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At the root of embodied cognition: Cognitive science meets neurophysiology

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Abstract

Recent experimental research in the field of neurophysiology has led to the discovery of two classes of visuomotor neurons: canonical neurons and mirror neurons. In light of these studies, we propose here an overview of two classical themes in the cognitive science panorama: James Gibson's theory of affordances and Eleanor Rosch's principles of categorization. We discuss how theoretical perspectives and neuroscientific evidence are converging towards the current paradigm of embodied cognition. From this perspective, we discuss the role of action and simulation in cognitive processes, which lead to the perceptual recognition of objects, and actions and to their conceptual categorization.

Keywords: Embodied cognition; Canonical neurons; Mirror neurons; Perception; Action; Categorization; Simulation

1. Perception, action, and simulation

1.1. From Gibson's theory of affordances to the paradigm of embodied cognition

The concept of affordance plays a central role in the ecological perspective, proposed by Gibson in his *The Ecological Approach to Visual Perception* (1979). Gibson coined the term of affordance to refer to the offers, consistent in opportunities of interaction, that the objects present in the environment possess in relation to the sensorimotor capacities of different animals: "The *affordances* of the environment are what it *offers* the animal, what it *provides* or *furnishes*, either for good or ill" (p. 127). Different objects in the world offer different affordances for manipulation or nutrition; other animals, in turn, offer complex affordances, like "a rich and complex set of interactions, sexual, predatory, nurturing, fighting, plying, cooperating, and communicating" (p. 128). Gibson maintained that affordances are intrinsically part of objects themselves and are not constructed from an observer's needs or intentions. The value and meanings of things in the environment can be directly perceived: "The observer may or may not perceive or attend to the affordance, according to his needs, but the affordance, being invariant, is always there to be perceived" (p. 139).

In reconstructing the origins of the concept of affordance, Gibson referred to what Koffka defined as the *demand character* of an object in his *Principles of Gestalt psychology* (1935) "Each thing says what it is ... a fruit says 'Eat me'; water says 'Drink me'; thunder says 'Fear me'; and woman says 'Love me' ... the postbox 'invites' the mailing of a letter, the handle 'wants to be grasped', all things tell us what to do with them" (Gibson, 1979, p. 138). Gibson acknowledged that his concept of affordance derived from Koffka's concepts of *valence*, *invitation*, and *demand*, but with a crucial difference: "The affordance of something does

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not change as the need of the observer changes. An affordance is not bestowed upon an object by a need of an observer and his act of perceiving it. The object offers what it does because it is what it is" (pp. 138–139).

Hence, the central point of Gibson's theory was his explicit refusal of the dichotomy between *action* and *perception* and the underlying dualism between physical and mental capacities; "So we must perceive in order to move, but we must also move in order to perceive" (p. 223). Gibson's pioneering efforts and his ecological perspective certainly represent a fundamental antecedent for the paradigm of *embodied cognition*, which is steadily making headway in the panorama of cognitive science. Lakoff and Johnson (1999) effectively described this progressive mutation of the cognitive science paradigm, by distinguishing between first generation and second generation cognitive science, defining them *disembodied mind* and *embodied mind*, respectively. The first generation of cognitive science coupled the computational metaphor of cognitive processes as software-independent of cerebral hardware- with an abstract conception of reason, which, in a Cartesian way, was considered as being independent from the body and its activity. Conversely, the central point of second generation cognitive science is represented by close interaction between mind and body, between thought and action, between rational schemas and sensorimotor schemas.

Just as Varela, Thompson, and Rosch (1991) before them, Lakoff and Johnson identified the matrix of the concept of *embodied* in the phenomenology of Merleau-Ponty (1945/1962) and in the dual valence of the notion of *body* within it: bodiness is a combination of a physical structure (to the biological body) and an experiential structure, which corresponds to the living, moving, suffering, and enjoying body. From here we arrive at the dual acceptation of embodied cognition, which refers, on one hand, to the grounding of cognitive processes in the brain's neuroanatomical substratum, and on the other, to the derivation of cognitive processes from the organism's sensorimotor experiences. Therefore, second generation cognitive science differs from the first, not only in its refusal of computational functionalism, but also in the actual conception of its subject, human cognition. Instead of abstract mental processes, which are describable in formal terms of logic, cognitive processes are considered in light of their intrinsic ties to the body's action, and sensorimotor experience (Feldman & Narayanan, 2004). This is a crucial aspect of the issue, underscored earlier by Gibson.

