Can I Pass?: Using Affordances to Measure Perceived Size in Virtual Environments

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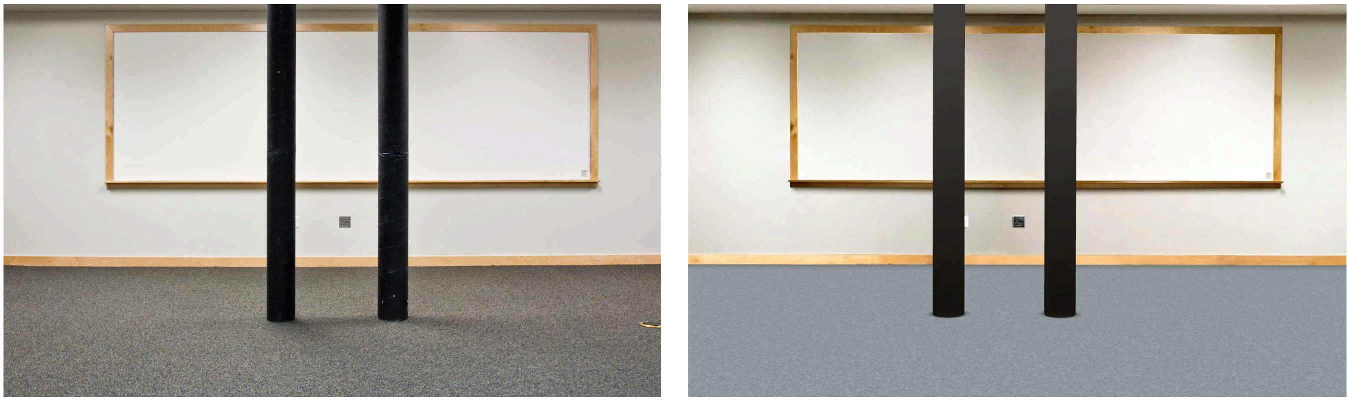

Figure 1: *Can the viewer fit between the two poles? Left: real-world, Right: virtual world.*

Abstract

Perception of an accurate sense of the scale depicted in computer graphics is important for many applications. How to best characterize the accuracy of space perception in computer graphics is a question that does not have a simple answer. This paper describes the use of perceived affordances as a way of measuring the perceptual fidelity of virtual environments with respect to how well they convey information about geometric scale. The methodology involves a verbal indication that a particular action can or cannot be performed in a viewed environment. By varying the spatial structure of the environment, these affordance judgments can be used to probe how accurately viewers are able to perceive action-relevant spatial information. The result is a measure relevant to action, less subject to bias than verbal reports of more primitive properties such as size or distance, and applicable to non-virtual-environment display systems in which the actual action cannot be performed. We demonstrate the approach in an experiment comparing one type of affordance judgment, perceived passability, with judgments of size and distance in matched real world and virtual world environments.

CR Categories: I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Virtual reality H.5.1 [Information Systems]: Multimedia Information Systems—Artificial, augmented, and virtual realities

Keywords: virtual environments, perception and action, human perception and performance, affordances

1 Introduction

The ability of the user to interact with graphic displays depends partly on how accurately the individual perceives the scale of the space in the display image. However, quantifying what is seen by a user is difficult. Traditionally, the investigation of space perception in virtual environments (VEs) has been limited to studying egocentric distances measured with actions directed toward a target and verbal estimates of distance to a target. We propose the use of affordance judgments to investigate perceived size in VEs as a new method to evaluate space perception in VEs.

Blind walking and verbal estimates of distance have been used effectively to assess perceived egocentric distances beyond reach and up to 10s of meters in the real world and in VEs, but these methods have their limitations. Blind walking is an example of a visually directed action task which requires the participants to walk to a previously viewed location of a target without sight. In the real world, participants are on average accurate when blind walking to a target [Loomis et al. 1992]. However, when blind walking in a head mounted display (HMD), participants have consistently shown underestimation of the distance to the target, with the amount of compression of perceived distance ranging from about 50% to 80% (e.g., [Loomis and Knapp 2003; Thompson et al. 2004]). While blind walking is an established and useful measure in the real world, the ability to use blind walking as a measure for VEs is limited by the physical space of the lab and to display types that allow movement, like HMDs. Verbal estimates, also used historically in real world distance studies, require participants to verbalize the distance to the target in a metric unit (i.e., meters). When making verbal

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estimates, participants have been shown to underestimate the distance to the target in a VE by 20%-60% [Loomis and Knapp 2003; Kunz et al. 2009]. In addition, verbal estimates can be influenced by cognitive biases, like one's concept of a metric, which can influence one's estimates [Loomis and Philbeck 2008]. Therefore both of these measures may not be ideal for all display types and may not give a good indication of how the user actually perceives space in VEs. Furthermore, egocentric distance judgments may not be sufficient on their own to characterize the full range of effects that virtual environment viewing has on the perception of spatial layout.

