CytoViz: an Artistic Mapping of Network Measurements as Living Organisms in a VR Application

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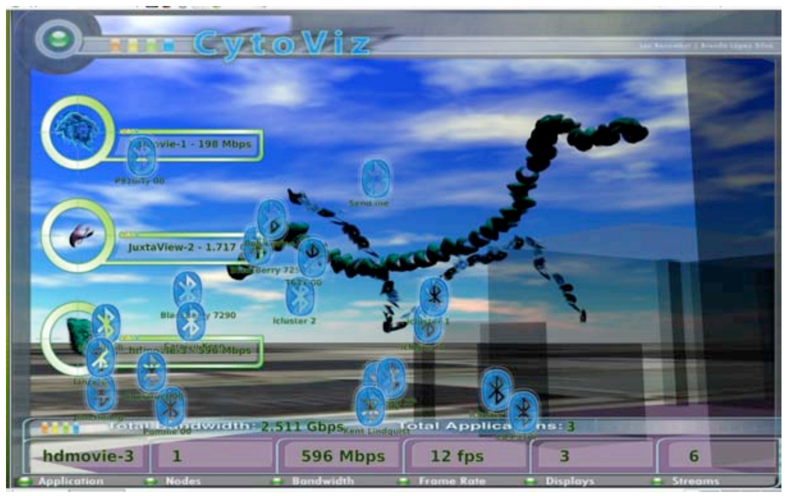
ABSTRACT

CytoViz is an artistic, real-time information visualization driven by statistical information gathered during gigabit network transfers to the Scalable Adaptive Graphical Environment (SAGE) at various events. Data streams are mapped to cellular organisms defining their structure and behavior as autonomous agents. Network bandwidth drives the growth of each entity and the latency defines its physics-based independent movements. The collection of entity is bound within the 3D representation of the local venue. This visual and animated metaphor allows the public to experience the complexity of high-speed network streams that are used in the scientific community.

Moreover, CytoViz displays the presence of discoverable Bluetooth devices carried by nearby persons. The concept is to generate an event-specific, real-time visualization that creates informational 3D patterns based on actual local presence. The observed Bluetooth traffic is put in opposition of the wide-area networking traffic by overlaying 2D animations on top of the 3D world. Each device is mapped to an animation fading over time while displaying the name of the detected device and its unique physical address.



CytoViz was publicly presented at two major international conferences in 2005 (iGrid2005 in San Diego, CA and SC05 in Seattle, WA).

Keywords: Visualization, network performance, Bluetooth, information visualization

1. INTRODUCTION

Network performance has been a subject of interest for mainly network administrators; the statistical data generated from network transfers is usually read in complex formats difficult to understand by a non-expert. Processing data for print and other static media may employ numerous designs, with digital and analog steps along the way; but the final product is dated at its release. In contrast, real-time visualization of data employs an active system capable of processing and rendering data as a dynamic presentation. Rather than displaying a single snapshot of data, real-time information visualization presents the data the moment it is queried. With today's powerful personal computers emerges the ability to observe both the immediate effects from data streams and to observe data behavior over a period of time.

Using computational data to generate computer graphic art work dates back at least three decades and has evolved into a discipline in itself—electronic visualization. The use of massive scientific datasets to generate real-time art is possible by the increasing ability to access high-bandwidth networks. Designing an information visualization backed by digital technology poses a unique set of challenges; but like all design processes, the goal is to make complex data simple and understandable.

The Electronic Visualization Laboratory (EVL) at the University of Illinois at Chicago is researching methods to use high-speed optical networks to support distance collaboration with multiple endpoints by streaming visualization to scientists in the world. The Scalable Adaptive Graphics Environment is a result of this effort. SAGE, the Scalable Adaptive Graphics Environment, is specialized middleware that simultaneously enables human-to-human communication and data-sharing communication on variable-sized tiled displays connected via optical networks. SAGE is being developed as part of the OptIPuter project, and is also a key collaboration technology of the Global Lambda Visualization Facility, a group of computer-graphics experts, social scientists, and network engineers from approximately 20 institutions worldwide who work on complementary distributed visualization and collaboration tools and technologies to benefit large-scale science.

