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Title

Exploring the Potential of Virtual Worlds for Decentralized Command and Control

Topics

Modeling and Simulation (Primary)
Approaches and Organization (Alternate)
Architectures, Technologies, and Tools (Alternate)

Authors
Walt Scacchi, Craig Brown, and Kari Nies
Institute for Software Research
and
Center for Computer Games and Virtual Worlds
University of California, Irvine
Irvine, CA 92697-3455 USA

Point of Contact
Walt Scacchi
University of California, Irvine
Irvine, CA 92697-3455 USA
949-824-4130, 949-824-1715 (fax)
wscacchi@ics.uci.edu

Abstract: This report describes results from a research study investigating how virtual world (VW) concepts, techniques, and tools can be employed to create an online environment that supports experiments in Decentralized Command and Control. We refer to this project and the VW we have prototyped collectively as the DECENT project and system platform. DECENT is a platform for exercising and assessing the potential of a game-based VW approach to decentralized C2, as well as to compare our efforts with others closely related. Overall, we find this effort gives rise to very promising results that point to additional opportunities and system extensions for new ways to consider the potential of decentralized approaches to C2 that merit further systematic investigation and experimentation. This report provides description of the approach to prototyping and initially evaluating some of the potential of DCC systems based on VW technologies.

Overview

Decentralized Command and Control (DCC) is emerging as a new strategic thrust [DoD JOAC 2012]. DCC is envisioned as a new approach and model for how to organize and experience command and control systems, mission planning and scheduling processes, and physically decentralized user practices, using low-cost or free open source software technologies. DCC are anticipated to operate as virtual enterprises that are physically distributed but logically centralized. They are used at the edge of a multi-site organization, and thus can engage participants in different locations.

This report describes results from a research study investigating how virtual world (VW) concepts, techniques, and tools can be employed to create an online environment that supports experiments in DCC. We refer to this project and the VW we have prototyped collectively as the *DECENT* project and system platform. DECENT is a platform for exercising and assessing the potential of a VW-based approach to decentralized C2, as well as to compare our efforts with others closely related. A companion paper further describes how DECENT has been used to support the creation and experimentation with C2 mission planning games [Scacchi, Brown, Nies 2012]. Overall, we find this effort gives rise to very promising results that point to additional opportunities and system extensions for new ways to consider the potential of decentralized approaches to C2 that merit further systematic investigation and experimentation.

Our choice to employ VW technologies is in part influenced by the growing pervasiveness of such technologies, their availability as open source software in user modifiable forms, and their widespread use by a new generation of online computer users who may see/anticipate that such technologies will become ubiquitous in future enterprise settings.

Next, our interest in not to simply replicate or mirror existing C2 systems, nor their traditional patterns of usage. Such usage generally assumes both centralized, hierarchical organizational authority and centralized location of users. Instead, our interest is to explore the alternative space where decentralized approaches to organizational decision-making and workplace location (e.g., top-down but physically dispersed versus peer-to-peer and physically dispersed) may be subject to experimental variance and study.

We similarly identify and compare a small set of related technologies that could be compared to the efficacy of the VW technologies that we employ (*OpenSim* [2012], an open source software toolkit for building, navigating, and socially interacting in VWs). OpenSim provides many interesting affordances, some which are common to most VWs. But it is these affordances that merit further study. Understanding the potential for how VWs may be designed, built, deployed, and evolved seems to be a significant opportunity area for further study. In addition, there is still need to determine how best to evaluate and compare the efficacy of VWs that seek to mirror physical sites or physically-located human problem solving and social interaction. There is also need to evaluate and compare the efficacy of alternative VW and computer game development technologies, whether open source software, or proprietary, closed source software.

Last, we also find that decentralized VW-based approaches may offer the potential to substantially reduce the cost and dramatically shorten the time to design, build, and deploy C2 systems that embrace new generations of low-cost, mobile technologies that future C2 workforces may expect, whether for use in physical or virtual/cyberspace worlds. So much remains to be studied, and time for appropriate and realistic research investments is at hand. In the near-term, such research is likely to still be considered risky, but the longer-term benefits may most quickly arise and be demonstrated through such near-to-mid term research investments. This future opportunity is now at hand.

Developing a DECENT Prototype

In the effort described here, we have prototyped a computer game and virtual world (CGVW) environment we call the DECENT project. Our efforts here represent a substantial departure from current C2 practice, and thus does not seek to primarily provide an incremental improvement to centralized C2 efforts. However, our research is informed by such efforts, like the C2 Rapid Deployment Continuum (C2RPC) highlighted in Figure 1, as they are critical to enhancing and demonstrating upgrades to current C2 operations which have high consequence [Garcia 2010, Gizzi 2011].

