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Discussion

Defining embodied cognition: The problem of situatedness

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ABSTRACT

The embodied view of cognition rejects the substantial dualism between brain and body, claiming the primary role of sensorimotor experience on the development of conceptual knowledge. From this perspective, knowledge is grounded on physical properties of the body and the surrounding world. Furthermore, cognition is situated in a social and environmental context. However, the terms embodied, grounded, and situated are not univocally defined. This article focuses on the notion of situatedness, developing the discussion from the point of view of a computational modeler and roboticist, showing that minor and negligible differences on the definition of the field causes major operational divergences in synthetic models of cognition. A definition of two notions of situatedness are developed *a posteriori*, that is, by considering epistemological and ontological differences on artificial models. Finally, strengths and weakness of the two approaches are discussed.

1. Introduction

Thorough the centuries, countless philosophers and scientists have tried to answer fundamental questions concerning the way we think. What is intelligence? What is the relationship between mind and body? What is the relationship between the external world and the subjective experience? These deep and theoretically challenging questions still struggle to receive a unique answer, thus leaving the debate still open. Crucial to understand the perspective of embodied cognitive science is the mind-body problem, including its extension, which entails comprehending how perception and action relate to our intelligence.

Although the dispute about the relation between mind and body can be traced back to the ancient Greek philosophy (Hicks, 2015; Plato & Lee, 1955) and medieval scholastic tradition (Aquinas, 2015), Descartes is the first author framing the problem in modern terms (Descartes & Cottingham, 2013). He supports the idea of substance dualism, giving to mind and body two different ontological statuses: the material *res extensa*, a mechanical body subjected to the laws of physics, and the abstract *res cogitans*, realm of the laws of thought. Clearly, this position has deep epistemological implications. By defining *res cogitans* as persistent and indivisible, the study of the empirical world is now freed of any religious implications, making the theory consistent with the scholastic tradition and the idea of a soul.

The idea of a substantial dualism between the domains of abstract thought and physicality is challenged by the embodied view on cognition, which stresses the importance of sensorimotor experience for structuring knowledge and concepts. However, the term embodiment and the associated concepts of grounded and situated cognition are vague and opaque, lacking of a precise and rigorous definition. A solution to this issue is particularly critical for computational modelers and roboticists, as the complete freedom of building ad-hoc and arbitrary artificial cognitive systems requires a solid theoretical background. Otherwise, minor differences on the theoretical ground inexorably lead to maximal differences on the operationalization of the concept of embodiment. This article confronts the problem from the perspective of a computational modeler, stressing the divergences surrounding the term situatedness.

2. Computationalism: the mind in a box

There are strong implications following the acceptance of an ontological dualism, and the most important for the field of cognitive science is an idealistic view of cognition. The central element for understanding intelligence is the mind, abstracted from any physical instantiation. The physical traits of the cogitating agent, including brain, body, and perceptual system, are marginal for the study of cognitive facts.

One of the most revolutionary inventions of the last century was the development of computers, which is rooted in the *a-machine* (Turing, 1936), also known as Turing machine. In 1928, David Hilbert challenged the community of mathematicians with the Entscheidungsproblem, asking whether a function on the natural numbers is computable. The solution of the problem addresses the notion of effective computability, which requires an algorithm for solving the given function, that is, a mechanical procedure based on a finite set of rules. The concept of algorithm was still lacking of a formal definition and

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Alan Turing proposed an anthropocentric explanation, finding the necessary and sufficient mental abilities that a human uses when solving a logical problem. The Turing machine has a tape of infinite length divided into discrete cells that can store one of the three symbols of the simple alphabet {0; 1; *B*}, where B is blank. The machine reads the content of a cell and acts according to a table that defines deterministic logical rules. The possible (computational) actions are writing a symbol, moving to another cell, and halting. The latter command solves the algorithm without entering in an infinite loop. The architecture of modern general-purpose digital computers has been developed by John von Neumann at Princeton and is explicitly based on Turing's theoretical work. The machine, now physical, has a central processing unit, a memory, and it is capable of receiving inputs from and showing some outputs to the user.

During the second half of the last century, classic cognitivism (Fodor, 1975) and computational theories of mind (Pylyshyn, 1986) developed a framework that bases the study of cognition and intelligence on the analogy between a computer and any form of mental activity, thus extending the original operationalization of human algorithmic thinking to every domain of cognition. From this perspective, the mind operates over abstract symbols following syntactical rules. The experience of the bodily-self, as well as the external environment, is a mere source of inputs (Fodor, 1975; Pylyshyn, 1986). Perception is passive and action is just an effect of the cognitive outcome produced by our inner thoughts. Therefore, the concepts developed throughout the process of thinking are abstract and amodal. One of the most notable examples of computational theory of mind is the physical symbol system hypothesis (Newell & Simon, 1976). A physical symbol system is a formal language capable of combining meaningful symbols to generate expressions that, in turn, can be manipulated in a combinatorial way to generate new expressions. According to Newell and Simon (1976), such a system is necessary and sufficient for describing and replicating general intelligence. Defining intelligence as the ability of manipulating symbols implies that machines based on computers may rightfully be considered as intelligent agents, since they are able to process a logical formal system. However, robots controlled by a system of first-order logic acting in an environment is a contradiction. In fact, such a system operates robustly only if the logical system includes a number of axioms that exclude any arbitrary change in the environment (McCarthy & Hayes, 1969).

