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What comes after the Semantic Web - PADS Implications for the Dynamic Web

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Abstract

The Internet started as a web of documents. The Semantic Web is targeting a web of data, enabling efficient machine-to-machine data exchange. In order to utilize the Internet for distributed simulation, procedures are needed for migration, alignment, and orchestration of the execution, which means higher levels of interoperation. This paper introduces related concepts leading to the idea of the Dynamic Web, which will be a web of composable services.

This paper is a concept paper written to encourage discussion. It summarizes related ideas and contributions in a loose style and doesn't claim to be complete or inclusive. Contributions are more than welcome.

1. Introduction

The Internet started as a *"web of documents"* to be displayed on request for use by humans. As long as this display was limited to pure text, it was mainly used by academics to easily exchange ideas on publications. With the advent of Internet browsers, the web became a medium used by many users so much so that the current use of Internet resources has become a standard for middle schools in technology driven countries.

The introduction of XML has produced dramatic changes: the Internet became a *"web of data"* instead of documents and it moves currently towards the Semantic Web. This has enabled new concepts, like machine-to-machine information exchange via the web without a human-in-the-loop. Web services allow web-based applications that are truly distributed in a way that has never before been possible.

However, when looking at the Principles of Advanced Distributed Simulation (PADS), the promise of the Semantic Web falls short. While the Semantic Web targets data to describe situations and common pictures, PADS drives towards the orchestration and alignment of highly agile and dynamic interdependent applications. Higher levels of interoperation are required to capture not only the semantics of data to be exchanged, but also the possible compositions of these data into business objects (pragmatics). Also affected is how the information exchange will influence the sending and receiving systems (dynamics) and the constraints for such compositions (concepts). In order to enable this, a vision beyond the Semantic Web is needed. Such a vision deserves the name *Dynamic Web* and it will be a *"web of composable services."*

2. Interoperation of Advanced Distributed Simulation Systems

The Internet is used by simulation experts on a daily basis: email is one of the main communication devices; literature research is initiated with an Internet browser; proceedings are published via the web; etc. Yet, while the Internet is such a commonly used piece of infrastructure for document and information exchange, the use of it as an M&S runtime infrastructure has yet to meet its potential use envisioned by the web-based simulation enthusiasts participating in early conferences, such as Web-based M&S [1]. More recent approaches on Web-enabled M&S conducted under a consortium of the Object Management Group (OMG), Open GIS Consortium (OGC), Simulation Interoperability Standards Organization (SISO), and the Web 3D Consortium also fall short in producing fertile ground for real web-enabled applications. The question is: Why is this happening? What is so special about web-based simulation applications? Why is the Internet being used for on-line shops, bank accounts, literature research, and thousands of other application domains, while Internet use for most of the advanced distributed simulations is still employing other infrastructure specifications?

The Society for M&S International (SCS) defined web-based simulation as *"representing a convergence* *of computer simulation methodologies and applications within the World Wide Web (WWW). There are many possible bridge areas between the web and the simulation field. Web-based simulation does not mean only "distributed simulation" or "simulation documentation." The introduction and widespread use of the web suggests that there are many areas where web science and technology will meet simulation to provide impetus to both fields."* [1]

As discussed in the introduction, the web changed from a web of documents to a web of data. The advent of XML in general and of web services in particular enabled its use for a variety of net-centric applications. In principle, every application based on data exchange and remote procedure calls can easily migrate using XML and web services, and it can play a role on the web [2]. Pullen et al. applied these principles showing a possible migration path for M&S applications [3]. Nonetheless, M&S on the Internet remains to be the exception.