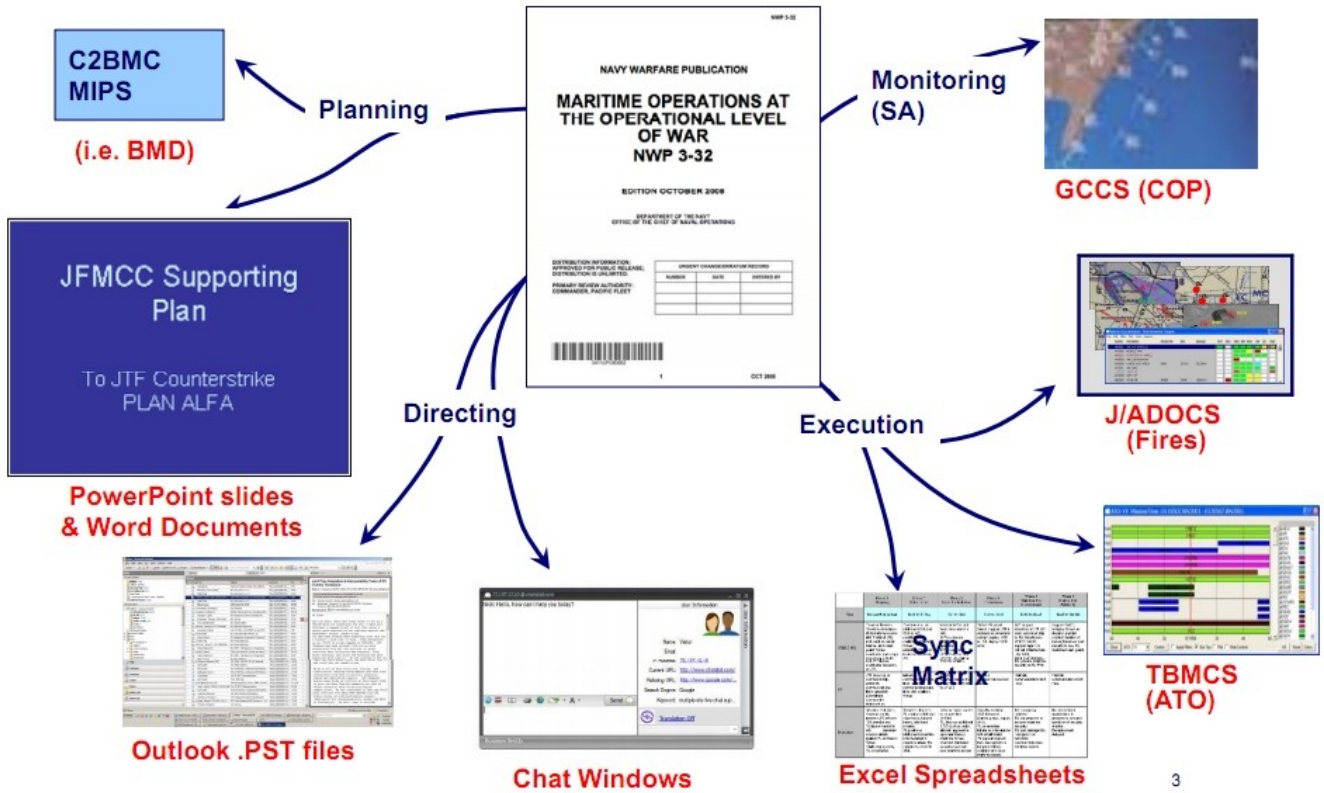

Figure 1. Common information objects and software applications that may be involved in C2 operations/tasking, as identified in publicly accessible C2RPC [2010] materials.

In such settings, C2 operations/tasks entail the creation, update, and sharing/presentation of information reports for C2 decision-making purposes, which may include mission plans and resource assignment schedules expressed as timelines or spreadsheets, for example.

However, as our efforts represent a basic research investigation, we can pursue more risky pathways and edgy alternatives that may or not yield significant advances. Furthermore, our attention is directed to technologies that enable network-centric, decentralized "edge" approaches to C2 [Albert and Hayes 2003]. Consequently, our goal is to advance scientific and technical knowledge for how decentralized C2 might be put into practice in the future, especially with regard to future workforces who may have grown up playing computer games and/or exploring virtual worlds.

Developing Virtual Worlds of Physical Places

In order to achieve the highest quality for DECENT, development began by examining existing C2 structures and identifying key features to replicate. Ground-based C2 facilities usually have several large screens on several walls, used for the display of two types of information: shared information that must be available to several personnel simultaneously, and key information that is either higher priority or more topically relevant. These C2 elements can be seen in Figure 2. While these large public displays are viewable by anyone in the command room, most C2 workers also have their own personal computer (often with multiple displays), housed on desks with assorted papers, files, schedules, etc.