Varela et al. (1991) clarified the dual valence of the concept of *embodied* in expounding their theory of cognition and embodied action: "By using the term *embodied* we mean to highlight two points: first, that cognition depends upon the kinds of experience that comes from having a body with various sensorimotor capacities, and second, that these individual sensorimotor capacities are themselves embedded in a more encompassing biological, psychological, and cultural context" (pp. 172–173). The authors also clarify the term *action* by affirming that sensory and motor processes, perception, and action are fundamentally inseparable in lived cognition. For biological organisms, action, and perception "are not merely contingently linked in individuals; they have also evolved together" (p. 173).

1.2. Neuroscientific evidence

This node linking action and perception so closely to the notion of embodied cognition has been further consolidated by the use of modern neuroscientific research instruments, thereby contributing to a mutation of the neuroscience paradigm, which centered on a new conception of the motor system. This system was previously considered to be exclusively at the center of action planning and execution. Gibson (1979) had already identified "the old doctrine of mental sensations and physical movements" (p. 225) in standard neurophysiological terminology, which classifies nerve impulses as *sensory* (incoming) and *motor* (outgoing). Contrary to this dualism, the most recent research in experimental neurophysiology allows us to see motor system in a new light. According to Gallese (2000) "the so-called 'motor functions" of the nervous system not only provide the means to control and execute action but also to represent it" (p. 23). This new research perspective allows for the correlation of action and perception on a neural level, thereby clarifying the concept of sensorimotor, which is at the core of the embodied cognition paradigm.

In a series of studies, Rizzolatti and colleagues (Di Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992; Fadiga & Craighero, 2003; Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Rizzolatti et al., 1988; Rizzolatti & Fadiga, 1998; Rizzolatti, Fadiga, Gallese, & Fogassi, 1996) described two classes of visuomotor neurons found in the premotor cortex of primates (including human beings), i.e., canonical and mirror neurons, which are bimodal neurons equipped with motor and visual properties. The fundamental characteristic of these neurons is that they can fire during tasks involving the execution of actions as well as during tasks involving pure observation. The two types of neurons are located in two different parts of area F5 (a sector of the lower portion of Brodmann's area 6): canonical neurons are found mainly in the rear section of the arcuate sulcus, while mirror neurons are found almost exclusively in the F5 cortex convexity.

Canonical neurons respond selectively to presentation of a three-dimensional object, in function of its shape, size, and spatial orientation. The above-mentioned studies found strong congruency between motor and visual specificity. For example, if a neuron activates during *whole-hand prehension*, it fires even during mere observation of a large object, but does not fire for a small one. Vice-versa, if a neuron is active during *precise prehension*, it fires even during observation of a small object, but it does not fire for a large one. The most interesting aspect of canonical neurons is that the same neuron fires not only in response to the same object, but also in response to a group of objects that have the same characteristics, in terms of the type of interaction they allow. At this level of description, an object can be codified "on relational terms," i.e., it can be identified and represented in relation to the type of action that it *affords* an interacting subject. This means that the type of interaction that is established with an object is a constitutive part of the representation of the object itself. In other words, different objects can be represented in function of the same type of interaction they allow. What makes this type of object representation possible is a mechanism of *as-if* neural simulation: while observing an object, the neural system is activated *as-if* the observer were interacting with it.

Mirror neurons represent the second class of bimodal visuomotor neurons. These neurons are active during the execution of actions, finalized at attaining an object. Like canonical neurons, even mirror neurons can fire during an observation task, in the absence of any active movement. Contrarily to canonical neurons, however, mirror neurons do not respond to the presentation of objects, but to observation of actions carried out by other individuals. Hence, mirror neurons represent a mechanism capable of coupling the execution and observation of actions: the observation of another individual's action, evokes a specular response in the neural system of the observer, which is activated *as-if* he himself were carrying out the action that he is observing.

