NPS-MV-20-001

NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

CREATING VIRTUAL ENVIRONMENTS FOR

EVALUATING HUMAN-MACHINE TEAMING

by

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January 2020

Distribution Statement A. Approved for public release: distribution unlimited.

Prepared for: Naval Research Program (NRP) and Marine Corps Warfighting Lab (MCWL)

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE ***(DD-MM-YYYY)*** 18-12-2019	**2. REPORT TYPE**	**3. DATES COVERED** ***(From-To)*** 1-10-2018 to 31-12-2019

4. TITLE AND SUBTITLE CREATING VIRTUAL ENVIRONMENTS FOR EVALUATING HUMAN-MACHINE TEAMING	**5a. CONTRACT NUMBER** **5b. GRANT NUMBER** **5c. PROGRAM ELEMENT NUMBER**
6. AUTHORS Donald P. Brutzman and Christian Fitzpatrick	**5d. PROJECT NUMBER** NPS-19-M285-A **5e. TASK NUMBER** **5f. WORK UNIT NUMBER**
7. PERFORMING ORGANIZATION NAMES AND ADDRESSES Information Sciences (IS) Department and Modeling Virtual Environments Simulation (MOVES) Institute, Naval Postgraduate School (NPS), 1 University Way, Monterey CA 93933-5000	**8. PERFORMING ORGANIZATION REPORT NUMBER** **NPS-MV-20-001**
9. SPONSORING / MONITORING AGENCY NAME AND ADDRESS Marine Corps Warfighting Laboratory (MCWL) Quantico VA 22134	**10. SPONSOR/MONITOR'S ACRONYM MCWL** **11. SPONSOR/MONITOR'S REPORT NUMBER(S)**

12. DISTRIBUTION / AVAILABILITY STATEMENT
Distribution Statement A. Approved for public release: distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

With the emergence of robots on the battlefield, it is critical for the Marine Corps to tactically integrate existing unmanned assets with manned systems during Marine Air Ground Task Force (MAGTF) operations. In parallel, the Marine Corps must also look forward to identify capability gaps that future unmanned systems might address. To do both requires extensive field testing, which is often unfeasible and always costly. This effort proposes the use of virtual environments (VE), virtual reality (VR) and agent-based modeling to conduct scenario-based assessments of Manned-Unmanned Teaming (MUM-T) during combat operations.

To pursue such goals, the project examined a variety of relevant tactical scenarios where Marines and robots act in concert to achieve specific mission objectives. Such tactical scenarios are further assessed using deterministic combat simulations to create a valid methodology for behavior creation and assessment within each scenario-specific problem space. Support for a complete range of combat simulations was determined as a necessary part of VE design explorations since specific MUM-T tactics, techniques and procedures (TTPs) are expected to co-evolve constantly as sensor, communication and vehicle capabilities continue to improve. Such diversity was supported through establishment of the MOVES Live Virtual Constructive (LVC) Laboratory for diverse simulation tools. Additionally two general approaches for the coordination of Manned-Unmanned Teaming (MUM-T) behaviors were considered, each beginning with a high-level description of expected behaviors. Completion of the goal tasks indicates that combined human-robot teams have achieved a desired world state.

This research surveyed a large variety of combat models and visualization tools to create the best and broadest possible environment for Marine Corps decision-makers to understand the complexity and warfighting value of the MUM-T battlespace. Even more broadly, shared VEs can potentially be used during force-development efforts to plan for the integration of human-machine teams into Naval combat forces. As the DoD is generally unfamiliar with such operations but is eagerly anticipating their development, it is quite clear that the use of live, virtual, constructive (LVC) simulations to wargame these capabilities becomes fundamental for all progress. Ultimately such human-machine teaming co-development is the critical path needed to expand Navy/Marine capabilities and avoid Navy/Marine vulnerabilities.

15. SUBJECT TERMS
Virtual Environments (VE), Virtual Reality (VR), X3D Graphics, SPIDERS3D, IEEE Distributed Interactive Simulation (DIS) Protocol, Live Virtual Constructive (LVC), MUM-T

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			Donald P. Brutzman
UNCLAS	UNCLAS	UNCLAS	NONE	107	**19b. TELEPHONE NUMBER** ***(include area code)***

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

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The report entitled "CREATING VIRTUAL ENVIRONMENTS FOR EVALUATING HUMAN-MACHINE TEAMING" was prepared for Naval Postgraduate School (NPS) under the Naval Research Program (NRP) and funded by Marine Corps Warfighting Lab (MCWL).

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ABSTRACT

With the emergence of robots on the battlefield, it is critical for the Marine Corps to tactically integrate existing unmanned assets with manned systems during Marine Air Ground Task Force (MAGTF) operations. In parallel, the Marine Corps must also look forward to identify capability gaps that future unmanned systems might address. To do both requires extensive field testing, which is often unfeasible and always costly. This effort proposes the use of virtual environments (VE), virtual reality (VR) and agent-based modeling to conduct scenario-based assessments of Manned-Unmanned Teaming (MUM-T) during combat operations.

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ACKNOWLEDGEMENTS

This work is based on many efforts by many people, most significantly by students and faculty in the NPS Modeling Virtual Environments and Simulation (MOVES) curriculum, working-group participants in the Web3D Consortium, and community volunteers in numerous open-source open-standards projects. We thank Major David Lemke USMC and the Marine Corps Warfighting Lab (MCWL) for all support and guidance received during the execution of this endeavor. It is clear that teamed operations between humans and unmanned systems are an important part of the Marine Corps future.

Partnered efforts with Nicholas Polys of Virginia Tech (VT), Anita Havele of Web3D Consortium, Richard Puk of IntelliGraphics and Vincent Marchetti of Kshell are central to the steady evolutionary progress demonstrated by the Extensible 3D (X3D) Graphics International Standard over the past 25 years. The current pace of progress is exceptional.

Insights and guidance regarding interdependency analysis by Scot Miller and Dan Boger (NPS) and Matt Johnson of Institute for Human-Machine Cognition (IHMC) were particularly helpful to discern future paths forward that might successfully compose multiple concerns from the robotics, tactics and analytics arenas.

Work on the SPIDERS3D virtual environment by Alex Viana at Naval Facilities Engineering Command (NAVFAC) and Gerritt Lang at NAVFAC Engineering and Expeditionary Warfare Center (EXWC) has been crucial for pursuing these fundamentally important capabilities “in the large” across the U.S. Navy and Marine Corps enterprise. Supporting teams executing key development efforts include Michael Russalesi, Tom Cowan and Gregg Miller at Synergy Software Design (SSD) along with John Ouellette at Versar.

Modeling concepts and open-source software implementations by Don McGregor, Mike Bailey, Terry Norbraten and Curt Blais have been essential for the OpenDIS and related codebases. Amela Sadagic has provided numerous insights regarding additive manufacturing, virtual reality (VR), augmented reality (AR) and additive manufacturing (AM).

Finally thanks to many students and faculty at NPS who helped push forward this work. Many important tasks lie ahead, and collaboration remains crucial as we work towards numerous long-awaited capabilities that have the potential to connect modeling and simulation to the command and control systems used daily by warfighters defending us all.

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I. OVERVIEW

A. PROJECT DESCRIPTION

This project conducted design analysis for an unmanned-Marine teaming virtualized environment that supports the evaluation of hardware, software, unmanned platforms, sensors, ethics, cyber, C2, and collaboration, as well as mission performance.

NPS performed diverse integrative work on IEEE DIS Protocol, X3D Graphics Standard and SPIDERS3D Virtual Environment to show that general solutions to this important challenge are possible. While much progress has been made to date, this is a multi-year, ongoing project. Recent progress reported here continues to positively impact continuing work.

This work is fully generalizable to related human-machine teaming challenges that are common to all Naval forces, including both the U.S. Navy and U.S. Marine Corps.

B. MOTIVATION

Manned-Unmanned Teaming (MUM-T) between humans and machines has multiple benefits: it enables Marines to do what they do best, and also enables machines to do what they do best. Further, teaming implies that Marines and Unmanned Systems are collaborating over common mission goals and objectives. Designing and engineering such capabilities is conceptually challenging. Teaming is based on interdependence, which can be achieved if observability, predictability, and directability is achieved between Marine and machine. MCWL cannot afford the time or money to evaluate every possible outcome in field experiments or exercises. A virtual environment makes it possible to allow for far greater evaluations of all possible combinations of Manned-Unmanned Teaming (MUM-T).

The use of virtual environments (VEs) for controlling unmanned systems combines two of the biggest areas of research activity in the Department of Defense. Applying both together for Manned-Unmanned Teaming (MUM-T) places such work in the highest possible priority of twenty-first century military challenges. Priority efforts in this project have worked towards achieve generality, scalability and functionality in all respects in order to meet such challenges over the long term. The following figures illustrate the primary capabilities needed.

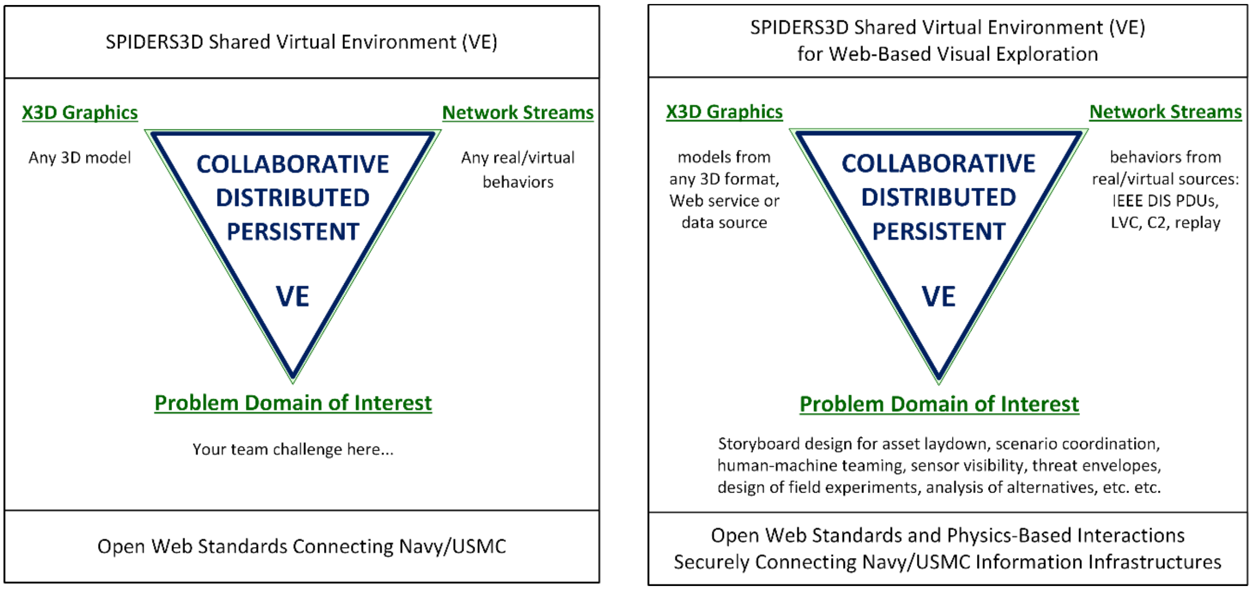

Figure 1. SPIDERS3D is a collaborative distributed persistent virtual environment (VE) that utilizes X3D Graphics models with coming capabilities for DIS-based network streaming from diverse LVC sources.

C. RESEARCH QUESTIONS AND ANSWERS

Questions 1-3 come from the original NRP topic portal, and questions 4-7 are taken from the approved NRP proposal.

1. What is Marine-machine teaming and how is it defined in terms of engineering evaluation?

In this work, Manned-Unmanned Teaming (MUM-T) was considered in the broadest possible sense. Exemplary scenarios were plentiful in field experimentation (FX), simulation and thought experiments. In essence, Marines succeed best when they can perform their existing roles with augmentation by better sensors and agility, without the burden of distracted situational awareness (SA). In the meantime, immense technical progress in unmanned systems and artificial intelligence (AI) is changing system capabilities on a continuous basis. Direct experimentation is needed for evolving the best approaches for proper teamwork, but FX takes a great deal time and expense. This often means that evaluation of team tactics, techniques and procedures (TTPs) can provide insufficient insight. As a result, our first primary realization was that *general solutions for Modeling and Simulation (M&S) that support human evaluation of Manned-Unmanned Teaming (MUM-T) are fundamentally important.* This is the case even beyond the creation of simple exemplars, which are plentiful and frequently changing without time for proper evaluation.

2. What constitutes a virtual environment and what is the best approach for this case?

Live Virtual Constructive (LVC) Modeling and Simulation (M&S) refers to the ability of diverse environments to interrelate and integrate compatibly. Thus virtual environments (VEs) that interconnect LVC scenarios are similarly broad, and general solutions are important. Decades of NPS education and research efforts in the Modeling Virtual Environments and Simulation (MOVES) Institute continue to utilize, assess and extend a wide variety of M&S virtual environments. Most are incompatible with each other, and interoperability with Command and Control (C2) is even rarer. Further confusion occurs when application teams, and even companies, mistakenly conflate different interface devices (small or large screens, see-through headsets, head-mounted displays etc.) as unique and different "virtual environments" of their own. This short-sighted state of affairs is mistaken, limited and insufficient for Marine needs. Thus we focused on how *general solutions can be achieved through interoperability among diverse LVC and C2 systems, accomplished by avoiding proprietary lock-in and achieving re-usability through archival Web publication using Web standards.* Scalable solutions for virtual environments (VEs) appear to be possible and are only achievable by the steady construction of working examples.

3. Can NPS use existing work to expedite construction of such an environment?

Multiple technologies are appropriate for mapping M&S to Manned-Unmanned Teaming (MUM-T), and three technologies in particular have been the long-term focus of work at NPS. First is the IEEE DIS Protocol which is bridge-able to multiple distinct network protocols. Second is the Extensible 3D (X3D) Graphics International Standard which can be used for composable publication of 3D models from diverse sources in a manner compatible with HTML and other Web standards. Third is the SPIDERS3D system which composes 3D virtual environments via Web browsers to any computer connected to Navy and Marine Corps Internet (NMCI) or public networks. *Together these capabilities (DIS, X3D, SPIDERS3D) can provide the basis of a large-scale virtual environment (LSVE) over the Web suitable for ongoing evaluation of the diverse hardware, software and TTPs essential to Marine-machine teaming.* This appears to be a novel capability with multiple far-reaching impacts, and much further implementation work continues.

4. How can Manned-Unmanned Teaming (MUM-T) be used to complement the capabilities of existing combat units in a manner where tasked roles and corresponding orders are well understood by humans and robots alike?

Two bodies of work pertain to this question, first by Dr. Matthew Johnson of Florida Institute for Human and Machine Cognition (IHMC) which is explored in detail by project NPS-19-M286, *Designing a Consistent C2 Approach for Marine-Machine Teaming* (Miller 2019). Key to this approach is formal interdependency analysis between human and robotic team members, explored via multiple NPS theses and summarized in "No AI Is an Island: The Case for Teaming Intelligence" (Johnson 2019). Related efforts showed how the methodology was applicable to the Unmanned Tactical Autonomous Control and Command (UTACC) Command and Control (C2) Framework (Boger 2019) (Spada 2019). Second is NPS work on Ethical Control of Unmanned Systems (Brutzman 2019) which matches well-formed mission orders of human teams with corresponding tasking for unmanned systems. *The necessary emphasis for all tactical operations is on maintaining human authority for lethal force, despite communication difficulties associated with distances in time and space.* Corresponding attention to Observe Orient Decide Act (OODA) principles can ensure that coordination of tandem activities by humans and machines achieves shared goals with coherent purpose.

5. How can we use VEs and VR to assess and visualize the effectiveness of Manned-Unmanned Teaming (MUM-T) in its augmentation of existing combat units?

This essential challenge is so broad that a correspondingly broad cross-cutting approach is necessary. *Virtual environments (VEs) are used to collect and integrate all manner of 3D models, behavior streams and information assets in a distributed manner using Web standards for repeatability.* Virtual Reality (VR) techniques such as head-mounted displays provide some additional value in visualizing and exploring such assets. Preceding questions 1, 2 and 3 above summarize the approach initially demonstrated in this project. Further NRP work on modeling manned and unmanned systems consistently for virtual environments can be found in (Blais 2016). The draft Compressed-DIS encoding holds further promise for sharing DIS behavior streams over bandwidth-challenged links used by mobile tactical vehicles and aircraft.

6. Can VEs and VR be used to define various Manned-Unmanned Teaming (MUM-T) mission sets within the MAGTF?

A wide range of unclassified scenarios were considered during this project, and these were sufficiently rich that no classified missions were necessary. *A range of representative amphibious expeditionary scenario laydowns were performed for Western Pacific locales such as American Samoa and other islands.* Over 300 vignettes authored using over 30 virtual locales have been created using SPIDERS3D. If those same SPIDERS3D capabilities are authorized to get ported to SIPRNET (as proposed separately) then significant rehearsal and analysis of alternatives becomes possible.

7. How can we use simulations to rehearse, real-time observe and replay VEs to best visualize Manned-Unmanned Teaming (MUM-T) operations?

Interoperable Web standards ensure that specialty systems can bridge together compatibility, rather than languishing as unusable disconnected blocks of isolated functionality. Prototype work in this project shows great potential for broad and repeatable solutions to these critical problems. The first key that leads to successful long-term use of VEs is to unlock all manner of simulations through composition of 3D models in real-world locations. Given that shared virtual space, realistic rehearsal, real-time viewing and replay can then occur by coupling such VEs together via behavior-stream interoperability. Such synchronization can be achieved by using the IEEE DIS Protocol to bridge among the diverse range of “stovepipe” (unique, standalone) simulations making up present-day repertoire of Live Virtual Constructive (LVC) systems.

D. SUMMARY OF WORK

Virtual environments can be used to practice, portray and assess MUM-T operations. The key challenge facing both government and industry today is achieving interoperability among incompatible technologies. NPS performed diverse integrative work on X3D Graphics Standard, IEEE DIS Protocol, and SPIDERS3D Virtual Environment to show that general solutions to this important challenge are both possible and repeatable. Based on project progress, much related work of value to USMC and the Navy continues.

E. REPORT ORGANIZATION

Following this overview, Chapter 2 lists mission design considerations of interest to USMC simulation. Chapter 3 considers 3D graphics visualization using the Extensible 3D (X3D) Graphics International Standard. Chapter 4 examines networking considerations using the IEEE Distributed Interactive Simulation (DIS) protocol for bridging a wide variety of Live Virtual Constructive (LVC) simulations and playbacks. Chapter 5 considers how VE and VR capabilities can be provided in a scalable Web-based manner using the SPIDERS3D system. Chapter 6 presents Conclusions and Recommendations for Future Work regarding this essential arena for warfighting development.

II. MISSION DESIGN CONSIDERATIONS

A. INTRODUCTION

This chapter first considers the multiple challenges for robotics and virtual environments that are posed both directly and indirectly by the USMC 37th Commandant's Planning Guidance. Storyboarding for portraying tactics techniques and procedures (TTPs) has long been shown to be a viable technique for virtual environments. Robotics and visualization are also shown to be closely relatable in this manner. Finally an exemplar mission shows simple yet powerful insights are possible using virtual environments.

B. NUMEROUS CHALLENGES FROM COMMANDANT'S PLANNING GUIDANCE

The 37th Commandant's Planning Guidance (Berger 2019) prioritizes five focus areas:

- *Force design* to "operating in contested maritime spaces, facilitating sea control, or executing distributed maritime operations" with close naval integration,
- *Warfighting* improvements that advance "through the strength of our innovation, ingenuity, and willingness to continually adapt to and initiate changes in the operating environment to affect the behavior of real-world pacing threats. This will require a break from the past practice of capability-based force development."
- *Education and training* to address "what we need to be doing based on the evolving operating environment."
- *Core values* of courage, honor and commitment that "are seen and felt in the shared experiences, hardships, and challenges in training and combat and embody what it is to be a Marine," and
- *Command and leadership* to "lead, educate, train, supervise, and enforce high standards. […] Our maneuver warfare doctrine depends on commander's intent and mission-type orders – we must train how we fight."

Cutting across these five broad areas, specific topics covered in detail include Command and Control (C2), Naval Operating Concepts, Composite Warfare, Stand-in Forces, Expeditionary Advanced Based Operations (EABO), future force development, training and education, unmanned systems, Artificial Intelligence (AI), Data Science and Emerging Technology, and multiple aspects of wargaming.

For modern warfighting, it is notable that each of these specific topics is completely dependent on the evolution and understanding of Manned-Unmanned Teaming (MUM-T). Thus any sustainable growth in the effective use of unmanned systems must provide the broadest, most scalable and most composable approach to the diversity of tools available. Only one system is able to connect all things to all people: the World Wide Web. Using Web standards for virtual environments is the logical choice for these major challenges.

C. STORYBOARDING FOR EXPLORING TACTICS TECHNIQUES PROCEDURES (TTP)

Storyboarding is the practice used in theater, film and other arts to portray key vignettes in a dramatic arc using "boards" of images that capture the essence of a story. Such techniques can also be applied to wargame and virtual-environment scenario design.

The *Scenario Authoring and Visualization for Advanced Graphical Environments (SAVAGE)* thesis (Nicklaus 2001) describes in detail how storyboarding can be used to capture the essential detail of an amphibious raid for use in virtual-environments rehearsal. The concepts and approaches explored then remain valid when considering emerging challenges today.

> *Abstract*. Today's planning and modeling systems use two-dimensional (2D) representations of the three-dimensional (3D) battlespace. This presents a challenge for planners, commanders, and troops to understand the true nature of the battlespace. This thesis shows how 3D visualization can give both operation planners and executors a better understanding of the battlespace that can augment today's 2D systems. Automatic creation of a 3D model for an amphibious operation allows the planner to view an operation order as a whole, from different perspectives. Recommended changes can be made and their effects immediately known. Warfighters can use the same tools for mission preparation and review. The United States and NATO nations use the Land C2 Information Exchange Data Model (LC2IEDM), formally known as the Generic Hub, as a common method for exchanging data between independent systems. As part of the Scenario Authoring and Visualization for Advanced Graphical Environments (SAVAGE) project, this research presents an integrated Web access and 3D visualization strategy for Department of Defense (DOD) tactical messaging and operation orders using the Generic Hub data model and the Extensible Markup Language (XML). A number of alternative yet consistent ways to represent an amphibious operation scenario demonstrate the power, flexibility and scalability of the SAVAGE approach.

D. USE OF ROBOTS AND VISUALIZATION TO PORTRAY OPERATIONS

The *Integration of Robotics and 3D Visualization to Modernize the Expeditionary Warfare Demonstrator (EWD)* thesis (Fitzpatrick 2009) describes how small-scale robots might be used to re-enact amphibious landings for historical purposes, with the potential to provide new capabilities for innovative agent-based simulation for education and advanced concept development. Such concepts also remain valid when considering emerging challenges today.

> Abstract. In the summer of 2008, the Commandant of the Marine Corps (CMC) released a message to all Marines and Sailors detailing plans to revitalize U.S. naval amphibious competency. Current responsibilities in Iraq and Afghanistan have significantly reduced available training time causing overall amphibious readiness to suffer. In response, this thesis evaluates 3D visualization techniques and other virtual environment technologies available to support these mission-critical training goals. The focus of this research is to modernize the Expeditionary Warfare Demonstrator (EWD) located aboard Naval Amphibious Base (NAB) Little Creek, Virginia. The EWD has been used to demonstrate doctrine, tactics, and procedures for all phases of amphibious operations to large groups of Navy, Marine Corps, Joint, Coalition and civilian personnel for the last 55 years. However, it no longer reflects current doctrine and is therefore losing credibility and effectiveness. In its current configuration, the EWD is limited to a single training scenario since the display's ship models rely on a static pulley system to show movement and the terrain display ashore is fixed. To address these shortfalls, this thesis first recommends the usage of the wireless communication capability within Sun's Small Programmable Object Technology (SunSPOT) to create robotic vehicles to replace the current ship models. This enables large-group visualization and situational awareness of the numerous coordinated surface maneuvers needed to support Marines as they move from ship to shore. The second recommendation is to improve visualization ashore through the creation of Extensible 3D Graphics (X3D) scenes depicting high-fidelity 3D models and enhanced 3D terrain displays for any location. This thesis shows how to create these scenes and project them from overhead in order to modernize the gymnasium-sized EWD into an amphibious wargaming table suitable for both amphibious staff training and operational planning. Complimentary use of BASE-IT projection tables and digital 3D holography can further provide smallgroup, close-up views of key battlespace locations. It is now possible to upgrade an aging training tool by implementing the technologies recommended in this thesis to support the critical training and tactical needs of the integrated Navy and Marine Corps amphibious fighting force.