Figure 2. Photograph of a physical C2 facility. Both shared (wall screens) and private resources (tabletop displays) can be seen, with other mission tasking resources.

Systems used in C2 facilities require a range of software, and information from one user may affect the relevance of another's information. Personnel are thus typically organized in a way that optimizes communication, with the most frequent communication being between neighbors. Nevertheless, spaces in C2 facilities are often seem crowded and cluttered, despite the need for efficiency.

Virtual world space

Using images like the one above in Figure 2, we have created a virtual C2 world. Taking advantage of the malleable nature of virtual worlds, we can make C2 rooms with more space and a less cluttered or cramped appearance. All the important aspects and features common to C2 facilities have been faithfully and dutifully recreated. Simple tables contain monitors, input devices, paperwork (which can be modified or made interactive), and speakerphone boxes. Varying levels of clutter can be used, as well, by adding or removing clipboards, pens, soda cans, coffee mugs, and other cosmetic/non-functional objects. This variability allows each DECENT implementation to be customized by whomever is running the training system. Chairs allow the user's avatar to be anchored to (i.e., seated) within given workspace, and two monitors act as that user's private information displays, such as DECENT training game data specific to that user. These details can all be seen in Figure 3.

Two of DECENT's walls have large displays for the display of public information, including the main screen for the DECENT training game. These images may be easily changed, and can be used to display streaming video, as well as static images and the DECENT mission planning training game. Due to the nature of virtual worlds, the modeling of bulky physical items necessary for actual C2 centers, such as computation and data reduction servers, PC boxes, and cabinets can be deferred to a later time or ignored entirely.

Figure 3. Perspective view of user-controlled avatars in a C2 mirrored VW operating in DECENT. The wall display in the upper right corner is an embedded video stream from a remote server.

Comparing Physical Places and Virtual Worlds

The strategy we have investigated in the DECENT environment is to prototype a mirrored virtual world for C2 that resembles and may operate like the physical world C2. In this way, we seek to explore and examine when/how the similarities and differences between the two can reveal potentially significant insights, opportunities, or advantages that one may pose over the other. For example, in studies with VWs at the Naval Postgraduate School's Center for the Edge, there has been sustained study examining how hypotheses about different models of team organization or theories of management might affect the course and outcome of play in the ELICIT multiplayer online counterterrorism intelligence game [Bergin, et al., 2010, Hudson and Nissen 2010, 2011, Winn, Ruddy and Nissen 2010]. Among other things, these studies seek to investigate the efficacy of organizational form, team play, and outcome in the ELICIT game when played in a physical setting (a large unadorned meeting room) in comparison to a virtual setting, seen in Figure 4.

Figure 4. On-screen view of a virtual meeting room that mirrors common meeting rooms, used to study team-oriented ELICIT game play [Hudson and Nissen 2010].

Studies by Bergin et al., [2010] suggest that decision-making performance in physical and virtual worlds can favor the physical. This may be due to the environmental richness and tacit knowledge affordances that familiar work spaces and co-worker gestures/gazes provide, compared to the paucity of similar affordances in a VW. However, DECENT VW may offer other benefits like low-cost, appropriateness for large-scale training, and absence of a centralized (potentially vulnerable) C2 physical center.

Elsewhere, other research groups have been experimenting with the creation of mirror worlds that intermix physical world sites, with VW interfaces, navigational and interactive controls to devices in the physical site. One noteworthy example is the effort by Back, Kimber, et al. [2010] who have modeled a physical factory (the TCHO chocolate factory located in San Francisco), as part of their efforts at Fuji Xerox Palo Alto Laboratory (FXPAL). Their VW system includes desktop PC and smart-phone based software clients that allow a user to navigate the VW space, and to enable/disable designated sensors (web cameras) located in the physical site, and thus demonstrate the potential to remotely control or monitor devices in the physical site though the VW client interface, shown in Figure 5.

The FXPAL system thus demonstrates the potential for mixed reality applications that span and interlink physical world sites that are mirrored in a VW. Their efforts in turn can be compared with one of our earlier efforts which focused on the modeling and simulation of semiconductor fabrication processes and diagnosis of manufacturing devices for training technicians [Scacchi 2010].

Figure 5. Smart-phone (iPhone) based views for monitoring and controlling devices in a physical factory, from Back, Kimber, *et al.* [2010].

However, this effort was based on abstractions of semiconductor and nanotechnology fabrication facilities on site at UC Irvine, but generalized into configurations that were suggested by the project sponsor at Intel Corporation [Scacchi 2010].

