White Paper

Display Design for Critical Decision Making in a Virtual Reality Environment

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Abstract

It would seem to be a marriage made in heaven—the needs of decision makers in critical functions to have access to enormous quantities of data and the ability of virtual reality (VR) systems to present complex data. Yet to date, very little use has been made of VR type displays for decision support. The author believes that the problem has been in the way data is presented in computer displays and that effort has not been expended to alleviate some of the barriers between decision makers and their data. To put it simply, displays tend to be designed by people removed from the uses of their products—not unique to this area—so the user must adapt to the peculiarities of the display, rather than the display being adapted to the user. In this paper, we will introduce some simple concepts that can be applied in creating what might be called "decision-centric" displays—designing the display around the decision to be made.

The difference between a good display and a bad display could be measured by the amount of time it takes to understand the situation represented by the display and to extract critical information needed to make decisions. It is the author's premise that a properly designed display can be understood at a glance and can be orders of magnitude better and more reliable than a bad display, which may hide or minimize critical data and cause the decision maker to have to dig it out.

Specific attention is paid to the particular attributes of virtual reality type display methods, which hold particular promise to increase the human bandwidth and drastically improve a decision-making process.

1.0 The Problem

"Above all else show the data." – Edward Tufte

This paper was written to help solve the problems that the author, and undoubtedly many of the readers, faces every day as a virtual reality designer. We have customers with problems that need solving and decisions that must be made. And they are drowning in a sea of data.

It seems that everything around us today collects data—from Web sites, tollbooths, candy machines, and cell phones to satellites and unmanned aerial vehicles. Getting the right information to the decision maker at the right time in an understandable form is our job.

It would seem that we have the right tools at our disposal—a virtual reality type system with an unlimited ability to display data in full, immerse environments. We can create rooms of data, worlds of data, galaxies of data. But is it the right data, and is it understandable in a rapid, intuitive fashion?

The author has had a chance to survey many different types of VR information displays and many other types of 3D presentations for a wide variety of applications. The sad fact is that most of them, from a decision-support standpoint, are inferior to 2D representations that they would replace. Bad scales, misleading perspectives, confusing colors, narrow fields-of-view, and poor symbology are common in VR display systems.

Take for example a command and control mission planning system that might be used by an army commander. Since the people who designed this display learned first to build simulators for pilots and drivers, the 3D representation looks like an out-the-window scene—camouflaged green tanks moving over a photo-realistic green terrain. Who are they hiding the 3D polygon tanks from—their commander? He or she is concerned with mission planning, not rehearsal, and needs to be able to clearly see what is going on. The color of the tanks in real life is irrelevant to this decision maker—which side they are on is! The time it takes for the commander to figure out if that particular green tank is a good guy or a bad guy is taking away from a life-and-death decision-making process.

So in this paper, we are not just talking about good displays and bad displays, but actual harm being done by computer information systems that provide misleading data or incomplete pictures. Some displays even require that users perform critical data integration tasks in their heads.

This is my premise: Displays for decision support should be designed around the decision to be made and tailored to the mental approach used to solve problems.

2.0 What Is a Good Display?

The goal of a good display is to minimize the interface between the user and the critical data that they need to make a decision. Good displays, then, would have the following characteristics:

- Critical data is represented clearly
- Critical data is presented in proper relation to other critical data
- The situation represented by the display is understandable at a glance. Is the situation good or bad? Are things going well or badly?
- There is a minimum of decoration or distraction from the information presentation (signal to noise ratio)
- The display is consistent in its use of graphical elements
- The amount of cognitive overhead, or additional thinking required of the decision maker to understand the data, is kept to a minimum

3.0 Approach

My example will be an Air Force general trying to decide how to conduct a rescue operation of a downed pilot from hostile territory, but this may apply to many situations. We will use this example as a design prototype to flesh out the concepts of the display design process. This is a valid method of advancing systems engineering tasks—keeping the end user's requirements firmly in mind with real-world applications. The common name for this type of approach is rapid prototyping.

