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I EMBODIED INTELLIGENCE: EPISTEMOLOGICAL REMARKS ON AN EMERGING PARADIGM IN THE ARTIFICIAL INTELLIGENCE DEBATE

Abstract: A new paradigm about machine-design in robotics, currently defined as 'Embodied Intelligence', has recently been developed. Here we consider the debate on the relationship between the hand and the intellect, from the perspective of the history of philosophy, aiming at providing a more suitable understanding of this paradigm. The new bottom-up approach to design is deeply rooted in a new kind of empiricism, which tries to overcome issues connected with the previous approach strongly committed with the Artificial Intelligence (AI) debate and its origin. Since Turing's time, the AI debate showed a rationalistic bias which remained undisputed until now. The paradigm shift we are witnessing nowadays is a reply to that bias in order to achieve not only a better way to design robots, but also to understand some underlying epistemological remarks.
Keywords: embodied intelligence, artificial intelligence, amputee case, robotics, bottom-up approach.

Riassunto: Embodied intelligence: considerazioni epistemologiche su un nuovo paradigma emergente nel dibattito sull'intelligenza artificiale. In robotica si è recentemente sviluppato un nuovo paradigma relativo alla progettazione e sviluppo dei robot, definito 'embodied intelligence'. Muovendo dal dibattito sulla relazione tra mano e intelletto, per come emerge dalla storia della filosofia, miriamo a guadagnare una miglior comprensione del nuovo paradigma. L'approccio progettuale bottom-up si qualifica come una risposta di conio empirico che tenta di risolvere alcuni nodi problematici connessi al dibattito sull'Intelligenza Artificiale sin dalle sue origini. Dai tempi di Turing, tale dibattito ha infatti presentato un profilo e una tendenza razionalistici finora non adeguatamente problematizzati. Il mutamento di paradigma a cui si sta assistendo può essere considerato una replica a questa tendenza sia per migliorare la progettazione dei robot sia per comprendere alcuni problemi epistemologici soggiacenti.
Parole-chiave: embodied intelligence, intelligenza artificiale, arto fantasma, robotica, progettazione bottom-up.

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What is mind? No matter. What is matter? Never mind
Berkeley

In this paper we want to analyze some philosophical and epistemological connections between a new kind of technology recently developed within robotics and the previous mechanical approach.

The epistemological framework is presented by R. Brooks (1991a) and defined by R. Pfeifer and J. Bongard (2007) as 'Embodied Intelligence': an emerging new paradigm that on the one hand highlights the need to overcome the classical top-down approach, somehow imbued with a rationalistic bias, and on the other hand shows how it is possible to gain a different conception of intelligence encompassing different kinds of causalities, i.e. material, formal and final causes.

1. Introduction: the hand case

Since the beginning of philosophy the hand holds a special place among the human organs. It has been recognized both as the instrument of the instruments and as the specific sign of the human intelligence[1].

Aristotle, in his *De partibus animalium*, polemized with Anaxagoras about the role assigned to the hand, while the former saw it as the best instrument of the intellect, the latter spoke about it somehow as the source of the human intelligence. It is worth to point out how in both these perspectives the link between the intellect and the hand was strong and undeniable. Besides, these two remarkable philosophers recognize the hand as a distinctive feature of the human body, more than any other part[2]. The hand should be seen as a sort of first incarnation of the human intellective activity.

The relationship between the intellect and the hand could be set in this way: is the human being intelligent because of the hands, or does he possess hands because he is intelligent? According to Aristotle[3], Cicero[4], Leon Battista Alberti (see Garin 1975, pp. 131-196), Marsilio Ficino[5], and Tom-

[1] Aristotle, *De partibus animalium*, IV, 10, 687 a8-b5.

[2] We can see an echo of this debate in Lucretius, *De rerum natura*, IV, vv. 823-831. For a review on the role of the hand from Aristotle to Bruno, see Del Soldato 2011.

[3] Aristotle, *De anima*, III, 8, 432a1.

[4] Cicero, *De natura deorum*, II, 60, 150.

[5] Ficino, *Theologia Platonica*, XIII, 3. On the hand problem in Ficino, cfr. Tirinnanzi (2000, pp. 83-86).

maso Campanella[6] the correct answer is the second one; whereas Anaxagoras[7], Lucretius[8] and Giordano Bruno[9] follow the first hypothesis.