Platform for VW development: *OpenSim*

Due to its ease of use and rapid development capabilities, DECENT is currently implemented in OpenSim, a open-source workalike of the closed-source *SecondLife* VW platform. SecondLife [2012] is the current market leader in rapid virtual world development and operation, with a high level of design flexibility and built-in tools for easy environment creation and maintenance. This makes it and OpenSim ideal for the creation of prototypes. Using OpenSim has allowed us to rapidly create a functional C2 VW analog, and populate it with users for concept prototyping, testing and experimentation. The degree of design freedom provided by OpenSim has allowed DECENT to evolve from a promising concept, into a functional training, experimentation, or demonstration environment.

While in OpenSim, DECENT has the potential to seamlessly interact and crossover with other, currently existing military projects, such as the Military Open Simulator Enterprise Strategy (MOSES [2012]) combat training environment and the Naval Underwater Warfare Center (NUWC) campus [Aguiar and Monte 2011]. Adding DECENT to to either MOSES or NUWC is a matter of adding a new region and importing the DECENT assets, or establishing a hypergrid connection (described later, and in [Lopes 2011]) or federation between these disparate virtual worlds. This could be done as many or as few times as needed, and each instance of DECENT would act independently. The person responsible for MOSES and NUWC, Douglas Maxwell, has stated "All of [OpenSim's] features are desirable for the new virtual trainers needed to meet the changing situation demands on modern warfighters" [Neville 2011]. Last, using the OpenSim/SecondLife modeling tools, it is possible to create relatively complex objects, as well as associating behavioral scripts (using LSL) to enable rich animated behaviors to be associated with different objects.

SecondLife versus OpenSim

While OpenSim is an open source project based on the SecondLife platform, each has its own strengths and weaknesses, as described by Korolov [2011]:

Cost: The cost of running a SecondLife server is $295 each month, as it must be hosted on a LindenLabs server. OpenSim can be acquired, installed, and run for free. It can be installed on a dedicated server to host one or more VWs which can also be configured into a local/wide-area grid through the OpenSim Hypergrid [Lopes 2011], described below. Reasonably simple OpenSim serves are available in download formats that allow for distribution via portable USB flash storage (thumb) drives, which means their potential to become widespread and disruptive is emerging. We currently host five dedicated OpenSim servers at UCI.

Users: SecondLife is a community, so it comes with a large established base of users from all conceivable backgrounds. OpenSim has access to smaller groups of existing users if connected to existing OpenSim servers, but is more often run as a stand alone server, only used by those whom the administrators give access to.

Stability: SecondLife maintains high stability for functions used by the largest majority of its users, but are unreliable for mission-critical operations due to problems with voice-chat and reoccurring connectivity issues. OpenSim tends to have much more stable connectivity and voice-chat, (and now integrated instant messaging support within and across worlds) due to the smaller number of users and lower required bandwidth.

Asset Ownership: LindenLabs retains the rights to all assets created in SecondLife (but not content uploaded to it), regardless of who created it; users pay for a license to use SecondLife and modify the contents of a region, but gain no ownership of actual content. Furthermore, Linden Labs reserves the right to revoke access to SecondLife. In contrast, owners of OpenSim servers determine the use policies and ownership of their servers, as well as control access to their servers.

Scripting: SecondLife uses the Linden Scripting Language (LSL), a domain-specific scripting language. OpenSim supports LSL, but can be modified to support many other scripting languages, including JavaScript and Lua (which is a popular scripting language employed by many computer games, including *World of Warcraft*).

The OpenSim Hypergrid

In addition to the reasons laid out about by Korolov [2011], we have decided to work with OpenSim because of its connections to the OpenSim *Hypergrid* [2012]. The Hypergrid is a system used to connect one OpenSim server to others, and allows for the seamless transfer of avatars between any of these interconnected OpenSim worlds, as depicted in Figure 6. Some large worlds span multiple servers. The virtual worlds are connected to each other via virtual world hyperlinks, similar to the links between web pages. The virtual world hyperlinks are places in the virtual worlds that act as doorways or entry/exit points for other worlds. To access one, a user simply moves his avatar to the VW hyperlink and activates it. VW hyperlinks could be used to connect DECENT to existing OpenSim-based military training systems, such as the MOSES Hypergrid [2012] facility, as displayed in Figure 7.