SAGE enables the real-time streaming of extremely high-resolution content − such as ultra-high-resolution 2D and 3D computer graphics from remote rendering and compute clusters and storage devices, as well as high-definition video camera output − to scalable tiled display walls over high-speed networks. In the SAGE framework, multiple visualization applications can be streamed to large tiled displays and viewed at the same time. SAGE serves as a window manager; allowing users to move, resize, and overlap windows as easily as on standard desktop computers. SAGE also has standard collaboration desktop tools, such as image viewer, video player, and desktop sharing capabilities, enabling participants to resize, pan, zoom and move through the data.

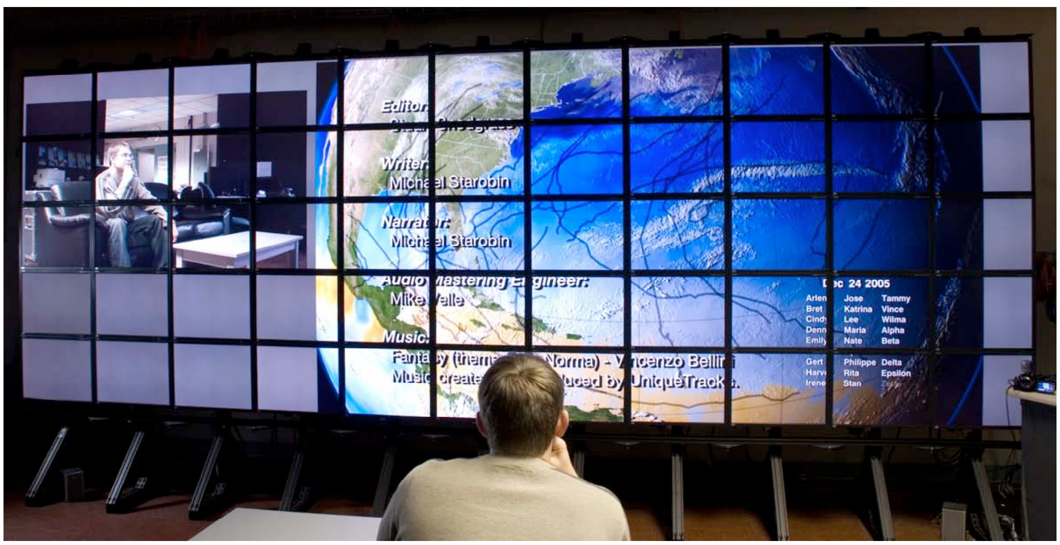


Figure 1 - SAGE driving the LambdaVision display (100Mpixels) at the EVL/UIC laboratory

The OptIPuter project, including several universities and research centers in the United States, is meant to develop a powerful distributed cyberinfrastructure to support data-intensive scientific research and collaboration. The OptIPuter, so named for its use of Optical networking, Internet Protocol, computer storage, processing and visualization technologies, is an envisioned infrastructure that tightly couples computational resources over parallel optical networks using the IP communication mechanism. The OptIPuter exploits a new world in which the central architectural element is optical networking, not computers - creating "supernetworks". This paradigm shift requires large-scale applications-driven, system experiments and a broad multidisciplinary team to understand and develop innovative solutions for a "LambdaGrid" world. The goal of this new architecture is to enable scientists who are generating terabytes and petabytes of data to interactively visualize, analyze, and correlate their data from multiple storage sites connected to optical networks.

The OptIPuter's broad multidisciplinary team is conducting large-scale, application-driven system experiments with two data-intensive e-science efforts to ensure a useful and usable OptIPuter design: EarthScope, funded by the National Science Foundation (NSF), and the Biomedical Informatics Research Network (BIRN) funded by the National Institutes of Health (NIH). The extremely data sets handled in this project are provided by organizing members of these projects, Scripps Institution of Oceanography and the National Center for Microscopy and Imaging Research at University of California, San Diego.

In this context, a large amount of data is transferred between the various sites of the projects over high-speed networks for data replication and for interactive data analysis and visualization during SAGE sessions. CytoViz strives to give domain scientists (biologists, geoscientists) and a larger public a better understanding of these data streams by visualizing their characteristics in a engaging and artistic fashion. CytoViz is driven by two factors, first is the performance of the streams in SAGE, the presentation is a metaphor of 3D living organisms affected specifically by the bandwidth, latency and frame rate of each transfer. Second is a local event directly related to Bluetooth activity in the physical space, where a scan of every Bluetooth device in the closer proximity is mapped to a unique 2D depiction overlaid in the 3D space.

