Using Web Services and Data Mediation/Storage Services to Enable Command and Control to Simulation Interoperability

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ABSTRACT

The Extensible Battle Management Language project has implemented XML based data mediation services to translate from legacy XML schemas into XML schemas, based on a common tag set generated from the Command and Control Information Exchange Data Model (C2IEDM). The C2IEDM was developed by NATO to enable interoperation among operational Command and Control (C2) systems of coalition forces. XBML's ability to exchange simulation information based on C2IEDM enables a major expansion in interoperability, in that C2 systems now can be coupled with modeling and simulation software. The benefit of our specific data mediation approach is that legacy systems are required only to provide information exchange interfaces based on XML, as the adaptation of such systems is done by configuring the layers of the recommended architecture. We present the architecture and operational principles used to achieve interoperation in this way.

1. Introduction

Current standards addressing simulation interoperability for the Department of Defense (DoD) are almost exclusively data centric. Both the protocol data units in the IEEE 1278 Distributed Interactive Simulation [1] and the Object Model Template of the IEEE 1516 High Level Architecture [2] define information exchange elements to be distributed among participating simulations. Time management and data distribution management add some complexity; however, the basic interoperation function to make sure that information is distributed in a standard form and reaches the participating simulations at a given logical, simulation internal time (for IEEE 1278, wall clock time).

The military command and control (C2) community recently has begun migration from system centric to network centric interoperability, using a common operational picture. This has resulted in an improvement of an order of magnitude in the quality of the command and control process. Still, the new approach is comparable to the techniques applied in the database domain for a couple of decades: information is exchanged based on a common logical or federated data model. As in distributed simulation, the main challenge in C2 is to agree on a common understanding of the data to be exchanged.

The DoD is in the process of deploying a major new information infrastructure, called the Global Information Grid (GIG), which features interoperability based on service-oriented architectures (SOA) using Web/Internet standards. This provides a high incentive for modeling and simulation (M&S) systems to follow the same approach in order to interoperate with other DoD systems. The minimal consensus in approach between C2 and M&S is the exchange of well-defined, standardizable business objects, described in XML, using Web services. Based on this, the information can be stored and displayed in a configurable way. Furthermore, migration of legacy systems is supported by XML based data mediation services utilizing the data engineering methodology in [3-6, 10-12].

The XMSF project group from George Mason University, Old Dominion University, the Naval Postgraduate School, and SAIC San Diego has initiated several prototypes that demonstrate this approach, funded by elements of the DoD. One of these is the Extensible Battle Management Language (XBML) project, based on a previous U.S. Army prototype, which under XMSF was first Web-enabled and then migrated into a joint context. Similar ideas evolved in France during the same period and the approach also has been advocated in the United Kingdom, leading to interest in an approach to BML that can be used across international collations. The Simulation Interoperability Standards Organization (SISO) chartered a Study Group on Coalition Battle Management Language (C-BML) in Fall 2004. In parallel activity, NATO's Research and Technology Organization (RTO) Modeling and Simulation Group (MSG) launched an Exploratory Team to evaluate the applicability of a technical activity to create a Coalition Battle Management Language implementation for the alliance. A common thread through these interests is data driven solutions to interoperability.

Within the XBML project, the Virginia Modeling, Analysis and Simulation Center (VMASC) is responsible for investigation and prototyping of emerging capabilities that can facilitate the project's technical goals more effectively. Most recently this took the form of a layered architecture for data management using Web services to enable technically sound and stable migration of data driven interoperability solutions, based on open standards and, to the maximum extent possible, open-source components. The principles we have employed in prototyping such solutions are:

- All products are based on open standards and should be applicable without commercial or classification barriers.
- Off-the-shelf products are applied only when the resulting software can be distributed without license restrictions.
- All of our software is open-source and it will be distributed to the community, which will allow others to enhance it.

