Artificial Realities as Data Visualization Environments: Problems and Prospects

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Preface

In the popular press, artificial reality sounds wonderful. It's just like real reality, except better: a wave of the hand, a simple, natural gesture, and a new world opens up. No longer will users have to struggle with arcane and cumbersome user interfaces. Everything will be intuitive. Unfortunately, it's really not that simple. A recurring theme of this chapter is that while some aspects of artificial realities are easy and natural to use, other aspects present a host of new design problems.

One of the critical problems we face is accessing, managing, interpreting, and sharing the ever-increasing amounts of information that are being generated by our society. Artificial reality environments, in tandem with a number of other developments, are likely to have an immense impact on our ability to deal with information. I begin by providing some background, and describing ways in which artificial realities can enable us to deal more effectively with data. However, I want to avoid presenting a sugar-coated picture of artificial reality: as it stands today, artificial reality has far to go before it becomes a useful tool. To this end, I describe my experience using one of today's artificial reality systems to visualize data, paying particular attention to the various problems that arose. Once we understand where artificial reality is today, I turn to the future, discussing potential application scenarios, as well as the some of the problems they

raise. I conclude by focusing on artificial realities as environments which support interaction, and suggest that there is much knowledge from the domains of architecture and urban design which might be profitably applied to the design of artificial realities. Ultimately, work from a variety of design disciplines will be necessary if artificial reality is to evolve from a laboratory curiosity and expensive form of entertainment into an environment which can be of use to those who do not love technology for its own sake.

Data and Visualization

Data

When I speak of data, I mean not only data generated by scientific experiments, but any sort of information ranging from news stories to maps to stock quotes. Regardless of the definition, no one will dispute that overwhelming amounts of data are being generated every day. Much of what we read in newspapers and magazines is already available in electronic form, and there are thousands of databases of specialized information ranging from legal cases to potato futures. Non-textual data is also abundant. NASA has been collecting immense stores of digital images of the solar system for decades. The Human Genome project, the ambitious attempt to decode human DNA, is generating massive amounts of data. Earth-orbiting satellites transmit detailed images of the earth’s surface, enabling digital maps of the earth’s surface to be updated every 16 to 20 days. Closer to home, the U. S. Census bureau has released its TIGER (Topologically Integrated Geographic Encoding and Referencing) system, a digitized map of the entire U. S., down the level of individual streets. Market research firms and credit bureaus have been collecting demographic information for decades, and new products -- collectively known as Geographic Information Systems -- are springing up to support the integration of geographic and demographic information. There is no sign that this torrent of data will do anything but accelerate.

But all this data is of little use unless people can easily get at it. Fortunately, there are several trends that promise to lay the foundations for more effective use of data. Increasing amounts of data are being generated in digital, and thus computer-accessible, form. More and more data is becoming accessible through on-line databases. The recent passage of the High Performance Computing and Communications Initiative by the U. S. Congress will facilitate the development of the National Research and Education Network (NREN), a gigabit network that will make it possible to transport and share much more data much more quickly. While there is far to go before any person can readily access any information, we are taking steps in the right direction. This leads to the next question: once we have access to all this data, how are we to efficiently make use of it?

Visualization

Visualization is one of our best hopes for making more effective use of data. It is no coincidence that visual terms are used as a pervasive metaphor for understanding: ‘I see what you mean,’ ‘let me shed some light on the subject,’ ‘let’s take a closer look at that argument,’ ‘I have a different view,’ as well as terms such as insight, foresight and overview. Although visualization is often associated with the colorful representations of exotic scientific phenomena such as the galactic jets, enzymes, or brain scans which frequently adorn the covers of magazines, it is important to recognize that visualization can be usefully applied to the most prosaic data. The goal of visualization is to represent data in ways that make it perceptible, and thus able to engage human sensory systems. There are three, non-exclusive ways in which visualization can help us in using and interpreting data: selective emphasis; transformation; and contextualization.

Selective emphasis allows the detection of previously hidden patterns by highlighting certain features of the data and suppressing others. One example, described in Perlman and Erickson (1983), is a visualization program which can assist technical writers in eliminating long, complicated sentences from their documentation. The program is quite simple: it reads a document and produces a 'punctuation graph' by leaving the punctuation intact, replacing "and" with "&", other words with underscore characters, and beginning each sentence on its own line (see figure 1 for a partial example).

