LVC Architecture Roadmap Implementation – Results of the First Two Years

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ABSTRACT: *The implementation of recommendations from the Live-Virtual-Constructive Architecture Roadmap (LVCAR), which was performed under the auspices of the U.S. Office of the Secretary of Defense (OSD), was begun in mid-2009. Under the leadership of the Joint Training Integration and Evaluation Center (JTIEC), the Johns Hopkins University Applied Physics Laboratory (JHU/APL) has undertaken multiple implementation efforts in the areas of common capabilities for LVC simulations, gateways for multi-architecture LVC simulations, and convergence of LVC simulation architectures. A number of papers presented at Simulation Interoperability Workshops since the spring of 2010 have described individual activities that are part of this overall effort.*

This paper provides a comprehensive summary of the results of the first two years of LVCAR Implementation (LVCAR-I) efforts. It describes accomplishments in the development of new prototype standards for the multi-architecture simulation systems engineering process and for multi-architecture simulation federation agreements, as well as a tool to aid in the implementation of such federation agreements. It also discusses candidate business models to enhance the potential for reuse of LVC simulation tools, and pilot efforts to explore the feasibility of such business models. Mechanisms for describing LVC simulation assets using standardized metadata are described, in conjunction with the development of a prototype implementation of a portal for discovering and locating such assets for subsequent download for reuse. Additionally, storage formats for LVC simulation-related data are categorized, along with opportunities for improved commonality. Advances in the description and characterization of simulation gateways are also provided that will permit more informed selection of gateways by users for particular applications.

With respect to current and future trends in M&S technology, the paper describes efforts related to Service-Oriented Architectures (SOAs) and identifying future technologies having potential use for the DoD Modeling and Simulation Community. Finally, the paper provides an overview of the way ahead for the next two years of the LVCAR implementation effort.

1. Background

The Live-Virtual-Constructive Architecture Roadmap Implementation (LVCAR-I) and Net-centric Environment project is the follow-on effort that stems from findings of the LVCAR Final Report [1]. The purpose of the LVCAR study was to: "Develop a future vision and supporting strategy for achieving significant interoperability improvements in LVC simulation environments." The focus of the study revolved around four dimensions of simulation interoperability: Technical Architecture, Business Models, Standards Evolution, and Management Processes. The precepts that guide the study's implementation are: do no harm, interoperability

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14. ABSTRACT

The implementation of recommendations from the Live-Virtual-Constructive Architecture Roadmap (LVCAR), which was performed under the auspices of the U.S. Office of the Secretary of Defense (OSD), was begun in mid-2009. Under the leadership of the Joint Training Integration and Evaluation Center (JTIEC), the Johns Hopkins University Applied Physics Laboratory (JHU/APL) has undertaken multiple implementation efforts in the areas of common capabilities for LVC simulations, gateways for multi-architecture LVC simulations, and convergence of LVC simulation architectures. A number of papers presented at Simulation Interoperability Workshops since the spring of 2010 have described individual activities that are part of this overall effort. This paper provides a comprehensive summary of the results of the first two years of LVCAR Implementation (LVCARI)efforts. It describes accomplishments in the development of new prototype standards for the multi-architecture simulation systems engineering process and for multi-architecture simulation federation agreements, as well as a tool to aid in the implementation of such federation agreements. It also discusses candidate business models to enhance the potential for reuse of LVC simulation tools, and pilot efforts to explore the feasibility of such business models. Mechanisms for describing LVC simulation assets using standardized metadata are described, in conjunction with the development of a prototype implementation of a portal for discovering and locating such assets for subsequent download for reuse. Additionally, storage formats for LVC simulation-related data are categorized, along with opportunities for improved commonality. Advances in the description and characterization of simulation gateways are also provided that will permit more informed selection of gateways by users for particular applications. With respect to current and future trends in M&S technology, the paper describes efforts related to Service-Oriented Architectures (SOAs) and identifying future technologies having potential use for the DoD Modeling and Simulation Community. Finally, the paper provides an overview of the way ahead for the next two years of the LVCAR implementation effort.

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is not free, start with small steps, and provide central management. Among the significant results of the LVCAR study is a set of 19 recommendations. These recommendations act as the requirements document found in formal programs and is used to guide the LVCAR-I tasks.

The principal aims of LVCAR-I are to explore organizational and structural (e.g., use of standards) options to better:
1. manage LVC architecture interoperability;
2. create reference models to focus data and service reuse efforts;
3. reduce LVC architecture divergence and tool proliferation; and
4. explore emerging technology issues related to future LVC architecture performance and requirements.

The planning, development, and execution of LVC events are universally recognized to require an investment of resources. Also, the M&S community has limited agility with regards to supporting unforeseen events. Given this situation, the objective of LVCAR-I is to reduce overhead and provide for an interoperable M&S environment, thus improving the ability to construct and conduct timely LVC events. Described another way, the goal for LVCAR-I is to get M&S support inside the military operations decision cycle.

The project leads have taken a holistic approach to organization and definition of an acquisition strategy. Fundamentally, LVCAR-I is designed to work in an environment where there are many different factors and incentives that influence decisions, including willingness to change and the adoption of technical solutions. Understanding these factors and their effects are as important to the success of the project as the technology advances themselves. As a result, the LVCAR-I team distilled the 19 recommendations found in the LVCAR study to the grouping of core, affiliated, and supporting efforts as described in Table 1.

