NPSNET - Large-Scale Virtual Environment Technology Testbed

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ABSTRACT

The NPSNET Research Group has a decade of experience in developing the software, interaction and networking technology for the large-scale virtual environment (LSVE). Our current group is focusing on the LSVE network software architecture, web-based interoperability, cross-platform VE toolkits, 3D VE construction, inertial motion tracking, locomotion devices, human modeling in the VE, spatial sound, wayfinding in the VE, and DoD applications of VE technology.

Keywords

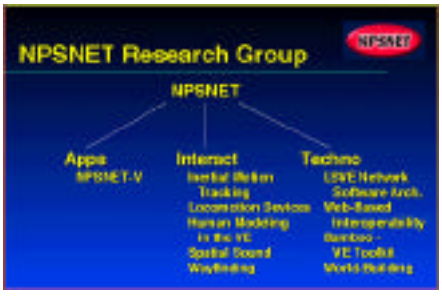
Large-scale virtual environments, NPSNET.

FOCUS

The focus of the NPSNET Research Group is on the complete breadth of human-computer interaction and software technology for implementing large scale virtual environments (LSVEs). We apply our research to construct virtual environments useful for the Department of Defense.

RESEARCH BRANCHES

The NPSNET Research Group has three main branches, Techno, Interact and Apps. The Techno branch focuses on developing the network and software technology for the LSVE. The Interact branch focuses on human-computer interaction technology for the LSVE and on the evaluation of the LSVE for training. The Apps branch focuses on the development of LSVEs useful for the Department of Defense, utilizing the technology developed by the other two branches.



TECHNO

The Techno branch of the NPSNET Research Group focuses on developing the network and software technology for the LSVE. There are four primary projects:

LSVE Network Software Architecture
Web-Based Interoperability
Bamboo - a cross-platform virtual environment toolkit
World-Building

The LSVE Network Software Architecture project looks at how we design the fundamental network and software architecture of the large-scale virtual environment. The Web-Based Interoperability project looks at how we design Internet-based, networked virtual environments. The Bamboo project looks at how we design cross-platform, high-performance virtual environment toolkits. The World-Building project looks at the fundamental design issues involved in constructing believable models for virtual worlds.

Large Scale Virtual Environment Network Software Architectures

We use the acronym LSVE (large scale virtual environment) to mean a networked virtual environment with greater than 1,000 players. When we say this large a number of players, we mean both live/interactive and autonomous/computer-generated characters.

Another term we use is Network Software Architecture (NSA). By network software architecture, we mean the combination of the network protocol used for the LSVE and the software architecture that supports that protocol within the confines of available bandwidth and processor cycles. There are many protocol-only and software architecture-only solutions. There are few full NSA solutions. Our research in this area is the entire spectrum of NSA issues, from how the protocol is specified to how the supporting software is designed.

Web-Based Virtual Environment Interoperability

To understand web-based VE interoperability, we first need to delineate the issues. The issues are:

What types of information need to be transferred between web-based networked VEs?

How do we transfer that information on the Internet (protocol)?
What is the NSA for this?

The types of information that need to be transferred between networked VEs are easily specifiable:

State changes/entity interactions (peer-to-peer).
Heavy-Weight Objects (http client/server requests).
Network pointers (URLs).
Real-time streams (Mbone audio/video).

The issue of how we transfer that information, the protocol, is somewhat more difficult. We have two research efforts on this issue:

Dial-a-protocol project (peer-to-peer).
virtual reality transfer protocol (vrtp) project.

Dial-A-Protocol Project

The focus of the Dial-A-Protocol project is on the development of tools/methods for the rapid generation of peer-to-peer VE applications layer network protocols. The key questions are how do we formally specify the state change and entity interaction information., how do we embed semantics in syntax in general and how do we do this on-the-fly?

