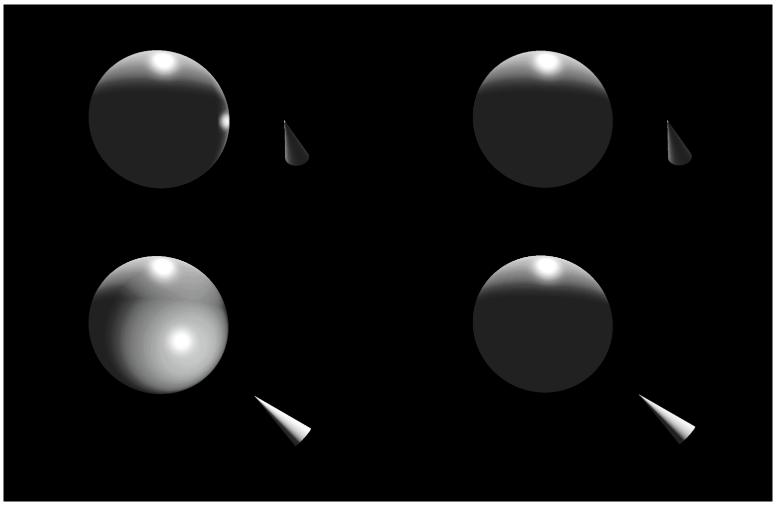

Figure 1: Relative Depth Between Cursor and Sphere (left: LEC; right: NLEC).

chose such a shape to allow us to expand future investigations to include directional considerations without having to confound the experimental design with a new cursor shape.

Hypothesized Advantages

Fig. 1 demonstrates the utility of a LEC in determining whether the cursor is closer to or further from the viewer than some other object. On the top-left, a LEC is further away from the viewer than the sphere, resulting in a small highlight along the right edge of the sphere, in addition to the highlight on top of the sphere, which comes from a static, overhead light source. On the bottom-left, the LEC is closer than the sphere, resulting in a large highlight on the front of the sphere, in addition to the same highlight on top of the sphere. On the right side of the figure are identical placements of the cursor and sphere, but this time the cursor is non-light-emitting (NLEC); note the lack of visual cues with respect to relative depth.

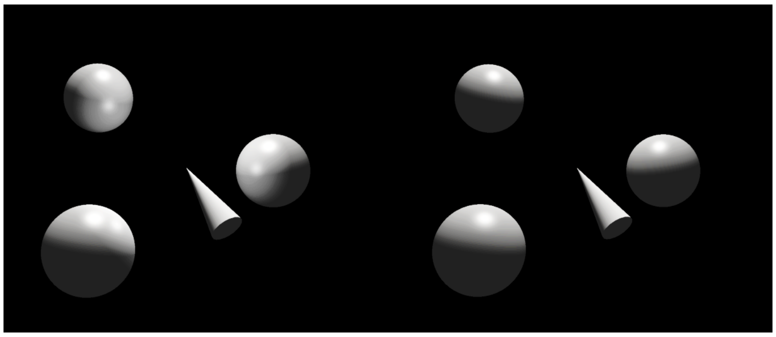

Figure 2: Relative Depth Amongst Spheres (left: LEC; right: NLEC).

Similarly, the reflections from a LEC can provide relative depth information amongst a collection of objects in the scene (Fig. 2), which might also aid in navigation planning. On the left, the LEC gives a clear perception of the depth ordering of the three spheres, whereas relative depth is difficult to determine on the right, where a NLEC was used. Note that, if it is known *a priori* that all three spheres are the same *physical* size, then the *projected* sizes can serve as a reliable depth cue, even with the NLEC; this potential confounding depth cue will be addressed below. Of course, for objects that vary in physical size, projected size alone is not a dependable depth cue.

In addition to depth perception, the use of a LEC can also aid in distance estimation, as seen in Fig. 3. In the series of images on the left, a LEC is moved closer to the sphere, from top to bottom. As the LEC approaches the sphere, the highlight due to the LEC becomes smaller and interacts less with the highlight from the overhead light. On the right, the same approach using a NLEC shows no such distance cue.

