Proceedings, IEA 2000/HFES2000
44th Ann. Meeting Human Factors & Ergonomics Socierty

ON THE DESIGN OF PERSPECTIVE DISPLAYS

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Perspective displays are a form of information display which capture many of the geometric features of a real environment. How their representational and analytic functions may be balanced is illustrated in terms of informative geometric distortions that may be introduced to aid communication of specific spatial messages.

FUNCTIONS OF INFORMATION DISPLAYS

Vehicle instrument panels, road signs, warning placards and maps are all examples of information displays. In general they may be designed to support either impressionistic, investigative, or communicative purposes.

An impressionistic display could be a picture intended by its artist to convey a general ambiance without unambiguous representation of the location of picture elements. An investigative display could be a data plot from a loosely controlled "experiment of nature" in which investigators were not able to manipulate experimental variables. In such a plot they would be examining data to direct subsequent possible analyses. A communicative display, in contrast, would be a plot or picture generated to specifically transmit a definite message such as the statistical significance of a particular measurement. Only this last type of display will considered below.

ENVIRONMENTS FOR INFORMATION DISPLAY

The most familiar information display experienced in daily life is nature itself. In most cases natural phenomena are self-documenting and they may be understood directly through their physical associations, e.g., a swinging hammer can drive a nail, or flatten a thumb. The omnipresence and predictability of natural phenomena make their understanding simple and effortless. Real objects in real environments, for example, present an inherently coordinated sensory presence which only begins to be perturbed when they are modified into tools for specific purposes.

Interactive 3D displays have allowed designers to exploit operators' familiarity with natural environments and phenomena, developing displays that can physically resemble the phenomena or data they represent. One compelling way these natural phenomena may be presented is through the use of a perspective projection. The perspective projection compellingly captures the geometric appearance of a real environment by visually presenting static and dynamic features as if the viewer were to be actually looking at them. A viewer looking at such an image can thus interpret the image as if it represented a virtual space on the far side of the picture plane.

If the geometric viewpoint used to project the perspective image is updated so as to reflect the motion of the viewer, the virtual space that the viewer sees will come to take on some of the interactive appearance of a virtual environment (Brooks, 1988, Ellis, 1991). But this updating requires high fidelity tracking of the viewer's position and is not always implemented for practical or economic reasons. The present essay will be accordingly limited to nonviewer-tracked, perspective displays.

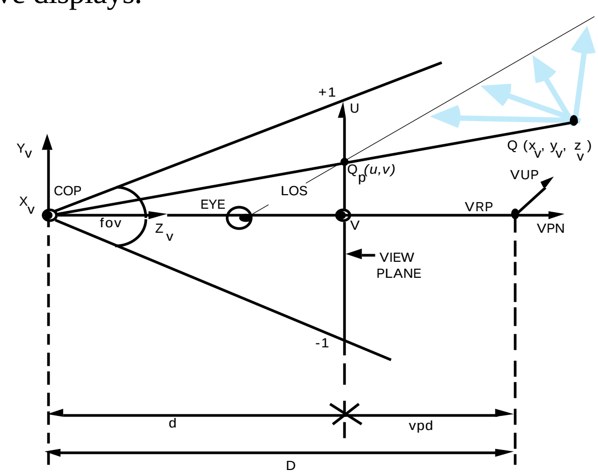

Figure 1. A perspective projection with field of view fov from the center of projection (COP) projects a point Q in the world coordinates into point Qp in picture plane coordinates. If the actual viewing position (EYE) is located at a point other than the center of projection (COP), observers must see Qp as originating somewhere along line of sight LOS. If each point in the depicted space is thought to move to a point on its corresponding line of sight (gray arrows) according to a fixed rule, the resulting process may be visualized as a point by point virtualization from which a virtual space is constructed. In such a reprojection process all points are projected independently. For an example see McGreevy & Ellis (1986).

