The Grounding and Sharing of Symbols[1]

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Abstract

The double function of language, as a social/communicative means, and as an individual/cognitive capability, derives from its fundamental property that allows us to internally re-represent the world we live in. This is possible through the mechanism of symbol grounding, i.e. the ability to associate entities and states in the external and internal world with internal categorical representations. The symbol grounding mechanism, as language, has both an individual and a social component. The individual component, called the "Physical Symbol Grounding", refers to the ability of each individual to create an intrinsic link between world entities and internal categorical representations. The social component, called "Social Symbol Grounding", refers to the collective negotiation for the selection of shared symbols (words) and their grounded meanings. The paper discusses these two aspects of symbol grounding in relation to distributed cognition, using examples from cognitive modeling research on grounded agents and robots.

1. Introduction

The main and most obvious function of language is its pragmatic role, i.e. that of facilitating interaction and communication between cognitive agents. Individuals use language to provide information (representative speech acts), ask for something (directive acts) and express internal states and emotions (expressive acts). A group of individuals engaged in dialog can be considered as a "dynamical" distributed cognitive system, where the different speakers (and listeners) collaborative perform a distributed social and cognitive task. Communication can be achieved not only through speaking, but also through other more "stable" forms of communication, such as written texts, audio recordings or other social artifacts. The fact that language is the means to represent and communicate about the world has one important consequence. It can also be considered as an autonomous distributed cognitive system, partially independent from the individual cognitive agents that have initially produced it. The system is distributed not only in the mind of language speaking individuals, but also

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in all other expressions of language such as books and the world wide web. It has also been suggested that this system can follow its own evolutionary dynamics, through the mechanisms of cultural transmission and meme evolution (Blackmore 1999; Croft 2000).

Language can also play a purely social and emotion role, when its communicative function is minimal or can sometime become totally irrelevant. For example, language and communication can be used as a means to increase bonding between the members of a family or social group. For example, it has been suggested that the evolutionary origins of language are linked to that of grooming behavior in animal groups (Dunbar, 1996).

In addition to being a social and pragmatic phenomenon, language has important "solipsistic" and cognitive functions. Vygotsky (1962, 1978) highlighted the importance of "speaking to oneself" as an essential cognitive mechanism in the development of the mind, although is an important social context. For example, recent computational modeling studies have demonstrated the role of speaking to oneself as an aid to cognition and categorization (Mirolli & Parisi 2005a; 2005b). The debate on linguistic relativism (Gumperz & Levinson 1996; Gentner & Goldin-Meadow 2003; also known as Worf-Sapir Hypothesis) has produced much evidence that the structure and lexicon of language influences how we perceive and conceptualize the world. This has also cultural implications, when we consider the effects of different languages in the way peoples represent and describe their world. For example, in the case of spatial language, different languages describe and carve the space in quite different ways (Coventry & Garrod 2004; Bowerman et al. 2001).

The double function of language, as a social/communicative means, and as an individual/cognitive capability, derives from its fundamental property that allows us to internally re-represent the world we live in, to process such representations to generate new concepts and explanations, and to communicate with others about our knowledge of the world. This is possible through the mechanism of symbol grounding, i.e. the ability to associate entities and states in the external (and internal) world with internal categorical representations. These representations become symbolic when we are able to combine them to generate sentences describing new concepts and meanings. The ability to create categories, such as the categorical perception mechanisms, and to combine their symbolic representations to generate new meanings, have been proposed by Harnad (1997) as the groundwork of cognition. This has also been invoked in explaining the adaptive value of language and its evolutionary origins (Cangelosi & Harnad 2000).

The symbol grounding mechanism, as language itself, has both an individual and a social component. The individual component, called the "Physical Symbol Grounding", refers to the ability of each individual to create an intrinsic link between world entities and internal categorical representations. The social component, called "Social Symbol Grounding", refers to the collective negotiation for the selection of shared symbols (words) and their grounded meanings. In the next two sections we will analyze the two aspects of symbol grounding and their contribution to distributed cognition. We will use examples form computational cognitive modeling research to demonstrate how to design cognitive systems able to develop linguistic capabilities from physical and social symbol grounding. Our understanding of the functioning of artificial cognitive systems will, in turn, improve our knowledge of the organization of natural cognitive systems.

2. Physical Symbol Grounding

The symbol grounding problem (Harnad 1990) refers to the need, for natural and artificial cognitive agents, to acquire an intrinsic link between symbolic representations and some referents in the external word. This is possible through the process of categorization that allows an individual to create an internal categorical representation of the external referent, and use it as the grounding (meaning) for symbols. These internal representations are acquired during interaction with the entities in the external world. During category learning, we can "sort out" our environment by forming discrete, useful categories. The cognitive mechanism at the basis of the physical symbol grounding is based on the following chain of entities and representations:

external entities ⇔ internal representations ⇔ symbols.

These are all bi-directional links that permit the external entities to influence internal representation and symbols, and at the same time the symbols to affect the way we represent our external world (Roy in press).