In the author's opinion, the reason for this exception is rooted in the fact that interoperation for advanced distributed simulation systems is based on much more than data exchange and remote procedure calls. While the Internet, in its current form and even as the envision Semantic Web [4], focuses on implementation issues, meaningful interoperation of M&S applications requires the alignment and harmonization of underlying conceptual ideas as well: *Interoperability of Simulation Systems requires Composability of Conceptual Models!*

This result summarizes the findings of several researchers on composability of M&S systems. Page et al. [5] state that, at least within the military simulation domain, composability has arisen as a cousin of the longstanding U.S. Department of Defense objective of interoperability. Page et al. also support the view of Petty and Weisel [6], whose research resulted in the view that interoperability covers the technical aspects and composability the conceptual aspects. The conclusions drawn by Page et al. [5] suggest defining composability as the realm of the model and interoperability as the realm of the software implementation of the model. In addition, their research introduces integratability coping with the hardware-side and configuration side of connectivity. The author supports this categorization and recommends the following distinction when dealing with issues of simulation system interoperability, to include meaningful simulation-to-simulation system interoperation:

- *Integratability* contends with the physical/ technical realms of connections between systems, which include hardware and firmware, protocols, etc.

- *Interoperability* contends with the software- and implementation details of interoperations, including exchange of data elements based on a common data interpretation, etc.

- *Composability* contends with the alignment of issues on the modeling level. The underlying models are purposeful abstractions of reality used for the conceptualization being implemented by the resulting simulation systems.

This recommendation is consistent with ideas promoted by other researchers. During a recent panel discussion on Priorities for M&S Standards, Zeigler explicitly stated that *standardization must be aimed at the modeling level* to ensure interoperability between systems, i.e., the standardized level must be higher than the programming level standards currently applied [7]. For "meaningful interoperability" the sharing of standardized data via standardized protocols, such as the Distributed Interactive Simulation [8] protocol or the High Level Architecture [9] standard is necessary, but it does not complete what is necessary for meaningful interoperability. Also needed is the coordination of the underlying conceptual models and the harmonization of the operational ideas simulated, as they are the real crux to create interoperable solutions. Instead of only standardizing the information exchange requirements, the underlying modeled cause-effect-chains must also be coordinated.

Sarjoughian et al. [10] proposes a framework for a general modeling formalism comprising the system formalism describing the model, the abstract simulator, a platform independent description of implementation ideas interpreting the formulism, the simulation algorithm computing the formalism and correctly implementing the abstract simulator, and finally the computational platform. The general model formalism manages the conceptual issues. Abstract simulator and simulation algorithms deal with the implementation layer, and the computational platform contends with technical levels.

Yilmaz [11] formulates the requirements for contextualized introspective simulation models to address the fact that models are driven by intent when they are created. Yilmaz suggests that this intent is the basis for the purposeful abstraction of reality resulting in the model, which is implemented by the simulation system. If the intent differs too much, the models cannot be aligned. Similarly, Hofmann [12] identified the need to capture the intent of a simulation application in a communicable layer as a conceptual model independent from its implementation.

In summary, there are three main challenges to applying the Internet for M&S as an enabler:

- *Migration:* existing solutions must migrate to this new infrastructure. In order to use the Internet as the backbone for advanced distributed simulation, the migration to supporting protocols and standards must be easy and supported by commercial products.

- *Alignment:* the information exchange must be unambiguously defined to ensure the correct data interpretation and use within the participating system and/or services.

- *Orchestration:* the execution of the distributed simulation systems must be choreographed and observed, and it must be ensured that all relevant cause-effect chains are executed in the right order.

All three aspects must be supported for the composition of models, the interoperability of implementing simulation systems, and the technical layers used for the execution. The Levels of Conceptual Interoperability Model (LCIM) was introduced to answer the question, what additional support is needed from the Internet to support these efforts effectively?

3. The Levels of Conceptual Interoperability Model

The LCIM evolved from observations and results of several composability and interoperability efforts, going back to the beginnings of the High Level Architecture [9]. During a NATO M&S Conference on High Level Architecture applications, Judith Dahmann introduced the idea of distinguishing between substantive and technical interoperability [13]. In his research on composability, Mikel Petty enhanced this idea [14]. He distinguished between the implemented model and the underlying layers for protocols (such as the IEEE1516 protocols), the communication layers, and hardware. Realizing the need to explicitly address the conceptual layer, Tolk and Muguira published the first version of the LCIM in [15]. The discussions initiated by [15], in particular the work of Page et al. [5] and

