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# Spatial Orientation and Wayfinding in Large-Scale Virtual Spaces II

## Guest Editors' Introduction

## 1 Introduction

Few things are as fundamental to the human experience as the interaction between humans and their environment—be it physical or virtual. A critical element of this interaction involves movement through space. We know that what we often refer to as *navigation* is not merely physical translation through a space, termed *locomotion* or *travel*, but that there is also a cognitive element, often referred to as *wayfinding*, that involves issues such as mental representations, route planning, and distance estimation. This collection of articles addresses issues related to both the physical and the cognitive aspects of navigation as well as theoretical models that bind them together.

## 2 Methods for Virtual Locomotion

Three of the papers in this special issue deal with movement through virtual spaces, with each addressing the problem from a different level of abstraction and thus revealing a number of interesting strengths and weaknesses. A literal technique may be easy to learn because it mimics the real world, but it must be extremely accurate because differences with the real world are more obvious (Darken et al., 1997). Although a very abstract technique doesn't have to deal with these problems, it must be learned, and therefore performance on associated locomotion tasks can show greater variance.

Iwata and Yoshida present the Torus Treadmill, which is a device that is intended to facilitate literal bipedal locomotion through a virtual space. The intention is to minimize differences between physical bipedal locomotion and virtual bipedal locomotion by capturing leg movements and translating them into virtual movement. The challenge here is that the physics of human walking and running are extremely complex and difficult to constrain in a confined space. People easily recognize and are aware of even subtle differences (Darken et al., 1997). The study presented in this paper illustrates some of the problems associated with devices of this type and shows how well this device fares on basic bipedal locomotion tasks.

The Torus Treadmill seems to have improved on the Omni-Directional Treadmill (Darken et al., 1997) in terms of noise and balance issues, but it severely constrains how fast the user can travel through the virtual environment. This constraint most likely explains why women perform better than men: their legs are generally shorter, and, therefore, their comfortable walking rate is slower than a man with longer legs. It would be interesting to compare performance of a similar

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sample group on the Torus Treadmill to real walking performance on the ground as a baseline measure.

Templeman, Denbrook, and Sibert present Gaiter which is also a bipedal locomotion mechanism but one that involves an abstraction from physical movement. Rather than capture physical movement and literally translate that information into virtual movement, Gaiter aims to capture the intention of movement using a walking-in-place metaphor. The advantage here is that many of the balance issues cited by Iwata and Yoshida and Darken et al. (1997) are resolved because the user does not walk on a physical device. The drawback is that the interpretation of intention is not so obvious. For example, what is the difference between walking forward and walking backward using a walking-in-place metaphor? Templeman et al. attempt to systematically disambiguate these issues.

While the authors clearly show that Gaiter is a functionally complete device, we still don't know how effective their walking approximation is in terms of performance on navigation tasks. The approach is analytical in nature. Templeman et al. have identified the essential components of bipedal locomotion and have algorithmically accounted for these motions using a robust set of sensors. However, we know from devices such as the Omni-Directional Treadmill and the Torus Treadmill that there are significant individual differences between users. Could a machine-learning technique be used to better match the motions of a specific user to intended virtual movements? This was done in a much more simplified form by Slater et al. (1995).

Bowman, Davis, Hodges, and Badre present a taxonomy of virtual travel techniques with a focus on pure abstractions which can sometimes be viewed as vehicular metaphors. While the resultant virtual movement may be the same as Templeman et al. and Iwata and Yoshida, the mechanisms do not involve the translation of walking motion. However, this is an important contribution in that these are currently the most widely used locomotion mechanisms in virtual environments. Techniques using hand pointing, gaze-directed movement, and such are extremely common. Understanding how to best fit a travel technique to virtual navigation tasks is essential to effective interface design. Bowman et al. investigated a number of alternative travel methods in terms of performance on specific navigation tasks.

The Bowman et al. taxonomy clearly addresses locomotion from a functional standpoint but not at the level of task execution. This is why it fits nicely for abstract movement techniques (such as a pointing mechanism) but not so nicely for literal mechanisms (like the Torus Treadmill). In other words, we don't think about walking in terms of indicating position and orientation. We move our limbs, keep our balance, shift our weight, and translate through space accordingly. Altering the proposed taxonomy from an implementation perspective to a user perspective could be a very useful extension of this work.

Bowman et al. make an excellent point about the need for consistency in the literature on these sorts of issues. In order to adequately compare the Omni-Directional Treadmill to the Torus Treadmill, for example, we should be using the same metrics and tasks. It is also interesting to note their description of strategies that they observed their participants using to solve some very difficult navigation problems. This result is similar to Darken and Sibert (1996) and Ruddle et al. (1999) in which available tools or cues were shown to have a direct effect on performance. Understanding this effect is critical to the interface design of virtual environments. The necessity to be able to compare results (both qualitative and quantitative) across experiments suggests a need for a model that is more widely accepted by researchers working in this area.

