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# Does intelligence require a body?

The growing discipline of embodied cognition suggests that to understand the world, we must experience the world

***Katrin Weigmann***

Our brain controls our body—every movement we make is guided by neuronal activity. But how about vice versa? Does the body influence our brain; does it have an impact on how we think? This question might seem odd. We usually stick to a simple 'sense–think–act' paradigm: we hear the phone ring (sense), we recognize that we should answer it (think) and grab the receiver (act). This is a one-way process: the brain receives input from the senses and calculates the output. After a long tradition of dualistic thought, influenced most prominently by the French philosopher René Descartes, we tend to regard cognition as virtually disembodied: Descartes argued that the mind and the body are distinct and that thinking is assigned to an immaterial soul that exists independently of a mechanically functioning organism [1].

**Does the body have an impact on how we think?**

This concept of cognition as something immaterial has influenced generations of biologists, psychologists, computer scientists and behavioural researchers. However, evidence from these fields paints a different picture that regards acting, sensing and thinking as inseparable processes, such that cognition depends much more on a physical body than commonly assumed. The new research programme that has provided these insights is called 'embodied cognition'. Within its framework, psychologists test the influence of defined movements on memory recall [2]; neuroscientists analyse the role of the brain's motor system in cognitive skills such as language comprehension [3]; and researchers in artificial intelligence build robots that grab objects [4], open screw caps (world.honda.com/ASIMO/technology/2011/performing/) and play football (www.robocup.org/).

Does the body have an impact on how we think? Seen from the practical perspective of artificial intelligence, it boils down to the question: does the shape of the machine matter when trying to model intelligence in said machine? Such a question would have been greeted with ridicule in the 1950s or 1960s, the early heydays of artificial intelligence. The prevalent thinking of the time was that cognition involved the manipulation of abstract symbols following explicit rules. Information about the physical world could be translated into symbols and processed according to formal logic [5–8]. "Cognition was described as a chess play," explained Giulio Sandini, Director of Research at the Italian Institute of Technology and Professor of Bioengineering at the University of Genoa, Italy. As such, because symbol processing is abstract, it is independent of a platform. Scientists therefore claimed that cognition is similar to computation: minds run on brains as software runs on computer hardware [7,9]. In his book, *Artificial Intelligence: The Very Idea* (1985), John Haugeland (1945–2010), Professor Emeritus and Chair of the Philosophy Department at the University of Chicago, coined the term 'GOFAI'—'good old-fashioned artificial intelligence'—to describe this approach [1].

The idea that thinking is merely the processing of symbols, can be traced back to the fifteenth and sixteenth centuries to thinkers such as Copernicus and Galileo, who described nature in terms of geometrical figures and mathematical formulas. In the seventeenth century, Thomas Hobbes (1588–1679) and René Descartes (1596–1650) extended this idea to human cognition. Hobbes proposed that reality was fundamentally mathematical and so was thinking. Hobbes was a materialist—to him thoughts were similar to particles—but Descartes regarded thoughts as symbolic representations of reality. To him, thought and body were two entirely different entities [1], and the mind merely uses the body to receive input and produce output. This dualist view of the world still exerts a strong influence today; we still tend to distinguish between the 'mind' and the 'brain'.

**As soon as it came to simulating natural behaviour, however—constructing robots that function in an unknown environment—GOFAI failed**

In the early years of artificial intelligence, scientists were optimistic that human-like intelligence was in reach. "Machines will be capable, within twenty years, of doing any work a man can do," Herbert Simon (1916–2001), former Professor at Carnegie Mellon University and one of the founders of artificial intelligence, wrote in 1965. Marvin Minsky, also a pioneer in the field of artificial intelligence and co-founder of the Massachusetts Institute of Technology's artificial intelligence laboratory stated in 1967 that "[w]ithin a generation the problem of creating 'artificial intelligence' will substantially be solved" [10]. Indeed, GOFAI was successful as long as it was concerned with solving problems on the basis of explicit rules. Computers played chess, solved algebraic problems and manipulated text. As soon as it came to simulating natural behaviour, however—constructing robots that function in an unknown environment—GOFAI failed. The idea of providing a machine with sensors and motors, but keeping the rule-based models of GOFAI, did not lead to anything as skilful as a cockroach [5,7].