The concept of affordances originated with J.J. Gibson [1979] and emphasizes the relationship between the observer's body, or capabilities for action, and the perceived extent. For example, a horizontal gap can afford passage if it is larger than the width of the actor. Many studies have demonstrated that participants reliably perceive whether an environmental extent affords a certain action [Mark 1987; Warren and Whang 1987]. For instance, Warren and Whang [1987] investigated how large a gap needs to be for participants to indicate they could pass through without rotating their shoulders. In their study, participants required an aperture width 1.16 times their own shoulder width to indicate the aperture afforded passage. Affordance judgments may be especially useful as a perceptual measure of size in graphic displays because they require the user to see the space in terms of their own ability to act and therefore may be considered more task-relevant. In relation to blind walking, these judgments allow us to assess perceived space in VEs, by priming an intention to act without requiring the action itself, which may cause problems or be impossible (i.e., concerns about collision or space constraints in the laboratory). Therefore, affordance judgments may be a useful tool to evaluate perceived space in VE systems that do not permit the use of other measures like blind walking. For instance, CAVE displays do not permit more than a few steps of actual movement. However, affordance judgments which require decisions about action, rather than actual action, would work well with CAVE displays. Likewise, these types of judgments have potential utility with non-immersive desktop displays. Also, affordance judgments are a type of verbal reports that may be less influenced by cognitive processes because they do not require the participant to encode the scene into an abstract metric.

Several previous examples exist of making affordance and affordance-like judgments in VEs. Stappers et al. [1999] provided informal descriptions of a number of experiments involving action measures designed to provide objective measures of the similarity of real and virtual environments. One of their measures involved walking through a narrow aperture, similar to the passability judgment we describe below. However, since their measure involved actually attempting to walk through the aperture, it did not measure the ability to judge scale from a distance. Loomis and Knapp [2003] described/ a virtual environment passability judgment very much like what we used, in which participants adjusted a virtual aperture until it appeared to be as wide as the viewer's shoulders. However, instead of reporting the accuracy of the adjusted width, they assumed that it corresponded accurately to actual shoulder width and, presuming size-distance invariance, used this as an indirect indicator of perceived distance to the aperture. Gross et al. [2005] gives a theoretical analysis of how to increase the accuracy of affordance judgments in virtual environments by altering the sensory experience, but provides no empirical findings. Stoffregen et al. [2006] provides an overview of the importance of correctly perceiving affordances in display systems and reviews relevant prior work.

To demonstrate the utility of affordances as a mechanism for probing the accuracy of the perception of spatial layout in virtual environments, we conducted an experiment comparing affordance measures with the blind walking measure commonly used as an indicator of distance perception, and also with a straightforward size judgment. Near identical methodologies were used in a virtual environment and in the real environment on which the VE was modeled, allowing a comparison of how the judgments changed between the real and virtual conditions. The results suggest that the three measures may be affected differently by VE viewing, though this needs to be confirmed by additional replications of the experiment and by considerations of different affordance judgments and different environments.

2 Using affordances and two other measures to probe perception of the scale of a space

In this experiment, participants' perception of virtual and real environments was assessed with multiple measures. The environment was manipulated between-participants, with participants viewing either a real or virtual environment only. The between-participants design was used to avoid any biases that may result from viewing one environment before the other. The virtual environment was modeled based on a real classroom that was used for the real-world condition, as shown in Figure 1. (The only intentional change made between the two environments was to modify the carpet pattern in the virtual environment to eliminate texture mapping artifacts that might have influenced the judgments.) In each environment, participants completed three perceptual judgments (size estimates, affordance judgments, and blind walking estimates) with respect to two vertical poles extending from ground to ceiling which formed an aperture. Twenty University of Utah students participated (10 in the real and 10 in the virtual environments).

