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RESEARCH ARTICLE

Evolving conceptual spaces for symbol grounding in language games

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Abstract
A standard approach in the simulation of language evolution is the use of *Language Games* to model communicative interactions between intelligent agents. Usually, in such language games, an agent uses the results from its perceptual layer to categorize and to conceptualize world objects, a process named categorization. In this paper, we develop an approach to the categorization process, where the decomposition of reality in meaningful experiences is co-evolved with the lexicon formation in the language game. This approach brings some insights on how meaning might be assigned to symbols, in a dynamic and continuously changing environment being experienced by an agent. In order to do that, we use Barsalou's notion of *mental simulation* and Gärdenfors' notion of *conceptual spaces* such that, together with ESOM neural networks, a cognitive architecture can be developed, where mental concepts formation and lexicon formation are able to co-evolve during a language game. The performance of our cognitive architecture is evaluated and the results show that the architecture is able to fulfill its semantics function, by allowing a population of agents to exchange the meaning of linguistic symbols during a naming game, without relying on ''a priori'' categorization scheme provided by an external expert or a set of examples for training a neural network in a previous discrimination game. These results, beyond bringing evidence on potential ways for symbols to get meaning on a biologically realistic way, open a set of possibilities for further uses of conceptual spaces on a much more complex problem: the grounding of a grammatical language.

Introduction

Many different representational structures have been proposed in classic artificial intelligence (AI) studies. Most of them rely on the concept of symbol, using symbolic

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logic as a background. Propositions, predicates, rules, features lists, frames or semantic networks are typical examples of such structures, most of them defined by an external expert. One of the main criticisms to classic AI is exactly this requirement of a ''human in the loop'', either acquiring and setting up knowledge, or interpreting the system results. It is not possible to say that these systems (using classic AI) really ''understand'' the meaning of symbols they use. Barsalou (1999) draws our attention to the fact that these symbols are amodal and arbitrary. Their internal structures bear no correspondence with the perceptual states that produced them and therefore they are linked arbitrarily. Thus, amodal symbols always require additional representational structures to express meaning. Fortunately, there came computational intelligence (CI)[1] for the rescue, with its many algorithms for classification, categorization, clustering and grouping, based on partial or vague information, and suitable to provide cumulative layers of perception in terms of abstractions of input signals. E.g., neural networks (or fuzzy systems) can be directly connected to sensors and actuators (i.e. connected to the ''real world''), and so provide this link to reality which was missing in classic AI. But now we are on the opposite side of the problem. Where are the symbols within a neural network or a genetic algorithm? Are they symbols for the system, or are they symbols for the system designer?

According to Balkenius, Gärdenfors, and Hall (2000), although the manipulation of symbols is fundamental to the acquisition of language, the use of just amodal symbols is far from a reasonable model of how humans acquire and make use of language. In his *Chinese Room Argument*, Searle (1980) assumes that what happens with these systems might be comparable to an individual who is inside a room translating words using only a dictionary, without any other connection to the real world. In this case, these symbols cannot be grounded on reality, but only on other symbols.

This leads us to the *Symbol Grounding Problem*, pointed out by Harnad (1990). Symbols cannot be described only in terms of their relations with other symbols. They have to maintain some kind of relationship with the real world, e.g. by means of sensory and motor information acquired from reality through perceptual experience. In fact, it is exactly due to these relationships that symbols can be grounded and gain some sort of meaning.

In this context, it is clear that the use of only amodal symbols imposes strong limitations for researching the emergence of language in intelligent agents. A promising approach is the perceptual symbol system theory proposed by Barsalou (1999), which has arisen in the context of embodied cognition (Anderson, 2003). It assumes that the meaning of symbols occurs by the re-enactment of experiences aroused during the acquisition of concepts from the real world.

[1] In the literature of intelligent systems, the term ''Computational Intelligence'' is used to designate computational techniques based on Neural Networks, Fuzzy Systems and Evolutionary Computation.

Barsalou explains that this comprises a new category of symbols, which he calls perceptual symbols. In the human mind, perceptual symbols might be associated to dynamic neuronal patterns, in structures he names *simulators*. In simulators, information is combined from different sensory sources and aggregated in order to constitute meaning. Thus, two processes are required for the development of a perceptual system: (i) the storage of multi-modal states in order to create simulators (arriving by perception, action and introspection, in long-term memory) and (ii) the partial re-enactment of these states generating a mental simulation.

Differently from amodal symbols, perceptual symbols are analogical and modal, because they are directly represented by the perceptual states which produce them. Consequently, a representational system based on both kinds of symbols, supports both perception and cognition, without the requirement of a human expert to ground them (Barsalou, 1999).

The use of simulators and simulations in a perceptual system offers a variety of functions that can be employed on cognitive skills, including language. For example, perceptual symbols, accessed during simulation, can represent an object, even when its referent does not exist in the physical world. They can produce infinite conceptual combinations, representing abstract concepts and allowing inferences and predictions about the perceived categories.

There is somewhat a consensus on the application of perceptual systems theory as an alternative to deal with the symbol grounding problem in computer simulations. This can be viewed by the increasing number of works using this approach to support their models elaboration (e.g. Bergen, Chang, & Narayan, 2004; Cangelosi & Riga, 2006; Dominey, Hoen, & Inui, 2006; Frank & Vigliocco, 2011; Lallee, Madden, Hoen, & Dominey, 2010; Madden, Hoen, & Dominey, 2010; Narayanan, 1999; Pezzulo & Calvi, 2011; Roy, 2005).

There are still other cognitive theories with a similar purpose as Barsalou's theory. A particularly attractive one is the semantic theory presented by Gärdenfors (2004). This theory considers that the mind organizes information involved in perception, attention, categorization and memory, using geometric and topological properties, in order to derive the notion of conceptual spaces.

Conceptual spaces are metric spaces providing a robust mechanism for learning and representing the meaning of different classes of words (e.g. categories of objects). This is explained further in the text.

According to Gärdenfors (2014), an unified theory of meaning about different word classes can be developed when conceptual spaces are used to provide linguistic grounding. In our conception, this theory is complementary to Barsalou's theory by exploring both semantic and lexical aspects of language. Besides, what Barsalou has defined as perceptual symbol, Gärdenfors defines as object categories and both are special kinds of a concept. Moreover, Gärdenfors concepts may involve perception but also memory, attention and imagination, while concepts from Barsalou's theory are formed only by perceptual experiences.

Consequently, the contribution of this paper is the proposition of a mental simulation framework based on