Icon and Abduction: Situatedness in Peircean Cognitive Semiotics

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Abstract Differently from the anti-cartesianism defended by some embodied-situated cognitive scientists, which is predominantly anti-representationalist, for C. S. Peirce, mind is semiosis (sign-action) in a dialogical form, and cognition is the development of available semiotic material artifacts in which it is embodied as a power to produce interpretants (sign-effects). It takes the form of development of semiotic artifacts, such as writing tools, instruments of observation, notational systems, languages, and so forth. Our objective in this paper is to explore the connection between a semiotic theory of mind and the conception of situatedness and extended mind through the notions of iconicity and abductive inference, taking advantage of an empirical example of investigation in distributed problem solving (Tower of Hanoi).

1 Introduction

Charles S. Peirce can be considered an important precursor of situated mind and distributed cognition thesis. But differently from the anti-cartesianism defended by some embodied-situated cognitive scientists, which is predominantly anti-representationalist, as recently explored in a Merleau-Pontyan [1], Heidegerian [2], or a Gibsonian [3] trend, for Peirce, mind is semiosis (sign-action) in a dialogical—hence communicational—materially embodied form, and cognition is the development of available semiotic material artifacts in which it is embodied as a power to produce interpretants. It takes the form of development of semiotic artifacts, such as writing tools, instruments of observation, notational

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systems, languages, and so forth, as stressed by Skagestad [4] with respect to the concept of intelligence augmentation.

Although only recently a more systematic discussion upon the distributed nature of the mental processes have been established in empirical fields (e.g. neurocognitive science, artificial intelligence), the philosophical basis of this thesis and its variations have well-known predecessors. Among them, the most quoted are William James, Wittgenstein, John Dewey, James Gibson, Vigotsky, Merleau-Ponty, Heidegger (see [2, 5]). However, Charles Sanders Peirce, the least mentioned among the pragmatists in this context, can be considered an avant-garde situated and embodied cognition proposer. In Peircean Semiotic Theory of Mind the fundamental unit of cognitive interest is reconceived—disembodied mind is replaced by environmentally embedded space of semiotic skills and artifacts.

Our objective in this work is to explore the connection between a semiotic theory of mind and the conception of situatedness through the notions of iconicity and abductive inference, taking advantage of an empirical example of investigation in distributed problem solving (Tower of Hanoi). In the following sections we introduce: (i) the basic semiotic relations that ground a semiotic theory of mind, (ii) the notions of iconicity and abductive inference as specially near to the conceptualization of situatedness and distributedness of reasoning, (iii) the experiment of the Tower of Hanoi, conducted by Zhang and Norman [6], analyzed through the framework provided.

2 Semiosis and Semiotic Theory of Mind

Peircean approach of semiotic processes (semiosis) is related to formal attempts to describe cognitive processes in general. This framework provides: (i) a pragmatic model of semiosis, (ii) a conception of mind as a sign-interpretation process (see [7]), and (iii) a list of fundamental varieties of representations based on a theory of logical-phenomenological categories.

According to the Peircean model, a meaning process involves a relational complex constituted by three terms *irreducibly* connected—Sign, Object and Interpretant (S–O–I). The *irreducibility* indicates a logical property of this complex: the sign process must be regarded as associated to the *interpretant*, as an ongoing process of interpretation [8], and is not decomposable into any simpler relation (CP 5.484). Peirce also defines a sign as a medium for the communication of a *form* or *habit* embodied in the object [9, 10]. This *form* is communicated to the interpretant, so as to constrain (in general) the interpretant as a sign or (in biological systems) the interpreter's behavior. The object of sign transmission is a habit (a regularity, a rule of action, or a 'pattern of constraints') embodied as a constraining factor of interpretative behavior—a logically 'would be' fact of response. The habit embodied in the object allows a semiotic system to interpret the sign as indicative of a class of entities or phenomena [11]. Meaning and meaning change are conceived as a constraining factor of possible patterns of