Since an image produced by a static perspective projection not based on viewer tracking provides only ambiguous cues for construction of a virtual space, the viewer must add information in order to recover the depicted spatial layout. The recovery of the spatial layout through the addition of information, in fact, can be achieved in several alternative ways: point by point reprojection of picture surface features into the virtual space, by assumed image structure, or by detection of higher order psychophysical invariants. These alternatives may be illustrated considering the basic geometry of perspective projection (see Figures 1-3)

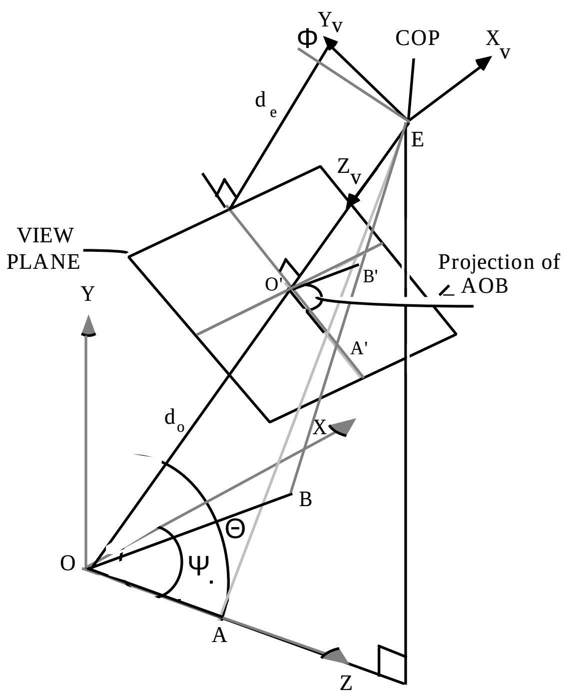

Figure 2. Since planar angles, e.g. AOB, in an environment project systematically to projected angles in the picture plane of a perspective projection (see image), measurement of the projected angles coupled with assumption of viewing direction (pitch roll yaw, Θ, Φ, Ψ) can be used to infer structures in the environment. Conversely, measurement of projected angles coupled with assumed image structure can be used to infer viewing direction (Grunwald, Ellis, & Smith, 1988; Tharp & Ellis, 1990)

ELEMENTS OF PERSPECTIVE PROJECTION

Computer generated perspective displays have three basic elements: their content, their geometry, and their dynamics. Their content consists of the graphics models of the objects that will be displayed. Their geometry consists of the rules of placement used to insert the objects into the displayed space. The dynamics consists of the rule of interaction among the objects and observer. These three elements provide the domains for design of the perspective image. Only the first two will be considered here.

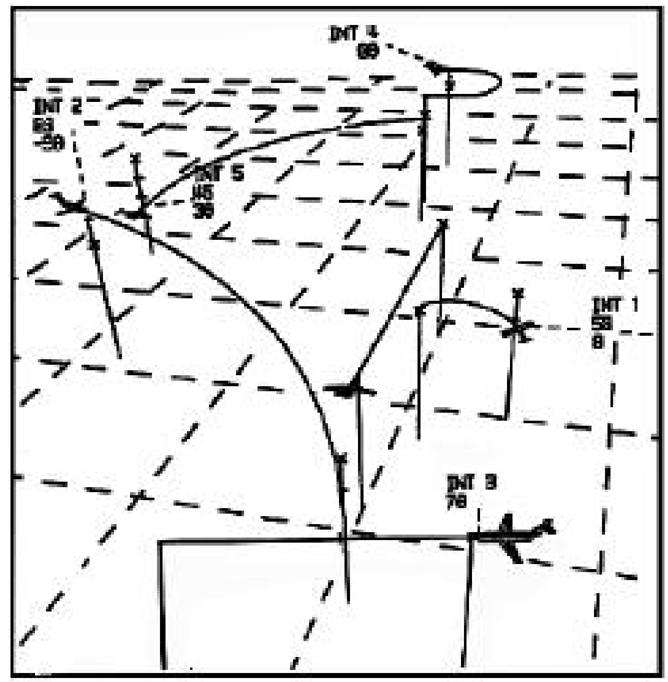

Figure 3. The horizon in a perspective image gives a direct cue to the eye height of the geometric eye point above the reference surface such as a grid. The eye height in turn plays a role in the extraction of image invariants needed for picture interpretation. A far clipping plane in the computer graphics can, however, introduce misleading horizon-like imagery which resembles a horizon into a perspective image. This effect is shown above (adapted from McGreevy & Ellis, 1991). Such features can interfere with observers' ability to recover the viewing eye height and viewing vector and thereby introduce distortions in their perceived virtual space.