The existence of a mechanism coupling the execution and observation of actions decidedly confirms the role of the premotor area, not only in the planning of movements, but also in the representation of action in the abstract terms of its underlying purpose. Activation of mirror neurons has been found only in relation to transitive movements, in which the hands or the mouth interact with objects. Intransitive movements, which do not imply interaction with an object, such as arm-waving or whole body gesticulation, do not activate these neurons. A classification of mirror neurons has thus been proposed, based on different types of transitive hand movements, e.g., neurons for *grasping*, *holding*, *manipulation*, and *releasing* (Fadiga & Gallese, 1997). This classification reveals the role of motor neurons in actions that are required for interaction with an object, action finalized towards reaching a determined goal. In fact, mirror neurons are intended for an action's underlying purpose and not for the single movements required or the effector used.[1] Furthermore, as Kohler et al. (2002) demonstrated, mirror neurons can represent the same action according to different modalities: the same neuron fires if a given action is either executed or observed, or even if the sound it produces is heard. In particular, mirror neuron activation was observed for a monkey that was kept in the dark and heard an action-produced noise. Specifically, the same neuron fired when the animal cracked a nut, as when it saw someone cracking it, as when it heard the noise of someone cracking it. These observations have lead researchers to conclude that it is the concept of "breaking a nut" that is somehow recorded in the neuron. The implication is that mirror neurons can represent the meaning of an action, independently of the fact that an animal has directly executed an action or has had simply heard or seen it.

1.3. The concept of affordance in light of the discovery of canonical neurons

"The observer who does not move, but only stands and looks is not behaving at the moment, it is true, but he cannot help seeing the affordances for behavior in whatever he looks at" (Gibson, 1979, p. 223). The concept of affordance implies interaction between characteristics in the environment and an organism's sensorimotor capacity. The mere observation of an object, even in absence of any explicit behavior directed at it, allows an organism to directly perceive the significance of the object in terms of the opportunities for interaction that it offers. Perception of an object's characteristics, its shape and its dimensions, or, as Gibson would say, its "surface's layout," becomes one with perception of the actions that could be executed with it. "The point to remember is that the visual control of the hands is inseparably connected with the visual perception of objects. The act of throwing complements the perception of throwable objects. The transporting of things is part and parcel of seeing them as portable or not" (p. 235). The concept of affordance directly couples perception and action: there is no elabo-

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[1] Mirror neurons present "average congruency," i.e., resemblance, and not necessarily identity between executed action and observed action (Gallese et al., 1996). This datum further confirms the "abstract" character of motor representation codified in the F5 area. The same neuron is activated during execution and observation of actions that are not identical in terms of the exact movements with which they are executed, but are similar in terms of their intended purpose.

ration of sensorial information, nor successive translation into motor input, but the motor interaction schema is already specified in its perceptual content and is an integral part of it.

Now, the discovery of canonical neurons provides definitive evidence for the existence of a mechanism in which object shape and function are coupled and directly perceived by the observer. As previously described, canonical neurons fire both when an object is only seen and when an action is executed with it. The activation is not specific only to the object's characteristics (shape, dimension, and spatial orientation), but to the type of interaction it allows, the exact same mechanism hypothesized by Gibson: "If the object is hand-size, it is graspable; if too large or too small, it is not. Children learn to see sizes in term of prehension: they see the span of their grasp and the diameter of a ball at the same time" (p. 234). Rizzolati and colleagues investigated congruency between motor and visual specificity, finding a strong correspondence between the two modalities: a neuron that is active during whole-hand grasping is also active during observation of an appropriately sized object, but not with a larger or smaller object. Canonical neurons allow identification and representation of an object according to the type of interaction it affords an agent: an interaction involves an object's characteristics at the same time it involves the organism's sensorimotor schemas.