E. EXEMPLAR MISSION DESIGN AND PORTRAYAL

During the course of NPS graduate education efforts for warfighter students, a wide variety of scenarios are often under consideration. Many share common characteristics, and each typically holds both clear differences and unclear nuances. Modeling and simulation can provide qualitative and quantitative alternative of analysis (AOA) insights when TTPS, sensors and the environment are modeled with fidelity.

A simple scenario was developed to illustrate these principles for this project. A small village model is defended by squads of Marines and various autonomous vehicles from a hostile platoon. Portraying the same situation multiple ways can yield insights when comparing

- Time of day effects including darkness or flares at night,
- Perspectives of various players,
- Sensor responses and decision logic of unmanned systems reacting to stimuli.

The scenarios created for this effort were on the Kilo 2 range at Camp Pendleton, CA. A fire-team sized red force was emplaced on the north west corner of the range. They were equipped with various small arms and rifles. They did not have supporting arms attached or use of Intelligence, Surveillance, Reconnaissance (ISR) assets. The blue force was a platoon-sized element on the east side of the range. They had a single UAS and two UGVs assigned for ISR operations.

Four versions of the scenario were developed changing the overall environmental conditions and the viewpoints. The first scenario was a daytime view from the deployed UAS. The second scenario was a daytime view from the UGV viewpoint. The third scenario was a nighttime view from the UAS viewpoint using illumination for better scene visualization. The fourth scenario was a nighttime view from the UAS with the UGVs engaging the red force.

Figure 2. UAV Feed Over UGV reconnaissance of Urban Environment using VT MäK's VRForces (DIS/HLA).

Figure 3. UGV Feed operating forward in an Urban Environment using VT MäK's VRForces (DIS/HLA)

Figure 4. Nighttime Illumination of Urban Environment.

Figure 5. Nighttime view from UAS with flare illumination as UGVs engage red force.

Figure 6. UGV Operations employing weapons with overhead flares at night.

F. SUMMARY

The USMC 37th Commandant's Planning Guidance poses multiple challenges for both robotics and virtual environments that must be addressed. Storyboarding is a useful methodology for sensibly showing how tactics techniques and procedures (TTPs) work using virtual environments. Robotics and visualization can go hand in hand since situated actors each maintain their own perspective while participating in simulated or hybrid Live Virtual Constructive (LVC) activity. Finally, an exemplar mission is presented to illustrate how virtual environments can provide useful insights to human mission designers and operational users.

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III. 3D GRAPHICS VISUALIZATION

A. INTRODUCTION

Hundreds of games and graphics systems exist without mutual interoperability. The Web3D Consortium is a non-profit organization dedicated to open use of 3D models for real-time communications on the Web. The Extensible 3D (X3D) Graphics International Standard provides numerous converters for interoperability and supports the consistency of Web standardization. Numerous tools, resources and libraries are available for using X3D.

B. PROBLEMS ASSOCIATED WITH DIVERSITY OF 3D MODELS

3D models are produced from a number of sources that include software programs, authoring tools, modification to previously created models, and numerous other sources.

Multiple problems pertain when comparing and contrasting 3D models.

- 3D data structures are inconsistent,
- Orientation position and scale varies,
- Units are inconsistent: feet, mm, cm, m, furlongs, etc. etc.,
- Metadata is rarely provided or else maintained inconsistently and separately, etc.

As a result 3D systems are rarely interoperable. Instead each use of a 3D model requires special handling by teams of experts that is undocumented, non-authoritative, rarely consistent and non-repeatable. This state of affairs is exacerbated by companies attempting to “lock in” customers with proprietary licensed software agreements.

C. WEB3D CONSORTIUM

From the www.web3D.org website:

> *About the Consortium.* Founded in 1997, we are an International, non-profit, member-funded, industry standards development organization. We develop and maintain royalty-free ISO standards for web-based 3D graphics. Our standard X3D (Extensible 3D) originated from VRML and is available in XML, Compressed Binary, and classic VRML formats. X3D is open, royalty free, extensible, interoperable, and runs on all platforms including desktops, tablets, and phones. Our members are from business, academia, government and the military.

Web3D is a Standards Development Organization (SDO) with a 23-year record of sustained accomplishment. NPS is a charter directing member of Web3D Consortium and has long benefited from working-group dialog and an open approach that examines and solves core challenges to scalable use of 3D graphics for real-time communication.

D. EXTENSIBLE 3D (X3D) GRAPHICS INTERNATIONAL STANDARD

From the www.web3D.org website:

- X3D is an ISO-ratified, royalty-free open standards file format and run-time architecture to represent and communicate 3D scenes and objects. X3D has evolved from its beginnings as the Virtual Reality Modeling Language (VRML) to the considerably more mature and refined ISO X3D standard. X3D provides a system for the storage, retrieval and playback of real time 3D scenes in multiple applications, all within an open architecture to support a wide array of domains and user scenarios.

- X3D fully represents 3-dimensional data. X3D has a rich set of componentized features that can be tailored for use in engineering and scientific visualization, CAD and architecture, Geospatial, Human Animation, 3D printing and 3D Scanning, AR/MR/VR. Today X3D has several applications in medical visualization, training and simulation, multimedia, entertainment, education, and more.

- As an open standard X3D can run on many platforms, but importantly can render 3D models in most web browsers without the requirement for additional or proprietary applications. Further, once models are developed utilizing X3D, these easily port to alternative platforms like holographic, head-mounted or other display devices.

Over three dozen converters, translators, import and export tools exist for X3D (and its compatible predecessor VRML). It is the most interoperable format available for interactive 3D models. An extremely large set of assets is listed on the X3D Resources page. Usage guidelines are provided on the X3D Scene Authoring Hints and X3D Tooltips pages:

- https://www.web3d.org/x3d/content/examples/X3dResources.html
- https://www.web3d.org/x3d/content/examples/X3dSceneAuthoringHints.html
- https://www.web3d.org/x3d/tooltips/X3dTooltips.html

Tremendous amounts of detail is available regarding X3D (Brutzman 2007) with assets including thousands of exemplar models and an online course. Current work is advancing X3D Version 4 which is expected to provide even-better support for X3D and HTML5.

The first key to understanding the archival "staying power" of X3D is that the format is royalty free (RF) and can be used for any purpose. While many 3D technologies have obscure patents or hidden license-renewal requirements, no known royalty-bearing patents have been introduced into X3D capabilities since its beginning as Virtual Reality Modeling Language (VRML), first devised cooperatively in 1994 and then ratified by the International Standards Organization (ISO) in 1997. This consistent design approach has continued throughout the subsequent renaming and continued growth of the original VRML97 standard as X3D. Furthermore, Web3D Consortium members commit to not introduce known patented technology for consideration unless all patent fees are waived. This strict adherence to unrestricted technologies makes X3D acceptable as a Web standard, suitable for any purpose and able to serve as an archival format that will always continue to be useable in an open way. Meanwhile, similar to works published in HTML or other formats, any rights to restrict or expose independent 3D content can be asserted on an individual model-by-model basis. For this project all models are unrestricted, and continued due-diligence care needs to be applied in future collections of X3D models used by SPIDERS3D to ensure that archival usage remains protected. Further information and references regarding these topics can be found at:

- About Web3D Consortium, https://www.web3d.org/about
- Web3D Consortium By-Laws, http://www.web3d.org/sites/default/files/page/Join%20the%20Web3D%20Consortium/Web3D_By-Laws_2006-11-00.pdf
- Web3D Consortium Intellectual Property Rights (IPR) Policy, http://www.web3d.org/sites/default/files/page/Join%20the%20Web3D%20Consortium/Web3D_IPR.pdf
- Savage Developers Guide, Free as in Freedom: https://savage.nps.edu/Savage/developers.html#Free
- Savage Developers Guide, Licensing and IPR Issues: https://savage.nps.edu/Savage/developers.html#Licensing

The second key to understanding the sustained technical growth of X3D is that an active community and multiple chartered Working Groups follow an open process for new work that might be used as part of a formal standard. Individuals and organizations can suggest improvements, explore alternatives, specify capabilities, implement software, and evaluate models using at least two different codebases in order to ensure that new capabilities proposed for the X3D Standard are fully considered. Primary work by each working group can be open or members only, as decided upon in the charter for each group. Software implementations can be open source or closed (proprietary) source, as desired by the owner. Exemplar X3D models and detailed discussions of results are typically conducted openly and archived online. Web3D Consortium members and the Board of Directors must review and approve any such improvements before submitting draft standards to ISO.

Each working group strives to achieve consensus on requirements, alternatives and results for the best and broadest possible impact. Interestingly, history has shown that failure to achieve consensus is a strong indicator that a given solution is imperfect or incomplete. While these processes might appear to be slower than some product lifecycles, the reliability achieved by such open efforts is unmatched. Each has a direct impact extending capabilities described in this report. Active groups are summarized in the following figure.

Web3D Consortium Working Groups are technical committees that consider and develop solutions for specific technical challenges and opportunities. Working group charters are reviewed by the Board of Directors to meet the needs of the Consortium and the community.

- **Extensible 3D (X3D) Working Group** coordinates all technical development efforts. Working groups are essentially driven by efforts of participants and focus on technology issues that produce improvements to open standards, always achieving results that are royalty free for any purpose. All efforts are geared towards improving a coordinated set of steadily evolving ISO standards including X3D Version 4.
- **Cultural and Natural Heritage (heritage) Working Group** is exploring the generation, handling, and display of digital 3D data for cultural and natural heritage.
- **Design Printing and Scanning Working Group** develops and demonstrates best practices for X3D support of Computer-Aided Design (CAD), 3D Printing, and 3D Scanning applications.
- **Geospatial Working Group** uses the Web architecture, XML languages, and open protocols to build a standards-based X3D geospatial specification usable by governments, industry, scientists, academia, and the general public.
- **Humanoid Animation (HAnim) Working Group** develops and demonstrates the Humanoid Animation (HAnim) International Standard. HAnim supports a wide variety of articulated figures, including anatomically correct human models, incorporating haptic and kinematic interfaces in order to enable sharable skeletons, bodies and animations.
- **Medical Working Group for X3D** develops and demonstrates open interoperable standards for representation of human anatomy based multiple imaging modalities.
- **X3D Semantic Web Working Group** mission is to publish models to the Web using X3D in order to best gain Web interoperability and enable intelligent 3D applications, feature-based 3D model querying, and reasoning over 3D scenes.

Figure 7. Web3D Consortium Working Groups, from https://www.web3d.org/working-groups

One further working group is currently under consideration by the Web3D Board of Directors that can likely improve effectiveness of SPIDERS3D collaboration by diverse end users, thus supporting even-broader diffusion of innovation throughout Navy and USMC. It is described as follows:

> “The Web3D User Experience (Web3DUX) Working Group's mission is to establish best practices and standardized capabilities that support rich user experiences (UX), intuitive navigation, and effective interaction techniques for a variety of 3D Web technologies.”

NPS is a charter, directing member of the Web3D Consortium with liaison roles restricted to act in non-fiduciary manner while participating in these critical activities. The capabilities described in this report are not possible to achieve without direct participation in these Standards Development Organization (SDO) efforts. Additional participation and membership by other government and academic organizations is highly advisable to help ensure successful execution of goals in the creation of Web-based virtual environments for collaboration, assessment and evaluation of performance across the Defense enterprise.

Two important recent references of related interest stand out in this regard:

- Department of Defense (DoD) Digital Engineering Strategy (Griffin 2018)
    - “The goals promote the use of digital representations of systems and components and the use of digital artifacts as a technical means of communication across a diverse set of stakeholders.”
    - “This approach can enable DoD programs to prototype, experiment, and test decisions and solutions in a virtual environment before they are delivered to the warfighter.”
- Department of Navy (DoN) Business Operations Plan, FY 2020-2022 (Spencer 2019)
    - “DESIGN AN INTEGRATED NAVAL FORCE STRUCTURE. In FY20, develop a fully integrated Department of the Navy and Industrial Base Management Plan for a modern, integrated naval force and supporting infrastructure capable of global projection, interoperable with partner nations and lethal overmatch from warfighting capability and capacity delivered ahead of global business trends.”

- o “Create an integrated priority list of range improvements that leverage live and virtual training and testing solutions to meet range capability requirements and mitigate encroachment.”

Thus many external activities are in motion, publicly and privately, that can provide ongoing benefits to shared virtual environments (VEs) utilizing Web standards. As appropriate to tasks of interest, each is worth tracking and adopting as best practices for 3D models, asset metadata and production/visualization software.

Suggested future work includes definition of common government contractual requirements for 3D data and metadata so that publicly funded developments can utilize specialty proprietary codebases for given purposes while retaining resulting sharable X3D models indefinitely without licensing time-out restrictions.

E. SUMMARY

3D models used by games and graphics systems rarely share interoperability, or even provide readable metadata describing terms of reference or usage. The Web3D Consortium is a non-profit organization that includes NPS which has worked for decades on the open use of 3D for real-time communications on the Web. The Extensible 3D (X3D) Graphics International Standard provides an open basis for interoperability by using Web standardization. Numerous tools, resources and libraries are available for using X3D. Open processes followed during working-group endeavors ensures that X3D models remain archival and reusable indefinitely.

IV. NETWORKING CONSIDERATIONS

A. INTRODUCTION

This chapter first examines the design and diversity of the MOVES LVC Laboratory for demonstration and analysis of diverse simulations. The two-course sequence in networking at MOVES provided direct student engagement and interaction with all elements of this project. Visit by CMC USMC indicated the relevance of MUM-T virtual environments work to current planning guidance. The IEEE DIS Protocol forms the basis for composability between different network streams, and advances in the NPS-produced Open DIS Software Library provided the basis for important course work and continuing research progress. Finally the annual NPS contribution of the IITSEC 2019 Tutorial “DIS 101” showed steady industry and inter-service interest in use of the IEEE DIS protocol.

B. MOVES LIVE VIRTUAL CONSTRUCTIVE (LVC) LABORATORY

To best understand how to integrate autonomous systems into expeditionary military operations, the MOVES Institute has developed a live virtual constructive (LVC) simulation lab containing 15 simulation systems and 3 interoperability architectures. Having this diverse set of simulations is critical as many are only built for specific tactical domains. For example, the Next Generation Threat System (NGTS) was initially developed to test and certify aircraft electronic warfare (EW) systems at NAVAIR Patuxent River. Through the Defense Advanced Research Projects Agency’s (DARPA) Distributed Experimentation Environment (D2E) project, NGTS later evolved to include sea and ground conflict modeling showing that simulations can be upgraded to support new analytic needs.

The MOVES LVC Laboratory has installed a large number of diverse simulations for student and analyst usage. The current operating inventory is shown in the next figure.

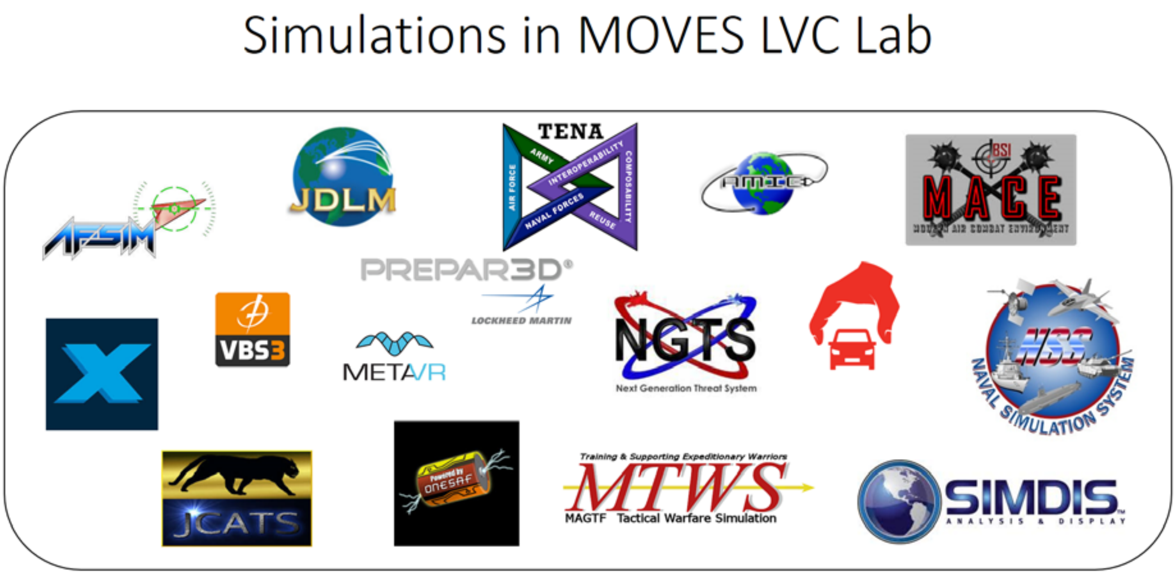

Figure 8. Simulation tools installed and available in MOVES LVC Laboratory, December 2019.

Given the specific focus of many simulations, the lab's interoperability architectures are crucial to enable the connectivity of multiple simulations to leverage and combine specific system strengths. Most recently, MOVES federated the MAGTF Tactical Warfare Simulation (MTWS) with the Joint Deployment Logistics Model (JDLM) to accurately model unit resupply and sustainment. This federation will be key when planning and programming for new autonomous systems to support the MAGTF.

To support MCWL's visualization requirements for MUM-T, we built relevant tactical scenarios in VT Mäk's VR Forces. Using this tool, we were able to create tactical behaviors modeling the integration of robotic systems into an urban patrolling operation conducted virtually at Kilo 2 aboard Camp Pendleton, CA. The scenario included a fire-team sized red force with various small arms deployed on the northwest corner of the range. The blue force was a platoon-sized element positioned to the east side.

For surveillance, the blue force deployed a single UAS and two UGVs to provide battlefield situational awareness. Following the initial reconnaissance of the virtual training area, the blue platoon moved northwest on the range to engage the red force. During the movement to contact, video footage from both the UAS and the UGVs were created using an entity viewpoint providing actual red force disposition data. Given the real-time intelligence available, we were able to plan and coordinate air, naval and ground fires to initially engage the red forces. It should be noted that the red forces did not deploy robotic systems and did not have the opportunity to target blue units. This red capability would have certainly changed the outcome of the simulation.

The team had the option to run the model open or closed loop. For our work, we selected open loop in order to be reactive to the surveillance data provided by the robots. We still allowed the scenario to unfold based on entity interactions, but we wanted to account for the increased capabilities and force deployment options offered by the robotic systems. The red and blue entities were programmed to search, acquire, target and engage enemy throughout the scenario. The warfighting outcome was based on internal parametric data which allowed for adjudication of specific engagements.

We were able to build and run our simulation on a small network utilizing the DIS protocol to pass entity state data. Distributed development allowed for consideration of using VR Forces to conduct wargames to investigate different tactics and force dispositions required when employing robotic systems to support operations.

In addition, since the scenario was small, we were able to perform assessments quickly based on number of red and blue kills and observation of the scenario. VR Forces' dashboard is robust and contains detailed entity data available for review during and after simulation execution. Larger scenarios would require external processing tools to extract key insights.

C. COMMANDANT MARINE CORPS (CMC) VISIT

On 5 December 2019, the Commandant of the Marine Corps, General David H. Berger, visited the MOVES Institute LVC Lab for an overview of M&S research conducted by past and present Marine students. During the visit, Christian Fitzpatrick provided a short description of NRP-19-M285-A, Creating a Virtual Environment (VE) for Evaluating Human Machine Teaming. For this effort, MV4503 students provided assistance in developing a realistic VE depicting a single UAS and two UGVs supporting an opposed, platoon-sized urban patrol. The students used VT Mäk's VR Forces to create this environment and complex tactical behaviors. In the discussion, students pointed out the benefits of using this simulation over the MAGTF Tactical Warfare Simulation (MTWS), which is currently in use at MSTP and MCLOG.

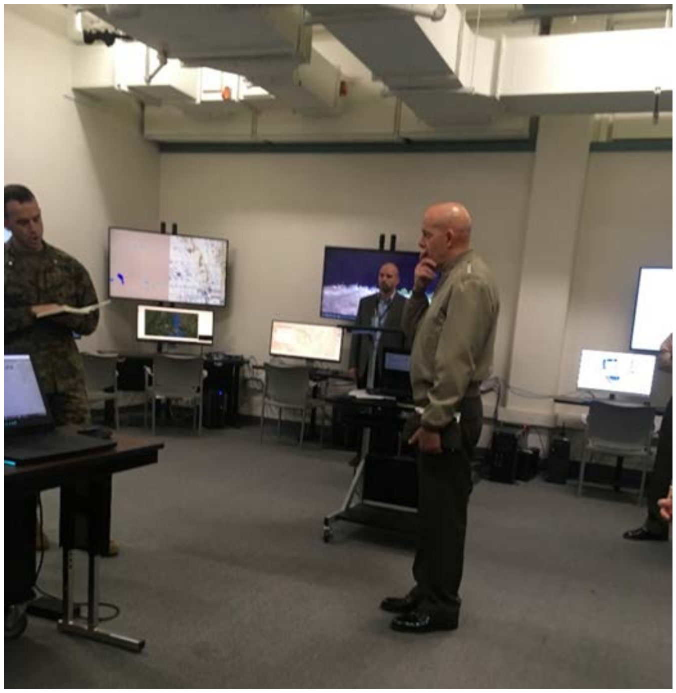

Figure 9. General Berger USMC Commandant receives MOVES briefing on LVC and MUM-T.

D. MOVES COURSE MV3500, INTERNETWORK COMMUNICATIONS AND SIMULATION

MV3500 is an introduction to network communications in simulation applications. Topics include an introduction to the TCP/IP protocol stack; TCP/IP socket communications including TCP, UDP, and multicast; and protocol design issues, with emphasis on Distributed Interactive Simulation (DIS) and High Level Architecture (HLA). The emphasis is on open-source Java and Web-browser applications.

All course examples, assignments and student projects were placed in version control for agile improvement and sharable "lessons learned." Students worked individually and in groups.

- https://gitlab.nps.edu/Savage/NetworkedGraphicsMV3500

During this time period, several interesting projects occurred. Two USMC students applied the just-released NPS Open-DIS Library to add Comment Protocol Data Units (PDUs) to a nearly complete thesis comparing the effectiveness of EM radio-based to optical low probability of intercept (LPI) communications by Forward Observer (FO) teams (Furr 2019). By emitting Comment PDUs when TTP logic provoked a state change in simulation models, these students essentially created a simple design pattern for creating a tactical log of key events occurring in each engagement. Such logging is a useful practice and similar to common practice in real-world operations.

Further work has led to unit-test repeatability thesis research by another MOVES student who is also investigating the possibility of unclassified long-haul networking between NPS and NATO. Further, NAVFAC has given permission for the SPIDERS3D source code to be installed at NPS so that software integration of DIS capabilities might occur. Much important work research, development and prototyping work is expected to continue as a result.

E. MOVES COURSE MV4503, ADVANCED NETWORKING

During the execution of NRP-19-M285, students from MV4503 Advanced Simulation Networking assisted in the development of the VEs depicting how to integrate robotic systems into tactical operations under various environmental conditions. The course is a practicum and faculty have the flexibility to integrate existing NPS research projects into the curriculum in order to facilitate learning. In this project, students were the lead developers of the VEs as they authored the behaviors, created the control measures and configured all of the environmental settings.

