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A computational model of the allocentric and egocentric spatial memory by means of virtual agents, or how simple virtual agents can help to build complex computational models

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Abstract

The ability to acquire, remember and use information about locations of objects in one's proximal surrounding is a fundamental aspect of human spatial cognition. In this paper, we present a computational model of this ability. The model provides a possible explanation of contradictory results from experimental psychology related to this ability, namely explanation of why some experiments have reproduced the so-called "disorientation effect" while others have failed to do so. Additionally, in contrast to other computational models of various aspects of spatial cognition, our model is integrated within an intelligent virtual agent. Thus, on a more general level, this paper also demonstrates that it is possible to use intelligent virtual agents as a powerful research tool in computational cognitive sciences.

Keywords: Spatial cognition; Paradigm of pointing; Disorientation effect; Intelligent virtual agent

1. Introduction

Computational approaches to cognitive science have become increasingly important in the past decade (Burgess, 2007; Sun, 2008). This is likely because, compared to verbally-based theories, *in silico* simulations enable a researcher to specify hypothetical mechanisms in precise detail, systematically explore the model and manipulate its parameters, and generate new predictions (Burgess, 2007; Marsella & Gratch, 2009; Sun, 2008; Tyrrell, 1993). At the same time, simulations can be both more complex and well-specified than analytical or numerical models (Kokko, 2007, chap. 8).

Intelligent virtual agents (IVAs) are pieces of software that are both autonomous and graphically *embodied* in a 2D or 3D virtual environment, capitalizing on the general agent metaphor used in software engineering and artificial intelligence (Wooldridge, 2002). IVAs are currently used in a large variety of applications, for instance, in educational simulations, virtual storytelling, cultural heritage, and computer games.

In general, research on IVAs attempts to make these entities more *believable*, that is, to increase the agents' ability to appear and behave in a lifelike manner. Believable IVAs enable users to suspend their disbelief by providing a convincing portrayal of the personality the user expects (Loyall, 1997). It is worth noting that for designers of many IVAs, the goal is to *imitate* a character's behavior, but not necessarily to develop a cognitively plausible model producing the behavior. Nonetheless, these agents can be used as tools for investigating plausible computational models

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of cognitive phenomena (Brom, Lukavský, & Kadlec, 2010) primarily because virtual worlds present convenient models of real worlds, and IVAs, owing to their modular architectures, can serve well as "vehicles" for carrying and testing the models. IVAs can generate input data for these models and allow output data to be meaningfully manifested. Compared to a robotic platform, which is sometimes used for research in computational cognitive sciences (e.g., Krichmar, Seth, Douglas, Fleischer, & Edelman, 2005), virtual reality is more technically accessible and allows for investigation of higher-level phenomena. The input representations can be more abstract and can enable researchers to ignore other difficult problems (e.g., robotic vision) (see Brom, Lukavský, et al. (2010) for a longer discussion of positives and negatives of IVA platform vs. robotic platform).

However, to date, the use of cognitively plausible IVAs has been quite limited. In the past, some parts of IVA control mechanisms were psychologically inspired; most notably emotion models (e.g., Gebhard et al., 2008) and spatial memory models (e.g., Thomas & Donikian, 2006). Yet even these psychologically inspired models are not necessarily cognitively plausible when judged by standards of computational cognitive sciences. Indeed, most of psychologically inspired models for these agents enable a researcher neither to do comparative analysis against real world data nor to make predictions. Similarly, it has been demonstrated that IVAs can be controlled by Soar (Laird, 2000) as well as ACT-R (Best & Lebiere, 2006) cognitive architectures and that ACT-R can be integrated with Leabra, a neural architecture, and implemented in an IVA (Jilk, Lebiere, O'Reilly, & Anderson, 2008). However, even though these works presented valuable proof of concepts of connections of cognitive architectures with IVAs, they did not demonstrate fully the alleged advantages of IVAs for computational cognitive sciences.

This article has two goals. First, we will present a computational model of one fundamental aspect of human spatial cognition: the ability to acquire, remember and use locations of objects in one's proximal surrounding. In contrast to other computational models of various aspects of spatial cognition, our model is integrated within an IVA, and provides one possible explanation of contradictory results of experimental psychology related to this ability (Holmes & Sholl, 2005; Waller & Hodgson, 2006; Wang & Spelke, 2000). Second, and more generally, this paper also demonstrates that it is possible to use IVAs as a powerful research tool in computational cognitive sciences.

1.1. Paradigm of pointing

Knowing locations of objects in one's environment is a critical component of many human behaviors. Accordingly, substantial effort has been devoted to understanding the processes and representations underpinning this ability. Most contemporary theories of human spatial knowledge posit (at least) two partly independent subsystems. First, a transient system is thought to update spatial relations as one moves through an environment. This system integrates multi-modal perceptual information and is generally thought to keep track of the locations of relatively few objects with respect to an egocentric frame of reference. A second system, based in long-term memory, codes locations of objects that are not perceptually available. This more enduring system of spatial knowledge may employ non-egocentric reference frames and has far greater capacity, although generally less precision, than the transient system (Burgess, 2006; Waller & Hodgson, 2006). The exact nature of these systems has been intensively investigated and debated in past (Easton & Sholl, 1995; Gallistel, 1990; Neisser, 1976; Wang & Spelke, 2002).

One experimental paradigm used to distinguish transient from enduring spatial knowledge involves pointing to remembered but unseen objects. In a typical experiment, a person learns the locations of several objects in a room-sized environment, e.g., Figs. 1 and 3. The person is subsequently asked to point to the remembered locations of these objects after the objects have been removed or occluded. Pointing while oriented to one's environment is generally assumed to tap into transient spatial knowledge, while pointing after being disoriented requires enduring spatial knowledge. Wang and Spelke (2000) documented a reliable increase in the variability of a person's pointing errors as a result of disorientation (referred to here as the "disorientation effect") and argued that such an increase is not well-explained by theories that posit exclusive control of spatial behavior by an enduring system using nonegocenctric reference frames. Subsequent research (Waller & Hodgson, 2006) interpreted this increase in variable error as evidence for a switch from the relatively precise transient representation to the coarser enduring one.

Despite the apparent reliability of the disorientation effect in Wang and Spelke's (2000) work as well as Experiment 1 of Waller and Hodgson (2006), Holmes and Sholl (2005) (Experiments 3–7) repeatedly failed to replicate it.

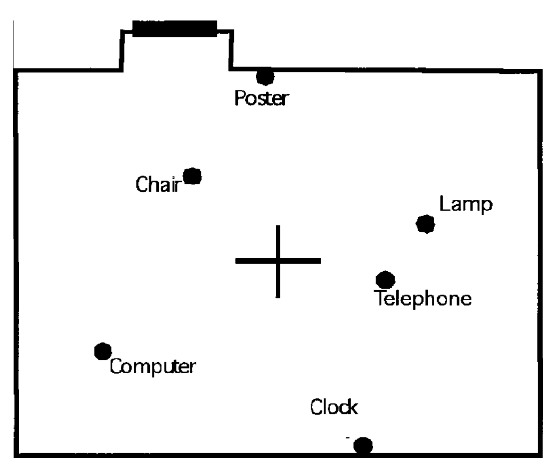

Fig. 1. Diagram of the arrangement of objects in the experiment of Holmes and Sholl. Cross-hairs indicate participant's position when making pointing responses. Adopted from Holmes and Sholl (2005) with the publisher's permission.