The physical symbol grounding problem refers to the individual's cognitive ability to create such links. The social symbol grounding problem, as discussed in detail the next section, refers to the need to acquire a set of symbols. These are used by a group of agents to refer consistently to the same external referents, or to some of their properties. Although Harnad (1990) does not explicitly restricts the use of the term symbol grounding solely to such an individual phenomenon, his discussion mostly focuses on the individual's cognitive capability for grounding symbols. Harnad's proposal that the internal representations that mediate grounding are essentially categorical has some important cognitive consequences. One of the fundamental characteristics of these representations is that of categorical perception (Harnad 1987). This is the process of warping the similarity space of internal categorical representations during learning. The perceptual, iconic representations of the members of a category are transformed so that the internal within-category differences are reduced (within-category compression). The differences between the iconic representations of the members of different categories are enhanced to make them appear more dissimilar (between-category expansion). These warped representations of the word facilitate the production of discrete representations that, as symbols, can be easily combined into propositions using logical and syntactic constructs.

The physical symbol grounding is a fundamental capability of natural (human) cognitive systems, since we are evolutionary endowed with the competence to build categorical representations of the world. Categorical perception is widespread in natural cognitive systems, and has been observed in animals (e.g. Zentall et al. 1986) and humans (e.g. Goldstone 1994). On the contrary, in artificial cognitive systems research, the physical symbol grounding can be a real "problem". In computational cognitive models purely based on symbolic representations and rule-based systems, agents use ungrounded symbols that require the interpretation of an external user (the researcher) to "understand" the meaning associated to symbols. Even if these models may include an additional set of symbols for the "meanings", such as a dictionary, these would still be ungrounded and self-referential symbols. Such situation is similar to Chinese room scenario (Searle 1980) where the symbolic task of responding to questions in Chinese, without knowing the language, can apparently be well performed whilst at the same time not understanding the meaning of the questions and answers.

Various approaches have been proposed to build grounded cognitive models based on physical symbol grounding. Hybrid symbolic-connectionist models have been proposed as ideal candidates for solving the symbol grounding problem (Harnad 1993; Sun 2002). The connectionist, neural network component is used to perform the task of grounding the symbols into perceptual and categorical representations. Input units receive iconic representation of the objects. These are transformed, in the hidden units, into warped, categorical perception representations. A symbolic module, such as a rule-based system, would use these categorical representations to perform symbol manipulation operations and high-level cognitive tasks (Miikkulainen 1994). An alternative approach to hybrid systems is that solely based on connectionist architectures (Cangelosi 2005; Cangelosi, Greco & Harnad 2000; Harnad, Hanson & Lubin 1004). These typically consist of neural networks that are able to acquire categorical perception representations during category learning tasks, to use these representations to ground the meaning of discrete symbols, and to perform simple symbol manipulation tasks.

A more recent approach to the symbol grounding problem in artificial cognitive systems relies on the use of embodied agent models and cognitive robotics (Vogt 2002; Cangelosi & Riga, in press; Cangelosi in press). These methodologies permit the grounding of symbols directly in sensorimotor representations, such as action categories. Some of these robotic approaches also include the use of connectionist networks, while others use different control architectures. This robotic approach, when embedded in a population-based setting, also permits the simulation of the social symbol grounding process, as discussed below.

3. Social Symbol Grounding

Social symbol grounding refers to the process of developing a shared lexicon of perceptually-grounded symbols in a population of cognitive agents. In natural cognitive systems, the social grounding of symbols can be observed at different temporal perspectives. In slow, evolutionary terms, it refers to the gradual emergence of language. Our ancestors started from a pre-linguistic, animal-like society with no explicit symbolic and communicative means. During evolution, this brought to the collective development of shared languages to talk about entities in the physical, internal and social world. In ontogenetic terms, social symbol grounding refers to the process of language acquisition and cultural transmission. In early ages, children acquire the language of the groups they belong to via imitation of their parents and peers. This leads to the gradual discovery and construction of linguistic knowledge (Tomasello 2003). During adulthood, this process continues through the general mechanisms of cultural transmission. Phenomena of cultural transmission such as variation, competition and preferential selection of words can results in slow historical changes in the language being transmitted (Croft 2000; Labov 2000). Finally, the social symbol grounding can also happen during temporary interactional games between individuals. For instance, this is the case of interactive alignment in dialogue. During dialogue, interlocutors fix local interpretations for expressions (routinization). This helps them to converge on particular ways of using the language in specific contexts (Garrod & Anderson 1987; Pickering & Garrod 2004).

Social symbol grounding involves not only speech, but also a more distributed approach to communication and symbol use. This entails a wider interpretation of communication symbols that includes artifacts and cultural symbols. For example, in evolutionary and ontogenetic terms, the invention of writing has had an important role on language evolution and transmission. In dialogue contexts, it has been demonstrated that individuals are capable of negotiating and develop shared on-line sets of graphical conventions (Fay 2004). Such a distributed view of language leads to a fully distributed cognition system, with symbols existing in the mind of the language-speaking agents, in other cultural artifacts and symbolic entities, and in the general distributed cognition capabilities of the individuals. The act of communication in a group of individuals constitutes a collaborative cognitive task based on negotiation and dialogue-based interactions. Following this distributed view, language development can be seen as under dual control by adult and child (Cowley in press). Both parties gear to each other's biomechanics and norm-based behavior prompting affective processes that drive prepared learning.