2. Overview of the LVCAR Implementation Effort

In addition to the 19 LVCAR recommendations being grouped as shown in Table 1, the technical efforts being performed as part of LVCAR-I were subdivided into four major technical areas:
1. LVC Common Capabilities;
2. LVC Gateways and Bridges;
3. LVC Architecture Convergence; and
4. LVC Future-Oriented Efforts.
Within the LVC Common Capabilities technical area, efforts were further subdivided into:

a. Systems Engineering Process
b. Federation Agreements
c. Reusable Tools and Common Data Storage Formats
d. Asset Reuse Mechanisms.

	Core Task	Affiliated Task	Supporting Task
Standards Development	Systems Engineering Process		
	Federation Agreement Templates		
	Reusable Development Tools		
	Asset Reuse Mechanisms		
Software Development	Common Gateways & Bridges	Joint Composable Object Model	
	Architecture Convergence		
Studies	Management – Product Transition Strategy	Management Organizations and Processes	SOA Concepts
			LVC Futures
Outreach	Core Task Workshops	Management Workshops	M&S Forums Presentations
			Working Group Presentations
			Web-based Information

Table 1. Overview of LVCAR-I Efforts.

Within the LVC Future-Oriented Efforts technical area, efforts were further subdivided into:
a. Service-Oriented Architecture (SOA) Application to LVC Simulations; and
b. LVC Futures.

From a functional perspective, however, these technical areas can be reformulated into several major objectives:
1. Prototyping LVC Simulation Standards;
2. Advancing the Reuse of LVC Simulation Assets;
3. Increasing the Commonality of Data Storage Formats;
4. Improving the Use of Gateways and Bridges for LVC Simulations;
5. Investigating LVC Architecture Convergence; and
6. Investigating the Application of Additional Technologies to LVC Simulations.

The following sections discuss each of the above objectives, and the progress made to date in achieving them in the first two years of LVCAR implementation. In most cases, these individual efforts have been documented in technical papers that have been previously presented at the semi-annual Simulation Interoperability Workshops (SIWs) and the annual Interservice/Industry

Training, Simulation & Education Conference (I/ITSEC), as well as other venues. For example, a full-day workshop on the initial progress of the effort was conducted at the 2010 Spring SIW [2] to get feedback from the broader M&S community. The purpose of this paper is not to repeat prior papers in detail, but rather to present a consolidated summary of the first two years of the project that can be used as a reference point for further exploration of the more detailed efforts. Citations of publicly available technical papers on the more detailed efforts are made, where appropriate. Project-specific technical reports on the various efforts are available through appropriate program channels.

3. Prototyping LVC Simulation Standards

Although simulation standards, to gain widespread acceptance within the community, need to be developed using a consensus-based process, it is sometimes necessary to "seed" the development of such standards by undertaking a funded effort to create a prototype upon which subsequent volunteer efforts can be based. In the area of LVC simulations, it was felt, based on the LVCAR study, that there were two areas in which such prototype efforts were needed:

- A Multi-Architecture Systems Engineering Process for LVC Simulations; and
- An LVC Federation Agreements Template.

3.1 Multi-Architecture Systems Engineering Process

Robust, well-defined systems engineering (SE) processes are a key element of any successful development project. In the distributed simulation community, there are several such processes in wide use today, each aligned with a specific simulation architecture such as Distributed Interactive Simulation (DIS), the High Level Architecture (HLA), and the Test and Training Enabling Architecture (TENA). However, there are an increasing number of distributed simulation applications within the Department of Defense (DoD) that require the selection of simulations whose external interfaces are aligned with more than one simulation architecture. This is what is known as a *multi-architecture simulation environment*.

Many technical issues arise when multi-architecture simulation environments are being developed and executed. These issues tend to increase program costs and can increase technical risk and impact schedules if not resolved adequately. One of the barriers to interoperability identified in the LVCAR Final Report [1] was driven by a community-wide recognition that when user communities, aligned with the different simulation architectures, are brought together to develop a multi-architecture distributed simulation environment, the

differences in the development processes native to each user community adversely affected the ability to collaborate effectively. Rather than developing an entirely new process, it was recognized that an existing process standard should be leveraged and extended to address multi-architecture concerns. The process framework that was chosen was the Institute of Electrical and Electronics Engineers (IEEE) standard called the Distributed Simulation Engineering and Execution Process (DSEEP).

The LVCAR-I team augmented the major DSEEP steps and activities with the additional tasks that are needed to address the issues that are unique to (or at least exacerbated by) multi-architecture development. These tasks collectively define a "how to" guide for developing and executing multi-architecture simulation environments, based on recognized best practices. Over 40 multi-architecture-related issues were identified, based on an extensive literature search. Each of these issues was aligned with the activity in the DSEEP for which the issue first becomes relevant. This information was provided as an overlay to corresponding information already provided in the DSEEP document for single-architecture development. A pictorial of the multi-architecture issues aligned with the DSEEP is shown in Figure 1.

The initial prototype of the DSEEP Multi-Architecture Overlay (DMAO) was produced by the team in the summer of 2010, and revised in the winter of 2010-11. The Simulation Interoperability Standards Organization (SISO) has formed a Product Development Group (PDG), in which members of the LVCAR-I team are participating, to take the initial prototype DMAO and evolve it into a consensus-based IEEE standard.