2.1 Design and Procedure

Before the experiment, participants were tested for visual acuity and the ability to fuse stereo images. All participants had normal, or corrected to normal vision. Participants were then fitted with noise canceling headphones to minimize the possibility of auditory cues providing a sense of location. In addition, they were instructed on how to complete the three measures and practiced each measure without feedback. After several minutes of familiarization, participants were led blindfolded into either the real classroom or the lab containing the HMD. They did not see either environment before the start of the experiment. In the real environment, participants were positioned in a 'viewing box.' The viewing box occluded vision of the ceiling tiles in the classroom so that these tiles could not be used when completing the perceptual judgments. Viewing through the box allowed for a full horizontal field of view, but was adjustable so that it restricted the vertical field of view in so far that it covered the edge between the back wall and the ceiling. Similarly, we modeled the viewing box in the virtual environment to occlude vision of the ceiling tiles and keep the view of the two environments as similar as possible. For the virtual condition, participants were given help donning the HMD. The virtual environment was displayed using an NVIS nVisor SX HMD with a resolution of 1280x1024 pixels in each eye and a 42° x 34° FOV, using pincushion correction and calibration as described in [Kuhl et al. 2009].

Participants viewed two vertical poles (20 cm diameter and 2.43 m tall) that were randomly placed at three distances from the observer (3, 4.5, & 6 m) in the real or virtual classroom (13.3 x 10.1 m). For each distance, participants estimated the width of the gap between the poles, judged whether they could pass through the poles, and then blind walked the distance to the center of the two poles. These estimates were all repeated twice for each distance.

Participants made size estimates of the width between the poles. For each distance to the poles, the poles were positioned with gaps between them at six different widths (25, 30, 35, 40, 45, and 50

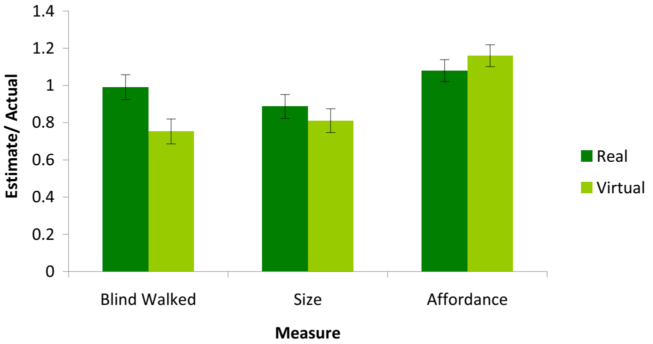

Figure 2: *Accuracy of distance, size, and affordance judgments in the real and virtual environments*

cm). Participants judged the width of the gap between the poles by moving their hands to be equivalent to the distance between the poles. The experimenter recorded the separation between the participants' hands. Vision of the hands was occluded in the real world to mimic conditions in the HMD that similarly restricted vision of the hands. The width was presented randomly.

Affordance judgments were also used to measure the perceived width of the gap between the two poles. At each distance from the participant, the two poles started close together (30 cm) and were moved farther apart at 5 cm intervals or started far apart (60 cm) and were moved closer at 5 cm intervals. At each interval, participants indicated if the distance between the two poles was wide enough to pass through without rotating their shoulders. The affordance judgments ended after participants' had switched from yes to no (or no to yes) and this switch persisted for at least two trials. At the end of the experiment, participants' shoulder widths were recorded.

A direct blind walking task was used to measure the perceived egocentric distance to the center point between the two poles. Participants were able to view the environment until confident about the distance to the center of the poles. Then, vision of the environment was removed (by blindfold in the real world or by blanking the image in the HMD), the occluding door on the viewing box was swung open by the experimenter, and participants walked until they believed they were standing at the center point between the two poles. The distance walked was recorded and the experimenter assisted the participant back to the starting position. The participants were given no feedback about the accuracy of their estimates.

2.2 Results

The results of the experiment are displayed in Figure 2. For distance and size, accuracy is depicted as a ratio between the value of the judgment given and the actual spatial dimension. For the affordance judgment, the ratio is the judged passable width to the width of the shoulders. Participants walked a substantially shorter distance in the virtual classroom (75% of physical distance) than in the real classroom (99%). This magnitude of compression in VEs is consistent with previous studies that have found about 20% compression. A 2 (environment: real or virtual) x 3 (distance: 3m, 4.5m, 6m) ANOVA revealed this difference was significant, F (1, 18) = 6.35, p = .02.