This representation, by selectively emphasizing punctuation, makes it easy for writers to analyze their work. Writers can look over a punctuation graph of a document to see whether they have adhered to such basic rules as 'vary the length of sentences'. They can also pick out potentially over-complex sentences (sentence 6), and recognize such common patterns as lists (sentence 2) much more easily than when looking at a full text representation.

1. _ _ _ _, _ _ _ _ _ .
2. _ _ _ _ _ _ _ : _ _ , _ _ _ , _ _ , _ _, & _ _ _ _ _ .
3. _ _ _ _ _ _ _ _ _ & _ _ _ .
4. _ _ _ _ .
5. _ , _ _ _ _ _ .
6. _ _ _ _ ; _ - _ _ _ _ -- _ _ - _ _ _ _ _ _ -- _ _ _ & _ _, _ _ ; _ _ _.

FIGURE 1. A punctuation graph of a paragraph. Selective emphasis of punctuation allows the writer to detect potentially over-complex sentences such as #6, as well as recognize familiar patterns (e.g., the list in #2).

Another way in which visualization can facilitate the interpretation of data is through transformation. Non-visual data can be transformed into a visual image by mapping its values into visual characteristics. Data which is thus represented can draw upon our extensive experience in interpreting such visual images and on our facility at pattern recognition. An example of the power of visually transforming data may be seen by trying to solve the following problem:

One morning a monk awoke and decided to make a pilgrimage to the top of a nearby mountain. At 6 am he began climbing a path that led from the foot of the mountain to its peak. After spending the night on the mountain top, he arose at 6am and began retracing his steps, following the path back to its beginning. The question: Was there any point on the path where the monk was at the same time on each day?

Most people find this problem difficult to solve if they try to think about it verbally or mathematically. However, if the problem is transformed into visual terms, it is easy to solve. Draw a graph, with the vertical access representing distance along the path from the bottom, and the horizontal axis being the time of day, beginning with 6am. The journey of the monk up the mountain, regardless of its speed, is represented by a continuous line from the lower left towards the upper right; the line for journey back down is from the upper left towards the lower right: clearly the lines must necessarily cross at some point, which represents the position on the path the monk was at on the same time each day (figure 2).

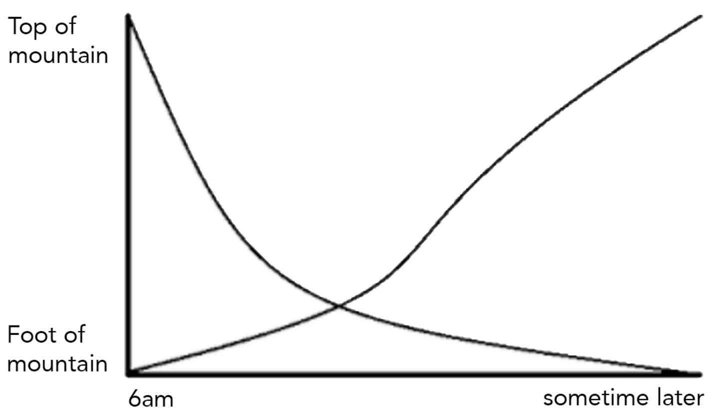

FIGURE 2. The monk on the mountain problem. The problem becomes easy to solve when it is transformed into visual terms: regardless of the speed of travel, or of when the monk begins, it is clear that the two lines always intersect at some point.

The third way in which visualization may facilitate the effective use of data is through contextualization, that is, by providing a visual context or framework within which the data may be displayed. Imagine a system that provided real time access to news stories coming across the UPI wire. One possible representation is to simply display a list in which each story is represented by an icon and a line of text containing its title and point of origin. However, if stories are coming in rapidly, it is likely that the user will get overwhelmed by the quantity of information. An alternative representation is to position the stories on a world map, locating them according to their point of origin. Such a representation would enable users to deal more effectively with the influx of data. Stories originating in particular areas could be focused on; patterns of activity, such as a flurry of new stories appearing in an unusual place, might signal newsworthy events such as earthquakes, riots, or other catastrophes. Note that the representation of each story is unchanged; the value added arises from providing a visual context within which the data can be interpreted.

