What's that Thing Called Embodiment?

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Abstract

Embodiment has become an important concept in many areas of cognitive science. There are, however, very different notions of exactly what embodiment is and what kind of body is required for what type of embodied cognition. Hence, while many nowadays would agree that humans are embodied cognizers, there is much less agreement on what kind of artifact could be considered embodied. This paper identifies and contrasts six different notions of embodiment which can roughly be characterized as (1) *structural coupling* between agent and environment, (2) *historical embodiment* as the result of a history of structural coupling, (3) *physical embodiment*, (4) *organismoid embodiment*, i.e. organism-like bodily form (e.g., humanoid robots), (5) *organismic embodiment* of autopoietic, living systems, and (6) *social embodiment*.

Introduction

The concept of embodiment has since the mid-1980s been used extensively in the cognitive science and AI literature, in such terms as *embodied mind* (e.g. Lakoff & Johnson, 1999; Varela et al., 1991), *embodied intelligence* (e.g. Brooks, 1991), *embodied action* (e.g. Varela et al., 1991), *embodied cognition* (e.g. Clark, 1997), *embodied AI* (e.g. Chrisley, in press; Franklin, 1997), and *embodied cognitive science* (e.g. Clark, 1999; Pfeifer & Scheier, 1999). Furthermore, there obviously are different types and notions of embodiment as can be seen in the variety of terms such as *situated embodiment* (Zlatev, 1997), *mechanistic embodiment* (Sharkey & Ziemke, 2001), *phenomenal embodiment* (Sharkey & Ziemke, 2001), *natural embodiment* (Ziemke, 1999), *naturalistic embodiment* (Zlatev, 2001), *social embodiment* (Barsalou, Niedenthal, Barbey & Ruppert, in press), plus in this paper *historical*, *physical*, *organismoid*, and *organismic embodiment*.

Embodiment is nowadays by many researchers considered a *conditio sine qua non* for any form of natural or artificial intelligence. Pfeifer and Scheier (1999), for example, argued that "intelligence cannot merely exist in the form of an abstract algorithm but requires a physical instantiation, a body". Furthermore, embodiment is commonly considered one of the key ideas that distinguish recent work on situated, embodied and distributed theories of cognition, from the approach of classical cognitive science which, based on functionalism, had its focus on 'disembodied' computation (cf. Chrisley & Ziemke, 2002; Clark, 1997; Pfeifer & Scheier, 1999; Varela *et al*., 1991; Ziemke, 2002). However, while many researchers nowadays agree that cognition has to be embodied, it is less clear so far what exactly that means. Wilson (2002) has recently pointed out that the diversity of claims in the field is problematic:

> While this general approach [of embodied cognition or embodied cognitive science] is enjoying increasingly broad support, there is in fact a great deal of diversity in the claims involved and the degree of controversy they attract. If the term "embodied cognition" is to retain meaningful use, we need to disentangle and evaluate these diverse claims.

In particular it is actually far from clear what kind of *body* (if any) is required for embodied cognition. Hence, while it might be agreed upon that humans are embodied cognizers, there is little agreement on what kind of body an artificial intelligence would have to be equipped with. Pfeifer and Scheier's (1999) view, for example, that intelligence requires a *physical* body, is not at all as generally accepted as one might think.

This paper identifies and discusses a number of different notions of embodiment in the cognitive science and AI literature. Due to space restrictions, none of these notions is here argued for or against in particularly much detail, although admittedly the notion of 'organismic embodiment', does receive more attention than the others, since it is derived from our own earlier work (Sharkey & Ziemke, 1998, 2001; Ziemke, 1999, 2001a; Ziemke & Sharkey, 2001).

The rest of this paper is structured as follows: The next section briefly discusses different views of embodied cognition, following the distinctions made by Wilson (2002). The section after that then identifies different notions of embodiment, focusing on the question what kind of body is required for embodied cognition. It should be noted that many of the notions and examples discussed here stem from discussions of AI systems, simply because the question of embodiment is usually most concrete and immediate in the synthesis of artificial systems. The guiding question in our discussion, however, is how useful different notions of embodiment are to cognitive science in general, in particular in identifying and understanding cases of embodied cognition. The final section then presents a brief summary.

[*] This paper is a revised version of Ziemke (2001b, 2001c).

Different Views of Embodied Cognition

Wilson (2002) recently identified six different views of embodied cognition, of which, however, only one explicitly addresses the role of the body.

