WEB-BASED 3D TECHNOLOGY FOR SCENARIO AUTHORING AND VISUALIZATION: THE *SAVAGE* PROJECT

Curtis Blais, Don Brutzman, Doug Horner, and Major Shane Nicklaus, USMC
Naval Postgraduate School, Monterey California
clblais@nps.navy.mil brutzman@nps.navy.mil

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http://web.nps.navy.mil/~brutzman/Savage/documents/WebBased3dTechnology-Savage-IITSEC2001.pdf

ABSTRACT

The purpose of this paper is to describe current work in specification and development of Web-based 3D standards and tools. The paper presents a Web3D application for military education and training currently in progress for the Defense Modeling and Simulation Office and the Marine Corps Combat Development Command.

Web-based 3D content development tools continue to evolve. The Web3D Consortium (http://www.web3d.org) promotes the specification and development of tools for exploiting 3D graphics in the World Wide Web. Current work is focused on developing the next-generation specification for Web3D, referred to as Extensible 3D (X3D – http://www.web3d.org/x3d.html). X3D is a scene graph architecture and encoding that improves on the Virtual Reality Modeling Language (VRML) 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. Primary target applications for X3D are electronic commerce product and technology demonstration, visual simulation, database visualization, advertising and web page animation, augmented news and documentaries, training, games, entertainment, and education. This paper discusses how X3D will address shortcomings of VRML 97, VRML 97 compatibility, interoperation with other relevant standards, tighter media integration, improved visual quality, component-based approach, file format issues, and time to market. The paper will also present the current progress of the X3D Working Group in developing the runtime core specification, component specifications, advanced graphics extensions (including GeoVRML for geographic representations and H-Anim for humanoid models), XML 3D tags definition, text file format, binary file format, conversion and transformation of existing VRML 97 content, conformance testing, demonstrations, and implementations.

The Defense Modeling and Simulation Office (DMSO) and Marine Corps Combat Development Command (Training and Education Command) have tasked the Naval Postgraduate School (NPS) to perform research toward development of a scenario authoring and Web-based visualization capability. Prototyping activities are employing Web-based technologies for information content (XML) and 3D graphical content (X3D) to create an initial presentation of an amphibious operation. The envisioned full capability will represent critical aspects of the battlespace, such as terrain, force dispositions, maneuvers, fires, coordination measures, and timing. This 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 describes application of the capabilities into other education and training domains.

ABOUT THE AUTHORS

Curtis Blais is a Research Associate at the Naval Postgraduate School, with joint faculty appointment to the Institute for Joint Warfare Analysis (IJWA) and 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 collaborative planning. 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 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 toward a PhD in MOVES at the Naval Postgraduate School.

Don Brutzman is Assistant Professor at the Naval Postgraduate School in the Modeling, Virtual Environments, and Simulation (MOVES) Institute and the Undersea Warfare Academic Group. Dr. Brutzman's research efforts include 3D real-time virtual worlds and 3D visualization of sonar signals and 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 PhD in Computer Science, with a minor in Operations Research, from NPS in 1994.

Doug Horner is a Research Associate at the Naval Postgraduate School with the Modeling, Virtual Environments, and Simulation (MOVES) Institute. His principle research areas at NPS include Web-based 3D graphics for military applications, development and implementation of computer simulation systems, and software interfaces for Autonomous Underwater Vehicles (AUVs). He served 12 years in the U.S. Navy as a Naval Special Warfare (SEAL) officer. Mr. Horner received his B.A./B.S. in Economics and Mathematics at Boston University, a M.S. in Applied Mathematics and M.A. in National Security Affairs at the Naval Postgraduate School, and is currently working towards a PhD in MOVES at the Naval Postgraduate School.

Major Shane Nicklaus, United States Marine Corps, is a student at the Naval Postgraduate School completing a M.S. in Information Systems Technology. His thesis research at NPS involves integrated Web access and a 3D visualization strategy for Department of Defense tactical messaging and operation orders using coalition data models and XML, with specific focus on Marine Corps amphibious operations. Prior to coming to NPS, Major Nicklaus served eight years in the Marine Corps as Financial Management Officer. Assigned billets included: Deputy Disbursing Officer, 1st FSSG; Disbursing Officer, 15th Marine Expeditionary Unit (deployed); Assistant REA Officer/Assistant Budget Officer/HQSVCCO Commander, HQSVCBN, Marine Forces Pacific. Major Nicklaus has a B.S. in Marketing from the University of Southern California. Following graduation from NPS in September 2001, Major Nicklaus will be assigned to the Marine Air-Ground Task Force (MAGTF) Staff Training Program Center (MSTPC) in Quantico, Virginia.

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PREFACE

Extraordinary growth in 3D graphics, Web accessibility, and networking presents new opportunities for education. Personal computing and data storage resources are no longer confined to desktops or Local-Area Network (LAN) resources, but extend to the myriad processing and storage resources interconnected world-wide. This extended computing medium continues to have a revolutionary impact on the way we work, learn, recreate, interact, conduct business, and store and retrieve information.

What is perhaps even more startling is that systems taking advantage of this new network-centric paradigm remain largely two-dimensional (2D), while problems of interest continue to be decidedly three-dimensional (3D). In real life, individuals are comfortably immersed within and can freely navigate 3D physical space. Nevertheless, despite 25 years of graphics research and a long line of competing proprietary technologies, creating compelling 3D virtual spaces is usually problematic. To date, interactive 3D graphics are noticeably missing from day-to-day production systems and most online web pages.

This paper presents current efforts in Web-based 3D technology by one key organization, the Web3D Consortium (http://www.web3d.org). In a pioneering endeavor, the Web3D Consortium is working to open the Web-based 3D frontier to all by charting the territory, establishing shared goals, and building lines of communication. The paper also describes efforts of the Modeling, Virtual Environments, and Simulation (MOVES) Institute at the Naval Postgraduate School (NPS) to introduce emerging Web3D technology into the forefront of military professional education. Specific techniques, models, and scenarios are presented from the Scenario Authoring and Visualization for Advanced Graphical Environments (SAVAGE) project at NPS.

