Epistemological Aspects of Embodied Artificial Intelligence

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1 From ingenuity . . .

The German composer Richard Strauss was once asked about musical ingenuity concerning his new big opera "Der Rosenkavalier". The story goes that—tired of these compliments—he replied: "Everybody talks about the genius and nobody sees the work. Did you ever try to only *copy* the score?"

This story may not be literally true, but it emphasizes that a good idea only marks the first step of a masterpiece. The rest is usually hard work. This is all the more true for sketches of scientific works of art. A decade after Rodney Brooks first described his ideas about the role of robotics in Artificial Intelligence [Brooks 86] we are now in a position to continue the hard work rather than elaborate on the basic concepts. While the credo of embodied AI is clear,

> Intelligence is determined by the dynamics of the interaction with the world. [Brooks 91]

its implications are not.

Embodied AI originated as a response to engineering problems in the field of robotics. It is based on the idea that in order to build intelligent autonomous systems it is necessary to have them interact directly and dynamically with the world. The departure from approaches that dominated the field until then is characterized by an increasing importance assigned to the physical structure of the robot body. Nowadays, it has been largely accepted in Artificial Intelligence that the notion of embodiment changes the constructs used for the generation of intelligently behaving systems. Embodied AI has been shown to improve on the dynamical qualities of intelligent embodied systems, i.e. to "get the interaction dynamics of robots right".

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Many newly devised robots succeeded in tasks that had not previously been mastered by traditional robotic systems. As a consequence of the engineering success, researchers in the field of embodied AI soon developed new concepts for the general study of intelligence and for the construction of proper models of human cognition. The central dogma of embodied AI is, of course, that it is necessary to study intelligence as a *bodily* phenomenon. This view originated from the successful implementation of robots that were no longer considered to be mere data processing facilities on wheels. Instead, the problem of making a robot navigate in its environment and fulfilling tasks there is now approached as a joint physical and informational problem. The new group of researchers also subscribed to the view that simulations of robots would *not* be of much practical value to this kind of scientific program. Robots have to be *built* in order to study their dynamics and make them "intelligent".

These basic ideas about how to proceed in robotics were paralleled by the development of new control architectures. Overall system goals are now described in terms of processes that lead to their fulfillment, not in terms of I-O characteristics and symbolic data abstractions. These new schemes often consist of strongly coupled, highly interconnected, parallel processes that ensure a tight connection between the system and its environment. As opposed to the more traditional functional modularizations, internal system time can be given a straightforward interpretation since many processes interact directly with the world. A reasonable notion of time thus consists in the delay that is needed for every individual module's interaction with the environment.

This view has now been recognized to have the potential for inducing also major changes in Cognitive Science. Even the notion of 'cognition' is altered as a result of the new concepts. Cognition, in the field of embodied AI research and embodied Cognitive Science, is no longer viewed in separation of its bodily substrate. It is regarded as a system that drives the body and operates in close contact with the body's environment. This means that the study of cognition is also the study of bodily action and perception in the system's environment, and cannot be viewed separately from either of the three (body, action, environment). It is easy to see that it is advantageous to study the constraints of physics with a system that 'automatically' inherits them from the real world by having a body [Prem 95].

2 ...to hard work

The strong claim that the body is a necessary condition for the study of human intelligence was, of course, to be criticized soon. Large parts of conventional Cognitive Science do not make explicit reference to the bodily control function of the human brain. Quite to the contrary, for a very long time intelligence was viewed as something that can and should be studied detached from its physical condition. Dating back to Aristotle's interest in theory, the history of the study of human intelligence is also a history of neglecting the role that the non-mental plays in guiding human intelligent behavior.

With this fact in mind, we see that the task of embodied AI is much more difficult than it probably seems to be at first sight. Not only do researchers in the field have to restart Artificial Intelligence and rephrase models of cognition in body-based terms, they also have to provide new theoretical and philosophical grounds on which their arguments can be based. So far, much work has concentrated on the explanation and justification of the basic beliefs within embodied AI. It is now time for the next step, in which the epistemology and consequences of an embodied perspective are stabilized, emphasized, and developed.

Stability can be achieved by a proper treatment of foundational issues. The themes range from a discussion of the conditions of the possibility of knowledge in embodied AI to necessary requirements for research in this field: What are necessary elements of embodied architectures? What are the philosophical implications of an "embodied" perspective? What are these systems driven by? What are the differences to more conventional approaches?

Emphasis must then be given to the development of new cognitive (and AI) models. The interesting themes range from motor control perspectives in technical and biological systems to the generation of 'abstract' cognitive schemas through embodiment. How can the study of body-based real world interaction further our understanding of cognitive phenomena?