The ratio used to analyze the affordance judgments was constructed by dividing the gap width at which participants transitioned their responses from yes to no or no to yes by their shoulder width. A 2 (environment: real or virtual) x 3 (distance: 3m, 4.5m, 6m) x 2 (starting position of the poles: far or near) revealed that participants' judgments of their ability to pass through were no different in the virtual classroom (1.16) than in the real classroom (1.08), F (1, 18) = .9, p = .37.

A 2 (environment) x 6 (width) ANOVA also revealed participants' width estimates were no different in the virtual classroom (81% of physical width) than in the real classroom (88% of physical width), F (1, 18) = .73, p = .41.

2.3 Discussion

There are several possible reasons why affordance judgments and size estimates in this experiment were not significantly different in the VE than in the real world while blind walked estimates were different. First, the measures inherently asked participants to judge distances defined by different frames of reference. Blind walking estimates required participants to judge an egocentric distance (from self to the target), but affordance judgments and size estimates required participants to judge an exocentric distance (the distance between the two poles). It is possible that in the VE, egocentric distances were perceived differently than exocentric distances. Related to this difference is a distinction in the plane in which the distance intervals are judged. The blind walking task required perception in the depth/saggital plane, whereas the size and affordance judgments were frontal interval judgments. Previous work in the real world has shown differences in matching of depth and frontal intervals [Loomis et al. 1992]. It is possible that VE distance compression generalizes only to the depth intervals and/or egocentric distances. Additional manipulations which tease apart egocentric versus exocentric intervals in depth and frontal extents are necessary to further explore these differences.

Second, the task itself may have led to different estimates. Walking to a location and judging size or affordances are distinct tasks with different task-goals. One possibility is that task-goals influence attention to different features in the environment which could lead to different perceptual representations of space. This explanation is consistent with differential response measure effects seen in a recent VE study which manipulated the quality of graphics [Kunz et al. 2009]. In this study, a manipulation of high versus low quality graphics affected verbal reports of distance, while blind walking judgments remained unaffected. We suggested that verbal reports may have involved additional attention to the context information that changed with quality of graphics such as texture and illumination cues. Similar accounts have also been proposed for different outcomes of different distance judgments in the real world. Future studies should assess whether these differences in results are due to the measure used or to the aspect of space being assessed.

Interestingly, the size estimates of width were similar to affordance judgments in that there were no differences between estimates in the real and virtual environments. Size estimates are often considered to be qualitatively different from affordance judgments because they do not invoke framing the space in terms of action [Wraga 1999]. Given the notable differences in these measures, the similar non-significant result on both measures when comparing between real world and VE would suggest that the conflicting results (between blind walking and the other two measures) may be due to the difference in the aspect of spatial layout being tested (e.g., frame of reference, depth versus frontal interval) and not fundamental differences between each measure. However, these speculative discussions need further controlled investigation to support these claims.

Only a few studies have examined size perception using VEs, but they are consistent with our present findings that size perception in VEs may more closely resemble size perception in the real world than has previously been found for egocentric distance. In studies conducted in a CAVE, observers were asked to adjust the size of a virtual object so that they perceived it to be the same size as a matched physical object. Given a condition with rich context of other objects in the scene, observers showed size constancy, in that the object was perceived to be the same size regardless of the distance from the observer [Kenyon et al. 2007]. Manipulations of other conditions suggested that scene complexity and stereo vision may influence the perception of size constancy [Luo et al. 2007]. Other work using verbal reports and matching hand position to virtual objects have found that with a full immersive HMD system and correct eye height, size judgments were accurate [Dixon et al. 2000]. Reduced immersion and manipulation of rendered eye height both reduced accuracy.

Finally, it is important to note that this experiment was run on a single virtual environment, using a particular display device and tracking system, and over a particular range of egocentric distances and exocentric extents. Understanding the generality of the result will require replication of the methodology across a range of virtual environments, displays, and geometric configurations.

While the current study investigated how participants perceived their potential for passage through an aperture, there are numerous different affordance judgments that could be evaluated both in real and virtual environments. For instance, perceived jump-over-ability could be used to measure perceived egocentric distances. This measure has been used successfully to evaluate space perception in real environments but has not been used in virtual environments. Height perception could also be evaluated by assessing participants' perception of step-on-ability or sit-on-ability. However, to successfully use affordance judgments to evaluate perceived space in VEs, the same judgment should be made in an analogous real world environment. As seen in our data and others [Loomis and Knapp 2003], participants are generally cautious about what aperture widths allow passage. Without a real environment comparison, this bias to be cautious could be inaccurately interpreted in VEs to mean that the space in VEs is underestimated. Therefore, when using affordances judgments, and any perceptual measure, to assess perceived space in VEs it is important to have an analogous real environment.

