Embodiment as a Necessary a Priori of General Intelligence

David Kremelberg(✉)

Icelandic Institute for Intelligent Machines, Reykjavik, Iceland
david.kremelberg@uconn.edu

Abstract. This paper presents the most important neuroscientific findings relevant to embodiment, including findings relating to the importance of embodiment in the development of higher-order cognitive functioning, including language, and discusses these findings in relation to Artificial General Intelligence (AGI). Research strongly suggests the necessity of embodiment in the individual development of advanced cognition. Generalizing from this body of literature, conclusions focus on the importance of incorporating a physical body in the development of AGI in a meaningful and profound way in order for AGI to be achieved.

1 Introduction

Work conducted in the field of neuroscience suggests the presence of a physical body may be necessary for the development of advanced cognitive functions, including language, and it has been argued that embodiment may be necessary for abstract and symbolic thought. Despite this, a focus on robotics, or more specifically, embodiment within AGI remains rare, with theoretical and philosophical discussion pertinent to embodiment and its importance also being uncommon. This paper presents a summary of evidence drawn from neuroscience suggesting the necessity of embodiment in achieving advanced cognitive functioning, along with the importance of real experience, and how embodiment may solve the symbol grounding problem. All of the above produces a number of important implications in relation to AGI, and by extension, general intelligence.

2 The Neuroscientific Basis Behind Embodiment

There exists a substantial body of evidence from the field of neuroscience suggesting the importance, or more strongly, necessity of embodiment in the achievement of advanced cognitive functions in humans. Within this and related fields, theories of embodied cognition suggest no separation between cognitive processing considered more rudimentary, such as perception and action, and what are considered higher-level processes, including language and thought [7]. According to this view, cognition associated with these "high" and "low" level processes is

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not processed in different domains. Similarly, language comprehension is thought to recruit the same sensorimotor areas as are recruited when interacting with the environment [3,4,7,11] and the state of the world described using language is thought to be simulated when this language is comprehended [5,16]. The key issue here is grounding; theories of embodied cognition suggest not only that the same neural units ground both actions as well as the language which refers to actions, but within this sensorimotor basis for cognition [12,14], the sensorimotor system also provides the grounding for abstract concepts [7]. Various proposals have been put forth within this school of thought with regard to how these abstractions might work [6]. Additionally, the embodied view of cognition is further supported by thoughts being composed of modality-specific representations, and with perception, thought, and action being co-constituted, or constitutively interdependent [12].

In particular, visio-motor processing, and specifically, manipulation, have been cited as necessary for higher cognitive development - which includes abilities such as social behavior and language [10]. Within the context of language comprehension, sensorimotor areas in the brain have been found to be closely linked to language processing, and with the motor system having an important role in language comprehension [7]. All of this suggests sensorimotor capabilities and relevant components of the brain are necessary for the achievement of our language abilities, and that mechanical or electronic counterparts of these may be necessary for language acquisition in machines, along with other advanced cognitive functions.

3 The Necessity of Embodiment and Sense Experience

An issue rarely discussed is the potential necessity of a body for the purposes of achieving general intelligence. One question that has been raised is the extent to which the body influences the brain, whether it impacts the way in which we think, and if the world must be experienced in order to be understood [15]. Work in the field of embodied cognition suggests that cognition is much more dependent on a physical body as has been assumed [12,15], with some stating that interactions are imperative for shaping the rapidly growing brain [10], and others arguing that the body is intimately connected with learning, even the learning of abstract concepts, such as mathematics [1], and that even symbol manipulation is embodied, activating "naturalistic perceptuomotor schemes that come from being corporeal agents operating in spatial-dynamical realities" [1, p. 2].

Evolutionarily, brains have always developed within the context of a body that interacts with the world to survive [15], while the vast majority of the work done in AGI has ignored this fact. Some have cited the necessity of machines acquiring their own experiences if human-level intelligence is a goal - and the fact that memories relate to something done with the body, or some real experience [15]. Without embodiment, agents cannot learn through experience, while approaches not incorporating embodiment assume that representations of physical objects can be sufficiently constructed through only theoretical measures [15].

