High Level Architecture (HLA)
as a basis of Systems-Engineering Automation for
Simulation Based Acquisition (SBA)

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ABSTRACT

This paper addresses the use of the High Level Architecture (HLA), the Department of Defense's official technical framework for simulation, as a basis for automated support to the systems engineering practice significant in the technical implementation of Simulation Based Acquisition (SBA) business practices. The paper particularly describes and educes the consequences of the logical 'dual' between the functional meta-encapsulation of simulation representation within the context of systems engineering operations on the one hand and the simple linear extension naturally provided by the HLA's open systems architecture structure on the other.

1 INTRODUCTION

1.1 Thesis

Using HLA technology for linearly extensible simulation systems to implement simulation-based systems engineering provides a sound basis for systematically developing simulation-based acquisition operational assets and processes appropriate for SBA business practices.

1.2 Overview

Included within the scope of the discussion of this paper are: 1) the circumstance of the need for practices appropriate to facilitate the intended SBA initiative in general and to provide automated support to simulation-based systems engineering practice in particular; 2) the ready availability of the HLA; 3) the explication of the concept of the dual relationship; 4) between linear extension of simulation system architecture and nesting encapsulation of systems engineering process control; 5) significance of the proposed concept; 6) the opportunistic use of HLA to support systems engineering process; and 7) the implications of such immediate application.

2 DISCUSSION

Simulation Based Acquisition is evolving, and within this context, considerable invention and effort has been invested in facilitating simulation-based systems engineering. Concepts, processes and tools exist and have been demonstrated to be effective to a degree; but, there has been little success in establishing a paradigm which is as comprehensive and amenable to third-party extension and refinement in the systems-engineering domain as has already been achieved by HLA in the simulation domain. The challenge is considerable, insofar as candidate SBA systems-engineering process paradigms must necessarily meet several criteria for flexibility, effectiveness, and scope of applicability; be consistent with existing standards and tools assets; conform to existing practice and evolving culture; and be perceptibly cost effective.

The fortuitous existence of a stable set of HLA standards and an evolving HLA systems development practice (the Federation Execution Process Model) with which to generate open and linearly extensible federation macro systems containing simulations-as-federates, suggests both a structural and process approach to regularizing simulation-based systems engineering. By overloading the HLA structure and process to encompass not only the simulation representation domain, but also the systems-engineering domain entities and operations, one can 'inherit' or 're-use' all the HLA investment and accrue all its intrinsic power and flexibility for simulation representation within what would become a 'systems-engineering federation'.

A 'dual' which may be seen to exist, then, is that each meta-level escalation above a representation component which is necessary to implement systems-engineering processes for SBA 'costs' only one additional (linear) HLA federate. The simplicity and directness of this dual relationship and the reduction of the more complex structure of 'inclusion by nesting' to the simpler structure of 'extension by addition' provides a natural design path for systems engineering process automation based on the HLA. Adopting this mapping of SBA meta-process to HLA structure extension seems to be consistent with existing standards, to capitalize on the considerable investment in HLA, to provide a framework for systematic design of simulation-based acquisition operational assets and processes, and to avoid having to establish development and enforcement of any very restrictive new concepts, standards and practices.

Naturally, some proof-of-principle experimentation is desirable; and the specification of the set of processes and tools necessary and sufficient to support this extension of HLA technology beyond mere representation to systems engineering practice will be necessary. The paper addresses several of the implications of adopting the recommended paradigm, and provides concrete recommended actions.

2.1 The Need - SBA

SBA, in effect, is an attempt to specify business practice for the comprehensive use of modeling and simulation in the context of the objective system's life-cycle acquisition.