"Early robots would often have processors outside their body. It was like a brain in a vat—the brain was apart from the body doing symbol processing," commented Larry Shapiro, Professor in the Department of Philosophy at the University of Wisconsin, Madison, USA. "The off-board computer would take the sensory input, do some manipulation on the input symbols, compute an output and instruct the robot to move in a particular way." This procedure was slow and subject to failure when small changes in the environment were not sufficiently taken into account—by the time the robot figured out what to do the environment had changed [5].

> **Eventually, neighbouring fields of research—philosophy, psychology, neuroscience and evolutionary biology—provided new insights about how intelligence works in the real world**

"Once you are caught up in this Cartesian world view that thinking is algorithms or a computer programme, it is enormously difficult to free yourself from that. It just seems so obvious: there is input, processing, output—how else could it be?" commented Rolf Pfeifer, Professor of Computer Science at the Department of Informatics, University of Zurich and Director of the University's Artificial Intelligence Laboratory. Eventually, neighbouring fields of research—philosophy, psychology, neuroscience and evolutionary biology—provided new insights about how intelligence works in the real world. "When you look at intelligence from an evolutionary perspective, you will find that brains have always developed in the context of a body that interacts with the world to survive. There is no algorithmic ether in which brains arise," Pfeifer explained. "Traditional cognitive science has really been very useful, but it does not function the way brains do. The good chess programmes do not play chess in the same way that people do." The past 50 years in psychology—and the past 15–20 years in artificial intelligence—eventually saw a paradigm shift, a new way of thinking about the nature of cognition.

This paradigm is already inspiring a new generation of robots in which sensing and acting are more closely linked [5,8,11]. "You can build the robot in a way that parts of the body perform the functions that otherwise would have been performed by the off-board computer," Shapiro explained. Sensors are directly coupled to motors, so the robot can react reflexively instead of having to calculate every step. Moving away from the traditional 'sense–model–plan–act' paradigm makes the system react faster and ensures that it is less prone to error as it processes only relevant information. Such robots constantly monitor their internal state and the real world, and adjust their movements correspondingly.

Making machines move more efficiently is more than just an objective in itself. It might, in fact, be the first steps towards human-like artificial intelligence. "If you want to develop something like human intelligence in a machine, the machine has to be able to acquire its own experiences," Sandini said. "I can close my eyes and imagine actions and imagine smell and sound and taste, but all these memories I have are the result of something that I did with my body—some real experience I had," he explained. Whereas in GOFAI any knowledge is typically preprogrammed, the basic idea in embodiment is to give the robot sensory and other capabilities to learn through experience [6,8]. Just as children learn by interacting with the world—shaking objects, sticking them in their mouth, pouring liquid from one container to another—the machine should also learn by using its body. "I don't think that one can build a representation of an apple with taste, size, shape and smell solely through theoretical measures. An apple is all these things that you have experienced yourself. You cannot preprogramme an intelligent system," Sandini concluded.

It also turns out that simply sticking a camera or other sensors on to a machine is insufficient. Vision, similar to any other form of sensory perception, is an active process and sensory experiences result from movement. "When I walk, the environment appears to move past my visual field. I actively induce this optical flow through an interaction with the environment. When I pick up a glass of water, I can feel it with the tactile sense of my fingertips. I feel the forces in my musculature. I generate these stimulations myself," Pfeifer explained. As with small children, a robot needs to interact with the environment to acquire input as the raw material to develop intelligence. These interactions also help to correlate experiences from different sensory systems. Accordingly, when a child sees an object, it knows immediately what movements are necessary to be able to pick it up. It learns to categorize, to distinguish cups from cars or people, not just on the basis of visual input, but on the basis of how it would interact with them [8]. "Categorization is the most elementary ability in cognition—and this is achieved through the sensori-motor system," Pfeifer explained.