Although each of the examples has focused on one way in which visualization assists us in interpreting data, most visualizations work in multiple ways. Transformation of data may facilitate selective emphasis or work hand in hand with contextualization. Geographic information systems are a burgeoning new application area, which support transformation and selective emphasis of data within a geographical framework. For example, a geographic information system could permit business owners to analyze possible sites for new locations. Such an analysis might involve displaying points representing households making over fifty thousand dollars a year on a city map showing major traffic patterns, exit ramps, natural patterns, and the locations of competitors. The reader interested in the finer points of data visualization will find many subtler examples in Edward Tufte's seminal work, Envisioning Information (1990).

Although there is much we do not understand about visualization -- deciding how to transform numeric data into a useful visual representation is still very much an art -- it is a very active area of research. Much recent work has been spurred by the development of scientific visualization, a new domain of computer science forming at the boundaries of computer graphics, supercomputing, and human computer interaction (see Friedhoff and Benzon, 1989, for a survey). Scientific visualization is aimed at creating tools for generating and manipulating visual representations of data from fields like astrophysics, molecular biology, geophysics, fluid dynamics, and so on. As a National Science Foundation report on Visualization in Scientific Computing, stated, “The ability of scientists to visualize complex computations and simulations is absolutely essential to insure the integrity of analyses, to provoke insights and to communicate those insights to others.” (McCormick, et. al., 1987). It is likely that tools and discoveries from scientific visualization will have broader applicability.

Finally, note that the word "visualization" is really too narrow. Perceptualization is probably more apropos, although it doesn't roll readily off the tongue. Sound and touch, as well as visual appearance, may be profitably used to represent data. For example, Gaver, Smith, and O’Shea (1991) have demonstrated the people can use changes in ‘textures’ of sound to detect problems in a computer simulation of a bottling plant. Similarly, Brooks and his colleagues (Brooks, 1988) have used force feedback to represent bump and electrostatic forces in a system for exploring molecular docking. Users of the system can feel resistance as they try to maneuver a substrate molecule into the active site of a protein. Although the use of sonic and force feedback by visualization systems has lagged behind visual feedback, rapid strides are being made in both domains. The key to ‘visualization’ is in representing information in ways that can engage any of our sensory systems and so draw upon our vast experience in organizing and interpreting sensory input.

Artificial Reality

In my view, artificial reality is not a radically new thing; rather it differs only in degree from previous systems. A system takes on the aura of artificial reality as it exhibits an increasingly tight coupling between an expanded range of input and a broader range of feedback options. In conventional graphic user interfaces, users are restricted to a keyboard and a single-point input device like a mouse, with visual feedback, and generally no sonic feedback beyond that of a system beep or two. Typically, the user can only move one thing at a time, and that only in two dimensions; to move an item in a third dimension, or to rotate it, the user must go into a different mode.

New position-sensitive interface devices like computer-interfaced gloves and head-mounted displays greatly increase the coupling between user input and system feedback: motion of the hand, the head, and the body can be tracked and used to adjust the view and other system characteristics appropriately. Alternatively, more conventional input devices such as 3-D mice or six-degree of freedom ‘space balls’ may be used to broaden input bandwidth, or input devices may be removed from the body altogether, with remote edge-detecting cameras interpreting hand and body movement taking their place. Similarly, an increase in the range of feedback options -- 3-D graphics, perhaps augmented with 3-D sound and force feedback -- especially when tightly coupled with increased input bandwidth, also moves a system towards the artificial reality arena.

Artificial Reality and Visualization

Artificial reality can enhance visualization in several ways. Most immediately, artificial reality makes it easier to interact with visualizations. In conventional computer systems interacting with data, particularly 3-D data, is often difficult. How is the user to obliquely rotate a 3-D object given only a 2-D image and a mouse? How is the user to change the scale of data? How is the user to change the perspective from which the data is viewed? While a variety of methods exist, they range from the unintuitive (obscure commands and icons) to the cumbersome (knob boxes for rotating each separate axis). Such methods require all but the most expert users to stop thinking about the data, and to instead think about how to use the interface to manipulate the data.

In an artificial reality where the user has a presence in a 3-D space, there are more natural possibilities for manipulating 3-D images. Images can be rotated in the same way as a corresponding object in the real world: by grabbing it, and moving the hands appropriately. Users can change their viewpoints simply by walking around the object. And so on. The power of artificial reality is that it makes part of the interface invisible: the user no longer has to manipulate the interface to manipulate the data; the user need only manipulate the data directly.

