

SISO-REF-057-2015

FINAL REPORT

for the

**Layered Simulation Architecture
Study Group**

24 November 2014

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SISO Standards Activity Committee**

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1 INTRODUCTION / OVERVIEW

The Layered Simulation Architecture (LSA) study group (SG) is an initiative that was presented at the 2012 Fall Simulation Interoperability Workshop (SIW). The initiative is based in the seminal article "A NEW APPROACH FOR CONVERGING LVC SIMULATION ARCHITECTURES".

The request for a SG was based on a desire to apply current thinking on network centric interoperability and open systems architecture to modeling and simulation. It was inspired by recommendations of the *Live, Virtual, Constructive Architecture Roadmap (LVCAR)* (Henninger et al, 2008), and drew upon advances made by other organizations such as the Network Centric Operations Industry Consortium (NCOIC), Object Management Group (OMG) and World Wide Web Consortium (W3C).

We proposed to establish the LSA SG to provide a forum to explore and develop a consensus view of the applicability of modern principles of network centric interoperability and open systems architecture; in particular, the definition of different layers to enable looser coupling among simulation applications.

Specifying all layers was beyond the scope of the LSA, which focused on identifying layers of a coherent simulation stack, referencing existing standards and specifying only key services.

It was anticipated that not only could an open wire protocol, provided by an existing Data Centric Middleware (DCM) form the lower (interoperability) layer of a simulation stack but could also provide an ideal normalized interoperability protocol to better facilitate integration among multiple heterogeneous protocols. See Appendix A for more details on protocol normalization. Previous efforts had already tried and failed to identify such a solution, however DCM standards had since advanced considerably and were expected to be in a position to offer a pragmatic solution.

The increase in flexibility could enable: easier integration with operational systems for embedded training or decision support; easier integration of legacy heterogeneous simulation architectures; easier integration of simulation services (new or existing); and easier integration of homogeneous simulation architectures that lack an open wire protocol.

LSA development provided a forum to explore and develop a consensus view of the applicability of modern principles of network centric interoperability and open systems architecture. In particular the definition of different layers to enable looser coupling among simulation applications. The architecture resulting from this study was expected to better define a modular, loosely coupled structure that enables more flexibility and performance than current approaches.

Scope and purpose of the group at an executive level.

The architecture resulting from this study is expected to better facilitate a modular, loosely coupled structure that enables more flexibility and performance than current approaches. It could be achieved with minimum investment by reusing existing technology standards and would aim to facilitate reuse of assets developed for existing legacy architectures.

A layered approach, enabling reuse of existing data centric middleware (DCM) such as OMG's Data Distribution Service (DDS) protocol by decoupling generic data distribution functions, could lead to a simple and pragmatic solution that not only provides open-wire protocol interoperability, but also offers a richer set of functions.

Possible layers could include:

- Object-model semantic representation;
- A model-level Application Programming Interface (API) for facilitating the reuse of simulation models among container applications;
- An application-level API for facilitating simulation application reuse;
- A simulation services layer that handles services specific to simulation such as time management;

- A generic data distribution layer that performs the publish and subscribe messaging and handles quality of service.

Overall progress of group at an executive level.

The study group:

- Determined that the use of a common communication layer is possible and could solve some of the current challenges facing the simulation community.
- Debated the opportunity of a new standard to achieve the simulation interoperability issue.
- Determined that an LSA standard could be developed which does not conflict with existing standards but is complementary to them.
- Determined that a data-centric middleware that originated outside the simulation community could still be applied to simulation.
- Demonstrated that the LSA approach can integrate heterogeneous implementations of current simulation standards without modification to the implementations or standards
- Eventually achieved consensus that the LSA aim is to develop a new simulation standard to describe the use of OMG DDS in supporting distributed simulation, and also how it can be used to integrate implementations of current simulation standards.
- Reached consensus that LSA is a novel way to solve some current simulation issues without having to reinvent or even to modify current simulation standards.
- Recommends the development of a SISO Standard to support the abovementioned objectives through a LSA Product Development Group (PDG).

2 REFERENCES

Author Name	Document Title	Event Name	Date Published	Name of Publication
Henninger, A., et al	Live, Virtual, Constructive Architecture Roadmap		2008	Institute for Defense Analyses
Jose-Ramon Martinez, Dan Gregory et al	Extending LSA philosophy to Real World Challenges	2012 Fall SIW	2012	SIW Proceedings
Jose-Ramon Martinez, Dan Gregory et al	Final Report	2013 Spring SIW	2013	SIW Proceedings
Jose-Ramon Martinez, Jose-Maria Lopez	A New Approach for Converging LVC Simulation Architectures	2014 Fall SIW	2014	SIW proceedings