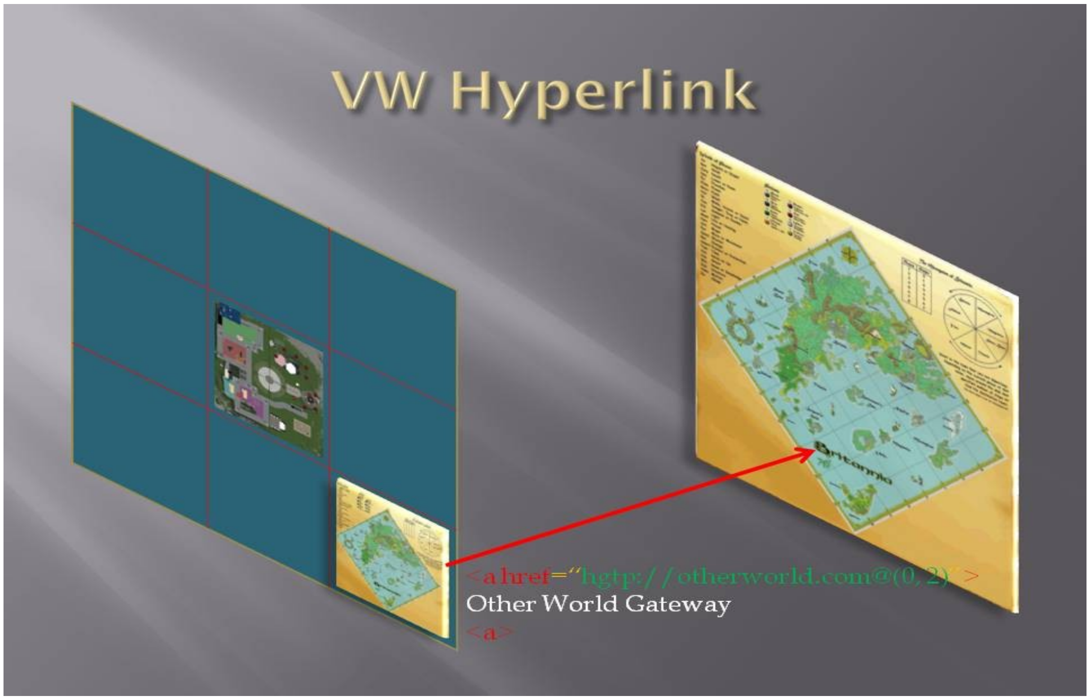

Figure 6. OpenSim Hypergird (Lopes [2011]) supports user/avatar teleportation to move from one VW region to another VW region, possibly on a different networked server.

Figure 7. Overview of the *MOSES Hypergrid* [2012] and server assignment map used in the Military OpenSim Enterprise Strategy by the US Army. Some hypergrid cells are empty indicating available capacity for future development of new virtual worlds.

Under-explored topics for DECENT

To no surprise, there are many other topics for investigation that were beyond the scope of resources available for us to explore. For example, most CG software technologies offer *little/no ready support for integration of external application programs or other software components*. So our efforts to model and simulate a decentralized C2 virtual world make no attempt to undertake such integration studies. Next, the *underlying software architectures of CGVW are rarely disclosed or made open*, even when realized using open source software (OSS) components. So it is a major technical challenge to evaluate, assess, or compare at a deep technical level what architectural choices or trade-offs have been made in designing, building, and/or deploying an operational game-based VW system. In simple terms, this makes comparing OSS VW technologies like Delta3D [see http://www.delta3d.org/], OpenSim, and any of dozens of OSS game engines accessible on the Web (e.g., via search at SourceForge.net) impractical at present. Thus, there is a basic research need to develop open architecture (OA) frameworks for specifying CGVW systems [Scacchi and Alspaugh 2008].

Similarly, the topic of *securing a game-based VW for military C2 applications* is a major concern. VWs like DECENT are envisioned, developed, and extended as an open architecture system [Scacchi and Alspaugh 2008]. Recent advances in developing architectural level security schemes for designing, building, and deploying open architecture software systems are relevant and readily applicable to VWs applications, and well as Web-based system architectures, such as those for the C2RPC [2010]. For example, Scacchi and Alspaugh [2011] have developed and demonstrated a conceptual approach based on existing research technologies that can be used to specify, model, and analyze the security of an OA system with secure/contained elements, as suggested in Figures 8 and 9.