To enable the students to make a significant contribution to this work, the course first ensured a strong foundation in networking. Initially, the students were introduced to the hardware, software, and network protocols required to run federated combat simulations. Students received “hands-on” exposure to the internal components of a computer where they performed labs that included adding more random access memory (RAM) to a computer and upgrading a computer graphics card. Next, routers set up and configured simple networks using various networking hardware including routers and switches, learning how to program these connectivity devices using a simulated command-line interface matching actual administrator consoles. These skills are critical for all Marine Corps 8825s as they may serve in M&S billets that require management of simulation labs. Students also learned about the various networking protocols used to transfer data across the network. Specifically, the Transport Control Protocol/Internet Protocol (TCP/IP) and the User Datagram Protocol (UDP) were covered. To understand both, students used Wireshark to inspect data packets passed on the network.

Later in the course, students began using constructive simulations to create environments for training, testing, and experimentation. To create these environments, students interoperated simulations using the DIS protocol or federated simulations using the High Level Architecture (HLA). Within the MOVES LVC Lab, students have 15 constructive simulations available for use. Most are DIS and HLA compliant, which enables the creation of more robust scenarios for analysis. As a capstone, students build a networked constructive simulation to develop a wargame guided by the steps of the Distributed Simulation Engineering and Execution Process (DSEEP).

This MOVES work by Christian Fitzpatrick to establish numerous diverse LVC codebases at one location appears to be a rarity – no other such locations are yet known. This has immense potential for future thesis research and also serves as a potent exemplar for cross-platform integration elsewhere in the DoD M&S community. The attached presentation illustrates these point further.

F. IEEE DIS PROTOCOL AND OPEN DIS SOFTWARE LIBRARY

Distributed Interactive Simulation protocol (DIS), IEEE-1278.1 and related standards have an immense number of uses. First developed in the early 90s, it has steadily evolved and remains active use and development through today. DIS is by far the most common sharable or bridgeable protocol for communicated shared state among the diverse players making up a distributed military virtual environment (VE).

- The Simulation Interoperability Standards Organization (SISO) maintains a Distributed Interactive Simulation / Real-time Platform Reference Federation Object Model (DIS / RPR FOM) Product Support Group (PSG) for DIS work.
- From Wikipedia: “Distributed Interactive Simulation (DIS) is an IEEE standard for conducting real-time platform-level wargaming across multiple host computers and is used worldwide, especially by military organizations but also by other agencies such as those involved in space exploration and medicine.”

OpenDIS is an open-source implementation of the protocol, available at SourceForge and primarily contributed by NPS. Major rework during this project renewed XML representations of IEEE DIS Protocol Data Units (PDUs) with a corresponding reworking of the XML Protocol Generator (XMLPG) to autogenerate library codebases for programmers to use. Release and testing of OpenDIS v7 Java library on SourceForge was accomplished for the Java programming language, upgrading from Java 8 to Java 13 (and matching upgrades from Netbeans 8 to

Netbeans 11). As occurred previously for OpenDIS v4, plans are in place to someday autogenerate similar codebase libraries for the JavaScript, Python, C++ and C# programming languages.

The latest Java version of the Open-DIS library is the first to implement all 72 DIS protocol data units (PDUs) which are the essential packet types which make up this vocabulary of functionality. Concurrent work also created strongly typed Java enumerations for 20,000 identifier codes for vehicles, nations, sensors, interactions, etc. Autogeneration of software source code from data definitions in XML allows this work to scale with the evolution of DIS, when further versions are eventually developed and approved by SISO and IEEE.

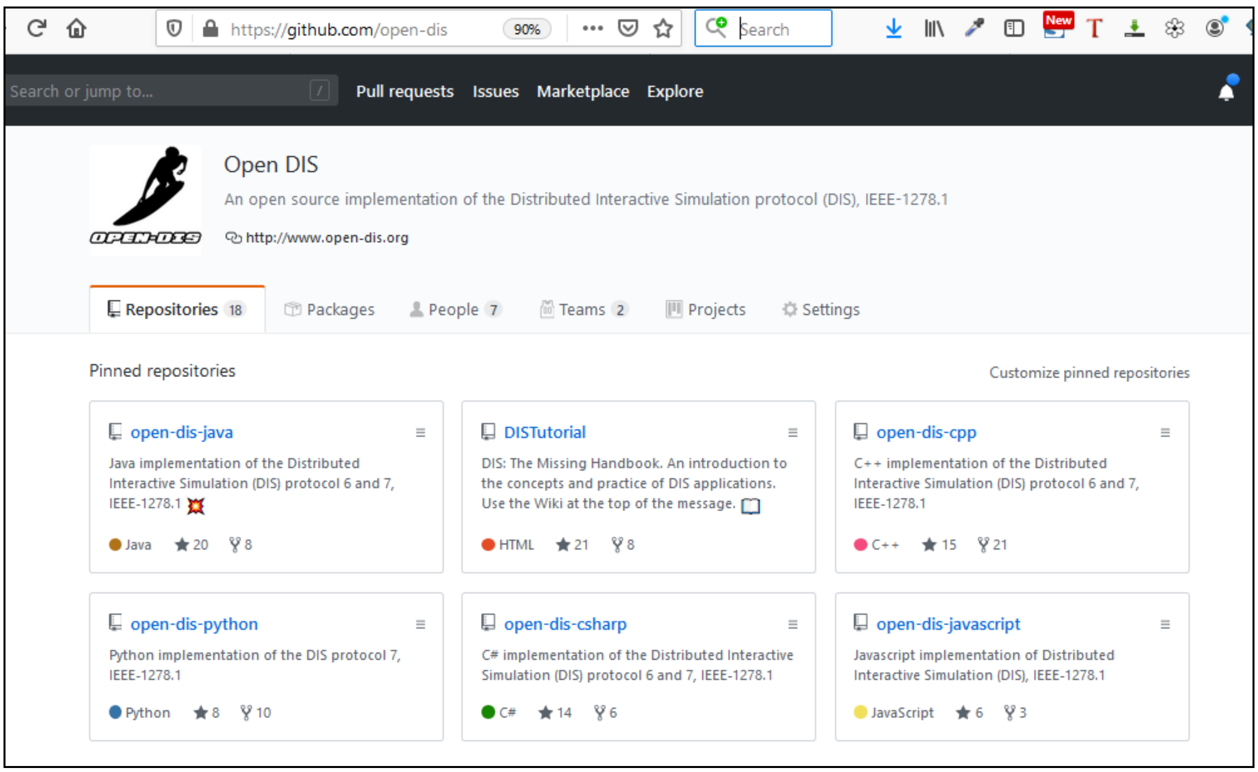

Figure 10. The Open-DIS Library implements this widely used IEEE protocol in multiple programming languages. Online at https://github.com/open-dis

G. DIS STREAMING AND UNIT TESTING

DIS Streaming and Unit Testing are new lines of work that have emerged from this research. A long-time UNIX aphorism is that “a stream is a stream,” meaning that binary bit sequences over the network are identical to recordings of those same bit streams in a file. A more contemporary notion is to consider a network stream as "data in motion" while a stored file is "data at rest." Curiously, decades of DIS usage remain centered around live network streaming. Storage of streams is implemented in the new OpenDIS v7 library (with further improvements planned). Meanwhile, "unit testing" is the creation of small blocks of source code that can be repeatedly invoked to verify that software capabilities remain sound throughout long-term development and modification. Adding version control to this mix of best practices allows tracking when and how diversions might occur over time.

We have successfully tested initial unit tests for OpenDIS streams, in the laboratory and as classroom assignments. This work proposes a path forward that establishes unit testing as a way to confirm that implementations are compliant with the DIS specification, both for PDU formats and also for verification and validation of semantically correct behaviors. Such a capability might modernize multi-participant network traffic in distributed VEs on a par with other software quality assurance (QA) approaches. This also allows Marine-machine analysts to determine whether participant behaviors matched TTP requirements, whether performance metrics reached success thresholds, and whether unexpected anomalies or dangerous outliers might occur during large-scale testing. The following diagram illustrates this process.

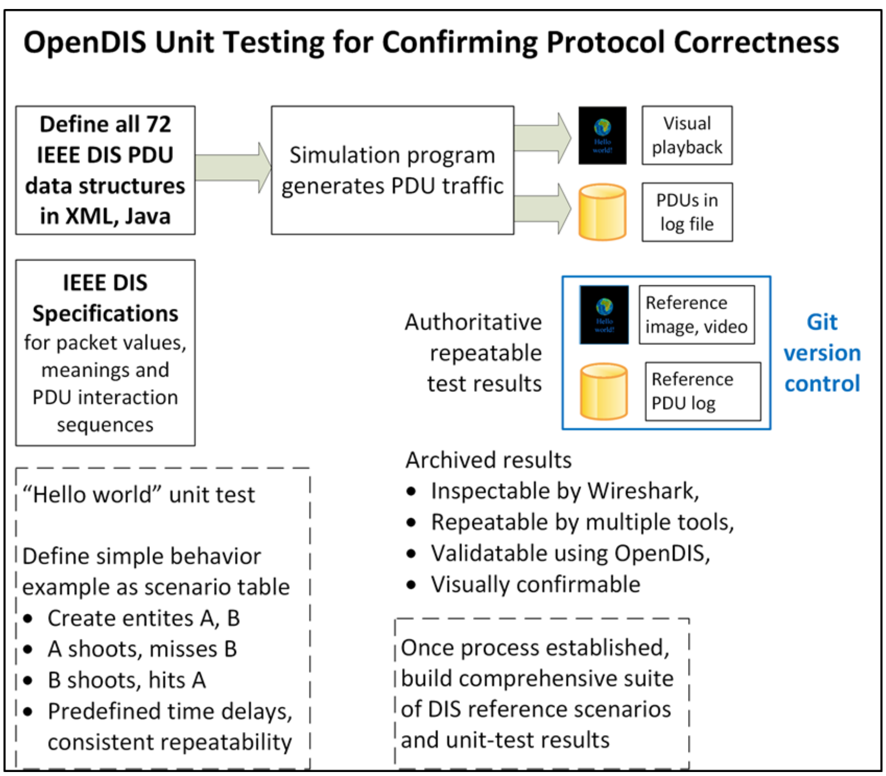

Figure 11. Open-DIS Unit Testing is a new technique with the potential for broad testing of diverse applications to ensure correctness and consistency of software protocol handlers.

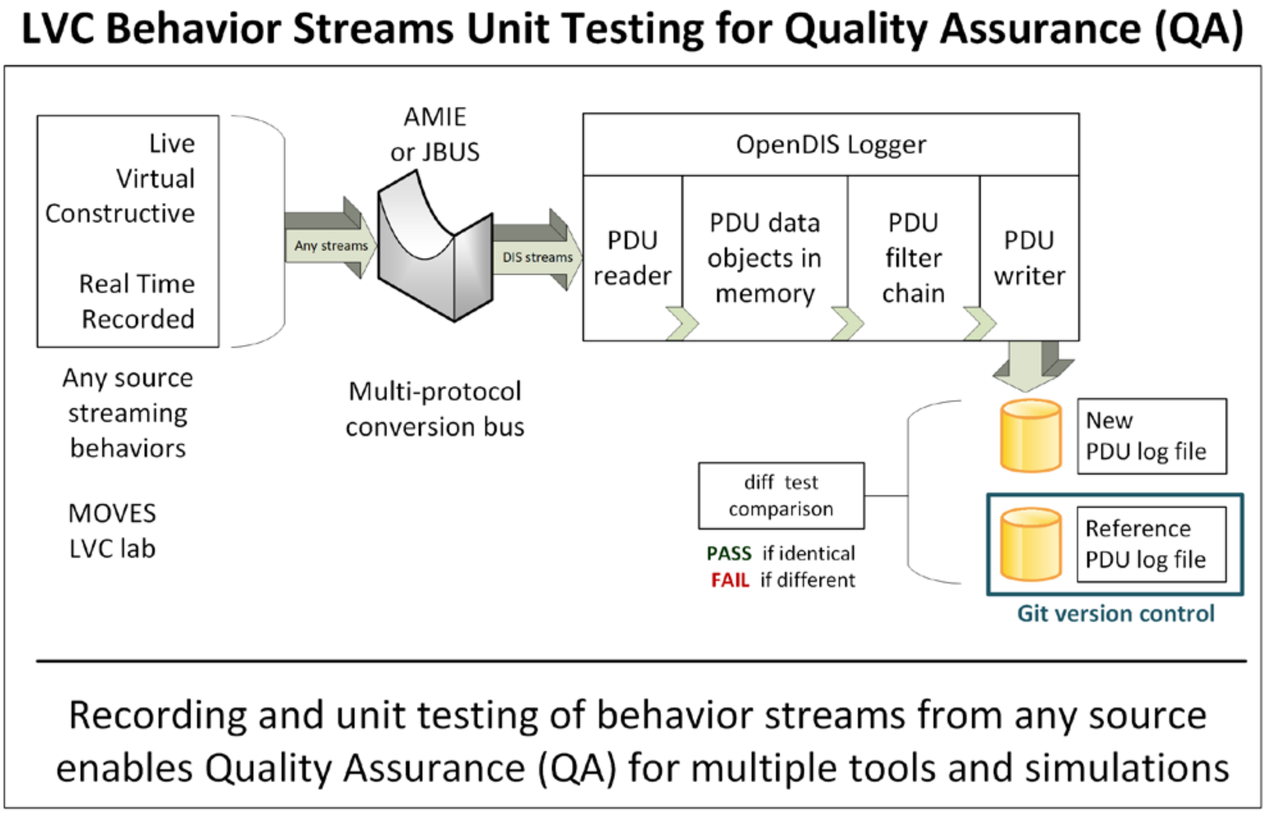

Figure 12. Also developed for this project, LCV Behavior Streams Unit Testing for Quality Assurance (QA) can further check simulation-software correctness when life-cycle changes are made.

H. ADDITIONAL DIS EDUCATION: IITSEC 2019 TUTORIAL "DIS 101"

IITSEC 2019 Tutorial: DIS 101 was given at Interservice Industry Training Simulation Education (I/ITSEC) in Orlando Florida 9 December 2019.

> *Tutorial Abstract.* The Distributed Interactive Simulation (DIS) protocol is a well-established IEEE standard for packet-level exchange of state information between entities in military simulations. DIS facilitates simulation interoperability through a consistent over-the-wire format for information, widely agreed upon constant enumeration values, and community-consensus semantics.
>
> Anyone can obtain the IEEE-1278 standard and implement their own compliant, interoperable, DIS application. A large variety of tools and codebases simplify this effort, and enable multi-architecture integration of simulations using the DIS stand baseline. DIS focus begins with real-time, physics-based, entity-scale simulations, providing state update and interaction mechanisms which can scale to large virtual environments.
>
> This tutorial is a "DIS 101" introduction for software implementers and an introduction to the DIS philosophy for simulation systems integrators. Examples

are provided using the open-source Open-DIS library for DIS v7 support, available in multiple programming languages. Ongoing work is included in WebRTC browser streaming, experimental implementation of DIS v8, plus Web-based implementations using 2D maps and X3D Graphics.

Updates from this MUM-T project were included. All assets are online as follows:

- https://www.iitsec.org
- https://www.iitsec.org/-/media/sites/iitsec/agenda/2019/archive/2019-abstracts.ashx?la=en
- https://www.web3d.org/event/iitsec-2019-tutorial-distributed-interactive-simulation-dis-101

Figure 13. Each year the DIS 101 course is well attended at I/ITSEC.

I. SUMMARY

The MOVES LVC Laboratory provides important and unique capabilities for demonstration and analysis using a wide variety of simulations. The NPS MOVES two-course sequence in networking supports student graduate education and research goals, providing direct exposure of practitioners to this project. A visit by Commandant USMC to NPS MOVES included an informational brief on MUM-T virtual environments and their relation to current service imperatives. The nearly 30-years and still-running IEEE DIS Protocol enables the possibility of bridging between highly different LVS simulations so that network streams might be composed in hybrid simulations. Graduate course work and ongoing research activity were boosted by impressive progress in the NPS-produced Open DIS Software Library. Wrapping up the year, the IITSEC 2019 Tutorial “DIS 101” by NPS described the basics of how to use the IEEE DIS protocol in modern simulation programs.

V. VIRTUAL ENVIRONMENTS (VE) AND VIRTUAL REALITY (VR)

A. INTRODUCTION

Virtual Environments using 3D graphics provide a means to compose and understand the numerous elements involved in a comprehensive tactical simulation. Virtual Reality (VR) user-interface devices such as Head-Mounted Displays (HMDs and overlay glasses provide alternate means of viewing and interacting with such environments. These specialty accessories are occasionally helpful but also include a number of drawbacks. Scalable interoperability through Web standards is the achievable capability needed for large-scale use of VEs by military personnel. NAVFAC's SPIDERS3D system works securely across Navy Marine Corps Internet (NMCI) and has excellent capabilities for UNCLAS storyboarding and scenario exploration.

B. VIRTUAL ENVIRONMENT (VE) CHARACTERISTICS

Virtual environments (VEs) are the composition of diverse resources into a single computing environment, and typically use 3D graphics for presentation of real-world scenarios. VE capabilities are especially appropriate for military scenarios that require diverse components such as model display, motion, physics-based motion, distributed participants, persistent state and coherently shared response. While a variety of systems claim to be virtual environments, only a small number of systems actually have a large inventory of data inputs available.

C. VIRTUAL REALITY (VR) AND AUGMENTED REALITY (AR) CHARACTERISTICS

From Wikipedia: "Immersion into virtual reality (VR) is a perception of being physically present in a non-physical world. The perception is created by surrounding the user of the VR system in images, sound or other stimuli that provide an engrossing total environment."

Virtual reality (VR) devices are interesting user interfaces that remain difficult to use and disconnect participants from direct interaction with their surroundings. VR devices also pose both safety, health and security concerns that are not well understood. Such problems tend to worsen when VE users spend long durations immersed, i.e. disconnected from the real world. Thus VR is an acceptable secondary mode for occasional VE interaction, but care must be taken to avoid user challenges.

Augmented Reality (AR) shares many characteristics. Wikipedia notes “Augmented reality (AR) is an interactive experience of a real-world environment where the objects that reside in the real world are enhanced by computer-generated perceptual information, sometimes across multiple sensory modalities, including visual, auditory, haptic, somatosensory and olfactory.” Often VR-style displays with see-though characteristics are utilized for VR. Many of the same concerns pertain regarding health, safety, long-term usability, and scalable utility.

D. ACHIEVABLE CHALLENGE: SCALABLE INTEROPERABILITY

The fundamental nature of the Web is based on scalable interoperability among distinct systems. This work contends that only Web-based virtual environments have the potential to scale across the full range of military needs.

Multiple prior NPS theses have explored capabilities and advanced progress in Web-based virtual environments. One is notable in relation to SPIDERS3D, *Modeling, Simulation, and Visualization for Submarine Transit Security and Coast Guard Contingency Preparedness* (Heron 2015).

> Abstract. The U.S. Navy’s Strategic Systems Program (SSP) and the U.S. Coast Guard (USCG) Maritime Force Protection Unit (MFPU) have a close working relationship, access to advanced Modeling and Simulation (M&S) tools, and a mutual interest in the safe escort of naval submarines. The USCG Contingency Preparedness and Exercises (CPE) Branch has a strong interest in maritime security, which extends to the safe navigation of vessels in U.S. territorial waters, including naval submarines. CPE rarely interacts with SSP and the MFPU; further, CPE does not have access to modern M&S tools. The goal of this thesis is to demonstrate that SSP and MFPU can greatly increase maritime security in the littoral waterways used by submarines and other naval vessels by partnering with CPE. A mixed method approach was used to provide an overview of existing maritime security roles and partnerships, and a 3D-simulation experiment was also developed to demonstrate how CPE can enhance exercises by utilizing robust 3D M&S resources. This thesis establishes that CPE can drastically improve maritime security and other missions by leveraging M&S and Visualization tools. The thesis also found that by partnering with SSP and the MFPU, CPE can accelerate maritime security improvements.

The following figure shows how X3D graphics can be combined with DIS networking to build an agent-based simulation. This simulation was used to examine force-protection tactics that illustrate quantitative measures of interest, permitting visualization of sensitive tactical and scenario characteristics.

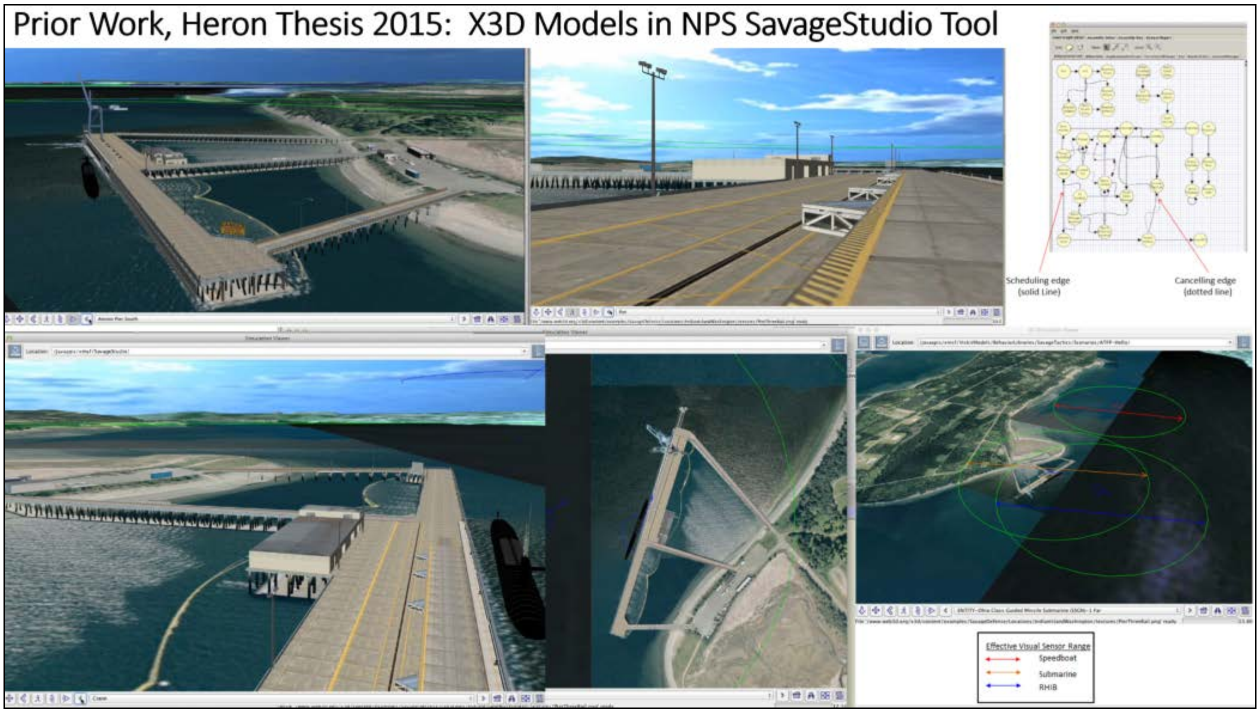

Figure 14. Thesis work (Heron 2015) combining a discrete-event simulation with X3D visualization via DIS.

E. SPIDERS3D VIRTUAL ENVIRONMENT

Naval Facilities and Engineering Command (NAVFAC) is the sponsoring organization in charge of SPIDERS3D. The system includes the following characteristics:

- Virtual infrastructure for Naval ports worldwide, via shared central https server
- Users can collaboratively create, share, explore, annotate persistent scenes
- Buildings, piers, pilings data converted into X3D from current database records
- Web3D X3D Standard for http server to Web browsers
- Web-based architecture: HTML pages with images and JavaScript controls
- Extensible 3D (X3D) Graphics International Standard, Web3D Consortium
- 3D models from any source format can be exported, published as X3D

- Open source and open standards throughout, no commercial licenses
- Deployed, available across both NMCI and public Internet
- Requires CAC access and prior account approval, use any time

Over 30 real-world locales are currently available in SPIDERS3D with more in production. Over 300 scenarios currently exist in SPIDERS3D, mostly created by cooperatively collaborating end users. As users explore each vignette, further improvements are possible. Creation of a snapshot image saves a well-defined viewpoint, allows visual annotation through the use of drawing tools, and essentially can build a storyboard describing scenarios of interest.