The rest of the paper is structured as follow: after the description of various related projects, we will describe the intent, the structure, and the development of the CytoViz application, we will give a description of the two CytoViz demonstrations, and finally we will conclude by describing some future directions of the CytoViz project.

2. RELATED WORKS

Various projects has been coupling art and design to scientific visualization by using high-end or emerging technologies for display and interactions. We describe here a few of them.

2.1. Kites Flying In & Out of Space

Matisse's "Kites Flying In & Out of Space" was originally developed in collaboration with NCSA, EVL/UIC, and Virginia Tech as a CAVE application for the iGrid2002 workshop in Amsterdam. It explored the physical properties of flying kites in virtual reality whose movements were driven by the bandwidth usage of several collaborative applications running over high-speed networks. "Kites Flying In and Out of Space" is the first high bandwidth virtual-reality art piece ever created.

The content is a study and replication of the flying kinetic artwork of Jacqueline Matisse-Monnier. Because the calculations for these kinetic art pieces (kites) are so computationally intensive, a single PC can only support the simulation of one kite. The complexity involved with calculating and rendering data is facilitated by distributed computing over high-speed networks, so called a Grid model. To support the many kites flown, collaborators with computing resources around the world are performing the physically based kite simulations at their home institutions and then streaming the results of the calculations, in real time, to Amsterdam. In essence, this is grid computing for arts. "Kites Flying In and Out of Space" used servers distributed across the globe in Chicago, Canada, Japan, Singapore and Virginia to calculate its forms. Each of these servers streamed its results for a single kite to Amsterdam where they are then displayed in a CAVE where a user can manipulate the kites and control the wind. It is an example of "Grid" computing, resulting in an original work of art.

2.2. Rutopia 2

"Rutopia 2", by Daria Tsoupikova is a virtual reality art project built for the C-Wall network environment. It was shown at the EVA 2006 international conference in London. It describes a magic garden with interactive sculptural trees that connect to distant worlds and unite them into a shared network community. "Rutopia 2" explores the aesthetics of virtual art inspired by the distinct cultural forms present in Russian folk arts and painting. It is based upon their principles of composition, bright colors, simplified shapes, and material culture.

"Rutopia2" was presented at the iGrid2005 conference, Calit2 at the University of California, San Diego, in September 2005. It is the International conference showcasing real-time application demonstrations and latest research and development in the use of international and national networks for scientific, educational and industrial fields. The project was shown networked with the Geophysical Center Russian Academy of Sciences (GC RAS), Moscow, Russia. The network used CAVEwave/National Lambda Rail connection between San Diego and Chicago sites, SurfNet connection between Chicago and Amsterdam sites, and GLORIAD connection between Amsterdam and Moscow sites.

It was a first VR network collaboration between Moscow, Russia and Chicago, USA. The installation and opening this new VR transatlantic bridge between USA and Russia established a partnership that will lead to further artistic and scientific cooperation and contribute to the extension of advanced global network community.

2.3. Skin

“Skin”, designed by Helen-Nicole Kostis and developed with a group of artists and computer graphics experts, is a real-time interactive installation that visualizes a dialogue between physical and digital senses of “touch”. The installation consists of a screen that works as artificial skin, onto which hyperstereo skin-related video imagery is projected. The imagery is accompanied by a generative composition of digitally manipulated and synthesized skin sounds: porous breathing, the friction of skin on various surfaces, and synthesized representations of the electrical impulses inherent in skin at the molecular level. These skin-derived media serve as an exploration of a new territory: the intersection of the human body as landscape/mindscape and the body’s own traces of touch. By reacting to physical interaction with the screen, the skin-derived media are virtually deformed by the participating audience. Physical gestures are translated into accentuated and non-literal digital deformations of the projected imagery while new sounds, both organic and synthetic, are added to the mix to accompany these deformations. “Skin” is a VR installation displayed on a C-Wall system and hyperstereo imagery is shot using HD prosumer video cameras.