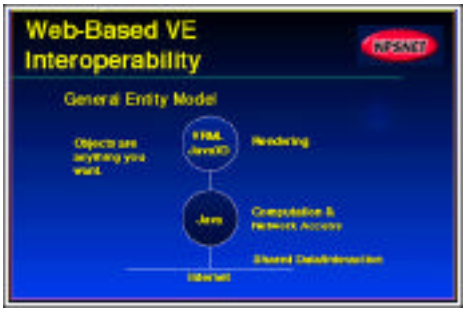
For the issue of how do we formally specify the state change and entity interaction information, we have looked at a number of things including the formal BNF specification of DIS, the development of a PDU specification editor and code generator for DIS readers/writers, and a web-based HTML combo-form PDU specification editor.

Our latest work has been to put together a piece of Java software to process DIS packets. The DIS-Java-VRML working group is looking at how we can provide DIS-like interoperability for the web. This is a fast-track effort with early success (1500 PDUs per second).

A major part of our dial-a-protocol work is examining how to embed semantics in syntax in general and how to do this on-the-fly. What we are looking at very much has the flavor of mobile agents. We encode behavior in a packet. Our syntax is simply (identifier type, number of bits). Our semantics is a Java object and methods

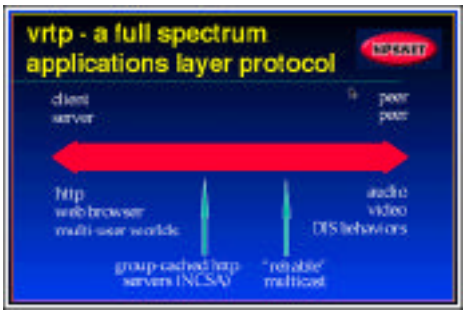
virtual reality transfer protocol (vrtp) Project

The dial-a-protocol project looks at a very small piece of the peer-to-peer, light-weight entity interaction problem in networking VEs. If we go back and look at our list of types of information to be transferred between VEs, we see there are other types of data in our VE. The virtual reality transfer protocol (vrtp) is our proposal for supporting all the types of data desired in a networked VE.



vrtp is the applications-layer protocol used to wrap together dissimilar other applications layer protocols. vrtp will support:

Light-weight entity interactions (peer-to-peer).
Network pointers (URLs).
Heavy-weight objects (http client/server request).
Real-time streams (Mbone audio/video)..



vrtp is a full-spectrum applications layer protocol. Just as http serves html pages, ftp, telnet, and other services, vrtp will serve the dissimilar applications layer protocols needed for LSVEs.

Network Software Architecture Project

We defined network software architecture to be the combination of the network protocol used for the LSVE and the software architecture that supports that protocol within the confines of available bandwidth and processor cycles. We've discussed protocol. We now discuss the software architecture end of things.

The primary problem we are trying to solve with respect to the network software architecture is how to optimize the available bandwidth and the available processor cycles for our LSVE. We don't want to bury the CPU in processing packets at the applications layer of the operating system. We don't want to flood the network with unnecessary packets.

We have done a lot of software experimentation and systems testing with DIS and have a pretty good understanding of the software architecture issues. We are now focusing on a layer of software we call the Area of Interest Manager (AOIM). With an AOIM, state changes and entity interactions are assigned to particular multicast groups (groups are interested parties, ala spatial partitioning, functional partitioning, temporal partitioning, ...) instead of being broadcast

to everyone. Multicast groups are subscribed to in a distributed fashion by appropriate parties (self-assignment). With this type of software architecture, packets not part of subscribed multicast groups are killed off at the network interface unit (hardware) rather than at the applications layer in the CPU. In this fashion, the VE only gets packets from groups to which it has formally subscribed.

Research Issues in AOIMs

- How do we program in a general way an AOIM?
- AOIMs are application dependent. How do we design such systems for dynamic AOIM replacement?
- In a distributed fashion, how do we dynamically assign information to a particular set of multicast groups?

