundaries of color, shape and spatial values. In addition, these perceptual patterns become associated with words that the agents
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