Development should be sustainable. This poses the question for further directions of research. How are we to proceed in a science of embodied systems? How does this influence scientific concepts such as knowledge or intelligence? What are the new scientific questions that need to be addressed? Which new research programmes are needed to answer these questions?

These and other topics are addressed in this special issue on epistemological aspects of embodied AI.

3 Papers in this issue

Merleau-Ponty, Embodied Cognition, and the Problem of Intentionality The problem of a well formulated theoretical foundation for embodied cognition is studied in Lewis A. Loren's and Eric Dietrich's contribution. In their paper, they examine Merleau-Ponty's possible contribution to embodied approaches. The philosophy of late Merleau-Ponty centered around the effort to ground the notion of consciousness in the body. This, together with his particulary scientific approach to phenomenology, makes him an interesting source for potential foundational contributions to embodied AI.

The Epistemology of Autism Horst Hendriks-Jansen makes the case for an embodied, dynamic, and historical explanation, especially of the phenomenon of autism. But the paper also serves to critically examine the theory of mind hypothesis by studying conditions that can be said to involve knowledge deficits. The paper then discusses the epistemological questions raised by the various explanatory strategies and argues in favor of a new conceptualization of knowledge. This new approach, in close connection with embodied theories of cognition, regards knowledge as the ability to act appropriately and shows how an embodied perspective can influence our understanding of basic cognitiveee concepts.

I could be you In her paper, Kerstin Dautenhahn studies the phenomenological dimension of social understanding. This form of 'communication' is based on empathy as a bodily phenomenon and on a process of biographic re-construction. Kerstin Dautenhahn argues on a philosophical as well as scientific basis. An agent's bodily experiences serve as the point of reference for social understanding. Besides of the philosophical arguments, a robot experiment is used to study the role of the human observer and designer as an active, embodied agent who is biased towards interpreting the world in terms of inentionality and explanation. The author also argues for bridging the gap between computationalism and phenomenology by means of artificial agents that enter the world of phenomenology and become social minds.

Studying the Role of Embodiment in Cognition The contribution of Maja J. Mataric centers around the important question of the connection between embodiment and higher-level cognition. Researchers in the field have argued before that lower-level processing (like motor interactions) is not—in principle—different from higher-level cognition. To answer these questions, Maja Mataric proposes and describes two directions of her own work: group behavior and imitative behavior. The former centers around the principle of basis behaviors that can be used for the generation of complex behavioral aggregates, the latter involves the study of a parallel development of perceptual and motor systems. The specific research question and its subquestions define a typical scientific program in the new field of embodied AI.

Post-modular systems Lynn Andrea Stein discusses architectural principles for cognitive robotics in relation to the more conventional approaches that have dominated AI and cognitive science throughout the last decades. The fact that embodied AI is much more rooted in anatomy and physiology offers support for a different approach to system decomposition. Traditionally, modular-functional decomposition is a basic tool within Computer Science. In embodied AI, however, a more opportunistic approach is taken. Three examples for neo-modular principles—imagination, shared grounding, and incremental adaptation—are discussed in the paper. It is explained how these principles can be used in the Gedanken experiment of a construction of a complex reaching system.

The Emergence of Representation in Autonomous Agents Mark H. Bickhard's contribution is concerned with another foundational concept of Artificial Intelligence, namely representation. However, the notion of representation is put in the very practical context of action selection. The problem of "What to do next?" occurs for any embodied agent and marks the origin for solutions to the problem of representation. It is based on the notion of "system detectable representational error" that connects representation with the outcome of system actions. This new body-based explanation of a basic concept of AI opens the door for furthering our understanding of other important and poorly understood terms, e.g. that of motivation.

Autonomous Agents as Embodied AI Stan Franklin's contribution is probably not as "embodied" as the others in this special issue, but it discusses two important questions: What are necessary elements of embodied architectures? and: How are we to proceed in the science of embodied systems? Stan Franklin is not as radically oriented towards physical embodiment, but he presents us with a system of cognitive architectures for embodied agents. This proposal makes the case for a parallel employment of an engineering approach and a scientific approach and puts embodiment in a wider context among software agents and artificial life agents.

Responsiveness in Dialog and Priorities for Language Research Nigel Ward's paper is an example for how an embodied perspective may change the research programmes of Artificial Intelligence. His contribution exemplifies an approach to situated action in the area of natural language understanding (and generation). As an example, Nigel Ward describes a system that can interact with unsuspecting speakers and appears to produce natural back-channel feedback, i.e. grunts, which serve to acknowledge understanding by a listener in a conversation. This system supports the hypothesis that principles of the embodied approach are also relevant for the study of social behavior. The implications for further research programmes in the area are also discussed in the paper.

References

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