There are two other ways in which artificial realities can enhance visualization. First, artificial realities allow multiple users to simultaneously interact with the same visualization. Several people looking at a visualization (or listening to it, or touching it) can do so from precisely the same perspective, thus easing problems of reference. Second, although this benefit lies somewhat farther out in the future, artificial realities can serve as environments for supporting human-human interaction. After all, visualization is not an end in itself--it's just a tool for interpreting data. Ultimately, whether the data is scientific or mundane, it is being interpreted so that it may be communicated to others. Before pursuing this in more depth, it is best to look at an example of artificial reality as it is today, and examine its benefits and shortcomings as a visualization environment.

An Artificial Reality for Visualizing the Brain

In the fall of 1989, a colleague and I visited a leading supplier of artificial reality interface hardware and conducted an informal experiment with a headmounted display and computer interfaced glove. The goal was to assess the value of artificial realities for interactive scientific visualization (see Mercurio & Erickson, 1990, for a full account). Although we had previously tried similar systems, our trials were with relatively simple data sets (typically rooms or buildings) created by vendors for demonstrations. We felt a more telling evaluation would be to use an existing data set created for scientific use, a 3-D contour map of a human brain (Livingston, 1976). While the data set had to be simplified by two orders of magnitude to be displayed within the prototype artificial reality system we were using, it retained three characteristics not usually found in demonstration artificial realities: it was extremely complex, it was opaque, and it lacked expanses of empty space.

The artificial reality system allowed its users to navigate through the data set in two ways, by moving physically, and by gesture-controlled virtual movement. Physical movement was quite simple: as the user's body moved in physical space, the image displayed by the head-mounted display was appropriately adjusted. As the user walked toward the image of the brain, it would get bigger, generating the illusion that the user was walking toward an image of a constant size. The user could walk right up to the brain, pass through its surface, and could walk around inside it. To view the brain from a different perspective, the user could walk around it, or crouch to view its underside. Users also needed to move virtually through the data (without corresponding physical movement), because the constraints of the physical environment -- walls and the length of cords tethering interface devices to computers -- could prevent the user from approaching parts of the model. Virtual movement was by gesture-controlled ‘flying.’ Pointing with a forefinger allowed a user to 'fly' forward; pointing with two fingers permitted backwards flight. The system also displayed an image of a hand whenever the user’s gloved hand was in his 'virtual field of vision' (what would have been his field of vision had the head-mounted display not occluded the view of the real world). This permitted the user to reach out and grasp virtual objects, which could then be manipulated by moving the arm or body.

Experiencing the Brain Visualization. When users donned the head gear and 'entered' the visualization environment, they could see a brain floating in otherwise empty space. Since the brain had been scaled up in size by a factor of ten, it was initially difficult to tell how far away the brain was, and thus whether a few steps would take the user into the brain, or whether it would be necessary to move virtually to enter it. The only other image that was present, was the image of a hand, which appeared whenever the user’s gloved hand passed in front of his face.

Although the resolution was poor and the image boxy, the stereopsis and interactivity greatly enhanced the reality of the brain image. The correspondence between real-world movement and the movement with respect to the data set was accurate and natural; there was no need to consciously consider which physical actions were required to achieve which effects. Virtual movement through the data set required a bit more thought. However, with a few minutes of practice, both users were able to effectively 'fly' through the data, in spite of the problems noted below.

Interface Problems. There were a number of minor pragmatic and technical problems. The headgear was heavy, the cable that tethered the user to the equipment could get wrapped around the legs, the system would fail if the user got too close to the position tracking receiver, and in spite of the simplified data set, the updating of the display in synchrony with head movements was a bit jerky. In addition, users required constant supervision to avoid walking into equipment, walls, and too close to or far from the position tracking receiver. Some of these problems have been addressed in the current version of the system, and all of them likely to be ameliorated by increases in the power and portability of the technology.