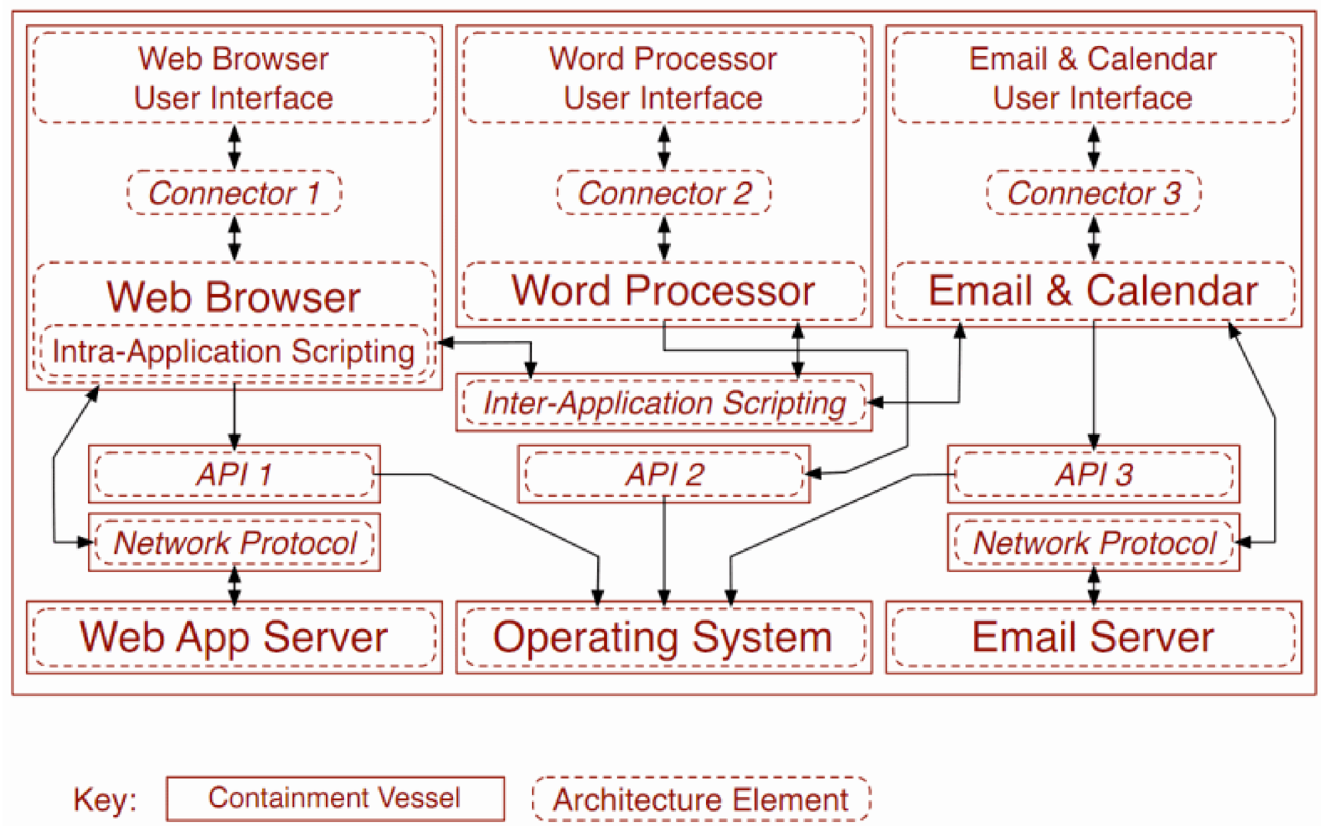

Figure 8. Secure architectural design for generic software applications common to C2 systems, from Scacchi and Alspaugh [2011].

Last, most CG software technologies provide very basic security mechanisms, and thus are quite amenable to remote attacks, penetration, and possible code injections. Furthermore, game-based VW may allow for new modes of malware that may enable activities including avatar impersonation or remote control (e.g., who/what is controlling this avatar, and with what authorization?) and other ill-defined vulnerabilities. So CG/VW technologies should only be considered for experimental purposes until more robust security capabilities are in place, tested, validated, monitored, and evolved [cf. Scacchi and Alspaugh 2011] and are not at this point of technology development ready for supporting real C2 applications, such as those in the C2RPC [Garcia 2010, Gizzi 2011]. However, they may be appropriate for experimentation with future C2 system architectures that may include Web-based and game-based VW software elements, that may be accessible from smart-phones, as well as open to access, monitor, and control physical devices and sensors deployed in physical world settings, whether on land, sea, air, or space.