3.2 Federation Agreements Template and Tool

Federation agreements are critical to the successful design, execution, and reuse of federation assets. However, inconsistent formats and use across federations have made it difficult to capture and compare agreements between federations. This lack of a consistent approach to documenting federation agreements makes reuse and understanding more difficult. Lack of consistent format also prevents tool development and automation. The LVCAR-I team developed a prototype Federation Engineering Agreements Template (FEAT) to provide a standardized format for recording federation agreements to increase their usability and reuse.

The template is an eXtensible Markup Language (XML) schema from which compliant XML-based federation agreement documents can be created. XML was chosen for encoding agreements documents because it is both

Step	(1) Define Simulation Environment Objectives (2 issues)	(2) Perform Conceptual Analysis (2 issues)	(3) Design Simulation Environment (22 issues)	(4) Develop Simulation Environment (7 issues)	(5) Integrate and Test Simulation Environment (7 issues)	(6) Execute Simulation (1 issue)	(7) Analyze Data And Evaluate Results (1 issue)
Activities	Identify Users/Sponsor Needs (no issues) Develop Objectives (no issues) Conduct Initial Planning (2 issues)	Develop Scenario (no issues) Develop Conceptual Model (no issues) Develop Simulation Environment Requirements (2 issues)	Select Member Applications (2 issues) Design Simulation Environment (14 issues) Design Member Applications (1 issue) Prepared Detailed Plan (5 issues)	Develop Simulation Data Exchange Model (2 issues) Establish Simulation Environment Agreements (1 issue) Implement Member Application Designs (2 issues) Implement Simulation Environment Infrastructure (2 issues)	Plan Execution (2 issues) Integrate Simulation Environment (1 issue) Test Simulation Environment (4 issues)	Execute Simulation Environment (1 issue) Prepare Simulation Environment Outputs (no issues)	Analyze Data (no issues) Evaluating Feedback Results (1 issue)

Figure 1. Multi-Architecture Issues Overlaid on the DSEEP.

human- and machine-readable and has wide tool support. Creating the template as an XML schema allows XML-enabled tools to both validate conformant documents, and edit and exchange agreements documents without introducing incompatibilities. Wherever possible, the LVCAR-I team leveraged existing, authoritative schemas for the representation of elements in this schema, including:

- Modeling and Simulation (M&S) Community of Interest—Discovery Metadata Specification (MSC-DMS)
- XML Linking Language (XLink)
- XML Metadata Interchange (XMI)
- Common Platform Enumeration (CPE)
- Intelligence Community Information Security Marking (IC-ISM)
- eXtensible Configuration Checklist Description Format (XCCDF)
- Geography Markup Language (GML)

The federation agreements are decomposed into eight categories:

1. Metadata—Information about the federation agreements document itself.
2. Design—Agreements about the basic purpose and design of the federation.
3. Execution—Technical and process agreements affecting execution of the federation.
4. Management—Systems/software engineering and project management agreements.
5. Data—Agreements about structure, values, and semantics of data to be exchanged during federation execution.
6. Infrastructure—Technical agreements about hardware, software, network protocols, and processes for implementing the infrastructure to support federation execution.

7. Modeling—Agreements to be implemented in the member applications that semantically affect the current execution of the federation.
8. Variances—Exceptions to the federation agreements deemed necessary during integration and testing.

The prototype FEAT schema was produced by the LVCAR-I team during 2010. SISO has formed a PDG, in which members of the LVCAR-I team are participating, to take the initial prototype FEAT and evolve it into a consensus-based SISO standard.

Because of the complexity of the schema, the LVCAR-I team recognized that most users would need a tool to be able to implement it effectively. In the winter of 2010-11, the LVCAR-I team developed an initial prototype FEAT editor tool that implements some key elements of the schema. The tool, which has received an "EAR 99" export designation so that it can be exported to all but a few countries, was provided in its initial prototype form to the SISO PDG so others could experiment with it and improve it. The intent, once required approvals are obtained, is to make the FEAT tool an open-source software product.

Both the prototype DMAO and the prototype FEAT and its editor tool were developed as part of the LVC Common Capabilities technical area of the project. A paper on all of the Common Capability efforts was presented at the 2010 I/ITSEC [3].

4. Advancing the Reuse of LVC Simulation Assets

It is generally accepted that LVC simulation assets, like assets in the broader M&S community, have not achieved the desired degree of reuse across DoD. Many reasons for that have been postulated. In attempting to advance

the reuse of LVC simulation assets, the LVCAR-I team explored two areas:

- Alternative Business Models for Reuse
- Asset Reuse Mechanisms

4.1 Investigation of Alternative Business Models for Reusing LVC Simulation Assets

The LVCAR Final Report [1], in its Comparative Analysis of the Architectures and Comparative Analysis of Business Models, identified two significant impediments to sharing and reuse of event development tools across programs and communities. The first is the existence of a wide range of tools utilizing a correspondingly wide range of business models. The second impediment is the current environment where different formats are used by the different architectures to store like event data. The LVCAR-I team first undertook a study effort to identify the most beneficial approaches to facilitate tool sharing across architectures based on a structured analysis of the current state.

