EMERGING WEB-BASED 3D GRAPHICS FOR EDUCATION AND EXPERIMENTATION

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ABSTRACT

This paper describes current work in the evolution of open standards for 3D graphics on the World Wide Web (*Web3D*) and provides examples of application of emerging Web3D authoring, visualization, and simulation tools for military education and experimentation. The paper presents an overview of the current state of Web3D standardization activities, including establishment of conformance tests and a reference implementation. The paper describes examples of the application of web-based 3D graphics for exploring complex military battlespaces supporting Limited Objective Experiments in Anti-Terrorism / Force Protection (AT/FP) and emerging joint command and control concepts for Web-based information management.

In February 2002, the Web3D Consortium (www.web3d.org) announced completion of the draft of the X3D (Extensible 3D) specification, the proposed next-generation standard for describing 3D content on the World Wide Web (http://www.web3d.org/x3d.html). X3D is a scene graph architecture and encoding that improves on the Virtual Reality Modeling Language international standard (VRML 97, ISO/IEC 14772-1:1997). X3D uses the Extensible Markup Language (XML) to express the geometry and behavior capabilities of VRML. The paper provides a brief overview of X3D and the current status of the standardization process and supporting efforts (e.g., development of an open source scene authoring and visualization tool and conformance test suite development), updating information presented in the I/ITSEC 2001 paper and conference briefing.

To demonstrate the capabilities of the emerging X3D standard, the Naval Postgraduate School is performing research toward development of scenario authoring and Web-based visualization capabilities. The paper describes the current status of research activities, including application of Web-based 3D graphics to a Navy Force Protection Limited Objective Experiment (LOE) and a Joint Futures Laboratory LOE investigating peer-to-peer Joint Interactive Planning concepts. The paper discusses technical challenges in representing complex military operations in Web environments and describes work in progress to demonstrate application of Web-based technologies to create and explore complex, multi-dimensional operational scenarios. The paper concludes with discussion of future research directions for application of Web-based 3D graphics in military education, training, and experimentation.

ABOUT THE AUTHORS

Curtis Blais is a Research Associate at the Naval Postgraduate School in the Modeling, Virtual Environments, and Simulation (MOVES) Institute. His principal research areas at NPS include Web-based 3D graphics for military education and training, Web-based instruction, and design of multi-agent simulations. Prior to coming to NPS, Mr. Blais spent 25 years in software development in industry and government working on Navy and Marine Corps command staff training systems and C4I simulations. He designed and developed combat models for several generations of Marine Corps systems, and continues to provide technical consultation to the Marine Corps for design of the next-generation command staff training system, the Joint Simulation System (JSIMS). Mr. Blais has a B.S. and M.S. in Mathematics from the University of Notre Dame, and is working on a Ph.D. in MOVES at the Naval Postgraduate School.

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autonomous underwater vehicles (AUVs); machine learning, sensing, perception, and control; and distributed audio, video, and graphics applications using multicast, distributed interactive simulation, and adaptive protocols for large-scale virtual environments. Dr. Brutzman is leading efforts in the Web3D Consortium to develop next-generation Web3D specifications and tools. Dr. Brutzman served 20 years in the U.S. Navy as Electrical Officer, Combat Systems Officer, and Navigator aboard submarines, and was Operational Test Director for testing of the MK 1 Combat Control System (CCS) and Mk 48 Advanced Capability (ADCAP) torpedo. Dr. Brutzman obtained a B.S. in Electrical Engineering at the U.S. Naval Academy and a M.S. in Computer Science at the Naval Postgraduate School. Dr. Brutzman received a Ph.D. in Computer Science, with a minor in Operations Research, from NPS in 1994.

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LT James Harney, United States Navy, is a student at the Naval Postgraduate School completing a M.S. in Computer Science. His thesis research involves the utilization of X3D Web-based graphics and software agent technologies to gain insight into planning and evaluation of Anti-Terrorism and Force Protection (AT/FP) measures for U.S. Navy warships. LT Harney has received a Fellowship from the Space and Naval Warfare (SPAWAR) Systems Center, San Diego, to support his AT/FP research. Prior to coming to NPS, LT Harney served as commissioning Damage Control Assistant in USS ROSS (DDG 71) followed by a tour as Combat Information Center Officer in USS PETERSON (DD 969). LT Harney earned a B.S. in Computer Science from the U.S. Naval Academy in 1996. Following graduation from NPS in March 2003, LT Harney will be assigned to Surface Warfare Officer's School in Newport, Rhode Island for department head training.

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PREFACE

The Internet and World Wide Web is providing an information resource of unrivaled breadth available to all at little or no monetary and technical investment. Through various initiatives, the United States Government is employing this vast domain to improve services across multiple fronts to benefit citizens at large as well as military and civilian employees in particular. As part of these initiatives, research is in progress to identify opportunities for enhancement of information management, presentation, education, and analysis through application of Web-based 3D graphics. Integration of 3D graphics into the World Wide Web continues to be an extraordinary area for opportunistic growth.

The Web3D Consortium is an international organization established to define and promote standards for 3D graphics representation on the World Wide Web. The Consortium is developing specifications for the next generation standard, Extensible 3D (X3D), for international review and approval. Once approved, the X3D standard will become the foundation for all X3D content on the Web. Furthermore, the organization is supporting development of conformance tests and an open-source implementation to provide a basis for community understanding of the specifications, from which both commercial proprietary and freely available implementations may be developed to further promote and extend use of the standard world-wide.

As a major participant in the Web3D Consortium and contributor to the Web3D standardization process, the Naval Postgraduate School (NPS) is pursuing a broad-based strategy for exploitation of World Wide Web technologies to support military modeling and simulation for education, analysis, and war fighting. Under initial funding from the Defense Modeling and Simulation Office, NPS launched the Scenario Authoring and Visualization for Advanced Graphical Environments (SAVAGE) project in mid-2000. The purpose of the SAVAGE project is to create authoring tools and techniques to generate interactive, multi-user, web-based 3D models of military operations. Foundational work at NPS and early work in the SAVAGE project focused on representation of 3D models and behaviors for visualizing communications plans (Laflam, 2000; Hunsberger, 2001), coordination of humanoid teams (Miller, 2000), air tasking orders (Murray and Quigley, 2000), and amphibious operations orders (Nicklaus, 2001). These generic efforts were extended to reconstruction of actual events, including: the USS GREENEVILLE/Ehime Maru collision off the coast of Oahu, Hawaii (Blais, et. al., 2001); the USS COLE terrorist attack in Aden Harbor, Yemen (Blais, et. al., 2002a); and Autonomous Underwater Vehicle (AUV) mine-hunting test tracks (Weekley, 2002).