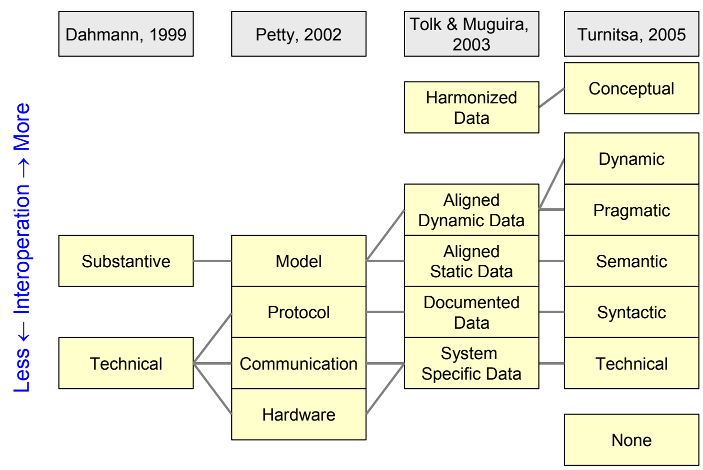

Figure 1: Evolution of Layered Interoperability Models

Hofmann [12], resulted in the currently used version, first published by Turnitsa [16]. Figure 1 shows the development.

The current version of the LCIM distinguishes seven layers, starting with stand-alone systems. The underlying approach was driven by bottom-up ideas.

- Level 0: Stand-alone systems have *No Interoperability*.

- Level 1: On the level of *Technical Interoperability*, a communication protocol exists for exchanging data between participating systems. On this level, a communication infrastructure is established allowing exchanging bits and bytes, the underlying networks and communication protocols are unambiguously defined.

- Level 2: The *Syntactic Interoperability* level introduces a common structure to exchange information, i.e., a common data format is applied. On this level, a common protocol to structure the data is used; the format of the information exchange is unambiguously defined.

- Level 3: If a common information exchange reference model is used, the level of *Semantic Interoperability* is reached. On this level, the meaning of the data is shared; the content of the information exchange requests are unambiguously defined.

- Level 4: *Pragmatic Interoperability* is reached when the interoperating systems are aware of the methods and procedures that each other are employing. In other words, the use of the data – or the context of its application – is understood by the participating systems; the context in which the information is exchanged is unambiguously defined.

- Level 5: As a system operates on data over time, the state of that system will change, and this includes the assumptions and constraints that affect its data interchange. If systems have attained *Dynamic Interoperability,* then they are able to comprehend the state changes that occur in the assumptions and constraints that each other is making over time, and are able to take advantage of those changes; the effect of the information exchange within the participating systems is unambiguously defined.

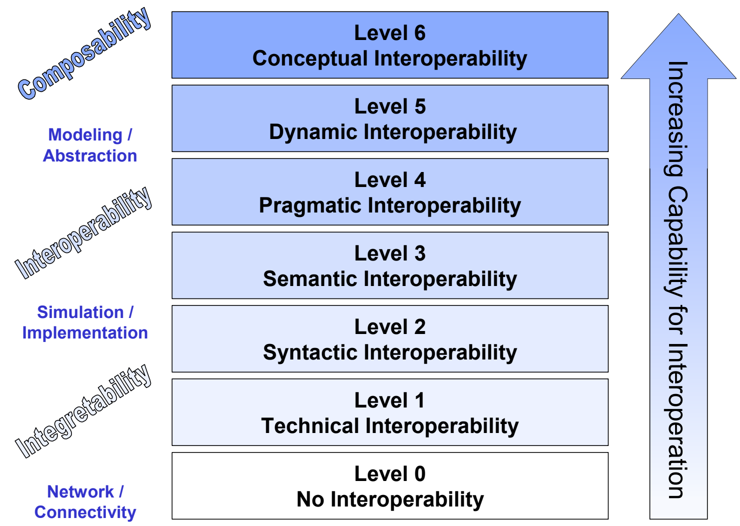

Figure 2: Levels of Conceptual Interoperability Model

- Level 6: Finally, if the conceptual model – i.e. the assumptions and constraints of the purposeful abstraction of reality – are aligned, the highest level of interoperability is reached: *Conceptual Interoperability*. This requires that conceptual models will be documented based on engineering methods enabling their interpretation and evaluation by other engineers. In other words, on this we need a “fully specified but implementation independent model” as requested in Davis and Anderson [17] and not just a text describing the conceptual idea.

