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DISTRIBUTED SIMULATION WITH FEDERATED MODELS: EXPECTATIONS, REALIZATIONS AND LIMITATIONS

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ABSTRACT

A critique of federated modeling and simulation (M&S) and the HLA approach is given from an external perspective. Recognized difficulties and the progress toward overcoming them are described. The role of HLA in developing consistency and uniformity in M&S within the Department of Defense is laudable. The program and its management by DMSO have succeeded in promoting communications and understanding, which has become a tremendous asset. However, the goal of universal interoperability is challenged as neither desirable nor achievable. This contention is based on two problems inherent in federated simulation.

1 INTRODUCTION

Distributed simulation with federated models is a technology created and shaped to a large extent by the Defense Modeling and Simulation Office (DMSO). Founded in 1991, DMSO is designated in the Department of Defense Modeling and Simulation Master Plan (DOD 1995) as the lead organization in the development of the High Level Architecture (HLA) "to facilitate interoperability among simulations and promote reuse of simulations and their components" (DMSO 1999, p. iii). HLA is defined by: (1) Rules describing HLA principles, (2) Interface Specification describing the functional interface between federates and the HLA Runtime Infrastructure (RTI), and (3) Object Model Template (OMT) specifying a common format and structure for documenting HLA object models. The basic components, Simulation Object Models (SOMs), are combined to form a Federated Object Model (FOM), which in turn can be linked to form expanded FOMs through a structured Federation Development and Execution Process (FEDEP). HLA enables "any number of physically distributed simulations systems [to be] brought together into a unified simulation environment to address the needs of new applications" (DMSO 1999, p. iii). However, HLA "provides a generalized architecture for simulation operability … strict adherence to the HLA specifications is not, by itself, sufficient to ensure a fully consistent, interoperable distributed simulation environment" (DMSO 1999, pp. iv-v).

Simulation within DOD is widely used with varying application goals that can be conveniently identified with one of three categories: (1) *analysis* of systems behavior, (2) *training* and education in numerous technical areas or military application domains, and (3) *acquisition and acceptance* of systems components and processes. Within each category the degrees of interaction can vary by application from quasi-independent to tightly coupled, but the forms of distribution typically are hierarchical, functional, and sensor versus weapon.

2 FEDERATED MODELING FOR SIMULATION

The federation concept is a natural extension of the object concept originating with SIMULA 67 (Nygaard and Dahl 1981). The active SIMULA objects or *processes* are generated as instantiations of *classes*, with each having identical attributes and operations (methods). Attribute values and operation definitions can vary with run-time assignment permitting considerable flexibility, as does the quasi-parallel processing environment. The federation extension is made in a far different world from that of the single processor execution environment of the 1960's.

The FEDEP provides a highly structured model by which SOMs from an Object Model Library are selected to form federates. Like the SIMULA process, the SOM contains its own data structures and operations, but going further, the SOM has its own time flow mechanism (TFM) and data collection and reporting capability. Through the Federation Development Plan, supported by the HLA Interface Specification and the OMT, the FOM is created so as to realize interoperability among simulations (at the object level) with differing basic characteristics (e.g., TFM, execution language, and data representation).

Component-based Software Development (CBSD), in the more general software development domain, encompasses goals very similar to federated modeling for simulation. A software component is a source code module considered as a definable unit for configuration management that provides a set of well defined interfaces (Rivas 1997, p. 62). In the opinion of Grady Booch, a popular software spokesman, "components provide a mechanism for the physical packaging and distribution of object-oriented abstractions, and in a manner that is largely language-neutral" (Booch 1997, p. 80). CBSD has the goal of large-scale sharing and reuse of components in on-going and future applications. Certainly at first glance, the goals and challenges in developing FOMs, as well as the approaches and techniques, appear to match well with those for component-intensive systems.