Today's robots are becoming astonishingly versatile at sensing and moving. Robots can dance (www.youtube.com/watch?v=ZHJf365p_zw&feature=related), play the flute [12], crawl as babies [13] or look surprised [14]. There is, of course, the danger that we might over-interpret the anthropomorphic nature of their 'intelligence', because even the most advanced robots do not understand what they are doing in a human way. In fact, understanding—attaching meaning to information—is an intriguing philosophical problem, which is often referred to as the 'symbol grounding' problem, especially when applied to artificial intelligence [7,8]. A computer based on traditional symbol processing, for example, can produce timetables for train schedules without understanding the nature of trains; it lacks any connection to reality. It might also produce a medical diagnosis on the basis of a patient's symptoms without having any medical knowledge. Whatever symbols it processes, they have meaning only to the user [8].

> **…the basic idea in embodiment is to give the robot sensory and other capabilities to learn through experience**

"An idea pursued in embodied cognition is that it's interaction with the environment that endows these symbols in the brain with meaning," explained Shapiro. Children learn that a chair is something to sit on through experience. Things acquire meaning through grounding, through connecting them with the real world. Contemporary robots are still practising basic abilities such

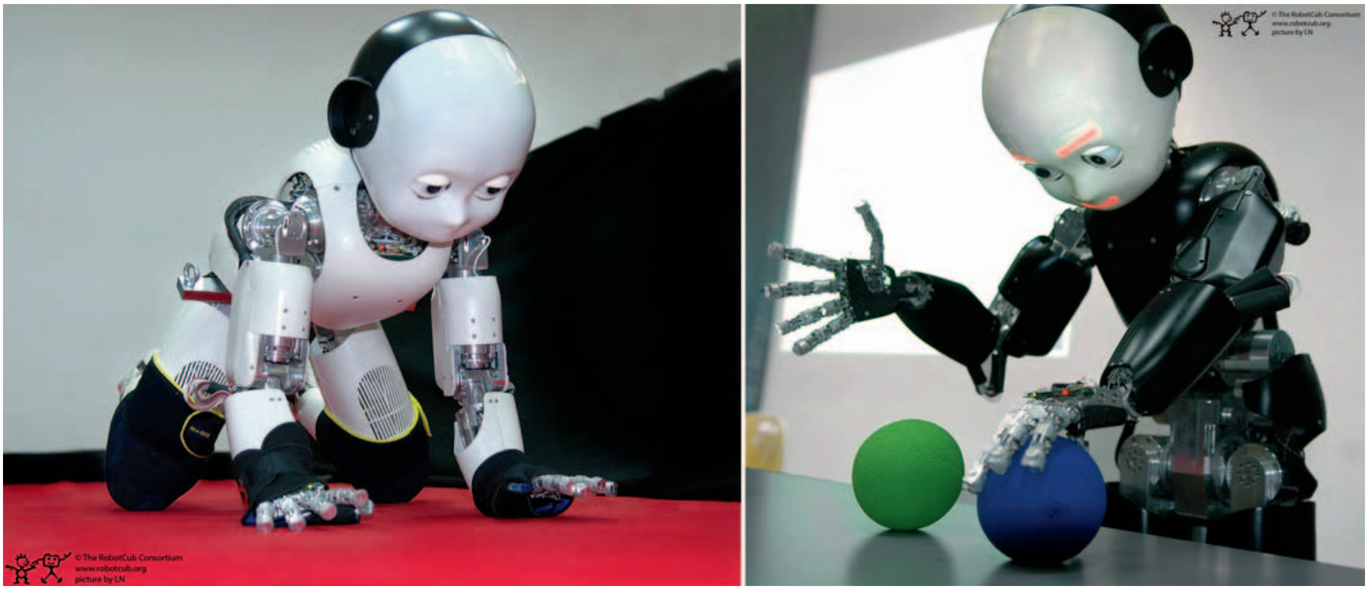

**Fig 1** | The iCub was designed to study the learning of cognitive capabilities. iCub is a humanoid robot the size of a three-year-old child with various sensory capabilities that allow it to interact with its environment. Images courtesy of the RobotCub Consortium and RBCS department—Istituto Italiano di Tecnologia.

as grabbing or vision and will therefore only acquire experience in a narrow segment of reality (Fig 1). But some possible future robot, which 'grows up' in a rich environment with improved sensory abilities, might start to gain some understanding of the objects it uses. "At least that's the hope," Shapiro said.