DoD Standards for Interoperability

The NPSNET Research Group has always been on the leading edge in the development and utilization of DoD standards for interoperability. NPSNET-IV is SIMNET and DIS compliant. We are currently evaluating the High-Level Architecture (HLA) for its utility in interactive LSVEs. We expect to make NPSNET-V HLA and vrtp compliant.

Bamboo - A Cross-Platform Virtual Environment Toolkit

One of the most important efforts in the NPSNET Research Group is that of the development of Bamboo - an extensible framework for networked VEs. The motivation behind the development is our need for a low-cost, general-purpose, cross-platform, high-level toolkit that provides a well designed framework facilitating VE application research and development. Current off-the-shelf toolkits do not readily provide the capabilities planned for Bamboo.

What is Bamboo? Bamboo is a collection of the core mechanisms common to networked VEs. It is an API toolkit for serious programmers. It has a dynamically extendible runtime environment. Bamboo is based on OpenGL++, which implies OpenGL, C++, and STL (standard template library). OpenGL++ is a multi-platform (SGI, PC, Macintosh, etc.) visualization toolkit that contains the best of Performer and Inventor. Bamboo sits along-side rather than on top of OpenGL++. Bamboo is designed based on plug-ins.

Bamboo's Mechanisms:

- Extensibility
- Networking
- Security
- Process Management
- Inter-Process Communication
- Remote Procedure Calls
- Callbacks
- Event Handling
- Device Manager
- Database Handling
- Statistics Manager
- Graphical User Interface
- Undo/Redo
- Physically-Based Modeling
- Friendly OpenGL++ Abstractions

Virtual Environment World Building

While developing the software technology for constructing virtual environments is our main focus, we have developed an additional VE development capability, that of world building. We have in-house staff that specializes in the construction of fully detailed, textured, 3D virtual environments using both VRML and MultiGen. Samples below are taken from the full-scale, blue-print and real-world accurate Naval Postgraduate School Hermann Hall model.

INTERACT

The Interact branch of the NPSNET Research Group focuses on human-computer interaction technology for the LSVE and on the evaluation of the LSVE for training. There are five primary projects:

- Inertial Motion Tracking
- Locomotion Devices
- Human Modeling in the Virtual Environment
- Spatial Sound
- Wayfinding

The Inertial Motion Tracking project is looking at how micromachined accelerometers and angular rate sensors and 3D positioning using RF can be combined to track human body motion in a manner similar to that of an inertial navigation system. The Locomotion Devices project focuses on

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integrating other people's locomotion devices into the NPSNET software platform. The Human Modeling in the VE project looks at how large numbers of low-cost, articulated humans can be placed into the networked virtual environment. The Spatial Sound project looks at the minimum auditory and visual display fidelities necessary for increasing performance and immersion in the virtual environment. The Wayfinding project looks at training spatial knowledge acquisition using a virtual environment.

Inertial Motion Tracking of Humans in the Networked Synthetic Environment

Current technologies are unable to provide a natural and intuitive interface for inserting a human into a large scale networked virtual environment. Advances in the design of micromachined accelerometers and angular rate sensors and 3D spatial positioning using RF, present the possibility of tracking human body motion inertially in a manner similar to that of an inertial navigation system (INS). Current human motion capture systems suffer from numerous limitations:

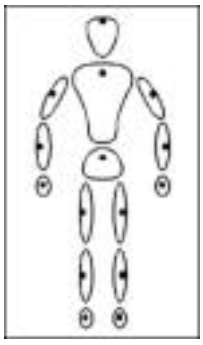
- User encumbrance
- Restricted Range
- Susceptibility to Interference
- Latency
- Shadowing

The hybrid inertial tracking system is essentially sourceless and does not suffer from these limitations. Inertial body tracking is based upon same algorithms as inertial navigation of missiles, aircraft and ships. The physics resemble those of the human vestibular system.