INTERACTIVE 3D GRAPHICS ON THE WEB

Creation of 3D model geometry, materials, lighting, and rendering are generally well-understood technologies (see Foley, van Dam, Feiner, and Hughes, 1990). Current graphics-acceleration hardware has eliminated previous frame-rate impediments and many complex scenes are now rendered quickly and stunningly. As more and more people utilize 3D worlds, user interactivity becomes a dominant requirement. There are four key aspects to interactivity in 3D graphical content:

- Movement – objects in the scene can move independently, relative to each other and relative to the viewer's viewpoint
- Navigation – the viewer can effectively look about and move within the scene, without getting disoriented or "lost in cyberspace"
- Responsiveness – the viewer can initiate object changes and trigger embedded behaviors and motions within a scene, usually based on realistic physics or plausible logic
- World models – a significant amount of world information is available, either via a local database or via shared network resources

Through these characteristics, the viewer is not constrained to remain a passive observer of the rendered scene, but can also become an active participant in the scene. Together these characteristics help the viewer attain a sense of autonomy, immersion and presence in the 3D scene (Zeltzer, 1992).

The phrase "Web3D content" refers to 3D graphics rendered via a web browser, such as Microsoft Internet Explorer or Netscape Navigator. 3D content needs to be as easy to access and view in a browser as 2D text and graphics in a Hypertext Markup Language

(HTML) document are today if similar scalability, ubiquity, and “ease of use” are to be attained.

3D content must be accessible via networked browsers in order to grow and interconnect without bound. This is different from the separate-program installation methodology required by most standalone or large-scale multi-player online games. For commercial reasons (i.e., billing), most large-scale commercial online games are separate customized applications that only allow authenticated users to join and depart distributed virtual environments. In return, such shared applications provide state management and communications among the host servers and other players. The application further provides specialized (usually proprietary) graphics rendering that only utilizes 3D content that is uniquely prepared for that application. While this is an effective business model for online gaming, it is not a very scalable or robust approach for long-term military and scientific applications that must steadily grow and improve (and perhaps even interoperate).

Open, scalable, nonproprietary Web-based 3D graphics technologies are available today. For example, Figure 1 shows a screen capture from a multi-player research game developed at the Naval Postgraduate School to study Web3D issues as well as broader networked virtual environment (NVE) architectural questions. The application was implemented using Distributed Interactive Simulation (DIS), the Java programming language, and Virtual Reality Modeling Language (VRML) standards for maximal interoperability.

Figure 1. Multiple helicopters, tanks and humanoid avatars move and interact within the NPS Capture-the-Flag research application, a synthetic battlespace on Fort Irwin terrain (45x55km^2), rendered here using Netscape Navigator, CosmoPlayer VRML 3D plug-in, and DIS-Java-VRML networking.

WEB3D CONSORTIUM

The Web3D Consortium Incorporated is a nonprofit organization dedicated to the creation of open standards, specifications and recommended practices for Web3D graphics (http://www.web3d.org). The Web3D charter goal is to accelerate the worldwide demand for products based on these standards through the sponsorship of market and user education programs. The VRML community and the Web3D Consortium led the development of specifications for versions 1.0 and 2.0 of the Virtual Reality Modeling Language (VRML), which became an international standard through the International Standards Organization (ISO) (VRML, 1997). 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.

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). Established in 1994, the Web3D Consortium today consists of leading-edge companies and technical experts from around the world working together to design, develop, and promote open, interoperable, and standardized technologies. Taken together, such works comprise “Web3D.” The Web3D Consortium sponsors symposia and operates numerous mailing lists for ongoing technical exchange on questions and issues relating to Web3D technologies and industry development.

Web3D Working Groups and Teams

Working Groups form the heart of the Web3D consortium. Here, members collaborate to develop Web3D Recommended Practices (i.e., practices recognized as the official position of the Consortium, but not yet advanced to ISO as an official specification), standards, tools, and technologies. The Working Groups operate under the jurisdiction of one or more of the

Consortium's Teams (Commercialization, Specification, Implementation and Communication).

The wide scope of the Web3D Consortium is evident in the topics addressed by the following sampling of currently active Working Groups. The Web3D Consortium web site provides further detail on all Working Groups.

- Extensible 3D (X3D) Specification – design, develop, implement, evaluate, and standardize the X3D/VRML 200x specification.

- Source Code Management – manage and develop open-source and community-source code contributions including the Xj3D (Java-based) loader/browser and blaxxun's Contact (C++ based) browser.

- GeoVRML – determine methods for representing geo-referenced data in VRML, and develop tools, Recommended Practices, and standards necessary to generate, display, and exchange such data. GeoVRML 1.0 is currently a Web3D Consortium Recommended Practice.

- Humanoid Animation (H-Anim) – create a standard VRML representation for humanoids (Figure 2; Miller, 2000). H-Anim 1.1 is currently a Web3D Consortium Recommended Practice.

Figure 2. A team of humanoid avatars, implemented in accordance with the Web3D Consortium H-Anim Recommended Practice, prepare to embark on a helicopter in the NPS Capture-the-Flag research application.

- Distributed Interactive Simulation (DIS) – establish networking conventions for building multicast-capable, large-scale virtual environments (LSVEs) (IEEE, 1996; Katz, 1998).

- Universal Media – define a small, cross-platform library of locally resident media elements (textures, sounds, and VRML objects) and a uniform mechanism by which VRML content creators can incorporate these media elements into their worlds.

- Virtual reality transfer protocol (vrtp) – provide client, server, many-to-many multicast streaming and network-monitoring capabilities in support of internetworked 3D graphics and LSVEs.

The Web3D Consortium has submitted Amendment 1 to the VRML 97 specification with a number of incremental improvements. The External Authoring Interface (EAI) specifies a stable interface between a VRML world and an external Web page. GeoVRML and H-Anim are formally specified. Clarifications to the event model and miscellaneous corrections update the VRML 97 specification to match several years of progress and "lessons learned."