Perhaps the greatest value of SPIDERS3D to end users is the ability to collaborate, providing shared inquiry and comprehension despite being in different locations. The following images show a series of storyboard vignettes created to demonstrate remote collaboration among multiple participants which was used to amplify and demonstrate multiple themes in this project.

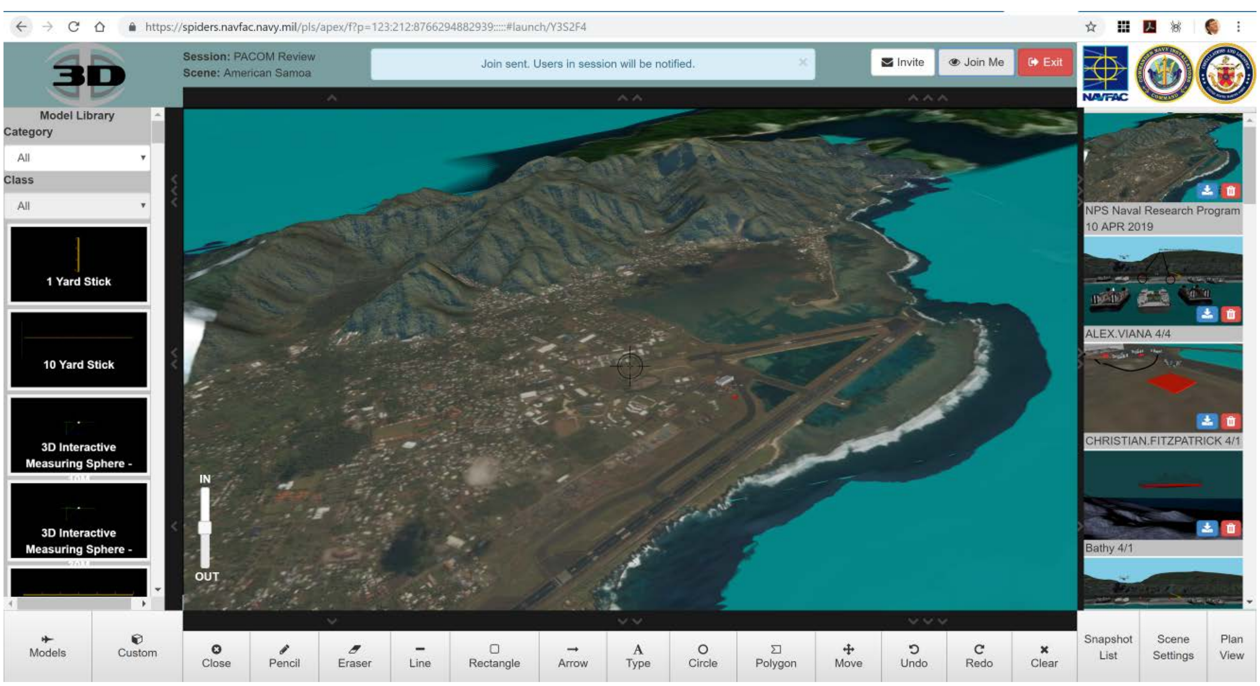

Figure 15. SPIDERS3D American Samoa scenario from above. Note model library on left sidebar, selectable drawing tools on bottom sidebar, and annotated viewpoint image links on right sidebar.

Figure 16. SPIDERS3D American Samoa scenario from viewpoint looking directly down, positioned above UAS (within circle) performing overflight of the airfield.

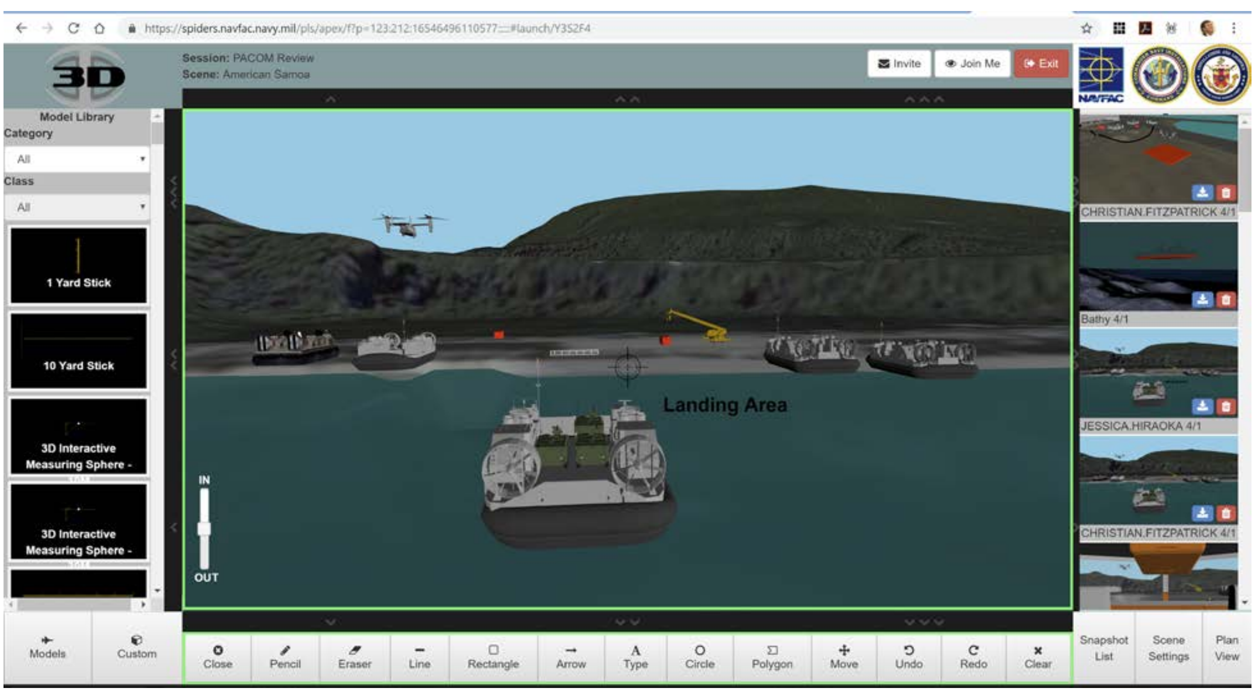

Figure 17. SPIDERS3D American Samoa scenario showing landing craft approaching the beach. Participants control the number, location and identification of entities shown in the world.

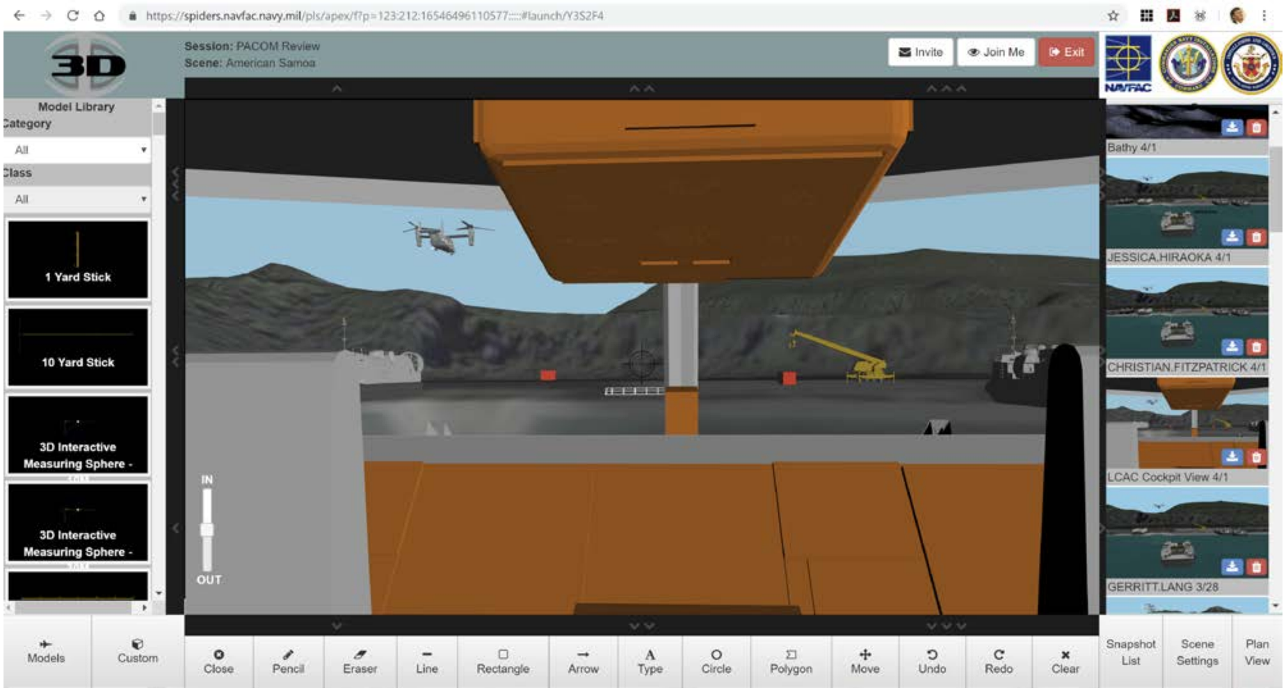

Figure 18. SPIDERS3D American Samoa scenario showing view from inside landing craft. All entities in this scene are static, the storyboard vignettes are key frames without connecting animation.

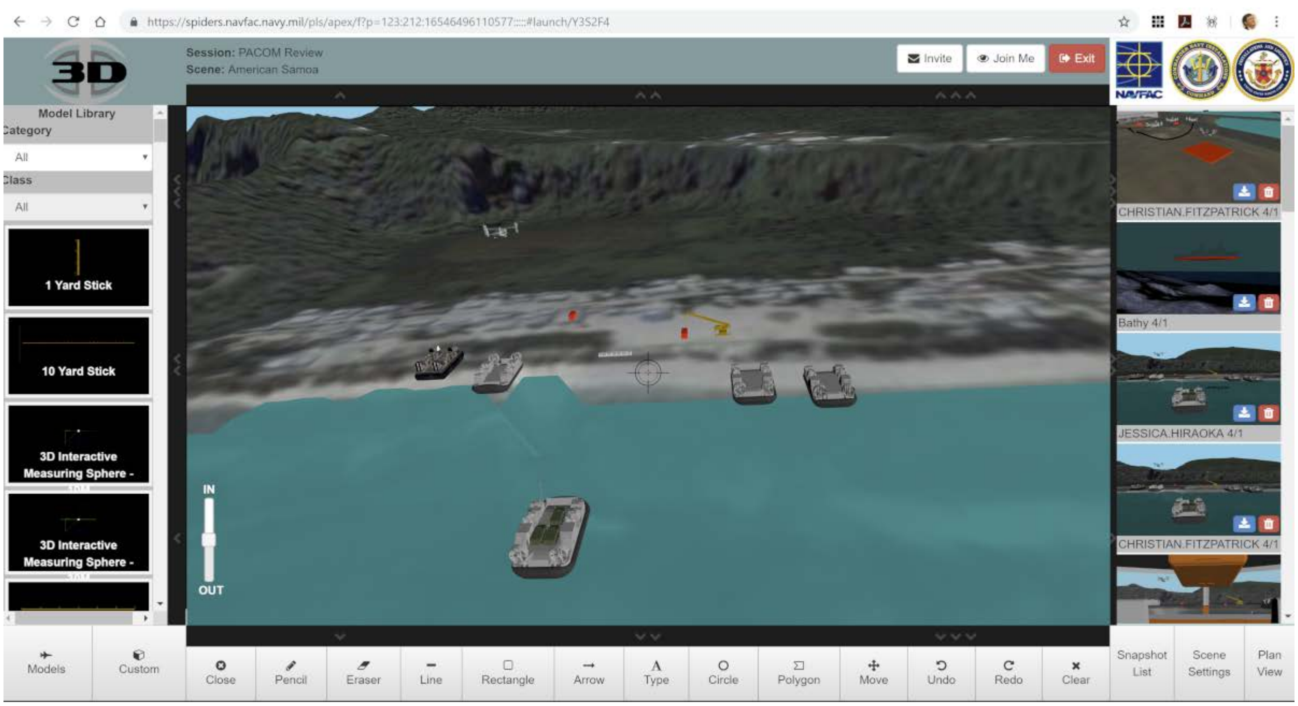

Figure 19. SPIDERS3D American Samoa scenario showing perspective view of landing craft crossing beach. Freedom of navigation for each user allows independent exploration and subsequent resynchronization.

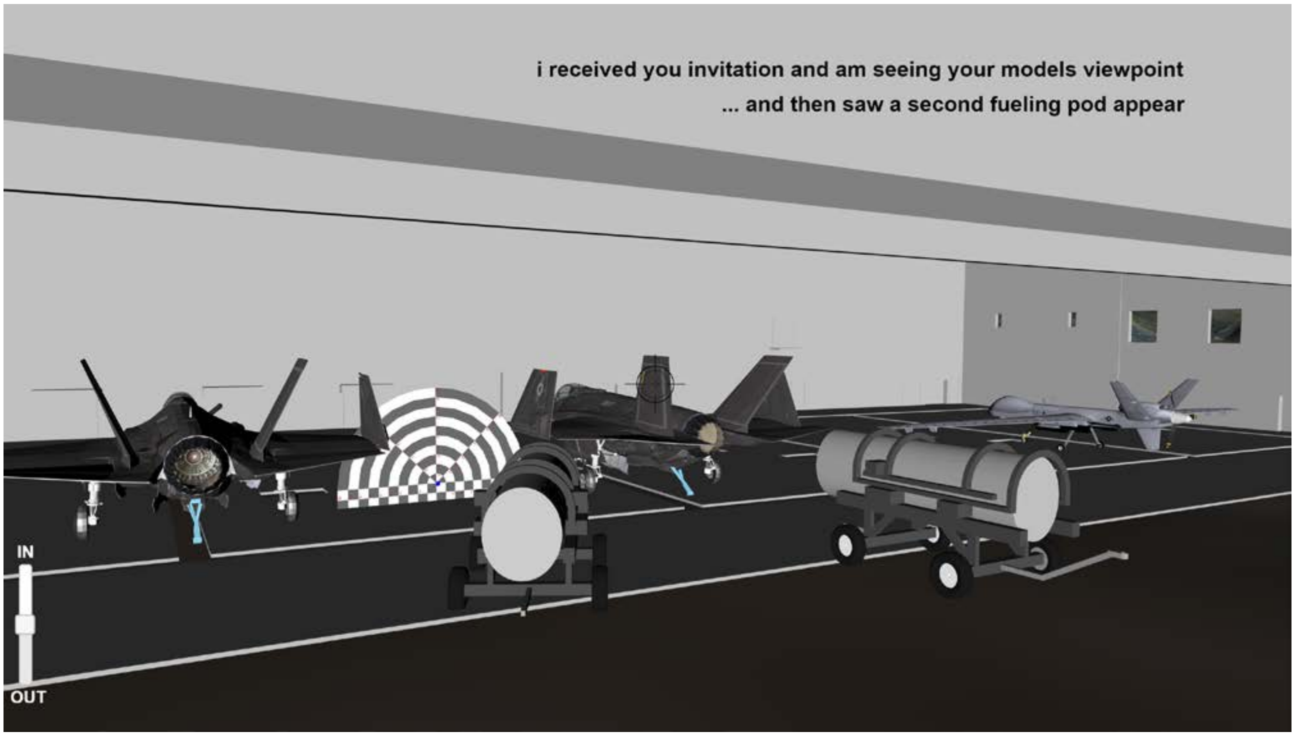

Figure 20. SPIDERS3D American Samoa scenario showing interior bay of maintenance hangar along with overlay annotations documenting participant invitation, synchronization and authoring activity.

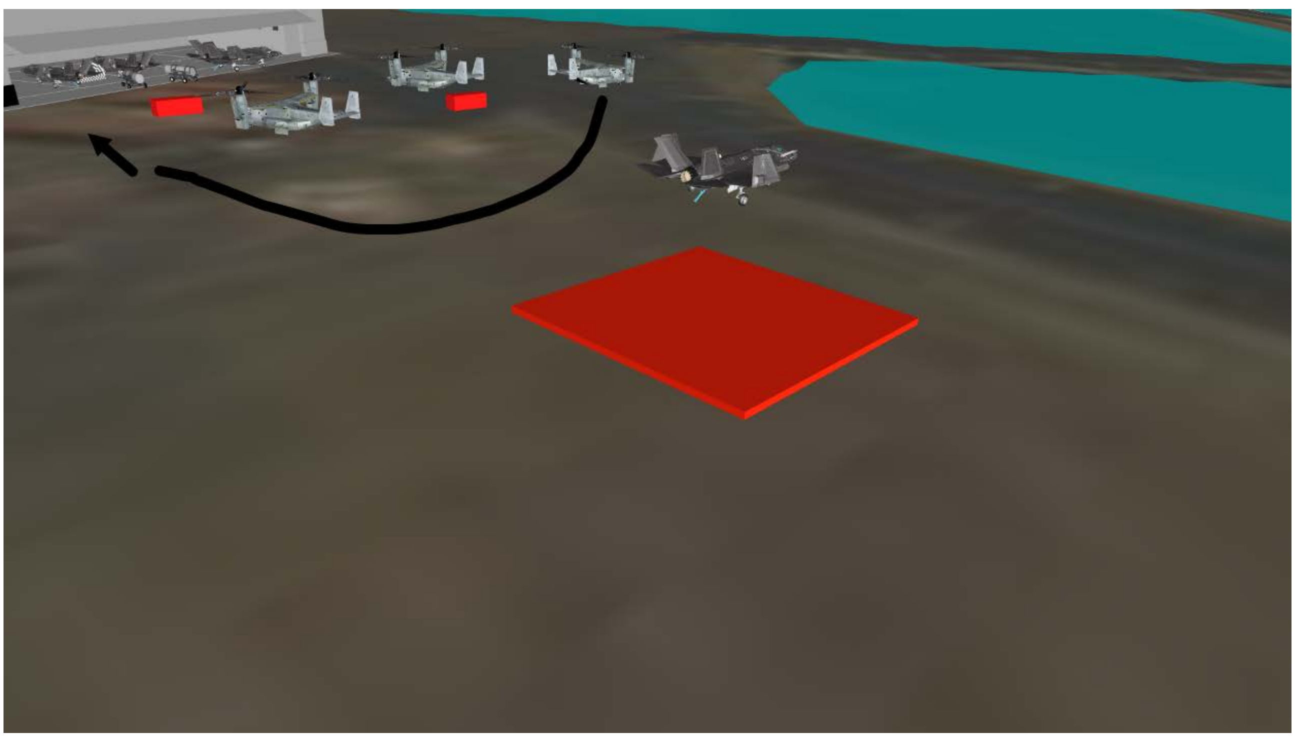

Figure 21. SPIDERS3D American Samoa scenario showing further collaborative planning no deployment of expeditionary forces using the maintenance hangar. Note user-drawn annotation arrow for path planning.

F. SUMMARY

Composing 3D graphics models into comprehensive Virtual Environments enables participants to collaborative explore comprehensive tactical simulations. Virtual Reality (VR) interface devices have a number of problems that discourage collaboration but sometimes provide useful means of closely examining virtual objects. Web standards are designed for scalable interoperability and standards such as DIS and X3D can be applied for large-scale use of VEs by military personnel. NAVFAC's SPIDERS3D system works securely across Navy and Marine Corps systems with excellent capabilities for UNCLAS storyboarding and scenario exploration. SPIDERS3D is free for use by military personnel and defense contractors. Further improvements to SPIDERS3D are ongoing and integration of DIS streaming is planned. Receiving the authority to operate (ATO) this nonproprietary software in NATO and secure environments is expected to provide further analytic opportunities needed for in-depth MUM-T experimentation.

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VI. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

Marines teaming with machines provide an essential margin on the battlefield. Success will be determined by human effectiveness to harness and lead such teams. Understanding, expertise and capability can grow through rehearsal and testing in virtual environments. Clearly a massive set of capabilities is emerging in each of these domains. The use of open standards (DIS, X3D) and open source (SPIDERS3D) means that diverse systems, models, streams and repeatable “lessons learned” can continue to grow more broadly and deeply.

Specific conclusions include:

1. Diversity of software is essential for tracking USMC progress in unmanned systems. Locking into a short set of vendors inhibits progress. Data standards enable information exchange and systems interoperability.

2. Publishing 3D models and metadata in archival X3D form, and recording DIS behavior streams from LVC simulations, can enable long-term re-use and composability of all forms of products needed for man-machine evaluation, regardless of whether source programs were open or proprietary.

3. General solutions to virtual environments are possible using Web Standards, in particular X3D Graphics and IEEE Distributed Interactive Simulation (DIS) Protocol.

4. SPIDERS3D by NAVFAC provides excellent capabilities for visualizing distributed human-robot teaming operations that meet all access and design restrictions with ongoing improvement.

B. RECOMMENDATIONS FOR FUTURE WORK

Every aspect of this project has unlocked bigger capabilities and challenges than previously existed. Virtual environments that integrate field experimentation (FX) results with modeling and simulation (M&S) data streams, using 3D models for visualization within shared collaborative virtual environments, provide a path for warfighters to understand capabilities, limitations, risks and progress. Future work best advances when grounded by cross-connected LVC interoperability testing to ensure that global progress can continue, avoiding the common “stovepipe” constraints that limit many current approaches. Much further implementation, evaluation and improvement awaits on these defense-critical challenges.

Specific recommendations for virtual environments supporting human-machine teaming include the following.

1. Further work in Web-based virtual environments holds great promise and needs to continue for both Navy and USMC.

2. Numerous potential next steps for X3D version 4 development were described and considered during the *Collaborative 3D Visualization for Ashore, Afloat and Expeditionary Readiness Workshop,* summarized with linked presentations in Appendix E.

3. Further work in the OpenDIS project on GitHub can help advance many systems and ongoing NPS graduate research. Addition of the draft Compressed DIS encoding to the Open-DIS library can broaden usage further in reduced-bandwidth environments.

4. 3D model archives such as those getting assembled for SPIDERS3D need to pay close attention to ownership, licensing and terms of use. The X3D model format is well suited for archival capture of commercially developed models and metadata, as appropriate for limited or unrestricted usage. Technical requirements for contracts need to be consolidated as best practices so that Government requirements are best protected over the long term.

5. Adapting SPIDERS3D as a “virtual sand table” where a vertical projector displays overhead views can likely allow human observers to physically augment surface displays with properly scaled 3D-printed objects. Sand-table techniques have been useful planning and collaboration tools for hundreds of years, modern portrayals using 3D graphics and 3D printing may be similarly effective.

6. Numerous scenarios of interest can be modeled realistically at an unclassified level. Gaining approval for porting SPIDERS3D to NATO or classified networks have strong potential to add further analytic capability with international partners.

APPENDIX A: PROJECT POSTER

The following Naval Research Program (NRP) poster notes and illustrates the primary themes for this project.