There were other problems that are more thought provoking. The system used gestures to control virtual movement through the data space. The pointing gesture used to fly was a relatively natural one. Both users accidentally flew several times when trying to point at something while describing it. (Even though the users were aware that no one else could see what they were pointing at, it was still natural to point.) Although users quickly learned that they ought not point at things, this was easier to realize than to achieve. At moments of particular interest or excitement, the user would forget, point, and go flying off, losing sight of the area of interest. The flying gesture also mapped into habitual gestures (e.g., placing a finger on the chin), again causing inadvertent flight.
An obvious solution to the 'accidental flight' problem is to make the flying gesture a bit less common and natural. However, this creates a new problem. With only a few, natural gestures, learning is not a problem; but as the number of gestures increases, and as they are made ‘narrower’ to prevent accidental invocation, they become more difficult to learn and remember. Gestures are particularly difficult because they can vary along so many dimensions. If a user makes a gesture which fails to work as expected, there are many possibilities for what went wrong. A gesture may vary in its starting position, size, speed, form, and ending position, as well as in its position relative to objects in the virtual environment. There is no magic solution here: the more natural a gesture is, and the more variations the system will tolerate in recognizing it, the easier it will be to do accidentally; the less natural a gesture is, and the more stringent the system is in recognizing it, the more difficult the gesture will be to perform.

Another problem is the use of ‘flying’ as a metaphor for virtual movement. While 'flying' is a provocative and engaging concept, the fact is that it doesn’t feel like flying. When the user is flying toward an object, it feels instead as though the object is approaching the user. Presumably this is because users have kinesthetic feedback regarding whether or not their bodies are moving. And although users can suspend their disbelief and ignore their kinesthetic feedback, in a very short time they'll be paying attention to such feedback as they walk around and through the object, or grab it to reposition it. A system that requires users to alternate between attending and not attending to a particular channel of feedback is probably not a good idea.

Another difficulty with ‘flying’ is that people don’t actually know how to fly. Flying suggests nothing about what gesture should be used to do it, and it suggests nothing about how to control speed or direction. Since the purpose of an interface metaphor is to leverage people’s understanding of the real thing to facilitate their use of the interface, flying is not a particularly apt metaphor. An example of a better metaphor is pushing and pulling. Besides avoiding the inconsistent kinesthetic feedback, ‘pushing-pulling’ also suggests natural gestures for doing it: palm open and fingers together for pushing; clenched fingers for pulling. The direction and speed of the push or pull obviously determine the direction and speed of the motion imparted to the object. As in the physical world, objects might be given momentum, so that an object would coast until it was grabbed. The pushing-pulling metaphor also has the virtue of extensibility: with two-handed input, the user could stretch or compress the data set, thus providing a natural way to scale the image as well. The point here is not that 'pushing-pulling' is the best metaphor for virtual movement; other investigators have suggested a variety of promising metaphors (e.g., Brooks, 1988). Rather, the point is that metaphors need to be carefully chosen so as to make the non-obvious parts of a system understandable to the system's users (see Erickson, 1990).

A final problem was due to the data set itself: in contrast to the landscapes or buildings generally favored for demonstrations of artificial reality, this data set was dense and opaque. It is one thing to fly through an architectural space, or over a 3-D map, but quite another to move through an opaque brain. This was not a major problem because the brain structures had been color coded ahead of time, and the users were familiar with their relative sizes and forms. Nevertheless, had the brain data set had more detail, or had the users been unfamiliar with neuroanatomy, orientation and navigation difficulties could have made use of the data set impossible. Making the brain structures translucent would help, but it would not solve the density problem: users would see a montage of superimposed colored shapes. It would probably be necessary to add a map-like overview which provided a third-person view of the user's position in the data space.

Summary. In this section we've looked at the use of an artificial reality as a visualization environment. As suggested, artificial reality did enhance the ease of interacting with the visualization. The users were able to interact quickly and naturally with the data, with only a very short period of trial and error. However, even in an environment that consisted only of one coherent data set, with a small number of commands, a number of problems occurred. Gestures used as a means of control were sufficiently natural that commands were unintentionally triggered. There is no ideal solution for this problem: the narrower a gesture is made, in an effort to prevent accidental invocation, the less natural, memorable, and learnable it becomes. It was also noted that the 'flying' metaphor for virtual movement may not be the most apt, in that it doesn't fit either the user's experience, or provide guidance in how to navigate in the artificial environment. Finally, it was noted that although the direct, first person experience is of clear importance and value, there is still a need for abstract, third person representations to prevent users from becoming lost or disoriented in virtual space.

These problems are raised not as insurmountable obstacles--clearly, there are many possible solutions--but to make the oft-neglected point that virtual realities do not eliminate the difficult problem of user interface design, but rather raise new design issues. This point is worth keeping in mind as we look at possible directions for the development of visualization environments.