As a result of the study effort, the LVCAR-I team identified a desired migration path based on the current states of LVC tools, which is shown in Figure 2.
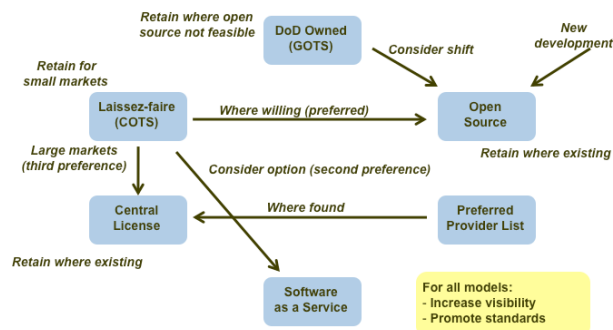

Figure 2. Migration Paths for LVC Tools.

Individual long-term recommendations based on the analysis represented in Figure 2 were as follows:

1. For legacy DoD-owned tools, consider a shift to open source, to reduce DoD costs and foster potential innovations. Use the experiences from an open-source pilot to decide if this should be done, and if so, what considerations exist for LVC tools.
2. For new tools, where there is a desire to provide DoD influence but to defray ownership costs, use an open-source model also informed by the open-source pilot.
3. Where small numbers of licenses are purchased from industry, do not make a change.
4. Where a large number of licenses have been and continue to be procured from industry, take the following actions in the order presented until a viable option is identified:

    a. Shift to open source. This assumes that vendors are willing and the open-source pilot experience indicates there is benefit to DoD.
    b. Shift to software-as-a-service. This assumes that vendors are willing and the experiences from a software-as-a-service pilot show benefit to DoD exists.
    c. Attempt to negotiate DoD-wide discounted licenses.
5. For current open-source efforts, make no changes.
6. If preferred-provider lists have been established, attempt to establish DoD-wide discounted licenses, using the experiences gained from a central-licensing pilot.
7. For existing centrally-negotiated licenses, do not make a shift.
8. The study team was unaware of any existing software-as-a-service arrangement for LVC tools, so no recommendations in terms of a shift from current practices are made.
9. For all business models, increase the visibility of what tools are currently used, and take steps to increase the visibility of user experiences as indicated by the LVC Asset Reuse Mechanism effort.
10. Consistent with DoD policy, use open standards as a basis for tool procurements, and participate in standards development activities to ensure DoD's needs are met.

Based on these recommendations, which were published in the summer of 2010, the LVCAR-I team embarked upon attempts to conduct pilot efforts for software-as-a-service, central licensing, and open-source software.

In the software-as-a-service area, a Request for Information (RFI) was drafted, and was issued via a new mechanism provided by the Program Executive Office, Simulation, Training, and Instrumentation (PEO-STRI). A relatively small number of responses were received, which are currently being evaluated for lessons learned for potential future such activities. A specific tool to use for the central-licensing pilot has not yet been identified, but discussions are underway in one area. Finally, for the open-source pilot, it is likely that the FEAT tool discussed above will be the primary open-source candidate, although sources of existing tools that use traditional business models that might be willing to migrate to an open-source business model are still being investigated.

4.2 LVC Simulation Asset Reuse Mechanisms

As mentioned earlier, the reuse of software, data, and other assets in DoD M&S development is seen as being neither as frequent nor as effective as it could be, and as a

consequence, the potential benefits of reuse to the DoD enterprise are not being fully realized. Improvements in the enterprise culture and processes supporting reuse are needed to increase the frequency of reuse. Three alternative approaches to accomplishing those improvements were defined and evaluated by the LVCAR-I team. An assessment of multiple existing repositories using a carefully developed set of M&S-oriented evaluation criteria was conducted to identify where enhancements are needed.

The LVCAR-I team examined 13 existing M&S catalogs, repositories, and registries of interest to the LVCAR-I effort and evaluated the applicability of these and other reuse initiatives. A detailed model of LVC asset reuse mechanisms based on 22 comprehensive reuse use cases tied to the DoD Net-Centric Data Strategy and commercial standards for repositories was developed and used to facilitate the research and analysis conducted. Consideration of the state of these LVC asset reuse mechanisms, together with feedback from stakeholders within all communities enabled by M&S in the form of questionnaires, workshop discussions, and interaction in the government-industry profession, informed this study and recommendations.

Three complementary approaches to improve LVC Asset Reuse Mechanisms were examined. The Transactional Approach focuses on enhancing the discovery and acquisition of reusable M&S assets through a set of distributed, interconnected M&S catalogs, registries, and repositories. The Social Marketing Approach addresses the long-term improvement of behaviors that promote reuse of M&S assets. The Process-Based Approach encourages more frequent reuse by enhancing reuse guidance within standard DoD M&S systems engineering process models. These three approaches were evaluated in terms of desirability, achievability, and affordability, as well as the likely barriers to their success.

The Transactional Approach was rated as the most affordable due to existing investments and is roughly equivalent to the Process-Based Approach in terms of desirability. The Process-Based Approach was rated as the most easily achievable based on its compatibility with ongoing standards initiatives in M&S systems engineering processes, and also an emerging impetus towards SOAs. A Social Marketing Approach was rated as the least mature in all three indices of desirability, achievability, and affordability, but it offers some unique methods to increase reuse frequency. Barriers to the success of the Social Marketing and Process-Based Approaches were rated as equal in difficulty.

