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INVITED ARTICLE

Origins and evolution of enactive cognitive science: Toward an enactive cognitive architecture

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Abstract
This paper presents a historical perspective on the origin of the enactive approach to cognitive science, starting chronologically from cybernetics, with the aim of clarifying its main concepts, such as enaction, autopoiesis, structural coupling and natural drift; thus showing their influences in computational approaches and models of cognitive architecture. Works of renowned authors, as well as some of their main commentators, were addressed to report the development of enactive approach. We indicate that the enactive approach transcends its original context within biology, and at a second moment within connectionism, changes the understanding of the relationships so far established between the body and the environment, and the ideas of conceptual relationships between the mind and the body. The influence on computational theories is of great importance, leading to new artificial intelligence systems as well as the proposition of complex, autopoietic and alive machines. Finally, the article stresses the importance of the enactive approach in the design of agents, understanding that previous approaches have very different cognitive architectures and that a prototypical model of enactive cognitive architecture is one of the largest challenges today.

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[1] Professor Leonardo Lana de Carvalho critically analyzed and improved the historical overview, leading to enactive cognitive architectures.

[2] Denis James Pereira created the first version on the historical overview on origins of cybernetics and enaction.

[3] Sophia Andrade Coelho collaborated with domains of language as complex systems.

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Introduction

Cognitive Science is an interdisciplinary field and its studies involve several areas of cognitive thought. The cognitive perspective is presented in many disciplinary sectors such as biology, education, linguistics, neurosciences, philosophy, psychology, anthropology, sociology, artificial intelligence, as well as knowledge engineering, ergonomics and human and social sciences. The methodological framework of cognitive science is research on the mind, cognition and behavior through computational models. Theories, models and computational implementations form a methodological triad on the basis of all cognitive investigation (Carvalho, Varenne, & Braga, 2014). This paper intends a historical presentation of the origin and evolution of enactive thought within the cognitive sciences, focusing on some of the major works in the area, related authors, and some of the scientific events of great importance for the consolidation of the cognitive science.[4] We start chronologically from cybernetics, with the aim of clarifying essential concepts, such as enaction, autopoiesis, structural coupling and natural drift. Thus showing their influences in computational approaches and modeling cognitive architectures.

It is interesting to start the historical overview[5] saying that cognitive science is embedded in natural philosophy and this maintains strong types of mechanical thinking today. A landmark of mechanicism we can say is the Digesting Duck built in 1739 by the engineer Jacques Vaucanson (1709–1782) who urged his spectators to think about the human being only as a very complex mechanical system. The *zeitgeist* involving natural philosophy, materialism and mechanism have enabled the development of cognitive science. Nevertheless, landmarks of enormous importance to the achievement of these sciences are Alan Turing's work (1912–1954). Turing published in 1936 the paper ''On Computable Numbers, with an application to the *Entscheidungsproblem*", and a correction in 1937, in which he exposes his machine. The Turing machine allowed to instantiate logical-mathematical operators in the machine and the manipulation of symbols through an algorithm in a limited and unambiguous system. Indeed, the view of Turing about the mind was nothing but a kind of mechanical procedure (Turing, 1950). Cybernetics as a social movement is considered to be the first academic discussion on the investigation of the mind/brain activity with logic-mathematical procedures (Silva, 2007). The Turing machine was the main influence for such debates and academic discussions. Warren McCulloch and Walter Pitts also contributed greatly to the development of cognitive sciences. In 1943, they published the article ''A logical calculus of the ideas immanent in nervous activity", which was considered another landmark for this interdisciplinary science.

With increasing interest in cybernetics issues, the cognitivism was founded in 1956 at the Symposium on Information Theory, held at the Massachusetts Institute of Technology. The great diversity of theoretical and methodological possibilities of cybernetics has been reduced or translated in the hypothesis of cognition as physical symbol systems. Despite the great importance of cognitivism, several objections arise to this thought; the most widespread is the Chinese Room of John R. Searle. After more than twenty years of cognitivism domain (Varela, Thompson, & Rosch, 1991/2001), important discoveries have led to the emergence and consolidation of connectionism. We highlight three relevant works: ''Perceptron" of Rosemblatt (1962); ''Neural networks and physical systems with emergent collective computational abilities", a work on neural network, written in 1982 by John Hopfield, and the work ''Computer Vision" published in 1982 and developed by Dana Harry Ballard and Christopher M. Brown.

Thus, this article presents the progressive context of the enactive approach to cognition from the development of the preceding cognitive approaches. Furthermore, the article focuses on the discussion of the enactive approach and a brief analysis of its influence in the renewal of computer models and cognitive architectures. Varela et al. (1991/2001) present the history of cognitive science as a normal science demarche, promoting theoretical advances with knowledge accumulation. The enactive theory is seen as the third way, followed by cognitivism and connectionism, respectively. We are sure that the misunderstanding about these previous approaches of cognition can profoundly deny any understanding of what the enactive cognitive science is, and its future development. This article proposes to bring out the history of cognitive science focusing on some foundations works of the different proposals of cognitive architectures.

[4] Seeking to highlight the interesting paths which led to the theory of enaction, we call the reader's attention to classic works of cognitive science. We seek to contextualize them with the publication dates, full titles already inside the text since these title are highly relevant and also mentioning academic events that occurred at that time, etc. What perhaps may be surprising to some people, is trying to show the history of science not only as a rational enterprise, ie, independently of the social body which accomplishes this individual activity (Laudan, 1977). Some authors, works and concepts are shared by approaches, however they diverge notoriously. We seek to present cognitive science not only as a tangle rational discourse on the mind, but also as an academic social movement, dynamic and non-linear.

[5] In relation to its historical aspect, this research follows the precepts of the theory of scientific growth of Laudan (1977, 1984). Laudan preserves scientific rationality and progress but shows that this is of great social influence, varying in function of social movements, especially academic networks. We can say that this social embodiment leads the process of evolution of science to numerous non-linear movements, which according to Laudan, can be best studied by cognitive sociology. Understanding how this social research activity is organized can enable better understanding about how individuals and scientists draw their ideas, comprehending better scientific growth. We invite the reader to scan the history of cognitive science and observe in details more than simple noises, but possibilities of realization. We argue that there have already been some instigating enactive notions in cybernetic fields, but at that time, researchers evolved in academic networks were not able to realize some concepts and procedures. Similarly, complex systems notions have occurred in the cognitive science, and prominently on the enactive theory of cognition, but only by the end of the nineties they have been presented as a research perspective on cognition and pointing innovations in the design of cognitive architectures.

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