DIMENSIONS OF ENHANCEMENT

Figure 4 illustrates where geometric enhancements may be introduced to improve communication of the intended message associated with an object in a perspective display. As shown, the range of enhancement greatly exceeds the usual considerations of color and surface quality. Object shape may be placed under parametric control so that some feature, such as its roundness, could be made proportional to a quantity that the object is intended to communicate. Systematic distortions in the placement of virtual objects may be introduced to alleviate crowding otherwise introduced by the projection. An object's shape and attitude could be generated by a totally separate perspective projection to improve the ease with which it may be identified on the screen. Subsequently, it could be positioned on the screen by an independently computed projection (e.g. Ellis, McGreevy and Hitchcock, 1987).

The kinds of transformations tabulated in Figure 4, of course, will introduce distortions into the image. These modifications could impair user interaction. But it is important to note that they need not disturb but could actually advance the analytic function of a display. Communicative displays are not designed to slavishly represent an environment, but rather to present information to a user in an analyzed image at the appropriate resolution, precision, and timeliness so that effective, necessary action may be taken. Like the symbols on a map, the elements of a display do not need to completely capture all features of an element but need only highlight a critical subset of features dictated by the intended message.

Adjustments in the geometry of a projection can produce widespread changes in the appearance of a display. From a representational point of view, the geometry of the projection should be adjusted and presented so that the viewer's eye is placed at the geometric center of projection when viewing the display. This placement will insure that the display correctly reproduces the lines of sight that would be present were the viewer actually coincident with the viewing vector in the virtual space. This condition is, of course, required for applications like heads-up displays which are intended to present spatially conformal imagery, but it may be relaxed on map-like formats.

