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Are Robots Present? From Motor Simulation to "Being There"

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Abstract

Even if the most sophisticated robot now available is unable to learn and move in the same way as humans, two decades of research in artificial intelligence and cognitive systems introduced the concept of embodiment: the mind has to be understood in the context of its relationship to a physical body that interacts with the world. One of the main outcomes of this vision is the dynamic sensorimotor account of conscious experience. Following this vision, the key feature of a cognitive robot should be the possession and exercise of sensorimotor knowledge. The main criticism against this argument is that such a robot will still lack self-awareness. In this paper, we suggest that a psychology of "presence" can offer new insights to overcome this point. In particular, we argue that in humans the evolutive role of presence is the control of agency through the unconscious separation of "internal" and "external" and the transformation (enaction) and/or recognition (reenaction) of intentions in action. How can we develop presence in robots? If we follow the development of presence in humans, we must use an evolutive process. First, the robot must learn to differentiate itself from the external world by correctly coupling perceptions and movements. Then the robot must learn to clearly separate perception and action planning, even if both share the same language: motor code. Finally, it is through social and cooperative activities that the robot may improve its intentional action and interaction.

Creating Cognitive Robots: The Challenge

What makes robots the most advanced technology now available is their ability to combine automation with action: they can walk, kick, lift, or explore. However, the road toward a cognitive robot is still long: the most sophisticated robot now available cannot learn and move in the same way as humans. Nevertheless, two decades of research in artificial intelligence and cognitive systems produced a significant result: a radical shift in how cognition is conceptualized through the introduction of the concept of *embodiment*.

In this paper, we suggest that the concept of presence, which is strictly connected to the concept of embodiment, can offer new insights into development of a cognitive robot. Specifically, we argue that in humans the evolutive role of presence is the control of agency through both the unconscious separation of "internal" and "external" and the transformation (enaction) and/or recognition (reenaction) of intentions in action.

Embodiment in Cognitive Sciences

The *embodied cognition* paradigm takes as its starting point the idea that cognition occurs in specific environments and for specific ends.[1] As underlined by Pfeifer and colleagues,[2] the main outcome of this vision for cognitive robotics is the critical role of the body in the development of intelligent agents: "By embodiment, we mean that intelligence always requires a body. Or, more precisely, we ascribe intelligence only to agents that are embodied, i.e., real physical systems whose behavior can be observed as they interact with the environment" (p. 18). Following this point in their recent review, Pfeifer and colleagues[3] suggest that a cognitive robot is not merely the outcome of an internal control structure (such as the central nervous system) but is always *embodied*: affected both by its physical structure and the ecological niche in which the system is physically embedded.

Nevertheless, even if these authors focus mostly on how the robot can master the sensorimotor interaction with the

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external world, another face of embodiment is the robot's somatic experience, its interaction with the "internal representation" of the body.[4] This internal embodiment view suggests that action and perception are more closely linked than has traditionally been assumed.

In particular, the integration of three different theories (see Table 1 for short description of these theories)—*the common coding theory, the situated simulation theory*, and the *covert imitation theory*—describes a new scenario in which this internal embodiment plays a critical role: *our conceptual system dynamically produces contextualized representations (simulations) that support situated action in different situations*. This is allowed by a common coding—the motor code—shared by perception, action, and concepts.

On one side, the vision of an object immediately activates the appropriate hand shape for using it; for example, seeing a red apple activates a precision grip for grasping and turning. On the other side, thinking an apple produces the simulation of an action with the apple related to a specific context of use. This common coding also allows the subject to natively recognize actions done by other beings. Further, the subject predicts the outcome of the recognized action using the same simulation mechanism described above: seeing someone grasping an apple produces a contextualized simulation of the action.

A Psychology of Presence

One of the main outcomes of this vision is the *dynamic sensorimotor account* of conscious experience.[5] This account claims that exercise of sensorimotor knowledge is constitutive of conscious experience.[6] Following it, a cognitive robot "could enjoy conscious experience just by exercising its mastering of sensorimotor dynamics [sensorimotor knowledge] in actively sensing the world."[6] The main criticism against this argument is that such a robot will still miss self-awareness. As underlined by Thompson,[7] the robot's sensorimotor knowledge "is merely attributed to the system by the observer, not original to the system itself. . . . It is not a self-producing and self-maintaining system that actively regulates its own boundary conditions so as to ensure its continued viability" (pp. 417–18). How can we overcome this issue? A possible answer may come from a psychology of presence: a robot has to be "present" in order to act effectively in the world.

