NEXT GENERATION IMMERSIVE VISUALIZATION ENVIRONMENTS

Frederic I. Parke, Ph.D.
College Station, Texas, USA
Visualization Sciences Program
Texas A&M University
parke@viz.tamu.edu

Abstract

This paper describes the initial development of ***next generation*** high performance, flexible, relatively inexpensive, spatially immersive visualization environments. The systems being developed have configurations utilizing polyhedral display surfaces with large numbers of identical modular components and networked visual computer clusters. For the most part, the computer clusters are created using off the shelf, relatively inexpensive, commodity items.

Current and near-future technologies and computational economics allow the development of better and more cost effective spatially immersive visualization systems. These systems promise better approximations to the ***ideal*** surrounding spherical display surface that presents very high resolution real-time wrap-around views of very complex data. The focus of this work is on exploring and evaluating this new class of systems to determine their practicality and effectiveness.

Resumen

Esta ponencia describe desarrollos iniciales en una nueva generación de espacios inmersibles de visualización que son flexibles, relativamente económicos y de alta performance. El sistema en desarrollo está configurado sobre la base de pantallas polihedricas modulares y agrupaciones de computadoras gráficas interconectadas en red. En gran parte, las agrupaciones de computadoras están constituidas por unidades comerciales de bajo costo.

Las tecnologías y economía computacional actual o de corto plazo permiten el desarrollo de entornos espaciales inmersibles a nivel económico. Estos sistemas prometen una mayor aproximación al ideal de pantallas esféricas de alta resolución, en tiempo real, mostrando la integridad de imágenes pertinentes a datos de alta complejidad. El centro de atención de este trabajo está en la exploración y evaluación de esta nueva clase de sistemas para así determinar su practicabilidad y efectibilidad.

Introduction

While fully immersive visualization facilities are still relatively rare, they are becoming key facilitators for many research and industrial projects. This paper describes the development of next generation high performance, flexible, relatively inexpensive, commodity based, spatially immersive visualization systems.

Immersive virtual environment systems fall into two categories - head mounted displays (HMDs) and spatially immersive displays (SIDs) such as the CAVE developed at the University of Illinois at Chicago (Cruz-Neira 1993). Head mounted displays are designed to present two separate views of the virtual environment to the user. One view is for the right eye and the other view is for the left eye. These two stereo views are fused by the viewer's perceptual system in the same way as right and left eye views of natural scenes. HUD systems must, in addition to computing the synthetic views, track the viewer's location and viewing orientation in the virtual world to create the correct right and left eye views (3Space 1987).

In SIDs, such as CAVE installations, the right and left head mounted displays are replaced by multiple rear projected displays that form the walls of an environment cube. CAVEs have at most six planar surfaces, each representing a large portion of the possible field of view. Each of the projection surfaces is usually driven from an expensive, high-end graphics system such as a SGI Onyx2 with one or more Infinite Reality$^{\text{TM}}$ graphics processors. Most CAVE installations have fewer than the maximum six display surfaces. Many of these systems use only three display surfaces - front, left, and right - and three image projectors. A fourth ***floor*** surface and a fourth projector utilizing a reflecting mirror are sometimes added. Only a few installations include all six display surfaces.

In spatially immersive systems, the projected displays are usually presented as time sequential stereo images. The user is required to wear special glasses that have liquid crystal shutters whose operation is synchronized to the display frame rate. As in the head mounted display version, the position and perhaps orientation of the viewer must be tracked if correct stereo views are to be projected on the CAVE walls.

An alternative to the active, time sequential, stereo presentation is a passive display approach that uses two projectors for each display screen – one for the right eye view and one for the left eye view.. Polarized filters are placed in front of each projector. These filters may have linear or circular (usually preferred) polarization. The projectors and filters are paired with opposite polarizations. The viewer also wears glasses with polarized lenses. These lenses are oriented so that the right eye sees only the right eye projected image while the left eye sees only the left eye image.

The *Ideal* System

It can be argued that the ***ideal*** spatially immersive environment would be one where the user is surrounded by a seamless spherical display surface that provides very high resolution, high update rate, 360 degree panoramic stereo views of extremely complex data. Current CAVE immersive environments are poor approximations to this ideal. Spherical domed immersive environments, requiring specialized optics, have been used for many years in flight training simulators (Reno 1989) and dodecahedron approximations to spherical projections have been developed (McCutchen 1991).