Artificial Reality Tomorrow: Some Visualization Scenarios

In this section I present three scenarios involving visualization and artificial reality. The goal is to explore a number of directions in which artificial reality and visualization may evolve, while remaining aware of the problems that will need to be addressed.

The following scenarios are based on assumptions that appear reasonably likely in the next decade:

- vastly increased computational power, disk space, data transmission speed, and graphics resolution
- computer support for multiple users from the level of the operating system to the human interface
- the ability to move about unencumbered by heavy displays, cables, or limitations in transmission distance.

Probably the most radical assumption embodied in the following scenarios is that the variety of data depicted will be cheaply and quickly accessible, and will be easily integrated with data from different sources; this assumption is radical only in that it requires changes in infrastructure and the development of standards which may take some time to achieve.

The Brain, II

Let's begin by expanding on the example of the brain visualization just described. An obvious use for this artificial reality environment is in planning a surgical operation. Imagine a team of neurosurgeons donning headgear and gloves and entering into the brain artificial reality to consult on removal of a brain tumor. The surgeons could explore various options, rotating, scaling, and showing cross sections of the brain image as appropriate. Perhaps each surgeon has a pointer to highlight areas being discussed; perhaps the other surgeons can adopt the speaker's perspective and get precisely the same view (and sound, and feel) of the data; such an ability would greatly ease problems of reference.

This scenario suggests other desirable attributes of the brain artificial reality. It is likely that surgeons are going to want to take notes, perhaps by capturing and annotating particular views of the brain data set. If there is a neurosurgery database of other cases, it would be valuable to superimpose different brain images to find those with similar tumors. Once similar cases are identified, proposed procedures can be evaluated in the context of success or failure of previous operations. As has been suggested, if the brain images are of sufficiently high resolution, navigation through opaque or even translucent images may be quite difficult. It would be desirable to have a means of traversing particular paths or jumping to particular locations: finding a small structure like the red nucleus might be quite time consuming in a high-resolution brain database.

While it is easy to think about the possibilities of such a scenario, it is wise to remain aware of the various problems that will arise in such an environment. The real world provides physical constraints which simplify interactions; but in an artificial reality, if two surgeons grab the brain and move it in different directions, what should happen? Should it tear, stretch, or should one surgeon be given automatic priority? While operating in the artificial reality will be reasonably simple, as long as the operations have real world analogs (e.g., rotating and translating the brain), many of the operations that make the artificial reality such a powerful tool will lack analogs. Methods for allowing users to adopt identical viewpoints, isolating neuroanatomical structures for independent observation, and jumping to particular points in a large data space will have to be invented, and when the number of such non-analogous operations becomes large, the user interface problem becomes non-trivial. Some of these functions can be represented as analogs of real world artifacts: a map for navigating the brain, a pointer for highlighting portions of the data set, recording devices and annotation tools for the students. But even here, there will still be a need for users to somehow obtain the artifacts when they're not present, and to store them when they are no longer needed.

Satellites and Wheat Fields

An interesting experiment involving satellite-based remote sensing and the control of semi-automated, position-sensing fertilizer spreaders has been taking place in Montana (Larsen, Tyler, & Nielsen, G. A., 1991; Petersen,1991). The experiment involves the analysis of satellite images of wheat fields for minute changes in color that indicate particular types of nutrient deficiencies in the wheat. On the ground, semi-automated fertilizer spreaders use global positioning satellite technology to determine their positions within the wheat fields, and use the information on the particular nutrient deficiencies for their current position to control the mix of nutrients in the fertilizer applied to that part of the field. It is hoped that this will result in increased quantities of wheat (better nutrition, thus higher yields), decreased cost of production (less fertilizer is used), and decreased environment pollution (from runoff of excess fertilizer).

At first glance, this seems a long way from artificial reality: no head-mounted display, no gloves, no user. Nevertheless, there are several elements of an artificial reality. The artificial reality environment is constructed from the satellite image; the position of the fertilizer spreader rather than the user is tracked; and, rather than updating a display image based on the user's position, the fertilizer mix is adjusted relative to the spreader's position. True there is no visual artificial reality, nor user to perceive it, but it is not much of a step to imagine such a system.