Proposed tracking system advantages:

- High data rates without perceptible lag.
- Tolerant to environmentally induced errors.
- Will produce consistent registration between physical and virtual worlds.
- Allow multiple users in a large working volume simultaneously.

Basic Concept:



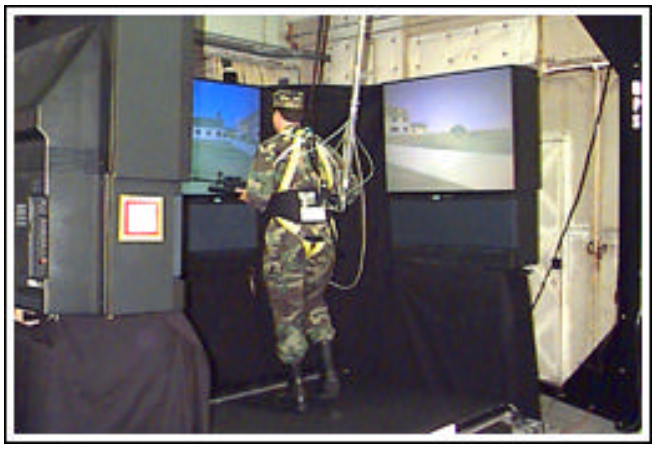
- Instrument the Human body with 15 micromachined inertial sensors.
  - Each sensor contains:
    - Three-axis accelerometer.
    - Three-axis rate sensor.
    - Three-axis magnetometer.

Complementary filtering corrects for sensor errors and drift. The sensors provide an orientation vector for each body segment. RF positioning of a single point on the body would accurately place the articulated human within the VE. The human body tracking sensor configuration is shown in the figure.

Locomotion Devices

Most of our work in locomotion devices has been to integrate other people's locomotion devices into the NPSNET-IV software platform. Two of our most successful demos were done for the Association of the United States Army (AUSA) annual Fall conference.

At AUSA 95, we demonstrated Treadport-NPSNET-IV-JackML integration. That demonstration was joint between Sarcos Engineering of Salt Lake City, the University of Pennsylvania, and the NPSNET Research Group. The AUSA 96 demonstration showed NPSNET-IV integrated with the Virtual Space Devices Omni Directional Treadmill, and the Boston Dynamics, Inc. DI-Guy software.

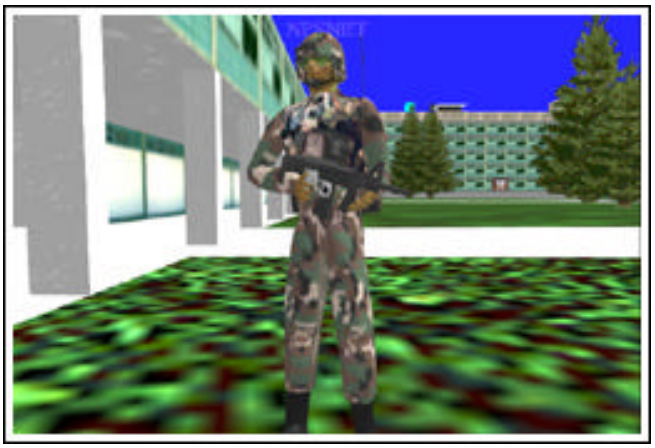


Human Modeling

We have explored commercial solutions for animating articulated humans in the VE. We have integrated the University of Pennsylvania Jack-ML and Boston Dynamics, Inc. DI-Guy software into NPSNET-IV. Each of these solutions is too slow once the number of humans in view becomes larger than five to ten. We are looking at developing articulated human support software capable of displaying 100 to 150 humans in the NPSNET-V VE.

Spatial Sound

The spatial sound component of the research group looks at virtual environment auditory and visual intersensory modality issues. We are measuring performance and immersion during wayfinding and target acquisition tasks in a VE. We are manipulating both auditory and visual display fidelities. We want to find out the effects of both modalities on performance and immersion.