"Cognition is situated": A claim obviously widely held in the literature on embodied cognition.[1] Wilson herself distinguished between situated cognition, which takes place "in the context of task-relevant inputs and outputs", and "off-line cognition", which does not.

"Cognition is time-pressured": That means, cognition is constrained by the requirements of real-time interaction with the environment, e.g. the 'representational bottleneck' (e.g. Clark, 1997).

"We off-load cognitive work onto the environment": Brooks (1991) made a similar claim saying that "the world is its own best model". A well-known example is Kirsh and Maglio's (1994) study of 'epistemic actions' in the Tetris game, i.e. decision-preparing movements carried out in the world, rather than in the head.

"The environment is part of the cognitive system": An example of this view could be Hutchins' (1995) work on distributed cognition, in which, for example, the instruments in a cockpit are considered parts of the cognitive system. However, according to Wilson, "relatively few theorists appear to hold consistently to this position in its strong form" (for a more detailed discussion see also Susi, Lindblom & Ziemke, in press).

"Cognition is for action": A claim made, for example, by Franklin (1997), who argued that minds are the control structures of autonomous agents.

"Off-line cognition is body-based": According to Wilson, this claim has so far received least attention in the cognitive science literature, although "it may in fact be the best documented and most powerful of the six claims". Perhaps the most prominent example is the work of Lakoff & Johnson (1980) who argued that abstract concepts are based on metaphors grounded in bodily experience/activity. This claim is discussed in further detail in the following section.

Different Notions of Embodiment

As noted in the previous section, perhaps somewhat surprisingly, many discussions/notions of em*bodi*ed cognition actually pay relatively little attention to the nature and the role of the body involved (if at all). Only Wilson's sixth view, of 'off-line cognition' as body-based, explicitly mentions the body as playing a central role. It does, however, leave open the question whether, for example, a humanoid robot, i.e. a robot with more or less roughly human-like form, could have the same type of cognition as its living counterpart.

We here would like to distinguish between the following six notions of what kind of body/embodiment is required for (embodied) cognition: (1) *structural coupling* between agent and environment, (2) *historical embodiment* as the result of a history of structural coupling, (3) *physical embodiment*, (4) *'organismoid' embodiment*, i.e. organism-like bodily form (e.g., humanoid robots), (5) *organismic embodiment* of autopoietic, living systems, and (6) *social embodiment*.

Each of the above notions of embodiment is in the following elaborated in a separate subsection. It might be worth pointing out beforehand that at least some of them are actually groups of more or less closely related notions rather than single, well-defined positions.

Embodiment as Structural Coupling

The broadest notion of embodiment probably is that systems are embodied if they are 'structurally coupled' to their environment. Note that this does not necessarily require a body. Franklin (1997), for example, argued:

> Software systems with no body in the usual physical sense can be intelligent. But they must be embodied in the situated sense of being autonomous agents structurally coupled with their environment.

The concept of *structural coupling* originates from Maturana and Varela's (1980, 1987) work on the biology of cognition, which will be discussed in a later subsection. Inspired by this concept, Quick et al. (1999)[2] have attempted to provide a "precise definition" of embodiment which is as follows:

> A system X is embodied in an environment E if perturbatory channels exist between the two. That means, X is embodied in E if for every time t at which both X and E exist, some subset of E's possible states with respect to X have the capacity to perturb X's state, and some subset of X's possible states with respect to E have the capacity to perturb E's state.

This notion of embodiment has the advantage that it is one of very few attempts to actually define embodiment. However, it might be considered to be of limited use to cognitive science since it is not particularly restrictive. Riegler (2002), for example, argued that "[w]hile this attempt to clarify the notion of embodiment is an important first step, it is at the same time an insufficient characterization" due to the fact that "every system is in one sense or another structurally coupled with its environment". That means, this definition of embodiment does not distinguish between cognitive and non-cognitive systems, which can be illustrated with Quick et al.'s (1999) example of a granite outcrop (X) on the Antarctic tundra (E). The outcrop is persistently perturbed by the wind, and in turn perturbs the flow of air. Hence, it is an embodied system according to the above definition, although certainly not many cognitive scientists would actually consider this an example of embodied cognition.

[1] It should be noted that the concept of situatedness itself is far from being well defined (cf., e.g., Ziemke, 2001a), and Wilson's notion is not uncontroversial. See also Clancey (2001), who made a useful distinction between functional, structural and behavioral perspectives on situated cognition.