But what is presence? In its more general use, presence refers to a widely reported sensation experienced during the use of virtual reality or other media.[8] However, a growing group of researchers considers presence as a neuropsychological phenomenon (inner presence) evolved from the interplay of our biological and cultural inheritance, the goal of which is to increase emotional fidelity and perceptual accuracy to produce a strong sense of agency and control:[9] presence as the feeling of "being in a world outside me." In fact, as suggested previously by Piaget (assimilation) and Gibson (affordance), we conceive places in terms of the actions we could take toward them.

Waskan[10] suggests that we represent phenomena by thinking in terms of the mechanisms by which the phenomena may be produced. In sum, according to Waskan, "One cannot see a place as being *there1* rather than *there2* without knowing what it would be to act *there1* rather than *there2*" (p. 170, our italics).

According to this vision, presence has a simple but critical role in our everyday experience:[11] the control of agency (enaction of intentions) through the unconscious separation of internal and external. Within this framework, presence is defined as the nonmediated (prereflexive) perception of successfully transforming an intention in action (enaction).

Presence: function and layers

What is the role of presence within our cognitive processes? On one side, the sense of presence allows the ner-

TABLE 1. THE MAIN THEORIES BEHIND THE EMBODIED COGNITION APPROACH

Theory	*Main Claim*	*References*
Common coding theory	The cognitive representations for perceived events (perception) and intended or to-be-generated events (action) are formed by a common representational domain: actions are coded in terms of the perceivable effects they should generate.	Hommel B, Müsseler J, Aschersleben G, Prinz W. The theory of event coding (TEC): a framework for perception and action planning. Behavioral and Brain Sciences 2001; 24:849–937. Prinz W. Perception and action planning. European Journal of Cognitive Psychology 1997; 9:129–54.
Situated simulation theory	To represent the concept, we prepare for situated action with one of its instances: rather than representing a concept in a detached isolated manner, people construct a multimodal simulation of themselves interacting with an instance of the concept.	Barsalou LW. Situated simulation in the human conceptual system. Language and Cognitive Processes 2003; 18:513–62. Barsalou LW, Simmons KW, Barbey AK, Wilson CD. Grounding conceptual knowledge in modality-specific systems. Trends in Cognitive Science 2003; 7:84–91.
Covert imitation theory	People use a real-time automatic action emulator of other subjects to generate perceptual predictions about their behavior.	Gallese V. Embodied simulation: From neurons to phenomenal experience. Phenomenology and the Cognitive Sciences 2005; 23–48. Knoblich G, Flach R. Action identity: Evidence from self-recognition, prediction, and coordination. Consciousness and Cognition 2003; 12:620–32.

TABLE 2. THE LAYERS OF PRESENCE

Layer	*Definition*	*Evolutive role*
Proto presence	The process of internal/external separation related to the level of perception–action coupling (self vs. nonself).	The more the organism is able to correctly couple perceptions and movements, the more it differentiates itself from the external world, thus increasing its probability of surviving.
Core presence	The activity of selective attention made by the self on perceptions (self vs. present external world).	The more the organism is able to focus on the relevant percept by leaving in the background the remaining neural processes, the more it is able to identify the present movement and critical tasks, increasing its probability of surviving.
Extended presence	The analysis of the relevance to the self of possible/future events in the external world (self vs. future external world).	The more the self is present in relevant representations, the more it will be able to reach its goals, increasing the possibility of surviving. An input representation is relevant when its processing yields a positive cognitive effect: a worthwhile difference to the self's representation of the world.

vous system to *differentiate between internal and external states* required by the equivalence between the motor codes used in perception, action, and cognition. As infants develop, they learn that some aspects of their perceptual worlds are part of the "self" (such as the movements of their arm) and that other aspects of the environment are "not self" (such as the movements of their mother's arm). Were it not for the development of the sense of presence, it would be impossible for the nervous system to reference perceptions to an environment beyond our boundaries.

Further, presence progressively evolves into the ability to distinguish external, perceived events from internal, imagined, or otherwise internally modeled events. From an evolutive viewpoint, an organism must be able to answer these questions:

1. Is this happening to me, or to someone else? (internal vs. external)
2. Is this true/acted or is it fiction/planned? (imagined vs. perceived)
3. Is this good or bad for me? (relevant vs. nonrelevant)

It is important to note that the meaning of these questions progressively evolves in time: in early infancy, it is related to the body only; in adulthood, it also includes the social and cultural space (situation) in which the self is included. In fact, even if presence is a unitary feeling, recent neuropsychological research has shown that, on the process side, it can be divided into three different layers/subprocesses (Table 2; for a broader and more in-depth description, see Riva et al.[9] and Riva[11]) phylogenetically different and strictly related to the evolution of self:[12] *proto presence* (self vs. nonself); *core presence* (self vs. present external world); and *extended presence* (self vs. possible/future external world).