True to the Consortium's charter, these initiatives illustrate the commitment of the organization to defining and fostering technologies that will enhance the online 3D experience for all users.

Virtual Reality Modeling Language (VRML 97)

Simply stated, VRML is a language for describing 3D scenes. The language uses the scene graph paradigm; 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) provides a good overview of VRML language features. An excellent textbook covering the language in detail is the VRML 2.0 Sourcebook by Ames, Nadeau, and Moreland (1997). A complete technical reference is the Annotated VRML 2.0 Reference Manual (Carey and Bell, 1997).

Figure 3 shows a portion of a scene graph representation of a Marine Corps amphibious

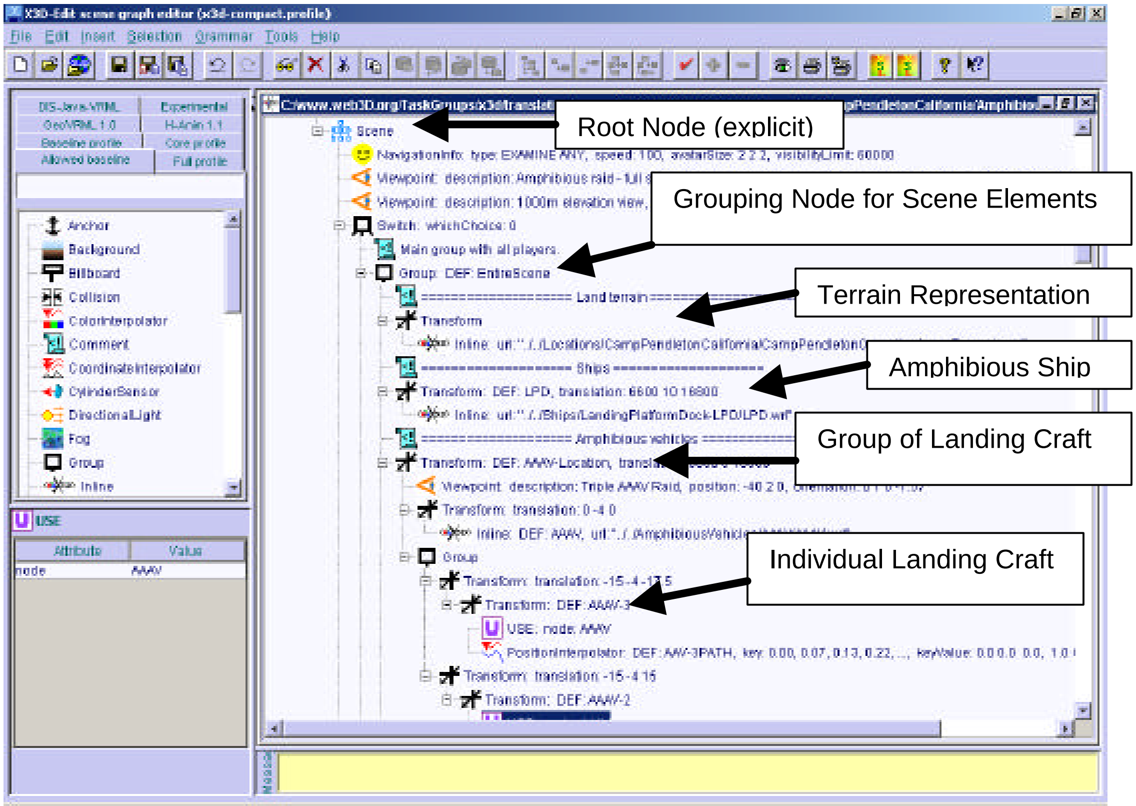

Figure 3. Scene graph representation of a Marine Corps amphibious operation, using the IBM Xeena XML Editor configured for X3D. Note the same content as in Figures 4 and 5.

operation. This diagram illustrates the hierarchical structure of the scene graph. Subordinate to the top-level (root) Scene node, the author has referenced a terrain file containing depiction of a portion of the Camp Pendleton operating area. The scene includes a Landing Platform Dock (LPD) amphibious ship and three Advanced Amphibious Assault Vehicles (AAAV). In each case, detailed geometries for the platforms (LPD and AAAVs) are imported from external files using the Inline node.

The landing craft are collected together in a Transform node, permitting the entire group to be placed and animated in the scene as an aggregate entity. Individual positions of the landing craft relative to the lead vehicle are animated using subordinate Transform nodes. In this fashion, both aggregate and individual entity behaviors and physics can be modeled simultaneously.

An excerpt from a VRML file describing the same scene is shown in Figure 4. Annotations on the figure relate language constructs to the same scene elements as shown in Figure 3. In general, the VRML language syntax (e.g. bracket and brace structures) is fairly hard to learn and debug without the use of an authoring tool. On the other hand, a strength of the standard is that graphical scenes can be created directly through text editing, and those files can be readily shared over the net.