Wayfinding

The focus in the wayfinding effort is on training spatial knowledge acquisition using virtual environments. The goal of the work is to show that VEs can be used to acquire spatial knowledge of a specific real space (training transfer). Future work will involve the investigation of environmental features and perceptual stimuli and their role in navigation and wayfinding so that we may understand how to degrade the fidelity of a VE without substantially degrading navigation performance. We will then extend these concepts to training general navigation skills, including map usage (perspective transformation) and landmarking abilities.

APPS

The Apps branch of the NPSNET Research Group focuses on the development of LSVEs useful for the Department of Defense, utilizing the technology developed by Techno and Interact. There are three primary projects:

NPSNET-IV Completion

NPSNET-V

An Amphibious Virtual Environment

The NPSNET-IV Completion effort is our continuing, albeit minimal, commitment to maintaining the availability of the NPSNET-IV source tree on the world wide web. The NPSNET-V project is our effort to rebuild the NPSNET LSVE, using NPSNET-IV technological know-how and the Bamboo toolkit. The Amphibious Virtual Environment is an effort to look at the network software architecture needed to support the docking of an amphibious landing craft into an LPD-17. This VE was prototyped with a toolkit similar to Bamboo.

NPSNET-IV Completion

NPSNET-IV is finally done! NPSNET-IV was started in March of 1993 and work continued on that code base through December 1996. We are now working on our next generation toolkit, Bamboo, which will be used to implement NPSNET-V. Resources formerly dedicated to maintaining NPSNET-IV and providing configuration management for that software are no longer available.

NPSNET-IV Capabilities:

Building walkthroughs.

Articulated humans - mounting/dismounting capability.

Networking - play across the multicast backbone of Internet.

Terrain database integration, terrain paging (70km x 70km).

Any vehicle capability - air, ground, articulated human.

Testbed for VE network software architecture issues.

Interoperability - SIMNET/DIS

Constructive model integration - Janus World Modeler

ModSAF integration.

NPSNET-V - Feature and Plans

We are redesigning the network software architecture of our NPSNET software platform. We plan for that architecture to be plug and play, where additional modules of capabilities (networking, human models, terrain models, walkthroughs, mounting/dismounting of humans, general interaction, ...) can be developed with a uniform, published API. We have much in-house technology from our NPSNET-IV efforts. We plan to adopt as many of them as possible within available funding and staff constraints.

Technologies for NPSNET-V:

Bamboo - Next Generation VE Toolkit

OpenGL++

C++/Java

vrtp & HLA

NPSNET - An Amphibious Virtual Environment

In redesigning our NPSNET software platform, we have examined other available commercial toolkits and have prototyped VEs with those toolkits. Using the Corypheaus Easy Scene toolkit, we built the world shown in the following images. A videotape is available on this unfunded effort.

EDUCATION

Education for students associated with the NPSNET Research Group comes from two different degree programs.

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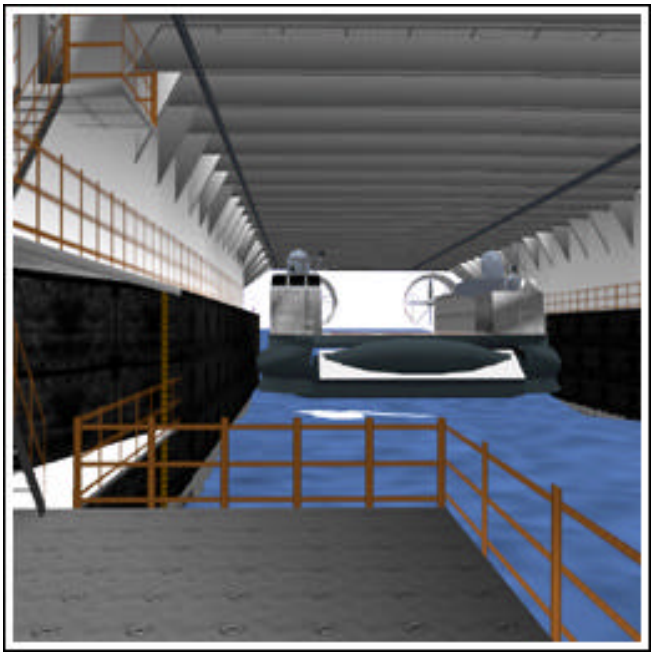