"Many SBA-related studies over the past 5 years have consistently concluded that the use of SBA-like practices will provide benefits in the cost, the time to acquire, and the quality of DoD systems."[1] Recognizing that while modeling and simulation has been an integral part for procurement (and operational) practice within the DoD for decades, there is now current, explicit, and authoritative commitment to rationalize the use of modeling and simulation in the quest of 'better, faster, and cheaper' systems acquisitions practices.[2] Consequently, "[t]he vision for SBA has been established, and the need for SBA in meeting DoD … goals is well recognized."[3] In particular, "[t]he vision for Simulation Based Acquisition (SBA), adopted in 1997 by the Acquisition Council of the Department of Defense (DoD) Executive Council for Modeling and Simulation (EXCIMS), is 'an acquisition process in which DoD and Industry are enabled by robust, collaborative use of simulation technology that is integrated across acquisition phases and programs.' "[4, 5]

However, the paradigm wherein SBA is to be specified and implemented is still being defined. Questions of operational architecture, process, and culture, and the identification and implementation of quantitative metrics, (generally denoted in short 'return on investment' (ROI)) are being energetically debated.[6] The precise scope of the SBA process and the details of operations which are to be included are somewhat unclear. The basis upon which operational criteria and evaluation metrics for SBA are to be based, while obviously in the domain of the traditional programmatic 'cost, schedule, quality', are mostly implicit. Nevertheless, there are some domains that are so near to the heart of systems acquisition practice that their relevance is more or less inevitable. I refer to simulation-based systems engineering. Based on the assumption that simulation-based systems engineering is well within the aegis of SBA (and in fact well within the interest of training and operations perspectives), we will proceed to consider how HLA technologies may be applied – through simulation-based systems engineering – to SBA.

If defining SBA was relatively straightforward, defining 'systems engineering' is

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[1] "A Road Map for Simulation Based Acquisition - Report of The Joint Simulation Based Acquisition Task Force", Acquisition Council Draft for Coordination, December 8, 1998.

[2] "Memorandum Subject: Modeling and Simulation (M&S) in Defense Acquisition", 16 March 1998, the Honorable Jacques S. Gansler, Under Secretary of Defense (Acquisition and Technology)

[3] *op cit.* 1.

[4] *Ibid.*

[5] A slightly expanded (and focused) definition of SBA, reads: "Simulation Based Acquisition is an iterative, integrated product and process approach to acquisition, using modeling and simulation, that enables the war-fighting, resource allocation, and acquisition communities to fulfill the war-fighter's materiel needs, while maintaining Cost As an Independent Variable (CAIV) over the system's entire life cycle and within the DoD's system of systems." - Simulation Based Acquisition – a New Approach, Report of the Military Research Fellows, DSMC December 1998.

[6] For a variety of relevant documents and links to associated information regarding the SBA initiative, see: http://www.msosa.dmso.mil/sba/.

practically outside the scope of this paper.[7] We assume for purposes of discussion that:

> *Systems engineering* denotes that discipline or set of practices whereby objective systems are brought into existence commensurate with the needs of their prospective users and the resources available for their conceptualization, design, development, production, fielding and operational maintenance.

Modeling and simulation are known to be useful in enterprises where the system matures from only a specification of need and functional requirements, throughout the various stages of the system life-cycle. Simulations may be used to 'represent' the system's desired effects (requirements), its intended composition (design), its expected behaviors (test planning and operational effectiveness evaluation), its human interface (for design or training), and its operational quality (reliability, availability and maintainability); or to 'stimulate' the system, as in hardware-in the loop (HWIL) exercises. In all such cases, we assume that there is some form of representation or stimulation of the subject-system in one or another of its life-cycle manifestations, under the control of the notional 'systems engineer' role-player who uses the simulation assets and such manifestations of the system as are available to affect and evaluate the prospect system.

We note that this description is intended to be sufficiently detailed (and sufficiently general) to support the following exposition, while confirming the centrality of 'simulation-based systems engineering' as specified to the SBA mission.

For the purposes of the ensuing explication, it will be convenient to remember that the scope of SBA (and simulation-based systems engineering) includes all phases of the subject system's evolution from its inception to requirements specification, conceptual and detailed design, prototyping and production, and inventory and operations. Each phase of this evolution involves derivation of necessary attributes, implementation of those attributes, and evaluation of the acceptability of the intermediate product.