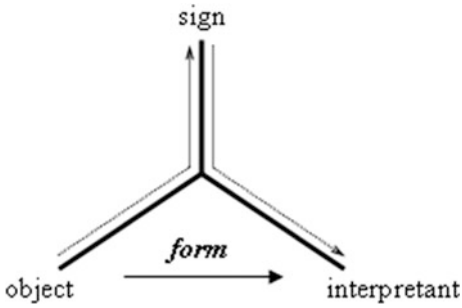

Fig. 1 Semiosis as a relation between three irreducibly connected terms (sign-object-interpretant, S–O–I). This triadic relationship communicates a form from the object to the interpretant through the sign (symbolized by the *horizontal arrow*). The other *two arrows* indicate that the form is conveyed from the object to the interpretant through a determination of the sign by the object, and a determination of the interpretant by the sign

interpretative behavior through habit and change of habit. The mediation of a sign results in a consistent relationship between variations in the form of the object and the corresponding effects on the interpreter (Fig. 1).

Sign-mediated processes show a remarkable variety. The construction of appropriate typologies of these processes is a requisite for a deeper and more refined understanding of cognition. In an attempt to advance in the understanding of semiotic processes, Peirce proposed several typologies, with different degrees of refinement and several relationships to one another. A basic typology in his framework differentiates between iconic, indexical, and symbolic processes.

3 Fundamental Kinds of Signs: Icons, Indices, and Symbols

Icons, indices, and symbols are differentiated by Peirce based on how the sign relates to its object, that might be defined as the item to which the interpretants are related by the mediation of sign (see [12]). This typology exhibits a property capable of functioning as an operational criterion to distinguish different kinds of signs: the relative dependence of sign-object-interpretant (S–O–I) components in triadic relation [13, 14].

A symbol is an S–O relationship logically dependent of I. This relation has been characterized as a law ascribing S–O. A symbol is "a Sign (q.v.) which is constituted a sign merely or mainly by the fact that it is used and understood as such, whether the habit is natural or conventional, and without regard to the motives which originally governed its selection" (CP 2.307). Differently, an index is dependent of O. The relation between S and O has been characterized as one of contiguity: constraints resulting from the space–time existence of the object—irrelevant in symbolic processes—are the reason for the representation of O

Table 1 The fundamental types of signs underlying meaning processes—icons, indexes, and symbols

Type of sign	S–O relation	S–O–I dependence	
Icon	Similarity	Monadic (S)	Dependent of intrinsic properties of S
Index	Contiguity	Dyadic (S–O)	Dependent of S–O spatio-temporal correlation
Symbol	Law	Triadic (S–O–I)	S–O dependent of I mediation

They are characterized in terms of relative dependence of sign-object-interpretant (S–O–I) components in triadic relation. The icon is the sign whose relevant properties for signification are its own intrinsic qualities: S depends on S

through S. In that case, S is really determined by O, in such a way that both must exist as events. The notion of spatio-temporal co-variation is the most characteristic property of indexical processes. When S is an icon, S signifies by means of qualities of S. Icons are dependent on the material, form and structure that are made–"An Icon is a sign which refers to the Object that it denotes merely by virtue of characters of its own, and which it possesses, just the same, whether any such Object actually exists or not" (CP 2.247). This relation between S and O based on the qualities of S has been characterized as one of similarity. The problem with the notion of similarity, however, is that it is too vague (see [15]). In order to detrivialize the notion of icon as a sign based on similarity it is possible to give an operational definition of the icon (Table 1).

4 Iconicity: Operational Notion

The icons' dependence of its own materiality makes them suitable for modeling and experimentation. When an *operational criterion* is adopted, the icon is defined as anything whose manipulation can reveal more information about its object. Algebra, syntax, graphs, and formalizations of all types should be recognized as icons. This definition is considered a detrivilization of the notion that the icon is fundamentally based on a relation of similarity (see [15]; also [16]).