Most recently, the project has supported Web-based 3D visualization for two Limited Objective Experiments (LOEs), a Peer-to-Peer Communications experiment (P2P LOE) conducted at the Naval Postgraduate School for the Joint Futures Laboratory (Pilnick et al., 2002) and an Anti-Terrorism / Force Protection (AT/FP) experiment. The former builds upon AUV track reconstruction work (Weekley, 2002), while the latter builds upon experience gained from the earlier USS COLE scenario reconstruction work (Blais, et. al., 2002b). These efforts demonstrate not only the power of the scene graph representation in the X3D language, but also application of the growing collection of Web-based software tools for the Extensible Markup Language (XML) to manipulate the information in the X3D scenes and benefits of 3D visualization for military operations planning, experimentation, and analysis.

The activities of the Web3D Consortium, X3D specification status, and the SAVAGE project were introduced in a paper and presentation at I/ITSEC 2001 (Blais, et. al., 2001). The current paper provides an update to that introduction, describing current status of specification efforts and development of the open-source X3D example implementation. To emphasize the potential of the technology to support military education and experimentation in Web-based environments, the paper presents techniques, models, and scenarios from the P2P and AT/FP LOE applications introduced above.

WEB3D CONSORTIUM

The Web3D Consortium Incorporated is a nonprofit organization dedicated to the creation of open standards, specifications and recommended practices for Web3D graphics (for a full description, see http://www.web3d.org). From the perspective of the Web3D Consortium, "Web3D" is an overarching term to describe protocols, languages, file formats, and other technologies that are used to deliver compelling 3D content over the World Wide Web (Walsh and Bourges-Sevenier, 2001). The Web3D Consortium's charter goal is to accelerate the worldwide demand for products based on these standards through the sponsorship of market and user education programs. Through various open Teams and Working Groups, consortium members and the 3D-graphics community focus on Web3D standards and technologies to promote evolution of capabilities that will help bring Web3D into the mainstream of online experience.

Virtual Reality Modeling Language (VRML 97)

Through the mid-1990's, the Web3D Consortium worked with the Virtual Reality Modeling Language (VRML) community to develop specifications for versions 1.0 and 2.0 of the VRML language. VRML is a language for describing 3D scenes as a *scene graph*; i.e., a hierarchical decomposition of the renderable components in a scene. Expressed as text, VRML files are readily accessible over the Internet and can be written and modified using simple text editing software (Brutzman, 1998; Ames, Nadeau, and Moreland, 1997). In 1997, the International Standards Organization (ISO) established the VRML specification as an international standard. Subsequently, VRML has enjoyed widespread use as a Web3D graphics language through numerous implementations (e.g., Nexternet Piveron, Parallelgraphics Cortona, Blaxxun Contact) available as plug-ins for common Web browsers (e.g., Microsoft Internet Explorer, Netscape Navigator). VRML is also widely used as a 3D graphics interchange file format.

Extensible 3D (X3D)

The next-generation specification for VRML is the Extensible 3D (X3D) standard (see http://www.web3d.org/x3d.html). X3D is a scene graph and text-based encoding designed to overcome several limitations of the VRML standard. X3D uses the Extensible Markup Language (XML) to express identical VRML geometry and behavior structures, and is therefore a backwards-compatible XML tagset for describing the VRML 200x standard for Web-capable 3D content. This content is not static but dynamic, driven by a rich set of interpolators, sensor nodes, scripts, and behaviors. Comparison of VRML and X3D scene graph representations was provided in the 2001 I/ITSEC paper (Blais, et. al., 2001).

The X3D Working Group within the Web3D Consortium is tasked with the design, development, evaluation, and standardization of the X3D/VRML 200x specification. This group works with others in the community to define the functional and technical content of the language, documented in a specification for community review and consensus. In February 2002, the Web3D Consortium announced completion of the X3D draft specification.

In June 2002, X3D was presented as a New Project (NP) proposal to the ISO/IEC Subcommittee 24 (SC24, Working Group 6; http://www.sc24.org/) (Reddy, 2002). After a strawman vote, the attending national bodies stated they would support the X3D NP. The X3D NP request will now go out for letter ballot to all national bodies. Five national bodies need to vote positively and to indicate participation in the project in order for it to pass. Following this step, the specification will enter a 2-year timeline for approval as an international standard.

X3D DEVELOPMENT

In parallel with efforts to draft the X3D specification, the Working Group is developing an open source implementation as a proof of concept and basis for future development. This work entails development of XML representations of the language constructs, partitioned into component layers for different categories of users (from extremely “light-weight” components with minimal essential language features to “heavy-weight” components with extended language features, such as multi-user networking support), as well as implementation of an open-source browser for authoring and visualizing scenes.

The current X3D/VRML 200x XML implementation is capable of compatibly using all legacy VRML 97 content through a VRML-to-X3D translator developed by the National Institute of Standards and Technology (NIST). X3D provides new interoperability with other relevant standards including MPEG-4 and an entire family of XML-based languages. X3D further addresses several shortcomings of VRML 97, provides tighter media integration, improved visual quality through advanced-rendering nodes, and enables a component-based approach. Combined binary and geometric compression has been deferred until other X3D deliverables are complete.

The full power behind the X3D representation is in the underlying XML technology. As an XML document, the 3D scene is simply structured data, which can be processed in a variety of ways without concern for how the data should be presented. In this case, the X3D file describes 3D content, but that content need not be rendered as a 3D scene. Through Extensible Stylesheet Language Transformation (XSLT; see Deitel, Deitel, Nieto, Lin, and Sadhu, 2001), the content in an X3D/XML file may be converted to VRML, pretty-printed to HTML, or converted to any number of other formats (including objects expressed as source code). As stated in the 2001 I/ITSEC paper (Blais, et. al., 2001), expression of VRML scenes in XML enables application of a wide range of existing and emerging XML-based tools for transformation, translation, and processing. XML is rapidly transforming the Web from a vast document repository to a vast data repository (Goldfarb and Prescod, 2001). XML provides numerous benefits for extensibility and componentization. It is also important to note that XML forms the infrastructure of the Web-Enabled Navy Architecture (Task Force ‘W’, 2001), providing the link between data content, applications, and presentation. For X3D, XML further provides the ability to develop well-formed and validated scene graphs, an extremely valuable constraint since it prevents “broken” 3D content from being allowed to escape onto the Web where it might cause larger scenes to fail.