3 Summary

One goal of graphical interfaces is to portray an environment in which users can, or believe they can, interact with the displayed image in an appropriate manner. Affordance judgments, as a measure of perceived space, provide an index to evaluate whether the graphic display achieves this goal by directly asking the user what he or she is capable of performing. They have potential advantages over measures that have been previously used to quantify the effectiveness of visual displays in accurately conveying a sense of spatial layout, and provide an alternative measure that may be better suited to evaluate both immersive and non-immersive graphical displays. We compared space perception in one virtual environment using affordances and two other measures, finding that the compression of egocentric distance judgments that occurs in such situations may not generalize broadly to different spatial features.

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References

DIXON, M. W., WRAGA, M., PROFFITT, D. R., AND WILLIAMS, G. C. 2000. Eye height scaling of absolute size in immersive and nonimmersive displays. *Journal of Experimental Psychology: Human Perception and Performance 26*, 2, 582–593.

GIBSON, J. J. 1979. *The ecological approach to visual perception*. Houghton Mifflin, Boston.

GROSS, D. C., STANNEY, K. M., AND COHN, J. 2005. Evoking affordances in virtual environments via sensory-stimuli substitution. *Presence: Teleoperators and Virtual Environments 14*, 4, 482–491.

KENYON, R. V., SANDIN, D., SMITH, R. C., PAWLICKI, R., AND DEFANTI, T. 2007. Size-constancy in the CAVE. *Presence: Teleoperations and Virtual Environments 16*, 2, 172–187.

KUHL, S. A., THOMPSON, W. B., AND CREEM-REGEHR, S. H. 2009. HMD calibration and its effects on distance judgments. *ACM Transactions on Applied Perception 6*, 3.

KUNZ, B. R., WOUTERS, L., SMITH, D., THOMPSON, W. B., AND CREEM-REGEHR, S. H. 2009. Revisiting the effect of quality of graphics on distance judgments in virtual environments: A comparison of verbal reports and blind walking. *Attention, Perception, & Psychophysics 71*, 6, 1284–1293.

LOOMIS, J. M., AND KNAPP, J. 2003. Visual perception of egocentric distance in real and virtual environments. In *Virtual and Adaptive Environments*, L. J. Hettinger and M. W. Haas, Eds. Erlbaum, Mahwah, NJ, ch. 2, 21–46.

LOOMIS, J. M., AND PHILBECK, J. W. 2008. Measuring spatial perception with spatial updating and action. In *Embodiment, Ego-Space, and Action*, R. L. Klatzky, B. MacWihnney, and M. Behrmann, Eds. Taylor & Francis, New York.

LOOMIS, J. M., SILVA, J. A. D., FUJITA, N., AND FUKUSIMA, S. S. 1992. Visual space perception and visually directed action. *Journal of Experimental Psychology: Human Perception and Performance 18*, 4, 906–921.

LUO, X., KENYON, R. V., KAMPER, D., SANTIN, D., AND DEFANTI, T. 2007. The effects of scene complexity, stereovision, and motion parallax on size constancy in a mobile virtual environment. In *Proc. IEEE Virtual Reality*, 59–66.

MARK, L. S. 1987. Eyeheight-scaled information about affordances: A study of sitting and stair climbing. *Journal of Experimental Psychology: Human Perception and Performance 13*, 3, 361–370.

STAPPERS, P. J., FLACH, J. M., AND VOORHORST, F. A. 1999. Critical ratios as behavioral indices of presence. In *Proc. 2nd International Workshop on Presence*.

STOFFREGEN, T. A., BARDY, B. G., AND MANTEL, B. 2006. Affordances in the design of enactive systems. *Virtual Reality 10*, 4–10.

THOMPSON, W. B., WILLEMSEN, P., GOOCH, A. A., CREEM-REGEHR, S. H., LOOMIS, J. M., AND BEALL, A. C. 2004. Does the quality of the computer graphics matter when judging distances in visually immersive environments? *Presence: Teleoperators and Virtual Environments 13*, 5, 560–571.

WARREN, JR., W. H., AND WHANG, S. 1987. Visual guidance of walking through apertures: Body scaled information for affordances. *Journal of Experimental Psychology: Human Perception and Performance 13*, 371–383.

WRAGA, M. 1999. The role of eye height in perceiving affordances and object dimensions. *Perception & Psychophysics 61*, 3, 490–507.