DEPTH PERCEPTION AS A FUNCTION OF LIGHTING, TIME AND SPATIALITY

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Abstract:

Perceptual qualities of luminous environment change based on spatiality, time, and observer. This paper focuses on the complex interrelationships between architectural configurations, luminance distribution patterns, and the perception of spatial depth. A computational framework that draws from the recent developments in computer graphics (physically based renderings and perceptually based tone mapping techniques) is utilized to generate pictorial spaces. Daylighting conditions are parametrically changed and psychophysical experiments are conducted to measure the perceived distances of targets. Results reveal that luminance contrast is an effective pictorial cue that can increase the perception of the spatial depth.

INTRODUCTION

Effects of various pictorial cues (i.e. occlusion, familiar size, relative size, aerial perspective, and texture gradients) on space perception have been extensively studied in real environments. Light and shade are known to be dominant visual cues for shape perception; and lighting is used as a design strategy to reveal architectural form. However, the impact of luminance distribution patterns on depth perception has not been systematically studied; and the related design strategies are based on experiential information.

In most of depth perception studies, subjects are asked to view a target in a test scene and then to adjust a target in a reference scene to match the perceived distance of the test target. Depth cues are systematically varied; and the measured difference between the perceived distances of test and reference targets allow researchers to quantify the effect of the manipulated depth cue. The dynamic character of lighting in physical environments poses challenges in terms of repeatability and manipulation of parameters in a controlled manner. Yet, with adequate modeling, visualization, and display technologies, computer generated images can provide the flexibility to simulate various lighting conditions through manipulation of input parameters including the spatial composition, materiality, lighting and the occupant's viewpoint. Therefore, computational approaches provide a unique opportunity to systematically study the impact of lighting as a pictorial cue. In this paper, physically based rendering and perceptually based tone mapping techniques are utilized to generate pictorial spaces that can provide surrogate models for physical environments to study the depth perception. The objective of this study is to demonstrate the relationship between the architectural configuration, luminance distribution patterns, time, and perceived spatial depth.

METHODOLOGY

The experimental setup is an elongated space that is divided into two hallways (Figure 1). Identical size floating luminous disks (12" in radius) are located at the center of each hallway as visual targets; and the camera viewpoint is set towards the center of the corridor at normal eye level. Two major variables are introduced into the experiment: The relative distance between the two disks are varied; and architectural configurations and sky conditions are changed to create different lighting conditions between the right and left hallways (Figure 2). In the base case ("no skylight" condition), the scene was illuminated with the daylight admitted from the rear end of the corridor. In other conditions, additional 5'x10' skylight was installed at 24' away from the viewpoint on one of the corridors. Different sky conditions and sun positions are simulated.

The location of the left disk is fixated at 40' away from the viewpoint and it is referred as the standard disk. Right disk, referred as the comparison disk, is located at 7 different positions (located 34', 36', 38', 40', 42', 44', and 46' away from the viewpoint). The variations of disk locations are rendered under five different lighting conditions both for left and right corridors to generate a total of 70 scenes.

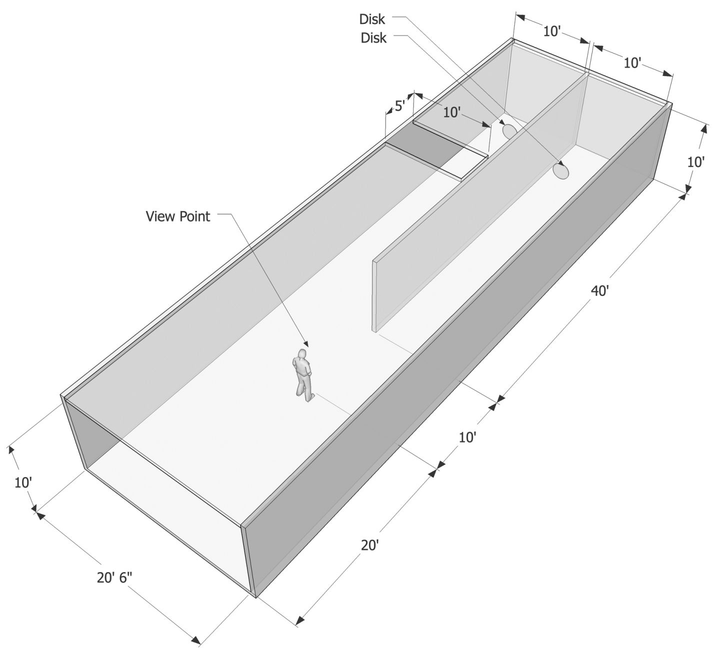

Figure 1. Architectural configuration for the experimental scenes.