> The key of iconicity is not perceived resemblance between the sign and what it signifies but rather the possibility of making new discoveries about the object of a sign through observing features of the sign itself. Thus a mathematical model of a physical system is an iconic representation because its use provides new information about the physical system. This is the distinctive feature and value of iconic representation: a sign *resembles* its object if, and only if, study of the sign can yield new information about the object [16, p. 102].

The icon is notably related to situatedness and distributedness of reasoning. It is the sign whose signification is S-dependent (that means, dependent on the sign itself) and allows, through its manipulation, some discovery about the object. The notion of iconicity attests the capacity of material features to be the semiotic basis of cognitive operation, and not only play a secondary role.

5 Abduction: First Stage of Inquiry

Inferences are also understood as semiotic processes and have a place reserved under Peirce's typology. They are classified into three irreducible types –abduction, deduction and induction—corresponding to three subsequent phases in the process of scientific inquiry (CP 6.469-473). Abduction rises from the observation of a mass of facts that doesn't fit into the habits and expectations of the observer and culminates with the formation and selection of a hypothesis. Deduction develops testable consequences of the previously generated hypothesis. Based on these consequences, induction performs tests to evaluate it.

The characterization of abduction as the transformation of mass of facts into hypotheses and the first stage of inquiry brings it close to perception (see [17, 18]). For Peirce, perception involves an interpretative process (CP 5.181). It is through an inferential-like perceptual judgment that percepts are subsumed under general classes. This perceptual judgment accounts for the transformation of sense data into knowledge applicable to theoretical or practical use. It is subconscious, but if it was subjected to logical analysis, it would present an inferential—abductive—form (CP 5.181). Therefore, "all that makes knowledge applicable comes to us via abduction" (MS 692).

As an "act of insight" that "comes to us like a flash" (CP 5.181) abduction is germane to creativity. For Peirce, abduction is also the logical inference by which new knowledge can be obtained: "Abduction consists in studying the facts and devising a theory to explain them. It is the only kind of argument which starts a new idea" (CP 2.96). Magnani [19] introduces the concept of "manipulative abduction" to refer to those cases where the inference depends on the exploration of external resources—it "happens when we are thinking *through* doing and not only, in a pragmatic sense, about doing" [19, p. 274]. According to Paavola [20], in abduction the iconic character of reasoning is more prominent. Icons, abductions and perceptual judgments all have important similarities between themselves.

> In all of them, some characteristics or phenomena suggest a potential way of interpreting or explaining these characteristics or phenomena and bringing them into some kind of an order [20, p. 305]

Paavola has referred to these characteristics that only *suggest* a way in which they could be interpreted as *clue-like* characteristics. In abduction, these clue-like characteristics, together with background knowledge, lead to the conclusion of a hypothesis (i.e., a promising way of arranging a mass of facts). This is a distributed process whenever these *clue-like characteristics* are predominantly material qualities of external signs. Abduction is especially near to the conceptualization of distributedness because it is an inference which relies on a mass of percepted data for its conclusion.

To see how iconicity and abduction are related to situatedness, we analyze in the next section an example of distributed reasoning. More specifically, we

identify the role of both icons and abductions in the distributed problem solving task of the Tower of Hanoi.

6 Externalization of Constraints as an Iconic-Embedded Abductive Process

The Tower of Hanoi is a puzzle game. It is (normally) constituted of three poles and several disks of variable diameters with a hole in the centre in order to be stacked in the poles (see Fig. 2). The diameter of the disks represents the hierarchy according to which they may be organized or moved across the poles. The goal of the game is to rearrange the disks from a specific initial state to a specific goal state, while observing some basic rules. The formal structure of the game is composed by the pieces (disks, for example), places (poles), hierarchy (disk diameters), rules, initial state, and goal state.

