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Illuminating Light: A Casual Optics Workbench

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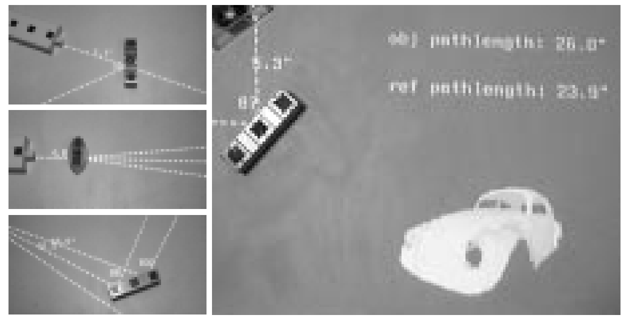
ABSTRACT
We describe a novel system for rapid prototyping of laser-based optical and holographic layouts. Users of this experimental direct manipulation tool – called *Illuminating Light* – move physical representations of various optical elements about a workspace; the system tracks these components and projects back onto the workspace surface the simulated propagation of laser light through the evolving layout. This application is built atop the *Luminous Room* infrastructure, an aggregate of interlinked, computer-controlled projector-camera units called *I/O Bulb*s.

Keywords
engineering simulation, optics, holography, luminous-tangible interface, direct manipulation, augmented reality, prototyping tool, interactive projection, tangible bits

SCENARIO-SYNOPSIS
A stylized plastic model of a laser is placed on an ordinary table; immediately a luminous beam, projected from above onto the table's surface, appears to shoot forward from the laser model's aperture. As the model is moved about the table the beam tracks along with it, always originating from same point on the laser's front surface. A beamsplitter model placed in the path of the beam splits it in two, half continuing forward and half reflecting off the splitter's surface. A mirror model bounces an intercepted beam at the incidence-equals-reflection angle. Lens models spread a

single beam into a fan of beams; recording-film models absorb beams incident upon them; and 'recording subjects' – a small automotive model, for example – scatter incoming beams, insuring that some are redirected to arrive at any recording film that may be nearby.

During such manipulations, the various 'inert' optics models behave very much as their real counterparts would, directing and modifying the light that passes through them; but these physically accurate 'beams' of light are wholly simulated and projected down in careful registration with the 'optics'. Simple metrics float in appropriate positions to indicate the angle at each beam bounce location and the distance between each pair of successively-traversed optics. As work progresses, a continuously updated display at the far end of the table shows the layout's relative optical pathlengths. Once a viable recording setup has been arranged a rendered simulation emerges, showing how the object

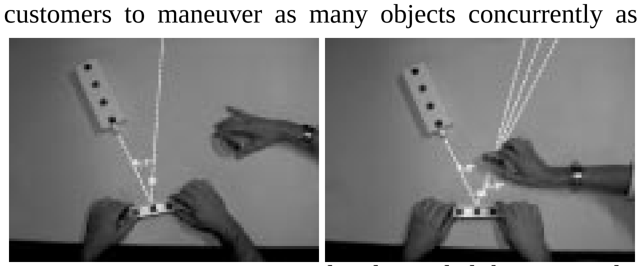


would appear in the optical reconstruction of a real, analogously recorded hologram.

INTRODUCTION
The scenario described above is *Illuminating Light*, the first full application of the *I/O Bulb* and *Luminous Room* infrastructures [5]. It is built atop a pipeline comprising a low-level machine vision system (called *glimpser*), and a toolkit (called *voodoo*) for constructing layout-based interactive simulations. Its half-physical, half-projective interaction style, an approach termed *luminous-tangible* [6], in part extends *tangible interface* ideas discussed elsewhere [3].

System Design Requirements
Our intent was to build a prototyping tool for holographic recording setups whose input and output were arranged to emulate the real thing – not just visually, but haptically and spatially as well – in order to both foster and exploit geometric-optical understanding skills. Although the optical elements and the laser beams (the former moved volitionally by human users, the latter computationally generated and projectively inserted into the real space) would be *implementationally* decoupled, the application would convincingly cause them to *appear* causally coupled.

We required, in acknowledgement of the comparative efficiency of two-handed work [1], that the system allow its customers to maneuver as many objects concurrently as



necessary or convenient; we also demanded that our application permit collaborative manipulation.