[2] See also Dautenhahn, Ogden & Quick (2002).

Historical Embodiment

Several researchers have emphasized that cognitive systems are not only structurally coupled to their environment in the present, but that their embodiment is in fact a result or reflection of a *history* of agent-environment interaction and in many cases co-adaptation. Varela, Thompson and Rosch (1991), for example, argued that "knowledge depends on being in a world that is inseparable from our bodies, our language, and our social history – in short, from our embodiment". In a similar vein, Ziemke (1999) argued that "[n]atural embodiment [of living systems] … reflects/embodies the history of structural coupling and mutual specification between agent and environment in the course of which the body has been constructed." Similarly, Riegler (2002) includes the agent's adaptation to its environment in his definition of embodiment: "A system is embodied if it has gained competence within the environment in which it has developed".

Although more restrictive than the previous one, and possibly useful in identifying the evolutionary and/or developmental roots of embodied cognition, even this notion is obviously not particularly restrictive, since it seems to apply to many, if not all living systems, and further does not exclude non-physical ones (cf. below).

Physical Embodiment

A notion of embodiment which excludes software agents is the view that embodied systems need to have a "physical instantiation" in the sense of Pfeifer and Scheier (cf. introduction section), i.e. a physical body. Again, in itself, this is not very restrictive, and it still includes Quick et al.'s (1999) above granite outcrop, as well as chairs, tables, and many other objects of seemingly limited interest to cognitive science.

It might be worth pointing out that although historical embodiment and physical embodiment both can be considered special cases of structural coupling, none of these two notions includes or excludes the other. Riegler (2002), for example, noted that his definition of embodiment (cf. above) "does not exclude domains other than the physical domain"; in particular "[c]omputer programs may also become embodied" if they are the result of self-organization rather than explicit design. Similarly, living systems are physically embodied systems that are also historically embodied, whereas many other physical systems are not.

A somewhat more restrictive version of the notion of physical embodiment is the view that embodied systems should be connected to their environment not just through physical forces, but through sensors and motors. From an AI perspective, Brooks (1990), for example referred to this as *physical grounding*, arguing that "to build a system that is intelligent it is necessary to have its representations grounded in the physical world ... [i.e.] it is necessary to connect it to the world via a set of sensors and actuators".

Possibly, this could be considered an independent notion, perhaps under the label of *sensorimotor embodiment*. However, since it seems rather difficult to define exactly what 'sensors' and 'motors' are and how they differ from other 'perturbatory channels', we abstain from doing so in this paper.

Organismoid Embodiment

Another, yet more restrictive notion of physical embodiment is that at least certain types of organism-like cognition might be limited to organism-like bodies, i.e. physical bodies which at least to some degree have the same or similar form and sensorimotor capacities as living bodies. It should be noted that the notion of 'organismoid' embodiment here is intended to cover both living organisms and their artificial counterparts. [3]

One of the simplest examples of organism-like embodiment might be the Khepera robot used by Lund, Webb and Hallam (1998). It was equipped with an auditory circuit and two microphones which had the same distance as the two 'ears' of the crickets whose phonotaxis it was supposed to model. In this case the placement of the sensors, in both cricket and robot, reduced the amount of internal processing required to respond selectively to certain sound frequencies. Note that in this case the bodies of the cricket and the wheeled robot were in fact *very* different, except for one crucial detail, the distance between the 'ears'.

The most prominent and perhaps most complex, example of artificial organismoid embodiment are humanoid robots such as the famous Cog (Brooks *et al.*, 1998), based on the argument that research in AI, in order to be able to address/investigate human-level cognition, has to deal with human-like artefacts. Dreyfus (1996), for example, pointed out that "there are many important ways in which [disembodied] neural nets differ from embodied brains". He argued that neural nets would need to be "put into [humanoid] robots" since the lack of body and environment

> … puts disembodied neural-networks at a serious disadvantage when it comes to learning to cope in the human world. Nothing is more alien to our life-form than a network with no up/down, front/back orientation, no interior/exterior distinction, … The odds against such a net being able to generalize as we do … are overwhelming.

This argument is closely related to Wilson's sixth view of embodied cognition and, for example, the aforementioned work of Lakoff and Johnson (1980, 1999) on the bodily/metaphorical basis of abstract concepts. Lakoff (1988) summarized the basic idea behind this theory as follows:

[3] It might be worth pointing out that while living and artificial 'organismoids' can be considered physically embodied, only the former are necessarily historically embodied whereas the latter are usually results of human design.