The concept is to look at the process of making decisions from a human factors standpoint and to create a display that uses those factors to enhance the decision-making process. This is different from the usual display design method of looking at the data to be displayed and trying to come up with an efficient method of displaying each part.

Another part of the problem is that a lot of information that the decision maker needs is abstract—not visible in the real world and difficult to portray in computer graphics. Some sort of metaphor, or intermediate graphics construct, will have to be imposed to turn abstract information into a meaningful output.

So we will look first at human factors that are relevant to displays, examine the decision-making process, introduce some methods of creating abstractions to display concepts that might not be visual, and then put it all together in our example scenario of a decision support system for rescuing a pilot lost behind enemy lines.

4.0 Human Factors

The human factor is of course the critical ingredient for any VR type system. Our objective, after all, is to improve things for the human users. So what we want to do with our displays is use our natural abilities to draw the decision maker's eye to critical information. There are several critical concepts that we can take advantage of to improve our displays.

4.1 Vision

In the design of computer displays, it is no surprise that the properties of human vision play a critical role. Our eyes are amazing instruments, with an almost 180-degree field of view and adaptable to a wide variety of lighting and conditions. Creating computer displays that can fully engage this wide field of view is a great challenge. It is interesting to note that we actually see clearly and acutely in only about a five-degree circle in the center of our vision—the fovea. Eighty percent of our vision sensing cells are located there. The rest of our vision is highly sensitive to motion, but not as acute. Humans are able to distinguish about 3 million different colors. (But it is important to note that 7 percent of males are color-blind to some extent, usually confusing red and green. Only .4 percent of women are color-blind.) Our vision works a lot more subjectively than we might be comfortable with, which means that the major part of the work happens in the brain.

4.2 Patterns

One of the properties of human vision is that we are strongly sensitive to patterns or to breaks in patterns. Put one white brick in a whole wall of red bricks, and the eye is drawn to it instinctively.

4.3 Motion

Human eyes, especially the peripheral vision areas, are very sensitive to motion or movement, and this can be used also as a cue for critical information.

4.4 Stereo Vision

Our binocular vision (two eyes) provides us with the ability to see depth or to judge distances based on the different angles presented to our two eyes. This facility is only useful out to about 20 feet (7 meters) or so. At distances greater than this the angles are too small for our eyes to resolve, and we use other clues to determine depth (perspective, other objects). This facility is easily fooled, as those tricked by optical illusions can attest. Many people exhibit poor depth perception. We can create computer displays that simulate (or should we say stimulate) this by providing two separate images, one for each eye. It is difficult to exactly match each person's eye geometry, however, and computer 3D stereo display systems often cause headaches as the eyes are forced into unnatural angles of convergence, resulting in muscle strain.

5.0 Abstractions

The concept of abstraction has made the jump from art into common computer usage. When computer engineers say abstraction, they mean creating a simple, common way of understanding a series of complex functions. An artist may use an abstraction to create a picture of pure thought—something without physical substance. We display designers borrow from these concepts to build what are commonly called metaphors—taking abstract concepts and making them into understandable objects. The common WIMPS interface used by X-windows takes our abstract concept of computer data organization and turns it into a desktop with file folders, files, and documents, which are easily understood and can be used without any knowledge of the complex data structures underlying them.

An example of this would be if I wanted to create a graphical abstraction of how some organization makes an decision—say how an air defense system (which is made up of officers and enlisted personnel, after all) decides when and how to attack our example of a rescue mission behind enemy lines. We could create a diagram with pipes showing the flow of information and valves showing who makes the decision, creating an easy-to-understand plumbing diagram that tells the whole story and can be understood at a glance.

6.0 Determining Critical Information

The single most important step in designing a good display is determining what data points are critical to the decision-making process and which ones are irrelevant. In our example of the search and rescue mission behind enemy lines, critical information might be where the enemy is located, how fast they can move, how far they can see or hear, where radar sites are located, and what terrain and trees are available for cover. The decision maker would also be concerned with how far and fast his rescue aircraft could fly, how long they would be at risk, and what emergency landing zones might be available. Sunset, sunrise, and weather information would also be critical data points that are missing from typical command displays.