Figure 2 shows the current LCIM including the relation to the ideas described in Page et al. [5], and showing the layers for modeling/abstraction, simulation/ implementation, and network/connectivity.

4. The Dynamic Web: A Web of Composable Services

The Semantic Web initiative described in [4] changes the Internet by transforming it from a web of documents into a web of data. Daconta et al. identify multiple layers for the support of unambiguous information exchange, which they call the Ontology Spectrum, reaching from weak semantics to strong semantics.

- *Taxonomies* ensure the syntactic interoperability. Taxonomy is a semantic hierarchy, a partially ordered set. The main purpose is the classification of terms.

- *Thesauri* ensure structural interoperability. Thesaurus is a controlled vocabulary arranged in a known order and structured so that equivalence, homographic, hierarchical, and associative relationships among terms are displayed clearly and identified by standardized relationship indicators. The main purpose is the classification of relations of defined terms with each other.

- *Conceptual Models* as defined in [4] target the semantic interoperability. These models seek to model a portion of a domain to which a system must perform work by providing users with the type of functionality they require in that domain. They are closely connected to *Logical Theory*. In order to ensure strong semantics, frame-based or axiomatic logical theories are needed. The main purpose is machine-interpretability of description, which is more than machine processing of information.

This ontology spectrum can help to ensure that data exchanged can be unambiguously defined, but this is only sufficient for levels up to semantic interoperability in the LCIM. The data must also be exchanged and the systems orchestrated. The currently used implementing technology for this task is the use of web services.

The fundamental idea behind web services is integration of software applications as services within a service-oriented architecture. The concept represents a defined set of industry supported open standard technologies that work together to facilitate interoperability between heterogeneous systems, whether within an organization or across the Internet. In other words, web services can web-enable applications to communicate with other applications according to web services standards. This is potentially a tremendous opportunity to build bridges between legacy stove-piped developed systems. At its core, web services are another approach to distributed-computing with application resources provided over networks using standard technologies. Because web services are based on standard interfaces, they can communicate even if running on different operating systems and being written in different languages. They are widely supported by industry and already successfully applied in a wide range of different domains. For this reason they are a valuable approach to building distributed applications that must incorporate diverse systems over a network.

Web Services, as seen within the actual M&S research, are a set of operations, modular and independent applications that can be published, discovered, and invoked by using industrial standard protocols, such as Simple Object Access Protocol (SOAP)**,** Web Service Description Language (WSDL) and Universal Distribution Discovery and Interoperability (UDDI). However, it should be noted that WSDL is not sufficient to describe M&S services, as pointed out in the recent report of the Extensible M&S Framework (XMSF) Group [18], which evaluated the applicability in detail. The use of web services is a distributed computing model that represents the interaction between program and program, instead the interaction between program and user, yet is part of the "web of data" idea. Web services can also be defined as discrete web-based applications that interact dynamically with other web services. In order to make this happen, several sub-functions are necessary, namely

- providing self-description of the service functionality,
- publishing the service descriptions using a standardized format,
- locating the service with the required functionality,
- establishing Communications with the service,
- requesting the required data to initiate the service, and
- exchanging data with other web services, including delivering the results.

The web service vision contends that services will work together seamlessly because they are developed by the same standards for self-description, publication, location, communication, invocation, and data exchange capabilities. As all the standards concerned are open, the technologies chosen for web services are inherently neutral to compatibility issues that exist between programming languages, middleware solutions, and operating platforms. As a result, applications using web services can dynamically locate and use necessary functionality – whether available locally or from across the Internet.

The studies conducted by the XMSF group [18] show the potential of web services in combination with the technologies defined in the ontology spectrum of [4]. Nonetheless, even a combination only satisfies the levels up to pragmatic interoperability: basic web standards, such as the Internet Protocol (IP), take care of the technical layers; the ontology spectrum supports the following levels up to semantic interoperability; and, the XML definitions of WSDL identify the methods and procedures that can be used. How to apply these ideas that enable XMSF based mediation services to translate dynamically between different dialects has been shown in [19, 20].