The authors (2009) previously investigated whether the depth perception of a 2D representation on a computer screen can adequately embody the perceptual qualities of a real 3D environment. The evaluation is done by repeating a classical research study on depth perception (Holway and Boring, 1941) in a computer generated pictorial environment. By acquiring the matching experiment results through psychophysical studies in physical and virtual environments, the credibility of using a computer generated pictorial space is established. The computational framework incorporates experimental scenes that were generated by Radiance Lighting Simulation and Visualization system (Ward and Shakespeare 1997) as physically based lighting simulations. The resultant high dynamic range images were tone-mapped with the Photographic Tone Mapping Operator (Reinhard 2002), which consistently performed well when compared to real physical scenes in various perceptual studies (Yoshida et al. 2005; Kuang et al. 2006; Cadik et al. 2008).

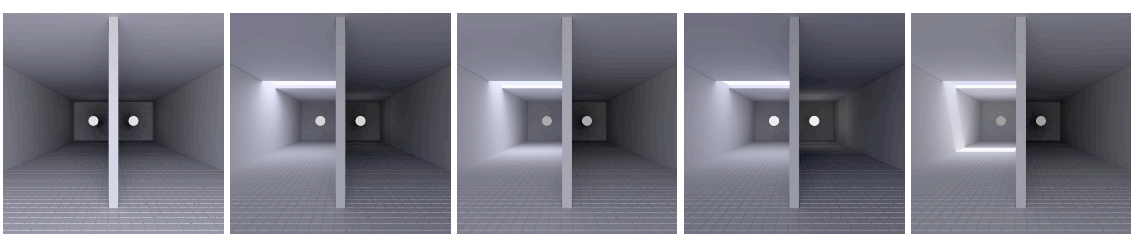

Figure 2. Experimental scenes with right and left disks configured at same locations of the five lighting conditions

In the experiment, images were displayed at the center of a LCD display in a dark room. Eight subjects participated in this study. The subjects, aged between 21 to 36, had normal or corrected-to-normal vision. They were asked to sit in front of the display at a normal viewing distance and angle; and were given enough time to adapt to the environment. They were informed that there were two identical disks floating at the center of each hallway and they were asked to use verbal methods to report the disk that appears to be closer. In each session, 70 images were shown in random order for 5 times. Each participant's responses were recorded as the number of times that the standard disk is reported closer.

RESULTS

The experiment results are illustrated in Figure 3. Subjects' responses are plotted as the proportion of scenes on which the standard disk is reported "closer" as a function of the comparison disk's location. Probit regression curve, a statistical function that specialized in modeling regression of binary response, is fitted to each data set. The intersection points of each curve with the 50% proportion line are taken as the point of subjective equality (PSE). The PSE represents when the comparison and standard disks are perceived equal in depth. The result demonstrates that in "no skylight" condition, the two disks were perceived equal when the two disks were configured at the same locations (PSE = 39.79±0.13). In "morning", "noon", "afternoon" and with "sun patch" availability, the PSEs shifted to right, the perceived distance of standard disk was increased from 40 feet to 41.78±0.14, 42.14±0.16, 41.12±0.14, and 42.98±0.16 feet respectively.