3. A new perspective on intelligence: embodiment and situatedness

In the following years, the symbolic approach to cognition and artificial intelligence has been widely criticized. One of the strongest and more robust argument against computationalism is a thought experiment that underlines the absence of a fully developed semantic in a cognitive theory that is solely based on an abstract symbol system. The Chinese room argument (Searle, 1980) creates a fictional scenario where an English speaker is locked inside a room with a set of rules for responding in a meaningful way to messages written in Chinese. Although the outcome is surely consistent with the Chinese language, the imaginary human subject does not have a true understanding of the ideograms. The central point of this argument is that a seemingly intelligent syntactical manipulation of symbols, an appropriate output given a certain input, is not a sufficient condition for intelligent behaviors. According to Searle's position (Searle, 1980), an intelligent agent must also understand the meaning of symbols, that is, the link between symbols and the real world (Cangelosi, Greco, & Harnad, 2002; Harnard, 1990).

Criticisms towards the physical symbol system hypothesis and computationalism come also from applied fields when roboticists realized that controllers based on formal symbolic logic are extremely fragile and inefficient (Brooks, 1990; Minsky, 1988; Moravec, 1988). During the sixties and seventies there have been several attempts to build intelligent robots with cognitive architectures based on abstract symbolic systems to represent the world. However, such cognitive systems had limited capacity to interact with the environment. In the middle eighties, Rodney Brooks proposed a completely different approach developing behavior-based robotics (Brooks, 1999). The central idea in Brooks' work is that the ”world is its own best model” (Brooks, 1999, p. 115) and using abstract symbols to represent the environment is expected to fail. As underlined by the author, evolution required a considerable amount of time to display basic locomotion skills and low level forms of intelligent behavior in the simplest organisms. Conversely, high level cognitive functions are a relatively novel fact in the history of life. Hence, human cognitive skills may not be the pinnacle of the evolutionary process. This argument is surely debatable and not immune from criticisms, for example following the biological theory of punctuated equilibrium that postulates sudden significant changes during the evolutionary process, rather than smooth and progressive modifications (Gould & Eldredge, 1977). However, the argument establishes a radical reinterpretation of the concept of intelligence, challenging an anthropocentric view of cognition. To overcome the inherent limits of representational architectures, Brooks developed the subsumption architecture: the problem that the robot faces, is divided into subtasks defined hierarchically. In the global architecture low level layers correspond to primitive behaviors such as obstacle avoidance, whereas high lever layers embody more abstract goals, for example exploring the world. The development of the whole cognitive architecture is build incrementally, following a bottom-up approach, where lower layers are implemented and debugged before the more abstract cognitive modules are added to the cognitive architecture.

The core idea behind behavior-based robotics is elegantly captured by Moravec's paradox (Moravec, 1988), claiming that it is relatively easy for a machine to successfully accomplish high-level tasks, e.g. playing chess, rather than solving real-time problems with a heavy load of sensorimotor activity and perceptual features. This view contrasts with the traditional opinion, based on an anthropocentric preconception, that higher level cognitive functions are the apex of intelligent behavior.

4. Defining embodied cognition: one word, several concepts

After 30 years of scientific investigation, the embodied view develops several ramifications with substantial different conceptualizations. A scientific field lacking of a precise definition and well-founded theoretical boundaries is especially problematic for computational modelers and roboticists. In fact, psychologists and neuroscientists deal with existing organisms, manifestation of phylogenetic and ontogenetic developments. On the contrary, computer scientists have to design and create their own agents and environments. Therefore, a well-founded theoretical ground is a necessary condition in order to operationalize and investigate a scientific theory. The debate around the definition of the umbrella term embodied cognition has been progressing for at least the past decade, without reaching a structured and univocal denotation. Several keywords have been created to name the novel perspective on cognition, each term bringing its own meaning of embodied cognition. In the existing literature, cognition is defined as grounded in perception and action (Barsalou, 2008), situated in a social and physical context (Barsalou, 2008; Beer, 1995; Maturana & Varela, 1991; Pfeifer & Bongard, 2006), and the mind is conceived as extended (Clark & Chalmers, 1998) and embodied (Lakoff & Johnson, 1999; Pfeifer & Bongard, 2006; Varela, Thompson, & Rosch, 1997). Furthermore, different approaches emphasize the role of either perception or action (Borghi & Caruana, 2015). All such terms share the same common ground, which is the fundamental role of the bodily interaction with the environment, thus rejecting an amodal explanation of conceptual knowledge. However, subtle differences drive the theory to substantial different paths.

Wilson (2002) made a first attempt aimed at organizing different