Conformance Test Suite

An extensive set of conformance examples has been created to enable browser companies and users to validate content and rendering capabilities. The Web3D VRML/X3D Conformance Test Suite integrates a body of work that originated from the NIST VRML97 Conformance Suite, and adds several new tests for new nodes. These tests are now available in XML format, allowing the tests to evolve with the VRML and X3D specifications. The test suite, consisting of approximately 850 tests, allows a viewer to evaluate a VRML/X3D browser by simply browsing through a CD (or online directory) of documented tests. Tests are organized by node group functionality (for example Geometry, Lights, Sounds) and include tests of browser state, field range testing, audio/graphical rendering, scene graph state, generated events, and minimum conformance requirements. Each test consists of an XML (X3D) file, its equivalent VRML97 file, plus an HTML “pretty print” version of the XML content for inspection. Also included with each test is a complete description of initial conditions and expected results. In addition, “sample results” in the form of .jpg or .mpg video are provided via hyperlink to give the tester a complete “picture” of a successful test result.

Xj3D Open Source

The Web3D Consortium maintains an open-source project written in Java called Xj3D. The primary goals of the project are to provide a freely available implementation of the X3D graphics specification as well as backwards compatibility with the ISO Vrml97 specification. The open source implementation allows both DoD and commercial organizations to incorporate and modify the code-base in a non-restrictive manner.

Work at NPS has employed the Xj3D code-base as a VRML97 and/or X3D content loader in Java3D in a framework-based application environment known as NPSNET-V. Figure 1 depicts the 3D visualization of an AT/FP Scene rendered using the code-base. Additionally, since the X3D graphics standard is extensible by allowing an author to define, implement, and deploy capabilities not found in the specification, the Xj3D developers have demonstrated the ability to add 2D mapping overlays, bumpmap texturing, and other graphical techniques and authoring features.

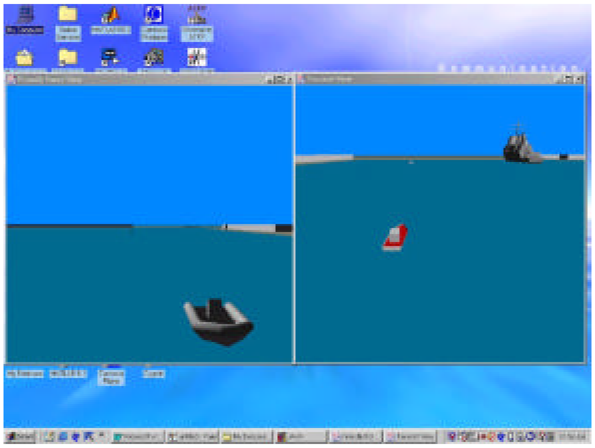

Figure 1. An X3D scene from the AT/FP scenario rendered in the NPSNET-V framework using the Xj3D code-base.

In addition to its utility as a loader/renderer within Java3D, Xj3D provides a VRML or X3D browser similar to commercially available plug-ins (such as Pivoron, Cortona, Blaxxun, etc.).

Although Xj3D is not yet complete, major releases of the software are provided to the community for testing and familiarization at approximately 6-month intervals. The Milestone 4 (M4) version of Xj3D was released at the annual Web3D Symposium in Tempe, Arizona in February 2002; Milestone 5 (M5) was released at SIGGRAPH 2002 in San Antonio, Texas in July 2002. Developer snapshot releases occur between major releases. All current source code is available through a CVS server located at http://web3d.metrolink.com.

As the Xj3D implementation becomes more complete, past difficulties experienced with the attempted widespread deployment and use of VRML97 content should be overcome allowing content authors to better utilize the Web to reach larger audiences for both training and education.

X3D IN MILITARY EDUCATION AND EXPERIMENTATION

NPS students and faculty are engaged in a number of projects and studies involving use of 3D visualizations in multi-user, interactive Web-based environments. The emerging X3D standard is used for these efforts to explore and exploit XML-based information technology tools and techniques while also providing complex and sophisticated testing of the X3D scene graph constructs. Each year, approximately 50 military students across several different curricula (e.g., MOVES, Computer Science, Operations Research, Physics, Information Technology, and others) attend introductory and advanced X3D courses at NPS. In each course, the students develop 3D models and dynamic, interactive scenes for class projects, some of which are frequently related directly to or supporting student thesis work (LT Harney's AT/FP modeling is an excellent example). Largely through student efforts, the school has developed a large library of Web-based 3D military models and authoring tools that can be reused to create ever more complex scenarios. The following paragraphs describe two significant efforts, one completed and one in progress, performed in calendar year 2002. These examples illustrate the application of X3D to create Web-based 3D visualizations supporting military experimentation.

Peer-to-Peer Communications LOE

In support of the Peer-to-Peer (P2P) LOE sponsored by the Joint Futures Laboratory, NPS created a web-based 3D visual reconstruction of the experiment scenario. The objective was to create a 3D model of the portion of the NPS campus where the experiment was conducted, together with graphical representations of the movement of student teams and their sightings as the scenario played out. The resulting dynamic playback scenes would be available in a form that could be readily shared across the network and viewed in standard browsers (Internet Explorer, Netscape Navigator) using freely available 3D plug-ins.

The setting for the P2P LOE was the NPS central Quadrangle, and consisted of several teams tasked with forward observation of an artificial hostage rescue scenario. It was not the intent of the scenario designers to replicate accurately the tactics and events of an actual hostage rescue operation. Instead, the purpose was to give the LOE a context (or back-story), making events and tasking more understandable and stimulating to the participants.

The goals of the experiment included creating a sense of shared situational awareness among the peer teams and a reach-back facility by using peer communications technologies other than reliance on voice communications alone. Reconnaissance and Surveillance Teams (RSTs) used chat, map views and the Internet to achieve this objective. In the LOE, web-based 3D visualization was used to reconstruct the scenario after the fact. We believe there is great promise in using 3D visualizations to augment experiment *planning* (for example, how the technology is being employed to support the AT/FP LOE), as well as augmenting the other means of establishing situational awareness *during* an operation.

Key tools used in the P2P LOE reconstruction effort included:

- A Java-based translator program from NIST to convert existing VRML97 models into X3D.
- X3D-Edit, a scene graph editing tool configured for X3D using the IBM Xeena XML editor (http://www.alphaworks.ibm.com/tech/xeena).
- A custom, Java-based tool to convert data generated by the participants into 3D tracks used to animate objects in the 3D world.