Today, authors seldom need to develop 3D content using a text editor to code “raw” VRML. Tools such as the XML-based scene-graph editor shown in Figure 3 make construction and understanding of VRML scenes much easier. In VRML/X3D courses taught at NPS over the past 3 years, the authors have witnessed significant increases in student progress through course materials and in producing complex 3D models through the introduction of this editing tool into the classes.

```
#VRML V2.0 utf8
# X3D-to-VRML-97 XSL translation autogenerated by X3dToVrml97.xsl
# http://www.web3D.org/TaskGroups/x3d/translation/X3dToVrml97.xsl
# [Scene]
NavigationInfo {
  avatarSize [ 2 2 2 ]
  speed 100
  type [ "EXAMINE" "ANY" ]
  visibilityLimit 60000
}
Viewpoint {
  description "Amphibious raid - full scenario seen from above"
  orientation -0.557 -0.799 -0.229 0.9506
  position -600 10000 25000
}
Viewpoint {
  description "1000m elevation view"
  orientation 0 1 0 -0.78
  position -200 1000 22000
}
Switch {
  whichChoice 0
  choice [
  DEF EntireScene Group {
    children [
    Transform {
      children [
      Inline {
        url [ "../../Locations/CampPendletonCalifornia/CampPendletonOperatingAreasExample.wrl"
"http://web.nps.navy.mil/~brutzman/vrml/examples/NpsMilitaryModels/Locations/CampPendletonCalifornia/CampPendletonOperat
ingAreasExample.wrl"
]
      }
      ]
    }
    DEF LPD Transform {
      translation 6600 10 16800
      children [
      Inline {
        url [ "../../Ships/LandingPlatformDock-LPD/LPD.wrl"
"http://web.nps.navy.mil/~brutzman/vrml/examples/NpsMilitaryModels/Ships/LandingPlatformDock-LPD/LPD.wrl"
]
      }
      ]
    }
    DEF AAAV-Location Transform {
      translation 6600 0 16800
      children [
      Viewpoint {
        description "Triple AAAV Raid"
        orientation 0 1 0 -1.57
        position -40 2 0
      }
      Transform {
        translation 0 -4 0
        children [
        DEF AAAV Inline {
          url [ "../../AmphibiousVehicles/AAAV/AAAV.wrl"
"http://web.nps.navy.mil/~brutzman/vrml/examples/NpsMilitaryModels/AmphibiousVehicles/AAAV/AAAV.wrl"
]
        }
        ]
      }
      Group {
        children [
        Transform {
          translation -15 -4 -17.5
          children [
          DEF AAAV-3 Transform {
            children [
            USE AAAV
            DEF AAV-3PATH PositionInterpolator {
              key [ 0.00, 0.07, 0.13, 0.22, … ]
              keyValue [ 0.0 0.0  0.0,  1.0 0.96 1.0, … ]
            }
            ]
          }
          ]
        }
        Transform {
          translation -15 -4 15
          children [
          DEF AAAV-2 Transform { …
```

Root Node (implicit)

Grouping Node for Scene Elements

Terrain Representation

Amphibious Ship

Group of Landing Craft

Individual Landing Craft

Figure 4. Excerpt from a VRML file describing a Marine Corps amphibious operation. Note that the same content is being described as in Figures 3 and 5.

Since establishment of VRML as an international standard in 1997, numerous authoring and rendering tools, including plug-ins for common Internet browsers, have been developed and made available to the public as freeware or commercial products. In addition, many 3D authoring products now provide the capability to import and export VRML formatted files, enhancing interoperability across multiple formats. All of these aspects have contributed to VRML becoming the most widely used form of Web3D on the Internet today (Walsh and Bourges-Sevenier, 2001).

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. X3D is thus a backwards-compatible XML tagset for describing the VRML 200x standard for Web-capable 3D content. Such content is not static but dynamic, driven by a rich set of interpolators, sensor nodes, scripts, and behaviors.

An excerpt from an X3D file is shown in Figure 5. The XML tags in the example correspond to the scene graph example in Figure 3 and the VRML excerpt in Figure 4. In fact, the VRML content in Figure 4 was generated directly from the X3D file shown in Figure 5. The conversion stylesheet from one format to the other was written using Extensible Stylesheet Language Transformation (XSLT; see Deitel, Deitel, Nieto, Lin, and Sadhu, 2001). This is part of the power behind using an XML representation: XML describes the 3D scene as structured data, which can be processed without paying attention to how the data should be presented. In this case, it describes 3D content, but that content need not be rendered as a 3D scene. Through different XSL files, the content in an X3D/XML file may be converted to VRML (as shown above), to pretty-printed HTML (see Figure 6), or to any number of other formats (including source code).

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), forming 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 "broken" 3D content would no longer be allowed to escape onto the Web where it might cause larger scenes to fail.

Primary target applications for X3D are e-commerce product and technology demonstration, visual simulation, database visualization, advertising and web page animation, augmented news and documentaries, training, games and entertainment, virtual characters, and education. This list was developed after months of surveys and extensive discussions by the Web3D Consortium, and still holds true. Of interest, the Consortium could not identify a single "killer application" that trumps all others. Instead, 3D graphics has a great variety of application areas which all need to be supported in combination. This situation provides significant guidance to X3D language designers.

X3D/VRML 200x is capable of compatibly using all legacy VRML 97 content. 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.