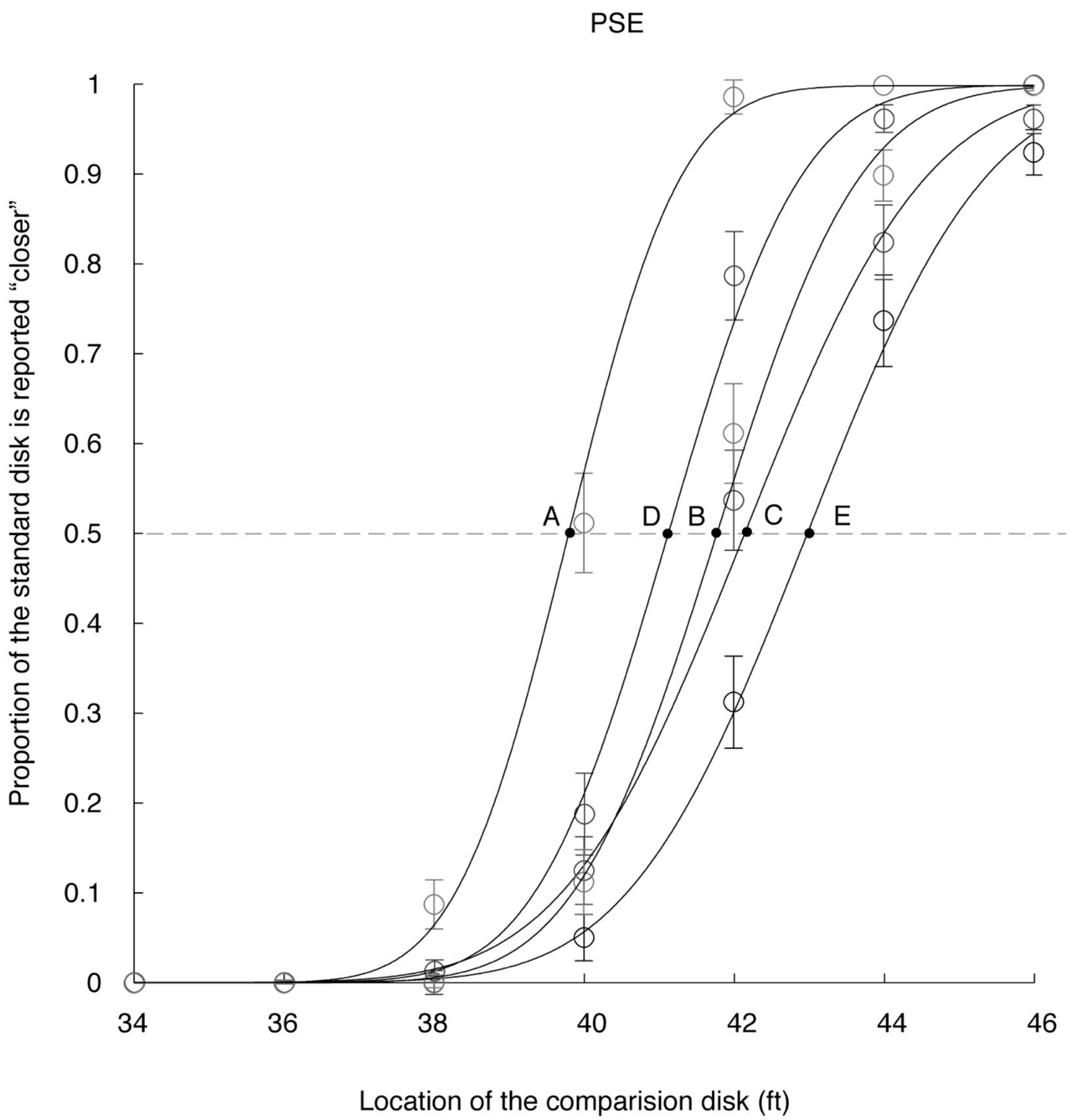

Figure 3. Probit analysis: A is PSE with "no skylight" condition; B is PSE with "morning" condition; C is PSE with "noon" condition; D is PSE with "afternoon" condition; and E is PSE with "sun patch" condition.