The remainder of this paper is structured as follows: Section 2 gives an overview of the services focusing on technical details, and explains how we envision the services to be applied. Section 3 focuses on the question of configuring data mediation layers based on common data engineering; this is where the main intellectual challenges lie. There are many additional challenges to be met; section 4 addresses some of these, while section 5 summarizes the paper.

2. Overview of the services

The evaluation of open standard and open source implementations applicable in the context of future BML reference implementations was conducted as part of projects in XBML and Air Operations BML by VMASC and GMU. An overview and a reference list are given in [3].

These efforts led to prototype implementation of

- an open-source implementation of a C2IEDM database accessible via Web services using the XML Schema describing the coalition namespace of the US DoD XML Repository,
- an XML based data mediation service translating XML dialects into C2IEDM, and
- a Web based user interface for the C2IEDM database, allowing configurable database access and display.

These prototypes have been developed to become the information exchange hub for the initial NATO C-BML demonstration. The concept and architecture were introduced in [4]. Figure 1 shows a conceptual architecture for the services.

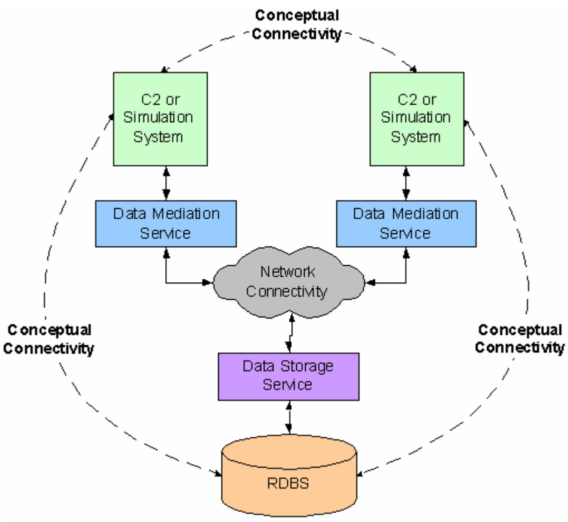

Figure 1: Conceptual View of Services

2.1 Web service accessible database

The centerpiece of the Web service architecture is a database ready to be populated with information structured following the rules of the Command and Control Information Exchange Data Model (C2IEDM). The advantages of the C2IEDM have been discussed in detail in other papers, including pros and cons discussed in [3,4] and a recent overview in [5]. Without repeating the details here, we can summarize by stating that we recognize that the main advantage of this data model is not technical. Although the model is mature and applicable in real-world, operational systems, as has been shown by various nations using the C2IEDM as their data model, the real reason why this model should be supported lies in the fact that it is built on the consensus of all participating nations. Any other data model will need to undertake a major effort in order to reach the same level of agreement when applied in the combined and joint domain.

The website http://www.mip-site.org of NATO's Multilateral Interoperability Programme (MIP) supplies interested users with the complete C2IEDM documentation set, including data models based on the software tool Entity-Relationships-for-Windows (ERWin) and schemas to instantiate a database using Microsoft Access. However, we preferred an operating-system independent, open source solution, so we based our implementation on the open source database MySQL. It is platform and operating system independent, sufficiently stable and reliable, and supports the standardized Structured Query Language (SQL) for relational databases. We adapted scripts from the Institute Defense Analysis (IDA) and from XBML participant company Atlantic Consulting Services Inc. (ACS) to populate the database with the current version 6.1 of the C2IEDM.

Our next task was to define how to structure the information in the database. Reference [3] addresses the degree to which a complex data model, such as the C2IEDM, can serve as the basis for a language, which should be not only machine readable, but also understandable by a human. Within the Coalition Battle Management Language project, we have agreed within several rounds of consensus building that using the standard schema WHO is doing WHAT, WHERE, WHEN, and WHY it is to be done (the 5Ws) is appropriate for this effort and closer to the language of the warfighter than the structures of C2IEDM. Nevertheless, we decided that all information elements must be aligned with information structured using the C2IEDM. There are multiple options for mapping the elements of the 5Ws to the C2IEDM elements; we will discuss this further in section 2.0.