Zhang and Norman [6] have used the tower of Hanoi game to study the influence of representations in cognition. More specifically, they were dealing with the Representational Effect: difference in cognitive behavior caused solely by representational features. The Representational Effect is investigated through the comparison of performance upon isomorphic representations in problem solving tasks, i.e., representations that carry the same amount of information, but that vary in the way that this information is presented. In the experiment treated here, the authors have used the isomorphic versions of the Tower of Hanoi puzzle showed in Fig. 3.

Zhang and Norman's tests covered several levels of isomorphism between representations (level of object representations, level of dimensional representations, level of rule representations and level of problem space structures). The particular experiment that interests us (experiment 2, Zhang and Norman [6],

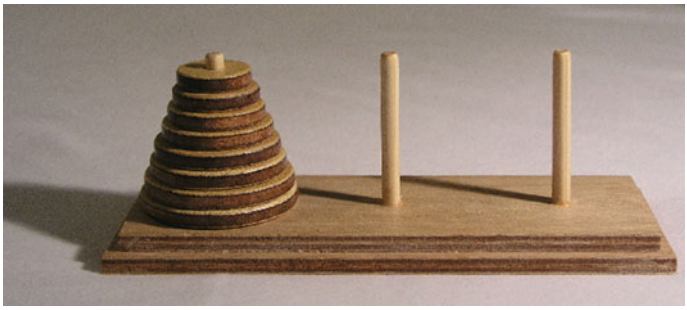

Fig. 2 The classical version of the Tower of Hanoi puzzle, with three poles and several disks stacked from the largest, in the base, to the smallest, in the top. In the experiments treated here, this order was altered: larger pieces should be put on top of smaller pieces. Image taken from Wikimedia Commons

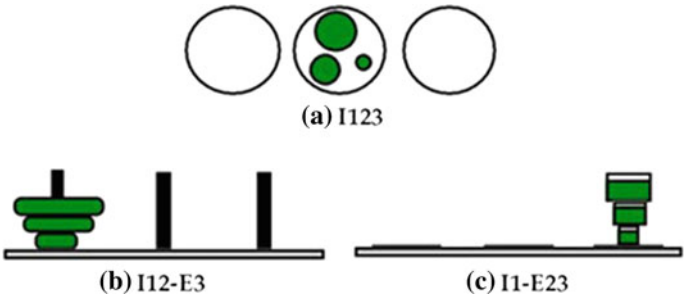

Fig. 3 Three isomorphs of the tower of Hanoi which vary in respect to the externalization of constraints. In **a** the three rules of the game are internal. In **b** two of the rules are internal and one is external. In **c** only one of the rules is internal, and the other two are external [6]

pp. 20–23) is the level of rule representations. In this level, the rules of the game itself can be represented in two ways: they are either (i) stated in instructions and memorized by the players or (ii) automatically embedded in the possibilities of move offered by the material of play. Rules introduced according to (i) and (ii) are termed, respectively, *internal* and *external* rules, kept, in the act of play, either in the memory of the players or in the material of play itself.

There were three rules in the game for this experiment (see Table 2) and two ways in which these rules could be introduced (internal or external rules). Three isomorphs were used (see Table 3) the, "waitresses and oranges", "waitresses and donuts" and "waitresses and coffee", that differently represent the elements that compose the formal structure of the game. The oranges version utilizes balls ("oranges") as the pieces, plates as the places and the size of the balls as the hierarchy. The donuts version utilizes disks ("donuts") as the pieces, poles as the places and the diameter of the disks as the hierarchy. The "coffee" version utilizes cups filled with coffee as the pieces, plates as the places and the size of the cups as the hierarchy. Each of the three rules were either internal (given as a list of

Table 2 Rules of the TOH, experiment 2

1. Only one piece can be transferred at a time
2. A piece can only be transferred to a place on which it will be the largest
3. Only the largest piece in a place can be transferred to another place