On the other side is the feeling of presence to provide the self with feedback about the status of its activity:[9] the self perceives the variations in the feeling of presence and tunes its activity accordingly. The possible mechanism is outlined by the embodied cognition theories: during self-produced actions, a sensory prediction of the outcome of the action is elaborated along with the actual motor command. The results of the comparison (which occurs at a subpersonal level) between the sensory prediction and the sensory consequences of the act can then be utilized to track any possible variation in its course (breakdown). If no variations are perceived, the self is able to concentrate on the action and not on its monitoring.

Social presence: function and layers

Rizzolatti and colleagues discovered functional cluster of premotor neurons (F5c–PF) containing *mirror neurons*, a class

TABLE 3. THE LAYERS OF SOCIAL PRESENCE

Layer	*Definition*	*Evolutive role*
Proto social presence	The process allowing the identification of other intentional selves in the phenomenological world (there is an other intentional self).	The more the self is able to identify other selves, the greater the possibility of its starting an interaction, thus increasing its probability of surviving.
Interactive social presence	The process allowing the identification of communicative intentions in other selves (the intention of the other is toward the self).	The more the self is able to identify a communicative intention in other selves, the greater the possibility of its starting an interaction, thus increasing its probability of surviving
Shared social presence	The process allowing the identification of intentional congruence and attunement in other selves (the self and the other share the same intention).	The more the self is able to identify intentional attunement in other selves, the greater the possibility of its conducting an interaction, thus increasing its probability of surviving.

of neurons activated both during the execution of purposeful, goal-related hand actions and during the observation of similar actions performed by another individual.[13] The existence of mirror neurons suggests that humans have an innate ability to recognize and simulate intentional actions. However, mirror neurons alone are neither able to detect the content of the other's intention (they do not recognize which specific intention or set of intentions is being enacted) nor to identify the motives of such content (they do not recognize why the specific intention, or set of intentions is being enacted). As suggested by Lee,[14] this requires "social presence," a specific neuropsychological process tracking the behavior of the other to understand his or her intentions. Social presence is described here as a defining feature of self allowing the detection of the content and motives of other's intentions: social presence can be defined as the nonmediated (prereflexive) perception of successfully recognizing the intention of an agent in its action (reenaction). As underlined by Wittgenstein,[15] this recognition process is not merely the acquisition of a theoretical belief but a manner of interacting with the agent: "My attitude towards him is the attitude towards a soul. I'm not of the *opinion* that he has a soul" (p. 158). This egocentric manner of understanding another agent is based on *covert imitation*, an automatic action emulator tracking the behavior of others in real time to generate perceptual predictions.[16] Through the sense of social presence, it is possible for the self to develop a theory of mind allowing the comprehension, explanation, and prediction of behavior and, in general, the management of the social interactions.

The study of infants and the analysis of their ability to understand and interact with people suggests that also social presence, on the process side, includes three different layers/subprocesses (Table 3; for a broader and more in-depth description, see Riva et al.[9] and Riva[11]) phylogenetically different but mutually inclusive: *proto social presence* (there is an other intentional self); *interactive social presence* (the intention of the other is toward the self); *shared social presence* (the self and the other share the same intention).

Further, presence and social presence converge and interact within social and cooperative activities.[9] In particular, it is *through their interaction* that the self improves his or her intentional action and interaction (Figure 1): the higher the level of presence and social presence experienced by the self, the higher the complexity of the expressed and recognized intentions.

When the self experiences full presence and social presence, he or she can express and recognize complex intentions, including subject, action, goal, way of doing, and motive. In this way, the social and communicative exchange is created and governed by a reciprocal intentional game between the communicators regulated by the level of presence and social presence experienced by the interactants: the display and ostension of a given intention by the speaker (intentionalization process) and the ascription and attribution of a certain intention to him or her by the addressee (re-intentionalization process). An important outcome of the model we just presented is a strict link between intentions, self and presence.[17] Specifically, presence and social presence evolve in time, and their evolution is strictly related to