After adopting the 5Ws approach to support the BML work, we sought an accepted XML schema for C2IEDM. In support of the U.S. Office of the Secretary for Defense (OSD), the Institute for Defense Analyses (IDA) has produced an XML schema based on the C2IEDM version 6.0. This schema was submitted to the U.S. Department of Defense XML Repository to provide a structure for the coalition namespace. We determined that it provides a sound basis for our BML work, so we have implemented a Web service interface to our C2IEDM database with an embedded XML schema using the tag sets of this coalition namespace.

A problem remains in that not every piece of information that can be tagged using this schema makes sense when stored individually in the database. Business roles, which normally are implemented within the applications making use of a database, should be supported independently from the application and as efficiently as possible. In collaboration with other XBML participants, we have begun to define business objects that cluster meaningful information together. We also have started to define rules to be implemented and supported by the final XML schema to be used when populating the database.

Examples for such business objects are military units and their weapon systems, allowable activities within an operation, and order of battle structures (*i.e.,* organizations for military operations). Examples for the construction rules are "before a unit can be used, the weapon systems of this unit must be defined" and "before a unit-action-association can be established, the unit as well as the action must be defined." By capturing these rules within the XML Schema, we minimize tests and parsing in using the database. MIP currently is working on the next version of C2IEDM, the Joint Consultation, Command, and Control Information Exchange Data Model (JC3IEDM). This data model extends and enhances the C2IEDM in a consistent manner and will support XML information exchanged based on the ideas described here, although it is likely that many more different business objects will result from the effort. Methods for extending and enhancing a reference data model are described in [7].

Our service-oriented architecture can be applied to projects such as C-BML, in that any application that is able to produce XML documents with a well-defined schema can exchange data with our service. Because they are limited to well defined and documented information elements, our systems provide a basis for rapid prototyping in the coalition domain.

2.2 Data Mediation Service

Any of the participants in C-BML can decide how to adapt their systems for information exchange. As in the adaptation chosen by our partners in the project described in [3], any participant can come up with an individual, system-specific mapping. However, as stated in [6], we have found the individual mapping to be a source of potential misinterpretations and errors. Although some information elements are similar, they are not equal, leaving room for interpretation even among experts. The automation of the mapping process based on common data management process also has been the topic of several papers. In section 3.3 below, we explain how this is supported in our prototype.

The core idea of the XML based data mediation service is described in [7]. Assuming that the data elements of an XML dialect also describe the information space captured by the C2IEDM elements, a mapping between the two is possible. This is the same sort of process that goes on, for example, when a Federation Object Model (FOM) is created in the High-Level Architecture (HLA) [2]. Our service conducts this mapping; while accepting XML documents from the participating system on the one side, it produces an XML document comprising the business objects based on the C2IEDM on the other side (and vice versa for data consuming systems). For the practical application, this mapping must go hand in hand with the alignment of services, which means, the procedures that are called remotely using the Web service paradigm. Mediation consists of the mapping of the parameter structure (input and output parameters), not the invocation of the implementing Web services.

While it is not possible to create a universal translator, it is possible to create a data mediation service that can be driven by a configuration file. Technical support for mediation is available in various software tools, such as Altova's MapForce that is used in our project (see section 0 below). Because considerable subject matter expert knowledge is necessary to conduct the academically challenging tasks of common data engineering (see section 3), we advocate using such mediation services to produce a consistent, common mapping. The alternative is a set of individual mappings without a well-documented basis for testing or a common way of documentation.

2.3 Configurable data access and display

A database is not useful if its content cannot be displayed and manipulated. One way to do this is through a Graphical User Interface (GUI) designed to fulfill the users' needs, derived from their requirements. Modern software tools support configurable data access and display services that can be easily adapted to different information structures, information needs, user requirements, etc. For example, one user may be interested in different views of the order of battle, while another focuses on logistics.