2.4. StarFlight

"StarFlight", developed by the University of Chicago's Center for the Presentation of Science in collaboration with EVL, is an interactive 3D VR exhibit that provides an interactive exploration of the Orion, Ursa Major and Scorpius constellations. Users can view the constellations from Earth or from outer space. "StarFlight's" virtual outer space is a visualization of the Hipparcos star catalog. Hipparcos, a satellite operated by the European Space Agency from 1989-1993, catalogued the position of nearly 120,000 stars in our galaxy.
StarFlight, an interactive virtual reality application that explores the three-dimensional nature of constellations, was setup in November 2006 in Mexico City's Laboratorio Arte Alameda and will run through February 2007. The exhibit was developed by the University of Chicago's Center for the Presentation of Science in collaboration with the Electronic Visualization Laboratory, with funding provided by the National Science Foundation. It is being exhibited in Mexico City as part of a cooperative educational outreach agreement between the University of Chicago and the Laboratorio Arte Alameda. "StarFlight" installations include "Outreach to space" at the SciTech Hands-On Museum (Aurora, IL), Space Visualization Laboratory at the Adler Planetarium (Chicago, IL) and "Laboratorio de Arte Alameda" (Mexico City).

By combining open-source software for the graphics, off-the-shelf based VR system (GeoWall stereo projection) and the most recent and accurate scientific data sets, “StarFlight” combines an artistic yet accurate rendering of the sky in an innovative fashion, affordable by most museums and schools.

3. CYTOVIZ

All the applications and demonstrations previously described try to convey information, education or sensation by leveraging emerging technologies (High-speed networks, HD cameras, off-the-shelves based VR system, advanced open-source software...) in an artistic and innovative fashion. The authors shared similar goals in the development of CytoViz.

Figure 3 describes the overall architecture where information from two sources is merged together to form a dynamic visualization. The SAGE display receives wide-area network visualizations with multiple streams, and send statistics to a SAGE server. This represents the network activity from the outside world into the location of the exhibit. Another server collects Bluetooth information using a wide-range antenna. This represents the local activity inside the location of the exhibit.

Complex information is usually discussed and analyzed within specific communities, in this case networking engineers. The Bluetooth component was a later addition to get the audience involved in a more personal manner in which their presence is captured and presented in real time. This component became very popular and people’s reaction was positive as soon as they found their Bluetooth device in the screen.

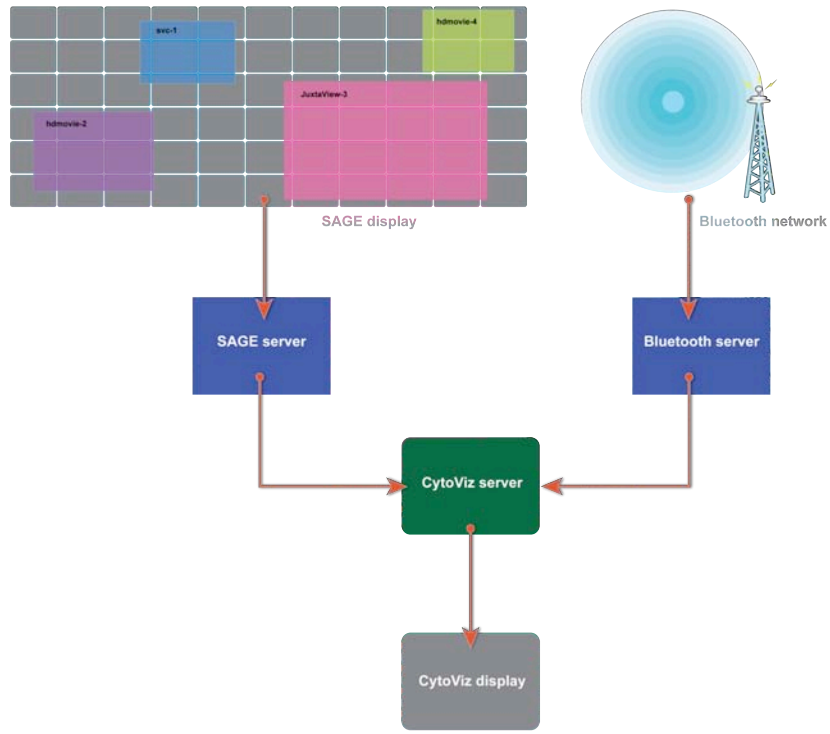


Figure 3 - CytoViz architecture aggregating wide-area and local activity

Visualization is a highly effective means way to interpret and understand data that is otherwise staid. A user's ability to interact with data in real time is both compelling and engaging, however, their ability to interpret their interactions using meaningfully applied art is a design challenge. We've attempted to meet this challenge with CytoViz, by tying together art and science to create an exciting and informative experience within which the user can explore and interact with data.