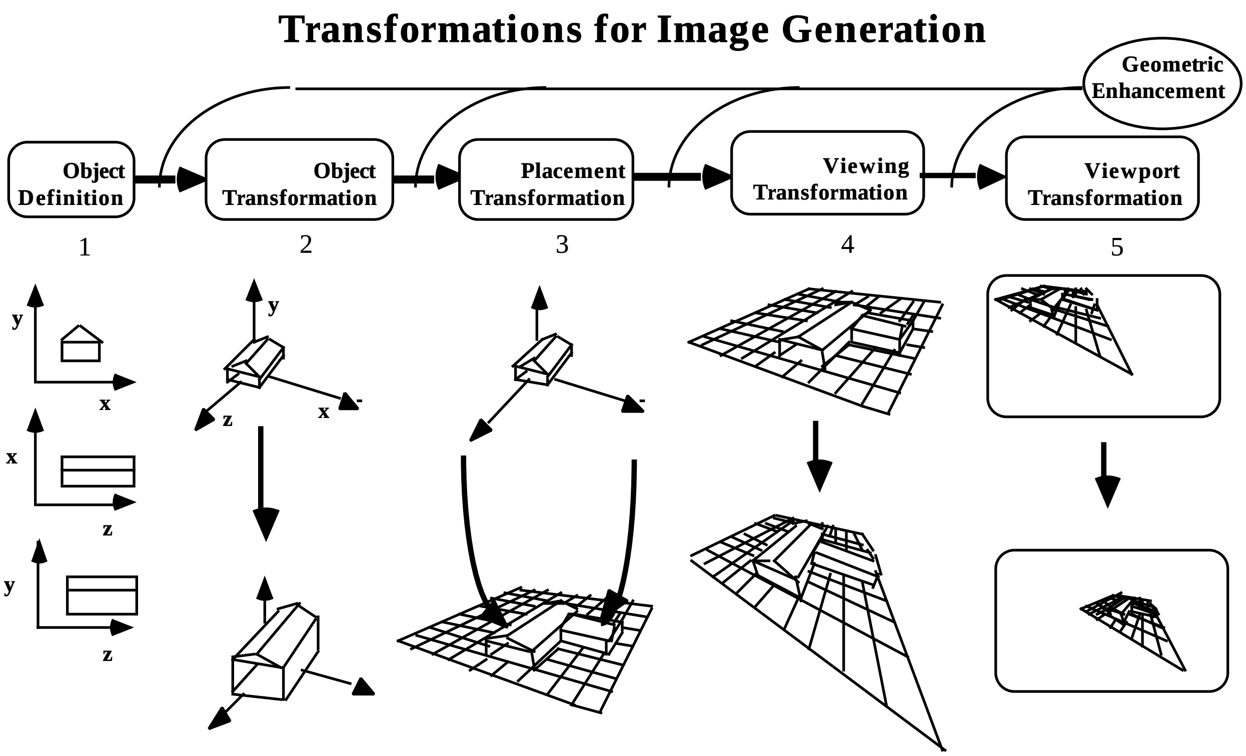

Figure 4. Process of representing a graphic object in virtual space allows a number of different opportunities to introduce informative geometric distortions or enhancements. These may either be a modification of the transforming matrix during the process of object definition or they may be modifications of an element of a model. These modifications may take place (1) in an object relative coordinate system used to define the object's shape, (2) in an affine or even curvilinear object shape transformation, (3) during the placement transformation that positions the transformed object in world coordinates, (4) in the viewing transformation (5) in the final view point transformation. For a mathematical summary of these transformations see Robinett & Holloway (1995). The perceptual consequences of informative distortions are different depending on where they are introduced. For example, object transformations will not impair perceived positional stability of objects displayed in a head-mounted format, whereas changes of the viewing transformation such as magnification will. In general, because nonimmersing viewing formats do not tend to trigger the psychophysical or physiological reflexes associated with observer movement, these formats give designers greater freedom to introduce informative geometric distortions. In particular, since perspective displays are especially amenable to informative distortion, generalization regarding their inherent limitations are difficult to make. Countermeasures may be easily introduced.

The benefits of the introduction of informative distortion may be illustrated by a technique to correct for unwanted clipping that may be associated with the zooming of the field of view as produced by change in a graphics call such as the GL's *lookat* command. As shown in Figure 5, simple changes in the projection's field of view or of the distance of the eye point from a reference point can produce changes in the range of objects displayed on projection screen. This feature is not necessarily desirable on a perspective projection based map in which the user may be given control over the fov and distance. Plan view displays, for example, are often described as having a map range. It is accordingly desirable to introduce this feature into perspective displays.

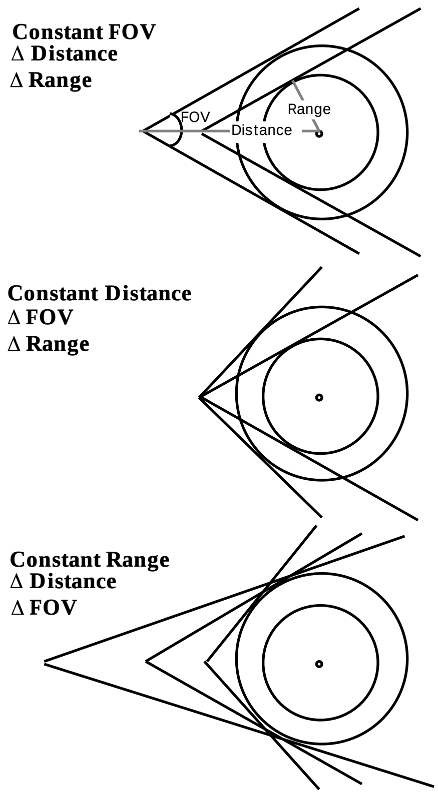

Figure 5 Alternative zooms of a perspective projection.

The lower part of Figure 5 illustrates how this characteristic may be achieved by trading off viewing distance and field of view. This solution, while preserving inclusion of a fixed range of objects with respect to a reference point, also preserves the feature of a zoom which changes the volume of space included in the projection (McGreevy & Ellis, 1986; 1991).

Since the coordinated changes in distance and field of view can substantially move the geometric eye point, they can produce considerable apparent distortion when the resulting displays are conventionally viewed. Psychophysical investigations, however, have shown that the resulting errors in direction judgment based on these distorted displays are not enormous and may be significantly reduced through practice (McGreevy & Ellis, 1986; Tharp & Ellis, 1990)

Indeed, since the analytic display function for a perspective map may not be to accurately depict the displayed space, the geometric distortions may become unimportant. An information display may only need to capture quantitative spatial patterns of the objects in question at sufficient resolution (Elllis, McGreevy & Hitchcock, 1987). In fact, it may only need to capture qualitative differences. The actual spatial separation of the objects may be conveyed alternatively by symbolic enhancements in the form of text, color, flashing or by introduction of geometric elements such as virtual rulers that can explicitly display separation (Ellis, McGreevy, & Hitchcock, 1987). In this sense the perspective display may be seen as primarily providing the context in which the precise information is sent by alternatives.

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