The Java program for converting track data to 3D visualization was an adaptation of track visualization software developed at NPS and employed in late 2001 for AUV mine warfare experiments (Weekley 2002).

Models of the campus buildings were developed several years ago for an earlier NPS project. These models were in a proprietary commercial product format, but could be exported to VRML format. The models were then converted to X3D using the VRML-to-X3D tool provided by NIST. This effort re-emphasized the value of the VRML standard as a 3D scene interchange format for multiple applications, including support for web-based 3D visualizations. Once the campus models were in X3D format, the products could be readily integrated into more complex scenes.

To construct the 3D model of the area of the campus that would be used in the P2P LOE, a physical survey of the Quadrangle was performed. This survey identified distinctive trees, shrubs, succulents and other small plants, fire alarms, pedestrian barricades, bicycles, bike rack, WWII-era contact mine display, fire hydrant, benches, picnic tables, "Thai Hut" food vendor trailer, phone booth, clock, satellite dish, as well as the primary buildings surrounding the quadrangle. In the final reconstruction, models of the following objects were used (see Figure 2): Root Hall, Spanagel Hall, Bullard Hall, Halligan Hall, Ingersoll Hall, Hermann Hall, Mechanical Engineering Building, sidewalks and roads, satellite dish, street lamp, green bench, contact mine, Thai Hut food stand and parasol, picnic pable, free standing fire alarm, fire hydrant, phone booth, wooden bench, and a low wooden bench.

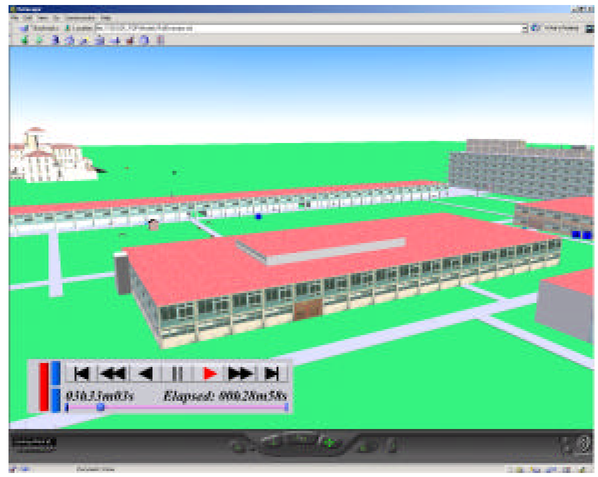

Figure 2 Virtual NPS Quadrangle with scenario playback control.

Because the 3D visualization needed to show the operation from perspectives not otherwise available, it was determined that the 3D campus should be built free of vegetation. This "tree-free" environment is still easily recognizable, while allowing unobstructed observation from various vantage points in the scene. Foliage and natural forms can be difficult to author and represent. The high polygon count of a single, realistic looking tree can reduce graphics rendering performance to the point of annoyance. While simplistic models could be created, it is questionable whether they would add significant value to the scene if they were not sufficiently detailed to give good indication of clear and obstructed lines of sight. Moreover, it was decided that tree and foliage models would not display well on handheld devices such as those used by the RST members in this LOE. An area of future work would be to create a visualization allowing the user to selectively display or not display trees and foliage in the scene, possibly in user-specified regions of the scene or for particular lines of vision.

A major aspect of the Peer-to-Peer communication infrastructure was the wireless LAN installed across the Quadrangle for the experiment. This was a combination of six wireless hubs and antennas. The coverage was purposefully spotty in order to investigate network traffic effects as teams entered and left coverage areas. To survey the experiment area, the Quadrangle was divided into 50 square meter sections, and signal strength was measured in each section. A graphical depiction of the signal strength in the area of coverage was created from the survey data. The resulting visualization served as the basis for a decision to place an additional wireless hub to provide somewhat better coverage of the region. Measurements were taken again, and the resulting signal visualization is shown in Figure 3.

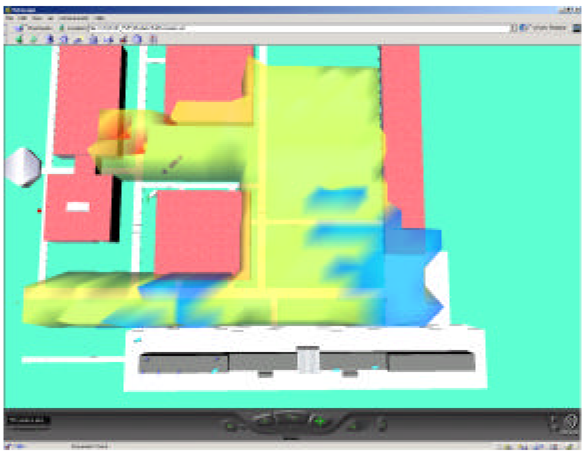

Figure 3. Wireless LAN signal strength visualization (from above).

The signal strength is indicated both by color and by height of the coverage region (i.e., poor signal strength is visualized in red at 10-meter height; moderate strength is visualized in yellow at 30-meter height; good signal strength is visualized in blue at 50 meter height).

During the 3.5 hours of the LOE execution, the Operations Center recorded over 20 Megabytes of data on own-team positions, situation reports, and sightings into a Microsoft Access database. Time-stamped position data were extracted and converted to XML structures to facilitate development of software to generate movement paths and other scenario event reconstructions in X3D file format. This activity demonstrated the power and simplicity of XML representations for automating data interchange operations.

The resulting 3D visualization (for example, Figure 4) provided representation of the teams, terrorists, and other scenario objects. On one level, the visualization provided similar graphical presentation as the 2D diagrams used in planning the LOE and scenario execution; however, as dynamic, interactive presentations, the 3D visualizations provide both spatial and temporal exploration of the scenario. Analysts could replay the experiment to see where each team was at any point in the experiment and what information each team held at that time.

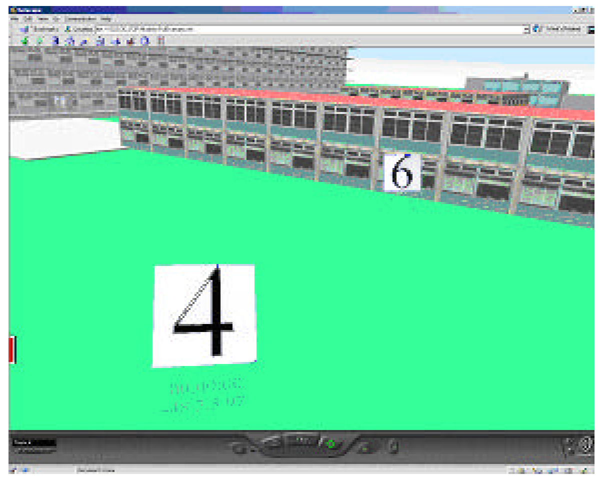

Figure 4. Team 4 and 6 icons positioned within the localized coordinate system.