A huge set of conformance examples now enable browser companies and users to validate both content and rendering capabilities. The Web3D VRML/X3D Conformance Test Suite integrates a body of work that originated from the National Institute of Standards and Technology (NIST) VRML97 Conformance Suite, and adds several new tests for new nodes. Those 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

```
<?xml version="1.0" encoding="UTF-8"?>
<!DOCTYPE X3D PUBLIC "http://www.web3D.org/TaskGroups/x3d/translation/x3d-compact.dtd"
                     "file:/                          skGroups/x3d/translation/x3d-compact.dtd">
<X3D>
  <Scene>
    <NavigationInfo avatarSize="2 2 2" speed="100" type="EXAMINE ANY" visibilityLimit="60000"/>
    <Viewpoint
      description="Amphibious raid - full scenario seen from above"
      orientation="-0.557 -0.799 -0.229 0.9506" position="-600 10000 25000"/>
    <Viewpoint description="1000m elevation view"
      orientation="0 1 0 -0.78"
      position="-200 1000 22000"/><!--ViewP
      prototype lets us find good viewpoint
      scene--><ProtoInstance name="ViewPosi
      <fieldValue name="enabled" value="tru
    <Switch whichChoice="0"><!--Ma    oup with all players.-->
      <Group DEF="EntireScene">
      <!--===================== Land terrai
        <Transform>
          <Inline
url="&quot;../../Locations/CampPendletonCalifornia/CampPendletonOperatingAreasExample.wrl&quot;&#10;&quot;http
://web.nps.navy.mil/~brutzman/vrml/examples/NpsMilitaryModels/Locations/CampPendletonCalifornia/CampPendletonO
peratingAreasExample.wrl&quot;&#10;&quot;../../Locations/CampPendletonCalifornia/CampPendletonOperatingAreasEx
ample.xml&quot;&#10;&quot;http://web.nps.navy.mil/~brutzman/vrml/NpsMilitaryModels/Locations/CampPendletonCali
fornia/CampPendletonOperatingAreasExample.xml&quot;&#10;"/>
        </Transform><!--==================== Ships ===========
          <Transform DEF="LPD" translation="6600 10 10   ">
          <Inline url="&quot;../../Ships/LandingPlatformDock-
LPD/LPD.wrl&quot;&#10;&quot;http://web.nps.navy.mil/~brutzman/vrml/examples/NpsMilitaryModels/Ships/LandingPla
tformDock-LPD/LPD.wrl&quot;&#10;&quot;../../Ships/LandingPlatformDock-
LPD/LPD.xml&quot;&#10;&quot;http://web.nps.navy.mil/~brutzman/vrml/examples/
tformDock-LPD/LPD.xml&quot;&#10;"/>
        </Transform><!--==================== Amphibious vehicl  ==========
          <Transform DEF="AAAV-Location" translation="6600 0 1   00">
          <Viewpoint description="Triple AAAV Raid"
            orientation="0 1 0 -1.57" position="-40 2 0"/>
          <Transform translation="0 -4 0">
            <Inline DEF="AAAV"
url="&quot;../../AmphibiousVehicles/AAAV/AAAV.wrl&quot;&#10;&quot;http://web.nps.navy.mil/~brutzman/vrml/examp
les/NpsMilitaryModels/AmphibiousVehicles/AAAV/AAAV.wrl&quot;&#10;&quot;../../AmphibiousVehicles/AAAV/AAAV.xml&
quot;&#10;&quot;http://web.nps.navy.mil/~brutzman/vrml/examples/NpsMilitaryModels/AmphibiousVehicles/AAAV/AAAV
.xml&quot;&#10;"/>
          </Transform>
          <Group>
            <Transform translation="-15 -4 -17.5">
              <Transform DEF="AAAV-3">
                <USE node="AAAV"/>
                <PositionInterpolator DEF="AAV-3PATH"
                  key="0.00, 0.07, 0.13, … "/>
              </Transform>
            </Transform>
            <Transform translation="-15 -4 15">
              <Transform DEF="AAAV-2">
```

Root Node (explicit)

Grouping Node for Scene Elements

Terrain Representation

Amphibious Ship

Group of Landing Craft

Individual Landing Craft

Figure 5. Excerpt from an XML file describing a Marine Corps amphibious operation. Note that the same content is being described as in Figures 3 and 4.

broken down 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 also 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 Xj3D codebase enables creation of a test bed for researching future standards and specification work, as well as a toolkit that allows easy incorporation of VRML content into other applications (Couch and Hudson, 2001). The source code is freely available, inviting technical collaboration, reuse and contribution by Web3D developers. Features of the Xj3D project include:

Figure 6. Amphibious Raid page from the online NPS Military Models directory showing a portion of the XML file "pretty-printed" in HTML. This is the same scenario as described in Figures 3, 4, and 5, with the addition of a representation of communications capabilities. In the upper right corner is an active 3D window with a top-level view of the scenario battlespace (rendered in Netscape Navigator using the CosmoPlayer VRML 3D plug-in).

- A collection of parsers for VRML-syntax files and raw field information ranging from strict to lenient specification compliance.

- A generic sequential programming interface with callbacks as various parts of a VRML stream is read.

- A set of interfaces that represent the core node concepts of the VRML specification.

- VRML rendering implementations currently have Java3D and pure-memory implementations, with an OpenGL implementation possible.

- An independent implementation of the XML Document Object Model (DOM) that combines both DOM and Scene Authoring Interface (SAI) access to the same graph. Of note is that the SAI is an Application Programmer Interface (API) that is *auto-generated* from the X3D Schema.

- Separate scripting engine supporting Java and Mozilla's *Rhino* ECMAScript, independent from the rendering engine used.

- Utility classes supplementing the main code (e.g. user interface components).

Having an open-source implementation is tremendously empowering because successful specification testing and validation is no longer dependent on the economic "ups and downs" of various commercial 3D browser companies.

SCENARIO AUTHORING AND VISUALIZATION

In August 2000, the Defense Modeling and Simulation Office (DMSO) Science and Technology Initiatives program provided initial seed funding to NPS for research and development of a scenario authoring and Web-based visualization capability. The Marine Corps Combat Development Command (MCCDC) Training and Education Command (TECOM) originated the concept for the project, delineating a requirement for 3D visualizations of the complex, multi-dimensional battlespace associated with Ship-to-Objective Maneuver (STOM) and other emerging Marine Corps operations. The NPS project is called Scenario Authoring and Visualization for Advanced Graphical Environments (SAVAGE).

Marine Corps expeditionary warfare education and training is being modernized to deal with the air/ground/sea complexities of the modern littoral battlespace. The Marine Corps has initiated a Distance Learning program to support Marine Corps training and education. The program seeks to integrate the use of innovative instructional technology to support distance-learning requirements. The Marine Corps Mission Needs Statement for Multimedia Infrastructure (USMC, 1994) states that the Marine Corps must capitalize on “an environment of graphics, visual displays, information call-up, filtering, interpretation, and computerized dissemination.” Moreover, the Mission Needs Statement cites the “emergence of modeling and simulation virtual realities” as “one example of the need to support technology delivery through classroom environments that can support the concept as well as the idea.” One envisions the creation of virtual classrooms where the student warfighter is able to investigate and explore tactical mission planning and execution anytime, anywhere. In addition to military education, there is also a need to educate the general public in the nature of Marine Corps operations.

The SAVAGE project seeks to exploit the concepts and techniques of on-line gaming and virtual worlds to create an environment for exploration of the battlespace. Users may be members of a command staff or civilians interested in understanding the nature of extended littoral operations. Users will be able to work individually or collaborate to create the representation of the battlespace. The purpose is not to create “yet another” combat model, but to provide a means to create a representation of the battlespace that can be explored and manipulated (virtual “shaping of the battlespace”). Follow-on efforts include interfacing the tool to one or more existing or emerging combat simulations, so that scenarios may be created in a common environment and executed in multiple environments.