This is a classical topic of the philosophy of biology[10], i.e. whether the function precedes the organ or, on the contrary, it is determined by matter: teleology vs. atomism, or, in modern terms, functionalism vs. determinism. It is worth noting that each of these contrapositions emphasizes some specific aspects of the question: the Greek notion of τέλος (*telos*) cannot be reduced to the modern concept of function. When that reduction took place and teleology was replaced by functionalism, we witnessed a paradigm shift from the final causes to the formal causes. Then again the paradigm that stressed the formal causes did not consider this form as its Greek correlate concept of εἶδος (*eidos*) anymore, but took it as a simple μορφή (*morphé*), degrading the notion of form into that of shape. What did get lost in this shift from the τέλος/εἶδος to the function/shape epistemology was the intellectual and immaterial sphere, in other terms the intelligibility of reality. We have to mention the root of this issue, which can be traced in the history of the notion of teleology. Although this concept[11] can easily be found in Plato dialogues, it has been defined as such just in 1782 by C. Wolff. At the beginning, teleological explanation involves the identification of some state as good, or at least as better than other choices[12]. This model, which is outlined in Plato's *Timaeus*, has been defined as external teleology, since the agent whose goal is being achieved is external to the object that is being explained teleologically, and the value aimed at is the agent's value. Not surprisingly this meaning of the term is nowadays adopted in robotics. Aristotle's approach to teleology is quite different, and in many respects it is the one followed by biology. According to his causal theory, something could be considered explained when we can see its cause, among different kinds of causes we find that: "And fi-

[6] Campanella (1939, pp. 337-338).

[7] Aristotle, *De partibus animalium*, IV, 10, 687 a8-b5.

[8] Lucretius, *De rerum natura*, IV, vv. 823-831.

[9] Bruno (2001, p. 718).

[10] A useful review on this topic can be found in Wouters A. (2005). The root of this debate can be traced in the famous and frequently misinterpreted Lamarck's sentence, according to which "function makes the organ". It is worth noting that the right quotation is a bit different and goes as follows: "In every animal which has not exceeded the limit of its development, the more frequent and sustained use of any organ gradually strengthens this organ, develops it, makes it larger, and gives it a power proportional to the duration of this use; whereas, the constant lack of use of such an organ imperceptibly weakens it, makes it deteriorate, progressively diminishes it faculties, and ends by making it disappear" (Lamarck J.B. 1809, chapter 7).

[11] A good history of this concept can be found in Lennox (1998).

[12] Wolff (1728, Chapter III, section 85).

nally, there is the goal or end in view, which animates all the other determinant factors as the best they can attain to; for the attainment of that 'for the sake of which' anything exists or is done is its final and best possible achievement"[13]. This conception, that in no way depends on the action of a rational agent, has been defined as immanent or internal teleology (cfr. Goudge 1961, Ayala 1970), and it is in this meaning that it has been considered in scientific works of the Padua school and can be seen most straightforwardly in the work of W. Harvey[14].

There is another classical topic in the history of philosophy we need to take into account in order to understand the paradigm shift that is currently going on: it is dualism. As a general view of reality, different kinds of dualism should be considered: metaphysical, ontological, anthropological and epistemological are the most important one.

While anthropological dualism could be found in Plato's dialogues, where body and soul are different – and actually separate – components of human nature, metaphysical dualism is a classical reference to the Cartesian position, with particular reference to the *Meditationes de prima philosophia*[15]. In this work, R. Descartes, considering the immaterial substance, *res cogitans* or *cogito*, as the only first safe step of every well-grounded way of thinking, concludes by defining a material substance, *res extensa*, which completes the existing reality. *Res cogitans* has no extension, thinks and is not material; *res extensa* cannot think, is material and subject to movement. All reality can be divided into these two substances: no other kinds of substances are admitted. Moreover, *res extensa* and *res cogitans* exclude one another: what thinks has no extension, what is extended does not think. This is the reason why we call it ontological dualism. Science deals with the material world, that which is measurable, while thought has no other forms of existence than the immaterial one. From the Cartesian dichotomy came a revolutionary notion of matter, essential for science: matter is a proper substance, which really exists and does not depend on the subject's activity.