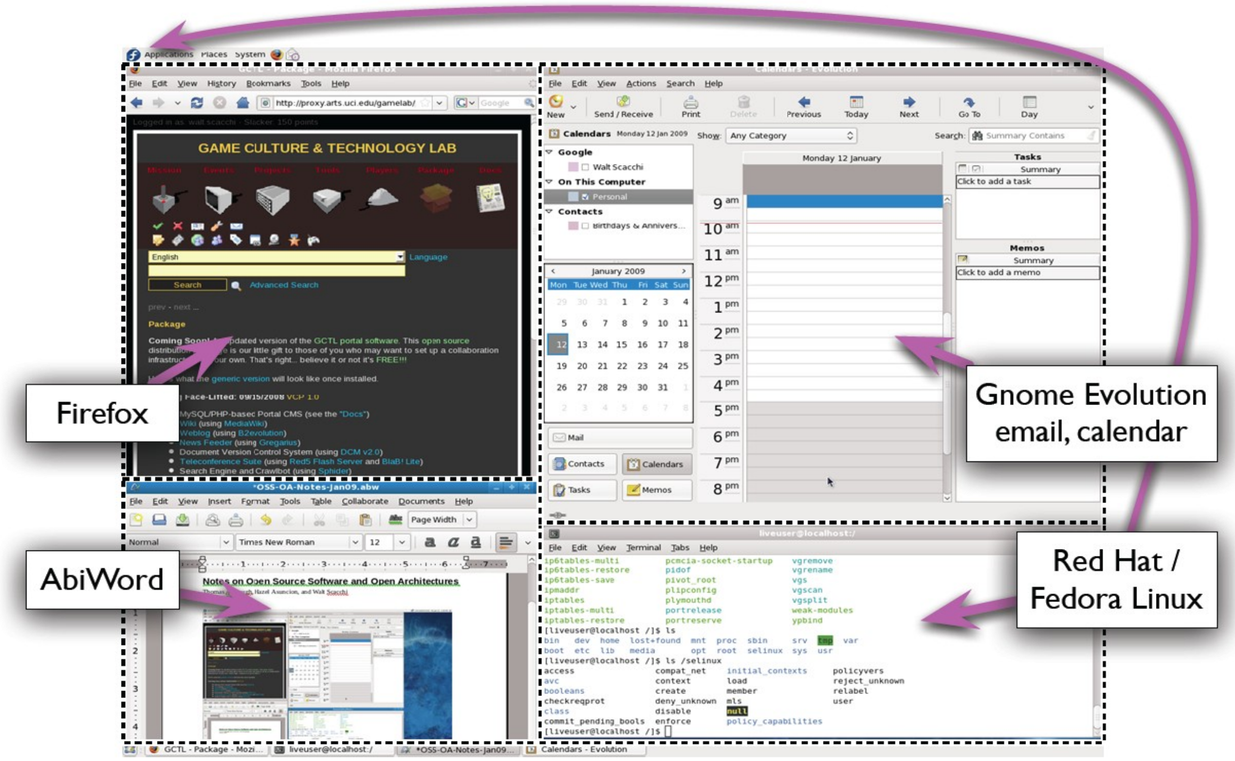

Figure 9. Sample run-time software application deployment for generic software applications available for use in C2 systems, from Scacchi and Alspaugh [2011].

Conclusions and recommendations for future study

This report seeks to describe and document the results of a small-scale one year research study that investigates how virtual world concepts, techniques, and tools can be employed to support experimental/prototyping efforts for command and control applications. We reported on our efforts to investigate and prototype a VW we called DECENT as a platform for exercising and assessing the potential of a VW-based approach to decentralized C2, as well as to compare our efforts with others closely related. A companion paper provides additional details and supporting materials on DECENT, [Scacchi, Brown, Nies 2012], and to our results presented here. Overall, we found this effort gave rise to very promising results that point to additional opportunities and system extensions for new ways to consider the potential of decentralized approaches to C2 that merit further systematic investigation and experimentation.

We similarly identified and compared a small set of related technologies that could be compared to the efficacy of the VW technologies that we employed (OpenSim, an open source software toolkit for building, navigating, and socially interacting). OpenSim provides many interesting affordances, some which are common to most VWs. In particular, the potential exists for creating and disseminating free open source software based versions of DECENT or similar DCC software systems using pocket-friendly mobile storage devices (e.g., USB flash storage) that can then be installed on most PCs. The DECENT prototype thus demonstrates a transformative reduction in the cost of rapidly creating and deploying C2 systems that can support DCC, as well as supporting the potential to integrate and control cyber space applications and remote commands.

Understanding the potential for how VWs may be designed, built, deployed, and evolved seems that a significant opportunity area for further study. In addition, there is still need to determine how best to evaluate and compare the efficacy of VWs that seek to mirror physical sites or physically-located human problem solving and social interaction. There is also need to evaluate and compare the efficacy of alternative VW and computer game development technologies, whether open source software, or proprietary, closed source software.

Last, much remains to be studied, and time for appropriate and realistic research investments is at hand. In the near-term, such research is likely to still be considered risky, but the longer-term benefits may most quickly arise and be demonstrated through such near-to-mid term research investments. This is the future opportunity now at hand.