The action–perception dichotomy has therefore proven to be inadequate in describing this new *sensorimotor* concept. In fact, bimodal neurons have also been identified (Buccino et al., 2001) in the parietal lobes, traditionally considered the center of sensorial elaboration. These neurons have visual and motor characteristics that are analogous to those of premotor cortex canonical neurons. Gallese (2000) suggests that if we are to fully understand the concept of sensorimotor as incorporated in bimodal neurons, we need to refer to an action's control strategy. It is interesting to note how even Gibson (1979) referred to *control* of an action to explain how an organism perceives both an object's shape and its appropriate interaction schema: "Locomotion and manipulation are neither triggered nor commanded, but controlled... Control lies in the animal–environment system. Control is by the animal in its world, the animal itself having subsystems for perceiving the environment and concurrently for getting about in it and manipulating... The question is how this can be" (p. 225). Gibson does not say what these "subsystems" are, which are used to perceive the environment and act within it, but he specifies a set of "rules for control", which he says are not "orders" or "commands," but "rules not formulated by words."

The discovery of canonical neurons allows clarification of this point and further specification of the concept of affordance in terms of *simulation schema*.[2] In fact, a third term must be added to the relation between *action* and *perception*, i.e., that of *simulation*. While observing an object, the neural system is activated *as-if* the observer were interacting with it. "To observe objects is therefore equivalent to automatically evoking the most suitable motor program required to interact with them. Looking at objects means unconsciously 'simulate' a potential action" (Gallese, 2000, p. 31). Only by virtually executing the action can we understand the relational significance of the object, i.e., the affordance it offers. The concept of simulation allows us to comprehend the relationship between *control* of action and *representation* of action. A motor schema allows us to execute an action as well as represent the object the action refers to; in the first case, there is explicit codification of the motor schema, in the second, there is implicit simulation of it.

This level of neurophysiological analysis supports Gibson's thesis, providing evidence for a dynamic dimension to perception and by emphasizing an intrinsic link with the sphere of action. Yet, by explaining the concept of affordance in terms of a simulation schema based on canonical neurons, Gibson's original intentions are partially betrayed. While Gibson saw cognitive processes as consisting of the *direct perception* of affordances an object offers directly to a perceiving subject, the hypothesis of a simulation schema can be better collocated in a constructivist paradigm, which emphasizes the role of subjective anticipation in the construction of a perceptual object. In explicit contrast with Gibson, Gallese (2000) has emphasized the positive role of action in integrating the perceptual process: "the object-representation is transiently integrated with the action–simulation... Gibson assigns to active but also to passive movement a purely instrumental role in defining the invariant features already present in sensory data" while conversely, an "object's invariance should not be considered an intrinsic feature of the physical world, but rather the result of the peculiar interactions with the acting organism" (p. 31).

While the concept of affordance can be considered part of direct realism, the *simulation schema*, emerging from research on canonical neurons, can be understood

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[2] A similar hypothesis of "simulation schema" was formulated by Paternoster (2001) within a cognitive theory of semantic competence. In his analysis of language comprehension mechanisms (of words and propositions) Paternoster found how the same procedure of applying words to the world, which can be considered "perceptual and motor routines," can actually be executed, when the objective reference lies in the perceptual horizon of the speaker. Conversely, in its absence, perceptual, and motor routines can be executed virtually through an implicit simulation process, which Paternoster called "simulation schema." Just as for the simulation mechanism described for canonical and mirror neurons, the virtual activation of perceptual and motor processes is apparently crucial to understanding the meanings of objects (words) and actions (propositions).

in light of a philosophical position, defined by Lakoff and Johnson (1999) as *embodied realism*. This type of realism differs from classical realism, which postulates the existence of an external world that is separate, and independent from the mind of whoever perceives it: "Our concepts cannot be a direct reflection of external, objective, mind-free reality because our sensorimotor system plays a crucial role in shaping them. On the other hand, it is the involvement of the sensorimotor system in the conceptual system that keeps the conceptual system very much in touch with the world" (Lakoff & Johnson, 1999, p. 44). The mind–world correspondence is therefore included at the base of the sensorimotor system, which, by allowing the organism to interact with the environment, allows the conceptual system to develop in close relation with the structure of the world and with the functions that this structure offers an organism's sensorimotor capacities. It is evident that, in this theoretical formulation, sensorimotor schemas fulfill the same medium-term function between mind and world that transcendental schemas fulfilled in the Kantian system, which allowed the application of categories of intellect to sensitive intuition. Contrarily, however, to Kantian-style constructivism, embodied realism postulates not theoretical or abstract a priori categories, but pragmatic categories, of action not of reason. These pragmatic categories condition perception of the environment and are, at the same time, conditioned by it, in that they have evolved under the selective pressure of the environment itself.