Current and near future technologies and computational economics allow the development of better and more cost effective spatially immersive visualization systems. The systems we are developing focus on configurations utilizing polyhedral display surfaces with large numbers of identical modular components and networked visual computer clusters. For the most part, the computer clusters are created using off the shelf, relatively inexpensive, commodity items.

Major Components

A spatially immersive visualization system consists of three major elements; the computational infrastructure, the surrounding display surfaces, and the viewer tracking and interaction elements. We are exploring new approaches to both the computational infrastructure and the display surface geometries to be used. We have not focused on the viewer tracking and interactive elements and expect to use the approaches in current practice.

Based on published performance benchmark results, collections of relatively low cost commodity visual systems compare very favorably in both cost and aggregate performance with the expensive high-end graphics systems typically used to support immersive systems. For example in late-1998, an entry level SGI Onyx2 Infinite Reality™ system with an approximate cost of $165,000 had a measured DX benchmark performance of about 42. A high-end Pentium III based workstation costing about $9,500 had a DX performance of about 20 (Viewperf 1998). The cost ratio was about 17 to 1 while the performance ratio was only about 2 to 1, yielding a 8 to 1 cost performance advantage for the commodity workstation. While one must be cautious when using such single measure comparisons, the trend was clear. During the past few years the advancement in commodity graphics workstation performance has been phenomenal (Viewperf 2002).

From a purely raw performance viewpoint the former high-end systems have clearly been overshadowed. They do still hold some advantage in terms of internal data bandwidth, the ability to handle extremely large image data sets and for their ability to carefully synchronize multiple display images.

A very compelling concept in recent years has been collections or clusters of commodity computers networked to form inexpensive powerful distributed parallel computing engines. Implementations of this concept often make use of extensions to the Linux operating system (Hekman 1997). One example of this is the Beowolf concept (Sterling 1999).

This very compelling concept has been extended in recent years into visual computing with the development of ***tiled*** display systems, primarily through work done at Princeton, Stanford and the Argonne National Laboratory (Hereld 2000). These systems make use of multiple computers, some utilizing commodity graphics cards, organized by software such as ***WireGL*** to support large, very high aggregate resolution displays (Humphreys 2001). Tiled displays are formed by dividing a two-dimensional display area into an array of adjacent regions or tiles. Each of these regions is projected by one of an array of image projectors. Each projector is driven by one of an interconnected array of commodity graphics systems.

We envision taking this approach one step further, creating next generation ***spatially immersive*** systems by arranging the display tiles or ***facets*** into a surrounding three-dimensional display surface and creating a commodity based computational architecture optimized to support such fully immersive systems. The computational infrastructure used is a ***visual computing*** extension of the commodity computer cluster concept which adds a high performance commodity graphics processor to each of the computational nodes. The result is a powerful parallel distributed immersive visualization system.

Having the visual computing distributed over a collection of processors allows innovation in the structure of the display surfaces. In our approach, the aggregate display surface is composed of many display faces or ***facets.*** In such configurations, each facet need only display a relatively small portion of the total virtual environment. The graphics computation needed for each facet falls within the capacity of today's, and certainly tomorrow's, high-end commodity graphics systems.

The envisioned faceted display elements could be arranged in a number of configurations. In fact, the display configurations could be tailored to meet specific applications. There are a number of polyhedral configurations whose faceted surfaces are good approximations to the ideal spherical display surface. Several of these are formed using many instances of only a single planar shape. These polyhedra require from 12 up to 60 or more planar faces (Holden 1971)(Wenninger 1971). Among these is the illustrated 24 facet Trapezoidal Icositetrahedra (figure 1). In addition to the three-dimensional form, the 24 identical facets are shown unfolded onto a plane.