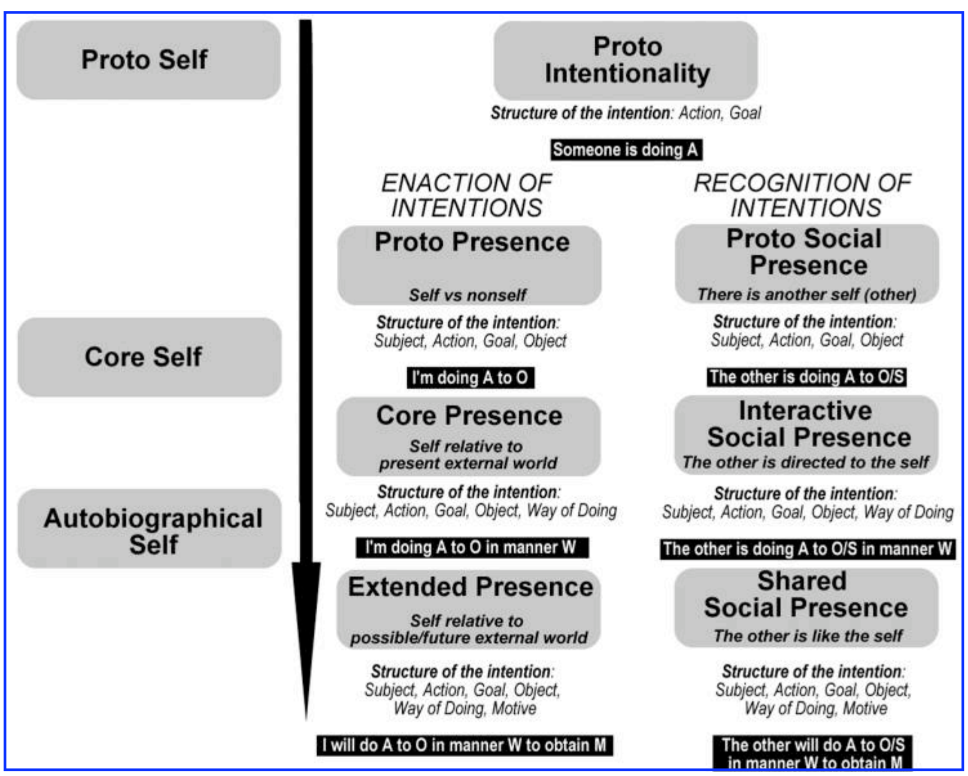

FIG. 1. The evolution of self, presence, and social presence.

the evolution of self. Following the three-stage model of the ontogenesis of self (proto-self, core self, autobiographical self) proposed by Damasio,[12] we can identify higher levels of presence and social presence associated with higher levels of intentional granularity (Figure 1).

Conclusions: Toward Presence in Robots

The road toward a cognitive robot is still long. However, in this paper, we suggested that a psychology of presence could offer new insights to move forward. We argued that the evolutive role of presence is to allow the process of self-identification through the separation between internal and external and between the enaction and reenaction of intentions. How may these concepts be useful for the development of intelligent robots?

First, if presence allows the control of agency through the separation of internal and external, an intelligent robot must learn to differentiate itself from the external world by a continuous process of self-modeling. A tentative approach following this line was suggested by Bongard et al.[18] They describe a four-legged robot that uses actuation-sensation relationships to indirectly infer its own structure. The inferred self-model is able to generate forward locomotion even when one of the leg is removed. To achieve it, the robot indirectly infers its own morphology through self-directed exploration and then use the resulting self-models to synthesize new behaviors.

Second, the robot must learn to clearly separate perception and action planning, even if both share the same language: motor code. The key to doing so is to verify the existence of specific intentions linked to the motor code, especially during imitation. Following this approach, Acosta-Calderon and Hu tried to develop a robotic platform able to imitate humans.[19] As described in their paper, the robot does not imitate the different physical motions and positions but tries to identify the goals of the perceived action. They used a covert imitation approach: the simulation of what the imitator believes the demonstrator is performing produces a change in the simulated agent state and also in the effects of the simulated environment. When the discrepancy between the imitator's simulation and what the imitator perceives is marginal, then the imitator is "confident" to know the state of the demonstrator and its effects on the environment. A similar approach was described by Metta et al. in their paper detailing the implementation of a humanoid robot that learns to mimic simple actions performed by a human on different objects.[20] Recognizing the goal is the key aspect of the learning process and subsequently works as a prerequisite to bias recognition by filtering out actions that are not applicable or simply less likely to be executed, given a specific context. This paper also underlines the possibility of implementing a mirrorlike approach for successful imitation in robots: in their experiment, a mirrorlike representation was developed autonomously on the basis of the interaction between the robot and the environment.

Finally, it is through social and cooperative activities that the robot may improve its intentional action and interaction. For this reason, Nielsen et al.[21] proposed the use of mixed-initiative interactions—the dynamic sharing of task roles and responsibilities between a human and a robot—to improve the efficacy of a scavenger hunt robot: the interactions between humans and robots to solve tasks will change until the solution is fully autonomous and the human is no longer needed for the task.

In conclusion, even if roboticists have begun to recognize the link between body, action, and cognition, the different attempts in creating intelligent robots do not currently consider the possible role of presence.[22,23] Perhaps the mutual rapprochement of presence research and engineering will help move toward a real cognitive robot.

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Disclosure Statement

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