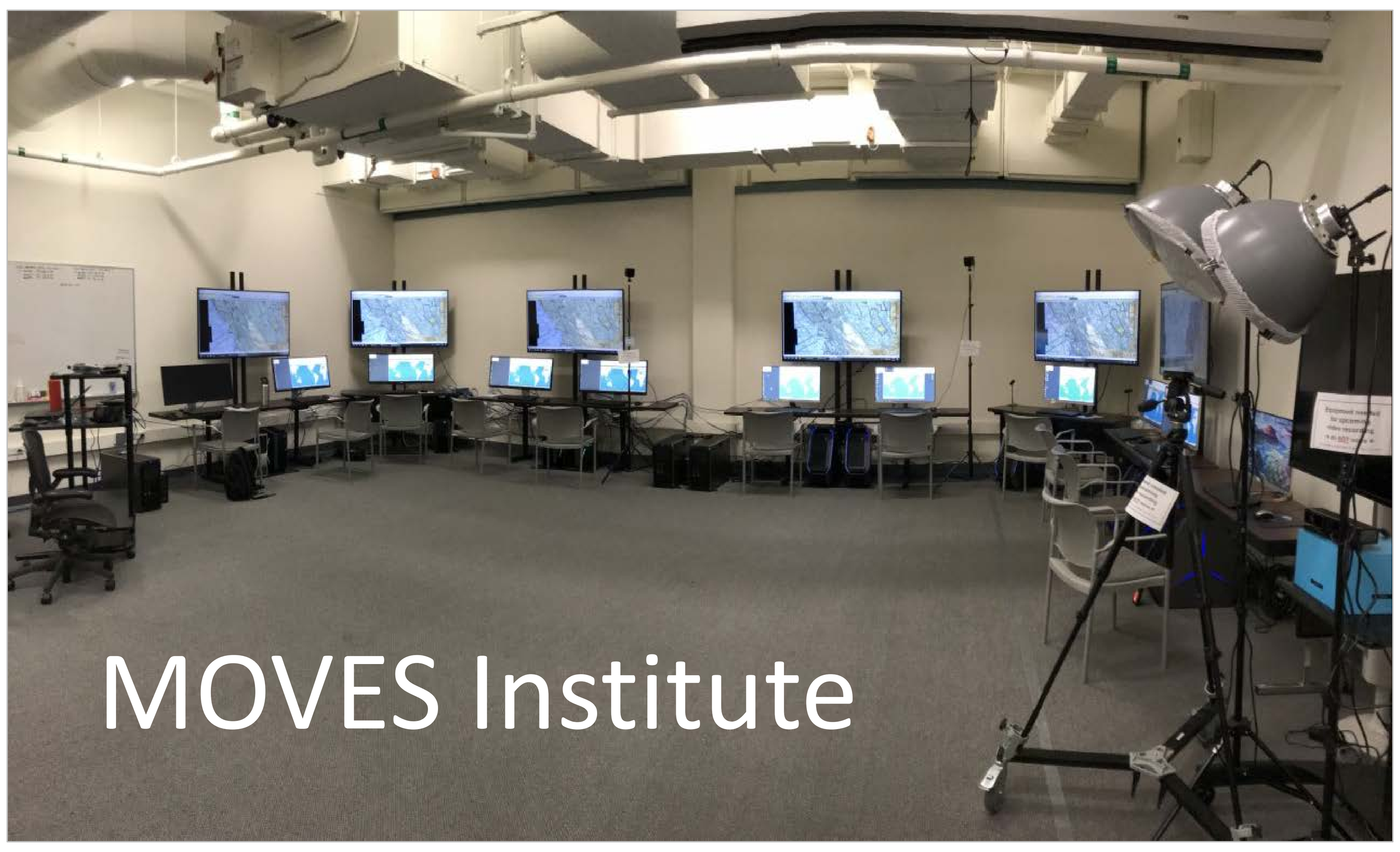
Creating Virtual Environments to Analyze Human Machine Teaming

Naval Postgraduate School

Human Machine Teaming

- Emerging deployment of robots on the battlefield makes tactical integration of manned and unmanned assets critical for MAGTF operations.
- Concept of Operations (CONOPS) capability gaps for future systems cannot depend solely on live field testing, which is intermittent and costly.
- This effort demonstrates use of virtual environments (VE), virtual reality (VR) and agent-based modeling to conduct scenario-based assessments of human machine teaming (HMT).

US Marines patrol with Unmanned Ground Vehicle (UGV)



MOVES LVC Lab offers networked VEs for analysis

Research Questions

- How can Web-based VE visualizations and VR interfaces help assess effectiveness HMT augmentation of existing combat units?
- How can HMT complement existing combat units so that tasked roles and corresponding orders are well understood by humans and robots alike?
- Can open standards for networked VEs and VR repeatably portray various HMT mission sets within the MAGTF?
- How can collaborative Live Virtual Constructive (LVC) simulations rehearse, observe and replay HMT operations?

Virtual Environment: SPIDERS3D

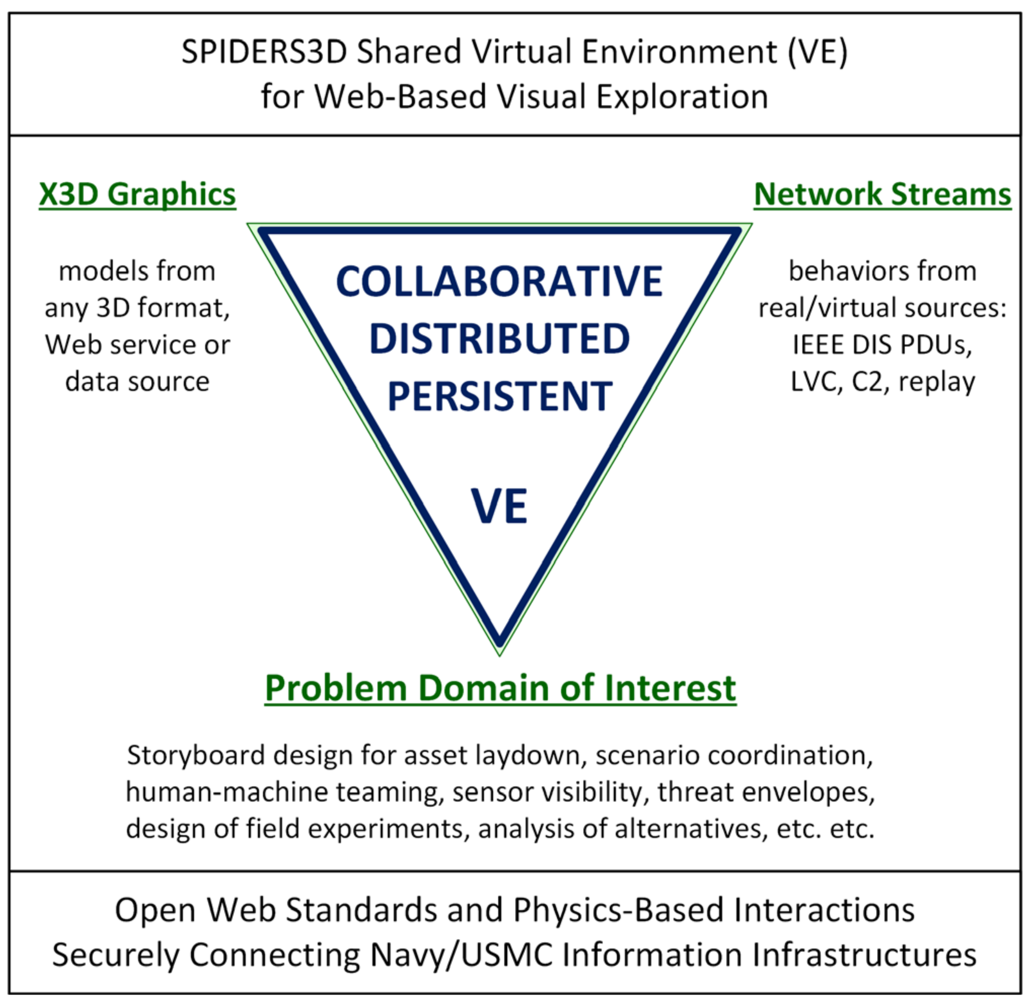
SPIDERS3D is an easy-to-use browser based application on the NAVFAC Portal www.navfac.navy.mil that offers users a variety of ways to employ three dimensional (3D) visualization to better understand how new platforms could potentially impact facilities.

- Provides a venue to test planning concepts and give context to discussions.
- Allows users to quickly create a variety of ship berthing and aircraft parking scenarios online at highly accurate virtual representations of Naval Installations worldwide. Users can virtually walk along a pier or inside the maintenance bay of a hangar.
- Offers a tremendous library of diverse 3D models for use including existing platforms as well as those being planned or currently in the acquisition pipeline. Users can visualize new weapon platforms as they would interact within an existing naval base environment.
- Affords multi-discipline working groups the ability to collectively collaborate in real-time within a spatially accurate, common virtual environment. Participants log in from their individual computers and communicate collaboratively onscreen in real-time.

SPIDERS3D developed by NAVFAC for the Navy and Marine Corps

Using VEs to develop HMT TTPs in the Future Battlespace

- The initial development and assessment of HMT TTPs ISO MAGTF operations.
- The initial application of VEs and VR to explore the interdependence of MAGTF units with autonomous systems.
- The expansion of LVC simulations helps define the future MAGTF battlespace.
- Virtual Environments help human leaders better explore and understand the digital interoperability required to execute HMT within MAGTF operations.



Conceptual diagram describing a methodology to create dynamic VEs for tactical system evaluation

Researchers: Dr. Don Brutzman and Mr. Christian Fitzpatrick
Modeling Virtual Environments and Simulation (MOVES) Institute,
Graduate School of Operations and Information Sciences (GSOIS)
Topic Sponsor: Marine Corps Warfighting Laboratory (MCWL)

NRP Project ID:
NPS-19-M285-A

APPENDIX B: SCENARIO DEMONSTRATION VIDEOS

Scenario demonstration videos for this project are saved and cataloged as permanent records in the NPS Calhoun archive. This approach supports long-term viewing and study. We foresee the eventual addition of similar capabilities for scenario authors in future updates to the SPIDERS3D system.

- Manned-Unmanned Teaming (MUM-T) Scenarios [video]
  https://calhoun.nps.edu/handle/10945/63698

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APPENDIX C: BRIEFING SLIDESET, CREATING VIRTUAL ENVIRONMENTS TO ANALYZE MANNED-UNMANNED TEAMING (MUM-T)

The following slideset provides primary information regarding project themes.

Creating Virtual Environments to Analyze Manned Unmanned Teaming (MUM-T)

NRP Project NPS-19-M285

17 DEC 2019

Don Brutzman

brutzman@nps.edu

Naval Postgraduate School (NPS)

Terms of Reference

Manned Unmanned Teaming (MUM-T)

- Coordinated Tactics Techniques and Procedures (TTPs) for unmanned systems operating under the direction of Marine forces

Virtual Environments (VEs)

- Composition of completely diverse resources into a common computing presentation, sharable with distributed networking, and presented using both 3D graphics models and 2D information displays

Virtual Reality (VR)

- User interface devices that provide participants with immersive displays, often at the expense of participant isolation and safety/security risks

Premises

- MANY systems relevant to USMC Manned Unmanned Teaming (MUM-T)
- Fundamental work by Matt Johnson, Scot Miller et al. providing framework for progress despite extreme diversity of AI and systems
- X3D Graphics international standard allows visualization via Web
- SPIDERS3D collaborative environment applies X3D models and locales safely with CAC FOUO security for Navy/USMC personnel around world
- IEEE Distributed Interactive Simulation (DIS) provides path to linking diverse Live Virtual Constructive (LVC) behaviors with visualizations
- NPS providing baseline capabilities that USMC will need to connect numerous diverse systems, trackers, datasets to build and evaluate HMT

Poster overview

Manned Unmanned Teaming (MUM-T)

- Emerging deployment of robots on the battlefield makes tactical integration of human and machine assets critical for MAGTF operations.
- Concept of Operations (CONOPS) capability gaps for future systems cannot depend solely on live field testing, which is intermittent and costly.
- This effort demonstrates use of virtual environments (VE), virtual reality (VR) and agent-based modeling to conduct scenario-based assessments of Manned Unmanned Teaming (MUM-T).

Original acronym: manned-unmanned teaming (MUM-T)

Research Question Summaries, 1

What is Marine-machine teaming, defined in terms of engineering evaluation?

- Considered in broadest possible analytic sense, for current emerging and evolving Marine supervision of diverse systems in combat environments

What constitutes a virtual environment, what is the best approach for this case?

- Composition of information assets in 2D/3D display interconnected with Live Virtual Constructive (LVC) Modeling and Simulation (M&S). Best approach is to use Web standards for scalable repeatability using NAVFAC SPIDERS3D system.

Can NPS use existing work to expedite construction of such an environment?

- Yes. Many capabilities are demonstrated and development is ongoing.

How can Manned Unmanned Teaming (MUM-T) be used to complement the capabilities of existing combat units in a manner where tasked roles and corresponding orders are well understood by humans and robots alike?

- Two compatible approaches considered, IHMC Interdependency Analysis and NPS Ethical Control of Unmanned Systems using coherent mission orders.

Research Question Summaries, 2

How can Web-based VE visualizations and VR interfaces help assess effectiveness of HMT augmentation of existing combat units?

- Demonstration examples using SPIDERS3D show characteristics in detail. VR interfaces provide occasional insight but have limited team value.

Can VEs and VR be used to define various Manned Unmanned Teaming (MUM-T) mission sets within the MAGTF?

- Initial exemplars are positive using SPIDERS3D (over 300 vignettes exist) and much further work can proceed.

How can we use simulations to rehearse, real-time observe and replay VEs to best visualize Manned Unmanned Teaming (MUM-T) operations?

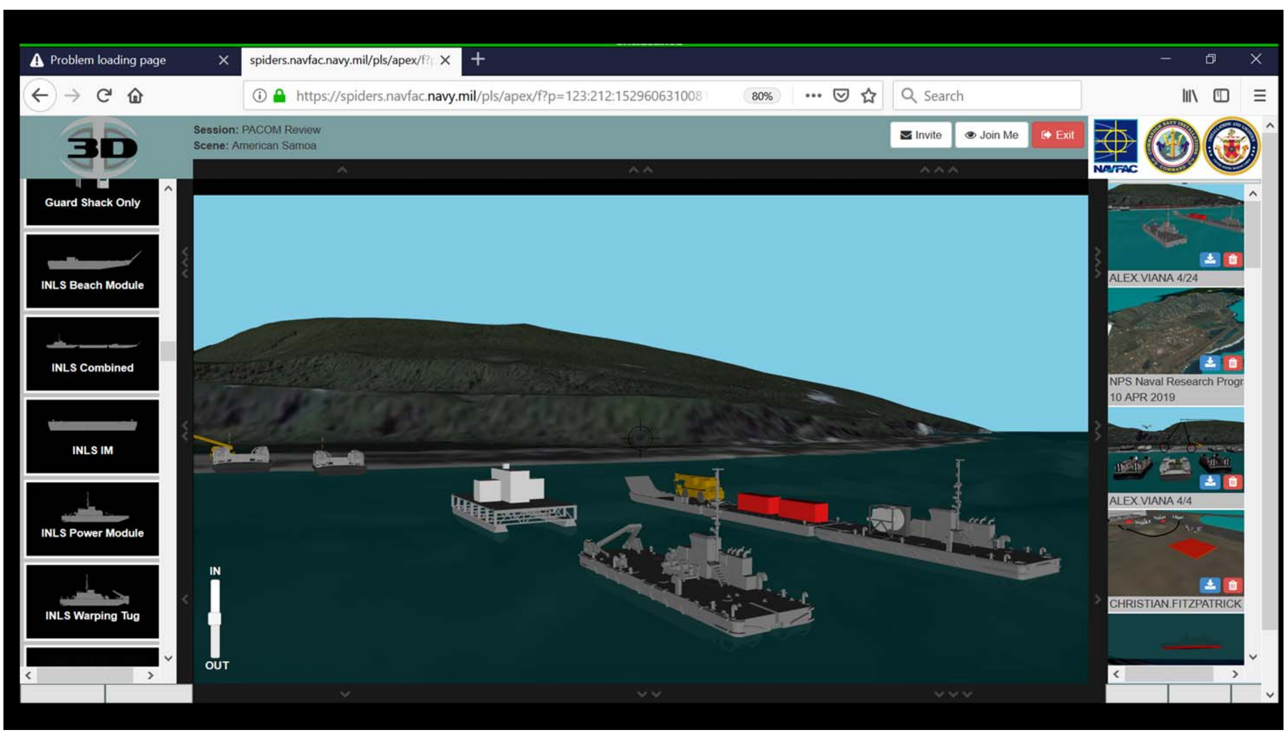
- Only Web standards such as X3D and DIS can bridge the wide diversity of LVC simulations and replays needed to scalably address these challenges.

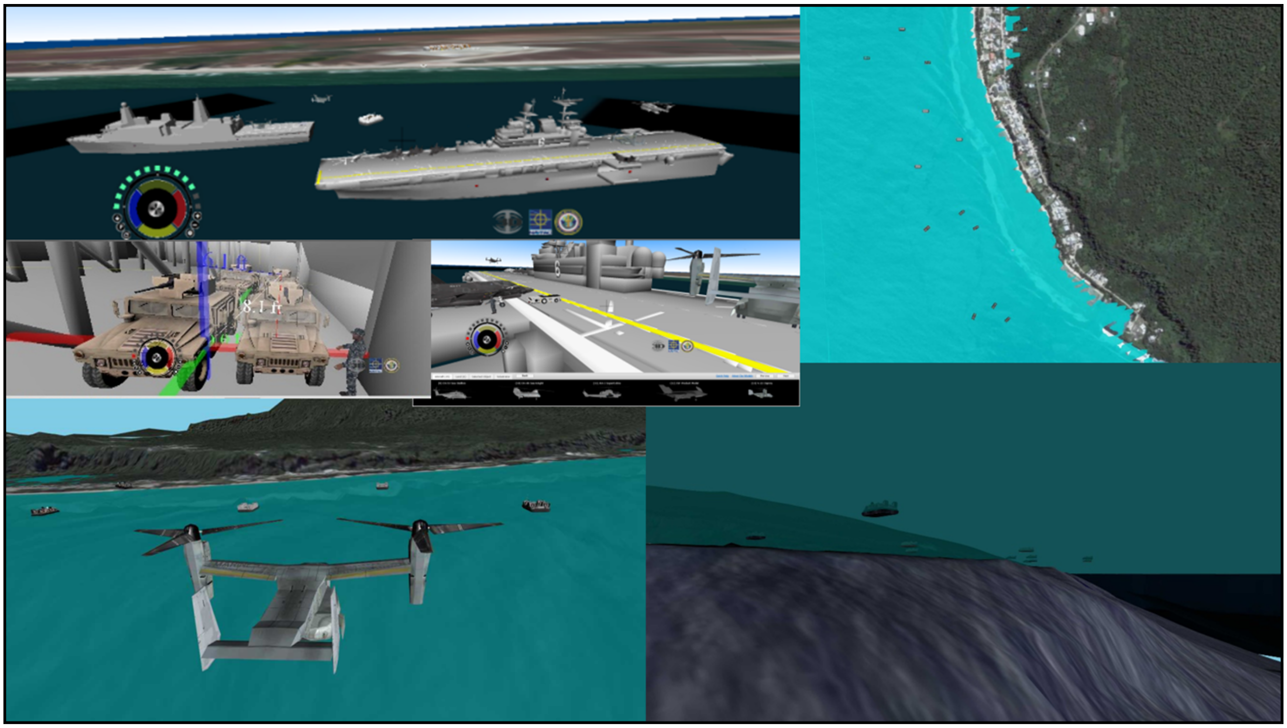
Virtual Environment: SPIDERS3D

- SPIDERS3D is an browser-based application on NAVFAC Portal offering users a variety of ways to employ three dimensional (3D) visualization using X3D Graphics International Standard to show how new platforms can potentially impact facilities.
- Provides a venue to test planning concepts and give context to discussions, running effectively on NMCI, MCEN, NIPRnet, .edu and other non-secure networks.
  - Affords multi-discipline working groups ability to collectively collaborate in real-time within a spatially accurate, common virtual environment. Participants log in from their individual computers and communicate onscreen in real-time.
  - Rejuvenate open-source codebases for IEEE Distributed Interactive Simulation DIS.
- NPS implementation work includes refresh to apply DIS protocol codebase, runnable in web browsers, using X3DOM player for X3D scenes.
  - … thus becoming actionable for eventual SPIDERS3D codebase integration by NAVFAC

Using VEs for HMT Tactics, Techniques Procedures (TTPs) in Future Battlespace

- Initial development, assessment of HMT TTPs ISO MAGTF operations.
- The initial application of VEs and VR to explore the interdependence of MAGTF units with autonomous systems.
- Consider expansion of LVC simulations all the way to NATO collaboration using the emerging C2SIM standard to support the potential future global battlespace.
- To better understand the digital interoperability required to execute HMT within MAGTF operations.
- (Examples follow from KOA MOANA 20 IPC planning vignettes)





MOVES Live Virtual Constructive (LVC) Lab

- Chris Fitzpatrick has assembled numerous LVC applications
- As usual, many major programs are fundamentally incompatible
- Meanwhile bridging to AMIE and JBUS hubs is common shared capability, thus exposing DIS protocol as a “common-denominator” channel
- NPS participating in multiple NMSO SISO efforts, AMIE working group, etc. in combination with courses, theses.

IEEE Distributed Interactive Simulation (DIS) Protocol is "glue" for sharing LVC behaviors

- Major rewrite of long-available open-source codebase github.com/open-dis
- Autogeneration of source code from published data structures has achieved full coverage of 72 IEEE DIS PDUs along with tens of thousands of SISO enumeration values for all known military/civilian platforms
- MV3500 class source-code examples just released this week
- Lead programmer retiring, handing over build processes by end of FY
- Next steps include integrating with activity of small but sustained Github community
- Next goal: round-trip unit testing for repeatability, stability and reuse

Related activities

- MOVES intermediate and advanced Networked Graphics courses
  - 5 USMC, 2 German Army officers (one has chosen this work as thesis topic)
  - All course assets (code, slides) in open-source version control at gitlab.nps.edu
  - Current class assignment: test restored wired/wireless multicast across NPS campus
  - Discussing student final course projects using OpenDIS
- IITSEC tutorial "DIS 101" again presented in Orlando FL, December 2019
- SPIDERS3D open-source HTML/JavaScript has major upgrade in progress
  - beta version tested at Web3D 2019 Conference Los Angeles CA July 2019
- SPIDERS3D NRP FY2020 project approved to support COMOPTEVFOR
  - Visualize ORCA XLUUV basing and deployment CONUS, Pearl Harbor
  - Common basis with all work in this project, USMC investment progress continues
  - NAVFAC releasing copy of GOTS source to NPS to integrate X3D models, DIS code
- CRADA NPS and Raytheon Missile Systems on Human Ethical Control of Unmanned Systems applying Semantic Web reasoning to mission orders

Next steps and future work

- Request that we keep “in the loop” for USMC HMT so that these emerging capabilities remain poised for potentially broad use
- Proposal submitted to NMSO for further DIS work – no response.
- Robodata research continuing to unlock all NPS Field Experimentation (FX) telemetry data + metadata, for repeatability and DTIC archiving
- Conceptual agreement and thesis student to pursue version of SPIDERS3D Virtual Environment for NATO-interoperable collaboration
- Potential work: Virtual Sand Table proposal to “mash up” X3D Model Exchange printed models with overhead projection of SPIDERS3D VE

Additional information

Virtual/Augmented Reality Sand Table using SPIDERS3D Web Visualization and X3D Model Exchange for Agile Remote Collaboration

Seeking Sponsor

Build no-cost VR/AR Sand Table using NAVFAC SPIDERS3D port/beach visualizations for Web collaboration using 3D-printed scale models. Varied headsets, user-interaction devices can be added and compared.

1. How can virtual sand tables be repeatably built at negligible cost, with (visual) SPIDERS3D plus (physical) Model Exchange assets?
2. Can practitioners demonstrate seamless use of diverse VR, AR, and MAR/XR technologies as part of effective team collaboration?
3. How can Navy/Marine warfighters best apply thesis techniques to visualize, interact and collaborate on urgent challenges?
4. How can publication using open standards and structured metadata protect DoD content and modeling assets for long-term use?