Cartesian mechanism offers a particular notion of matter, in contrast with the idea of τέλος (*telos*) that the Aristotelian substantial forms presents. Science in the 17th and 18th century keeps in mind this Cartesian notion of matter. Whatever is matter – pure aggregate, energy, chaos or atoms – cannot be addressed as intelligent *in se et per se*. What we can say about matter is only that "it is extended" and "it moves in space", as Descartes

[13] Aristotle, *Physics*, II.3, 195a, 22-26.
[14] O'Malley (1961).
[15] Descartes (1974).

says. Human rationality recognizes a τέλος (*telos*) in χάος (*chaos*), but science has to study the material world only through extension and movement.

2. The new paradigm in robotics

The above remarks are meant to situate the new and emerging paradigm in robotics which is called 'Embodied Intelligence'. While in the previous decades the approach to themes like Artificial Intelligence and more generally to robotics was dominated by a rationalistic orientation, whereby intelligence was conceived like an independent and autonomous set of instructions, contained in a piece of software, nonetheless nowadays a different perspective, which could be defined as a bottom-up approach, is becoming more common.

The main idea of this new paradigm is to no longer consider intelligence as something restricted to the brain only, or located in a specific spot, like software, but to see it somehow spread out in the body, or in the prosthesis. This idea brings to mind the Scholastic conception of the *vis aestimativa*[16]: the faculty we have in common with animals to discover, without (and before) any intellectual instrument, what is good and what is bad for our welfare[17]. In other words the intelligence that is strongly connected to the body is a sort of art of calculating what is useful and what is dangerous in specific situations. This practical sense, a very specific kind of adaptive intelligence, is mostly unconscious and does not refer to logical reasoning. This does not mean it cannot be investigated by means of logic, but rather that it does not stem from superior and explicit reason.

As stated by R. Brooks (2007) there are some tenets of modern rationalism usually involved in the metaphors adopted to talk about intelligence, some of them are: whether our nervous system works as a computation machine, whether there are separate control systems for our body, and whether there can truly be disembodied reasoning.

Tracing the source of the still dominant model of computation intelligence back to A. Turing (1950) and his famous *Computing Machinery and Intelligence*, it is worth noting that such a theory came from considering the externally observable behaviour of a human computer, a person who car-

[16] Furthermore, for the apprehension of intentions which are not received through the senses, the 'estimative' power is appointed: and for the preservation thereof, the 'memorative' power, which is a storehouse of such-like intentions. Thomas Aquinas, *Summa theologiae*, I, q. 78, a. 4.

[17] Newman (1957).

ried out computations with pen and paper, and "is supposed to be following fixed rules", so that Turing modelled what a person does, not what a person thinks. It is also Turing who said that such computation is independent of the medium in which it is expressed.

What can be said after almost three decades of rationalistic-oriented science and technology? Probably it did not succeed in facing the adaptation issues connected with intelligence. The field was in dire need of a real paradigm shift. This paved the way for the Embodied Intelligence paradigm, whose description could be summarized briefly in the phrase: "Intelligence requires a body". This shift did not just imply methodological change in relation to Artificial Intelligence issues, but also an objective one: scientists dealt less with symbol processing, internal representation, and high-level cognition, and focused instead on interaction with the real world. As the orientation shifted, the nature of the research questions also changed: the community got interested in locomotion, manipulation and, in general, how an agent can successfully act in a changing world.

The rejection of the previous computational approach can even be seen in the provocative titles of papers meant to open a new way in the field of robotics, e.g. Brooks' works: *Intelligence Without Reason* (Brooks 1991a), *Intelligence Without Representation* (Brooks 1991b) or *Elephants don't play chess* (Brooks 1990), where the author is ironic about the efforts to improve the computer chess game skill. The new paradigm stresses the attention on the system-environment interaction, rather than sophisticated reasoning processes. From a theoretical point of view we can always see the typical goal-oriented intelligence structure in these models, though the difference between these two paradigms lies in the meaning to ascribe to the word "goal". While the classical A.I. approach sees the goal as an abstract calculation power, the E.I. approach sees it in the ability to overcome the environmental challenges.

3. The amputee case

Focusing on pathological cases could shed some light on the way the body feels in normal cases. One of the most interesting cases in perception disturbances is the famous 'phantom limb' experience. The case of amputation is investigated both in philosophy and in medical science from the 16th century onwards, and leads us towards our topic, since it represents a testing ground for the dualistic conception.