The Naval Postgraduate School's Computer Science Department offers an MS in Computer Science with specialization in Computer Graphics and Visual Simulation.

http://www.cs.nps.navy.mil/curricula/acas

NPS additionally offers an MS and Ph.D. degree in Modeling, Virtual Environments and Simulation (MOVES). The programming, systems, computer graphics, networking and virtual environments courses of the Computer Science Department are half of the MOVES degree program. The remainder of the MOVES program consists of the mathematical modeling courses necessary to understand constructive and other modeling and simulation systems.

http://www.moves.nps.navy.mil/

SPONSORS

The NPSNET Research Group is a reimbursably funded organization within the Naval Postgraduate School. Our research efforts are funded by a number of US government agencies, including the Defense Advanced Research Projects Agency (DARPA), the Defense Modeling and Simulation Office (DMSO), the Office of Naval Research (ONR), the National Imagery and Mapping Agency (NIMA), and Advanced Networks and Services, Armonk.

PEOPLE

The NPSNET Research Group consists of reimbursably funded faculty and staff. Faculty receive six months salary from NPS and the remainder from research contracts. Staff are 100% reimbursable.

Faculty:

Professor Michael Zyda
Assistant Professor Don Brutzman
Assistant Professor Rudy Darken
Professor Robert McGhee
Senior Lecturer John S. Falby
Lecturer Eric Bachmann

Development and Support Staff:

Joel Brand Student Intern (U.C. Berkeley)
Bill Cockayne Human Interaction and Training Systems Analysis (Ph.D. student)
Holly Cuellar Administrative Assistant
Rosalie Johnson Systems Administration
Ben Kavanagh, Systems Architect (Ph.D. student)
John Locke 3D Modeling; Network and Communications; Documentation
Andrzej Kapolka Student Intern (U.C. Santa Cruz)
Don McGregor Portable DIS Library, VRML-Java-DIS
Russell Storms CPT USA: Spatial Acoustic Sound Rendering
Kent Watsen Senior Development Architect (Ph.D. student)

NPSNET RESEARCH GROUP WEB SITE

The NPSNET Research Group maintains a world wide web site that provides additional information about our research, our published papers, personnel and the complete software distribution for NPSNET. It is reachable via the following URL:

http://www.npsnet.nps.navy.mil/npsnet

PUBLICATIONS

The NPSNET Research Group puts all its papers on the world wide web in either Postscript or Adobe Acrobat form. Some selected publications from the last two years:

Books

Singhal, Sandeep and Zyda, Michael “Networked Virtual Environments,” text being written for ACM Press. Book due to be published by SIGGRAPH 98.

Zyda, Michael and Sheehan Jerry “Modeling and Simulation: Linking Entertainment & Defense,” National Academy Press, NRC/CSTB report due out by summer of 1997. Report in galleys.

Cockayne, William C. and Zyda, Michael J. “Mobile Agents: Explanations and Examples,” Manning Press, ISBN: 1-884777-36-8, June 1997.

“Virtual Reality: Scientific and Technological Challenges,” Editors: Nathaniel I. Durlach and Anne S. Mavor, Committee on Virtual Reality Research and Development, National Research Council, National Academy of Sciences Press, Washington, DC 1995. Sections written or with major contributions: Chapters - “Executive Summary”, “Overview”, “Computer Hardware and Software for the Generation of Virtual Environments”, and “Networking and Communications”, ISBN 0-309-05135-5.