The analysis performed by U.S. Army domain experts when setting up the first BML prototype included evaluation of military doctrine contained in 70 field manuals. Results were captured in the BML tables describing the database and a GUI, which was bound to the specific format of BML, to support the user with selections rooted in the doctrine. For example: ground units cannot conduct air operations; therefore, when a ground unit is selected, only ground operations are offered in follow-on selection boxes.

While this approach was appropriate for the original BML demonstration prototype, it seemed to us too limited for exploratory projects. For example, artillery units have performed military police duties in Iraq; the ability to consider such an expansion over pure doctrine is important. Developing such alternative GUIs is costly and time-consuming. In addition, we wanted our prototypes to be platform and operating system independent. To achieve platform independence and flexibility, we chose to use cascading Web services as our implementation philosophy, as shown in Figure 2.

The first layer of our service is used to configure the selection and preparation of the information to be displayed. This includes user-specific manipulation of data, such as aggregation, composition, etc. That information is the basis for the next layer, which is used to display the information in a configurable way. Instead of coding in dependencies, we use XML configuration files to drive the display. This approach is consistent with ideas of Web Service Interest Management (WSIM) and federation independent visualization described in [8]. Currently, we information only in text boxes and pull-down menus; however, a real graphical display in the form of a map or even as three-dimensional visualization is planned.

3. Data engineering to configure the mediation Service

Beyond designing the architecture of the layered Web services and how they interact without deadlock, the other main challenge is to create a common understanding of the information space. The method we use to cope with this challenge is data engineering, as described in [9].

3.1 Overview of data engineering

Data engineering supports a holistic view of data related efforts. Its concepts are based on the principles of federated and distributed databases. It focuses on the need to combine the often independent and unaligned disciplines of data administration, data management, data alignment, and data transformation.

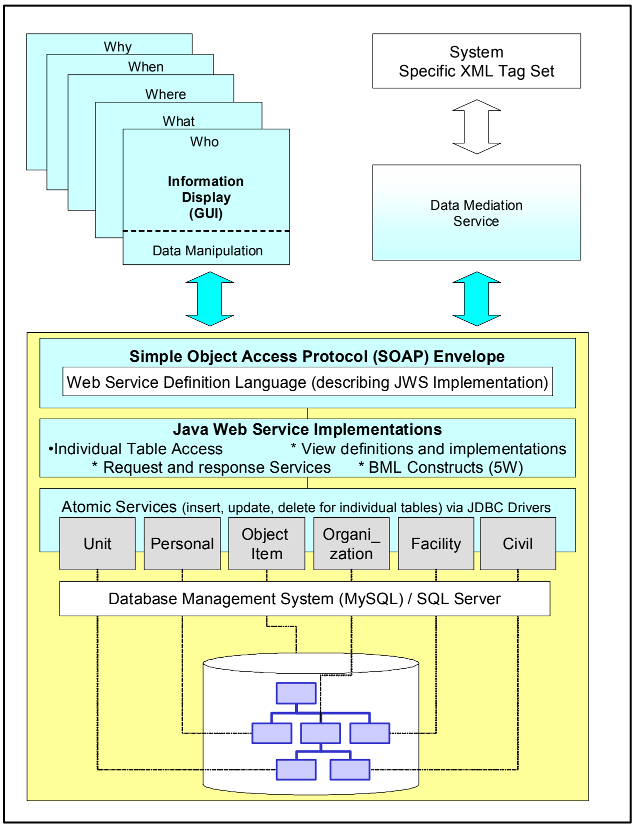

Figure 2. Layered Web Services Architecture

- *Data Administration* is the process of managing the information exchange needs that exist between services, including documentation of the source, the format, context of validity, and fidelity and credibility of the data. Data Administration therefore is part of the overall information management process for the service architecture.
- *Data Management* consists of planning, organizing and managing data by defining and using rules, methods, tools and respective resources to identify, clarify, define and standardize the meaning of data through their relations.
- *Data Alignment* ensures that the data to be exchanged will exist in the participating systems as an information entity or that the necessary information can be derived from the data available, *e.g.*, using the means of aggregation or disaggregation.
- *Data Transformation* is the technical process of aggregation and/or disaggregation of the information entities from the component systems to match the information exchange requirements, including the adjustment of the data formats as needed.