Building upon the results of the initial evaluation, which was completed in the summer of 2010, the LVCAR-I team embarked upon an effort to build a prototype product that would enable better asset reuse. The Enterprise Metacard Builder Resource (EMBR) Portal prototype was completed in early 2011, and is instantiated on a web-accessible server maintained by SimVentions, Inc. It provides the ability to create metacards, based on the MSC-DMS, for LVC assets, allows links to locations where those assets may be obtained, and provides a mechanism for users to comment on their use of the assets, and interact with other users. Further information on the EMBR Portal may be found in Ref. [4].

5. Increasing the Commonality of Data Storage Formats

The LVCAR Final Report [1] recommended actions to promote the sharing of tools, data, and information across the DoD enterprise and to foster common formats and policy goals to promote interoperability and the use of common M&S capabilities. One of the recommended actions was to examine different data storage formats used across the various architectures to determine the feasibility of creating a set of architecture-independent formats. Such formats would be used for storage of classes of data in order to mitigate the cost and schedule impacts of database conversion, minimize conversion errors, and improve consistency across LVC architectures. The focus of the LVCAR-I effort in this area is limited to data interchange formats and applicable standards where the data is persistent, e.g., in stored datasets.

The LVCAR-I team identified nine categories of data storage formats, based on expertise and feedback received at the LVC Common Capabilities Workshop at JHU/APL in November 2009 and questionnaires administered in person at the 2009 I/ITSEC conference and online. This stakeholder feedback was used to assess the priority for rationalization of data storage formats for each category. The team examined the contents of eight metadata standards registries, catalogs and repositories for each category identified. These sources included the DoD Metadata Registry, the DoD Information Technology Standards and Profile Registry (DISR), the North Atlantic Treaty Organization (NATO) and DoD M&S Standards Profile, and the Acquisition Streamlining and Standardization Information System (ASSIST) database, in addition to privately maintained source materials.

For each of the nine format categories, a list of applicable formats was compiled and characterized in terms of currency, openness, maturity, and applicability as a source (producer), interchange (mediation) and

executable (consumer) data format. This information was used to assess the difficulty of rationalizing formats within each category.

In addition, the team developed a strategy for each of the nine categories by evaluating the feasibility of moving to a state of greater reuse via a combination of:
1. Reduction in the number of formats used in each category;
2. Standardization of formats in each category if no standards exist;
3. Increased adoption of mediation formats to reduce translation errors; and
4. Creation or engagement with category-specific communities of interest (COIs).

Using this prioritization approach, the team concluded that the standardized formats should be pursued in the following order:

Priority 1: Manmade features and event results
Priority 2: Geospatial
Priority 3: Unit Order of Battle (UOB) and Plans / scenarios
Priority 4: Platform/weapons performance and behavior
Priority 5: Electronic Order of Battle (EOB)/network and logistics.

The initial assessment effort was completed in the early summer of 2010. Based on an assessment of where these priorities were already being investigated or planned to be investigated within the broader DoD community, as well as the expected cost of developing reasonable solutions, the team narrowed its focus to making specific recommendations in five of the original nine categories starting in the summer/fall of 2010:
1. Three-dimensional (3D) manmade features
2. Platform/weapon performance/characteristics
3. Event results
4. Logistics
5. UOB / force structure

Of the above, there appeared to be little Service-based interest in standardization of platform/weapon performance/characteristics. In the logistics area, extensions to the Joint Land Component Constructive Training Capability (JLCCTC) Entity Resolution Federation (ERF) logistics data model and representations were recommended.

In the 3D manmade features category, the LVCAR-I team has developed recommendations for specific extensions to X3D. In the event results category, although mature after-action review systems exist, the data formats they use are both non-standardized and custom-tailored to the data model of the simulation they are logging. So the LVCAR-I team has developed a draft XML schema for event results. In the UOB / force structure category, the team continues to monitor the progress in standardized data formats being performed by Military Scenario Definition Language (MSDL) and Coalition Battle Management Language (C-BML) efforts. Technical papers on the team's work in each of these areas are being prepared for presentation at the 2011 Fall SIW.

6. Improving the Use of Gateways and Bridges for LVC Simulations

The LVCAR Final Report [1] presented a vision for achieving significant interoperability improvements in LVC simulation environments. The study recommended several activities intended to reduce the time and cost required to integrate mixed-architecture events. Three of the key LVCAR report recommendations were to determine whether existing gateway and bridge applications were effective in meeting user requirements, whether improvements in gateway/bridge capabilities were necessary to address identified gaps, and how these improvements could be best implemented to maximize DoD return on investment (ROI). The term "bridge" in this context refers to intelligent translators that link together enclaves of simulations that use the same underlying simulation architecture. A "gateway" is also an intelligent translator but is designed to link simulation enclaves that use dissimilar architectures.

Early during the LVCAR-I effort, the team performed gateway and bridge literature research, compiled the team's gateway and bridge usage and development experience, and developed formal gateway and bridge operation terminology. At this point, it became clear that the distinction between "gateway" and "bridge" was moot from a development and usage standpoint. Starting with the initial delineation of capabilities, the team compiled a Gateway Capabilities Matrix Template, and created two structured questionnaires (one for gateway developers, and one for gateway users). A one-day workshop, the "LVCAR Common Gateways and Bridges Workshop," was held in March 2010 to present the findings of the questionnaires. There was wide agreement that there are several potential improvements that can be made that will lower the technical and cost risks generally associated with the use of gateways.