The issue of the social symbol grounding has been directly addressed in various cognitive agent and robotics models of the emergence of language (e.g. Steels 1999; Cangelosi 2001; Cangelosi & Parisi 2002). These simulate the emergence of language in a group of cognitive agents that are able to ground and negotiate a shared set of communication symbols through direct negotiation. Steels and collaborators (1999) have developed a model of the cultural emergence of language in a population of robotic agents called "Talking Heads". These robots perform a collaborative task, based on language games, to name objects (colored shapes) randomly placed on a whiteboard. The speaker selects the topic of communication through shared attention, and produces an utterance to communicate its internal representation of the topic. In turn, the hearer guesses the meaning (topic) of the utterance and updates its linguistic knowledge. The success/failure of the language game results in the update of the agents' own lexicons, including the invention of new words when necessary. This model has also been extended to study a web-based distributed cognitive system consisting of simulated agents and humans. Human participants can, through a web-based interface, be "embodied" into one of the Talking Head agents. This allows them to play the language games with other robots or humans, to learn the existing artificial lexicons, and also to influence it by inventing new words.

Other grounded agent models have simulated the emergence of language through the simulation of both evolutionary and ontogenetic learning processes. Cangelosi and collaborators (Cangelosi 2001; Cangelosi & Harnad 2000; Munroe & Cangelosi 2003) have simulated the emergence of compositional lexicons in a population of foraging agents in a mushroom world metaphor (Harnad 1987). Simulated agents evolve, though a genetic algorithm, according to their ability to recognize and name mushrooms. They must eat edible mushrooms and discard toadstools. During their lifetime, parent agents communicate with their own children by producing two-word utterances describing actions on mushrooms. Child agents also learn their parents' lexicons through a process of imitation and cultural transmission. Although at the beginning of evolution the lexicon is totally random and meaningless, towards the end of the evolution the agents are able to evolve shared compositional languages, i.e. lexicons consisting of the name of an action ("approach" or "avoid") and the name of a mushroom (e.g. "champignon" or "porcino"). This model has been used to study the emergence of compositional languages based on two-word combinations. Simulations demonstrate that structure of the lexicon directly reflects the sensorimotor structure of the stimuli (Cangelosi 2001; Cangelosi & Parisi 2004). The manipulation of cultural transmission mechanisms also affects the evolution of language through the presence of Baldwin effect (Munroe & Cangelosi 2003).

4. Conclusion

The models described above demonstrate that the combination of social and physical grounding of symbols leads to the design of psychologically-plausible cognitive systems. Cognitive agents and robots are able to acquire a language based on a shared set of grounded symbols. These agents are also able to autonomously transfer the grounding of symbols from directly grounded words into higher-order symbols. At the beginning, they learn new symbols through trial-and-error and feedback-supervised experience with their perceptual referents. Once a set of grounded basic symbols is acquired, the agents can use these symbols to communicate with each other and create new meanings and new definitions of the world. For example, the combination of the basic symbols "horse" and "stripe" can be used to describe a new concept, that of "zebra". They can even create concepts of entities that might not necessarily exist in the world, such as with the definition of "unicorn" through the combination of the basic and directly grounded concepts of "horse" and "horn". The combination of previously-grounded symbols such as "horse", "stripe" and "horn" permits the transfer of grounding from the basic-order symbols to the new higher-order symbols. This has been demonstrated to occur in connectionist model of symbol grounding (Cangelosi et al. 2000) and in grounded robotic models of the grounding and combination of action words (Cangelosi & Riga in press).

The procedure used for the autonomous production of high-order symbols, as in Cangelosi & Riga's (in press) model of action name grounding, can be considered an implementation of Barsalou's (1999) perceptual symbol system hypothesis. In particular, when the agents, in a distributed and collaborative way, provide definitions of new concepts, they apply a symbol productivity mechanism. During word combination and the transfer of grounding, the agent plays some kind of internal re-enactment (simulation) of the meaning of the basic symbols. These re-activated internal representations are then used by the agent to merge the results of the two basic "mental" simulations and create a new combinatorial, grounded symbol and their corresponding combinatorial meaning (Wisnieski, 1997).

The combination of the individual's physical grounding process and the group's social grounding of symbols permit the design of a psychologically-plausible distributed cognitive system. Knowledge is distributed in the individual agent's linguistic representation of the world, as well as in the social groups sharing the same symbols. Future research should consider extending this distributed approach to study additional phenomena in distributed cognition. For example, future grounded cognitive agent models might investigate the emergence of physical and cognitive artifacts that agents use in collaborative and distributed tasks. Although some past agent-based models have focused on the emergence of artifacts (Ugolini & Parisi, 1999), they have not addressed their explicit role in a distributed view of language (Cangelosi in press; Coley in press).

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