Table 3 Isomorphic representations of the game's formal structure

	"Oranges" (I123)	"Donuts" (I12 E3)	"Coffee" (I1 E23)
Pieces	Balls	Disks	Cups filled with coffee
Places	Plates	Poles	Plates
Hierarchy	Size of balls	Diameter of disks	Sizes of cups
Rules	1. Instruction	1. Instruction	1. Instruction
	2. Instruction	2. Instruction	2. Material
	3. Instruction	3. Material	3. Material

instruction read before the experiment and memorized by the players) or external (automatically embedded in the material of play). In the "oranges" version, all the three rules were internal (I123). In the "donuts" version, rules 1 and 2 were internal and rule 3 was external (I12 E3). In the "coffee" version, only rule 1 was internal and rules 2 and 3 were external (I1 E23). The oranges version is internal in respect to all rules because the balls in plates can be physically moved without any constraining in relation to each other. The donuts version is external in respect to rule 3 because the stacking of disks in poles only allow that the disk in top be physically moved (unless you take more than one disk, but in this case you would be breaking the internal rule 1). The coffee version is external in respect to rules 2, 3 because, beyond being stacked one on top of the other (rule 3), a smaller cup, filled with coffee, cannot be placed on top of a bigger cup, filled with coffee, because in this case the coffee will spill. In a context where it is understood that spilling coffee is bad, rule 2 has also been externalized.

The experiment measured the time required for solution, the number of steps required for solution and the number of wrong moves for each of the three isomorphs. In the three cases, the results for the most internalized version (oranges) were the worst: more time to solve, more number of steps required to solve and more wrong moves. For the most externalized (coffee) the results were the best: less time to solve, less number of steps required and almost no wrong moves. The donuts version stayed in the middle (see Fig. 4). This experiment, together with others in the same article, have led the authors to propose that more externalized representations are also more efficient representations for problem solving (see also [21, 22]).

The criterion the authors have used to classify between internal and external rules matches a criterion for iconicity, namely, dependence of material properties, i.e. S-dependence. The different isormophs of the experiment can be modeled as semiotic processes of communication of a form or habit from an object to an interpretant through the mediation of the sign. The object (O) of this triadic relation is the formal structure of the game that is common to all isomorphs. The sign (S) is the medium through which the game is played, i.e., the specific pieces and places and also the list of written instructions. The interpretant (I) is the constraining in behavior that characterizes the act of play itself. With this

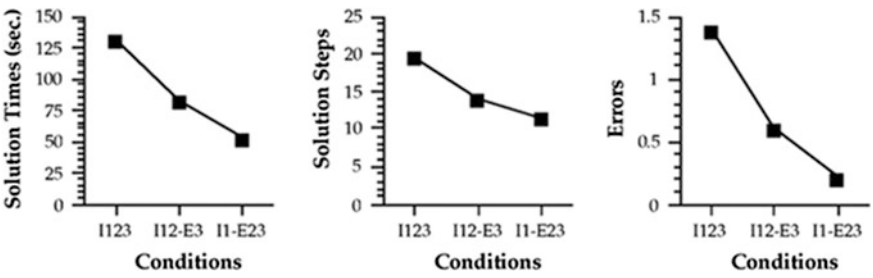

Fig. 4 Results of the experiment for each of the isomorphs [6]

framework in mind, and taking into consideration the criterion of relative dependence of terms for the fundamental classification of signs, we conclude that, for the (i) internal and (ii) external cases:

(i) O (formal structure of the game) is independent of S (material of play). If you change the materials used to play, the game remains the same. The S–O relation cannot be established by these two terms alone, it requires the mediation of a third term (I). The constraining upon the specific material of play, that makes it correspond to the formal structure of the game, only happen as a cognitive constraining in the behavior of the player, in the act of play itself. As S–O relation is dependent of I, this is an example of symbolic semiosis.
(ii) The game is S-dependent. If you change the materials used to play, the formal structure of the game changes. The S–O relation is already established independently of the third term (I), because the constraints of S are a materialization of the formal structure of the game. The constraining upon the specific material of play, that makes it correspond to the formal structure of the game, is already given in the material of play, before the game is played. As S–O is dependent of S, this is an example of iconic semiosis.