This work further demonstrated that the generation of meaningful 3D worlds for Web-based distribution is becoming practical for a wide range of applications. Such visualizations can enhance LOE planning, allowing globally separated planners to “walk through” the timeline and major scenario events within the 3D world over network connections. Moreover, 3D visualization of the scenario area would have enriched pre-experiment team and participant orientation sessions, particularly for those participants not familiar with the NPS campus. Given a reliable data stream of position information and sightings during conduct of the scenario, the 3D visualization could have been updated in near-real time, augmenting the 2D situation displays that were provided in the Operations Center and on RST devices.

As shown in Figure 3, possible visualizations provide more than what “meets the eye.” Visualization of the signal strength across the physical LOE area demonstrated the potential to see and understand aspects of a problem not normally visible to planners and participants.

A key quality of the Web3D visualization that was not fully exploited during the P2P LOE is its Web-based capability. As an XML representation of the scene graph, the X3D models developed for the P2P LOE reconstruction are simply text files that are readily exchanged over networks, and can be viewed in common Internet browsers (using freely available 3D plug-ins). Moreover, as an XML file, the information in the scene is simply data that can be readily converted through stylesheet transformations into other formats.

Anti-Terrorism / Force Protection LOE

U.S. Naval forces are increasingly at risk when deployed to foreign ports and harbors. To continue to carry out the National Military Strategy of *engagement* with foreign countries through the navy, increased focus has been placed on the application of non-traditional, non-lethal weapons along with new doctrinal development in order to ensure the security of our forces. To address this issue, NPS is conducting research and development in a Web context utilizing agent technologies to assist the analysis of LOE execution for the testing and evaluation of new weapons types. A follow-on goal is to provide a prototype Force Protection tool for training and planning that can be expanded and utilized by fleet units.

A near term application for this emerging tool is an upcoming Force Protection LOE. LOE planners requested development of a visualization of the planned area of operations and primary scenario events for pre-experiment planning and post-experiment reconstruction. To provide a more complete capability to address "what-if" questions of interest in an AT/FP scenario, we are incorporating agent-based simulation into the model. The idea is to create a "laboratory" in the Web3D virtual environment to enable deeper investigation of both planned and actual scenario events, as well as exploration into "could have happened" events.

Earlier efforts in the NPS SAVAGE project developed authoring tools and techniques for reconstruction of the Al-Qaida sponsored terrorist attack on the USS COLE (DDG 67) in Aden, Yemen in October 2000. Models and techniques from the COLE scenario provided a foundation for the AT/FP LOE work, including:

- Techniques for creating the land and sea space encompassing the area where the major events occurred.
- Ship and small craft models in X3D format.
- Visual representation of physical explosive effects to maintain scientific validity as closely as possible.
- Animation of all entities within the scene as portrayed in the Court of Inquiry documentation.
- A means of allowing the user to control the animation (stop, play, rewind, fast-forward, reset) as he views the simulation.

For reconstruction of the land and sea space, Digital Terrain Elevation Data (DTED) Level 1, providing terrain elevation postings at approximately 100-meter intervals, was considered to be sufficient for our modeling purposes. For the COLE reconstruction (Figure 5) and AT/FP scenario, we chose to create sufficient land and sea space to reconstruct events from the beginning of the transit into the port. Of course, the size of the area to be represented depends on the locations and actions of entities participating in the scenario.

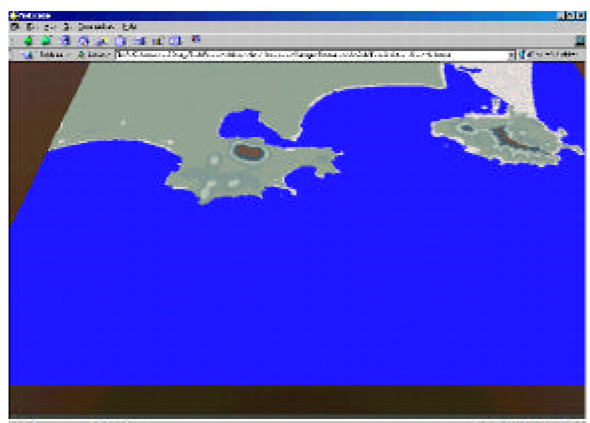

Figure 5. VRML97 rendering of the X3D representation of Aden Harbor, Yemen.

Many models of interest to the AT/FP scenario, including structures such as piers and buildings, can now be found in the SAVAGE repository generated from past student class projects and NPS research projects (see http://web.nps.navy.mil/~brutzman/Savage). This allows an author to focus on the modeling and simulation of entity relationships and scenario dynamics rather than the geometric modeling. Figure 6 is a depiction of the Arleigh Burke class Destroyer model utilized in the reconstruction of the COLE attack. In considering the use of Web3D models from the SAVAGE repository, it is important to note that, while "photo-realism" can be achieved with visual model content, it has been generally desirable to create models that correctly represent the geometry of a craft so that it can be recognized and then utilized in physics-based simulation, rather than investing undue time and effort in creating extremely high visual realism. In general, that level of visual realism is not needed for the planning and analysis activities targeted for this work. More important is the accuracy of the event timelines and object behaviors.

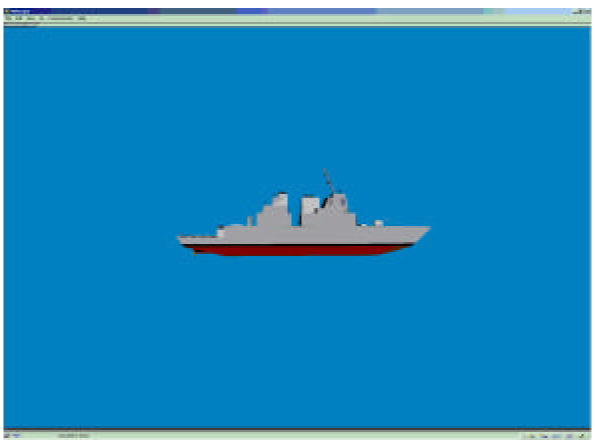

Figure 6. VRML97 rendering of the X3D representation of an Arleigh Burke Class Destroyer model from the SAVAGE model library.