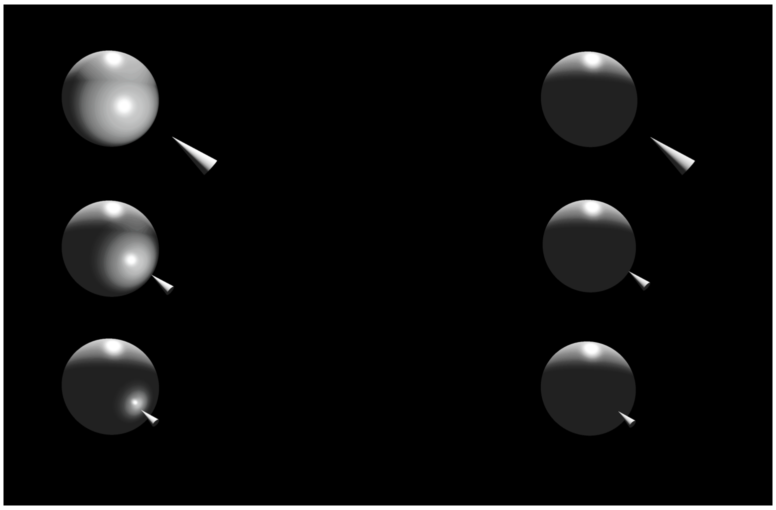

Figure 3: Relative Distance Between Cursor and Sphere (left: LEC; right: NLEC).

Navigation Experiment

To evaluate the effectiveness of having a cursor emit light, we had 4 subjects (one of whom was also an experimenter) carry out a navigation task with both a LEC and a NLEC and analyzed a number of performance measures, such as completion time and distance traveled (see below). All subjects had extensive prior experience with 2D computer systems, but none had any prior experience with 3D systems. All subjects had corrected-to-normal vision, were familiar with the goals of the experiment, and had previous experience participating in vision and/or interaction experiments.

The experiment was carried out on a SGI Indigo^2 Extreme workstation with a Mitsubishi color monitor (model HL7965KW-SG); the input device was a 6 degree-of-freedom Spaceball™.† Subjects were free to position their chairs and the Spaceball™ so as to make

† While most users will have available to them only 2D input devices, the physical and cognitive mappings from such devices to a 3D space are themselves complex issues and are unrelated to our interest here in the LEC. Consequently, we chose a 3D input device available to us and ensured that subjects had sufficient training in its use (see below).

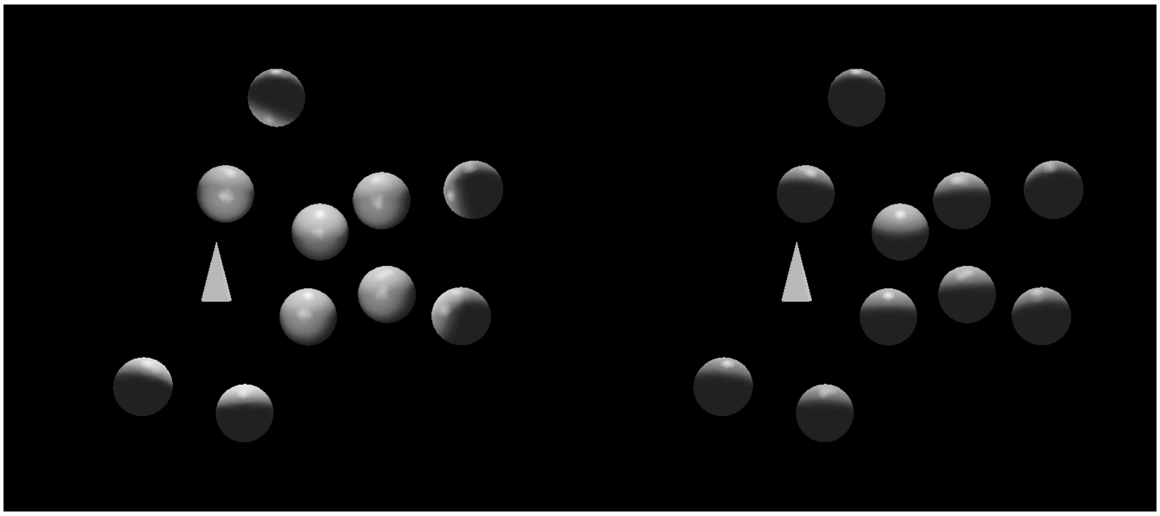

Figure 4: Sample Trial in Navigation Experiment (left: LEC; right: NLEC).