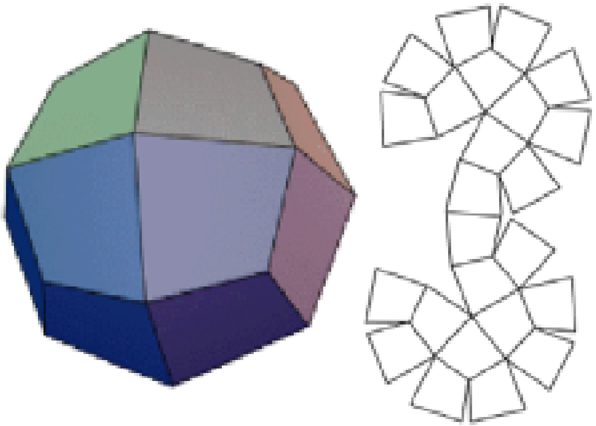


Fig 1 - The 24-facet Trapezoidal Icositetrahedra (also known as a Deltoidal Icositetrahedra)

The array of projectors needed for a display environment using the Trapezoidal Icositetrahedra form is shown (figure 2). Each of these projectors would be driven from its own graphics computer or computational node. The set of these 24 computational nodes would form a visually extended cluster system as discussed above. Recent reported work has demonstrated the feasibility of low cost projected stereo displays based on commodity graphics systems (Pape 2002).

An illustration of how such a display system might be located within a high ceiling building is shown (figure 3). The human figure shows the scale of this 5 meter diameter display structure. The building entrance shown is approximately 6 meters wide.

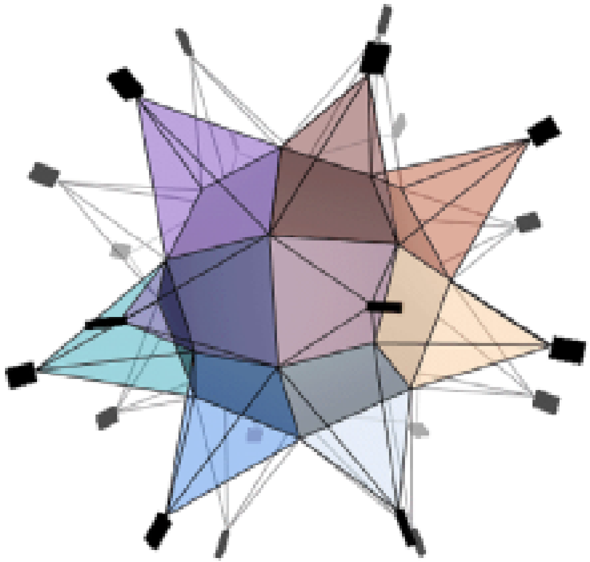


Fig 2 - A 24-facet immersive environment with projector positions indicated

Fig 3 - How a 24-facet immersive display structure might be located within a high ceiling room. The entrance shown is about 6 meters wide.

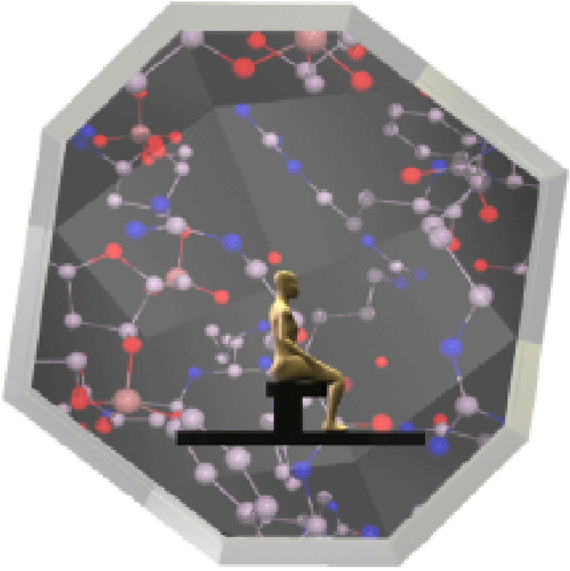
A cross-section view through the 24 facet structure is shown (figure 4). The human figure is included to give scale to the illustration and to show where the viewer would be located relative to the display surfaces. A set of simulated molecular images is shown projected on the display surfaces.

Objectives

We are focused on exploring and evaluating this new class of spatially immersive visualization systems. We are concerned with determining whether these new visualization environments are practical and effective.