2.2 The Opportunity – HLA

The High Level Architecture (HLA) is the Department of Defense's official technical framework for simulation. Developed by and for the DoD M&S community[8], but being adopted more broadly[9], the HLA standard consists of three technical specifications[10], which form a significant part of the DOD's Joint Technical Architecture (JTA)[11]. Conceived to provide to the DoD M&S community technical infrastructure analogous to municipal building codes and infrastructure services, the HLA is being mandated across DoD[12] and is expected to improve significantly the interoperability and reuse (and thereby corporate cost-effectiveness) throughout the several DoD M&S domains. The individual standards provide guidance for: 1) the specification of the externally visible representational and executive-operational

[7] While definitions are available, (e.g. "Systems engineering is a branch of engineering that 'concentrates on the design and application of the whole [of a system] as distinct from the parts…looking at the problem in its entirety, taking into account all the facets and all the variables and relating the social to the technological aspects.", Systems Architecting – Creating and Building Complex Systems, Eberhardt Rechtin, 1991.); few are sufficiently focused for our purposes.

[8] For information pertaining to the HLA Development process under the auspices of the DoD, see: http://hla.dmso.mil/hla/. For details of the standing and operations of the Architecture Management Group (AMG) and that organization's role in HLA evolution, see: http://hla.dmso.mil/hla/amg/.

[9] For information about the establishment of HLA as an IEEE standard (e.g. IEEEP1516) and the role of the Simulation Interoperability Standards Organization (SISO) in that process refer to: http://www.sisostds.org/index.htm. For information about the adoption of HLA as a NATO M&S standard, see: natomsmp@msis.dmso.mil.

[10] For DoD standards references, see http://hla.dmso.mil/hla/tech/, providing in particular the three seminal documents:

- U.S. Department of High-Level Architecture, Rules, Version 1.3, 5 February 1998.
- U.S. Department of Defense High Level Architecture, Interface Specification, Version 1.3, 2 April 1998.
- U.S. Department of Defense, High-Level Architecture, Object Model Template Specification, Version 1.3, 5 February 1998.

[11] Department of Defense, Joint Technical Architecture, Version 2.0, 26 May 1998.

[12] Original guidance, since reinforced by Mr. Gansler, was provided in the Memorandum, SUBJECT: "DoD High Level Architecture (HLA) for Simulations", Paul G. Kaminski, then , Under Secretary of Defense (Acquisition and Technology).

capabilities of the individual simulation federates[13] and of composite federations[14]; 2) the functional and data interface between the federates and a necessary structural component designated the Runtime Infrastructure (RTI) by which means the federates intercommunicate; and 3) the rules of behavior of the federates and federations respectively. Well documented and relatively well supported as an emerging new technology with process guidance, tools, training, and user support help-lines[15]; HLA is maturing toward its intended stature as a stable and broadly used set of standards, applicable and effective over extremely diverse domains, and supported by commercially available services and tools.

From reference to defining documentation, the fundamental architectural properties of HLA (i.e. properties having to do with identification and characterization of entities, relationships among entities, and comprehensive behaviors of component entities and composite HLA system whole) are evident. Federation system entity components are 'federates' and the 'RTI'. Federates have mutually symmetric relationships to one another and to the RTI; and the RTI is the only entity logically contiguous to all others. RTI-to-Federate interface syntax and function are governed by the Interface Specification. Semantics at the interface is governed by the Federation Object Model (FOM), constructed in conformance with the Object Model Template (OMT) Specification. The semantic representation (operation) of the federates is, likewise, governed by the OMT-compliant Simulation Object Model (SOM). Finally, the behaviors of both the component federates and the composite federation are governed by the Rules Specification. It is important to note that while other extensions of the fundamental topology of HLA are possible,[16] the 'baseline' structure for which HLA standards were developed and are guaranteed to suffice and for which nearly all the implementations to date have employed is that of a linearly extensible set of federates, in a bus or star distribution relationship to the RTI. It is just this guaranteed linear extensibility which is leveraged to advantage in the concept described below.