2.1 Rationale and Motivation for Federated Simulation

The claim of similarity among goals, approaches and techniques for CBSD and FOM above suggests that explicit description of the rationale and motivation for federated simulation is in order. A definition of *federation* is given in (Dahman and Lutz 1998, p. 1): "A federation is a named set of simulations interacting via the services of the HLA Runtime Infrastructure (RTI) and in accordance with a common object model and a common HLA rule set to achieve some desired purpose." While defining a concept in terms of a specific implementation is generally undesirable, the understanding of the concept and the HLA motivations are clarified by coupling the definition above with the following, "The purpose of this architecture [HLA] is to facilitate interoperability among simulations and promote reuse of simulations and their components" (DMSO 1999, p. 1). Clearly, the goal of federated simulation and of HLA is the extension of reuse and interoperability as broadly as possible in DoD uses of simulation.

The rationale that federated simulation represents a means to assure interoperability and reuse seems sound and, to a degree, it is. Simulations constructed to meet prescribed interface definitions, to use common services, and by adherence to the same development process should facilitate cooperative use as components in a larger simulation study, reducing both time and cost. Such simulations should provide better candidates for later use in other studies involving simulations produced following the same procedures to meet the same specifications.

Initially viewed by many in the simulation community as a successor to DIS (U. S. Congress 1995) in the training domain, HLA has experienced expanding expectations. Proponents tout the architecture as applicable to the full range of DoD modeling and simulation applications, which includes analysis and acquisition (Dahman and Lutz 1998, p. 1).

2.2 The Challenge of Federated Simulation

The need to bring structure and organization to the simulation modeling investment within DoD is undeniable. Federated simulation with HLA amplifies reuse opportunities and offers a viable basis for distributed development of interoperable simulation components. The persistent federation concept (Dahman and Lutz 1998) extends reuse to multiple levels of granularity, enabling the model repository to adapt to an organization's expanding needs. Such high potential payoff is not be obtained easily, for realizing the promises in federated simulation is going to require a lengthy process, marked by discipline and determination. Numerous challenges are already documented in the DMSO repository and elsewhere in the simulation literature.

2.2.1 Recognized Difficulties and Perceived Resolution Strategies

Although a number of issues are described in the literature on HLA federated simulation, many can be allocated to one of three categories: (1) enabling and facilitating communication among the federates, (2) responding to differing time flow mechanisms, and (3) achieving uniformity and consistency in model representations. The nature of the issues and the attempts to resolve them are described in this section.

2.2.1.1 Evolving Data Interchange Format Standards

Enabling communication among simulation components developed by different organizations and at different times is an obvious challenge. This problem is addressed in all three components of the HLA: (1) the Rules, (2) the Interface Specification, and (3) the Object Model Template (OMT). The FEDEP sets forth a six-step process describing the creation of HLA federations (DMSO 1999, p. 2-4). Some 17 activities are described within the six steps, providing detailed guidance in the federated model development.

Key in the communications among federates is the Data Interchange Format (DIF). The contention that data interchange should be supported by "a stable, common format optimized to preserve application investment" (McLean, et al. 1998, p. 1) is widely accepted. However, as the authors note, the basis for data exchange needs to evolve as technology changes and experience with HLA provides more complete understanding of the needs. Evolution of DIF is made more difficult by the use of an exchange format rather than an exchange mechanism. The suggestion is to employ self-defining data interchange formats – an abstraction of the DIF (a metaschema) by which any format can be described.

2.2.1.2 Differing Time Flow Mechanisms in Federates

The predecessors of HLA, DIS for training applications and ALSP for war-gaming, use different approaches to time management. DIS employs fixed-time incrementing with time advances paced by a real-time clock. ALSP uses the Bryant/Chandy/Misra (BCM) conservative protocol. While DIS does not guarantee the observance of temporal causality (because of communication latencies) and messages are processed in the order of receipt, ALSP promotes strict causality observance. Note that strict temporal causality may be much less important a factor in training simulations than in war-gaming.

A principal goal of HLA time management (HLA-TM) is "to support interoperability among federates utilizing different internal time management mechanisms" (Fujimoto and Weatherly 1996, p. 61). All conceivable mixtures of time management within interoperable federates is advocated, and transparency is the goal. To recognize the contention between communication latencies and observance of temporal causality, the HLA-TM defines five event ordering mechanisms: (1) Receive Order, (2) Priority Order, (3) Causal Order, (4) Causal and Totally Ordered, and (5) Time Stamp Order.