The results for this particular case can be generalized to any other case of externalization of constraints. First, because to be *external* implies to be physically materialized. Second, because the constraints of the physical material limit cognitive behavior, and not the other way around. Therefore, to say that a representation is external in respect to some constraints already implies that these constraints are S-dependent, and that we are dealing with iconic semiosis.

To identify the role of abduction in this process, we stress the inferential activity involved in making each move in the game. To solve the game, the player must arrive at some conclusion as how to arrive at a goal state departing from an initial state. To do that, he/she passes through intermediary problem states. The player is making inferences whenever he makes decision as how to pass from one problem state to another. To go from one problem state to another, the player needs to move according to the rules. The rules give the player a certain number of possibilities that he can choose between. This inference is abductive because it is fallible (i.e., it doesn't necessarily conclude the best solution to play) and takes the form of the formation and selection of possible hypothesis of play by departing from a set of constraints.

Figure 5 shows three diagrams depicting constraints in the game. Each node of the diagrams is a problem state, i.e., a particular arrangement of pieces in their places. Each line of the diagrams is a possibility to move from one problem state to another, i.e., to move a piece in the game, according to the rules. One of the nodes is the initial state. Another node is the goal state. To play the game is to go from the initial state node to the goal state node through the possibilities offered by the lines. In the first diagram we have the possible moves as constrained only by the rule 1. In the second diagram we have the same, but now for rules 1, 2 and 3. Let's imagine that these diagrams corresponded to externalized isomorphic representations of the TOH. The first diagram would be a representation in which only rule 1

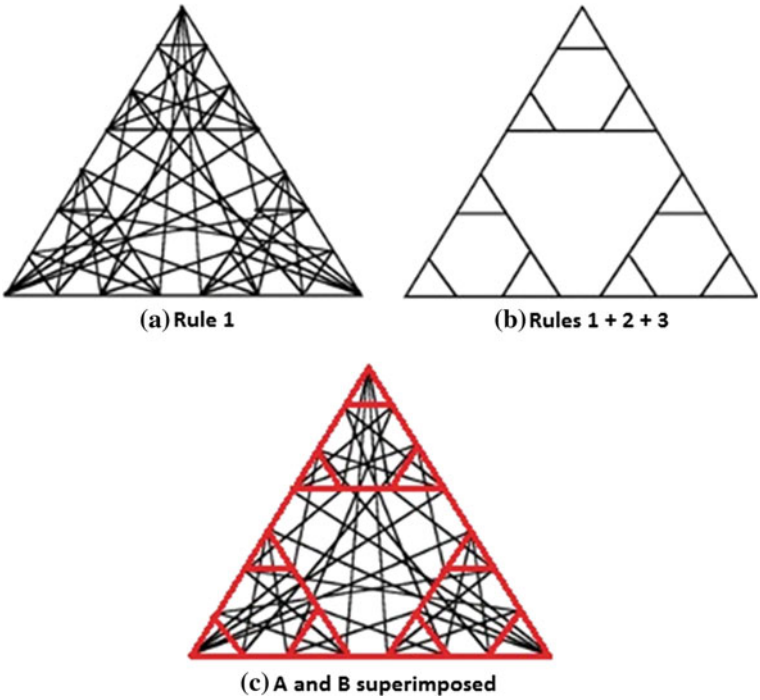

Fig. 5 Constraints of the game for Rule 1 (**a**) and Rules 1 + 2 + 3 (**b**). **c** A superimposition of **b** upon **a**. Adapted from Zhang and Norman [6]

is externalized. The second diagram would be a representation in which all the three rules are externalized. In the game, to perform a move that is out of the rules is considered an error. Therefore, the second diagram, which includes the constraints of all the rules, represents an error-proof scenario (regarding errors that are caused because of moves that are out of the rules). The third diagram shows a comparison between the two isomorphs. In black, is all that was wrong and have been ruled out by the second isomorph in relation to the first. In this sense, we can see the material as a selector of possibilities of play.