The next step of related research must focus on the dynamic and conceptual interoperability. Several ideas are currently evaluated. One of them is the use of OMG's Model Driven Architecture (MDA) [21]. For some M&S related ideas see [22]. The MDA defines three levels of abstraction used to describe systems and services. These models are Computation Independent Model (CIM), Platform Independent Model (PIM), and Platform Specific Model (PSM). To document these artifacts, MDA uses the following standards: the Meta-Object Facility (MOF), the Unified Modeling Language (UML), and the XML Metadata Interchange (XMI). Specifically, the community is evaluating the use of UML and capturing the information using XMI to generate the necessary metadata [23]. The relation of MDA and ontology is captured in [24]; the application of MDA for web services is described in [25]. Xie et al. [26] generalize these ideas, including the earlier version of the LCIM [15], for grid computing applications. Some examples for the military domain on applying these principles are given in Morse et al. [27].

A final domain directly related to the topic of this paper is the choreography and composition of web services, as these results are directly applicable to supporting standards for dynamic interoperability. Srivastava and Koehler conclude in their overview on current solutions for web service composability that the functionality of a web service needs to be described with additional pieces of information, either by a semantic annotation of what it does or by a functional annotation of its behavior [28]. Furthermore, they show that current solutions based on the Resource Description Framework (RDF) or the

Business Process Execution Language for Web Services (BPEL4WS) are not sufficient. Tosic et al. come to similar conclusions in [29]. Lopes and Hammoudi describe how the use of CIM, PIM, and PSM could support the composition of web services [25]. Alternatively, concepts such as the Web Service Conversation Language (WSCL) could enable services to negotiate their composition, as discussed in Banerji et al. [30]. However, in order to support such negotiations, a semantically rich environment for orchestration is needed. Agerval et al. summarize similar results and recommend a framework to represent the underlying concepts in the form of a common ontology [31].

In summary, all evaluated reports are pointing towards the necessity of capturing the meaning of services in order to compose them correctly. Technically, the composition of web service is solved, but the challenge remains to connect only functions being conceptually compatible with each other. As stated earlier, substantive interoperability on the implementation level requires composability of models on the abstraction level.

5. Principles of Advanced Distributed Simulation Implications for the Dynamic Web

In order to support M&S application, a web of composable services is needed. What layers of interoperation are needed for such a dynamic web has been derived from the LCIM: technical, syntactic, semantic, pragmatic, dynamic, and conceptual.

In summary, the technical layer of the LCIM is well covered by applicable standards. The current work on the semantic web is primarily focusing on unambiguity of exchanged data. As such, the levels of syntactic and semantic interoperability are supported.

Current research focuses on pragmatic and dynamic layers capturing the use of data and information within the system. The research on composition of web services contributes to recommendations for metadata and standards capturing the result in machine- interpretable form.

Nonetheless, M&S is a special domain, because the modeling part of M&S creates a *purposeful abstraction of reality* as the basis for the simulation implementation. In order to enable composable M&S services, conceptual models based on engineering methods are required that capture the assumptions and constraints. While the layers below the conceptual level cope with what we model in detail, only the conceptual level can express what we exclude from a model. For substantial interoperability, this information is as important as how the simulation system itself works. Even many established methods, such as DEVS [32] or completely UML documented models, fall short in this respect; they only document WHAT and HOW something is implemented, but not what has been cut in the process of purposeful abstracting the domain. Some first ideas on how to cope with this challenge are considered in [33], but this is just a start.

The special challenges of M&S applications must be met and captured in standards for the Dynamic Web. Among these topics requiring research are

- Migration of existing solutions and capturing their assumption and constraints in standardized metadata;
- Alignment of Data, in particular solving the issues of standardized description of scope and resolution, which includes the domain of aggregation and disaggregation of data between different levels of resolution [34];
- Orchestration of M&S service execution, including the domain specific aspect of time-management, such as described in [35].

Another important aspect not dealt with in the necessary detail so far is the topic of how to use bottom-up driven ontologies – such as described in the approach of this paper – and top-down driven ontologies – such as described by Sousa-Pousa in [36] – which are two sides of one medallion. The research group around the author is convinced that both approaches are necessary and should be aligned, as sketched in [33]. How this should be done, however, is topic of ongoing research.

