Immersive Virtual Reality for Scientific Visualiztion: A Progress Report

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By immersive virtual reality (IVR), I mean the sensory experience in which the participant feels him/herself immersed in a computer-generated world, including avatars of other participants and, potentially, subsets of his/her own physical environment. The user looks around using whole-body movement but may also navigate through the virtual world using a variety of other more or less realistic forms of locomotion and/or teleportation.

We can divide the set of applications for IVR (Immersive Virtual Reality) into problems that are ***human-scale*** (e.g., walk-throughs of buildings, refineries and chemical plants as well as massive, multi-player simulations such as battlefield simulations) and those that are ***non-human-scale*** (e.g., visualization of phenomena from nanoscale to cosmic scale). IVR has become a cost-effective technology for complex and expensive human-scale applications, such as the interior and exterior design of vehicles, walkthroughs of large mechanical constructions, and flight simulators. It is simply the most advanced part of the spectrum of digital design tools, and should be thought of as merely one of many digital design tools. The case for IVR for non-human-scale problems is much less clear thus far. In particular, there is considerable anecdotal evidence that it is easier to visualize complex scientific data in a IVR environment such as a CAVE™ than to use workstations with high resolution displays. However, we still need compelling scientific studies showing that task performance for actual scientific tasks is significantly improved in immersive environments. Meanwhile, IVR is proving cost-effective in such highly competitive and expensive fields as drug design, where “dry labs” are augmenting wet labs.

Why should IVR be an advantage for the tasks described above? First, it is easier to navigate by looking around, visually finding features and anomalies in large data sets, than it is to use a mouse. Second, multi-modal interaction is much higher bandwidth and much more natural than WIMP interaction. Third, relative size, position and angle judgments are easier to perform. Fourth, collaboration may be easier (for two, if not for more people) in immersive environments. Finally, immersive environments typically have more raw pixels than workstation surfaces and make better use of our peripheral vision. In particular, standing in the center of a CAVE™ allows you to see not only the front wall, but appreciable portions of at least side walls and the floor, effectively doubling or tripling the number of pixels in view. Tiling each wall of the CAVE™ allows even more pixels to be viewed (and cuts down on the problem of noticeable pixel granularity), a commensurate increase in cost and system complexity.

Barriers to wide-scale applicability of IVR.

Even though IVR has distinct advantages for human-scale applications and anecdotal support for non-human scale applications, there are still a number of barriers that must be overcome before it can attain wide-scale applicability. Below, I enumerate some of these problems, which, while they are being addressed by academic, government, and industrial labs, will still require many years of effort before they are satisfactorily resolved.

(1) ***Cost***. High quality IVR installations are expensive and require significant space. This results in the need for a return to single-facility time-sharing. Most knowledge workers prefer using an inferior tool in their workspace to having to walk to a facility that must be scheduled in advance. On a positive note, one of the main costs, that of the realtime renderer, will soon become a non-issue due to commoditization. In some respects, the Sony Playstation-2 will be the equal if not superior to the highest end SGI rendering pipe. The N-Vidia GeForce chip will also have amazing performance. The trick will be to gang these kinds of rendering engines together to create scalable graphics the way commodity CPUs have been ganged together to create scalable supercomputers. Interaction devices will continue to present a cost-bottleneck because there is no commoditization of them as yet.

(2) ***Spatio-temporal resolution.*** For output, we are still orders of magnitude from approaching the visual acuity of human beings. For input, devices have terrible resolution, repeatability and lag, not to mention terrible ergonomics.

(3) ***Lag.*** We are all painfully aware of various forms of cyber-sickness which are at least in part attributable to unacceptable lag. This is a systems problem,

starting with the devices and rippling into all software components involved in a round-trip, including our non-realtime operating systems and various queues and buffers. The problems of IVR at a distance, i.e., tele-immersion, involve unpredictable network delays and are therefore even more severe. Latency management through such techniques as QoS (quality of service) and AIM (area of interest management) is needed.

(4) ***(Tele-)collaboration.*** While there is a reasonable level of accomplishment in 2D CSCW tools (e.g., shared whiteboards, shared applications, and video conferencing), the IVR equivalent is still in its infancy, with no accepted standards.

(5) ***Design of virtual worlds.*** Crafting large-scale virtual worlds is still more an art than a science and requires enormous talent, dedication, and resources. I believe this is essentially design for a brand new medium and requires the interdisciplinary design team approach that links the combined expertise of specialists in: 1) perceptual, cognitive, and social sciences, 2) design arts (from industrial to graphic to user interface and Web design), 3) communication arts (advertising, storytelling in film and video), 4) device engineering and computer science.

(6) ***Software development environments.*** Despite the presence of some frameworks such as the CAVE™ libraries and higher level libraries built on top, implementing designs is still a huge effort. Only organizations with large resources can afford to expend the manpower required. We are a long way from being able to put sufficiently high level tools in the hands of mere mortals that they can craft interesting new applications and content, VRML/X3D and its equivalents notwithstanding.

(7) ***Differences between the real and virtual worlds.*** It is too easy, especially for computer scientists who know too little about how human beings work, to think that in the limit we can make the virtual world appear just like the real world. With neural implants, perhaps someday that will be true. Meanwhile, there are many unknown and potentially serious differences between the best we can create and the real world. For example, cyber-sickness has a number of things in common with motion sickness, but neither its causes or its manifestations are identical. We have almost no data on the effects of long-term immersion and on the possibly harmful primary or side effects. There is some data about negative training effects (e.g., for simulator training) but none for scientific visualization.

Summary

As Fred Brooks observes in his very useful survey, “What’s Real About Virtual Reality?” (*Computer Graphics and Applications*, November/ December, 1999), IVR has made, and will continue to make, steady progress. My main concern is that a lot of our field is focussed on technical issues without adequate factoring in of the human dimension. I certainly plead ‘guilty’ as an inadequately informed computer scientist. While others continue the hard work of making better devices and development environments, those of us interested in such questions as new interaction and navigation paradigms and new immersive visualization techniques should subject our supposed innovations to the ‘acid test’ of proper scientific validation through comparisons between traditional and the new technologies.