## Navigating Virtual and Real Environments

Given the body of literature on navigation in the real world, it makes sense to use what is known about physical navigation as we try to better understand virtual navigation. However, we can look at this issue in two ways. In our attempt to make better interfaces for virtual environments, we must understand what carries over from the real world to the virtual world. On the other hand, in some cases, we want to go in the other direction: we want to carry skills or knowledge gained in a virtual world to the real world. Two of the papers in this issue address these ideas.

Koh, von Wiegand, Shinn-Cunningham, Garnett, and

Durlach present a training transfer study that explores the extent to which different kinds of virtual environments can be used to acquire spatial knowledge of a real architectural environment. They concluded that the various species of virtual environments (for example, immersive, nonimmersive, or virtual model) were all as effective as the real world for acquiring spatial knowledge about the real world. This result concurs with earlier studies such as Bliss et al. (1997) and Witmer et al. (1995), but contradicts other recent studies such as Darken and Banker (1998), Goerger et al. (1998), and Goerger (1998).

Whatever the case, we must conclude that virtual environments are useful for acquiring spatial knowledge because it has already clearly been shown that they are. But, given the existence of contradictory results, it should be noted that it must be the interfaces to these systems, the fidelity of the environments, the training mediators, and/or the methods of training that facilitates the acquisition of spatial knowledge. Koh et al. also point out the significant role of individual differences in their results. This may suggest that a "one size fits all" solution is improbable. Simply practicing a navigation task using a virtual environment that replicates a real environment does not necessarily, in and of itself, facilitate spatial knowledge acquisition more effectively than less expensive, conventional methods.

Waller discusses an experiment in which he shows that immersion improves distance estimation and that, in general, effects related to distance estimation are similar in virtual worlds to what is known about the real world. Most importantly, as suggested by Koh et al., a simple feedback loop was shown to significantly improve performance. If a bias exists but can be eliminated (or at least greatly minimized to the point of irrelevance to task performance) by providing feedback, then the source of the bias is probably not an important issue.

## Models of Navigation

There is clearly a need to better understand the process and fundamental components of navigation as a whole, especially given that virtual environments are inherently different from the real world in so many ways and that the effects of those differences on navigation performance are unknown. A number of attempts have been made to model navigation (for example, Downs & Stea, 1977; Goldin & Thorndyke, 1982; Jul & Furnas, 1997; Neisser, 1976; Spence, 1998). Chen and Stanney go one step further by attempting to associate phases of the task to navigation mediators in an effort to determine what mediators are most appropriate in what situations and environments.

They break the process into three primary parts: cognitive mapping, decision making, and decision execution. In many ways, this is a navigation-specific version of Norman and Draper's (1986) model of interaction. They have attempted to fill in items that have been shown in the literature to affect the navigation process such as experience, search strategy, and planning. However, the literature is replete with conflicting data making it difficult, if not impossible, to confidently say exactly what these relationships are. For example, Bliss et al. (1997) and Witmer et al. (1995) show how a virtual environment was used to acquire spatial knowledge of a real space while Koh et al. (this issue), Darken and Banker (1998), and Goerger et al. (1998) show how this seemingly similar approach failed. What was the difference between these that caused different results? Can this difference be accounted for in such a model?

## Conclusions

It would seem that one of the primary explanations for the inconsistent results that we have seen in the literature must have to do with effects of individual differences in knowledge, aptitudes, abilities, and strategies and their impact on perceptual, motoric, and memorial knowledge of virtual environments. This issue was recently addressed by Waller (1999). However, Waller points out that individual differences can account for only a small portion of performance differences as we understand them today. Koh et al. and Waller agree that there must be more to this and that more research is needed to better identify these differences, understand them, and relate them to individual performance.

The motivation behind the taxonomy proposed by

Bowman et al. has to do with a desire to structure research in this area, allowing more-substantial comparisons of results across experiments and across institutions. Another part of this involves having some basic agreement on experimental methodologies (for example, dependent measures and metrics) so that we can avoid situations in which we are comparing apples to oranges, which happens so often today. However, to accomplish this, it would seem that we need to work towards a more refined framework of the fundamentals of navigation (for example, Jul and Furnas, 1997; Chen and Stanney, this issue). But, before we can have a refined framework of navigation, it would seem that we need to know more about the principles of human spatial abilities, orientation, mental representations, and so on. It is important to understand how the building blocks of this research arca fit together so we can address issues in a logical manner.

Every author of every paper in this special issues cites the need for further basic research in areas associated with spatial orientation and wayfinding in large-scale virtual spaces. It is imperative that we focus and structure this future research in such a way that it generalizes across application domains, yet remains specific enough to be a real contribution to the field. Eventually, designers of virtual environment applications who do not have any knowledge of spatial cognition and perception will need to draw concrete conclusions for design decisions based on current and ongoing work. Shaping that work into something meaningful must be an important part of our research agenda.

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