The objectives in this research can be summarized as follow:

1) Explore and evaluate, at the conceptual level, possible geometric display structures and their implications for next generation spatially immersive environments.
2) Develop and evaluate software simulations of some of the more promising configurations identified in the conceptual phase.
3) Construct and evaluate operational prototype systems for the most promising geometric configurations.
4) Develop the software need to support simulated and operational prototype systems. Some of the issues to be addresses include; effective distribution of the graphic computation, dynamic data partitioning, synchronization of the displays, the required projection and image clipping algorithms, and automated display system calibration.
5) Develop a deeper understanding of the technical and effectiveness issues and trade-offs of these systems. How are technical considerations and user effectiveness related to geometric configuration?
6) Investigate the feasibility of mass replicated, modular, implementations of these systems.
7) Develop experimental designs to be used to evaluate prototype systems and experimentally measure the effectiveness of the systems.



.Fig 4 - A simulated cross-sectional view of a 5 meter diameter 24 facet immersive display environment.

We are currently in the conceptual development, initial simulation, and reduced-scale prototype phases of this project. Simulation and reduced-scale prototypes are being used to verify conceptual results prior to committing to the construction of full-scale prototype designs. Selection and development of the prototypes involves detailed simulation, physical structure design, supporting software design, physical fabrication and assembly, and software implementation. A three-fourths scale operational prototype of the 24-facet design is under construction.

Prototype evaluation will include both a technical evaluation of the system and an effectiveness evaluation. The technical evaluation will address issues such as computational complexity, computational loading, dynamic performance, and cost/performance.

Effectiveness Evaluation

In addition to the design and development of prototypes systems of this new class, we are concerned with the effectiveness of the immerse experiences they will provide. That is, do they empower the participant by affording new insights and deeper understandings, as well as by facilitating performance generally? It remains the case that relatively little published research has attempted to characterize either the immersive experience in a simulated environment or establish whether an enhanced sense of immersion results in either improved performance or less task effort (Nemire 1993).

Our approach to this evaluation will be to measure the concomitant cognitive, affective and physiological processes occurring during and after immersive experiences. Physiological activity such as heart rate and skin conductance have proven to be useful indicators of effort and attention in complex settings (Lang 1994), and the electromyographic measurement of facial muscle activity has proven to be a robust indicator of affective processes (Tassinary 1992). Continuous response measurement and secondary reaction time techniques have also proven to be useful measures of such ongoing psychological processes. Traditional measures of task performance, such as error rates, as well as somewhat novel measures of such performance, such as standardized performance trajectories, along with measures of the encoding, recall, or recognition of information, will also be explored to assess the cognitive concomitants of immersive experiences.

Expected Outcomes

We expect that this work will result in:

1) The development of an improved class of spatially immersive environments, including the construction and evaluation of several polyhedral prototypes utilizing low cost commodity components.
2) Specialized graphics software to support these prototypes.
3) System software to manage graphics data distribution, coordinated operation of many graphic computation nodes, display synchronization, and user interaction.
4) A much deeper understanding of the issues related to polyhedral immersive virtual environments.
5) Suggested designs for ***modular*** mass replicated immersive environments

This work has the potential to fundamentally influence the economics, availability, and pervasiveness of spatially immersive environments. It has the potential to influence the design, development, and viability of future spatially immersive systems. It may contribute to the availability of these environments across a wide range of users in many disciplines.

Future Directions

In addition to the 24 facet polyhedra used above to illustrate the basic concepts, there are many other polyhedra formed from larger numbers of identical planar shapes. Two of these, with 60 facets each, are the Deltoidal Hexecontahedron and the Pentagonal Hexecontahedron. These and polyhedra with even larger numbers of facets could be the basis for future spatially immersive systems. In fact, the larger the number of facets, the larger the number of visual computing nodes used. This increases the overall aggregate visual computational power of the system. It also decreases the size of each display facet for an environment of given size. More facets also result in a better approximation to the ideal spherical environment.

Faceted display configurations hold the promise of truly modular systems where the immersive environment is created by literally ***bolting*** together mass replicated modules. Each module would contain the required structural, computational, and display elements. The display elements of these modules might eventually be flat panel displays similar to those currently used in laptop computers.

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