At this juncture only some of the problems of mixing federates with dissimilar time management mechanisms is recognized. Whether HLA-TM can fulfill its objectives is not known. Lyons and Neel (1998, p. 6) report no difficulty in integrating event driven and time-stepped simulations; however, only 13 base classes, including three management federates, comprise the FOM. Nielsen and Salisbury (1998, pp. 7-8), describing the time management decisions in the JTLS-GCCS-NC3A Federation development in terms of *time-regulating* versus *time-constrained*, consider the issues to be plagued with subtle complexities. Feinerman et al. (1999, p. 6) comment on the joining of NSS ("event-stepped") and EADSIM ("time-stepped") in the Trailblazer federation, "While the two may work efficiently by themselves, when they are mixed (as in this federation), the sum can introduce inefficiencies." The authors note that "One area of federation development that is not well codified revolves around time management issues" (Feinerman et al. 1999, p. 5).

2.2.1.3 Uniformity and Consistency in Model Representation

The cost and time to achieve interoperability and reuse in a FOM are strongly affected by the uniformity and consistency of federate representations. When the intent is to include legacy models, constructed without HLA guidance, perhaps prior to the acceptance of object-oriented principles in modeling, and possibly before the recognition of general software engineering techniques, the effects are magnified. Goldberg and Dworkin (1998, p. 2), recognizing the variations in practices among the DoD Command, Control, Communications, Computing and Intelligence (C^4I) community, conclude that, "Consequently, most existing models … represent many of the same C4I functions but, having been built independently, have dissimilar model architectures and data structures; dissimilar languages and operating systems; and even dissimilar algorithms."

All three components of the HLA specification seek to support uniformity and consistency, but the Rules address the issues quite directly. Strategies for dealing with legacy simulations include the development of middleware in ModSAF for the Joint Precision Strike Demonstration (JPSD) (Beebe et al. 1998. pp.3-4). This federate common software (FCS) serves as the interface with the RTI. Lyons and Neel (1998) use mini-federations to assess potential risk and to drive "data marshalling" agreements. They also employ wrapper methods to overcome variations in legacy simulations.

Strategies for achieving interoperability and reuse for federates developed under HLA include the creation of the HLA Object Model Data Dictionary (Hammond et al. 1998); design and introduction of a prototype environment (AMASE) to support reuse and model interoperability (Goldberg and Dworkin 1998); and the attempt to provide a mechanism so that SOM data representations can be transformed more readily to meet future FOM needs (the FOM agile federate) (Macannuco et al. 1999).

3 ADDITIONAL SIGNIFICANT DIFFICULTIES

The difficulties described in this section are not widely recognized in published HLA documents or in conceptual treatments of federated computing outside DMSO. Yet, the negative effects emanating from these three problem areas have the potential to overshadow the many benefits that can accrue in the widespread adoption and use of HLA.

3.1 Unrecognized Difference from Component-Based Software

Much is being made about CBSD in the general software community. A brief description is given above to acquaint readers with the principal ideas and the *apparent* similarities to federated simulation. Proponents might be tempted to classify federated object modeling as simply an application of CBSD. Such an assertion is neither warranted nor accurate.

Distinguishing simulation model components (SMC) from general software components (GSC) is the centrality of *objective* in the former. The description of the function for a GSC is usually sufficient to suggest or impose the necessary level of descriptive detail. The GSC has an invariant function, and wherever and whenever used that function is applicable.

In contrast, the appropriate description of the SMC is as dependent on the objective of the simulation study as it is on the capture of attributes of the system being simulated. To use popular parlance, the appropriate *level of abstraction* for a SMC is inherently tied to the study objective – the questions that must be answered to reach a correct decision. Consequently, the same system entity, performing the same function, might be described in far greater detail in one model than in another, simply because the study objective mandates the difference. The GSC does not possess an analogous influencing factor.