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Refereed Publications: Accepted Papers/Published Papers/Book Chapters

Macedonia, Michael and Zyda, Michael "A Taxonomy for Networked Virtual Environments," IEEE Multimedia, Volume 4, No. 1, January - March 1997, pp. 48-56.

Macedonia, Michael R., Zyda, Michael J., Pratt, David R., Brutzman, Donald P. and Barham, Paul T. "Exploiting Reality with Multicast Groups," IEEE Computer Graphics & Applications (revised from appearance in the VRAIS 95 Proceedings), September 1995, pp.38-45.

Macedonia, Michael R., Zyda, Michael J., Pratt, David R., Barham, Paul T. and Zeswitz, Steven "NPSNET: A Network Software Architecture for Large Scale Virtual Environments," Presence, Vol 3, No. 4, Fall 1994, pp.265-287.

Appearances/Participation in/on Videotape & Live Demonstrations

"NPSNET-IV: Inserting the Human into the Networked Synthetic Environment," SIGGRAPH Video Review, SIGGRAPH 97, Los Angeles, California, 3 - 9 August 1997.

"NPSNET Research Group Dismounted Infantry VR Demo at AUSA 96" at the 13 - 16 October 1996, Association for the United States Army Conference, Washington, DC.

"NPSNET Research Group Dismounted Infantry VR Demo at AUSA 95" at the 16 - 18 October 1995, Association for the United States Army Conference, Washington, DC.

Macedonia, Michael R., Brutzman, Donald P., Zyda, Michael J., Pratt, David R., Barham, Paul T., Falby, John and Locke, John "NPSNET: A Multi-Player 3D Virtual Environment Over the Internet," in the Video Proceedings of the 1995 Symposium on Interactive 3D Graphics, 9 - 12 April 1995, Monterey, California.

Conferences: Accepted Papers/Published Papers

Brutzman, Don, Zyda, Michael, Watsen, Kent, Macedonia, Michael "virtual reality transfer protocol (vrtp) Design Rationale," Proceedings of the IEEE Sixth International Workshop on Enabling Technologies: Infrastructure for Collaborative Enterprises (WET ICE 97), Distributed System Aspects of Sharing a Virtual Reality workshop, to be held June 18-20, 1997, at the Massachusetts Institute of Technology in Cambridge, Massachusetts, USA.

Brutzman, Don and Zyda, Michael "Cyberspace Backbone (CBone) Design Rationale," Proceedings of the 15th Workshop on Standards for DIS, Orlando, Florida, September 1996.

Storms, Russell, Biggs, Lloyd, Cockayne, William, Barham, Paul, Falby, John, Brutzman, Don and Zyda, Michael, "The Auralization and Acoustics Laboratory," Proceedings of ICAD 96, International Conference on Auditory Display, Palo Alto, California, November 4-6, 1996.

Cockayne, W., Zyda, M., Barham, P., Brutzman, D., and Falby, J. "The Laboratory for Human Interaction in the Virtual Environment," Proceedings of the ACM Symposium on Virtual Reality Software and Technology 96, Hong Kong, July 1-4, 1996, ACM Press, New York, NY, pp 157-160.

Stone, Steve, Zyda, Michael, Brutzman, Don and Falby, John S. "Mobile Agents and Smart Networks for Distributed Simulations," in the Proceedings of the 14th DIS Workshop, 11 - 15 March 1996, Orlando, Florida.

Bible, Steven R., Brutzman, Don and Zyda. Michael "Using Spread-Spectrum Ranging Techniques for Position Tracking in a Virtual Environment," in the Proceedings of Network Realities 95, 26 - 28 October 1995, Boston, Massachusetts.