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References

Aguiar, S. and Monte, P. (2011). Virtual Worlds for C2 Design, Analysis, and Experimentation, *Proceedings 16th International Command & Control Research & Technology Symposium.*

Albert, D.S. and Hayes, R.E., (2003). *Power to the Edge: Command and Control in the Information Age*, Command and Control Research Program, Washington, DC, http://www.dodccrp.org/files/Alberts_Power.pdf

Back, M., Kimber, D., Rieffel, E., Dunnigan, A., Liew, B., Gattepally, S., Foote, J., Shingu, J. and Vaughan, J. (2010). The virtual chocolate factory: mixed reality industrial collaboration and control. In *Proc. Intern. Conf. on Multimedia* (MM '10). ACM, New York, NY, USA, 1505-1506. Also see, http://www.youtube.com/watch?v=-J5qi8yquoo for video recording.

Bergin, R., Adams, A., Junior, R., Hudgens, B., Chinn Yee Lee, J., and Nissen, M. (2010). Command & Control in Virtual Environments: Laboratory Experimentation to Compare Virtual with Physical, *Proceedings 15th International Command & Control Research & Technology Symposium*, Paper 075, Santa Monica, CA.

C2RPC (2010). Command and Control Rapid Deployment Continuum Overview, http://www.afcea-sd.org/wp-content/uploads/2010/12/YoungAFCEA_C2RPC.pdf

DoD JOAC (2012). Department of Defense, *Joint Operational Access Concept*, Version 1.0, 17 January 2012, http://www.defense.gov/pubs/pdfs/JOAC_Jan%202012_Signed.pdf

Garcia, P. (2010). Maritime C2 Strategy: An Innovative Approach to System Transformation, *Proceedings 15th International Command & Control Research & Technology Symposium*, Paper 147, Santa Monica, CA.

Gizzi, N. (2011). Command and Control Rapid Prototyping Continuum (C2RPC) Transition: Bridging the Valley of Death, *Proceedings 8th Annual Acquisition Research Symposium,* Vol. 1, Naval Postgraduate School, Monterey, CA.

Granlund, R., Smith, K., and Granlund, H. (2011). C3 Conflict: A Simulation Environment for Studying Teamwork in in Command and Control, *Proceedings 16th International Command & Control Research & Technology Symposium.*

Hudson, K., and Nissen, M. (2010). Command & Control in Virtual Environments: Designing a Virtual Environment for Experimentation, *Proceedings 15th International Command & Control Research & Technology Symposium*, Paper 052, Santa Monica, CA.

Hudson, K., and Nissen, M. (2011). Understanding the Potential of Virtual Worlds in Improving C2 Performance, *Proceedings 16th International Command & Control Research & Technology Symposium.*

Lopes, C.V., (2011). Hypergrid: Architecture and Protocol for Virtual World Interoperability, *IEEE Internet Computing*, 15(5), 22-29, Sept-Oct 2011.

MOSES, (2012), *Military Open Simulator Enterprise Strategy*, http://fvwc.army.mil/moses/

MOSES Server Map, (2012). http://fvwc.army.mil/moses/server-allocation-map/

Neville, James, (2011). "Army Extends MOSES to Other Researchers". *Hypergrid Business*. 21 May 2011. http://www.hypergridbusiness.com/2011/05/army-extends-moses-to-other-researchers/

OpenSim, (2012). *The Open Simulator Project,* http://opensimulator.org/

OpenSim Hypergrid, (2012). *The OpenSim Hypergrid*, http://opensimulator.org/wiki/Hypergrid

Scacchi, W. (2010). Game-Based Virtual Worlds as Decentralized Virtual Activity Systems, in W.S. Bainbridge (ed.), *Online Worlds: Convergence of the Real and the Virtual,* Human-Computer Interaction Series, Springer-Verlag London Limited, 225-236.

Scacchi, W. and Alspaugh, T. (2008). Emerging Issues in the Acquisition of Open Source Software within the U.S. Department of Defense, *Proc. 5th Annual Acquisition Research Symposium*, Vol. 1, 230-

244, NPS-AM-08-036, Naval Postgraduate School, Monterey, CA

Scacchi, W. and Alspaugh, T. (2011). Advances in the Acquisition of Secure Systems Based on Open Architectures, *Proceedings 8th Annual Acquisition Research Symposium,* Vol. 1, Naval Postgraduate School, Monterey, CA.

Scacchi, W., Brown, C. and Nies, K (2012). Exploring the Potential of Computer Games for Decentralized Command and Control. *Proceedings 17th International Command & Control Research & Technology Symposium,* Washington, DC, June 2012.

Scacchi, W., et al. (2011). *The Future of Research in Computer Games and Virtual Worlds*, NSF Workshop Report, February 2011.

Second Life (2012). *What is Second Life*, http://secondlife.com/whatis/

Wynn, D., Ruddy, M, and Nissen, M., (2010). Command & Control In Virtual Environments: Tailoring Software Agents To Emulate Specific People, *Proceedings 15th International Command & Control Research & Technology Symposium*, Paper 019, Santa Monica, CA.