Cells are the structural and functional unit of living organisms; any organism contains one or more cells, depending of their complexity. Metaphorically cell could be seen as data packets in networking streams. Each stream is a complex organism in a living state. We have large network streams composed by smaller parts (bytes) that if not analyzed one by one, the total integration of them makes the streams meaningful and useful. The integration of several cells, which we call entities, is an analogy that considers the importance of a unit and the conjunction of them to represent something useful.

For each application, SAGE reports various statistics that are use to build and animate biological entities or cell organisms within the virtual representation space of the exhibit (3D model of the building or exhibit floor). When a new application is created, a new organism is created, when the application is stopped, the organism dies and disappears from the space. The size of an entity is derived from the bandwidth usage of the corresponding application: the more bandwidth used, the longer the entity becomes. Variations in bandwidth are dynamically reflected on the entity size. The motion and behavior is driven by the frame rate of the application: the faster is the application, the more chaotic and dynamic the entity becomes. If the frame rate drops to zero, the entity rests on the floor on the space. To give a sense of presence and a better understanding, a high-resolution map (aerial photography) is place around the 3D model of the location, at the correct scale. The user can navigate freely inside the space and outside within the boundary of the map.

3.1. A network stream is mapped to a unique entity in 3D space

Each application streamed over the network, is represented by a strand composed by a sequence of unique entities in 3D space. Every entity distinguishable by shape, color and pulsing speed is a living organism in the virtual environment, and its motion is a direct response to network stimuli. The pulsing speed behavior represents the frame rate of the corresponding stream. The faster they pulse, the higher the frame rate is, this makes it easier to identify how fast and healthy each transfer's rate is. Realistic physical forces and weights of the objects drive the motion and collision between the entities.

The graphics engine used (Electro) implements a realistic physics engine, which makes this implementation relatively easy. The next figure shows example of the cell designs used in the application.

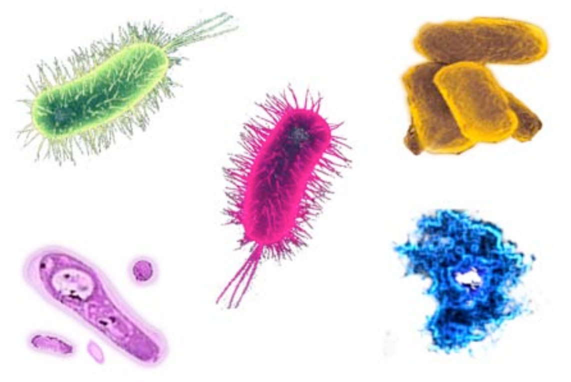


Figure 4 - Various cells used by the organisms

3.2. Length depicts the bandwidth utilized by the network streams

The length of the strand of entities represents the bandwidth used by the streamed application in SAGE. High bandwidth streams make the strand longer and low bandwidth streams are represented with shorter strands. Because it would require a great amount of computation to map one bit per second per entity, we are mapping a hundred megabit per second per entity. For instance, the maximum bandwidth available per application is 10 gigabit per second so the maximum number of entities per strand would remain manageable. The first entity leads the movement of the strand; it has forces to determine the direction of the movement in 3D space.

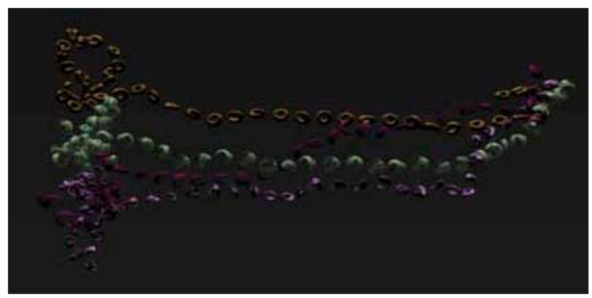


Figure 5 - Organisms of various length, made of different cells

3.3. Description of the map and 3D space

The virtual environment takes place from a macro to micro level. The visualization starts with a view of the city where it is demonstrated , these is accomplished using two dimensional satellite images from USGS and Google maps. The user can initiate a predefined flight-through to get a closer view of the organisms. The organisms (strands) are physically constrained to a three-dimensional bounding box that symbolizes the building where the application is being demonstrated.

The user has the option to hide and un-hide the three-dimensional geometry of the map and building in the scene.