Based on the above, in the early summer of 2010, the team developed three potential strategies for execution, referred to as Educate, Enhance, and Create (as well as a "Status Quo" strategy), as shown in Figure 3. Of the four strategies, the team recommended that the Enhance strategy be executed, because it was perceived to have the

greatest ROI. More information on the LVCAR-I team's first year of efforts on gateways may be found in Ref. [5].
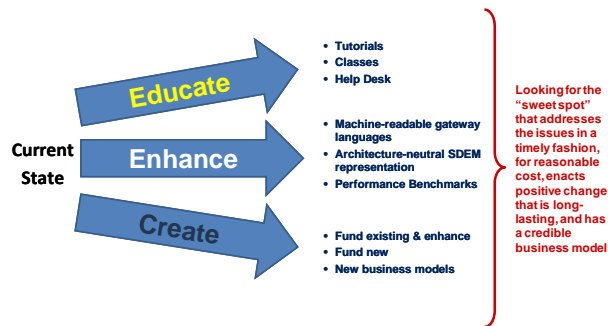

Figure 3. Potential Strategies for Improving Gateways.

The LVCAR-I team then embarked on the execution of the Enhance strategy, also incorporating the tutorial recommendation given as part of the Educate strategy. During the past year, the LVCAR-I team has developed the following products:

- A *Gateway Configuration Model* that identifies an explicit set of gateway requirements, and discusses how the emerging gateway products and processes will address those requirements.
- A *Gateways Capability Description* document, which formally delineates the various capabilities that individual gateways can offer to user programs, along with specific levels of implementation for each unique capability.
- An assessment of the *Architecture-Neutral Data Exchange Model* (ANDEM), originally developed by the Joint Composable Object Model (JCOM) effort, to support Simulation Data Exchange Model (SDEM) mapping and/or translation in gateways.
- A preliminary set of *Gateway Performance Benchmarks* (GPBs) to identify specific gateway performance measures, along with use cases that describe how and where these measures should be applied.

The following efforts are in progress:

- Development of a common *Gateway Description Language* (GDL), in a machine-readable format/syntax, for describing both user gateway requirements and the capabilities that individual gateways can offer, to support user discovery of needed gateway capabilities.
- Development of a common *SDEM Mapping Language* (SML) to formalize format and syntax of mappings between different SDEMs, to reduce the number of required mappings, and to support reuse of mapping data.

- Development of a repository for GDL-based gateway descriptions, incorporating applicable search and requirements-to-capabilities matching algorithms.
- Development of tools for GDL and SML file creation and editing.
- Development of SML Translators for selected gateways
  - JBUS and Gateway Builder (GWB) are likely choices
- Socialization of the preliminary set of GPBs with gateway developer organizations, incorporation of feedback, and preparation of a formal specification.
- Development of a gateways tutorial.

Early work in the second year of effort on gateways is documented in Refs. [6] through [8].

7. LVC Architecture Convergence – Perhaps a Bridge Too Far

The LVCAR Final Report [1] developed a vision for achieving significant interoperability improvements in LVC simulation environments. The study recommended activities proposed to lower the time and cost required to integrate mixed architecture events by building better bridges between the legacy architectures (discussed in the previous section) and making the architectures more compatible. As part of the LVCAR-I effort, the team explored converging the current architectures.

Rather than, for example, making the current HLA like the current TENA, the team's goal was to make future HLAs more like future TENAs. Subject matter experts (SMEs) from each architecture (HLA, TENA, DIS, and the Common Training Instrumentation Architecture (CTIA), participated together on the LVCAR-CT. Each SME provided existing documentation resources and identified where in the documents to extract the key services and tools. Using this information, the team first developed a document that characterized the existing architectures.

The next step was to determine what actions would lead to convergence. The vision was that in 2015, new versions of CTIA, DIS, HLA, and TENA would emerge that would incorporate the results of the convergence effort. The LVCAR-I team described the envisioned converged architecture in terms of how it would execute in a multi-architecture event. This converged execution would contain
1. Simulations that need not be aware that multiple architectures are in use,
2. Parts of the support infrastructure of the legacy infrastructures, and
3. A common shared library for communication.

This concept was selected because it requires no changes to the simulations (which are the area of greatest DoD M&S investment). As a result, changes under this proposed solution would impact only a few infrastructure providers and require significantly less investment to achieve convergence. Construction of software to gradually evolve legacy infrastructures and achieve convergence would involve several years of effort.

As part of its first-year efforts, the LVCAR-I team also calculated an estimate of the investment that would be required over a number of years to achieve the envisioned converged state, as well as the return that was expected to be realized over many years. Those estimates are shown in Figure 4. Upon review of the timelines and costs, the government decided, because of the magnitude of the investment, and the number of years required to achieve a "break-even" state, to terminate any continuing effort on architecture convergence activities during the summer of 2010. More details on the year-long convergence effort may be found in Ref. [9].
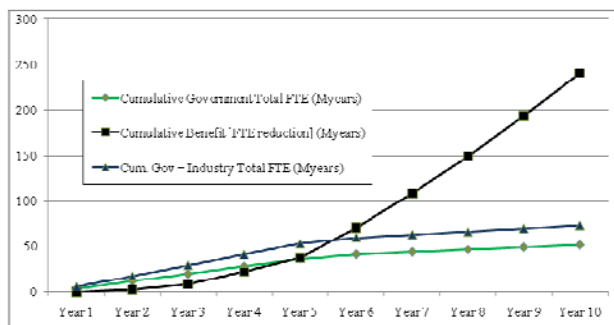

Figure 4. ROI Estimates for Architecture Convergence.