The first description of the phantom limb case by the Frenchman A. Paré appeared in 1551[18], and then it was inherited by later philosophers and physiologists of post-Galilean science. Descartes, in his *Sixth Meditation*, considers the amputee case: "Is there anything more intimate or more internal than pain? And yet I have learned from some persons whose arms or legs have been cut off, that they sometimes seemed to feel pain in the part which had been amputated"[19]. On the one hand, in the Cartesian conception matter is deprived of soul; on the other hand, the amputee case shows the soul deprived of matter, as if the soul missed its limb. It is worth noting that the amputee case arose within a rationalistic view, but it could not be explained in the same terms. We can understand this paradox by adopting a renewed non-rationalistic paradigm whereby "the body shapes the way we feel", that is to say that the missing limb is not just a missing piece of matter, but a *living* piece of matter of the *living* body.

How do we explain the amputee sensations? If we consider perception as 'matter grounded' it is not possible at all: the absence of a limb means lacking the material support that transmits information. But this is a reductionist way of examining perception. Perception, in fact, is to be seen as a complex process that involves matter in a different, and higher, sense. A short quotation from one of the major scientific journals translates Cartesian's argument into current language: "One of the most intriguing and bursting innovations that can have a dramatic impact in the application of such a new generation of hand prostheses is the enhancement of the exteroceptive and proprioceptive inputs that the device is able to feed back to the patient in a physiological fashion in order to partially replace natural sensations and re-obtain full consciousness of the missing limb by embedding it again in the body scheme" (Di Pino *et al*. 2009, p. 117). This quotation has an intrinsic philosophical meaning, considering the hand-prosthesis, giving another chance to re-think about 'raw' matter and his relationship with the intelligence, τέλος (*telos, goal)* or εἶδος (*eidos, form*), in order to redefine the connection between these terms, in the firm belief that "matter shares a proper intelligibility".

As we have read above, biomedical research should enable us to "partially replace natural sensation and re-obtain full consciousness of the missing limb by embedding it again in the body scheme". This sentence calls to mind a certain renaissance way of thinking about the graduality of intelligence in living beings, a philosophy deeply rooted in the classical plutarchian work *De sollertia animalium*, where we can read: "Nothing is en-

[18] Michelet (1930).
[19] Descartes (1974, p. 155).

dowed with sensation which does not also partake of intelligence and that there is no living thing which does not naturally possess both opinion and reason, just as it has sensation and appetite"[20]. According to this perspective, there is no substantial difference between the domain of perception (αἴσθησις) and that of intelligence (σύνεσις), except that of degree. This is the well-known plutarchian zoo-psychological continuism, which is somehow regaining approval in this new epistemological paradigm.

Oscillating between body and mind, and between physiology and self-consciousness, we take for granted that their relationship and mutual influence is clear. We still move in a dualistic framework, even if more refined and technologically advanced with respect to Cartesian mechanism. Some questions: what is meant by "replace *natural* sensation"? What is the link between 'natural' and 'normal'? Does adding parts to the body mean growing in consciousness? Does self-consciousness grow as a material entity by further addition of elements? In this case, it would be nothing more than a pure aggregate, without an identity principle.

The "exteroceptive and proprioceptive inputs" are really complex phenomenological notions according to our usual experience, which open our world of perceptual activity. When we touch our knee we feel the sensation of being touched: that's because our body is, at the same time, touching and being touched. When we bite our hand with a fork we just feel touched, not touching; while if we touch the table with the hand we just touch and do not feel touched. If you project a hand-prosthesis you have to make the hand able to touch and to transmit the reverse information of being touched: a top-down model is necessarily implied by a bottom-up one. In the hand, the internal world meets the external one and gets fused and somehow con-fused. We are not only saying that perceptual activity is confused, in leibnizian terms[21], but, moreover, that it is an activity – not mere passivity – that has to do with both matter and mind, as neural information arriving at the brain is actually 'meanings' and not mere electrical information.

In this order of considerations, the phenomenological notion of *Leib*[22] can shed some light: while *Körper* is the material level of our corporeity, our anatomy, *Leib* is the living body, the centre of all our perceptual activities and self-oriented life. We are always in our living body, which is always crossed by perceptions, deriving from the complex interaction of the external world and the entities in it. The amputee case illustrates the richness of a deeper and

[20] Plutarch (1957, p. 329).
[21] Leibniz (1965).
[22] The notions of *Leib* and *Körper* are explained in Husserl (1950).

wider notion of the body as *Leib*: the amputee can feel pain in his missing leg because of his missing *Körper*, but his *Leib* does still have it, and it feels pain. The body does not derive from the simple sum of its parts, and cannot be diminished by progressive subtraction: there must be a principle of unity and an immaterial criterion for material life that maintains integrity as identity.