Zyda, Michael, Pratt, David R., Pratt, Shirley, Barham, Paul and Falby, John S. "NPSNET-HUMAN: Inserting the Human into the Networked Synthetic Environment," in the Proceedings of the 13th DIS Workshop, 18 - 22 September 1995, Orlando, Florida, pp.103-106.

Lentz, Fred C., Shaffer, Alan B., Pratt, David R., Falby, John S. and Zyda, Michael "NPSNET: Naval Training Integration," in the Proceedings of the 13th DIS Workshop, 18 - 22 September 1995, Orlando, Florida, pp. 107-112.

Waldroup, Marianne S., Pratt, Shirley M., Pratt, David R., McGhee, Robert B., Falby, John S. and Zyda, Michael J. "Real-time Upper Body Articulation of Humans in a Networked Interactive Virtual Environment," in Proceedings of the First ACM Workshop on Simulation and Interaction in Virtual Environments, University of Iowa, 13 - 15 July 1995, pp. 210-214.

Brutzman, Donald P., Macedonia, Michael R., Zyda, Michael J. "Internetwork Infrastructure Requirements for Virtual Environments," in the Proceedings of the Virtual Reality Modeling Language (VRML) Symposium, San Diego Supercomputer Center (SDSC), San Diego, CA, December 13-15, 1995.

Macedonia, Michael R., Brutzman, Donald P., Zyda, Michael J., Pratt, David R., Barham, Paul T., Falby, John and Locke, John "NPSNET: A Multi-Player 3D Virtual Environment Over the Internet," in the Proceedings of the 1995 Symposium on Interactive 3D Graphics, 9 - 12 April 1995, Monterey, California.

Macedonia, Michael R., Zyda, Michael J., Pratt, David R., Brutzman, Donald P. and Barham, Paul T. "Exploiting Reality with Multicast Groups: A Network Architecture for Large Scale Virtual Environments," Proceedings of the 1995 IEEE Virtual Reality Annual Symposium, 11 - 15 March 1995, RTP, North Carolina, pp. 2-10.

Zyda, Michael J. “VRAIS Panel on Networked Virtual Environments” in the Proceedings of the 1995 IEEE Virtual Reality Annual Symposium, 11-15 March, 1995, RTP, North Carolina.

Invited Papers

Zyda, Michael J. “Networking Large-Scale Virtual Environments,” Proceedings of Computer Animation 96, 3-4 June 1996, Geneva, Switzerland, IEEE Computer Society Press, pp. 1-4. (an earlier version of this paper also appeared in the Proceedings of the Second International Conference on the Military Applications of Synthetic Environments and Virtual Reality, Stockholm, Sweden, 6-8 December 1995, pp. 119-125.)

Lentz, Fred C., Shaffer, Alan B., Pratt, David R., Falby, John S. and Zyda, Michael J. “Virtual Reality: Naval Training for the Future,” accepted as a Professional Note for the Naval Institute Proceedings.

Pratt, David R., Zyda, Michael and Kelleher, Kristen “Virtual Reality: In the Mind of the Beholder,” IEEE Computer, July 1995, pp. 17 - 19 (editors notes for the special issue on virtual environments).

Macedonia, Michael R., Zyda, Michael J., Pratt, David R., Brutzman, Donald P. and Barham, Paul T. “Building Large-Scale Virtual Environments: A Network Software Architecture,” Proceedings of Industrial Virtual Reality 95, Tokyo, Japan (as invited speaker), 28 - 30 June 1995, pp.18-28.

RELATED WEB SITES

Information Infrastructure Research Group (IIRG)
http://www.stl.nps.navy.mil/~iirg/

virtual reality transfer protocol Web Site
http://www.stl.nps.navy.mil/~brutzman/vrtp

Interact Research Group
http://www.interact.nps.navy.mil

Bamboo Web Site
http://www.npsnet.nps.navy.mil/Bamboo

Auralization & Acoustics Lab Web Site
http://www.npsnet.nps.navy.mil/npsnet/aa-lab