DISCUSSION AND CONCLUSION

False color studies of the images with different lighting conditions illustrate the luminance distribution patterns (Figure 4). The luminance contrast of the two disks and their backgrounds were identical in the base case (“no skylight” condition). However, the luminance contrast between the disk and its background was reduced when the hallway was illuminated with the additional skylight. The addition of the skylight reduces the luminance contrast between the disk and its background, and therefore, increases its perceived distance. These results are in agreement with a previous study (O’Shea et al. 1983), which argues that 2D targets with higher luminance contrast appear closer to the observer. Our results reveal that this relation can be observed in 3D environments, as well. Daylight apertures and varying sky conditions create scenes with different luminance distribution patterns, and therefore enrich the perception of spatial depth over the time.

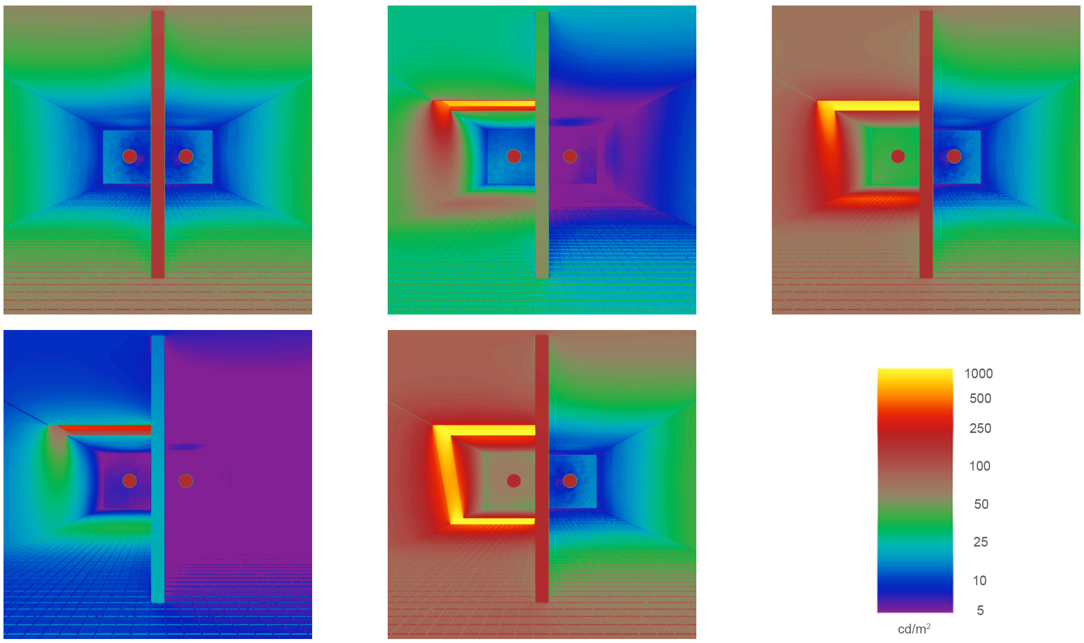

Figure 4. False color studies of experimental scenes (from left to right: “no skylight”, “early”, “noon”, “late” and “sun patch” condition).

REFERENCES

Cadik, M., Wimmer, M., Neumann, L., and Artusi, A. (2008). Evaluation of HDR tone mapping methods using essential perceptual attributes. *Computer & Graphics*, 32, 35-44.

Holway, A. H. & Boring, E. G. (1941). Determinants of Apparent Visual Size with Distance Variant, *American journal of psychology*, vol. 54, 21-37.

Kuang, J., Liu, C., Johnson, G., and Fairchild, M. (2006). Evaluation of HDR image rendering algorithms using real-world scenes, *International congress of imaging science*, 4(2), 1-27.

O'Shea, R.P., Blackburn, S. G., and Ono, H. (1994). Contrast as a depth cue. *Vision research*, 34, 1595-1604.

Reinhard E., Stark, M., Shirley, P., and Ferwerda, J. (2002). Photographic tone reproduction for digital images. *ACM transactions on graphics*, 21(3):267–276.

Ward, G. & Shakespeare, R. (1997). *Rendering with Radiance.* San Francisco: Morgan Kaufman Publisher.

Yoshida, A., Blanz, V., Myskowski, K., and Seidel, H. P. (2005). Perceptual evaluation of tone mapping operators with real-world scenes, *Human Vision and Electronic Imaging X, IS&T/SPIE's 17th Annual Symposium on Electronic Imaging*, 756-768.