Meaningful conceptual structures arise from two sources: (1) from the structured nature of bodily and social experience and (2) from our innate capacity to imaginatively project from certain well-structured aspects of bodily and interactional experience to abstract conceptual structures.

If, for example, the concept of 'grasping an idea' is grounded in the bodily experience/activity of grasping physical objects, then a robot without any gripper arm/hand could hardly be expected to be able to understand that concept. A related argument has been presented by Keijzer (1998) who questioned the suitability of wheeled robots as models of organisms with completely different means of locomotion.

For obvious reasons, artificial human-like or actual human embodiment could be considered a special case of particular interest to cognitive science. It should be noted, however, that this still leaves open the question what exactly the supposedly cognition-relevant bodily differences between humans and other organisms are. That means, it might very well be true that having hands, arms, legs, etc. is essential to human (-like) embodied cognition, but this notion in itself does not tell us why this might be so.

Organismic Embodiment

The notion of organismic embodiment holds that cognition is not only limited to physical, organism-like bodies, but in fact to organisms, i.e. *living bodies*. This notion has its roots in the work of theoretical biologist von Uexküll (1928, 1982) and its modern counterpart, Maturana and Varela's (1980, 1987) work on the biology of cognition, which holds, roughly speaking, that cognition is what living systems do in interaction with their environment.[4] According to this view, there are crucial differences between living organisms, which are *autonomous* and *autopoietic*, and man-made machines, which are heteronomous and allopoietic (cf. Sharkey & Ziemke, 2001; Ziemke & Sharkey, 2001).

Von Uexküll (1928) argued that the behavior of organism depends on an historically created basis of reaction, i.e. a context-dependent behavioral disposition. Machines, on the other hand, at least in von Uexküll's time (1864-1944), did not have such an historical basis of reaction, which, according to him, could only be grown - and there is no growth in machines. He further elaborated that the rules machines follow are not capable of change, due to the fact that machines are fixed structures. That means, the rules that guide their operation, are not their 'own' but human rules, which have been built into the machine, and therefore also can be changed (or repaired in the case of damage) only by humans, i.e. mechanisms are *heteronomous*. This can be summarized by saying that *machines act according to plans* (their human designers'), whereas *living organisms are acting plans*.

[4] See also Lemmen (1996), Zlatev (in press), and Stewart (1996), who summarizes this view as "Cognition = Life".

This is also closely related to what von Uexküll (1982) called the "principal difference between the construction of a mechanism and a living organism", namely that machines are constructed centripetally, i.e. from parts that have to be produced first, whereas organisms 'construct' themselves centrifugally, i.e. the whole comes first and the parts 'grow' from it.

Similarly, Maturana and Varela (1980, 1987) distinguished between the organization of a system and its structure. The *organization*, similar to von Uexküll's notion of a building-plan (*Bauplan*), denotes "those relations that must exist among the components of a system for it to be a member of a specific class" (Maturana and Varela, 1987). Living systems are characterized by their autopoietic organization. An *autopoietic* system is a special type of homeostatic machine for which the fundamental variable to be maintained constant is its own organization. A system's *structure*, on the other hand, denotes "the components and relations that actually constitute a particular unity, and make its organization real" (Maturana and Varela, 1987). Thus the structure of an autopoietic system is the concrete realization of the actual components and the actual relations between them. Its organization is constituted by the relations between the components that define it as a unity of a particular kind. These relations are a network of processes of production that, through transformation and destruction, produce the components themselves. It is the interactions and transformations of the components that continuously regenerate and realize the network of processes that produced them.

Hence, according to Maturana and Varela, living systems are not at all the same as machines made by humans, such as cars and robots, which are *allopoietic*. Unlike an autopoietic machine, the organization of an allopoietic machine is given in terms of a concatenation of processes. These processes are not the processes of production of the components that specify the machine as a unity. Instead, its components are produced by other processes that are independent of the organization of the machine. Thus the changes that an allopoietic machine goes through without losing its defining organization are necessarily subordinated to the production of something different from itself. In other words, it is not truly autonomous, but heteronomous. In contrast, a living system is truly autonomous in the sense that it is an autopoietic machine whose function it is to create and maintain the unity that distinguishes it from the medium in which it exists. It is worth pointing out that, despite differences in terminology, Maturana and Varela's distinction between autopoietic and allopoietic machines, is very similar to von Uexküll's (1928) distinction between centripetally constructed mechanisms and organisms which as 'living plans' 'construct' themselves in a centrifugal fashion.

