Theoretical accounts to practical models: Grounding phenomenon for abstract words in cognitive robots

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Abstract

This review concentrates on the issue of acquisition of abstract words in a cognitive robot with the grounding principle, from relevant theories to practical models of agents and robots. Most cognitive robotics models developed for grounding of language take inspiration from the findings of neuroscience and psychology to get the theoretical skeleton of these models. To better understand these modelling approaches, it is indispensable to work from the base (theoretical accounts) to the top (computational models). Therefore in this paper, succinct definition of abstract words is presented first, and then the symbol grounding issue and accounts of grounded cognition for abstract words are given. The next section discusses the computational modelling approaches for abstract words grounding phenomenon. Finally, important cognitive robotics models are reviewed. This paper also points out the strengths and weaknesses of relevant hypotheses and models for the representation of abstract words in the grounded cognition framework and helps the understanding of issues such as where and why modelling efforts stand to address this problem in comparison with theoretical findings.
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1. Introduction

Cognitive modelling is shifting towards a more realistic and interactive acquisition of knowledge. This new approach links the internal computational system to the external world to emulate human level skills, which is a benchmark for intelligence in all areas related to the under-standing and acquisition of intelligent behaviour in machines/artificial systems. Cognitive robots are gaining a special place as a research platform for the study of cognition because they provide a way of "understanding through building" in relevant fields (D'Mello & Franklin, 2011; Morse, Herrera, Clowes, Montebelli, & Ziemke, 2011; Pezzulo et al., 2012). In addition, the requirements of robotic applications have also changed since the old days of generic industrial manipulator robots. Robots can now be seen in many applications with challenging missions, such as the space exploration rovers, underwater robots, and domestic service (Bajracharya, Maimone, & Helmick,

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2008;Moo, Wang, Zhao, & Pumera, 2014;Schwarz, Stückler, & Behnke, 2014). These challenging tasks require more intelligent behaviour from the robot than an industrial robot that is confined to a tight and controlled workspace.

Linguistic skill is one of the most important capabilities of cognitive agents for interaction with the environment and understanding situation. Cognitive robotics takes inspiration from children's learning mechanisms to implement the language developmental phenomenon in cognitive robots. To achieve this objective, robotics models based on this approach get their theoretical skeleton from the findings of different fields that include cognitive science, neuroscience, and developmental psychology (Asada, MacDorman, Ishiguro, & Kuniyoshi, 2001; Asada et al., 2009; Cangelosi & Schlesinger, 2015) and deals with issues such as symbol grounding and grounded cognition.

On one hand, the grounding phenomenon has become a prominent view of cognition; on the other hand, the computational models inspired by the grounding principle are contributing to the technological advancement of robot design. To achieve language comprehension and understanding in cognitive robots by bearing in mind human intelligence, grounding language only through direct interaction with world is inadequate (Harnad, 1990), and it is also very important for an autonomous cognitive agent to have its own cognitive and linguistic skill through which it can enhance basic knowledge. Higher order or abstract words pervade the whole realm of human language experience, play important role in human cognition and also in social interactions (Lakens, 2010). The acquisition of abstract words provides the capability of knowledge enhancement from basic to higher level in cognitive agents/robots, since these words/concepts are formed through the combinatorial language property (Barsalou, Santos, Simmons, & Wilson, 2008; Cangelosi & Schlesinger, 2015). Furthermore, in the grounded cognition area, the recent research trend is towards an increasing interest in understanding the representation of abstract words, because it is a test bed for the grounded and embodied theories of language comprehension (Chatterjee, 2010; Scorolli et al., 2011).

Nevertheless, a lack of physical referents and little knowledge about how abstract words are represented and computed in the brain make theorizing, modelling, and experimenting difficult for the relevant fields. The nature of abstract words poses a challenge for the hypothesis of grounded cognition (Barsalou, 2008, 2010; Borghi & Pecher, 2012; De Vega, Glenberg, & Graesser, 2008; Gentner, 2010; Semin & Smith, 2008) and also for other important issues, such as the need to consider the philosophical aspect of the "symbol grounding problem" in symbol processing systems (Harnad, 1990). Therefore, the problem of grounding of abstract words in cognitive robots is an important issue that is linked to many issues and matters.

This paper systematically reviews theories and models that are relevant for the grounding of abstract words in cognitive robots. Additionally, highlights about the pros and cons of theoretical accounts and practical models of grounded cognition are also given, which will help to view this problem from a broader perspective.

Specifically, the organization of the paper is as follows: the definition and role of language for abstract words are described in Section 2. After that, concerns like the symbol grounding problem and grounded cognition are discussed in Section 3. In Section 4, we look at the state of the art for grounded cognition accounts relevant to abstract words. In Section 5, important computational approaches that have been presented to address the grounding problem for concrete and abstract words are discussed. Three prototype cognitive robotics models are also presented in this section. The review ends with the concluding remarks in Section 6.

2. Abstract words and role of language

In informal language, abstract words refer to things that generally do not have a tangible form, for instance "democracy" and "peace". One of the definitions of an abstract word is that these words represent everything that cannot defined physically or spatially constrained and that get their meaning through the mind, not through the senses (Stramandinoli, Marocco, & Cangelosi, 2012). Another recent definition, found in Borghi and Binkofski (2014), states that abstract words normally are less imaginable and more complex than concrete words because they often do not refer to a single object as in the case of concrete words but rather represent the relations between elements, and they are characterized by higher inter- and intra-subjective variability.

What makes a human able to represent abstract words? One prominent element is language. It is obvious that humans learn abstract words by being told or through extraction of meaning from linguistic input (Andrews, Vigliocco, & Vinson, 2009; Vigliocco et al., 2014). Although many theories that differentiate between abstract and concrete words conflict in many respects, involvement of a verbal system for abstract words has been accepted by all of these theories (Barsalou & Wiemer-Hastings, 2005; Barsalou et al., 2008; Borghi & Binkofski, 2014; Borghi, Capirci, Gianfreda, & Volterra, 2014; Borghi, Cimatti, Taatgen, & van Rijn, 2009; Dove, 2014; Paivio, 2014; Schwanenflugel, 2013; Schwanenflugel & Shoben, 1983). One of the pioneering theories, called the Dual Code Theory (Paivio, 2014), proposed that there are two independent systems for cognitive processing: one is verbal "linguistic" system and the other is non-verbal "imagistic" system. According to this theory, concrete words are linked with information stored in both (verbal and non-verbal) systems. However, abstract words are associated with information only stored in the verbal system. When a