The last significant and necessary notion associated with the capability of HLA technology to support SBA systems engineering practice has to do with domains of object models which may be conceived to exist within any HLA simulation federation system.[17] On the one hand, there is the 'simulation representation domain' wherein conceptual objects, their attributes, behaviors, and interactions which are derived from the conceptual model of the mission space (CMMS) and are correlated to those prospective entities in the real-world being represented. It is within this domain that the attributes of the system under study in the simulation based systems engineering reside. It is also the domain which correlates most highly to the HLA SOM, at least insofar as the SOM denotes classes of entities from the real-world which the federate models or interfaces into the federation. On the other hand, there is the 'simulation executive domain' wherein conceptual objects are derived from and correlate to the conceptual abstraction of entities which are artifacts of simulation implementation, execution, and operational control. It is this domain within which the entities having to do with the mechanics of operating an HLA federation and implementing systems engineering operations reside. HLA supports the specification of simulation-executive domain object entity classes both within the SOM (insofar as they are peculiar to the individual simulation federate) and the Management

[13] "Federate. A member of a High Level Architecture Federation. All applications participating in a Federation are called Federates. This may include federation managers, data collectors, real world ("live") systems (e.g., C4I systems, instrumented ranges, sensors), simulations, passive viewers and other utilities.", Glossary of Modeling and Simulation (M&S) Terms, 15 January 1998.

[14] "Federation. A named set of interacting federates, a common federation object model, and supporting Runtime Infrastructure, that are used as a whole to achieve some specific objective.", Glossary of Modeling and Simulation (M&S) Terms, 15 January 1998

[15] See within scope of the DMSO web site (http://hla.dmso.mil) for information on process guidance (http://hla.dmso.mil/hla/federation, and http://hla.dmso.mil/hla/testing/), tools (http://hla.dmso.mil/hla/fed_tools/, and http://www.dmso.mil/cgi-bin/hla-cgi/tools/bboard.pl), training (http://hla.dmso.mil/hla/edu_trng/), and user support services (http://www.dmso.mil/).

[16] See for example published accounts of analyses of alternative system topologies as those recommended for security partitioning (e.g. federations joined by bridge federates) and for special purpose system composition (e.g. nesting federations as federatess in high-order federations). "Classes of Federation: A conjecture on Federation Lifecylces.", Spring 1997 Simulation Interoperability Workshop, 3-7 March 1997, John P. Hancock.

[17] For a discussion of the role of such alternative object domains in context of simulation system architecture specification, see: "WARGAME 2000 Architecture Description - Analysis and Guidance", 26 October 1998, W. F. Waite.

Object Model (MOM) designed to support federation system executive management.

By overloading the HLA structure and process to encompass not only the simulation representation domain, but also the simulation executive domain entities relevant to the systems-engineering operations, one can 'inherit' or 're-use' all the HLA investment and accrue all its intrinsic power and flexibility for simulation representation within what would become a 'systems-engineering federation'. Since HLA puts no bounds upon Meta levels of operation of the federation, systems engineering functions can be applied over the simulation representation 'kernel' of the traditional federates. Since HLA federations are linearly extensible and since each such extension might effect the incorporation of a meta-level process, HLA technology may serve as the implementation basis of SBA simulation-based systems engineering for an indefinite number of levels of Meta control or enclosure.

2.3 The Concept - Dual

The concept of a 'dual' is that of a pared transform of representations of some single, invariant, and complete semantic domain. Common examples of duals are current versus voltage equations of electronic circuits; object-oriented versus process-oriented descriptions of systems architectures, and wave versus particle (or, in a slightly different vein, Heisenberg's versus Schrodinger's) representation of quantum physics. In each case, the underlying 'reality' is invariant and what it 'means' is unaffected by the choice of representational schema. Further, the representations may be considered reversible transforms of one another under rules of operation, which might be explicitly defined.

We assert that there is a virtual dual relationship between the functional, control relationship which exists in simulation-based systems engineering operations on the one hand and the structural membership which exists in the construction (or extension) of an HLA federation system on the other. Further, we propose that since this dual does not affect the semantic content of the reality to which it pertains, and since on the HLA structural side, the extension of federation structures is both demonstrably viable and practically unlimited; then *we can expect an extremely open and flexible opportunity to use the HLA structure to implement the SBA simulation-based systems engineering practice*.

The significant 'dual' which exists then is that each meta-level escalation above a representation component which is necessary to implement systems-engineering processes 'costs' only one additional (linear) federate. Process levels (and cycles) are mapped into structural extension. Meta-structures and controls are manifest by 'operations' (e.g. operator-federates) against subordinate bracketed operands. The simplicity and directness of this dual relationship and the reduction of the more complex structure of 'inclusion' to the simpler structure of 'extension by addition' provides a natural design path for systems engineering process automation based on the HLA.