The scenario authoring and visualization tool must be simplistic and intuitive in operation, yet rich in representation to capture the complexities of the modern battlefield. The tool must operate effectively in a networked environment to enable multi-user interactions and collaboration in creation of scenario elements and for playback of scenario events and actions.

Authoring Component

The scenario authoring component will enable subject matter experts (SMEs) to create graphical representations of the extended littoral battlespace, including terrain, weather, and forces. The SMEs are similar to film directors, using the tool to lay out the story-line (missions), cast (forces), setting (environment – terrain, weather), and scenes (key objectives and events), within the digital medium. The SMEs configure the forces and assign missions and actions, drilling down to the lowest unit that is desired for formulation and assignment of planned actions in detail. Represented activities include embarkation, debarkation, movement, assault, fires, engineering, intelligence, and logistics.

The tool will provide 2D and 3D views of the battlespace for force placement, route planning, assignment of missions, and exploration. SMEs will be able to collaborate by sharing views and graphical annotations over local area or wide-area networks. Timelines are built for operational maneuver from the sea, coordinated fires, air strikes, and subsequent movements ashore. For example, members of a team may be responsible for different functional areas in the plan (fires, maneuver, intelligence, etc.). Each user can identify the forces and behaviors to perform their assigned area of responsibility, and then the functional areas can be introduced as separate “layers” over the battlespace. Visualization of the layers individually and in various combinations, with the added dimension of time, will allow the participants to identify resource and space/time conflicts in the battlespace.

Products of the authoring activity may differ in level of interaction allowed to the viewer. At one extreme, authors can produce a scripted presentation of the scenario, with preset viewpoints allowing little or no user interaction with the scene other than to use video player controls (pause, play, fast-forward, rewind). At the other extreme, authors can produce a scenario that allows the user to "step into" the scene, taking control of the movement and actions of an entity or force within the scenario. Different levels of interactivity between these two extremes are possible, and will be determined by the scenario author.

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) 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. NUWC is extending this model to also support the Maritime domain.

In the SAVAGE project, an XML representation of an amphibious operation order is of particular interest. One challenge is that much of the important information in the operation order is contained in the unstructured free-text portion of the order. Work is needed to integrate various XML schemas to precisely tag the semantics of important information. This is a major challenge because each service varies the amount and type of information contained in the general text section. Nevertheless, the broad applicability of both XML-MTF and LC2IEDM make such a task feasible.

In addition to these exciting developments, a number of programs are 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, such as the X3D editor shown in Figure 3, 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 VRML structures for 3D visualization.

Available planning data from other sources can be used to assist scenario generation. Such sources may include the Contingency Theater Air Planning System (CTAPS) Air Tasking Order (ATO), Time-Phased Force Deployment Data (TPFDD), or emerging concepts such as Effects Tasking Order and Maritime Tasking Order.

Clearly, strategic opportunities for coherently connecting diverse systems and data sources are emerging. It is compelling to think that networked 3D visualizations of all standardized orders and plans might soon be available to all commands, provided as simple message attachments.

Visualization Component

Today's planning and modeling systems most often use 2D representations of the 3D battlespace. This presents a challenge for planners, commanders, and troops to understand the true nature of the battlespace with regard to best routes, cover and concealment, obstacles, and probable enemy strongpoints. While the SAVAGE visualization component will offer the ability to toggle between 2D and 3D views of the battlespace, it is the added benefits that 3D offers that make this visualization component so unique and robust.

Once authoring is complete, the XML to VRML translation is invisible and automatic. A 3D plug-in, such as Cosmo Player, Cortona, or Contact, must be loaded on the user's computer to view the 3D battlespace. Using communications protocols such as the DIS, the local computer or any other computer that it may be networked to can see and manipulate the same 3D environment. The visualization component reuses graphical, database, and scenario control elements provided in the scenario-authoring component, but will disable scenario definition elements for the common user.

The user will navigate the virtual battlespace using predefined or freeform fly-over ("magic carpet"), by accessing a predefined set of static viewpoints, or by taking the perspective of a particular unit or entity in the battlespace. The user can query meta-data encapsulated in the battlespace objects to obtain mission and status information (What am I? Where am I? Where am I going? What is my mission? What is my firepower? What is my organization? What is my load? What is my knowledge of the enemy?). Objects can be driven by embedded behaviors defined by the scenario author, or the user may intervene and directly control objects in the scenario. By zooming in or out, the user can choose the level of visualization detail desired.

As the scenario unfolds, the visualization component will display resource assignment conflicts, time lags, supply problems, and other battlespace issues. Event conflicts will "pop-up" on the display at the location and time of occurrence. The measures of interest may be selected from a predefined set, or defined based on the system database schema, to configure the feedback in a tally board for a particular operation. Options will allow the user to reconstruct and display event tracks.

The user may stop, rewind, pause, and replay the scenario. When reviewing a scenario, authors may rewind a scene, toggle over to the authoring component, make a change, and toggle back to the visualization component to view the results of the changes. Note that the full set of visualization capabilities will be available to scenario authors to facilitate development of the scenarios.

Tool Prototyping

NPS efforts during the first year of the SAVAGE project have focused on the visualization side of the problem. The goal was to obtain a better understanding of the visual elements of the battlespace that need to be represented to provide effective content. As the visual representation of a scenario was constructed, the nature and scope of tools needed to assist in authoring a scenario became clearer. The work has resulted in representation of a small scenario, numerous 3D models of military platforms, and an initial set of VRML extensions (through the PROTO mechanism) to facilitate scenario authoring. The following discussion describes work accomplished to date and research directions for the project.