3.2 Expanding Claims of HLA Suitability

The DoD Modeling and Simulation Master Plan (DOD 1995) does not bound HLA applicability to any subset of the three application goals: training, analysis or acquisition and acceptance. Those in positions to know state that HLA is intended to have "wide applicability, across a full range of simulation application areas, including education and training, analysis, engineering and even entertainment, at a variety of levels of resolution" (Dahmann, Fujimoto and Weatherly 1998, p. 797). In the same source (p. 802) the authors admit "Universal interoperability (the ability of any simulation to interoperate with any other simulation, regardless of original purpose or technical implementation) is not feasible with today's technology." However, universal interoperability is implied to be both a desirable and an achievable future goal.

Universal interoperability is <u>not</u> achievable and should not be a goal. It should not be a goal for precisely the reason stated above: simulations created for use in different application areas have vastly different objectives. The simulation created for entertainment has the objective of entertaining its user, and the superficiality of the representation is quite acceptable. In many cases the laws of physics need not be observed; fictional entities with super-human, or super-non-human, capabilities are exceptionally entertaining. The objective in training is to impart operational experience, and the observance of temporal causality is not a constraining requirement. However, observance of the laws of physics, in particular temporal causality, <u>is</u> critical in simulations supporting acquisition and acceptance decisions. To propose the imposition of HLA compliance on the modeling efforts across all application areas is to force artificial levels of abstraction with the consequences that simulations for entertainment and training and education are far more costly in development and execution than necessary. The effect on models for analysis and acquisition and acceptance is likely to be coercion toward a compromise that could jeopardize the validity of the simulation for the originating use.

Universal interoperability is not achievable in general for the reason described in the following section.

3.3 Logical Extension of the Federation Concept

Simulation experiments with HLA object models report success in supporting over 300 federates and 5000 objects (Dahmann, Fujimoto, and Weatherly 1998, p. 800). However, the Synthetic Theater of War (STOW) exercise is only scratching the surface of what is needed to meet future expectations. Consider a theater-level joint operations model to analyze the value added of a new computer system for network communications on a surface combatant. (This example is hypothetical but plausible.) Using this example, the following scenario is inevitable.

The FOM is formed of federates with local time management ranging in granularity from minutes (surface ship to surface ship relative positioning) to picoseconds (computer system internal clock). The number of objects is high, but the number of object interactions is immense. The global event list is so dense as to force global time-stepped management; and the granularity forced by the computer system is on the order of a picosecond. The resulting computational load approaches an inconceivable level.

This problem of incompatible timing granularity is first described in a seminar presentation (Nance 1998). Since then, Pham and Bagrodia (1998) independently have encountered the same problem in the context of investigating speedup by introducing parallel simulation within a HLA federation. They describe the problem as follows (Pham and Bagrodia 1998, p. 1560):

> The time scale difference can have a dramatic impact on the execution of a parallel federate. For a conservative federate, the existence of at least one federate working at a much smaller time scale has disastrous consequences on the performance of the simulator. For an optimistic one, the probability of time errors increases dramatically. Special care must be taken when constructing a federation execution to verify that there is no time scale incompatibility, in which case the idea of interoperability is impossible.

4 CONCLUDING SUMMARY

The HLA program as managed by DMSO is having significant impact on improvements in M&S technology within DoD and potentially even more broadly. These improvements stem from the visibility given to Issues that are common, but in the past the recognition of commonality is lost because it occurs at different points in simulation projects. Moreover, through the DMSO website and the Simulation Interoperability Workshops, good practices are published, lessons learned are shared, and stove-piped legacies are being transformed. The uniformity and consistency of model representation is vastly improved, and the reuse of ideas, techniques, designs and in some cases code is enabled.

Federated computing as a concept has limitations, and cautions against "overselling" need to be observed. The prospect of universal interoperability should be explicitly recognized as unachievable and undesirable. Failure to do so could jeopardize the benefits already accrued and hinder achievement of much greater potential in the future.

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