2.4 The Significance

Adopting generally and employing widely the aforementioned concept of mapping of the meta-*process* associated with the systems engineering and business practices of SBA to the intrinsic extensibility of the baseline topology of HLA technical *structure* seems to be significant in a number of ways.

First of all, this concept affords achieving considerable return-on-investment (ROI) for investments already made. While 'chasing-sunk-cost' is widely recognized as a no-no, employing the recommended concept is merely finding a use for the evolving HLA technology. HLA is virtually a 'gimmie'. It exists. And while recognizing that 'there is no free lunch', HLA is demonstrably viable, and potentially useful in highly disparate domains involving extremely dissimilar simulation assets and operations. HLA may realize its expected potential for fostering re-usability and interoperability or not, but proof-of-principle demonstrations and some trends within the DoD market toward HLA migration are auspicious. In systematically adopting the use of HLA technology in support of SBA operations, one inherits the infrastructure of HLA (e.g. tools, process, and user support) contingent on its likely survival.

Following the tenants of Buddhist and Existential philosophy and of medical professionalism, we consider that adopting the proffered concept 'does no harm'. The proposed concept doesn't break the SBA or the HLA paradigm anywhere. Further, it is consistent with existing standards and evolving practice throughout the M&S community. In respect to a related conservative concern, employing the concept respects the principle of parsimony by avoiding having to establish (and not to require) development and enforcement of any very restrictive new concepts, standards and practices. Under the circumstances of the rate of evolution of the industry and the difficulties of establishing constraints on practice in context of existing cultural commitment, this is extremely significant.

Most significantly, of course, the recommended concept 'meets the need' - *the concept provides a sound framework for systematic design of simulation-based acquisition operational assets and processes*. As a matter of detail, the concept meets most *a priori* criteria for simulation based systems engineering. For that purpose, candidate process paradigms must necessarily accommodate iterative use of simulations, of variable maturity, in disparate contexts (e.g. requirements, design, development, evaluation), supported by a conceptual schema, standards and tools (automation aids, components, etc.). Candidate processes must encompass a fairly wide range of *ad hoc* practice, namely, what people are already doing; and they must admit to tailoring and collegial elaboration. Finally, such practices must be cost-effective. While clear-cut proof of conformance of the proposed concept to these criteria is not yet available, HLA was certainly developed, and has been shown to be reasonably capable of supporting these needs.

Finally, any such concept must be found to be widely applicable, powerful in its effects, easy to use, regularizable as a practice, and consequently sharable (supporting, thereby, re-use and interoperability). Whether the proposed concept in actuality meets these criteria may be anticipated but will need to be further debated.

2.5 The Implementation

By way of proving the feasibility of the concept proposed, AEgis Research Corporation is including as part of its AEgis'99 IR&D Initiative the use of a intelligent-agent federation-executive federate to control other simulation representation federates and to conduct systems-engineering operations within an HLA compliant system.

AEgis' IR&D Initiative is the most recent of a succession of exploratory experiments of HLA systems development and use in which AEgis has been instructed.[18] Leveraging the resources and experience of its IITSEC system for an annotated briefing of the AEgis IITSEC '98 multi-domain federation contract the author. AEgis staffers have conceived the use of an alternative federate in the role of federation control agent, operating upon the residual simulation representation federates. This is a natural extension of the intended use of the Federation Control™ component of AEgis' HLA LabWorks™ product suite. In this case, however, rather than to provide general purpose federation control as is common with the Federation Control component (e.g. start and stop federation operation, save data, etc.), the new federate is intended to serve as the systems-engineering Meta agent identified in the concept above.

