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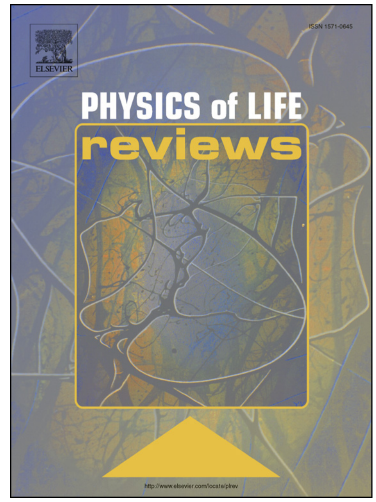

Comment Internal simulation in embodied cognitive systems

David Vernon

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Comment

Internal simulation in embodied cognitive systems
Comment on "*Muscleless* motor synergies and actions *without movements*: From motor neuroscience to cognitive robotics" by Vishwanathan Mohan *et al.*

David Vernon

Carnegie Mellon University Africa, Rwanda

What it is to be cognitive? This simple question proves more difficult to answer than one might suspect, partly because of the variety of perspectives taken in different disciplines, e.g. neuroscience, cognitive science, AI, and robotics [1], and partly because of the many different issues on which it touches, e.g. autonomy, perception, learning, anticipation, action, and adaptation [2]. Arguably, however, the essence of cognition is the capacity for effective action [3], i.e. actions that are goal-directed and guided by prospection [4, 5, 6]. Cognitive agents — humans or cognitive robots — continually predict the need for actions and their outcomes [7]. There is emerging consensus in the field that internal simulation plays a key role in such prospectively-guided goal-directed action [8, 9]. What is not so clear, at least in the cognitive architecture literature, is the manner in which internal simulation is accomplished. Some cognitive architectures opt for an explicit module in the architecture (e.g. [10, 11, 12]) while in others internal simulation is effected by the same sub-systems as those responsible for sensorimotor-mediated action but using covert, internally-generated endogenous sensorimotor signals, i.e. using afference and efference copies, rather than exogenous sensorimotor signals (e.g. [13, 14, 15] and also see [8, 16]).

The central theme articulated by Mohan *et al.* in this review [17] resonates strongly with this view of cognition, focussing as it does on "the dual processes of shaping motor output during action execution and providing the self with information related to *feasibility, consequence and understanding of potential actions* (of oneself/others)" (emphasis in original). Crucially, it makes a compelling case, based on empirical evidence, in favour of the latter approach to internal simulation as a covert mode of cognition rather than a module of cognition, in the manner suggested by Hesslow [18, 19] (as the authors themselves note) as well as providing further evidence for the prospective stance on cognition. Specifically, the core message in the review is that both actual and simulated action (' "real and imagined' actions" [17]) result from an internal simulation process driven by a goal-directed animation of the agent's body schema, a schema that can, as has been noted by others [20, 21], be expanded to include tools that are held by the agent. It is significant that the expandable body schema mechanism presented in the article is consistent with contemporary work on ideomotor theory [22, 23, 24], as well as the work cited in the review, including cognitive architectures that expoit ideomotor theory [25]. Furthermore, the review highlights, in a manner similar to Demiris [13], that internal simulation is not simulation of a single possible outcome, but of many, with overt action being just one that is selected for execution.

The review also sheds new light on aspects of embodied cognition, i.e. the role that an agent's body plays in the cognitive function of that agent. The cognitive systems community is divided into two schools: those that think an agent's body plays no causal role and those that think it does. Among the latter, there are several stances that vary according to the strength of the assertions made. All, however, adhere to the idea that cognitive systems are intrinsically embodied and embedded in the world around them, developing through real-time interaction with their environment, an idea neatly encapsulated in the *embodied cognition thesis*: "Many features of cognition are embodied in that they are deeply dependent upon characteristics of the physical body of an agent, such that the agent's beyond-the-brain body plays a significant causal role, or physically constitutive role, in that agent's cognitive processing" [26]. More specifically, there are three hypotheses on embodiment associated with the embodied cognition thesis: the conceptualization hypothesis, the constitution hypothesis, and the replacement hypothesis [27]. Briefly, these hypotheses assert, respectively, that (a) that the physical morphology and motor capabilities of a system has a direct bearing on the way the cognitive agent understands the world in which it is situated; (b) that the body (and possibly also the environment) plays a constitutive rather than a supportive role in cognitive processing; and (c) that, because an agent's body is engaged in real-time interaction with its environment, the need for representations and representational processes is removed, since all of the information it needs is already immediately accessible as a consequence of its sensorimotor interaction.

It is relatively easy to be convinced of the correctness of either the conceptualization hypothesis or the constitution hypothesis and the body schema approach described in the article clearly supports the constitution hypothesis in that it builds on the idea that "posture ... is a 'biomechanical consequence' of equilibrium among a large set of muscular and environmental forces [achieved by] allowing the intrinsic dynamics of the neuromuscular system to seek its equilibrium state when triggered by *'intended goals'*." [17] (emphasis in original). However, the replacement hypothesis has caused considerable debate in the cognitive science community, with arguments in favour (e.g. [28] and against (e.g. [29]). To an extent, the body schema approach finesses these concerns by positing a representational framework that is distributed and implicit in the neuromuscular system, thereby obviating the need for symbolic representations and, as the authors point out, an associated complex optimization process, with the control being guided instead by the goal-directed intrinsic dynamics of the neuromuscular system.

The article also touches on the issue of *Theory of Mind* [30], the process wherby a cognitive agent takes a perspective on the actions, intentions, and goals of another agent. The article suggest that it is the very same internal simulation mechanism which facilitates this, by recruiting the motor representation, not on the basis of internally-generated goals, but on the basis of the observations of the actions of other agents, in a manner that is consistent with the mirror neuron system [31]. What is significant about the article, apart from the comprehensive review and synthesis of these matters, is that the authors also present a viable computational basis to support their case.

Finally, although the authors don't draw this out explicitly in their article, there is yet another way in which the position they put forward resonates with contemporary thinking in internal simulation. While the approach described in the article is focussed on effective action through goal-directed animation of the body schema, there remains the issue of the source of the goals. Again, internal simulation may provide the answer. Internal simulation involves mental construction of an imagined alternative perspective [32], allowing the agent to pre-experience its future in a process sometimes referred to as *episodic future thinking* [33] in which the agent projects itself forward in time when it forms a goal, creates a mental image of itself acting out the event, and then episodically pre-experiences the unfolding of a plan to achieve that goal. Episodic memory is a fundamentally constructive process [34], in that old episodic memories are reconstructed slightly differently every time a new episodic memory is assimilated or remembered, and this provides the basis for the *constructive episodic simulation hypothesis* [32, 35, 36, 37] whereby episodic memory facilitates the simulation of multiple yet-to-be-experienced futures. The concept of body schema fits very neatly with this framework of episodic memory and, arguably, one might consider it to be a form of episodic memory or a joint episodic-procedural [9], raising the possibility of embedding the internal simulation scenario set out in the review in a more general framework of internal simulation in cognitive agents, while also providing the much-needed computational mechanism required to realize it in cognitive robots. The authors make a passing reference to their work on episodic memory [38] in the review but do not draw out this possibility.

Going further still, Schacter et al. [39] have highlighted that episodic memory and episodic future thinking can be modulated by semantic memory, opening up the possibility that language might be used both to express a desired goal and recruit episodic memory in constructing internally-simulated intermediate and final goal states that drive the internal simulation of the actions required to achieve these goals.

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