Translating object specifications into a computer-generated three-dimensional graphic to be reproduced as a high efficiency, reflection photo-polymer hologram suitable for mass-production

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A process is described for translating the specifications of an object and its interrelationship with another object into a three-dimensional computer graphic and then into a photo-polymer hologram. The capability to translate specifications about objects and their interrelationships into accurate holograms without having to create either a physical model or the manufactured object itself opens exciting possibilities in the areas of creative design and communication. It may assist in the manufacturing process by allowing designers to specify objects and to study accurate, three-

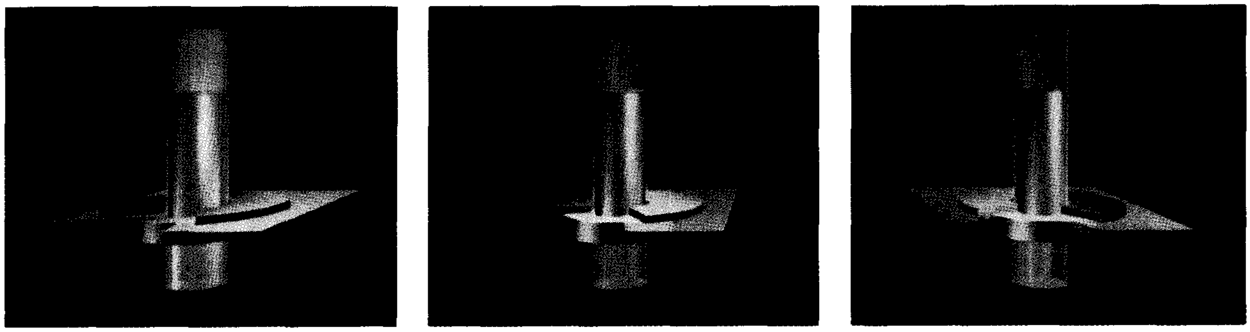

Figure 1

Three of the 120 different views of the image.

dimensional representations of those specifications, including interrelationships with other objects, without the need for an actual physical model. Finally, the hologram may become a means for effective representation of an image produced through the use of three-dimensional computer graphics for people without access to appropriate computer graphics. The process described here was divided into two segments. The MIT Media Lab was responsible for creating a sequence of computer-generated images and transferring those images to film. *Polaroid Corporation* was responsible for creating the hologram from the images on film.*

The MIT Media Lab

The process by which the MIT Media Lab generates an image for use in the production of a hologram requires four basic steps: recreating the object on the computer, assembling the images in space in reference to a virtual camera and light sources, reproducing 120 different views, and transferring the computer screen images to photographic film.

The project demonstrates that previsualization of a design can be accomplished through the use of three-dimensional computer graphics reproduced as holograms without first having to go through the modeling and manufacturing stages to create a solid object. MIT Media Lab researchers used off-the-shelf graphics software (S-Geometry, on a Symbolics workstation) to create the image of the pin and washer. The image was created from polygons based on the specifications provided by IBM researchers Jayaraman and Srinivasan [1]. Virtual half-spaces, spatial abstractions which define the constraints of the physical object, were also created.

Beveled edges were added to produce sharp boundaries. This beveling involves adding extra edges between the edges of adjoining polygons, preventing the edge from being shaded as a curved surface.

In the second step, the objects were assembled in space, along with a virtual camera and several light sources. The aspect ratio of the hologram was changed from 3:4 to 2:3 to accommodate mass-production requirements. Lighting was used both to illuminate the object and to enhance depth. Specular highlights provide important depth cues when the hologram is viewed, so the positioning of the light sources had to be carefully adjusted to bring out the most detail from the pin and the washer.

Traditional photographic lighting techniques were followed. Two lights in front, one low and one high, provide the primary illumination. Four other lights were positioned to the side and rear of the objects to enhance the three-dimensionality and provide depth cues. For example, when a cylindrical object has a light source behind it, the light appears to swing around as the viewer moves. The disparity between the viewer's left and right eye, as the motion is detected, emphasizes the sense of depth.

Once the final design was completed, the third stage was the rendering of the scene, including virtual half-spaces and the specular lighting. In rendering, 120 perspectives, each from a slightly different angle, were made (**Figure 1**). These are required in order to create the impression of a solid object in the hologram, where the multiple views are melded into an apparently seamless, single image.

As part of the rendering process, the virtual half-spaces surrounding the objects were rendered transparent. In

* The hologram appears on the cover of the *IBM Journal of Research and Development*, Volume 33, Number 2, March 1989.

viewing the final hologram, the virtual half-spaces can be glimpsed when looking from the side. These virtual half-spaces are discussed by Jayaraman and Srinivasan [1].

Finally, the 120 images were transferred from disk memory to a single strip of 35-mm movie film. This was done using a computer-controlled raster film recorder.

Polaroid Corporation

Computer-generated images today provide the high resolution (preferably, a minimum of 1000 × 1000 lines) necessary for effective holographic imaging. With the availability of computer-generated representations, three-dimensional holograms can be made of objects which do not (and often cannot) exist in the physical world.

The following holographic imaging process differs from a more conventional holographic method because the computer can generate a series of two-dimensional perspective views. Conventional laser holography requires an actual solid, three-dimensional object. The computer-generated image requires the creation of a holographic stereogram. This stereogram synthesizes the angular views into what one would see while looking at a three-dimensional object; this synthesis is absent in two-dimensional representations on a computer screen.

The process begins when the object information (in this case, the image of the pin through a washer) is delivered to the holographic lab on a standard 35-mm motion picture filmstrip. This film was 120 frames long. Each frame contained the image from a slightly different horizontal perspective. With a computer-controlled step-and-repeat exposure system, this series of perspective views can be sequentially exposed holographically onto a single large sheet of high-resolution black and white film. The more frames there are, the greater the effect of looking around the object. This composite of sequentially exposed holograms is created on a single light-sensitive plate from the 120 frames by recording a 2.5-mm by 200-mm vertical hologram of each perspective while masking the rest of the plate. From a single left-side holographic slice, the viewer sees a left-perspective, two-dimensional view. From a right-side holographic slice, the observer sees a right-perspective view. With the left slice at the left-eye position and the right slice at the right-eye position, the viewer sees a stereoscopic image. Because there are many slices, the viewer sees a continuous stereoscopic image with "look-around." The final size of the composite, laser-viewable hologram is 300 mm by 200 mm.

To complete the process, a second hologram was made following a similar holographic process but using the real image of the object, obtained with reverse conjugate laser illumination of the composited hologram. A second light-sensitive plate is positioned in this real image. After development, the 120 composited holograms are effectively eliminated from the viewer's perception. This final reflection hologram is easily viewable in ordinary white light.

The striking appearance of this hologram is the result of its ability to diffract light back to the viewer's eye almost as if an object had really existed there.

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The hologram was manufactured by the MIRAGE™ Holographic Division of Polaroid Corporation.

Others at the MIT Media Laboratory who participated in the project were Dr. Stephen Benton, Director, Spatial Imaging Group (who performed underlying research in computer graphic holography, particularly for viewing with white light, as it is practiced at Polaroid Corporation and MIT); Dr. David Zelter, Director, Computer Graphics and Animation; Walter Bender, Director, Electronic Publishing Group; and Professor Patrick Purcell. John Underkoffler, Mike Halle, Mike McKenna, David Chen, and Peter Schroeder, Media Lab students, also participated.

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