As discussed in detail elsewhere (Ziemke, 2001a; Ziemke & Sharkey, 2001), much progress has been made in the direction of self-organizing robots in recent AI and artificial life research. Unlike the machines in von Uexküll's time, today's adaptive robots can 'grow' in interaction with their environment through the use of artificial evolutionary and learning techniques. Furthermore, robot bodies can be evolved centrifugally over generations in some sense (e.g. Lipson & Pollack, 2000). Providing artifacts with the capacity for self-organization can be seen as the attempt to provide them with an *artificial ontogeny*. However, the attempt to provide them with autonomy in the above strong sense this way seems to be doomed to fail, since it follows from the above argument that autonomy cannot from the outside be 'put' into a system, that does not already 'contain' it. Ontogeny preserves the autonomy of an organization, it does not 'construct' it. The attempt to bring the artifact into some form of structural congruence with its environment, on the other hand, can 'succeed', but only in the sense that the criterion for congruence cannot lie in the heteronomous artefact itself, but must be in the eye of the observer. Hence, given the limitations of current technology, organismic embodiment so far in fact remains limited to biological living systems, but this does not at all rule out the possibility of future artificial autopoietic systems, e.g. based on so-called self-repairing materials.

The notion of organismic embodiment has the advantage that it limits cognition to a natural kind of systems, i.e. living organisms. Obviously, however, its usefulness to cognitive science, as traditionally conceived, is limited in the sense that by equating life and cognition to some degree it simply dodges the question of what exactly it is that makes human or higher-animal cognition particularly interesting.

Social Embodiment

Barsalou et al. (in press) have addressed the notion of *social embodiment* by which they mean that

> … states of the body, such as postures, arm movements, and facial expressions, arise during social interaction and play central roles in social information processing.

To some degree their discussion of social embodiment is orthogonal to the previous five notions in the sense that it addresses the role of embodiment in social interactions rather than the question what kind of body is required for what type of cognition. Focusing on human cognition and social interactions, Barsalou et al. are simply not particularly concerned with different types or notions of embodiment in the above sense. Nevertheless, this aspect is addressed indirectly in their discussion of four types of "embodiment effects":

> First, perceived social stimuli don't just produce cognitive states, they produce bodily states as well. Second, perceiving bodily states in others produces bodily mimicry in the self. Third, bodily states in the self produce affective states. Fourth, the compatibility of bodily states and cognitive states modulates performance effectiveness.

The space limitations do not allow us to address in detail the relations and (in-) compatibilities between this notion of social embodiment and the five previous notions, but it should at least be mentioned that Barsalou et al.'s notion of knowledge as "partial simulations of sensory, motor, and introspective states" is highly compatible with the notions of organismoid embodiment and ('off-line) cognition as body-based. The question whether social embodiment requires a living body, or it could as well be realized in physical or computational systems is a question to be addressed in future research (cf. also Dautenhahn, 1997).

Summary & Conclusion

This paper has discussed a number of diverse notions of embodiment as well as some of their respective pros and cons. The motivation has been similar to that of Wilson (2002), i.e. to disentangle the different claims and notions in the field (see also Chrisley & Ziemke, 2002). However, unlike Wilson, we have here focused on different notions of embodiment and the question exactly what kind of body is considered to be capable of embodied cognition. The notions we have identified in the literature are the following: (1) *structural coupling* between agent and environment, (2) *historical embodiment* as a result of a history of agent-environment interaction, (3) *physical embodiment*, (4) *'organismoid' embodiment*, i.e. organism-like bodily form, (5) *organismic embodiment* of autopoietic, living systems, and finally (6) *social embodiment*.

Obviously, this short paper has serious limitations: the notion of organismic embodiment, the most restrictive of the notions discussed here (or at least the first five), does in fact apply to all living systems, which is not particularly restrictive at all. Humanoid and human embodiment could be considered more restrictive, special cases of organismoid and organismic embodiment respectively. In particular in connection with the notion of social embodiment, these might be considered to be of particular interest to cognitive science, but no arguments have been presented here as to why the more specific cases could or should allow for substantially different types of embodied cognition than other members of the more general categories.

Nevertheless, we hope that the distinctions presented here will help to disentangle the large variety of claims, notions and theories that currently characterizes research on embodied cognition.

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