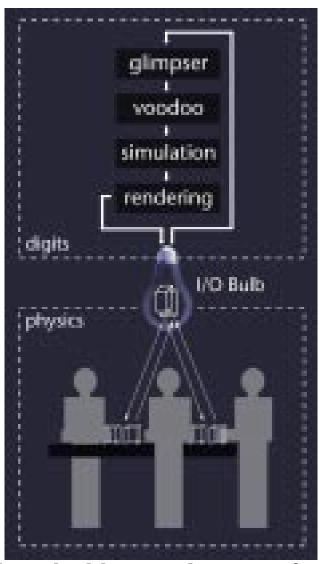
Application Domain: Optics & Holography
High-quality optical elements are simultaneously expensive and notoriously susceptible to damage. The breadboarding tables on which experiments are constructed and prototypes are built are a scarce resource. At the same time, the preci-

sion required of laser-based optical systems frequently results in setup and refinement times that greatly exceed the time spent actually running the experiment. All of this suggests that a well-designed ‘simulated optics workbench’ could be a valuable tool. Such a workbench should permit the optical engineer to manipulate an accurate simulation of an evolving layout and its operation, and then rapidly reproduce the setup on the real table to perform the end experiment.

In holography – a higher level ‘goal’ whose specific domain knowledge we chose to include in the system – a fine-grained photographic plate must be exposed simultaneously to an ‘object beam’, comprising light scattered from laser illumination of the object being recorded, and to a ‘reference beam’: uniform, unmodulated laser light [2]. These two beams must not only originate from the same laser but also follow paths of equal lengths. Additional geometric requirements are imposed according to physical and aesthetic demands. Thus the principal challenge of engineering a workable hologram-recording layout is the simultaneous satisfaction of multiple geometric constraints.

THE I/O BULB AND THE LUMINOUS ROOM

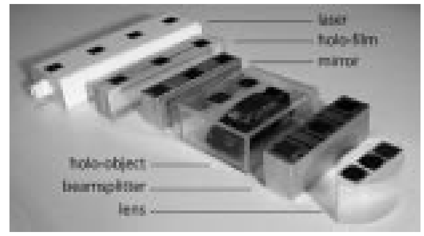
Our overarching research goal is the wholesale transformation of architectural space to make of each surface an information-display-and-interaction structure (*Illuminating Light* is just one application built to illustrate some of these ideas). The approach we espouse requires the evolution of the familiar lightbulb into the *I/O Bulb*, as follows: if an ordinary incandescent bulb is actually a low-resolution digital projector – specifically, 1x1 pixel(s) – then we must increase this resolution, so that the lightbulb is capable of projecting images into the space around it, while at the same time incorporating a tiny video camera that looks out at the world around the bulb. The resulting structure, called an *I/O Bulb*, is capable of simultaneous optical input and output. The work described here makes use of a prototype *I/O Bulb* constructed with commercially available projectors and cameras.



The notion of a *Luminous Room* involves extrapolating from just one to a collection of many *I/O Bulb*s, computationally interlinked and distributed throughout an architectural space. The resulting aggregate of two-way optical nodes visually addresses every portion of a room and is one way of achieving our space-transforming goal [4].

THE FULL PIPELINE

Experimenters manipulate six basic optical elements required for the proper execution of hologram-recording setups: a laser, mirrors, beamsplitters, lenses, a ‘holo-object’ (the physical thing being visually recorded), and the holographic film plate itself. Each element is represented by a simple object designed to clearly suggest its identity with minimal detail, and each has affixed to its top a unique pattern of small colored dots. Optical input from the workspace is passed from an overhead *I/O Bulb* to a very modest ‘raw vision’ system: the *glimpser* program simply identifies colored dots in its visual field. Built as a client-server facility, *glimpser* accepts commands over a network connection and, frame by frame, reports back to the originating client a collection of located dots. An application-independent geometric parsing toolkit called *voodoo* interprets *glimpser*’s simple colored-dot-location output, analyzing each batch of color dots into a list of unique patterns (those physically present on the optics models) registered with it by the application it serves. The instantaneous spatial configuration – i.e. the recovered positions and orientations for all recognized optical models – is then used by a ray-based optical simulator to determine the resultant path of laser light, which is visually rendered and accurately projected via the same *I/O Bulb* back into the workspace.



RESULTS, DISCUSSION, CONCLUSION

Illuminating Light runs on a Silicon Graphics O_2 (R5000) at a framerate of twenty to forty Hertz. The system heavily exploits the advantages of control via graspable interface elements (as explored in other tangible interface work), but with the additional strength that its components act not just as physically instantiated abstractions but as direct representations of the ‘real thing’. This allows *Illuminating Light* to provide constant visual feedback in a form that is already intrinsic to the simulation’s real-world counterpart – and so the ‘virtual’ part of the application does not seem distracting or glaringly distinct from its ‘real’ part.

A much more complete treatment of the design, implementation, testing, and refinement of *Illuminating Light* is contained in [5].

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