As an initial exemplar, the project team selected a small amphibious raid scenario. Study of Marine Corps and Navy publications (Naval Warfare Publication 3-02.1 and Amphibious Warfare School Course 8603) resulted in description of the principal stages of the operation; for example, launching a helicopter patrol, launching landing craft, scouting the beach approach, and so on. Each key event in the amphibious raid operation was treated as a separate scene. Storyboards were developed to document and depict elements of each scene. Each storyboard included:

- A textual description of the scene using terminology from the doctrinal publications
- A hand-drawn sketch of the scene
- One or more photographs of the scene from real-world military operations, including a set of photographs taken during a Capabilities Exercise at Camp Pendleton in December 2000
- A static 3D rendering of the scene, developed using the X3D Edit tool (Figure 3)

Storyboard depictions helped the development team understand the amphibious doctrine involved, and clearly indicated the objects, conditions, and behaviors that would need to be represented. Moreover, transitions from one scene to the next helped define positional changes and timing for animation of the elements in the scenes.

Figure 7 shows a sketch of landing craft being launched from the well deck of an amphibious ship. Figure 8 shows a photograph taken during a Marine Corps Capabilities Exercise at Camp Pendleton in December 2000. A 3D depiction of the scene with a simplified LPD model is shown in Figure 9.

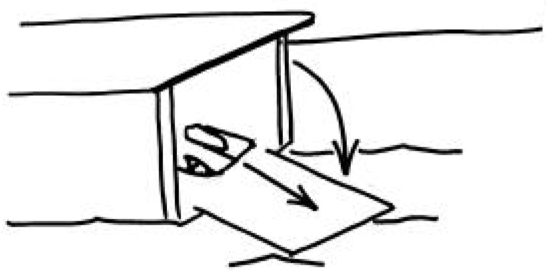

Figure 7. Storyboard sketch of landing craft exiting the well deck of an amphibious ship.

Figure 8. Storyboard photograph from a Marine Corps Capabilities Exercise at Camp Pendleton in December 2000.

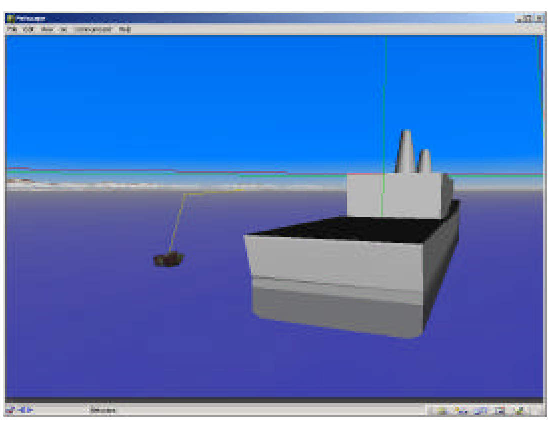

Figure 9. Storyboard 3D rendering of an AAAV launch from a simplified model of an LPD-17 amphibious ship, with transparent ocean surface and Camp Pendleton terrain.

One of the advantages of a synthetic battlespace is the opportunity to examine future platforms. For prototyping purposes, we decided to depict the new LPD-17 class amphibious platform, as well as the Advanced Amphibious Assault Vehicles (AAAVs). These systems are currently in procurement, and will not be delivered to the Fleet for several years. However, in the virtual battlespace, we can examine the operational characteristics of these platforms now.

Another choice made in the creation of the 3D scene shown in Figure 9 was to use color mapping to indicate bathymetry data. In order to see the coloration, the ocean surface is transparent (which is why the entire hull of the LPD is visible). The virtual battlespace enables the user to see dimensions that have not been readily available in the past. As the project proceeds, the team will identify sets of information or feature selections that should be made available to the user to allow him/her to choose which aspects of the battlespace to view, in isolation or in combination with other features.

Figure 10 shows an AAAV on the beach. It is worth mentioning that the 3D models used in the SAVAGE project have been created by students and faculty at NPS (using the X3D Editing tool shown in Figure 3). The project is not employing a staff of 3D artists to do this work. Since the research is concerned with how to more readily and effectively develop meaningful 3D content, a good measure of success is the ability for new students (with military backgrounds, but not trained artists) to be able to create content. Through coursework, student projects, student theses, and faculty research, NPS is building a collection of freely available, reusable components that can be used to rapidly create content (currently, over 275 models and tools to use as building blocks in creation of scenarios).

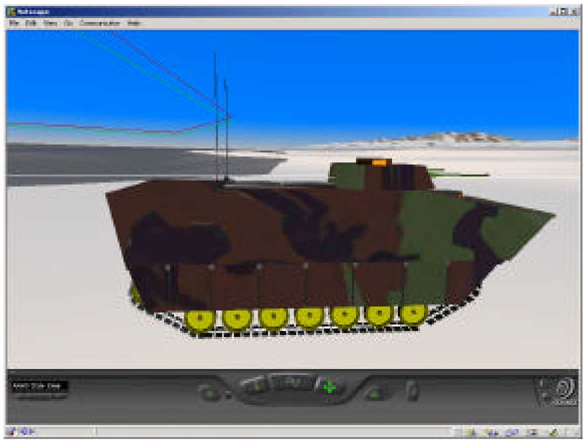

Figure 10. Storyboard 3D rendering of AAAV coming ashore at Camp Pendleton's Red Beach, with helicopter route lines overhead (AAAV model has articulated tracks, turret, and front and rear planing extensions for high-speed water movement).

In creation of the exemplar scene, the project team developed a number of extensions to VRML to facilitate the authoring, including: (1) a WayPointInterpolator, enabling an author to describe the planned movement of one or more platforms; (2) a BooleanSequencer and IntegerSequencer, providing a mechanism for sending signals to nodes in the scene graph to activate or modify behaviors in the scenario; (3) an ExecutionControl, providing user controls to run, pause, rewind, and fast-forward the scenario; (4) CameraCompass heads-up display to provide a visual indication of the direction the user is viewing.

A number of enhancements are in progress, including: (1) user control over the execution mode of a scene, enabling the user to indicate if the scene is running locally (off its own timers), with or without acting as a DIS Protocol Data Unit (PDU) writer (master), or as a DIS PDU receiver (ghost); (2) extension of the DIS Entity State PDU Transform (EspduTransform) to permit the user to modify read/write time intervals and to change operation mode (local, master, ghost). These changes will enable the scenario to execute over a network so that multiple users may participate in the scenario simultaneously.