Meanwhile, technical discussions between AEgis Research, Huntsville and Boeing's Phantom Works Organization have resulted in the election of Boeing's System Modeling Architecture (SMA) Model Interrogator (MI)[19] as the application-of-choice for the intended systems-engineering control federate. This application effectively "asks questions of models which comply with the SMA model interface conventions supporting, with other members of the SMA family, an extensive range of system engineering activities. The SMA is predicated on the idea that information about a system can be represented in a machine intelligible and machine-interrogable way….The role of the Model Interrogator is to support direct interaction between a [live or virtual] user and the collection of models registered for use in a [systems engineering] project. With MI [one] can make single model runs, generate trend curves, calculate sensitivities, search for optimal conditions and generate reports in Microsoft® Word. [One] can also wire together multiple models into a supermodel and perform the same interrogation activities on the combination."[20]

The current experiment is entering detailed design from its concept definition phase now concluding. Design trades having to do with the determination of the FOM and the detailed mechanisms

[18] AEgis Research has participated in three of these as lead system integrator, and documentation of each is available. These exploratory HLA systems include:
- the Joint Training Federation Prototype (JTFp) conducted under the auspices of the AMG as proof-of-principle of the HLA concept and standards
- the HLA C2 Experiment conducted by DMSO to demonstrate the proof—of-principle of extension of HLA technologies to interoperate with real-world C2 systems
- the ITSEC '98 AEgis Demonstration conducted as an IR&D Program to illustrate the HLA FEDEP and demonstrate the feasibility of using HLA economically to support interoperation of significant simulations for analysis, TEMO, and RDA simultaneously.

[19] Model Interrogator User Handbook, SMA Model Interrogator Version 1.0.34 - A component of the Boeing System Modeling Architecture (SMA), 10/26/01, Byron Purves.

[20] *Ibid.*

whereby the systems engineering federate will operate upon the system representational federates are being decided. The FEDEP is being tailored for the intended application and those tailorings documented. Scenarios relevant to SBA simulation-based systems engineering are being established, and the necessary and sufficient modifications to federates for HLA-compliant operation are being made. Finally, arrangements are being made to capture and document significant lessons learned from the experiment using the same techniques and systems engineering databases employed in support of predecessor federation experiments.

Our expectation is, of course, that the federation will succeed to prove-in-principle the subject concept. Demonstration of simulation-based systems engineering is as clearly within the capacity of HLA as the successes of earlier federations were for their own intended uses. The interesting outcomes will relate to 'what it takes' to make it work, and 'how well' in relation to criteria indicated above, the SBA business practice of simulation-based systems engineering is supported by HLA simulation technology.

3 CONCLUSION

In this paper, we addressed the use of the High Level Architecture (HLA), the Department of Defense's official technical framework for simulation, as a basis for automated support to the systems engineering practice significant in the technical implementation of Simulation Based Acquisition (SBA) business practices. From the logical 'dual' between the functional meta-encapsulation of simulation representation within the context of systems engineering operations and the simple linear extension naturally provided by the HLA's open systems architecture structure, we have inferred *a sound basis for systematically pursuing simulation-based acquisition operational assets and processes appropriate to support SBA business practices*.

Within the scope of this paper, we have introduced the standing of SBA and HLA for the DoD M&S community. We introduced the concept of the dual relationship between the nested business process of SBA systems engineering and the linear extensible structure of the HLA technology. Leveraging the fortuitous availability of HLA technology, we are embarking upon an exploratory experiment to illustrate the viability and efficacy of the proposed concept, and we are looking forward to reporting the results of that experience.

We do, of course, recognize and acknowledge that we have identified and described only one point of the intersection of HLA *technology* and SBA *business practice*. Other areas of intersection remain to be identified and investigated. From the point of view of HLA-related technology, data standardization and regularization of practices in conceptual modeling may provide significant points of departure from which implications for SBA business practice may be approached. From the point of view of business practice, distributed collaborative engineering and associated systems engineering practices for systems specification, requirements management, and changes in the culture of custodial responsibility of systems evolution may admit to technical amelioratives as yet unanticipated.

Resume

As founder and President of AEgis Research Corporation, Mr. Waite directs a staff involved in a wide variety of modeling and simulation activities including: simulation technologies evolution; simulation systems development; simulation verification, validation, and accreditation; simulation–based studies and analyses; and the development of hardware and software products supporting modern M&S practice. Mr. Waite has over twenty-five (25) years of technical hands-on experience in weapon system development and analysis; software and simulation development, evaluation, and application; real-time Hardware/Man-in-the-Loop (HW/MIL) simulation design and development; and sensor, missile, and architecture system development and evaluation. Current technical interests include: distributed simulation systems architectures, object-oriented simulation-based systems engineering practice, and the economics of modeling and simulation.