After focusing successfully for decades on solving the simulation challenges of PADS, it is now time to seriously think about standardization requirements and engineering-driven solutions for the modeling side of M&S. The community needs to agree on how to capture assumption and constraints so that intelligent software applications, such as intelligent software agents, can understand the assumptions and use this knowledge to compose services in support of the immediate needs of users. This will be beneficial in particular when they use operational systems supporting the ideas of service-oriented architectures, such as the Global Information Grid (GIG) currently envisioned by the US Department of Defense [37].

References

[1] *IEEE Proceedings of the 1998 International Conference on Web-based Modeling & Simulation,* January 1998, Catamaran Resort Hotel, San Diego, California, Part of the 1998 SCS Western Multi-Conference on Computer Simulation

[2] Tilley, S., Gerdes, J., Hamilton, T., Huang, S., Muller, H., and Wong K. (2002). "Adoption Challenges in Migrating to Web Services." *Proceedings Fourth International Workshop on Web Site Evolution* (WSE02)

[3] Pullen, J.M., Brunton, R., Brutzman, D.P., Drake, D., Hieb, M.R., Morse, K.L., and Tolk, A. (2004). "Using Web Services to Integrate Heterogeneous Simulations in a Grid Environment." *Proceedings International Conference on Computational Science* 2004: 835-847

[4] Daconta, M., Obrst, L., and Smith, K. (2003). *The Semantic Web: The Future of XML, Web Services, and Knowledge Management.* John Wiley, Inc.

[5] Page, E.H., Briggs, R., and Tufarolo, J.A. (2004). "Toward a Family of Maturity Models for the Simulation Interconnection Problem." *Proceedings IEEE Spring Simulation Interoperability Workshop,* IEEE CS Press

[6] Petty, M.D., and Weisel, E.W. (2003). "A Composability Lexicon." *Proceedings Spring Simulation Interoperability Workshop*, IEEE CS Press

[7] Simulation Interoperability Standards Organization (SISO) / Society for Modeling and Simulation (SCS) Panel Discussion on Priorities for M&S Standards; *IEEE Spring Simulation Interoperability Workshop* in Orlando, Florida, March 2003.

[8] IEEE Standard Group 1278: *Distributed Interactive Simulation* (Revision 2002)

[9] IEEE Standard Group 1516: *High Level Architecture* (Revision 2000)

[10] Sarjoughian, H.S., Zeigler, B.P., and Hall, S.B. (2001). "A Layered Modeling and Simulation Architecture for Agent-Based System Development." *IEEE Proceedings*, 89 (2), pp. 201-213

[11] Yilmaz, L. (2004). "On the Need for Contextualized Introspective Simulation Models to Improve Reuse and Composability of Defense Simulations." *Journal of Defense Modeling and Simulation* 1 (3): 135-145

[12] Hofmann, M. (2004). "Challenges of Model Interoperation in Military Simulations." *SIMULATION*, Vol. 80, pp. 659-667

[13] Dahmann, J.S. (1999). "High Level Architecture Interoperability Challenges." Presentation at the *NATO Modeling & Simulation Conference*, Norfolk VA, October 1999, NATO RTA Publications

[14] Petty, M.D. (2002). "Interoperability and Composability." *Modeling & Simulation Curriculum* of Old Dominion University, Old Dominion University

[15] Tolk, A., and Muguira, J.A. (2003). "The Levels of Conceptual Interoperability Model (LCIM)." *Proceedings IEEE Fall Simulation Interoperability Workshop*, IEEE CS Press

[16] Turnitsa, C.D. (2005). "Extending the Levels of Conceptual Interoperability Model." *Proceedings IEEE Summer Computer Simulation Conference*, IEEE CS Press

[17] Davis, P.K., and Anderson, R.H. (2003). *Improving the Composability of Department of Defense Models and Simulations.* RAND Corporation

[18] Blais, C.L., Brutzman, D.P., Drake, D., Moen, D., Morse, K.L., Pullen, J.M., and Tolk, A. (2005). *Extensible Modeling and Simulation Framework (XMSF) 2004 Project Summary Report.* NPS-MV-05-002, Naval Postgraduate School, Monterey, CA