As we shall see in the following paragraph, the problem of attenuating direct realism without denying the structured character of the perceptual world was already present in Eleanor Rosch's work. It was also common to find recourse in biological evolution, which allows us to deal with the problem by playing on the adaptive dimensions of the categories.

2. Categorization, action, and simulation

2.1. Basic level of categorization

In stating her famous *Principles of categorization*, Eleanor Rosch (1975, 1977, 1978) identified two levels of the category-specific organization of concepts: a vertical level consisting in the hierarchical inclusiveness of categories (e.g., collie, dog, mammal, animal, and living being) and a horizontal level, which consists of categorical segmentation at the same level of inclusiveness (e.g., dog, cat, and frog). In horizontal systems, Rosch noted how categories tend to form around prototypes, i.e., exemplary objects that contain attributes that are most representative of items within the category and least representative of items outside the category. Conversely, in the vertical system, Rosch identified a *basic level* of categorization. This level is the most inclusive (abstract) level at which the categories can mirror the structure of attributes perceived in the world with minimal cognitive effort. The basic level has four fundamental characteristics:

1. From a *perceptual* point of view, the basic level is the highest level at which members of a category are conceived as having a uniform gestalt, that is to say, as objects with a common form.
2. From a *functional* point of view, the basic level allows the classification of objects according to the type of interaction they afford to an individual in terms of motor program.
3. From a *linguistic* point of view, basic level categories are the first learned during language acquisition and occur more frequently in communicative interaction.
4. From an *informative* point of view, the basic level is the level that contains the largest amount of useful information for communicative purposes.

The epistemological premises of Rosch's work are the two well-known principles of categorization: (1) the principle of *cognitive economy*, according to which the cognitive effort an individual must make to differentiate one stimulus from another must be proportionate to the advantage that such a distinction provides to the organism's purpose, and (2) the principle of the *perceived world structure*, according to which the perceptual world reaches us as structured information, rather than as a set of arbitrary and unpredictable attributes. It is important to emphasize that a fundamental assumption of research on a basic-level object is that incoming information from the external world is already structured in and of itself in intrinsically interlinked perceptual and functional attributes. Categorical distinctions on the basic level reflect the same perceptual and functional discontinuities and belong to objects in the external world.

Yet, even if functional attributes are intended as belonging to an object itself (as Gibson saw it), they still require an interacting subject whose motor programs allow to perceive the pertinence of the object's functional attributes in order to relate to the object according to a determined scheme of interaction. Rosch, in fact, plays down the direct realism implied in Gibson's principal of the structure of the perceptual world. She specifies that the structured character of the real must, in any event, be understood not as a metaphysical type of assumption, but always in relation to a perceiving subject and his or her specific sensorimotor characteristics. Rosch maintains that the *functional needs* of an interacting subject determine the way in which objects are perceived by different organisms. For human beings, these needs are not only biological, but are also determined by cultural and social factors.

2.2. From the research of Eleanor Rosch's to experiments on premotor cortex neurons

The emergence of the adaptive value of categories, consistent with a functional relationship of an organism with its environment, was already implicit in Rosch's definition of the basic level: from a functional point of view, the basic level is that which allows classification of objects in function of the type of motor interaction that they afford to a perceiving subject. Rosch conducted her experiments by showing different objects to participants and asking them to describe, as accurately as possible, the *sequence of movements* one must execute in order to use the objects and interact with them. The most inclusive class was the basic level, defined by a common set of motor sequences. By shifting to another experimental context, in neurophysiological laboratories where the properties of canonical and mirror neurons are studied, we can describe a series of experiments that recall Rosch's work, i.e., the basic idea that an object is categorized in terms of the motor interaction schema assigned to it. Positron emission tomography (PET) studies on humans have revealed cerebral activation in participants when they are presented with commonly used objects, even in the absence of any request for motor interaction with them. Mere observation of these objects provoked strong activation in the premotor cortex, which was also activated when participants heard the name corresponding to the action the object evoked (Fadiga, Arbib, & Rizzolatti, 1997; Chao & Martin, 2000). Rosch's participants were asked to list motor sequences that were appropriate for interacting with the commonly used objects they were observing. Yet now, in modern neurophysiology laboratories, we can directly observe actual activation of those same motor sequences on a neural level. The basic level of categorization then might be defined by the highest number of common motor sequences executed virtually by the observer's neural system.