To model explosions, we used the U.S. Army's unclassified TNT equivalency model to represent the various ranges of damage that occur. An unclassified failure rate of steel was utilized to determine three levels of damage (structural failure, severe damage, and light damage). Each range was then represented through the use of different colored spheres that would allow the analyst to have a visual indication of the effectiveness of an attack while viewing the simulation (Figure 7). Although a more realistic appearing explosion might look better, it would give less insight to an observer of the simulation as to what the real effects of an explosion might be, or in the case of the COLE, what the actual effects were. By designing the explosion model as an X3D prototype, it is now available in the SAVAGE library for reuse or extension in LOEs or other projects.

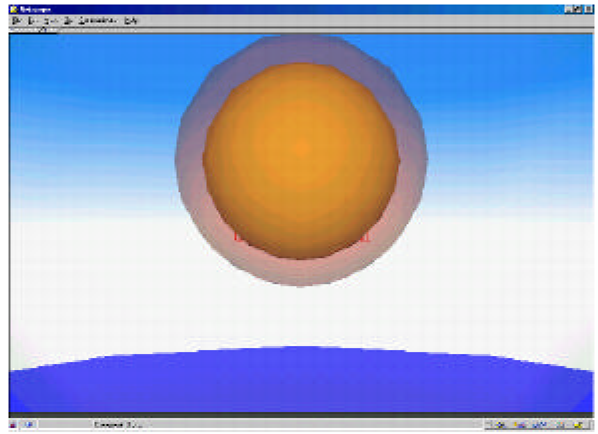

Figure 7. Physics-based explosion prototype from the NPS SAVAGE model repository.

Realistic animation of entities in scenario reconstruction can prove to be a difficult task when one considers the various factors that have to be taken into account in a 3D representation (e.g., 6 degrees of freedom and physics-based modeling for all entities that are being portrayed). Smooth yet accurate animation of entities transitioning through a course change can prove to be mathematically tedious when the number of craft increases. As a simplification for rapid development of scenarios, the SAVAGE project team previously developed a Waypoint Interpolator prototype. This was employed to create the known track of the COLE and for the possible tracks of the terrorist boat and other craft (i.e., fixed tracks for planning or reconstruction, separate from introduction of agent or human control of entity movements).

One of the most useful components developed within the SAVAGE project during the reconstruction of the attack on the COLE was the Digital Virtual Display (DVD) Prototype (Figure 8). Before its development, testing the reconstruction of scenes was extremely tedious when the developer had to wait a prolonged time period to observe critical events. Using the DVD controller, a user has multiple options by which to view a scene. The user can play, pause, fast forward, rewind, or even dynamically move the scenario forward or backward in time using a slider located on the bottom of the controls. This is one of the advantages of reconstructing events with an interactive 3D tool – the user can analyze events from a spatial or temporal perspective in various ways that might provide insights more rapidly.

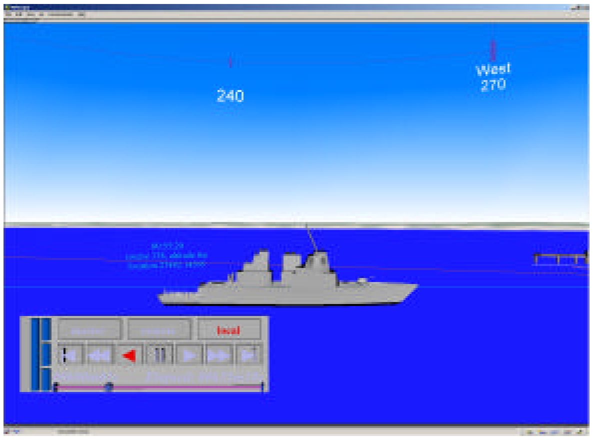

Figure 8. Digital Virtual Display (DVD) prototype example embedded in USS COLE scenario.

Static reconstruction of experiments allows us to examine events as they happen, but the capability to truly leverage current visualization technologies in this arena lies within the ability to dynamically simulate events and play "what if" scenarios. Coupled with the use of agent technologies, the analyst can explore a much greater range of questions and possibilities before expending vital funds and other resources in an actual experiment.

For the planned AT/FP LOE, a 2D planning tool (see Figure 9) was developed to facilitate craft positioning and movement planning. A Web3D visualization of the scenario is generated automatically from the planning tool input. To explore the planned scenario, a multi-layered intelligent agent approach is used (Figures 10 and 11). The initial layer can be considered as a "hands-off" approach wherein the planner defines the setup for the experiment, initiates the run, and views the computer-driven offensive and defensive agents playing out the simulation. The analyst can choose to run multiple scenarios with the same starting parameters without the visual display in order to more rapidly gather statistical data on the planned conditions. From the model output, the analyst can gain insight into various tactical parameters such as optimal picket boat placement against a surface threat, range parameters for identification and possible engagement of small craft, and redundancies required for effective defense, and then decide how to best arrange the naval forces taking part in the LOE to test the targeted equipment or doctrine without losing valuable experiment time.

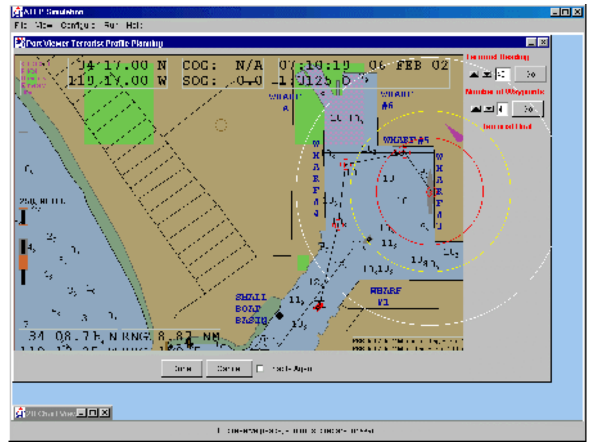

Figure 9. Depiction of simulation 2D setup with simulated threat profile for a AT/FP LOE planned to be conducted in Port Hueneme, California.