themselves comfortable. Before each series of trials, the computer screen was calibrated so that a white screen produced 80 cd/m^2 at its center and luminance was linear in DAC setting (i.e., gamma-corrected). Other than the light provided by the computer screen, the experimental environment was kept dark.

Fig. 4 shows a sample static image from a trial with the LEC (left) and NLEC (right). In each trial, 10 gray spheres and the cursor (also gray) were placed randomly in a (black) 3D design space, constrained so that they were all completely visible in the scene's 2D projection onto the computer screen. Spheres were deliberately chosen because their lighted surfaces provide optimal depth information and, hence, the greatest likelihood of demonstrating an effect for LECs; consequently, any benefits realized using spheres serve as upper-bound improvements. A static light source was placed above the center of the design space (but outside of the projected image); this served as the only light source when using a NLEC and as a secondary light source when using a LEC.

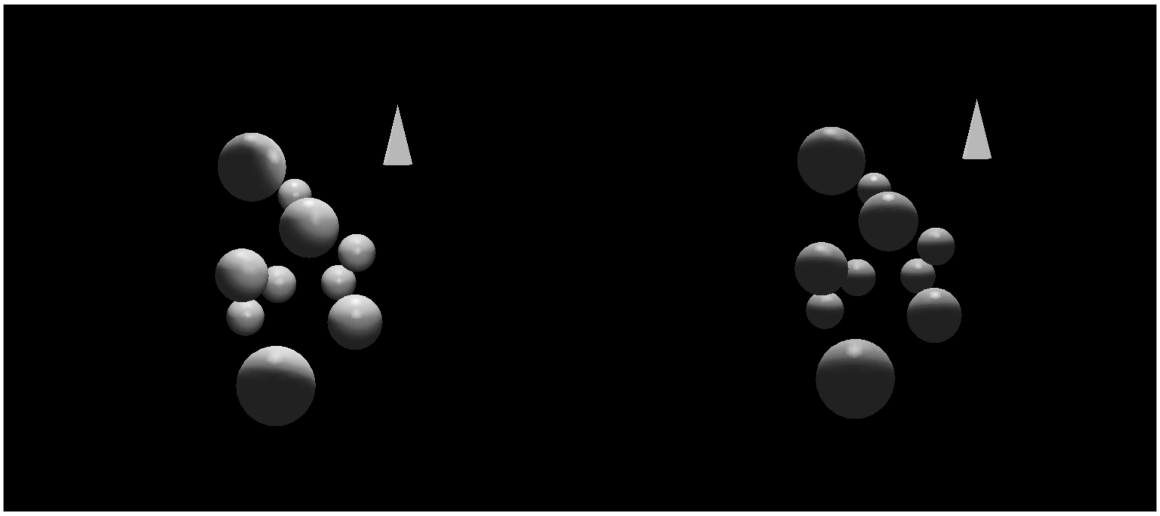

Figure 8: Sample Trial When Projected Size Varies and Occlusion is Allowed (left: LEC; right: NLEC).

there was a significant improvement even when projected size varied. That is, even though path planning showed no significant improvement, both completion time and distance traveled still exhibited significant and substantial improvements (though somewhat reduced from the improvements achieved in the original condition). Hence, use of a LEC provides a depth cue and associated performance improvements that are not otherwise available.

Conclusions

To aid in 3D navigation using a 2D display device, we have designed a cursor that emits light. The experiment described here clearly demonstrates the utility of the LEC as a 3D tool for judging relative position and for homing in on objects, even when combined with other depth cues such as projected size and occlusion. It is particularly noteworthy that improvements were obtained for a variety of performance measures. In the absence