3 DEFINITIONS

Term	Definition
n/a	

4 ACRONYMS AND ABBREVIATIONS

Acronym	Definition
ANDEM	Architecture Neutral Data Exchange Model
API	Application Programming Interface
C-BML	Coalition-Battle Management Language
DCM	Data Centric Middleware
DDS	Data Distribution Service
DDSI	DDS Interoperability Wire Protocol
DIS	Distributed Interactive Simulation
HLA	High Level Architecture
JAUS	Joint Architecture for Unmanned Systems

Acronym	Definition
LSA	Layered Simulation Architecture
LVC	Live, Virtual and Constructive
LVCAR	Live, Virtual, Constructive Architecture Roadmap
MSG	Modelling and Simulation Group (NATO Task Group)
MSG 086	NATO Modelling and Simulation Group Simulation Interoperability
NCOIC	Network Centric Operations Industry Consortium
NOGESI	NODo GEnérico de Simulacion
OMG	Object Management Group
PDG	Product Development Group
PDU	Protocol Data Unit
RPR FOM	Real-time Platform Reference Federation Object Model
RTI	Run-Time Infrastructure
SG	Study Group
SISO	Simulation Interoperability Standards Organization
SIW	Simulation Interoperability Workshop
TENA	Test and Training Enabling Architecture
W3C	World Wide Web Consortium

5 SG REPORT

5.1 SG OFFICERS

Officer Role	Name	Organization	Country
Chair	Dan Gregory	Thales	France/Uk
Vice Chair	Jose-Ramon Martinez	NADS	Spain
Secretary			
Technical Area Director	Kevin Gupton	University of Texas, Austin	USA

5.2 SG MEMBER LIST

Name	Organization	Country
Dan Gregory	Thales	UK
Jose-Ramon Martinez	NADS	Spain
Jose-Maria Lopez	NADS	Spain
Martin Tapp	CAE	Canada
Saikou Y Diallo	Virginia Modeling Analysis and Simulation Center	USA

5.3 TASK DESCRIPTIONS FROM THE TOR

No.	Task Title	Task Description
1.	Recommendations for next step	Establish recommendations for next steps for the topic within SISO.
2.	Support to other SISO SGs and PDGs	Provide support to other SISO SGs and PDGs (as related to the topic).
3.	Seek collaborations	Become and remain cognizant of other organizational efforts to research and address M&S architecture standards and practices and make every possible effort to make contact with such organizations for the purpose of expressing interest in their efforts and findings, potential collaborations, and in sharing the findings of the efforts of this group.
4.	Technical approach	Develop a technical approach.

No.	Task Title	Task Description
5.	Identify standards	Identify existing and emerging standards and specifications for which a framework for coordination should be defined, e.g., HLA, TENA, OMG products.
6.	Recommendations	Recommend whether a PDG should be established to produce a SISO Standards Product and if so, what process should be used to develop the specification—SISO, IEEE, or ISO.
7.	Operation	Operate in accordance with all applicable SISO administrative products.
8.	Discussions	Conduct SG discussions and business utilizing the open electronic discussion forum established for the use of the SG.
9.	Post products	Post SG products in an appropriate area of the SISO website for community review and comments as products are developed.
10.	Provide annual report	Provide the Standards Activity Committee an annual report detailing the progress and activities from the previous year and the goals for the following year.

5.4 PRODUCT DESCRIPTIONS FROM THE TOR

Products resulting from the establishment and execution of the SG shall include:

No.	Product Title	Product Description
1.	Kickoff meeting	Kickoff meeting at 2012 Fall SIW
2.	Progress report	Interim Progress Report at 2013 Spring SIW
3.	Final Report	Final Report (Due 2014 Fall SIW), including: <ol style="list-style-type: none"> 1. Description of LSA's proposed technical approach; 2. Relationship of LSA to existing standards, and plans for coordination; 3. Recommendation to SISO on the topics and issues described in this TOR, and (if appropriate) an accompanying Product Nomination.

5.5 ACCOMPLISHMENTS RELATIVE TO THE TOR

5.6 SIGNIFICANT RESULTS AND/OR ACHIEVEMENTS

As a summary, the results and achievements of the LSA SG can be divided in three main areas:

Results about the use of current standards and protocols of simulation.

- Use of current standards without change,
- Demonstration of the viability of the use of LSA with High Level Architecture (HLA),
- Demonstration of the use of LSA with Distributed Interactive Simulation (DIS),
- Demonstration of the potential use of LSA with Test and Training Enabling Architecture (TENA).

Results about the use of DDS/Interoperability Wire Protocol (DDSI) as core communication technology

- Interoperability demonstrated: between implementations and between vendors,
- Demonstration of the viability of the use of DDS over internet,
- Use of core communication infrastructure for simulation,
- Identification of the potential to use the DDS Security Specification.