The motor system's role in categorization processes was shown earlier in canonical mirror neuron studies conducted on primates. Canonical neuron experiments demonstrated that the same neurons fire and simulate an interaction schema, not only in response to the same object, but also in response to a group of objects with the same characteristics, in terms of allowing a certain type of interaction. In other words, objects are categorized according to the type of interaction they allow. Similarly, mirror neuron experiments demonstrated that the same neurons are activated and simulate an observed action in response to different movements, e.g., movements that are executed with one effector rather than another, but which have a common purpose. The conclusion was that actions can be categorized according to their intended purpose.

As with Rosch's categories, an adaptive dimension also emerges for canonical and mirror neuron simulative mechanisms. Being able to represent objects according to their motor function is certainly advantageous in the evolutionary sense, as it allows the immediate production of an interaction schema that is appropriate to the object's use. Mirror mechanisms also offer great adaptive value in understanding other people's actions. In fact, being able to represent objects in terms of their purpose can help us predict other people's behavior (Gallese, 2003; Gallese & Goldman, 1998). Furthermore, the same advantage has been observed for categorization based on simulative mechanisms found to be implicated in the emotional system: "the evolutionarily most ancient systems linked to emotional life may also provide a further, and possibly even more basic, description of objects such as 'edible,' 'not edible,' 'dangerous,' 'sweet,' etc." (Gallese, 2000, p. 32).

Motor and emotional simulation have therefore proved to be excellent candidates for establishing a basic level of categorization of reality, which presents an adaptive advantage, in that it allows us to establish a functional relation with the world and an empathetic relationship with other individuals.

3. Conclusions

The paradigm of embodied cognition is progressively asserting itself in the domain of Cognitive Science: the mind is no longer conceived of as a set of logical/abstract functions, but as a biological system rooted in bodily experience and interconnected with bodily action and interaction with other individuals. From this perspective, action and representation are no longer interpreted in terms of the classic physical–mental state dichotomy, but are closely interconnected. Acting in the world, interacting with objects and individuals in it, representing the world, perceiving it, categorizing it, and understanding its significance are perhaps simply different levels of the same relational link that exists between organisms and the local environments in which they operate, think, and live.

Research on canonical and mirror neurons reinterprets the motor system's role within the entire schema of the central nervous system and is particularly important for going beyond the mind–body split, the dichotomy between thought and action. Our motor system not only allows us to plan actions to be executed, but to represent them as well. If the same mechanism that drives us to explicit execution of an action is virtually activated, we can represent it and represent the objects that correspond to it.

From this perspective, the very concept of *mental representation* can be reformulated: in place of abstract representations of formal logic expressed in propositional format, representation proves to be intrinsically linked to the sphere of action and is expressible in the same terms that control it. Therefore, representation does not consist in a duplication of reality, but in the virtual activation of perceptual and motor procedures—the same procedures that, when actually executed, allow us to recognize objects and interact with them.[3] There is no construction of a symbolic representation, but there is representation and, with it, a form of constructivism: the sensorimotor scheme, inasmuch as a scheme always has an anticipatory component, is in itself a mental representation in which the experience is "constructed" on the bases of categories, which are not longer theoretical, but pragmatic, deriving from the dynamic interaction of the organism with its adaptive environment.

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[3] Andy Clark (1997) proposed a similar view with his concept of *minimal representationalism*. In his conception, representation is "local and action-oriented rather than objective and action-independent" (p. 149): the representational process is not a creation of an "objective world model" and a subsequent activation of "a costly procedure that takes the model as input and generates actions as output", but it is "already geared toward the production of appropriate action" (p. 152).