The idea of motor experience as a prerequisite to understanding has its parallels in biology. "One of the reasons I believe that intelligence requires a body comes from the discovery of mirror neurons in neuroscience," Sandini commented. In the 1990s, Giacomo Rizzolatti at the University of Parma, Italy, and his colleagues discovered neuronal cells with visuomotor properties in the premotor cortex of macaque monkeys [15]. The cells not only control motor activity, but also are activated on sensory stimulation. In particular, mirror neurons fire both when a monkey carries out an action such as grabbing a banana and when it observes someone else carrying out the same action. It seems that these neurons are important for understanding the actions of others through an internal simulation of the observed process. "In order to understand what is going on in the world, you use not only your sensory information, but also your motor experiences. You need a body in order to acquire the motor experiences that you can then use to interpret actions performed by other," Sandini explained. "Anticipating the goal of actions is the basis of social interaction."

In humans, sensation and action are equally linked. Moreover, both sensory and motor areas of the brain are involved in reading, listening to spoken language, memorizing and any other way of conceptualizing. When we hear verbs such as 'kick' or 'lick', the corresponding motor areas become activated [16]. When we retrieve information about things, the same regions of the motor cortex are activated that are also active when we carry out actions with these objects [17]. Similarly, when we conceptualize food or things that smell, gustatory or olfactory brain areas become involved [18]. "From an engineering point of view this is a very sensible solution. You have a piece of hardware that processes taste—so why not use it when you think about taste," Sandini said.

However, there is a lot more to human intelligence than knowing about objects. Humans write and read articles, think about politics, conduct experiments and ponder their own existence or the meaning of the universe. We usually conceive of intelligence as something that goes beyond acting and sensing. Yet, it seems that our bodies remain intimately involved. Einstein conceived his theory of general relativity as he imagined that he was travelling along a light beam at the speed of light.

In the 1980s and 1990s, George Lakoff and Mark Johnson argued that even abstract thought is rooted in our experience of interacting with the world [19,20]. According to Lakoff and Johnson, there is a ground stock of concepts to which other concepts can refer and these basic concepts are related to our body and how we move in space. Indeed, this idea is reflected in our language and our use of metaphors. When we plan a project, for example, we have a goal somewhere 'ahead of us' [5]; we equate being happy with being 'up', or being sad with being 'down' or 'depressed'. With a different body, Lakoff and Johnson argue, our concept of happiness would be a different one [7].

> **The idea of motor experience as a prerequisite to understanding has its parallels in biology**

Along these lines, experiments in psychology show that our thinking might be influenced by our bodily state in a way reminiscent of the metaphors that we use to describe certain ideas. John A. Bargh at Yale University, USA, and his colleagues have shown how sensory experiences influence the way we think [21]. Bargh's test subjects were asked to review the résumés of fake job candidates that were presented to them on either heavy or light clipboards. The people holding heavy clipboards rated candidates as being more serious, consistent with our equating of seriousness and metaphorical heaviness. In a similar experiment, subjects were asked to complete a puzzle with either rough or smooth puzzle pieces before evaluating social interactions described in a text. The participants who completed the rough puzzle rated the interactions as harsher and more difficult, consistent with our equating of metaphorical roughness and being socially difficult [21]. Clearly, our thinking is not nearly as rational as we think.

> **Einstein conceived his theory of general relativity as he imagined that he was travelling along a light beam at the speed of light**

“Maybe abstract concepts are more related to the body than we might think,” Pfeifer commented. But the nature of this relationship is still not clear. There is more to happiness than just an upward direction. There is more to interpreting social interactions than just the texture of a surface. As such, it is still unclear how this ‘more’ arises, and robotics is still far from even attempting to approach these questions. But, if an answer is ever to be found, the body will have to be taken into account. “If we want know what intelligence is, we need to understand how it develops,” Pfeifer said. And that requires a body.

## CONFLICT OF INTEREST

The author declares that she has no conflict of interest.

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