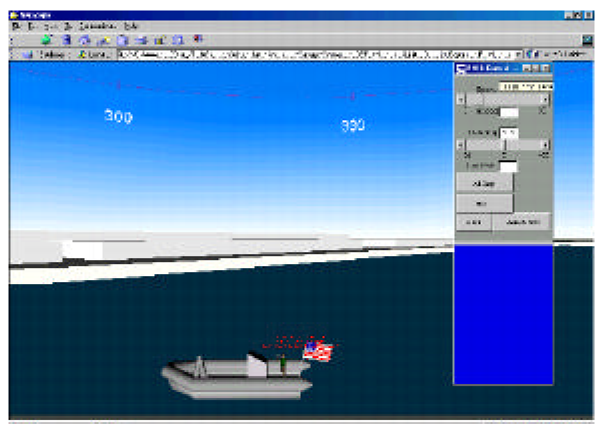

Figure 10. Graphical representation of defending RHIB in user control mode. Depicted is a conceptual representation of a non-lethal net entanglement system on the forward end of the RHIB.

Alternatively, a "human-in-the-loop" control layer allows the planner to play the role of the defense against the computer-driven offense, or to play the offense against the computer-driven defenses. In the Web-based environment, multiple human analysts can control various craft in the scenario, permitting analyst-versus-analyst interactions for collaborative examination of the scenario possibilities. Through these various layers of control, an analyst can more thoroughly examine alternative experiment set-ups and then demonstrate the planned approach to other planners/sponsors.

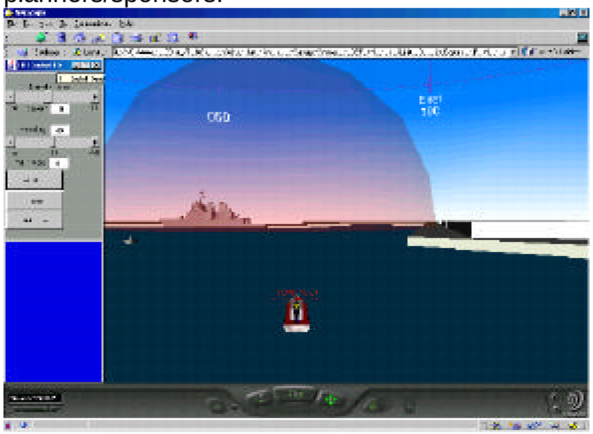

Figure 11. Graphical representation of attacking surface craft in agent control mode. Red (shaded) sphere depicted in background represents the High Value Unit's (DDG) lethal engagement range.

Finally, new weapons and their employment can be simulated with enough fidelity to aid in the overall study. In this case, a specific non-lethal weapon under consideration for employment in the FP LOE was simulated in order to gain insight to potential employment possibilities and drawbacks.

Work is currently underway to describe the initial scenario conditions in XML so that the information can be used for model initiation as well as for input to other processes. Similarly, the output data are being expressed in XML, enabling stylesheet transformations to other XML tagsets, such as Scalable Vector Graphics (SVG) for generation of output charts. As discussed in the previous example of the P2P LOE and further demonstrated in the AT/FP modeling, X3D is proving to be a valuable tool for Web-based 3D visualization addressing all phases of LOE execution, from planning to conduct to post-experiment reconstruction.

FUTURE RESEARCH DIRECTIONS FOR WEB3D APPLICATIONS

The X3D specification is an exciting ongoing area of work, expressing the geometry and behavior capabilities of VRML using the Web-compatible tagsets of XML. Scene graphs, nodes, and fields respectively correspond to document, elements, and attributes in XML parlance. At its foundation, XML benefits are numerous, including customized metalanguages for structuring data easily read by humans and computer systems and validatable data constraints. Moreover, XML is license-free, platform-independent and well-supported. Together these qualities ensure that the VRML ISO standard is being extended to functionally match the emerging family of next-generation XML-based Web languages.

Web3D is a powerful medium for construction, dissemination, and employment of dynamic, interactive, multi-user virtual environments. Used for simplistic, rapid, low-cost visualization or integrated with sophisticated software for agent-based behaviors and physics-based models, Web3D is proving to be an effective tool for providing insights into real-world scenario planning and reconstruction. The technology is helping analysts more effectively assess tactics, techniques, procedures, weapons, and other systems that can benefit today's and future warfighters. Research is needed in determining optimal methodologies for integration and execution of agent-based simulation in the scenarios, and for analysis of execution outcomes, to facilitate user efforts in configuring scenario conditions for analysis.

The Department of Defense is currently converting standard United States Message Text Format (USMTF) messages into XML (XML-MTF, 2001). Research at NPS has shown the potential of autotranslating 3D models directly from USMTF operations-order messages (Murray and Quigley, 2000; Nicklaus 2001) and from tactical communications planning systems (Laflam, 2000, and Hunsberger, 2001). In a collaborative effort with the Naval Undersea Warfare Center (NUWC) and NPS, the Institute for Defense Analysis (IDA) has created an XML-based Land Command and Control Information Exchange Data Model (LC2IEDM; IDA, 2000) to form a basis for interoperability among command and control systems. Work is needed to enable greater automation in this process, both through refinement in the operational messaging process and in the ability of software to extract necessary visualization requirements and components from the operational message (e.g., terrain and environmental data for the scenario location, behaviors for the scenario participants, 3D models for the entities to be represented).

Efforts to create a common "dialect" for autogenerating Web3D content from operational messages is complemented by work underway in the Department of Defense to define a common XML tagset for scenario descriptions to facilitate interoperability among simulation systems and command and control systems. Two efforts are being monitored closely for applicability to the SAVAGE project: (1) Joint Simulation System (JSIMS) Common Control WorkStation (CCWS) scenario generation (JSIMS, 2000); (2) DMSO dynamic scenario builder initiatives (Lacy, Stone, and Dugone, 1999, and Lacy and Dugone, 2001). It is expected that these efforts will provide a set of abstractions describing scenario elements, from which an XML-based tool can be configured to enable a user to construct the scenario in a hierarchical manner with time sequenced behaviors. The resulting XML file can then be manipulated in any number of ways, including transformation into X3D for Web-based 3D visualization. Additional representation schemes for asymmetric warfare, military operations in urban terrain, information warfare, and other "nontraditional" battlespaces present a significant research challenge.