7.0 Cognitive Overhead

I coined the term cognitive overhead to mean the amount of extra mental work that a decision maker has to do in order to understand a display or to turn the graphics and text into a mental picture of the situation. This term came from practical experience with the command and control centers of Navy ships, where I was helping study the design of ship self-defense systems. Each sensor system aboard the ship had its own display system that was designed in complete isolation from the other systems and therefore had its own particular symbology, interface, orientation, and trained operator. The captain of the ship had to go from display to display and integrate in his or her head what the overall situation was. The tragedy of the USS *Vincennes* shooting down an Iranian airliner directly illustrated the poor data fusion of the command and control displays. We have all seen movies where the sailors aboard a ship are transferring data from various radar and sonar displays and drawing them on Plexiglas boards with a grease pencil to create an overall situation display. Surely we can do better than that!

So then, a good display should strive to minimize this extra mental effort. How would you do that? Look at the steps necessary to make decisions based on the display, and try to incorporate as many as possible into the display. For example, if determining the relative bearing of an incoming aircraft is critical, adding a compass rose under the aircraft's icon makes that a simple determination. A normal practice is to mix displays with "north is up" with "my heading is up" orientation. Use common orientations for all displays, or integrate displays into a big picture overview.

8.0 Signal-to-Noise Ratio

While the term signal-to-noise ratio comes from radio, it has equal applicability to our work in VR. We wish to separate the pixels representing data and information from the borders, decorations, textures, and other pixels that might make the presentation more aesthetic but do not add information necessary for decision making. The typical example is the photo-realistic out-the-window view with camouflaged vehicles driving over terrain draped with imagery. It is not important to the decision maker what the vehicles look like—it is what they do that is important. Likewise, the side (friendly, enemy, neutral) needs to be clearly indicated. So it may be necessary to exaggerate the distinguishing characteristics of certain vehicles to make their function clearly visible. For example, the vehicle that launches a particular surface to air missile looks like a big truck with a boxy trailer. For a decision-support display, we would replace that with a more recognizable missile with fins on a stand with wheels, clearly showing the purpose of this object (a mobile SAM site). The resulting rendering, while nonrealistic, increases the signal-to-noise ratio and makes data clear and understandable.

9.0 VR Displays for Decision Makers

One hypothesis that I am proposing for this paper is that it is a mistake to think that one display can fulfill all needs for all situations all the time. I propose to look at the decision makers, try to determine how they would intuitively want to look at their data, and design around that. For example, the decision makers we are currently working with deal a lot with maps, which are normally spread out on a table, horizontally. Another example, again seen often in movies about the subject, is the giant map laid out on the floor, where groups of aides push markers representing aircraft or ships around with big sticks. The technical term for these displays is bird tables (from "bird's eye view"). In the U.S., these are also referred to as sand tables from the practice of days gone past of sculpting terrain from sand on tables and using toy soldiers to plan battles. We might then create an electronic or digital sand table to reproduce this.

Another feature that decision makers in my area like is the ability to annotate the maps. Traditionally, this has been done with grease pencils on plastic overlays on maps. The 21st century equivalent would be a light pen or laser pointer that would have the same effect. It is also important that the users be able to create alternative plans and overlays and be able to save and retrieve them easily.

The point is that the designers of displays must carefully tailor our display ideas to the user's work and process and not try to fit our round solutions into their square problems.

10.0 Guidelines for Designers

Now I have the difficult task of trying to distill the ideas in this paper into some simple suggestions (not rules) that may assist the designer in creating usable displays to support critical decision making. I welcome, and indeed challenge, readers to add their own wisdom to create additional guidelines.

1. Determine what information is critical to decision making.
2. Display that data clearly.
3. Save realistic rendering for simulators, not for its own sake.
4. Minimize cognitive overhead needed to extract data from the display—if more supporting data is needed, include it.
5. Maximize the signal-to-noise ratio. Watch overpowering critical data points with bright backgrounds, photo textures, or map data.
6. Present data in clear orientations, and keep them consistent.
7. Look for displays that work with the user's normal workflow or improve upon it.
8. Don't try to make one display do everything.

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