Other results

- Incorporation of current simulators without modification,

- Viability of a core simulation services layer for DDS,
- Discussion of the need for a coordinated data model approach (overlapping with Architecture Neutral Data Exchange Model (ANDEM) and Real-time Platform Reference Federation Object Model (RPR FOM)),
- Separation of the data model.

5.6.1 Discussion for Significant Result Area 1

Results on the use of current standards and protocols of simulation.

These results are related with the use of LSA with current simulation standards (DIS and HLA) and protocols (TENA)

1. Use of current Standards without change

Different studies like LVCAR and MSG 086 propose addressing new simulations challenges by evolving current simulation standards. On the other hand, LSA approach proposes the use of current simulation standards as they are now. That way, it won't be necessary to redefine the standards or the products made with them. Of course, this doesn't imply that the standards cannot incorporate DDS in the future. The latter is not considered within the scope of the present study.

There are three approaches we can take to enable interoperability with implementations of current simulation standards without the need for modification of those standards. The first is to use a gateway. There are some factors to address with that approach:

- Latencies of the gateway may need to be minimized.
- The architecture of the gateway is key to guarantee maintainability and reusability. Thus the architecture has to be chosen carefully.
- Data types must match on both sides without loss of precision.
- Data models on both sides should match.

There is already a lot of experience in building this kind of gateway using the architecture of LSA with HLA and DIS. Here, data matching is easy due to the flexibility and strong data typing of DDS. There is no experience yet in integrating DDS with TENA.

A second approach is to use DDS as the communication layer of an implementation of HLA. HLA allows the use of such a technology as a lower communication protocol as it is left to individual implementations to determine.

- DIS: The standard specifies the wire protocol down to the multicast layer – it specifies the port and the rules for sending Protocol Data Units (PDUs) as well as the binary structure of those PDUs. So, it is not possible to use DDS as the communication layer into the current standard. Still, it is possible to encapsulate the DIS messages (the PDUs) in a very simple DDS data structure and then use the DDS as the communication layer, taking advantage of DDS Quality of Service. Also the full PDU model can be mapped with DDS data model structures.
- HLA: The HLA standard does not specify the communication layer. So, it is possible to use DDS "as is" as the communication layer (the HLA RTI) for a HLA implementation and still comply with the standard. This approach has already been built and tested in commercial products and real projects.
- TENA: TENA uses for low level exchange of information the ACE/TAO Real-Time Event Channel. It would be possible to change this channel with a DDS implementation without changing the TENA API above (only small changes would be needed).

The agreed approach is to describe the use of DDS to support distributed simulation alongside existing simulation standards.

2. Demonstration of the feasibility of the use of LSA with HLA. The feasibility of the use of LSA architecture with HLA was demonstrated. There are commercial products already implementing this approach in all of the abovementioned approaches (using gateways and using DDS as the communication protocol in a HLA RTI implementation). Interoperability between different versions and vendors of HLA has been proven in real projects like Spanish NOdo GEnérico de Simulación (NOGESI).
3. Use of LSA with DIS: The use of LSA architecture for connecting DIS simulators was addressed using gateways. The implementation of PDUs encapsulated in DDS objects has not been tested, but due to the nature of both PDUs and DDS, this implementation is believed to have no technical challenges.
4. Use of LSA with TENA: This use has only been theorized for the two abovementioned approaches. There are some commercial implementations of gateways (not related with LSA architecture) between HLA and TENA so the technical issue of the creation of such a gateway looks possible. More interesting, and yet to be explored, is the possible use of DDS as the communication layer of TENA.
5. Demonstration of the use of LSA with Coalition-Battle Management Language (C-BML): A prototype of the integration between C-BML and a LSA like architecture was built and has been used extensively. A full implementation is planned.
6. Demonstration of the use of LSA with standards not related to simulation: In different projects an LSA-like architecture has been used in combination with different standards not related with simulation. These standards can use DDS as its communication layer without going out of its norm. For example:
 - Joint Architecture for Unmanned Systems (JAUS) in robotics. This is very important since can open the LSA concept to include other areas of interest close to simulation.
 - Command and Control for Interoperability of Unmanned Systems (CITIUS) project (will finish in 2014) we have created combinations between JAUS and DDS, and also between the Sharable Content Object Reference Model and DDS.
 - Next version of the Robotic Operating System (ROS 2.0), planned for release on 1st Quarter 2015, will use DDS as the communication layer.

5.6.2 Discussion for Significant Result Area 2

Results on the use of DDS/DDS-I as core communication technology.

The use of DDS as the proposed core communication technology presents some interesting challenges

1. Interoperability demonstrated: between implementations and between vendors.
The use of LSA architecture demonstrates the interoperability between different standards and also between different vendors and implementations. E.g., connection through gateways has been made between MÄK RTI and Pitch RTI including ownership transfer.