An artificial reality based upon remotely sensed, satellite gathered imagery would have a variety of uses. Remote sensing can detect a variety of environmental conditions, ranging from drought and disease, to nutritional deficiency, to the paths of animal migrations. Processing and transformation of the image could make these conditions readily detectable, particularly given the unmatched facility of humans at pattern detection. Being able to enter an artificial reality and get an overview of a large land area could be of considerable use in managing farm and range land, controlling the spread of disease, or making decisions about resource allocation in times of drought or other environmental crises. While ranchers could probably not count their cows or look for fence breaks, since the current resolution of satellite images is limited to about four meters, they could still do quite a lot. Another limitation is that satellite flight paths provide complete coverage of the entire earth's surface only every 16 to 20 days. Thus, one would not necessarily be able to track a fire or a rapidly spreading disease. On the other hand, a much more frequently updated image could be generated from aerial photos of a particular area, albeit probably at a greater cost. Obviously, aerial photographs would also offer better resolution, so that ranchers who cared could, in fact, count their cows.

Again, as with the brain visualization environment, there are a number of design problems. If such an artificial reality consisted of imagery derived from a mix of aerial and satellite photographs, how are the differences in scale to be represented? The images will also have been taken at different times, something which may be crucial in certain analyses--how is that to be represented? An image transformed to make evidence of a crop blight visible may not show evidence of drought or a Caribou migration--how will users be allowed to switch between different views or image transformations, or even find out what different transformations are possible? Will artificial realities come with pop-up menus?

Site Simulation

'Location, location, location,' thus goes the old saw about what's important for a business. Today business people in search of a new site can superimpose demographic information on top of geographic information: commercially available systems and data allow users to get answers to questions like, 'Show me married couples with children who live on a major road within five miles of the site, and have an income over $40,000.'

Translate such functionality into an artificial reality environment, combine it with satellite imagery or aerial photography, and the user can not only make decisions in terms of the demographics, but can take the physical appearance of the site into account. Add basic information about the surrounding buildings and the location and orientation of the site, and the user can see whether a cafe's patio will get full sun in the winter. Combine data about traffic flow rates and the type of construction of the building with the ability to do acoustic modeling, and the user can evaluate the impact of the traffic noise at rush hour. Not only can the owner do all this, but financial backers, employees, and consultants can also evaluate and confer on the sites being considered. Assume a high bandwidth optical network, and various parties needn't travel to do any of this.

As before, new problems arise as new functionality is added. Simulations and modeling capacities require means of controlling them. It seems unlikely that most users will have either the knowledge or the inclination to simulate the effect of the sun during winter by shrinking the artificial reality way down, and adjusting the tilt of the earth.

Artificial Reality as an Environment: Design for Interaction

The scenarios described in the previous section were focused around visualization. People were depicted as entering artificial reality environments to view, interpret, interact with, and operate upon data. However, I believe that artificial reality environments will become more than sophisticated, interactive, 3-D movie theaters. The real promise of artificial reality is that it can provide a framework for human-human interaction, a stimulating and engaging environment that people will enter for a variety of reasons and purposes. Yet, with the exception of the seminal work of Myron Krueger and his colleagues (Krueger, 1991), most designers of artificial reality systems have neglected the question of how to make an artificial reality a rich and engaging place.

Although there is no fixed set of rules for achieving this, we are not without useful knowledge. There is significant body of work by urban designers, landscape architects, and architectural theorists, on how environments affect the interactions that occur within their bounds. In what follows, I describe some ways in which environments can promote interaction, and suggest some guidelines, and warning signs, that designers of artificial realities may do well to heed.

Christopher Alexander, noted architect and design theorist, writes of the corner of Hearst and Euclid, in Berkeley, in the context of discussing the design of cities (Alexander, 1988). It is quite an ordinary corner: sidewalks, a stoplight, a drugstore, and a news rack in the entrance to the drugstore. As pedestrians wait for the light to change, they browse the news rack, and perhaps buy a paper: traffic flows, coins move from pockets to the news rack's coin slot, and papers from rack to hands. In a real sense, the traffic light helps sell papers. Alexander argues that the corner functions as a coherent, interactive system, a unit of the city.

It is instructive to note that what makes the news rack-stoplight system function effectively is a variety of constraints. Most obviously, physical constraints are operative: pedestrians don't want to get run over crossing against the light, and most would prefer to avoid a cross street dash. But there are also social constraints. While flagrant violations of traffic lights by pedestrians are not uncommon, neither is it uncommon to watch a pedestrian wait patiently for a light when no cars are in sight. Such social constraints are the reason, although it is a much subtler effect, it is accurate to say that the news rack helps people obey the traffic light: if there is something of interest, people are less likely to transgress the relatively weak social constraints on obeying traffic lights. From this description, I propose the following conjecture: constraints generate interactions. Will designers of artificial realities want to build in constraints? Perhaps. However, people who have struggled to realize the potentials of a technology are often unwilling to place artificial constraints upon it, regardless of their utility.