[19] Tolk, A. (2004). "XML Mediation Services utilizing Model Based Data Management." *IEEE Proceedings of the 2004 Winter Simulation Conference*, IEEE 04CH37614C, pp. 1476-1484

[20] Tolk, A., and Diallo, S.Y. (2005). "Model-Based Data Engineering for Web Services." *IEEE Internet Computing,* Vol. 9, Nr. 4, 2005

[21] Object Management Group (OMG) (2005). *Model Driven Architecture (MDA) Resource Page* at http://www.mda.org

[22] Tolk, A., and Muguira, J.A. (2004). "M&S within the Model Driven Architecture." *Proceedings Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC)*

[23] Morse, K.L. (Chair). (2005). *XMSF Profile Study Group Final Report.* SISO-REF-014-2005, Proceedings IEEE Fall Simulation Interoperability Workshop, IEEE CS Press

[24] Arpinar, B., Zhang, R., Aleman-Meza, B., and Maduko, A. (2005). "Ontology-driven Web services composition platform." *Journal on Information Systems and E-Business Management* 3 (2): 175 - 199

[25] Lopes, D., and Hammoudi, S. (2003). "Web Services in the Context of MDA." *Proceedings International Conference on Web Services*, IEEE CS Press

[26] Xie, Y., Teo, Y.M., Cai, W. and Turner S.J. (2005). "Towards Grid-Wide Modeling and Simulation." Sin-

gapore-MIT Alliance (SMA). *Computer Science*, MIT Libraries

[27] Morse, K.L., Drake, D., and Brunton, R. (2004). "Web Enabling HLA Compliant Simulations to Support Network Centric Applications." *Proceedings of the 2004 Symposium on Command and Control Research and Technology,* San Diego, CA, 2004

[28] Srivastava, B., and Koehler, J. (2003). "Web Service Composition - Current Solutions and Open Problems." *Proceedings ICAPS 2003 Workshop on Planning for Web Services*

[29] Tosic, V., Pagurek, B., Esfandiari, B., and Patel, K. (2001). "On the Management of Compositions of Web Services." *Proceedings Object-Oriented Web Services* (OOPSLA 2001)

[30] Banerji, A., Bartolini, C., Beringer, D., Chopella, V., Govindarajan, K., Karp, A., Kuno, H., Lemon, M., Pogossiants, G., Sharma, S., and Williams, S. (2002). *Web Services Conversation Language (WSCL).* W3C Note Mar 2002

[31] Agarwal, S., Handschuh, S., and Staab, S. (2005). "Annotation, Composition and Invocation of Semantic Web Services." *Journal on Web Semantics* 2 (1): 1-24

[32] Zeigler, B.P., Praehofer, H., and Kim, T.G. (2000). *Theory of Modeling and Simulation.* 2nd Edition, Academic Press

[33] Tolk, A., Turnitsa, C.D., and Diallo, S.Y. (2006). "Ontological Implications of the Levels of Conceptual Interoperability Model." *Proceedings of WMSCI 2006,* IEEE Press

[34] Tan, G., Ngee Ng, W., and Moradi, F. (2001). "Aggregation/Disaggregation in HLA Multi-Resolution Distributed Simulation," *Proceedings 5th IEEE International Workshop on Distributed Simulation and Real-Time Applications (DS-RT),* p. 76 ff., IEEE CS press

[35] Fujimoto, R. (2001). "On-Line Simulation Techniques for Real-Time Management of Systems." *Proceedings 9th International Symposium on Modeling, Analysis and Simulation of Computer and Telecommunication Systems*

[36] A.A. Sousa-Poza, A.A. (2005) "Pragmatic Idealism as the Basis for Understanding." *Proceedings of the International Conference on Systems, Man and Cybernetics,* IEEE Press

[37] Tolk, A. (2005). "An Agent-based Decision Support System Architecture for the Military Domain." In G.E. Phillips-Wren and L.C. Jain (Eds.), *Intelligent Decision Support Systems in Agent-Mediated Environments*, Volume 115 Frontiers in Artificial Intelligence and Applications, IOS Press