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Beyond bodily anticipation: Internal simulations in social interaction

Henrik Svensson, Serge Thill *

School of Informatics, University of Skövde, 54128 Skövde, Sweden

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Abstract

There is a long history of implementing internal simulation mechanisms in robotics, typically for the purpose of predicting the outcomes of motor commands before executing them. In the literature on human cognition, however, the relevance of such mechanisms goes beyond that of prediction: they also provide foundational aspects of social cognition and interaction.

In this paper, we present a review of internal simulation mechanisms from this perspective. We contrast the roles they play in human cognition, in particular in the context of social interaction, with robotic implementations. We further discuss work in social robotics, emphasising in particular that a substantial effort currently goes into evaluating social robot systems, but that social robots to date are still limited in their abilities. We further discuss episodic simulations, which are functionally distinct from the type of internal simulations we consider here, and note their role in prospective thought in particular. Overall, we conclude that one of the necessary next steps on the road to social robots may be to develop social abilities from the bottom up using internal simulations. By reviewing how these aspects all tie together in human cognition, we hope to clarify how this may be achieved.

Keywords: Internal simulations; Social cognition; Self-other distinction; Prediction; Social robotics

1. Introduction

The context of social interaction is crucial for understanding the development and functioning of human cognition. Fogel, de Koeyer, Secrist, and Nagy (2002), for example, argues that "being-in-relation, participating in an interpersonal relationship, is a fundamental, irreducible, primary, way of being. Individuals are born into interpersonal relationships. We never, not for a single moment of life, exist outside of relationships even when we are physically alone. Our thoughts, our movements, the artefacts carried with us are all grounded in cultural processes that were conceived, composed, and codified by individuals-in-relation (Fogel, 1993)" (p. 623). De Jaegher, Di Paolo, and Gallagher (2010) additionally points out that even social interaction itself cannot merely be reduced to cognitive processes in an individual's head – rather, the interaction may in itself be a constitutive aspect of social cognition.

Many, if not all, mechanisms that underlie cognition thus play a role in social interaction. For those interested in the study of human cognition, social interaction therefore provides an important setting. For those interested in artificial cognitive systems – which is the perspective we will take here – social interaction is equally important, not the least because real-world artificial cognitive systems are built to interact with humans. There is also an increasing trend towards making such systems explicitly "social", see for example recent developments towards "companion" robots

* Corresponding author.
E-mail addresses: henrik.svensson@his.se (H. Svensson), serge.thill@his.se (S. Thill).

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such as Jibo[1] or Pepper[2]. Other examples of robots designed explicitly for social interaction include those for use in therapies, for instance for children with autism spectrum disorder (see Scassellati, Admoni, & Matarić, 2012; Thill, Pop, Belpaeme, Ziemke, & Vanderborght, 2012, for comprehensive reviews).

Here, we are primarily interested in the role of internal simulation in these social interactions for two reasons. First, internal simulations are a necessary component of social cognition. We will begin the review by making this case in the next section. Second, internal simulation has already received some attention in robotics (see, for example, Vernon, 2014, Section 7.5.3 and Svensson, Thill, & Ziemke, 2013), but robotic efforts are mostly limited to predicting the outcome of immediate actions in relatively simple environments or tasks (see Svensson, 2013; Svensson et al., 2013, for examples). The second part of this review therefore contrasts such efforts with current work in social robotics (from which the inclusion of simulation mechanisms is still largely lacking). We conclude with a reflection on what internal simulation can bring to social robotics. While presenting this argument, we also consider related concepts – primarily, we need to distinguish between embodied and episodic simulations, and discuss theory of mind and prospection. First, however, we clarify what precisely embodied simulation is, and how it relates to social cognition.

2. Embodied simulation

Simulation (or emulation, the term preferred by *e.g.* Grush, 2004) has been implicated in nearly all cognitive phenomena (*e.g.* perception, mental imagery, long-term memory, short term memory, and language; see Svensson, 2013). While some of the arguments tie simulations to specific cognitive phenomena (*e.g.* language, see Zwaan, 2003), others see them as a general principle of cognition (*e.g.* Hesslow, 2002).

The various simulation theories primarily differ somewhat with regard to their relation to certain epistemological or theoretical frameworks. For example, some accounts are representationalist (Barsalou, 1999; Grush, 2004) while others are purely associationist (Hesslow, 2002). That said, there are two general defining aspects of simulations: *reactivation* and *prediction* (Svensson, 2013). Here, we use *embodied simulation* to refer to this general view of simulation.

The term simulation is easily confused as referring to explicit, conscious, and/or, deliberate mental simulations, such as the type of cognitive ability that is implied by prospection (the ability to envision oneself in future situations). We refer to such simulations as *episodic*, and return to them later. For now, it is therefore important to underline that embodied simulation refers to a particular cognitive mechanism, which can be described at different levels of analysis: the phenomenological, the functional, and the neural level (see Hurley, 2008, for a concrete example).

Although embodied simulations do not always involve consciousness or awareness, some of the phenomenological aspects of cognition reported in mental imagery and dreams are thought to reflect the functioning of embodied simulations (Svensson et al., 2013). For example, first person motor imagery involves feeling "as if" actually performing the action (Decety, 1996; Jeannerod, 1994), and visual imagery can, at least under certain conditions, be similar to our perception of external objects to the point that they are hard to distinguish (Perky, 1910, cited by Cotterill, 1998, pp. 19–20).

At the functional level, as previously mentioned, embodied simulations function as reactivations and predictions: first, they reactivate modality-specific information, thereby providing access to the epistemic properties of previously experienced situations (Barsalou, 2005; Meyer & Damasio, 2009; Zwaan, 2003). For a more thorough discussion of the relation of simulation to representation, see Chapter 2 of Svensson (2013). An example by Barsalou illustrates the basic concept:

> Consider a situated conceptualisation for interacting with a purring house cat. This conceptualisation is likely to simulate how the cat might appear perceptually. When cats are purring, their bodies take particular shapes, they execute certain actions, and they make distinctive sounds. All these perceptual aspects can be represented as modal simulations in the situated conceptualisation. Rather than amodal redescriptions representing these perceptions, simulations represent them in the relevant modality-specific systems. (Barsalou, 2005, p. 626–627)

Second, embodied simulations function as predictions by chaining simulated experiences into sequences (Hesslow, 2012). Most commonly, *simulated* perceptions are coupled to *simulated* actions – that is one is generated based on the other without any overt movements or perception/interoception. Svensson, Morse, and Ziemke (2009) argue that embodied simulations can consist of at least three different anticipatory functions (implicit anticipation, bodily anticipation, and environmental anticipation), each likely implemented by several different neural systems. For example, implicit predictions of varying complexity are found in cortico-cerebellar loops (Downing, 2009; Wolpert, Miall, & Kawato, 1998), basal-gangliacortex loops (including amygdala influence) (Downing, 2009; Prescott, Redgrave, & Gurney, 1999), corticocerebellar loops (Downing, 2009; Wolpert et al., 1998), and neocortical loops (Wise & Murray, 2000).

3. Embodied simulations in social interaction

Embodied simulations are involved in fundamental aspects of social interaction such as the self-other distinction. They are often elicited by present social stimuli and are closely tied to self-locomotion (Lindblom & Ziemke, 2006) and bodily aspects (Barsalou, Niedenthal, Barbey, & Ruppert, 2003). In this section, we expand on this,

[1] https://www.jibo.com/.
[2] https://www.aldebaran.com/en/coolrobots/pepper.