Note that constraints may have non-local effects: for example, the effects of the news rack-traffic light system are not simply confined to the system itself. The news rack, situated in the entrance to a drugstore, overlaps with another system: the news rack-entrance-drugstore system. William Whyte, a researcher of interactions in urban spaces, notes that entrances which contain things of interest are more likely to draw people into a store, even though the things of interest may be totally unrelated to the content of store. "Pauses lead to successive pauses. When a person has stopped to look at one attraction, he is more likely to be responsive to other stimuli in the same vicinity." Pedestrians who pause to look at the news may see something of interest within the store, or recall a need for some sundry item, and be drawn within, into yet another system. Whyte also points out that traffic lights, because they cause pedestrians to bunch up, create a rhythm in the flow of people which may have an impact at some distance away. For example: "Window shoppers attract window shoppers. One person stops, another stops, then a couple. They attract others." (Whyte, 1990).

It is likely that other phenomena occur at the corner of Hearst and Euclid. Perhaps one stranger asks another if she has change for a dollar; or, a particularly outrageous headline may cause one pedestrian to exclaim in disgust, prompting a bystander to agree. Whyte calls this phenomenon triangulation, the tendency of an environment to encourage spontaneous interactions between strangers. Whyte has described examples of triangulation provoked by things ranging from inanimate objects (e.g., large sculptures in urban squares) to eccentric pedestrians. What sort of factors might encourage triangulation in an artificial reality?

Finally, it is worthwhile to note that even minor features of the physical environment can structure behavior in subtle ways. In a study of ATM use (Marine, 1990), it was observed that people waiting to use an automated teller station typically left an area of open space between the head of the line and the person using the machine. This in itself isn't surprising: entering a secret code to withdraw cash is an activity widely regarded as private. What is surprising is that the lines of users usually formed behind a crack in the pavement, which happened to be at a reasonable distance from the ATM. An obviously accidental environmental feature served to structure the behavior of ATM users. This type of phenomenon is apparently well known to building contractors. Don Norman, a cognitive scientist who has done extensive work on human interface design, reports that he recently had a section of his driveway re-poured, and that the contractor suggested putting in a colored border between the old and new sections. The contractor explained that it would act as a natural boundary that people who used the driveway to turn around in would not venture beyond. Norman lives on a dead-end, popular beach street, and gets about ten turnarounds a day: he reports that it works. On telling this story to his neighbor across the street, his neighbor reported being told the same thing by his contractor, and pointed to the cement entryway to his brick driveway (Norman, 1991).

It is instructive to speculate about what might happen if someone was to try to incorporate the corner of Hearst and Euclid into an artificial reality. It would be easy for designers to go wrong. There would be strong pressure for relaxing constraints in the artificial reality version of Hearst and Euclid. Clearly, no one really likes to wait for traffic lights. Why not just allow users (and our virtual autos on both streets) to magically traverse the intersection without regard for one another? On first glance this would seem to improve things. No need for pedestrians to wait. No need for a stop light. No need for cars to stop. No (virtual) traffic accidents. Very efficient. But it is an efficiency which is likely to lead to sterility. With an uninterrupted flow of pedestrians it is less likely that people would stop to browse and buy, or fall into a chance conversation. And if an automatic teller shows up (and you see them everywhere these days), will there be cracks in the pavement for people to line up behind?

I would like to close with a description that captures some of the richness and changeability that characterizes a good environment. Kevin Lynch, an environmental and urban design theorist, is writing of cities, but he might just as easily be writing of a large data set, or a well-designed artificial reality:

> *"At every instant, there is more than the eye can see, more than the ear can hear, a setting or a view waiting to be explored. Nothing is experienced by itself, but always in relation to its surroundings, the sequences of events leading up to it, the memory of past experiences.... While it may be stable in general outlines for some time, it is ever changing in detail. Only partial control can be exercised over its growth and form. There is no final result, only a continuous succession of phases."*

Kevin Lynch
The Image of the City

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