However, simulations are inherently limited, while goal-oriented behavior derives its success from experience: even the simple task of picking up an object is easily accomplished only due to our past physical experiences with such objects.

All of this suggests that intelligence requires a physical body that interacts with the world, and that intelligence needs to grow and develop over time concomitant with experience, as opposed to being pre-programmed, with embodiment and sense experience being intimately connected with cognition. It has been argued that even abstract thought is rooted in our physical experiences with the world - that we have a large set of basic concepts which relate to our body and how we move in space, and that more advanced and abstract concepts build upon these [8,9]. It has even been suggested that conceptions like happiness would differ in different bodies [8,9] - which implies that all emotions, and maybe all concepts, as well as the nature and form of consciousness, may vary on the basis of the physical form of the agent.

Additionally, embodiment also assists with the symbol grounding problem [12]. In humans, meaning is imbued in objects and the words that represent them through our experiences with these objects, our history with them, our memories, and so forth. Grounding even a single concept is thought to require a set of physical skills and experiences which are very specific; for example, grounding the word "chair" involves reliable detection of these objects, as well as responding appropriately to them [2]. Incorporating physicality in agents should allow them to gain similar experiences to ours, which should allow for grounding by attaching meaning to physical objects as well as their representation of these objects. This grounding would allow for a connection to the real world which, so far, has not been attained by any artificial agent, while also allowing for cooperation and communication, which have been said require symbolic thought [10]. This is also highlights the importance of the extent to which this physicality may need to be similar to ours, and with all forms of sensory perception being active processes, with sensory experiences being tied to movement, this would suggest the insufficiency of simply adding sensors to a robot [15].

4 Conclusions

Searle argues that machines cannot understand, as they simply operate on the level of symbol manipulation [13]. Agreeing that an agent that only manipulates meaningless symbols is qualitatively different from one whose symbols are grounded and are linked to other grounded symbols, the question then becomes how to imbue meaning in the symbols used by machines. With the literature suggesting that meaning is imbued through embodied experience, if this is not the only way in which machines can be created whose symbols are meaningful to themselves, it may at least be an efficient approach to creating such an entity.

While those in AGI have realized the probable errors of the approaches used in AI in the attempt to create general intelligence, the work done in the field still largely encapsulates the view that cognition can be reduced to a series of algorithms; input, processing, and output. Furthermore, the idea that knowledge

of how intelligence develops may be necessary in order to replicate it has largely been ignored. All of this would suggest an embodiment-focused approach to AGI, which, as stated, would not simply involve the addition of sensors to a robotic body, but would allow for a richer and fuller qualitative experience, akin to the qualitative deepness of the sensory experience and the nature of embodiment experienced by humans. In addition, this would further suggest a strong focus on the use of learning algorithms similar to those manifested in the human brain, and that through extensive and continuous interaction with the environment, AGI would be achieved. AGI may not be expected to bootstrap from nothing; in the case of many artificial agents, some innate abilities as those manifested in babies are pre-programmed [10]; this may at least be conducive to the bootstrapping process without impeding the path to AGI. Similar arguments could be made for our other innate abilities such as language.

In sum, strong evidence exists for the necessity of embodiment in grounding and the development of advanced cognitive functions, including language, and this evidence likely applies to all agents, which suggests that embodiment and experience is a necessary a priori for AGI. An embodiment approach should allow machines to think about and understand concepts in a manner which is no less in quality than that of a human. This suggests the great importance of those in AGI to not simply put their system in a robotic body or to add sensors, but for the entire process of development to be intimately connected with embodiment; great detail should be afforded to the body from the earliest planning stages, and with no detail planned or made without consideration of the body, and for the artificial body to be as similar as possible to a human body. This then suggests the importance of those in AGI to be working closely with those in the field of robotics; associations should be made, and these two groups of researchers should be closely collaborating on AGI projects as partners.

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