8. Investigating the Application of Additional Technologies to LVC Simulations

In addition to the primary areas of investigation discussed above, the LVCAR-I team was asked to look toward the future at different technologies that might improve LVC simulations. The first, SOAs, have been in use in other communities, so the question is the degree to which SOA might apply to LVC simulations. To address this, a study of benefits and barriers of SOA application to LVC was undertaken by JHU/APL members of the LVCAR-I team, and a pilot application of SOA to LVC was undertaken by MITRE. Looking even farther ahead, members of the JHU/APL LVCAR-I team undertook a small "LVC Futures" study to see how future technologies might be applied to LVC simulations in the 2025 timeframe.

8.1 Service-Oriented Architectures – Benefits and Barriers

The goal of the DoD to reuse M&S assets, such as visualization software, data management applications, and interoperability middleware, is similar to the goal of the business community to reuse existing business applications in the architectural paradigm of SOA. This common association with reusability suggests that the integration of SOA and distributed simulation would be a good combination, but not all M&S applications lend themselves to SOA-based solutions.

Although SOA infrastructures can and have been applied to mid-size LVC distributed simulations in a few efforts, the question remains, is SOA a good fit? To answer this question, an examination of the benefits of and barriers to the application of SOA to LVC distributed simulations is required. The LVCAR-I team enumerated eight benefits of, and seven barriers to, applying SOA to LVC distributed simulations.

In short, SOA was assessed to be an excellent architectural choice for an LVC distributed simulation if the criteria below are met.

- If there exist multiple contributors to a LVC distributed simulation that have clearly defined areas of interest, each have a willingness to take ownership, and all have a stake in the overall success of the resulting simulation system.
- If there is a critical need for the ability to dynamically add components, allow updates to keep components current, or reconfigure a system in relatively short order.
- If the simulation components are well-encapsulated through the use of an agreed upon common SDEM for the LVC distributed simulation.
- If all simulation components will be operating at similar levels of abstraction for the objects and interactions within the simulation.
- If all simulation components will be operating at the same echelon of security.
- If the modeling, visualization, and management control can be segmented within the infrastructure.
- If translation components, i.e., gateways, can be incorporated into the federations, or are definable as services themselves, then scalability of the system is increased.
- If a business model can be defined and maintained where it is beneficial to share the cost of LVC distributed simulations.

On the other hand, SOA was assessed to be a poor architectural choice for an LVC distributed simulation if any of the following conditions exist.

- If all parties cannot agree on goals, interfaces, and an evolution plan, and the ability to record these agreements in governance documents.
- If the funding and time are not available to permit components to be written so that they are usable in a more general way, are available as a service, and external requests for updates are heeded.
- If the LVC distributed system being developed does not need to be updated frequently to meet its goals, such as static training, testing, experimentation, or demonstration that is unchanging; then, SOA is too heavyweight an infrastructure.
- If throughput is a significant concern, as SOA infrastructures are traditionally written as remote services employing request-response-based communication protocols, such as web services.
- Being able to create services out of simulation components is difficult, since simulation components are not traditionally a request-response entity. However, the SOA infrastructure most likely should not be applied at the level of the simulation component, but rather at the level of the simulation cluster. The exception to this is that the SOA infrastructure can be used exclusively to initialize, configure, and deploy simulation components, and allow the distributed simulation infrastructures, i.e., HLA, TENA, and DIS, to process the simulation-to-simulation-component communication.
- Current simulation infrastructures are often composed in brittle ways. If components are reconfigured and redeployed on-the-fly, the distributed simulation is not likely to not operate properly. Most components would have to be updated to handle the challenges of rapid deployment.
- The use of a SOA infrastructure in the DoD M&S community is only cost effective if the system gains a wide-enough acceptance for the services to be used.

In summary, SOA does appear to have a greater upfront cost and may provide a greater cost savings over the long-term through reuse and a potentially cost-effective business model, such as software-as-a-service. SOA requires greater cooperation among distributed simulation developers than traditional development. In addition, the challenges associated with SOA are both political and social, as well as technical. Whether the successes achieved on a few mid-size distributed simulation tasks can be scaled up to full-size simulation exercises still remains to be seen.

In addition to documenting the benefits and barriers of SOA application to LVC simulations in a technical report, the LVCAR-I team has produced a tutorial on this topic. Evolving versions of the tutorial were presented at the 2010 Fall SIW, the 2010 post-I/ITSEC tutorial session, and the 2011 Spring SIW. A DVD of the tutorial has also been produced and distributed to the LVCAR-I DoD sponsoring organizations, to enable the tutorial's use in a non-classroom setting.

8.2 Service-Oriented Architecture Pilot Effort

The concept of using SOA-based software technologies is not new and is being eyed with keen interest by many in the simulation industry. However, no extant program of record can afford to put their program at risk on an unproven approach, no matter how promising. The 2008 DoD study, LVCAR Final Report [1], recommends to "Take actions that can reduce or eliminate the barriers to interoperability across the architectures." As an early step toward addressing the LVCAR recommendation, a "SOA Outlook" pilot effort was developed to determine if commercial SOA architectures, software, and principles are an appropriate solution space for achieving LVC interoperability.