In service-oriented architectures such as the one we describe here, these disciplines are supported by Web-based standards. Every service defines its information exchange needs using XML; this common syntactical standard facilitates each of translation. Service definitions are published using Universal Description, Discovery, and Integration (UDDI) registries, so that data administration also can be directly supported. The mediation process in essence becomes a translation among different dialects of XML. As a result, the main intellectual process in data engineering is the data management process, in which data elements are identified and described, and equivalent expressions of information are mapped to each other. The process is described in more detail in [7].

3.2 Model based data management

The main idea of Model Based Data Management (MBDM) is described in [5] and [6]. MBDM uses a distinguished common reference data model as the hub for mediation. Instead of defining a peer-to-peer translation process, all data models are translated into a reference data model. The reference model is enhanced and extended to define standardized data elements in case of need. The following important cases result:

- Where an information element can be described by a standardized data element already in the common reference data model, no action is needed beyond using this mapping as the unambiguous definition for the semantic interpretation of the information element.
- Where an information element can be described by a group of standardized data element already in the common reference data model, this mapping is used to define unambiguously the semantics of the information element, in this case using the aggregate of the elements. It may be necessary to add new relations among the defining standard data elements in order to generate the aggregation.
- Where an information element has no counterpart in the common reference data model, we have found a new piece of information that needs to be modeled with the common standard, leading to an extension of the standard.
- Where several information elements can be grouped together and mapped to one standardized data element, we have to increase its resolution by replacing the current standardized data element by the group of new, associated data elements. This occurs when the resolution of the common reference data model is not high enough to cope with the new information exchange requirements.

Combinations of these cases are possible. References [5] and [7] give additional detail and describe the underlying methodology of property values, properties, propertied concepts, and associated concepts for different levels of resolution.

3.3 Implementation example

To prove the feasibility of these ideas, VMASC implemented a prototype using Java Web services, which are vendor and platform independent. Implementation details are summarized in the following table.

Table 1: Mediation service implementation details

Domain	Solution	Version
Connectivity	NetBeans	V.3.6
Data Mediation	GLUE	5.0.2
Database	MySQL	V4.0.21
Mapping Software	Altova MapForce	2005 Enterprise Edition
ODBC Driver	MyODBC	3.51.9-win
Web Services	Tomcat Server	V5.0

We implemented a MySQL database and populated the database with the C2IEDM as defined by the version 6.1.5. We then wrapped this database using Web services. We chose the composite services approach, as schematically depicted in Figure 2:

- For each table of interest, there is a Web service allowing insertion, update, and selection of information in an atomic message.
- For each business object, which is defined as a collection of information of interest for the warfighter distributed over more than one table, multiple views were defined. These views are presented as one service, but they make use of the underlying atomic messages. They are called composite messages.
- We implemented "Request" and "Response" Web services to cope with the services to get information or to distribute information using either atomic or composite messages.

```
<?xml version="1.0" encoding="UTF-8" ?>
<wsdl:definitions
…
xmlns:soapenc="http://schemas.xmlsoap.org/soap/encod
ing/"
xmlns:tns1="http://www.w3.org/1999/XMLSchema"
xmlns:wsdl="http://schemas.xmlsoap.org/wsdl/"
xmlns:wsdlsoap="http://schemas.xmlsoap.org/wsdl/soap/
"
xmlns:xsd="http://www.w3.org/2001/XMLSchema">
…
+ <wsdl:types>
+ <wsdl:message name="getMilOrgTypeRequest">
+ <wsdl:message name="getAircraftRequest">
+ <wsdl:message name="getActEffectItemRequest">
+ <wsdl:message name="getActionsRequest">
+ <wsdl:message name="getUnitsRequest">
+ <wsdl:message name="getVehiclesRequest">
+ <wsdl:message name="getOrgMaterialsRequest">
+ <wsdl:message name="getTaskFormationRequest">
+ <wsdl:message name="getMilPostRequest">
+ <wsdl:message name="getLandWeaponryRequest">
+ <wsdl:message name="getActEffectTypeRequest">
+ <wsdl:message name="getLocationRequest">
+ <wsdl:message name="getEquipmentRequest">
<wsdl:message name="getOrganizationsRequest" />
+ <wsdl:message name="getLandWeaponryResponse">
…
+ <wsdl:portType name="WSmethods">
+ <wsdl:binding name="WSmethodsSoapBinding"
type="impl:WSmethods">
+ <wsdl:service name="WSmethodsService">
</wsdl:definitions>
```

