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Background

Recent advances in laser-based display technology are in the form of devices that create 3D images capable of being viewed from a 180 degrees without distortion. These displays are termed “Volumetric” since they represent images and data inside a volume. As such, points within the display are termed “voxels” for volume pixels. A voxel represents a three dimensional point in space (a point with x,y,z coordinates) . One implementation at the Naval Research And Development Lab [1] uses a spinning helical mirror that is struck by three laser scanners tuned to the primary colors (Red, Green, Blue). Thus, the technology provides psychological and physiological depth cues needed for true three dimensional imaging.

Although the technology is embryonic with such basic technical issues as refresh rates and resolution yet to be resolved, this paper examines some of the perceptual and cognitive assumptions that underlie the effort. The impetus for this research comes from the belief that a truer 3D representation will have value in complex decision making and, by extension, decision making under stress.

Research in display mode has been conducted in a variety of fields including cognitive science, the psychology of perception, neuroscience, ergonomics, and human factors. Much of the work has been conducted in university and federal labs where the primary focus is the development of more effective display technology to convey radar imagery. For example, a volumetric display might be used to represent air traffic around a ship such that airborne threats to the ship might be better and more quickly understood.

Perceptual Advantages of Volumetric Display

The creation of the perception of 3D in a 2D medium (such as a CRT) is accomplished through a variety of visual tricks discovered during the Renaissance and are well developed in visual art and well understood in the psychology of perception. 2D images are rendered into 3D images through the application of algorithms that provide the following *psychological* depth cues [1]:

- Linear perspective (distant objects appear smaller)
- Shading and shadowing (near vs. distant objects
- Texture gradient (distant objects have less detail)
- Color (distant objects are darker)
- Aerial perspective (distant objects appear cloudy)

Volumetric display technology may use all of the above plus an additional set of depth cues that have a *physiological* basis:

- Motion parallax (image changes due to the motion of the observer)
- Accommodation (changes in focal length of the eye lens)
- Convergence (inward rotation of the eyes)
- Binocular disparity (difference between left and right eye images)

2D and 3D Representation: Empirical Investigations

An interesting and well-documented phenomenon in human interface design is the tendency for people to prefer features of a human-machine interface which do not provide them with the best performance [2]. For example, Steiner and Dotson [3] examined the effects of adding 3D stereoscopic altitude information to a standard tactical situation display. They found that for all levels of number of threats, the 2D display resulted in faster response times and fewer errors. However, subjects preferred the 3D displays.

This performance-preference dislocation is of particular interest to an understanding of new display technologies such as the volumetric display since implicit in the technology is the belief that it will be superior to 2D and 3D in 2D for many task domains. However, several studies [4],[5] have shown possible detrimental effects of 3D. Spence [6] showed detrimental effects of 3D representations of 2D data particularly for line graphs. Carswell [7] showed that subjects had different attitudes toward 2D and 3D graphs. Subjects reported that 3D graphs were more modern and distinctive than 2D graphs and that, by implication, they were superior in information content.

An argument if favor of the efficacy of the volumetric display is that it has greater fidelity than either a 2D or a 3D in 2D display. However, some studies have shown that high fidelity representations can actually lead to performance degradation in complex environments. For example, Williams and Wickens [8] examined the relationship between scene detail and performance in flight rehearsal and the development of navigational knowledge. The experiment compared user performance on high versus low fidelity simulators and found no effect of scene detail on performance. Holding [9] found a negative transfer effect in motor coordination activities when there was too much similarity between displays in the training and transfer environments. Users *preferred* high fidelity environments during training but their performance dropped in the real problem domain. There is some speculation that, for complex or time pressured tasks, excessive detail leads to poor performance. Indeed, these results conform to many resource allocation theories of attention [10], [11]. A study by Tsang [12] showed that a resource allocation model successfully predicted performance of tracking and memory tasks. As the number and similarity of tasks increases, performance declined. An interesting finding is that similarity of objects in the tasks played an important role in performance degradation. If objects in the task domain were similar, they had greater negative impact on performance. In short, attention is a scarce resource, therefore, increased fidelity may have a price in terms of cognitive effort particularly when complexity is accompanied by similarity. Andre [13] demonstrated this effect with head-up displays that used the same symbology in the near and far domain. It is demonstrated that the same symbology causes the user to see both domains as a single object which leads to poorer performance. The tendency for humans to interpret phenomena as organized wholes, rather than as aggregates of distinct parts, is the core belief of Gestalt psychology and has been well-demonstrated in perception research. This point may be relevant to volumetric display since objects in the display might more easily be perceived as a unit when viewed from some angles. Although not tested empirically as yet, this fact may dictate the future volumetric display design. For example, one of the major benefits of a volumetric display is the ability to change perspective by moving around the display. However, if the user is immobile, the display may be less beneficial than a 3D in 2D display for certain tasks since objects in the display may obscure each other. In addition, a requirement to have the user frequently change perspective may, in itself, be problematic. Pan and zoom functions may be required to achieve optimal benefits.

Discussion: Volumetric Display and Decision Making Under Stress

Time pressure is a type of psychological stress brought on by uncertainty about whether there is sufficient time to complete a task. Time pressure is related to information load [14]. In many cases the task is a decision, and stress is related to the amount, complexity, and presentation mode of relevant information. A major impetus for the development of volumetric display is its perceived benefit as a decision aid in creating an information environment which contributes to enhanced performance, particularly in stressful environments such as battle space management. However, perceived or preferred benefits are not always real. Although the display has clear psychophysiological benefits, these may not translate into increased performance.

One important feature of the volumetric display is increased fidelity. For example, a true 3D image of an airspace is just a miniature representation of the real air space. However, as previously noted, fidelity does not always correspond to increased performance. Very high fidelity may actually impede performance by adding unnecessary details to the representation.

Another characteristic of the volumetric display is the reliance on user position change to provide a perspective view. When viewed from some angles, objects may appear clustered and may be perceived as a unit or, under certain circumstances, be obscured by one another. These problems also appear in other display representations, but they are not solved by volumetric display.

It is interesting to note that in the time pressure literature *effort* is defined as a limited resource, and in the display-oriented human factors literature *attention* is viewed as a limited resource. Of course, attention can be viewed as a type of cognitive effort. As such, volumetric display is thought to reduce the amount of attention required for a task. However, an argument might be made that by presenting display objects in a 3D hemisphere, more attention is required since, by its nature, a volumetric display has added a true third dimension requiring additional cognitive resources. A comparison might be made between an old 2D game such as "Pong" and a newer, virtual reality game: which game requires the most cognitive effort? Which would be more stressful? Volumetric display media are still in an experimental stage of development. Empirical experiments varying many of the features described in this paper will shed light on their true benefits and limitations.

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