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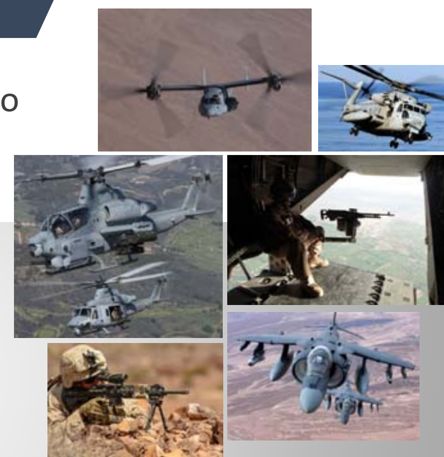
Monterey California 93943-5000 USA
1.831.656.2149 work
1.831.402.4809 cell

APPENDIX D, BRIEFING SLIDESET: VIRTUAL ENVIRONMENTS TO ASSESS HUMAN-MACHINE TEAMING (HMT)

The following slideset summarizes MOVES LVC Laboratory and other capabilities related to this project.

NPS-19-M285-A Using Virtual Environments to Assess Human-Robot Teaming

Mr. Christian Fitzpatrick and Dr. Don Brutzman
MOVES Institute
Naval Postgraduate School



The "Augmented" Battlefield

"Train as you fight"…does this DoD mantra still apply?

- As the complexities of armed conflict have evolved, so to has our ability to anticipate and train for future threats. We are in search of new ways to predict future wars
- New technologies are emerging more quickly than ever and traditional battlefields of the past are no longer relevant
- The new battlefield is global

2

LVC: A Broadly Used Taxonomy

Live*

A live simulation involves real people operating real systems. Military training events using real equipment are live simulations. They are considered simulations because they are not conducted against a live enemy.

Virtual*

A virtual simulation involves real people operating simulated systems. Virtual simulations inject human-in-the-loop in a central role by exercising motor control skills, decision skills, or communication skills.

Constructive*

A constructive simulation includes simulated people operating simulated systems. Real people stimulate (make inputs) to such simulations, but are not involved in determining the outcomes. A constructive simulation is a computer program

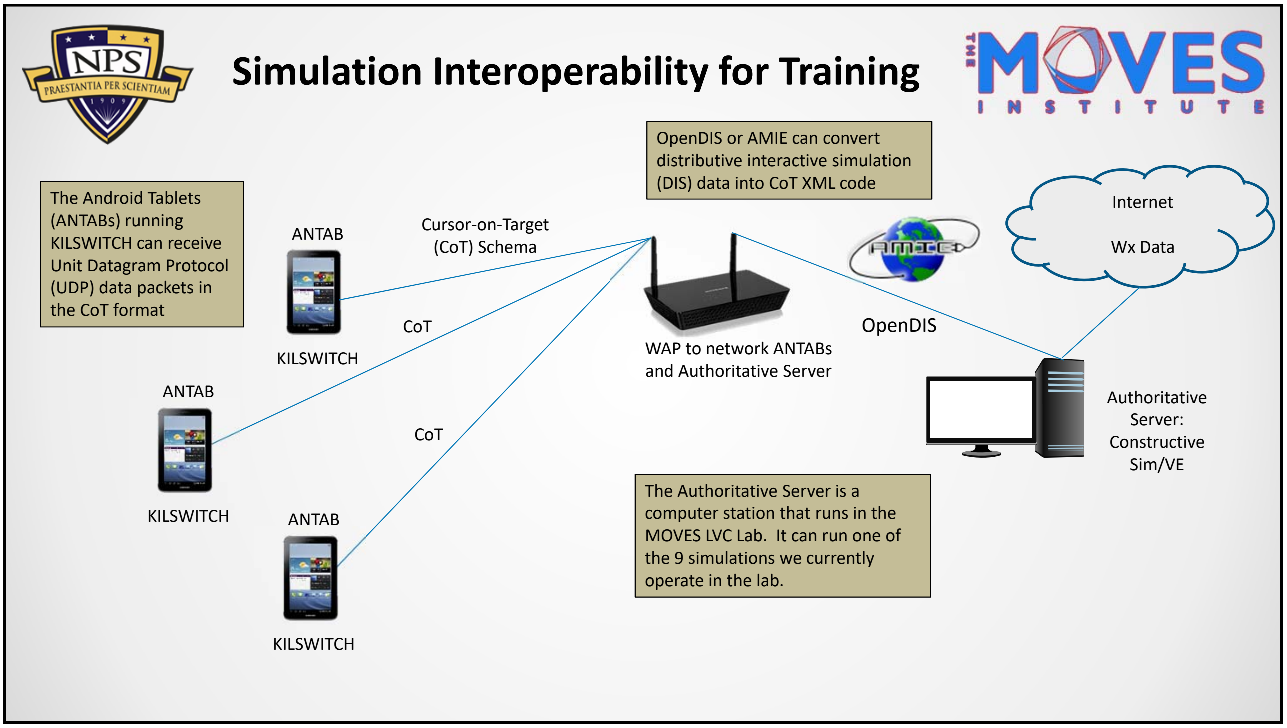
*DoD M&S Glossary 1 Oct 2011

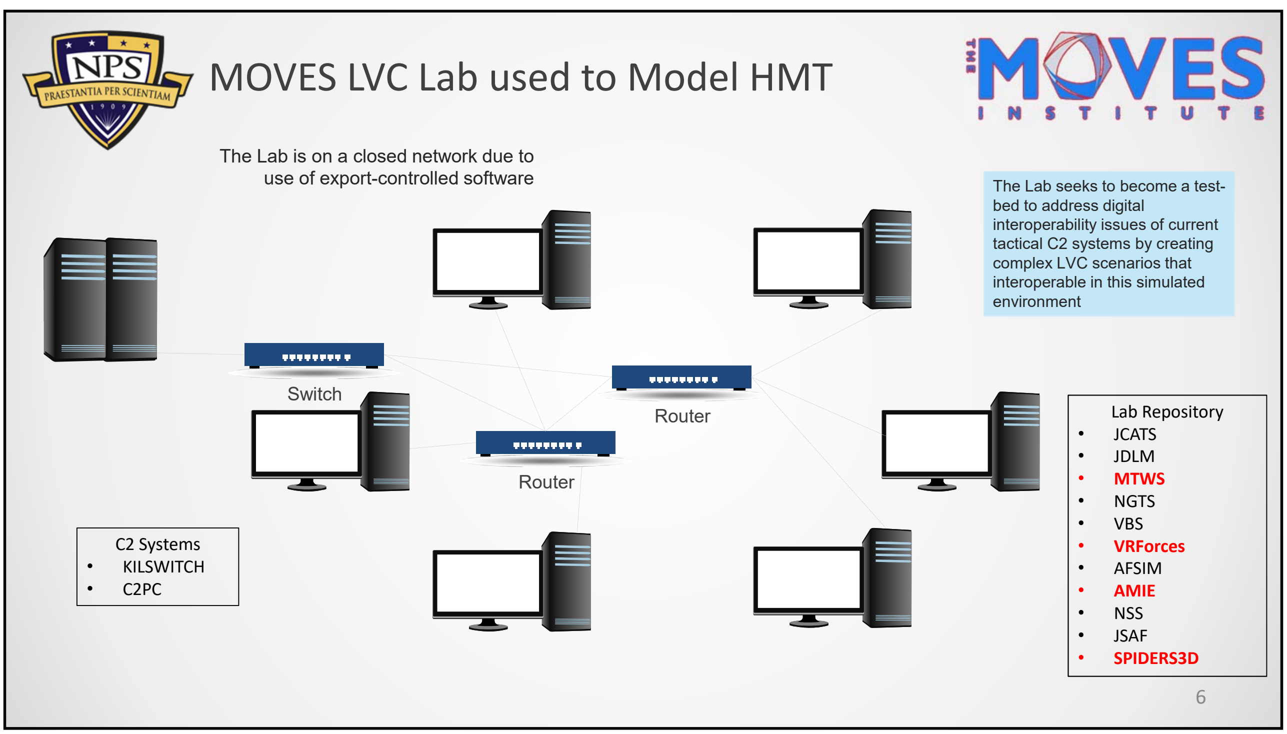
3

LVC and VEs: Using Simulation Interoperability to develop future HMT TTPs

Virtual Environments depicting relevant systems performing realistic tactical behaviors can model the types and flow of data to be expected on future battlefields where robots augment unit operations

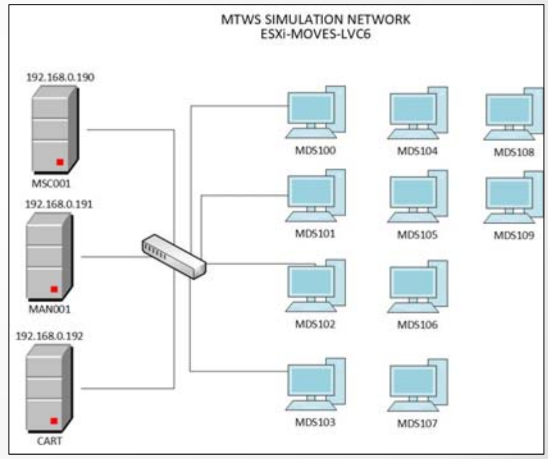
Robots will be integrated across the MAGTF into the missions depicted. OpenDIS or AMIE will be the critical link to enable constructive simulations to stimulate C2 systems. For our work, KILSWITCH was used


Simulation Interoperability for Training
MOVES INSTITUTE
NPS PRAESTANTIA PER SCIENTIAM
OpenDIS or AMIE can convert distributive interactive simulation (DIS) data into CoT XML code
The Android Tablets (ANTABs) running KILSWITCH can receive Unit Datagram Protocol (UDP) data packets in the CoT format
ANTAB
KILSWITCH
Cursor-on-Target (CoT) Schema
CoT
CoT
ANTAB
KILSWITCH
ANTAB
KILSWITCH
WAP to network ANTABs and Authoritative Server
OpenDIS
Internet
Wx Data
Authoritative Server: Constructive Sim/VE
The Authoritative Server is a computer station that runs in the MOVES LVC Lab. It can run one of the 9 simulations we currently operate in the lab.


MOVES LVC Lab used to Model HMT
MOVES INSTITUTE
NPS PRAESTANTIA PER SCIENTIAM
The Lab is on a closed network due to use of export-controlled software
The Lab seeks to become a test-bed to address digital interoperability issues of current tactical C2 systems by creating complex LVC scenarios that interoperable in this simulated environment
Switch
Router
Router
C2 Systems
• KILSWITCH
• C2PC
Lab Repository
• JCATS
• JDLM
• MTWS
• NGTS
• VBS
• VRForces
• AFSIM
• AMIE
• NSS
• JSAF
• SPIDERS3D
6

The MOVES LVC Lab with MTWS

The lab setup below is for execution of MTWS, which is currently in use at MSTP, MCLOG and the MEF Battle Simulation Centers

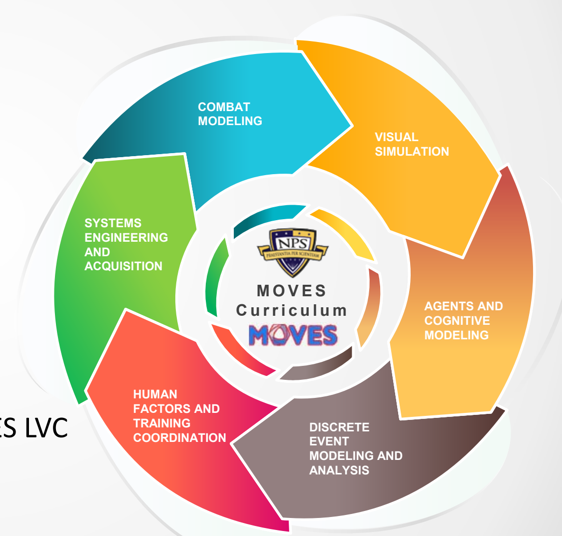


The MOVES LVC Lab is current used in both MV3500 and MV4503 to test OpenDIS, AMIE and other simulation interoperability protocols using our constructive simulations to show data transfer

The MOVES Curriculum

How we educate military officers in LVC

- **Two course sequence in Networking**
  - MV3500 Basic Simulation Networking
  - MV4503 Advanced Simulation Networking
- **MV3500**
  - Focuses on basic networking protocols
  - Distributed Interactive Simulation (DIS)
- **MV4503** - Hands-on course
  - Focuses on network configuration
  - Network analysis
  - Federating various DoD simulations
  - **Finishes with a networked wargame**
- Offering in FY19 will include the new MOVES LVC Lab



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APPENDIX E, BRIEFING SLIDESET: REPEATABLE UNIT TESTING OF DISTRIBUTED INTERACTIVE SIMULATION (DIS) PROTOCOL BEHAVIOR STREAMS USING WEB STANDARDS

The following slideset summarizes thesis work in progress.

Repeatable Unit Testing of Distributed Interactive Simulation (DIS) Protocol Behavior Streams using Web Standards

Tobias Brennenstuhl
tobias.brennenstuhl.gy@nps.edu

Thesis advisor: Dr. Don Brutzman

2 December 2019

Problem Statement

- It is hard for simulation systems to interconnect, especially with partner nations and C2 systems
- Utilizing open-source Web Technology is a valuable resource that can help numerous systems regardless of classification
- Partnerships with NATO partners can improve shared understanding of mutual goals and challenges
- M&S is not relevant to active warfighting unless we can achieve interoperability between Live, Virtual and Constructive (LVC) simulations, robot telemetry, and Command and Control (C2)

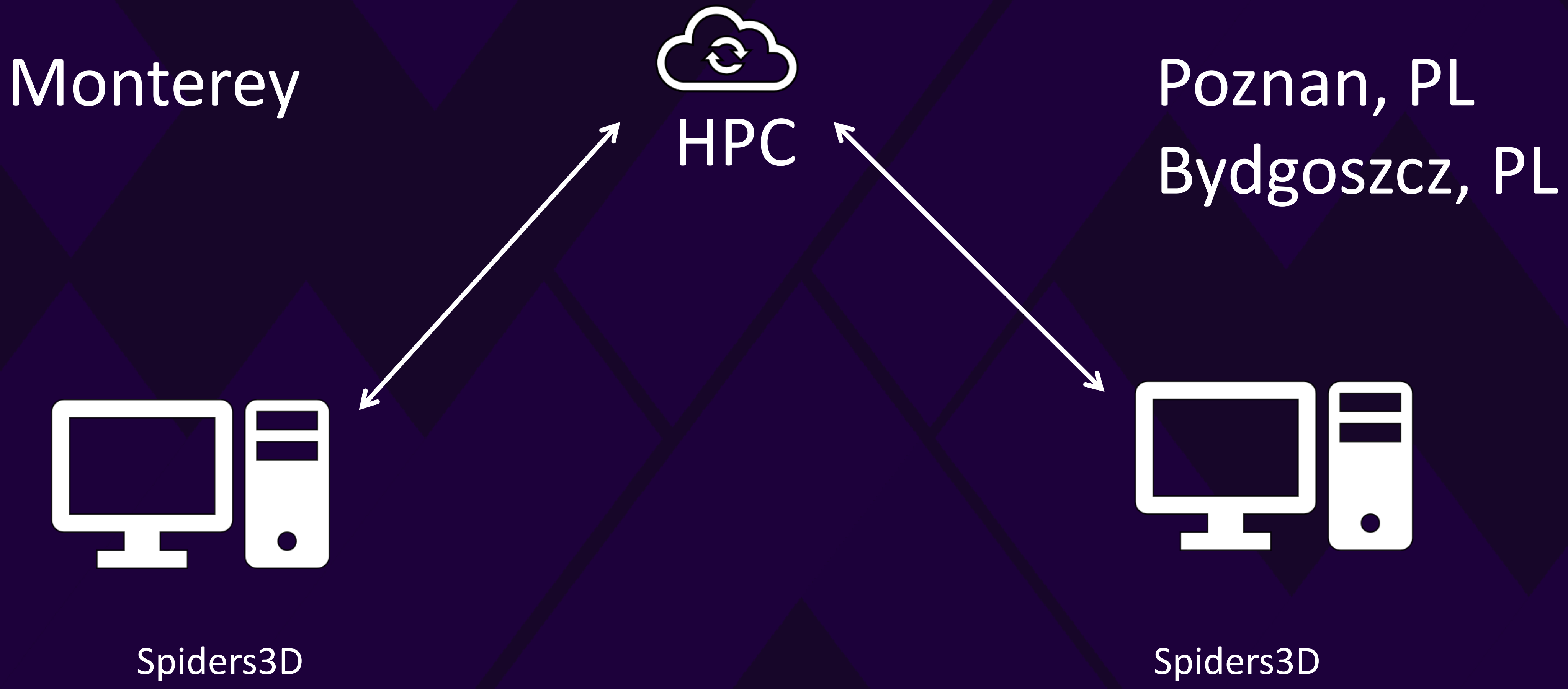
Research Questions

- Stability of IEEE DIS specs and capabilities of MOVES LVC Lab offer excellent new opportunities for broad interoperation
  - Open-source codebase by Mike Bailey offers entire vocabulary
  - Curt Blais dissertation work on Rich Semantic Track (RST)
  - How can these best be adapted and applied?
- How to promote DIS behavior streams as first-class media type?
  - Coherent data streams for collaboration, simulation, telemetry
  - Unit testing of recorded streams for adaptable repeatability
  - Establish archivable annotated records of simulation activity

Basic Premises

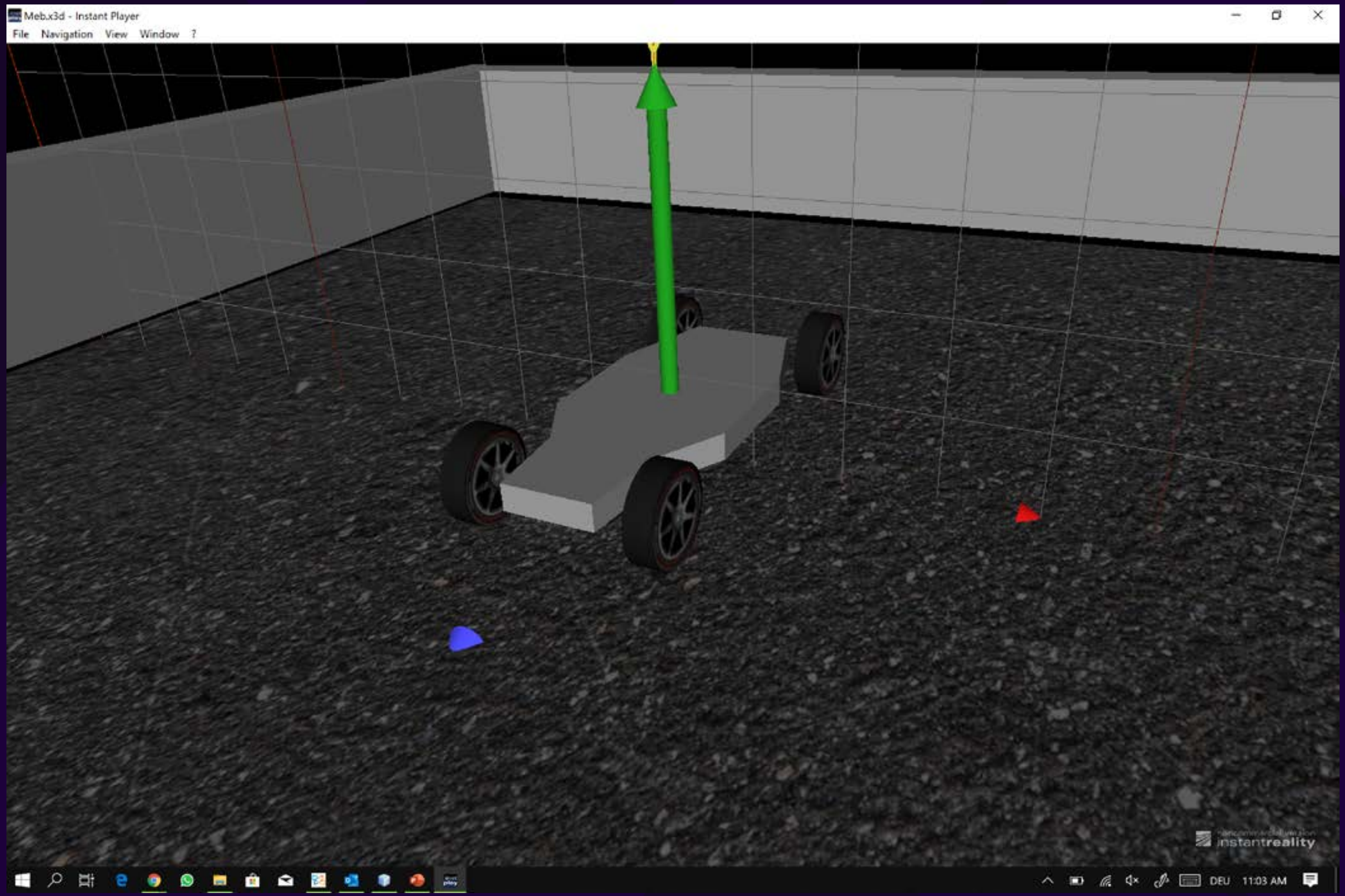
- Multiple open-source codebases available, initially Java with more languages to follow (JavaScript, Python, XML, JSON, etc.)
- X3D Graphics standard allows dynamic 3D in any Web browser
  - Install Spiders3D on a local web server for experimentation
  - Record remote animation of a model using PDUs
  - Distill concise first-order linear interpolators from streams
- A stream is a stream, at rest in a file or in motion over the network
  - Playback recorded manipulation of a model using PDUs
  - Stream manipulation of models using OpenDIS library

Use Case: Long-Haul DIS for Collaboration



Achievements:

- Taking MV3204 Introduction to X3D Graphics



Way Ahead

- ~~Taking MV3204 Introduction to X3D Graphics~~ Half complete
- Further test Java implementation, then create JavaScript
- Contact teams producing open-source X3D players:
  - Fraunhofer X3dom.org and Create3000.de/x_ite
- Inspect Spiders3D JavaScript Virtual Environment Web Server
- Collaborate on distributed LVC models and simulations
  - Take advantage of campus-wide Multicast capability
  - Explore possible HPC network connection to Germany
  - Consider NATO C2SIM and CWIX 2020/2021 participation

APPENDIX F, WEBSITE: COLLABORATIVE 3D VISUALIZATION FOR ASHORE, AFLOAT AND EXPEDITIONARY READINESS WORKSHOP

A. WORKSHOP SUMMARY

Virginia Tech and Web3D Consortium hosted a one-day workshop 6 DEC 2019 to provide Naval enterprise leaders with presentations on the use of collaborative Web-based #X3D visualization techniques by Government, Academia and Industry practitioners. The workshop included an interesting and busy agenda with 20 presenters and 40 attendees. The workshop website appears on the following pages with all presentations linked at https://www.web3d.org/event/collaborative-3d-visualization-ashore-afloat-and-expeditionary-readiness-workshop

Following the agenda are snapshots of a threaded series of twitter posts that include high-resolution images excerpted from the workshop and each presentation. Online at https://twitter.com/Web3DConsortium/status/1206336936979206144

The workshop is intended to foster networking and showcase current and emerging capabilities for enterprise-scale, networked geo-enabled 3D communications. Increasing shared understanding and technical coordination agility can be feasibly adapted to improve digital connectedness, accelerate consensus/decision making processes across systems engineering, advance planning conceptualization, and collaborative virtual rehearsal for ashore & afloat logistics activities.

Building shared priorities adds value for everyone. Workshop participants discussed their reactions "around the table" together to share ideas about opportunities and potential synergies that can further the art of the possible to realize shared innovation.

B. WORKSHOP PROGRAM

A dozen highly detailed presentations have been archived online to capture the breadth and depth of the capabilities shown by workshop speakers. Participants had the opportunity to note questions, conclusions and recommendations during the conduct of the workshop. These are captured on the following pages, along with workshop agenda with linked presentations and Twitter summaries of each session.