The SAVAGE project is a long-term research program seeking to push the frontier of Web-based 3D scenario authoring and visualization. In addition to the numerous models and case-study examples previously described, directions for the work include:

- Expanding the palette of models and events that can be inserted into a scenario, including representation of control measures and other non-physical concepts in the battlespace.
- Creating scenarios of greater complexity depicting the interplay of represented land, air, sea, and littoral objects and operations. Include the interaction of operations with control measures.
- Creating branching flows in the scenario script to present decision points that engage the user in the unfolding scenario.
- Investigating assignment of behaviors to scenario objects; for example, from XML libraries of pre-scripted actions (see Lacy and Pearman, 2000) with adaptation mechanisms to the current situation.
- Developing techniques for rapidly generating battlespace terrain, to include representation of built-up areas and vegetation cover, for use in the Web3D environment.
- Automating extraction of scenario information from doctrinal operations orders and plans.
- Integrating Web3D graphics into an overarching Web-based Modeling and Simulation framework

The Department of Defense (DoD) is engaged in both warfighting and institutional transformation for the new millennium. DoD Modeling and Simulation (M&S) also needs to identify and adopt transformational technologies providing direct tactical relevance to warfighters. The only software systems that have proven to scale to worldwide scope utilize the World Wide Web. Therefore, it is evident that an extensible Web-based framework shows great promise to scale up the capabilities of M&S systems to meet the needs of training, analysis, acquisition, experimentation, and the operational warfighter. By embracing commercial Web technologies as a shared-communications platform and a ubiquitous-delivery framework, DoD M&S can fully leverage mainstream practices for enterprise-wide software development. NPS, with partners SAIC and George Mason University, has initiated the Extensible Modeling and Simulation Framework (XMSF) project to promote Web-based technologies to support the spectrum of DoD M&S (constructive, virtual, and live, together with increasingly important distance-learning capabilities). The X3D standard for Web-based 3D visualization is a key component in the set of technologies showing potential to achieve the far-reaching goals of XMSF for future training, education, and experimentation.

REFERENCES

Ames, A., Nadeau, D. & Moreland, J. (1997). VRML 2.0 sourcebook (2nd ed.). New York: John Wiley & Sons.

Blais, C.L., Brutzman, D. Horner, D.P. & Nicklaus, S. (2001). Web-based 3D technology for education – the SAVAGE project. In Proceedings, 2001 Interservice/Industry Training, Simulation, and Education Conference (Orlando, FL, Nov. 26-29).

Blais, C.L., Brutzman, D., Harney, J.W., & Weekley, J. (2002a). Web-based 3D reconstruction of scenarios for limited objective experiments. In Proceedings of the 2002 Summer Computer Simulation Conference, San Diego, 17-19 July.

Blais, C.L., Brutzman, D., Harney, J.W. & Hiles, J. (2002b). Analyzing anti-terrorist tactical effectiveness for force protection using X3D graphics and agent based simulation. Presented at

70th MORS Symposium, Military Operations Research Society Conference. (Ft. Leavenworth, Kansas, June 16-18).

Brutzman, D. (1998, June). The virtual reality modeling language and java. Communications of the ACM, 41:6, 57-64.

Couch, J., & Hudson, A. (2001, draft). Viewing and incorporating VRML content with Xj3D.

Deitel, H. M., Deitel, P. J., Nieto, T. R., Lin, T. M., & Sadhu, P. (2001). XML how to program. Upper Saddle River, New Jersey: Prentice Hall.

Goldfarb, C. F., & Prescod, P. (2001). The XML handbook (2nd ed.). Upper Saddle River, New Jersey: Prentice Hall PTR.

Hunsberger, M. G. (2001, June). 3D visualization of tactical communications for planning and operations using virtual reality modeling language (VRML) and extensible 3D (X3D). Monterey, California: Naval Postgraduate School.

IDA (2000, July). Overview of the land C^2 information exchange data model. Institute for Defense Analyses.

IEEE (1996). IEEE standard for distributed interactive simulation application protocols. IEEE Std 1278.1-1995. Institute of Electrical and Electronic Engineers.

JSIMS (2000, October 3 draft). Battlespace XML schema. Orlando, Florida: Joint Simulation System (JSIMS) Common Controller Work Station (CCWS) Scenario Generation Team.

Katz, W. (1998). Networked synthetic environments: from DARPA to your virtual neighborhood (pp 115-127). In C. Dodsworth (Ed.), Digital Illusions. Reading, Massachusetts: Addison-Wesley.

Lacy, L., Stone, G., & Dugone, T. D. (1999, September). Sharing HLA scenario data. In Proceedings of the Fall 1999 Simulation Interoperability Workshop. Paper 99F-SIW-190.

Lacy, L., & Pearman, G. M. (2000, September). Computer generated forces behavior representation and reuse using the extensible markup language (XML). In Proceedings of the Fall 2000 Simulation Interoperability Workshop. Paper 00F-SIW-121.

Lacy, L. W., & Dugone, T. D. (2001, May draft). Military scenario definition language. Monterey, California: US Army TRADOC Analysis Center.

Laflam, D. (2000, September). 3D visualization of theater-level radio communications using a networked virtual environment. Master's Thesis. Monterey, California: Naval Postgraduate School.

Miller, T. E. (2000, September). Integrating realistic human group behaviors into a networked 3D virtual environment. Master's Thesis. Monterey, California: Naval Postgraduate School.

Murray, M. W., & Quigley, J. M. (2000, June). Automatically generating a distributed 3D battlespace using USMTF and XML-MTFAIR tasking order, extensible markup language (XML) and virtual reality markup language (VRML). Monterey, California: Naval Postgraduate School.

Nicklaus, S. (2001). Scenario authoring and visualization for advanced graphical environments. Master's Thesis, Naval Postgraduate School.

Pilnick, S.E, Curtis, K., Richards, F.R., Kemple, W., Bordetsky, A., Buddenberg, R., Hutchins, S., Kline, J., Adamo, R. & Boger, D. (2002). Peer-to-peer limited objective experiment. Technical Report (to be published). Naval Postgraduate School, Monterey, California.

Reddy, M. (2002). Trip report for ISO/IEC JTC1/SC24 meetings. Web3D Consortium.

Task Force 'W' (2001, January). Web-enabled navy architecture, version 2.0. Vice Chief of Naval Operations. http://www.tfw.navy.mil

VRML (1997, December). VRML 97 international specification. ISO/IEC 14772-1.

Walsh, A. E., and Bourges-Sevenier, M. (2001). Core web3D. Upper Saddle River, New Jersey: Prentice-Hall.

XML-MTF (2001). Principles and derivations in support of XML-MTF. XML-MTF Development Team. Reston, Virginia: Mitre Corporation.

Weekley, J. (2002). Technical report for AUVFest 2001. ROLANDS & ASSOCIATES Corporation, Monterey, California.