Between different standards: It has been proved the interoperability between HLA, DDS and DIS. This has been included in real projects.

Between vendors:

- Between HLA vendors: It has been proved between MÄK RTI and Pitch RTI using IEEE 1516-2000; can be easily extended to IEEE 1516-2010 (HLA-Evolved)
- Between DDS vendors: Demonstration of DDS-I interoperability (Berlin OMG meeting¹) in 2013 demonstrated the interconnection of seven different vendors.

Between versions:

¹ <http://www.omg.org/news/meetings/tc/berlin-13/info.htm>

- Between HLA versions: HLA 1.3 has been successfully connected with IEEE 1516-2000
2. Demonstration of the feasibility of the use of DDS over internet.

The use of DDS over internet was demonstrated and a recording is available. Websocket technology was used, demonstrating the capability of running over different types of device and network.

3. Use of core communication infrastructure for simulation

LSA architecture relies on the use of a communication infrastructure. This is provided by OMG DDS. There are various papers² describing the advantages of using DDS for communication in simulation. Outside of the LSA group, the topic has been discussed in NATO between MSG 128 (Incremental Implementation of NATO Mission Training through Distributed Simulation Operations) and NATO Industrial Advisory Group 162 (Distributed Simulation for Air Combined and Joint Mission Training) and different national armies of the world (including USA, UK, France and China). DDS has been proven to be a valid and relevant alternative and complement to the rest of simulations standards and norms. The creation of DDS-based simulators has also been demonstrated.

4. Use of DDS Security Specification to provide security enhancements.

This feature was not evaluated in the study but was considered potentially relevant.

5.6.3 Discussion for Significant Result Area 3

Other results:

1. Incorporation of current simulators without modification:

The use of standards as they are now has as a corollary the possibility of incorporating or reusing current simulators in new simulations with the use of LSA architecture. This point has to be taken with great care since it is impossible now to guarantee mixing together every possible kind of simulator. For example, it is possible to guarantee mixing together all HLA simulators of different vendors, but it is not clear if we can guarantee the same with all HLA simulators and TENA. More experiments are needed to establish the limits of the reusability and interoperability of current simulators in LSA architecture. We can sure guarantee now the interconnection of

- HLA simulators between different vendors (tested with MÄK, Pitch, and the U.S Modeling and Simulation Coordination Office (formerly the Defense Modeling and Simulation Office). In some commercial packages this even includes the translation of ownership between different vendors,
 - DDS pure simulators between all DDS vendors. This can be guaranteed by the use of DDSI and has been probed a lot of times in different OMG meetings,
 - HLA with DIS simulators in bidirectional interoperability,
 - HLA with DDS simulators in bidirectional interoperability,
 - DIS with DDS simulators in bidirectional interoperability.
2. Feasibility of a minimum common service layer:
It was considered essential to specify a core set of simulation-specific services that describes how typical simulation functions such as interactions, object attribute reflection, time management would be implemented using DDS .

² You can find all the relevant papers in: http://simware.es/index.php/resources-and-faq/resource?view=featured&catid_doc=22&page=1

3. Discussion of the need of a coordinated data model approach (overlapping with ANDEM and RPR FOM): In all the practical uses of an LSA architecture (or an LSA-like architecture) the discussion about the use of a coordinated data model is raised. In summary, the use of such a data model (that can be a FOM model, an evolution of it or any other model) has some PROS and CONS.
 - PROS
 - Semantic interoperability is guaranteed with a fixed data model if the implementers share an understanding of the semantics of that data model.
 - CONS
 - The full flexibility of DDS in dynamic data modeling is not exploited.
 - The joint simulation would be limited to the data model constraints.
 - Integration with real (not simulation) applications can be limited by such a fixed model.
 - Current "de facto" data models are being reviewed and updated by other groups (e.g., RPR FOM in HLA or ANDEM group)

It has not been decided whether to include the data model in an eventual LSA standard. This will be addressed during any future PDG discussions.

5.7 SUMMARY OF TECHNICAL FINDINGS

No.	Finding Description
1.	DDS can run over internet
2.	LSA architecture can be built in a real project (NOGESI and CITIUS projects)
3.	DDSI allow a simulation to interoperate with different DDS vendors
4.	Protocol APIs should be abstracted as proposed by FACE 2.0 C137 from The Open Group
5.	System interoperability involves strong interface management

5.8 RECOMMENDATIONS FOR FUTURE SISO ACTIONS - THE WAY AHEAD

No.	Recommendation
1.	<p>The group's consensus was to recommend the creation of a PDG to develop a LSA Standard based on the concepts proposed in the Study Group.</p> <p>In conjunction with this Final Report, the Study Group will be submitting a Product Nomination to the Standards Activity Committee requesting the creation of a LSA PDG</p>