Collaborative 3D Visualization for Ashore, Afloat and Expeditionary Readiness Workshop

View Repeats

Submitted by anita.havele on Wed, 2019-11-20 09:35

Virginia Tech and Web3D Consortium are hosting a one-day workshop to provide presentations to Naval enterprise leaders on the use of collaborative Web-based #X3D visualization techniques by Government, Academia and Industry practitioners.

Friday, 2019, December 6 (All day)

Virginia Tech Executive Briefing Center, 900 N Glebe Rd, Arlington, VA 22203. Falls Church room, second floor.

Collaborative 3D Visualization for Ashore, Afloat and Expeditionary Readiness Workshop

Virginia Tech and Web3D Consortium are hosting a one-day workshop to provide presentations to Naval enterprise leaders on the use of collaborative Web-based #X3D visualization techniques by Government, Academia and Industry practitioners.

We have a very interesting and busy **agenda**. There is a lot happening, we want everyone to get the most out of their valuable networking time together! Photos of the group and slideset excerpts can be found on this Twitter thread.

The workshop is intended to foster networking and showcase current and emerging capabilities for enterprise-scale, networked geo-enabled 3D communications. Increasing shared understanding and technical coordination agility can be feasibly adapted to improve digital connectedness, accelerate consensus/decision making processes across systems engineering, advance planning conceptualization, and collaborative virtual rehearsal for ashore & afloat logistics activities.

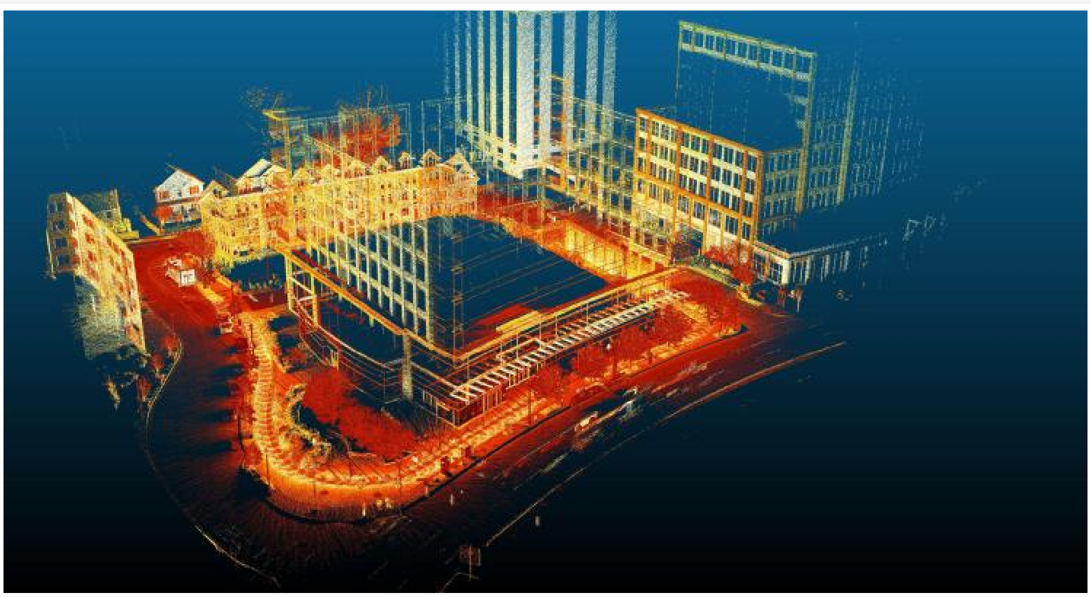
Building shared priorities adds value for everyone. Workshop participants will discuss their reactions "around the table" together to share ideas about opportunities and potential synergies that can further the art of the possible to realize shared innovation.

Workshop Program

	TOPICS	SPEAKERS
presentation	**Web3D Consortium offers Value Proposition.** *Enabling Enterprise Connectedness and Real-Time Networked Communications via ISO Standards.*	Anita Havele (Web3D Executive Director) and Dr. Nicholas Polys (VT and Web3D President)

	TOPICS	SPEAKERS
presentation	**SPIDERS3D Collaborative Visualization for Navy and US Coast Guard Risk Assessment Support.** *Accelerating Pace of Group Understanding and Consensus.*	Dr. Don Brutzman (NPS MOVES)
presentation1, presentation2	**Virginia Tech (VT) 3D Blacksburg and VT Visionarium: Translating Theory into Real-World Practice.** *Exploring Software Infrastructures to Related Structure & Function in Dynamic Geo-enabled Systems.*	Peter Sforza (Virginia Tech Director of Center for Geospatial IT) and Dr. Nicholas Polys (Virginia Tech Director of Visual Computing)
presentation	**Web3D Geo-Enabled Interoperability.** *Unlock Adaptation, Reuse of Existing GIS Data Investments.*	Tom Cowan (Synergy Software Design) and Anthony Scardino (GISinc)
presentation	**3D Models for Naval Underwater Archeology.** *Challenges and Requirements that Match Operational Needs.*	Shanna Daniel (Naval History and Heritage Command, NHHC)
presentation	**3D Metadata Model for Archival Data Publication.** *Identify Reference Terms, Create Exemplars, and Standardize Metadata Models that describe Digital Twins and Surrogates.*	Dr. Nicholas Polys (Virginia Tech and Web3D)
presentation	**3D Visualization for Contingency Preparation and Master Planning.** *Enabling New Joint Service Collaboration Capabilities.*	John Ouellette (VP, Versar)
VTARC building scan image	**Capability Demonstrations: Hand-Held Laser Scanning and Measurement**. Large demonstration files: slideset and two movies.	Bill Gutelius (Qntfi Inc.)
presentation	**Enabling Better Shore, Naval Expeditionary Readiness via Networked 3D Virtual Environments.** *Model-Based Collaboration Capabilities Accelerate Pace of Technical Coordination and Planning Across Naval Commands.*	Alex Viana (NAVFAC HQ) and Gerritt Lang (NAVFAC Engineering & Expeditionary Warfare Center)
presentation to follow	**Naval Innovation and Long-Term Impacts.** *Exploring Future Benefits, Risks and Outcomes through Agility .*	Dr. Dale Moore
	NavalX Playbooks Provide Potential Pattern for Growth. *Sharing High-Impact Knowledge, Skills Across Naval Enterprise.*	CDR Sam "Chubs" Gray USN, NavalX Tech Bridge National Director
video presentation	**5D Virtual Environments Collaboration Capability.** *Emerging SPIDERS3D Functionalities For Navy Decision Making.*	Mike Russalesi (Founder and COO, Synergy Software Design)
presentation and examples	**X3D Best Practices for Computer-Aided Design CAD, 3D Printing, and 3D Scanning Applications.** *Enable Visualization and Interchange of X3D Across Technologies.*	Dr. Vince Marchetti (Kshell, Inc. and Web3D), Dr. Nicholas Polys (VT), Web3D Design Printing and Scanning Working Group)

	TOPICS	SPEAKERS
video and presentation	**Increasing Afloat Readiness via UAV 3D Scanning.** *Accelerating 3D Ship Configuration Data to Shore Maintainers.*	LT Todd Coursey (NSWC PHD) and Chuck Spaulding (Aerial Alchemy)
presentation	**Converting LiDAR Scan Data to X3D Data.** *Automating Point Cloud Data Conversion into 3D Mesh Models.*	Mark Senior (Pointfuse)
presentation and site	**NPS Center for Additive Manufacturing and X3D Model Exchange for NPS Additive Manufacturing Makers.** *Web-Based Additive Manufacturing and 3D Model Re-Use.*	Dr. Amela Sadagic, Dr. Edward Rockower, and Dr. Don Brutzman (NPS MOVES Institute)
presentation	**X3D Version 4 International Standard Update.** *Specification Milestones, Multiple Implementations for HTML5 Publishing and (Emerging) X3D Semantic Web.*	Anita Havele, Don Brutzman, Nicholas Polys, Vince Marchetti (Web3D Consortium)
discussion	**X3D VE Requirements Review, Shared Action Items** • Collected Requirements: Must Have, Like to Have, Don't Need • Timeline for workshop publication • Technology Deliverable Drumbeat • 2020 Proposal Opportunities Milestones and Events Schedule	Anita Havele (Web3D Executive Director), Dr. Nicholas Polys (Web3D), Dr. Don Brutzman (NPS MOVES), Alex Viana (NAVFAC HQ)



Attachments:

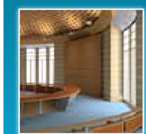
- Web3D Collaborative Naval Visualization Workshop agenda
- Open Standards for Collaborative 3D-AHavele20191206.pdf
- NHHC UA Presentation_Shanna Daniel.pdf
- X3dCadDesignPrintingScanningExamples.pdf
- AerialAlchemy.pdf
- 2019-12-06-Web3D-NavalViz-workshop-ASadagic-NPS-CAM.pdf
- X3D_Best_Practice_CAD_Print_Scan.pdf
- VirginiaTech_CGIT_Sforza_20191206_NAVY_Web3D.pdf
- Virginia Tech US Navy Briefing_ Technologies for Place and Space December 6, 2019.pdf
- X3D_Metadata.pdf
- Web3DGeo-EnabledInteroperability_Synergy.pdf

- Converting LiDAR Scan Data to X3D Data - Pointfuse.pdf
- Ouellette- 3DVE for CE and MP- 6 December 2019 (V005).pdf
- Ouellette- 3DVE for CE and MP- 6 December 2019 (V005).reduced.pdf
- Web3DCollaborativeNavalVisualizationWorkshop-NAVFAC-SPIDERS3D-Overview.pdf

Press Release: No

Release Date: Wed, 2019-11-20

Case Studies

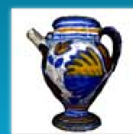


Great Projects by our Members

X3D & VRML

The Most Widely Used Formats

3D in HTML



X3DOM... 3D Without Plugins

Web3D Videos

X3D and VRML

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Web3D is a nonprofit organization that develops and maintains the X3D, VRML, and H-Anim international standards. These are 3D graphics file formats and run-time specifications for the delivery and integration of interactive 3D data over networks. Web3D Consortium members work together to produce open, royalty-free and ISO-ratified capabilities for the Web.

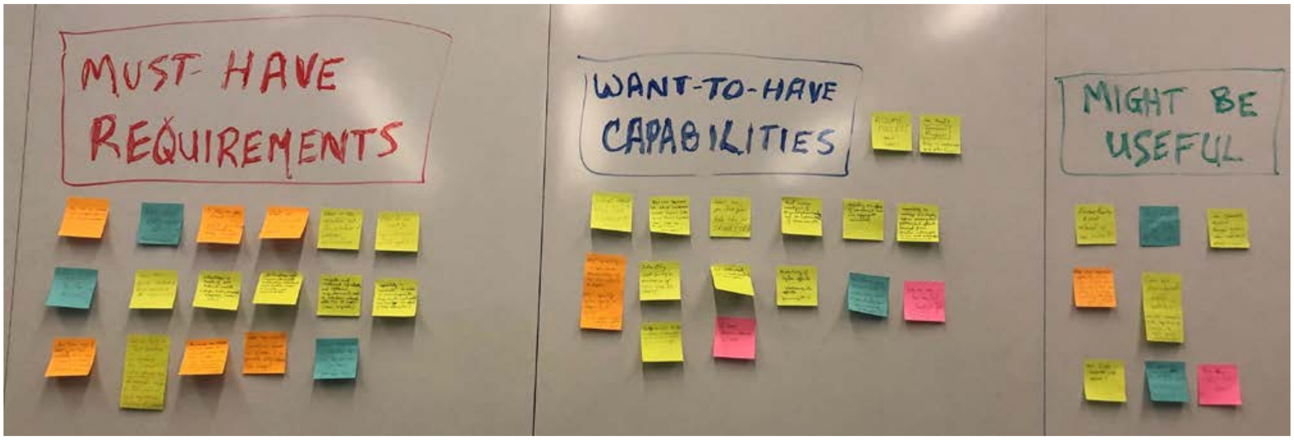

Figure 22. Workshop participants contributed necessary requirements, goal capabilities and potentially useful features in distributed Web-based X3D Graphics for Collaborative Visualization using SPIDERS3D.

C. "MUST HAVE" REQUIREMENTS

1. What are all of the requirements for the "input" data getting scanned, shared and used?
2. How do we manage large collections of 3D models?
3. Need capability to "animate" 3D models in real-world environments where they exist and analyze the effects of those interactions.
4. User requirements: what are the computer, network infrastructure and software requirements needed to interface and interact with the 3D capabilities?
5. What is the metadata taxonomy for artifacts of undersea archaeology?
6. Discoverability of X3D metadata at scale…
7. Repeatable process to get updated Building Information Model (BIM) representations into X3D form for use in SPIDERS3D.
8. What metadata is needed to use these new 3D scans repeatably, 1 year from today?
9. How can Web3D Consortium connect to NavalX to promote usage of Extensible 3D (X3D) and Humanoid Animation (HAnim) standards?
10. Are there ways of locking in the metadata to an X3D component or model? How is that association verified as authentic (i.e. checksum)?
11. Is there a "best practice" for marking anchor points and key locations in point scans? For example, QR codes showing name and universally unique identifiers, pasted on objects in real world at each registration point of interest. (These define correlation points between real and virtual worlds.)

12. Building or utility system data points visualized in near-real-time using X3D. For example, room temperature sensor reading displayed at room's (virtual) location in 3D.
13. (Motivated by COLUMBIA class construction) What are the contract requirements for 5000 contractors to share 3D models with the Navy?
14. Authoritative 3D models of USN material assets: ships, submarines, aircraft, weapons, sensors, etc.
15. How can metadata requirements be described?
16. Data Strategy and associated data collection standards that enable model validation and accreditation.
17. Is X3D an XML format? (Yes, plus other equivalent forms such as VRML, JSON and compressed binary).
18. Can an X3D model pass through the allowed XML binary compression? (Yes, round-trip conversion is supported with either lossless or lossy data reproduction as desired.)
19. How can we integrate tide and current data into a live Web 3D environment?
20. "Metadata to the Rescue!"

D. "WANT TO HAVE" CAPABILITIES

1. Can systems automatically analyze and classify scan data intelligently?
2. Virtual capability to calculate mensuration for real-time analysis of 3D models.
3. Capability to run reports on changes to 3D models, e.g. coherent change detection that is either visual or report based.
4. Three major Project Lifecycle Management (PLM) vendors used by Navy don't talk to each other (i.e. don't readily exchange data). How can they?
5. Identify cost saving or avoidance of problems by using SPIDERS3D, Web3D standards.
6. Major real-world event occurs that requires time-based reconstruction, visualization and re-enactment of the event timeline.
7. What about "high side" SIPRNET availability?
8. Modeling of Cyber activities: electromagnetic (EM) effects, jamming radio frequencies (RF) communications, etc.
9. How can SPIDERS3D help collaboration across Product Lifecycle Management (PLM) systems used by acquisition programs?

10. Are there any issues with proprietary data rights/restrictions when adding metadata?
11. What are prerequisites and precautions for Personal Identifying Information (PII) when scanning human individuals?
12. Capability to analyze and display debris-propagation patterns and effects, derived from kinetic intercepts in air and subsurface environments.
13. For scuba divers, what does pre-dive plan look like in SPIDERS3D? How can this enhance diver safety?
14. Can we use the old standby "teapot" (or maybe a new "oilcan") model as a reference exemplar (for scanning point clouds, generating meshes, correlating to geometric models, 3D printing, etc.)
15. Perform root cause analysis (RCA) of physical phenomenology and then provide 3D representations of the results.
16. Model the effects of component-level and aggregate reliability.
17. Can NavalX "Innovation Playbooks" help us communicate best practices and best paths forward in this cross-cutting domain of activity?

E. "MIGHT BE USEFUL" CAPABILITIES

1. Can scanners record normal vectors when collecting point clouds? (Answer from scanning companies present: yes.)
2. What are good unclassified logistics and scenario exemplars with collaboration requirements similar to those needed for real-world operations?
3. Can we storyboard and reenact naval battles in SPIDERS3D?
4. Can the InstantReality **`aopt`** conversion tool be released as unrestricted open source?
5. How might SPIDERS3D storyboard-narrative products align with Microsoft Project?
6. Can SPIDERS3D work with ESRI Story Maps? Will ESRI add X3D capabilities?
7. Does the Rhino tool support X3D import and export?
8. Need definition capability for user requirements, allowing users to provide thresholds and objective desires. Goal is that when building a 3D mode, the system can automatically tell a user whether a design will (or will not) meet user specifications.
9. Need physics response in X3D. (Some capabilities are well defined already in X3D Rigid Body Physics Component.)

Web3D Consortium
@Web3DConsortium

Collaborative 3D Visualization for Ashore, Afloat, Expeditionary Readiness Workshop to provide Naval enterprise leaders presentations on Web-based #X3D visualization techniques by Government, Academia and Industry practitioners, Arlington VA, 6 DEC 2019

VIRGINIA TECH | web|3D CONSORTIUM | X3D
NAVAL RESEARCH PROGRAM NAVAL POSTGRADUATE SCHOOL | NPS | NAVFAC Naval Facilities Engineering Command

2:15 PM · Dec 15, 2019 · Twitter Web App

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Web3D Consortium @Web3DConsortium · Dec 15, 2019
Replying to @Web3DConsortium
Venue @vtncr Virginia Tech Executive Briefing Center, 900 N Glebe Road, Arlington Virginia 22203 ncr.vt.edu/discovery/rese...

1 2

Web3D Consortium @Web3DConsortium · Dec 15, 2019

Welcome Aboard, Stand By for Action! Big agenda planned, participants introduce themselves.
web3d.org/sites/default/...

1 2

Web3D Consortium @Web3DConsortium · Dec 15, 2019

SPIDERS3D Collaborative Visualization for Navy and US Coast Guard Risk Assessment Support: Accelerating Pace of Group Understanding and Consensus. Don Brutzman, @NPS_Monterey MOVES savage.nps.edu/presentations/...

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Web3D Consortium @Web3DConsortium · Dec 15, 2019

SPIDERS3D images

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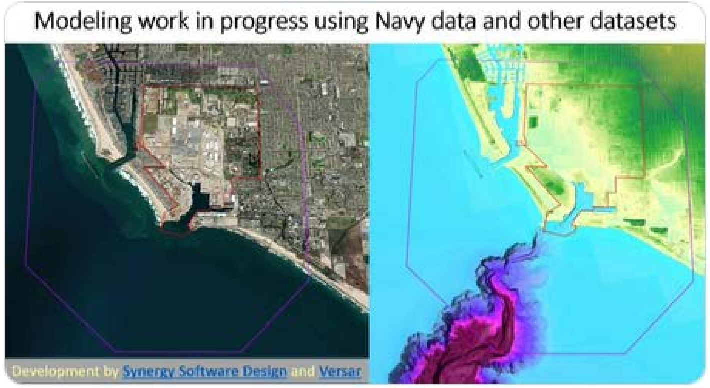
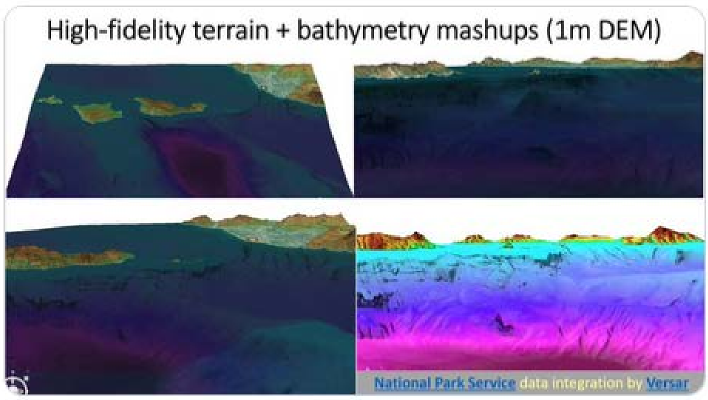
Web3D Consortium @Web3DConsortium · Dec 15, 2019

In-depth #X3D modeling by @Synergy_SSD and @VersarInc



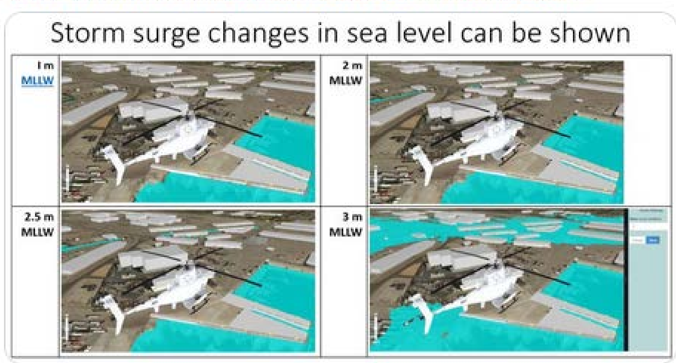
Web3D Consortium @Web3DConsortium · Dec 15, 2019

High-fidelity terrain and bathymetry mashups of @CHISNPS 1M digital elevation model data by @VersarInc



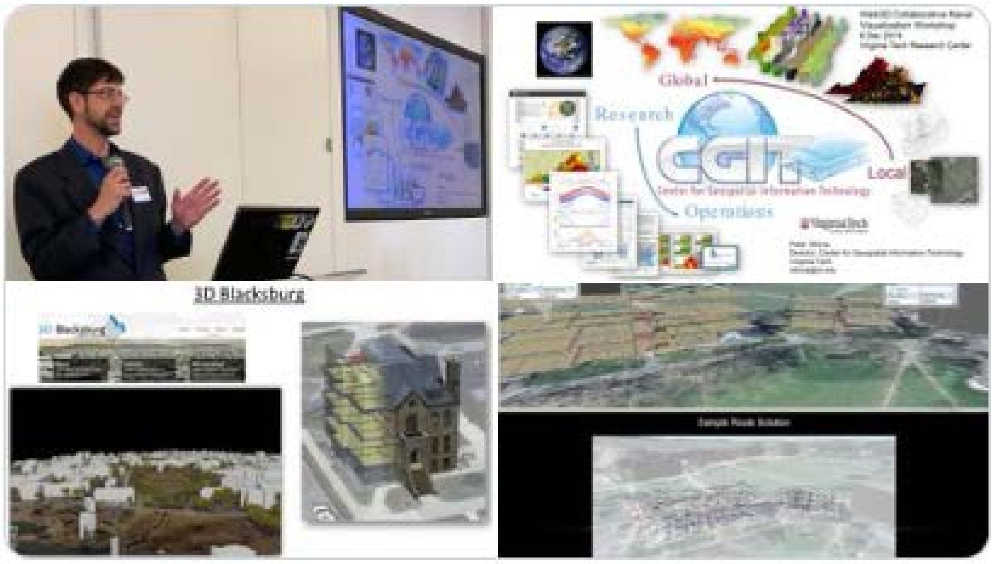
Web3D Consortium @Web3DConsortium · Dec 15, 2019

SPIDERS3D can show possible storm-surge tidal changes in Port Hueneme flood plain, all in #X3D and HTML. Why not hook up tide tables from @NOAA data sources? tidesandcurrents.noaa.gov/noaatidepredic...



Web3D Consortium @Web3DConsortium · Dec 18, 2019

Peter Sforza, Director @VT Center for Geospatial IT on #X3D for 3D Blacksburg: Geospatial Information Science for Decision Making. Slides web3d.org/sites/default/... and site cgit.vt.edu/research/proje... all shown @vtncr



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Web3D Consortium @Web3DConsortium · Dec 18, 2019

Nicholas Polys @VT Director of Visual Computing, experience and outlook on #X3D GIS and Facilities Management, over last 18 years and into future! slides web3d.org/sites/default/... and site arc.vt.edu/visionarium shown @vtncr

1 4

Web3D Consortium @Web3DConsortium · Dec 18, 2019

Tom Cowan @Synergy_SSD and Anthony Scardino @GISinc presentation "GeoReadiness Enterprise and SPIDERS 3D Interoperability: Systems of Record to Systems of Engagement." Real deal! web3d.org/sites/default/...