A renewed notion of matter is coming out of these brief considerations: shape and function cannot be considered in isolation or independently, because formal causes shed light on efficient ones, and they are, in the end, the same aspect of reality.

4. Conclusions

Let us consider two notions elaborated in the bio-engineering context, which represent a new way of thinking of human nature in its complexity. Firstly, 'smart materials'. In scientific literature we often read about the development of new, each time more refined, technologies, which are fundamental in the construction of prosthesis. These materials have to be compatible with the human body and, moreover, they have to grant a correct and full integration of the artificial limb in the body. That means not only facing rejection problems, but also the need for the owner to feel the prosthesis as his hand. 'Smart materials', in this sense, could represent the match meeting point between matter and intelligence and a sort of crasis between sign and meaning. Besides, the idea that matter can be smart shows an interesting change of perspective: no more clear-cut separation between matter and intelligence, rather a degree of participation of matter with intelligence. Another note of interest is to consider the concept of smartness compared to that of intelligence. While the latter is the classical and generic one, meant to indicate the broad domain of the intellect, the former is more specific, referring to a particular kind of intelligence: the adaptive one. (It is also worth noting) that in literature material is labelled as smart when it is able to receive and maintain a given shape, which is fundamental for the adaptive process. Moreover these kinds of materials, such as complex fluids, metamaterials, claytronics, cellular automata, and those derived from synthetic biology share the ability to modulate their physical properties according to the inputs received from the environment.

Secondly, communication between humans and machine is one of the most problematic aspects in cyber-technologies. How do we perfectly integrate these two dimensions of reality as if they were one? Human-machine interfaces could be seen as a modern translation of the famous 'pineal gland', the physical location where body-mind communication takes place, where

'raw matter' becomes 'smart', since it is involved in the same teleological process.

At the end of these short considerations on the hand-mind connection, what can we say about their relation? The classical question may need to be reformulated, since we can no longer maintain a perspective which divides the two domains too rigidly. We have learnt that the hands can see while the eyes can touch, and this is not just a metaphor, but a neurological truth referring to the way the eye behaves in order to grasp the object of its sight (Kandel 2000, p. 785). Besides, the relationship between the intellect and the hand can easily be seen even from a neurophysiological perspective. Indeed studies (Schlaug *et al* 1994; Rizzolatti, Arbib 1998) showed that the Broca area appears to be linked both with language ability and with hand grasping. This evidence provides empirical proof of the continuity between hand and language, both rooted in the same cerebral area.

We also have to pay attention in order not to slide into a sort of plutarchian pan-psychism, whereby there are no qualitative differences between living beings, but only minor differences in degree, this would be a naïve mistake. Of course there is a kind of continuity between perception and intelligence, but continuity does not mean identity. On the contrary it means a dialogue between two different kinds of entities, unified by a third element that in this case we could call intentionality. Intentionality is a crucial concept under many respects; it played a central role in the epistemological field, where it has been considered the link between the mind and the world, the connection that allows the mind to talk about the world in a realistic meaning. In this case the gap between perception, gathered by means of senses, and intelligence is fulfilled by intention, which acts as a medium between these two domains, both being distinct but not separate. Besides the concept of intention itself shares somehow the nature of intellect and that of perception, since on the one hand it is a spiritual movement toward its object, and on the other hand, allowing the object to appear to the subject, it reveals itself as 'object-oriented'. These two characteristics are fundamental to allow intentionality to play the bridge role between man and the world in an epistemological perspective grounded on a realistic framework.

Bearing this in mind we can observe that in the Embodied Intelligence paradigm precisely this aspect is stressed. It is not only the intelligence (the smartness) of the hardware that is recognized, and analogically that of the perception systems, but the degree of knowledge embedded both in the perceptive system and in the robotics' hardware is also explicated. In this perspective we can understand the Berkeley sentence we stated at the beginning, that is, matter is not so dark as to be 'mind-unfriendly', and mind, after all, is not so unrelated to matter.

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