The pilot was designed around the use of open standards wherever possible and attempts to illustrate SOA principles like composition and reuse. A common data abstraction layer in the application server provided an abstraction of the storage mechanism through the Java Persistence Application Programming Interface (JPA) standard and allowed for non-system-specific storage of shared data. Integration with existing legacy systems used a two-part adaptor / plug-in architecture where the adaptor connects directly to the existing infrastructure and communicates with its plug-in counterpart inside the application server infrastructure. (See Figure 5.) The pilot also included a sample of other services that would be required for a complete interoperability framework.

The SOA pilot successfully provided a limited interoperability framework based on the constraints of the use case selected and the level of effort involved. Cursory performance data was also gathered and reported.

8.3 Potential Future Technology Application to LVC Simulation

The "LVC Futures" study effort set out in 2010 to investigate emerging technologies and processes in the 2025 timeframe and their impact on M&S activities in support of future DoD activities. By first proposing a set of possible future operational vignettes (e.g., military, disaster relief), the LVCAR-I team applied near-term technologies that could have substantial impact in an M&S context for the DoD and other coalition partners within the context of these vignettes. Additionally, the

LVC Futures task looked towards processes that would impact future socialization of and collaboration within M&S.
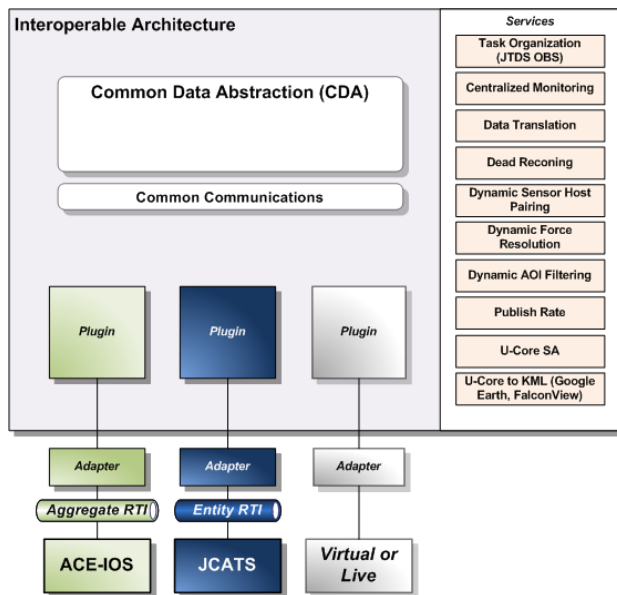

Figure 5. LVC SOA Pilot Architecture.

To frame the technology investigation, the team generated five vignettes to capture the scope of future operational needs. Each of these vignettes included consideration of:

- Operations – conventional, cyber, joint, stability/aid, irregular, counter-insurgency
- Services – Army, Navy, Air Force, Marine Corps
- Reserves / National Guard
- Time Horizon – weeks, months, years
- Foreign military participation
- Non-governmental organizations / Corporations

Using the vignettes, the team estimated a technology's impact for M&S activities, including skill training, unit training, mission planning, environmental analysis, C4I structure, and acquisition. These impacts were summarized in tables for each technology to create an effects matrix with seven possible gradations of impact.

Technologies and processes were binned into nine categories in the broader areas of implementation, and socialization and adaptation, as follows.

Implementation
- Mobile computing and augmented reality
- Ubiquitous surveillance and automated reasoning
- Event-model driven architectures

- Self-healing / self-managing systems
- M&S social graph

Socialization and adaptation
- Crowd-sourcing
- Mash-up software and FIST (Fast, Inexpensive, Simple, Tiny)
- Cloud encapsulation
- Everything is a game

Results of the team's efforts during 2010 are given in Ref. [10]. In the summer of 2011, an implementation plan is being prepared for a potential prototype for rapid situational awareness that builds on the "everything is a game" category above.

9. The Way Ahead

The LVCAR-I task was approved for continuation through fiscal years 2011 and 2012 by the DoD M&S Steering Committee. The LVCAR-I team is currently building upon the accomplishments in the first two years described in this paper to advance LVC processes and products.

In the standards area, working through SISO in conjunction with the larger M&S community, the DMAO is expected to become an IEEE standard, and the FEAT a SISO standard, by the end of the LVCAR-I project. Similarly, the tool to aid users in implementing the FEAT is expected to become a complete product, under an open-source licensing arrangement.

Lessons learned in the exploration of alternative business models for DoD LVC tools, including the use of open source software, software-as-a-service, and central licensing, will be documented so that future LVC tool developments can take better advantage of these business models. Common data storage format advances in several areas will have been made by the end of the LVCAR-I project in the areas of 3D formats and battle management languages, which will provide a strong baseline for future efforts in this area by other projects, such as the Rapid Data Generation (RDG) effort.

Gateway users will have automated tools at their disposal to aid in discovering appropriate gateways for specific uses. Additionally, some common components for SDEM translation will have been developed to aid in the application of gateways. Building on the EMBR portal, an LVC asset reuse repository will be available to support LVC gateway discovery and reuse, which can serve as a model for expanded repository efforts for the broader M&S community.

10. Acknowledgments

The authors would like to recognize the technical contributions of all of the LVCAR-I team members, whose work is described in this paper. The majority of those individuals are listed as authors/co-authors of the technical papers listed as references below.

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