1 1 2

Web3D Consortium @Web3DConsortium · Dec 18, 2019

Shanna Daniel @USNHistory presentation "3D Models for Naval Underwater Archeology" Clearly this important domain includes many challenges and requirements that also correspond to match operational needs. web3d.org/sites/default/...

1 1 4

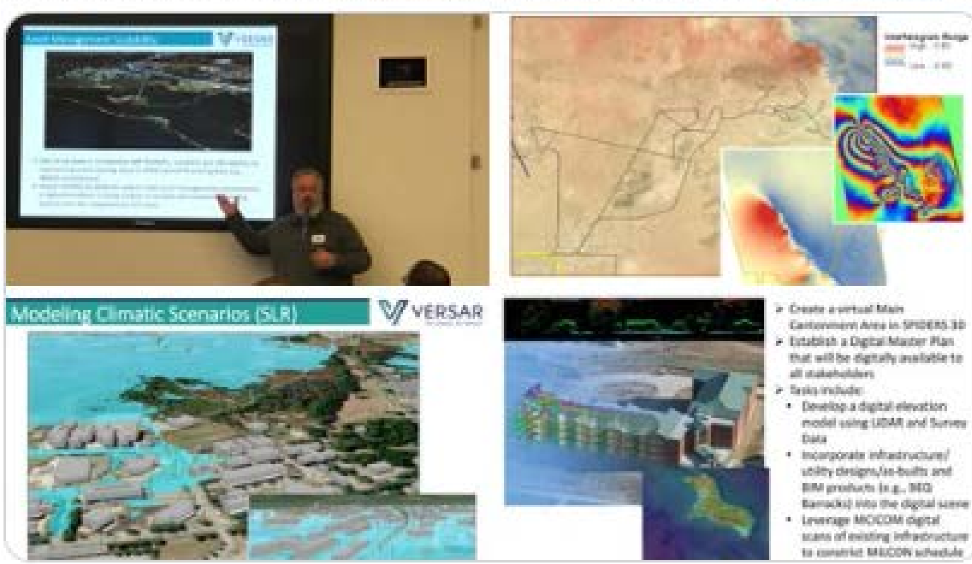
Web3D Consortium @Web3DConsortium · Dec 18, 2019

Nicholas Polys @VTresearch presentation "3D Metadata Model for Archival Data Publication: Identify Reference Terms, Create Exemplars, and Standardize Metadata Models that describe Digital Twins and Surrogates" shows how 3D models require metadata @vtncr web3d.org/sites/default/...

1 2

Web3D Consortium @Web3DConsortium · Dec 19, 2019

John Ouellette @VersarInc
presentation "3D Visualization for Contingency Preparation and Master Planning: Enabling New Joint Service Collaboration Capabilities." #X3D places and spaces are getting broader and deeper! web3d.org/sites/default/...



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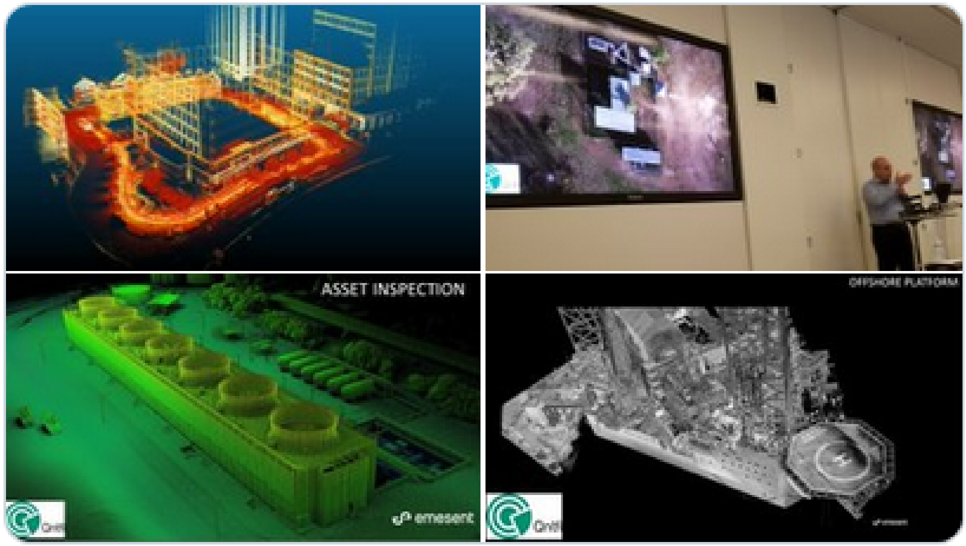
Web3D Consortium @Web3DConsortium · Dec 20, 2019

Bill Gutelius @Qntfii Capability Demonstrations: Hand-Held Laser Scanning and Measurement. 3D products include external scan @vtncr performed that same morning, walking around building - wow! Hovermap LiDAR Mapping Autonomy Payload capabilities impressive. app.box.com/s/1tb0nqsr9i9f...



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Web3D Consortium @Web3DConsortium · Dec 25, 2019

Alex Viana @NAVFAC and Gerritt Lang Engineering and Expeditionary Warfare Center (EXWC) "Enabling Better Shore & Naval Expeditionary Readiness via Networked 3D Virtual Environments" for model-based collaboration capabilities, coordination and planning web3d.org/sites /default/...

1 3

Web3D Consortium @Web3DConsortium · Dec 25, 2019

Alex Viana @NAVFAC and Gerritt Lang Engineering and Expeditionary Warfare Center (EXWC) "Enabling Better Shore & Naval Expeditionary Readiness via Networked 3D Virtual Environments" for collaboration across any Navy/USMC, simply using #X3D in Web browsers web3d.org/sites/default/...

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Web3D Consortium @Web3DConsortium · Dec 25, 2019

Dr. Dale Moore, "Naval Innovation and Long-Term Impacts - Exploring Future Benefits, Risks and Outcomes through Agility." How do we effect positive change across entire enterprises?

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Replying to @Web3DConsortium @vtncr and 11 others

CDR Sam "Chubs" Gray USN @NavalAgility Tech Bridge National Director: NavalX Playbooks Provide Potential Pattern for Growth, Sharing High-Impact Knowledge, Skills Across Naval Enterprise. secnav.navy.mil/agility/Pages/...

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Web3D Consortium @Web3DConsortium · Dec 25, 2019

Replying to @Web3DConsortium @vtncr and 12 others

Mike Russalesi @Synergy_SSD and Mark Senior @Pointfuse 5D Virtual Environments Collaboration Capability:
Emerging SPIDERS3D Functionalities for Navy Decision Making.

1 2

Web3D Consortium @Web3DConsortium · Dec 25, 2019

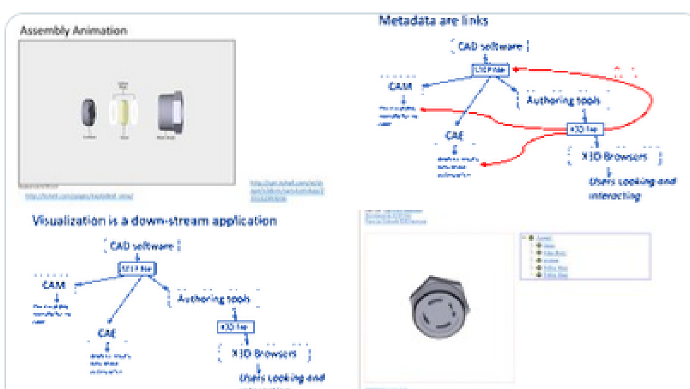
Mike Russalesi @Synergy_SSD video: SYVE is a collaboration platform that enables multiple users to capture and describe complex spatial scenarios. It combines a 3D virtual environment with extra dimensions of time and data.

SYVE 5D Collaboration Demonstration
SYVE is a collaboration platform that enables multiple users to capture and describe complex spatial ...
youtube.com

1 3

Web3D Consortium @Web3DConsortium · Jan 6

Vince Marchetti (kshell.com) and Web3D Design Printing and Scanning Working Group: #X3D Best Practices for Computer-Aided Design CAD, 3D Printing, and 3D Scanning Applications to Enable Visualization and Interchange of X3D Across Technologies. web3d.org/sites/default/...



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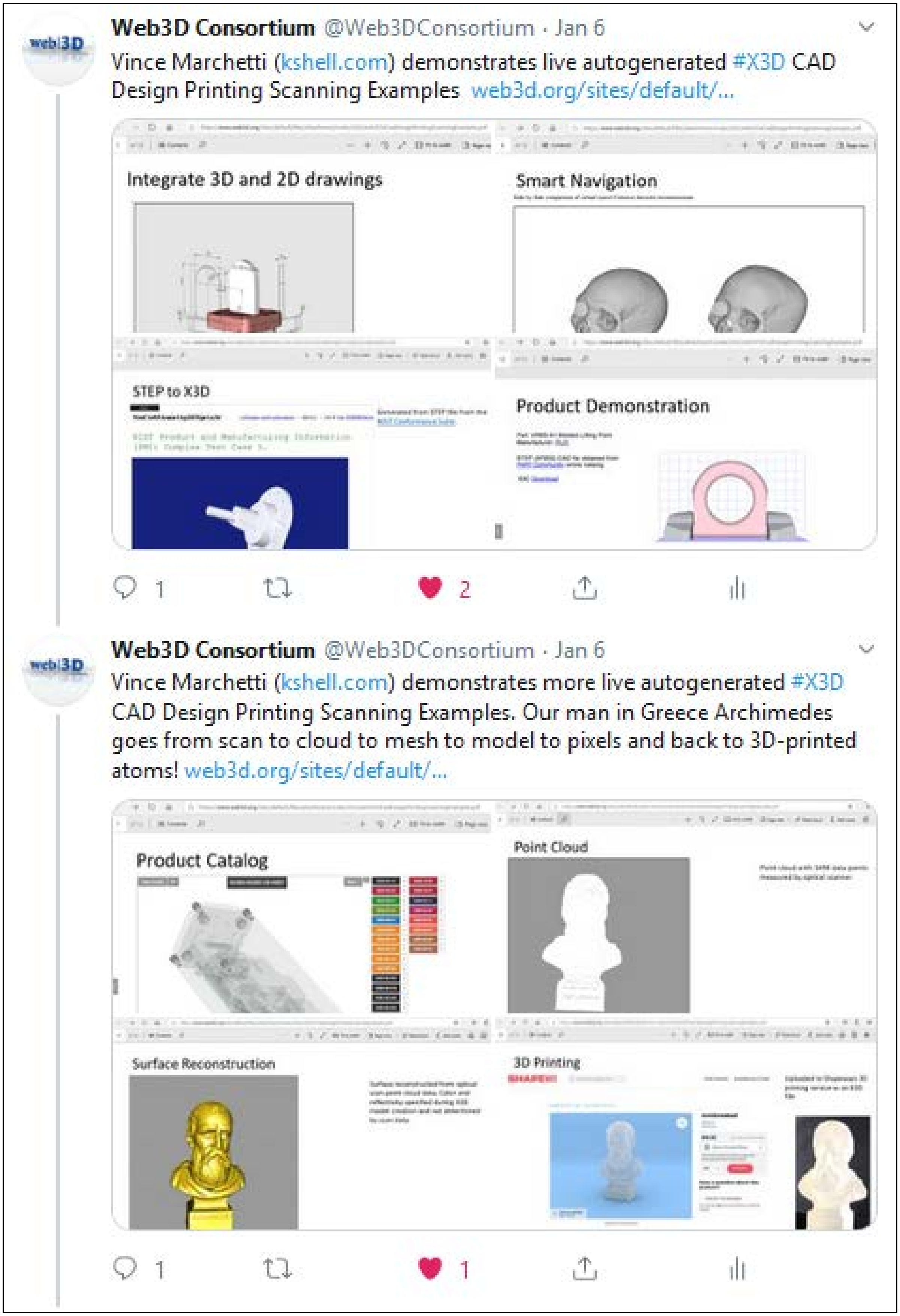
Web3D Consortium @Web3DConsortium · Jan 6
Vince Marchetti (kshell.com) demonstrates live autogenerated #X3D CAD Design Printing Scanning Examples web3d.org/sites/default/...
Integrate 3D and 2D drawings
Smart Navigation
STEP to X3D
Product Demonstration
1
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Web3D Consortium @Web3DConsortium · Jan 6
Vince Marchetti (kshell.com) demonstrates more live autogenerated #X3D CAD Design Printing Scanning Examples. Our man in Greece Archimedes goes from scan to cloud to mesh to model to pixels and back to 3D-printed atoms! web3d.org/sites/default/...
Product Catalog
Point Cloud
Surface Reconstruction
3D Printing
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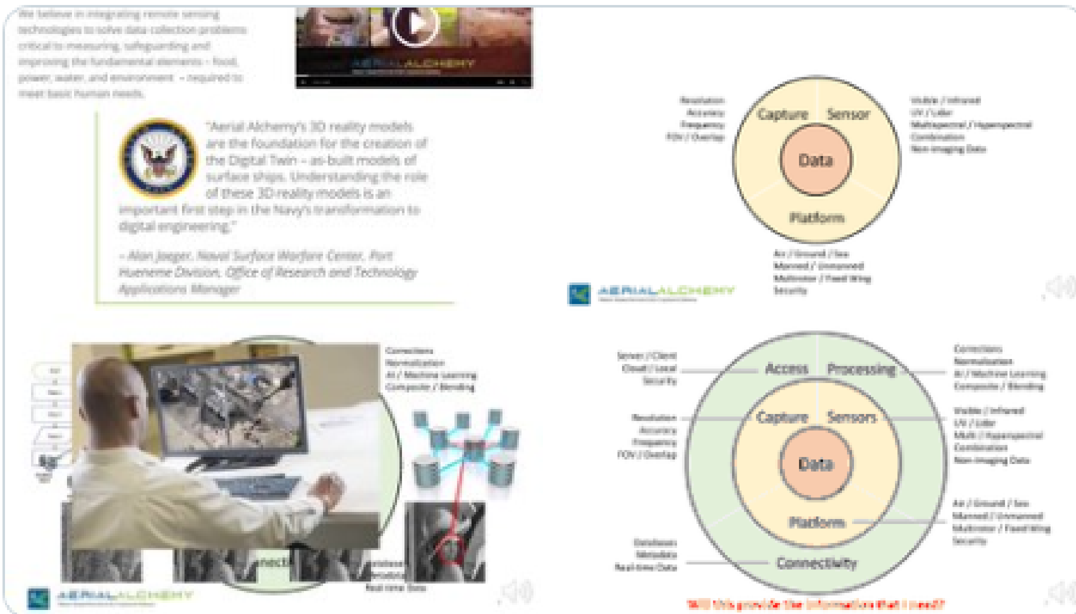
Chuck Spaulding (aerialalchemy.com) and Todd Coursey (NSWC PHD) Increasing Afloat Readiness via UAV 3D Scanning - Accelerating 3D Ship Configuration Data to Shore Maintainers. What are you going to do with the data? web3d.org/sites/default/...



9:40 AM · Jan 6, 2020 · Twitter Web App

Web3D Consortium @Web3DConsortium · Jan 6

Chuck Spaulding (aerialalchemy.com) and Todd Coursey (NSWC PHD) Increasing Afloat Readiness via UAV 3D Scanning - Accelerating 3D Ship Configuration Data to Shore Maintainers. What are you going to do with the data?

AERIAL ALCHEMY

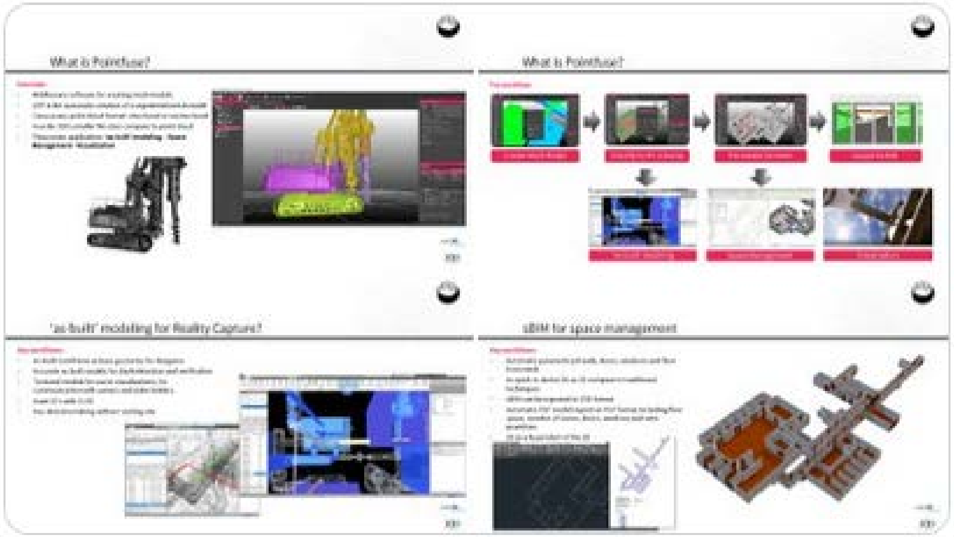
Non-narrative overview of Aerial Alchemy This video was an introduction to a presentation of where drone...

youtube.com

1 2

Web3D Consortium @Web3DConsortium · Jan 6

Mark Senior @Pointfuse Converting LiDAR Scan Data to X3D Data - Automating Point Cloud Data Conversion into 3D Mesh Models. web3d.org/sites/default/...



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Web3D Consortium @Web3DConsortium · Jan 6

Amela Sadagic, Edward Rockower, and Don Brutzman @NPS Center for Additive Manufacturing plus #X3D Model Exchange for NPS Additive Manufacturing Makers:
Web-Based Additive Manufacturing and 3D Model Re-Use. web3d.org/sites/default/... and modelexchange.nps.edu

1 2

Web3D Consortium @Web3DConsortium · 2h

Anita Havele, Executive Director and Dr. Nicholas Polys, President. Web3D Consortium offers a tremendous Value Proposition: Enabling Enterprise Connectedness and Real-Time Networked Communications via ISO Standards. Check the interoperability timeline! web3d.org/sites/default/...

1 1

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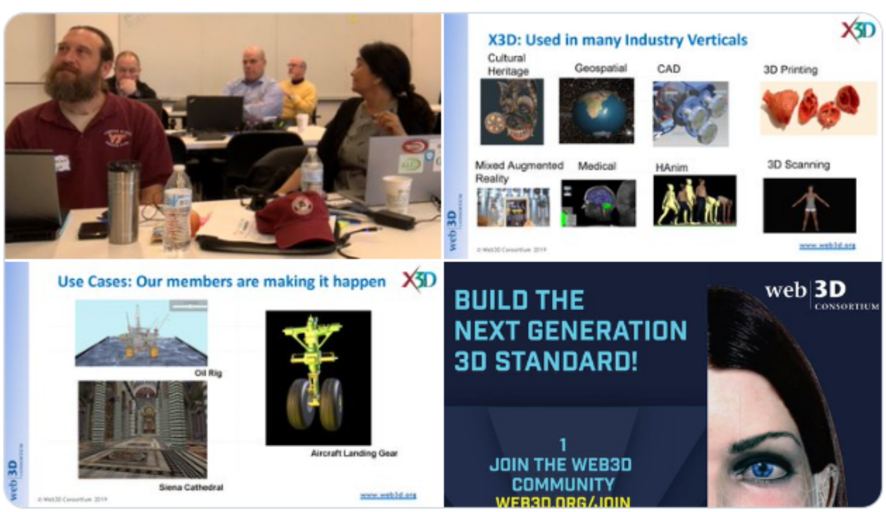
Replying to @Web3DConsortium @vtncr and 14 others

Membership and participation has impact! Anita Havele, Executive Director and Dr. Nicholas Polys, President. Web3D Consortium offers a tremendous Value Proposition: Enabling Enterprise Connectedness and Real-Time Networked Communications via ISO Standards. web3d.org/sites/default/...



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LIST OF REFERENCES

Berger, David H., Gen USMC, *37th Commandant's Planning Guidance*, July 2019. Available at https://www.marines.mil/News/Messages/Messages-Display/Article/897680/37th-commandants-planning-guidance-cpg

Blais, Curtis L. and McGregor, Don, *Modeling Manned and Unmanned Systems*, Technical Report NPS-MV-16-002, Naval Postgraduate School (NPS), Monterey CA, September 2016. Available via https://calhoun.nps.edu/handle/10945/50678

Brutzman, Don, *Network Optional Warfare: Ethical Control of Unmanned Systems*, wiki resources, 2019. Available at https://wiki.nps.edu/display/NOW/Network+Optional+Warfare

Brutzman, Don, and Daly, Leonard, *X3D: Extensible 3D Graphics for Web Authors*, Morgan Kaufmann Publishing, 2007. 468 pages, book website is http://x3dGraphics.com

Brutzman, Don, "Navy/USCG Scenario-Based Planning using SPIDERS3D Collaborative Visualization: Notional Concept Study and Scenario Exploration," invited presentation, *Maritime Risk Symposium (MRS) 2019*, Maritime University, Bronx New York, November 2019. Online at https://calhoun.nps.edu/handle/10945/63797

Fitzpatrick, Christian R., Capt USMC, *Integration of robotics and 3D visualization to modernize the Expeditionary Warfare Demonstrator (EWD)*, Masters Thesis, Naval Postgraduate School (NPS), Monterey CA, September 2001. Available at https://calhoun.nps.edu/handle/10945/4520

Furr, John M., MAJ USA, Modeling Forward Observer (FO) Operations using Optical Data Communications, Masters Thesis, Naval Postgraduate School (NPS), Monterey CA, September 2019. Available at https://calhoun.nps.edu

Griffin, Michael D., Office of the Deputy Assistant Secretary of Defense for Systems Engineering, *U.S. Department of Defense (DoD) Digital Engineering Strategy*, Washington DC, June 2018. https://sercuarc.org/wp-content/uploads/2018/06/Digital-Engineering-Strategy_Approved.pdf

Heron, Marlon, LT USCG, *Modeling, Simulation, and Visualization for Submarine Transit Security and Coast Guard Contingency Preparedness*, Masters Thesis, Naval Postgraduate School (NPS), Monterey CA, June 2015. Available at https://calhoun.nps.edu/handle/10945/45872

Johnson, Matthew and Vera, A., "No AI Is an Island: The Case for Teaming Intelligence," AI Magazine, vol. 40 no. 1, Spring 2019. Online at https://aaai.org/ojs/index.php/aimagazine/article/view/2842

Miller, Scot, Dan Boger and Capts Mike Franco and Steve Spada, USMC, *Designing a Consistent C2 Approach for Marine-Machine Teaming*, Naval Research Program (NRP) Project NPS-19-M286, Naval Postgraduate School (NPS), Monterey CA, October 2019. Available via https://my.nps.edu/web/naval-research-program

Nicklaus, Shane, Capt USM, *Scenario Authoring and Visualization for Advanced Graphical Environments (SAVAGE)*, Masters Thesis, Naval Postgraduate School (NPS), Monterey CA, September 2001. Available at https://calhoun.nps.edu/handle/10945/2016

Spada, Steven G. and Franco, Michael T., *Unmanned Tactical Autonomous Control and Command (UTACC) Command and Control (C2) Framework*, Masters Thesis, Naval Postgraduate School (NPS), Monterey CA, September 2001. Available at https://calhoun.nps.edu

Spencer, Richard V. and Modly, Thomas B., *U.S. Department of Navy (DoN) Business Operations Plan FY 2020-2022*, Washington DC, 11 October 2019. https://www.secnav.navy.mil/bop/Pages/default.aspx

Wikipedia, "Augmented reality," https://en.wikipedia.org/wiki/Augmented_reality

Wikipedia, "Sand table," https://en.wikipedia.org/wiki/Sand_table

Wikipedia, "Virtual reality," https://en.wikipedia.org/wiki/Virtual_reality

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