OTHER APPLICATIONS TO MILITARY EDUCATION AND TRAINING

Web-based 3D visualizations will enhance a broad set of military education and training topics by making dynamic battlespaces available anytime, anywhere through network access. In addition to directly supporting Distance Learning initiatives, the capability to create and explore dynamic battlespaces enables creation of virtual command and control environments for command staff training (Blais and Garrabrants, 2000). Other key target areas of interest to NPS include education in mission planning and rehearsal for amphibious operations, 3D visualization for Military Operations in Urban Terrain (MOUT), and development of 3D visualization for selected simulation systems.

Mission Planning and Rehearsal Tool for Amphibious Operations

Amphibious assault operations are especially difficult to execute because of limited abilities to conduct rehearsals. This places a premium on planning. Web3D can improve amphibious assault preparation by providing a tool to mission planners to better convey operational concepts to individual units as well as capture the overall operation. 3D visualization of the terrain combined with physically based models can provide critical information not readily apparent with current two-dimensional planning techniques. This includes: route planning, recommended selection of firing positions, pre-positioning of reconnaissance teams, and deconfliction of ground, sea, and air forces.

Military Operations in Urban Terrain (MOUT)

The combination of urban terrain and ambiguous environments, where identification of combatants is not always clear, normally make MOUT a difficult and arduous operation. Web3D is particularly well suited as a planning and rehearsal tool for reducing operational risk. It can do so in several ways:

***Close Quarter Combat (CQC)*.** Assaulting a building for hostage rescue or to secure a series of buildings takes detailed planning and rehearsal. Establishment of fields of fire can be critical to minimizing casualties. Web3D can accurately model the interior and exterior of the building to facilitate planning and "walk-through" rehearsals.

Route Planning. A Web3D map of city streets can assist foot and vehicular patrols in establishing ingress and egress routes. It can also provide accurate contingency training for mistakes in navigation.

Spotter/Firing Positions. Web3D can give reconnaissance and sniper teams the ability to select the best available positions, as well as determine positions the enemy is likely to be postured. This can be especially difficult in urban terrain where it is difficult to estimate range of view and firing positions from overhead imagery. 3D mapping can put the warfighter at the simulated position to assess its feasibility.

Rapid 3D Visualization. It currently takes a significant amount of time to create a 3D visualization of a large urban area. Unless accomplished prior to the start of operations, it would not be available for initial missions. It may be possible to rapidly develop Web3D visualization of urban terrain using an accurate overhead database. This would be updated with the latest available information to provide forces with an ideal planning and rehearsal tool. For education in MOUT tactics, synthetic urban areas may be "grown" from specifications of general characteristics of the built-up area (terrain features, population density, construction materials, etc.) using techniques similar to commercial game simulations.

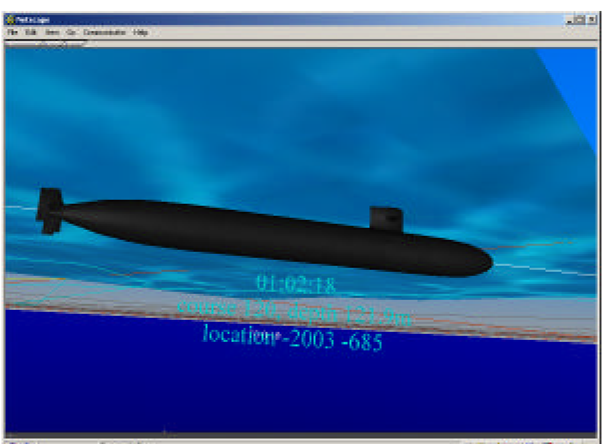

Figure 11. USS Greeneville in a reconstruction of the tracks in the *USS GREENVEVILLE – MV Ehime Maru* collision. The user can adjust sea-state levels to observe effects on the ability to view surface contacts through a virtual periscope.

3D Visualization of Simulation Systems

There are a number a simulation models that can provide Tactical Decision Aids to the warfighter. These can be enhanced through the introduction of Web3D capabilities. For example, the Naval Simulation System (NSS) is a good candidate for augmentation with 3D visualization. NSS is designed to support Naval and Joint operations planning and decision support, C4ISR analyses/assessments, Fleet exercise and experiments, and Fleet Training.

NSS currently provides a 2D scenario mapping of the simulation runs. Incorporating 3D visualization of the scenario to the system would enhance the user interface and, in combination with accurate terrain models, could provide the user with better understanding of the simulation results.

Other Application Domains

New generations of students are making their way through our educational systems. These students are familiar with a world of high-speed personal computers and Internet access that provides media-rich digital visual and interactive experiences. These students and future members of the workforce are expecting the same from the educational and employment environments (Prensky, 2001). The techniques discussed in this paper may be applied to any story-telling venue. As discussed at the outset, the key issue today is interactivity – the user must have a sense of involvement in the delivery of the instructional material, regardless of the domain.

Students at NPS have examined accounts of the USS GREENEVILLE/MV Ehime Maru collision and are constructing a 3D recreation of the incident (Figure 11). Although this incident falls within the military domain, it illustrates the applicability of the technology to a much broader set of learning situations.

FUTURE PLANS

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, planned 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.

- Adapting the multi-user architecture to employ the High-Level Architecture (HLA).

- 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.

CONCLUSIONS

Web3D graphics have finally come of age due to widespread hardware acceleration and interoperable 3D content using X3D/VRML, mostly thanks to open-standards efforts sponsored by the Web3D Consortium. The NPS SAVAGE project (in partnership with multiple collaborators) demonstrates that across-the-board integration of operational planning, message systems, worldwide command and control systems, and networked 3D visualization is a powerful use of XML-based standards. These amazing hardware and software capabilities open a range of opportunities for enhanced educational experiences through powerful Web-enabled technologies.

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