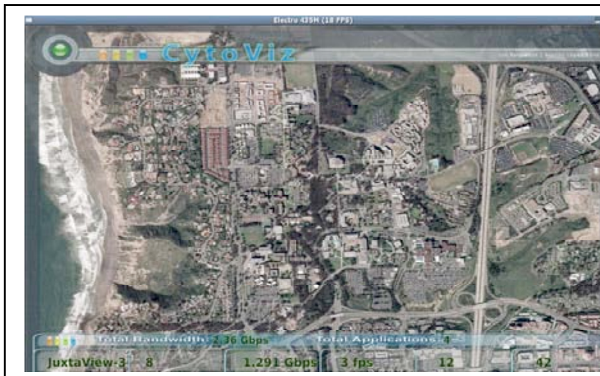


Figure 6 - Map surrounding the exhibit location

3.4. Wide-area activity

The network-centered architecture of SAGE allows collaborators to simultaneously run various applications (such as 3D rendering, remote desktop, video streams and 2D maps) on local or remote clusters, and share them by streaming the pixels of each application over ultra-high-speed networks to large tiled displays. A motivation to create an application that allows an accessible and easy way to read complex data is to make it available to a wider audience.

Network statistics of SAGE streams are portrayed using CytoViz, the activity is generated from multiple endpoints streaming to gigabyte optical networks.

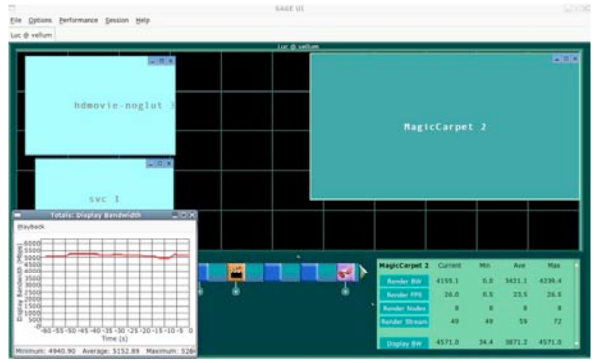


Figure 7 - SAGE user interface showing the various application streaming content to a tiled display

3.5. Local Activity

Bluetooth (BT) is a short-range wireless radio standard and communication protocol designed for communication. Devices such as mobile phones, computers, printers can connect and exchange information with each other if they are within range. The range of this type of local area network is power class dependent (1m., 10m., 100m.) and the devices can be in different rooms.

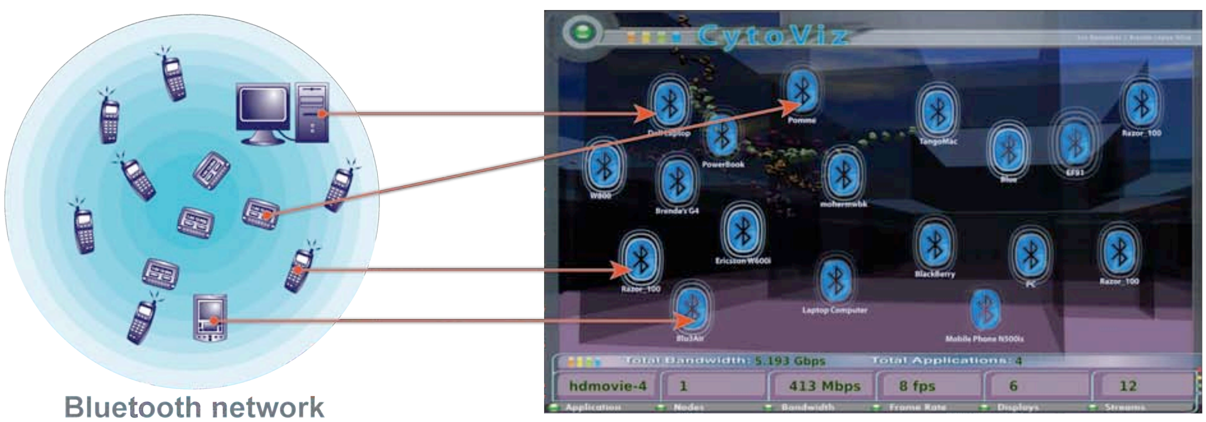


Figure 8 - Bluetooth activity from mobile devices represented as an overlay

Bluetooth is supported and used in products by over 3000 companies, including large corporations such as Sony Ericsson, Nokia, Motorola, Intel, IBM, Toshiba, Motorola, Apple, Microsoft, and even Toyota, Lexus and BMW. A variety of products available on the market have short-range Bluetooth radios installed, including printers, laptops, keyboards, cars and the most popular type of Bluetooth enabled devices - mobile phones, driving 60% of the Bluetooth market. The technology has already gained enormous popularity. According to IDC, there will be over 922 million Bluetooth enabled devices worldwide by 2008. The technology seams to be very interesting and beneficial, yet it can also be a high threat for the privacy and security of Bluetooth users.