A more externally constrained representation is also one where there are fewer possibilities to move the pieces. This doesn't mean that no inferences are present. There is an inferential and perceptual process in the act itself of dealing with the external constraints. For example, when a player chooses to move a cup of coffee to a certain place instead of another because in this better place the coffee will not spill. This inference is supported by external constraints that, as we have seen, are icons of the formal structure of the game. Externalization of constraints (and therefore iconicity) acts as a way to build *better* materials of play. *Better*, here, refers to an economy of possibilities, to the supporting of abductions by the materials of play. In this sense, we have an example of abductive process which is distributed in iconic-embedded features of an externalized semiosis.

7 Situated Semiotic Theory of Mind: Some Implications of Abduction and Iconicity

We have presented an externalist semiotic perspective of cognition, where mind is the result of manipulation of signs and (i) manipulation is described by irreducible forms of inferences; (ii) signs are classified by different morphologies. Abduction and iconicity correspond respectively to the categories of inference and sign processes in which the situated aspect of Peirce's conception of mind is especially conceptualized. Abduction is a weak form of inference (see [23]) related to perceptual features, while the icon is the S-dependent semiotic process. This treatment suggests that a reconsideration of the embodied-situated paradigm's own philosophical foundations can behave in semiotic terms. Peirce's semiotic theory of mind neither restricts representations to symbolic semiosis and inferential processes to deduction and induction as in ortodox representationalism, nor rejects representations and inferences as in anti-representationalism (see Table 4).

This position was exemplified in the case of externalization of constraints in the Tower of Hanoi puzzle. In the example, the task of deciding how to move the pieces of the puzzle was crucially dependent on the materiality of the play, so that isomorphic representations that varied their representational features had great influence on the cognitive behavior of the players (Representational Effect). The game play was facilitated when constraints (the set of rules) were externalized. Externalization of constraints in this context corresponds to the embedment, in an external sign, of better chances to reach an adequate conclusion. We have argued that this process is abductive: it limits the universe of possible moves to a few optimal ones, performing a selection of hypotheses; it provides, through perception, an optimal hypothesis for further consideration; it gives the first step for the solution of the problem.

Table 4 Comparison between orthodox representationalism, anti-representationalism and the Semiotic Theory of Mind

	Representationalism	Anti-representationalism	Semiotic theory of mind
Signs	Symbolic	No	Not only symbolic but indexical and iconic
Inferences	Deductive, inductive	No	Deductive and inductive and abductive
Locus	Internal	External	Inference relies on internal and external resources

8 Conclusion

Recently, the distributed cognition and extended mind approach (see [24, 25]) have questioned the legitimacy of skin and skull to serve as criteria for the demarcation of the boundaries between mind and the outside world. The acceptance of external representation as parts of human cognition leads to different conceptions on the relation between cognition and environment. As we adapt the environment to facilitate our purposes, deploying our mind in external representations, we participate in the construction of cognitive niches, which fundamentally alter our cognitive capabilities (see [26]).

According to Peirce's semiotic theory of mind, thinking *is* semiosis, the process of sign action. While "representationalist", the semiotic theory of mind expands the understanding of signs and inferences beyond orthodox representationalist notions, making it possible to combine representations with an externalist view of the mind. Against any form of internalism, Peirce can be considered a precursor of situated mind and distributed cognition thesis. In the example treated, some of the best solutions, or "ideas" about how to win the game, were embedded in the outside world. Inferences were drawn based on perceptual qualities of material objects rather than an abstract understanding or the 'mind's-eye'. Peirce's broad ideas concerning signs and inferences are an important tool for advancing in the development of an externalist theory of mind.

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