The common uses of BT technology nowadays include:

- Using a wireless mobile phone headset during a call while keeping a phone in the bag
- Synchronizing a calendar, phone book and other information between a PDA and a PC

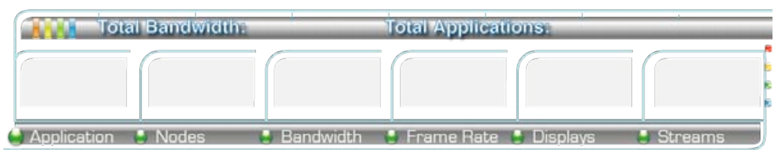
- Connecting a printer, keyboard, or mouse to a PC without cables
- Transferring photos or ring tones between mobile phones

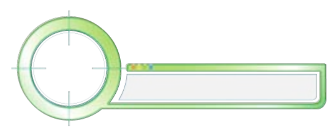
In CytoViz, the local activity is captured with Bluetooth, any Bluetooth device transmits a set of information on demand such as device name, class, list of services and more technical information like device features, manufacturer, etc. The information we use for CytoViz is the device name and address, updated every minute.

Each device is mapped to a 2D depiction of a Bluetooth icon and device name over the 3D world. It is a screen overlaying the rest of the information on the 3D space. The Bluetooth representation contains an animation of an expanding wave pattern that fades out over time. When the Bluetooth server scans the environment the next cycle, it detects the new devices reachable and display them.

3.6. Graphic Interface

The information captured in the CytoViz is presented in a two dimensional interface that can be displayed or hidden at any given time. The interface contains two main sections; one is a series of icons with the three-dimensional model of the entity and the corresponding name of the stream to the right. The second section is a panel on the bottom of the application window with detailed information about each stream and the sum of the streams and bandwidth usage.





Each entity has the color, texture and pulsing behavior as represented in the 3D environment. The information panel displays numeric representations of each stream, the information cycles every 10 seconds, to allow users read and analyze the network activity of each application. Information represented includes: Application name in SAGE, Number of rendering nodes used by the application, Amount of network bandwidth used, Frame Rate of the application, and number of network streams involved. Various sound effects are implemented to alert the user of some events: application creation, application death, change in user interface modality, and Bluetooth activity.

Navigation through the 3D space is available in two different modes: first, we defined a set of camera positions and interpolate through time between each position giving the user an automated walk through the space. At anytime, the user can take control of the navigation and decide to explore the space at will.

4. DEMONSTRATIONS

CytoViz was demonstrated at two major networking conferences, in conjunction with SAGE demonstrations. CytoViz was used to show to non-expert the network activity of the SAGE demonstration, in opposition of the local Bluetooth networking activity. Several thousands of people saw the demonstration, and generated a large amount of Bluetooth activity.

4.1. SuperComputing2005 demonstration

Co-sponsored by ACM and IEEE Computer Society, the SC conference series brings together scientists, engineers, researchers, educators, senior managers, programmers, and system managers from the world's leading computing installations and companies to showcase innovative developments that are sparking new ideas and new industries, as well as reinvigorating older ones. SAGE was supporting the following applications in the National LambdaRail booth, onto EVL's 20Mpixel 5x3 tiled display, driven by up to 20Gbps of bandwidth: HDTV live streaming from EVL in Chicago; JuxtaView (UCSD/NCMIR microscopy data and USGS Urban Area datasets); Magic Carpet (New Orleans, San Diego and Blue Marble datasets); and UIUC/NCSA and EVL HD animations. All these applications were successfully mapped into the VR world described by CytoViz.

Figure 9 – EVL's tiled display at the SC05 show floor, generating network statistics for CytoViz

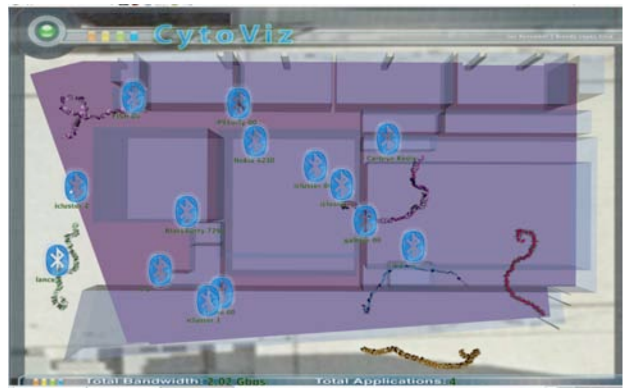


Figure 10 - CytoViz snapshot at SC'05

4.2. iGrid2005 demonstration

iGrid 2005 workshop held in September 2005 in San Diego was the fourth community-driven, biennial iGrid event. It was a coordinated effort to accelerate the use of multi-10-Gigabit international and national networks to advance scientific research, and to educate decision makers, academics and industry researchers on the benefits of these hybrid networks. The workshop demonstrated 48 real-time applications from 20 countries. A companion symposium featured more than 50 lectures, presentations and master classes on the applications, middleware, and underlying cyberinfrastructure making those applications possible. iGrid 2005 was organized by institutions, organizations, consortia and National Research & Education Networks who also participate in the Global Lambda Integrated Facility (GLIF).

The International Grid (iGrid) collaborative event showcases ongoing global collaborations in middleware development and applications research that require high-performance multi-gigabit networks. The iGrids are organized every two or three years by institutions, organizations, consortia and National Research & Education Networks who also participate in the Global Lambda Integrated Facility.

Figure 11 - CytoViz application at iGrid2005

Figure 12 - SAGE display at iGrid2005

The emergence of a global LambdaGrid cyberinfrastructure is leading e-science from a bandwidth-constrained to a bandwidth-rich world. In this new LambdaGrid architecture, it's possible to access scientific data anywhere in the world over optical networks with almost the same immediacy as if the data were stored on a local hard disk. We see at iGrid a few pioneering researchers who are showing us how this transformed cyberinfrastructure allows them to carry out a new level of science and discovery, using persistent high-performance collaboration on a planetary scale that allows global teams to interactively obtain, analyze, and share vast amounts of distributed data.

Here again, CytoViz helped visualize the large amount of data transfered during the exhibit and let everyone easily associates which application was active or not, and which application was using a large amount of network bandwidth.

5. IMPLEMENTATION

Cyto-Viz is being developed using Robert Kooima's Electro 3D graphics environment which is cross platform and allows interoperability of many display types, such as desktop display, stereo environment, and high-resolution tiled displays.

Electro is an application development environment designed for use on both cluster-driven tiled displays and desktop systems. Electro is based on the MPI process model and is bound to the Lua programming language. With support for 3D graphics, 2D graphics, audio, and input handling, Electro provides an easy-to-use scripting system for interactive applications spanning multiple processors and displays. Electro supports Linux, Windows 2K/XP, and Mac OS X.

To collect network information, we used Quanta. Quanta is a cross-platform adaptive networking toolkit for supporting the diverse networking requirements of latency-sensitive and bandwidth-intensive applications. The project seeks to develop an easy-to-use system that will allow programmers to specify the data transfer characteristics of their application at a high level, and let Quanta transparently translate these requirements into appropriate networking decisions. Quanta is a toolkit for supporting OptIPuter applications over optical networks. (National Science Foundation grant)

The technical requirements of the CytiViz application are relatively limited, by using aLinux PC, with 3D graphics card and a Bluetooth USB card, one large LCD or plasma monitor (or projector, depending on display environment) and a sound card connected to some speakers for audio feedback.

6. CONCLUSION

CytoViz is an artistic, real-time information visualization driven by statistical information gathered during the execution of network streaming applications over high-speed networks. Data streams are mapped to cellular organisms defining their structure and behavior as autonomous organisms. This visual and animated metaphor allows the public to experience the complexity of high-speed network streams that are used in the scientific community. It also displays the presence of pervasive Bluetooth devices carried by nearby persons. CytoViz combines in one application and opposes on one hand the wide-area network streams and on the other hand the local activity surrounding the location of the event. It helps non-expert to grasp the complexity of today's research applications.

We would like to extend the CytoViz application to include more local sensor devices such as RFID tags (Radio Frequency Identification) and wireless networks, so pervasive in today's laboratories and homes. We envision including high-definition cameras to engage the spectator in a more interactive fashion.

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