Figure 3. WSDL excerpt for mediation service

The Web service approach is not limited to storage and retrieval of information within relational databases. The "Request" and "Response" messages encoded in this WSDL can be used for general information exchange based on push and pull principles, independent of their locations. Unambiguous information exchange between sender and receiver is achieved, using push and pull orders using the "native" XML code of the sender, mapped to the corresponding "Request" and "Response" messages used for the storage and retrieval service. We configure these composite services by mapping them to the BML Who, What, Where, When, and Why messages, based on doctrinal analysis.

There also is a requirement for direct access to the C2IEDM database via a GUI. Our "Configurable Data Access and Display" Web client provides this function by accessing the mediation service. We use the Web service information structure defined within BML to display the current content of the database and the information exchanged. The display formats are based on XML configuration files, which are stored in a database to facilitate their consistent manipulation, so that users can establish what information is to be displayed, how and where.

The overall system diagram, as proposed for the first NATO C-BML limited prototype, is shown in Figure 4. The French C2 planning system SICF and simulation system APLET are shown notionally, along with the US C2 planning system CAPES and the US simulation system JSAF. The overall system thus allows different national C2 systems and simulation systems to share the same data. This example does not include explicit external mediation, as all systems are planned to be C2IEDM compliant. In other words: the mapping of system internal information elements to C2IEDM elements is done internal to the system. If a non-compliant system is to be interfaced, it will be necessary also to use the mediation service. The diagram is for an initial, limited demonstration of the utility of the concept, using only a minimal "core C2IEDM". Data to be exchanged is limited to a simple set of business objects. These business objects are captured in subsets of the C2IEDM similar to those in [10], but they will be described in the form of an XML schema document, allowing part of the consistency checking to be performed automatically:

- Military units and organizations and their platforms
- Organizational structures in the form of an order of battle
- Structuring Tasks in temporal and logical order
- Assigning tasks to organizations at an appropriate level *(e.g.* platform tasks to platforms, company tasks to companies, etc.)

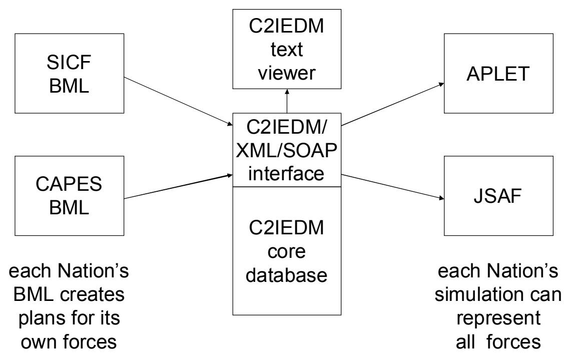

Figure 4: Planned use of services in NATO C-BML

3.4 Necessary migration steps

Data mediation and Web services are powerful tools, but they are not magic; some work still needs to be done to make the system to be attached conformant:

- The candidate system must unambiguously define its input- and output-data structures and how they are mapped to existing input- and output-procedures, which can be invoked from the outside.
- The candidate system must support the input- and output XML structure requested by the supported Web services.

4. Future work

Clearly, the Web service architecture is a step in the right direction to help standardize an effective and efficient data engineering method. However, other critical issues remain for data interoperability. Similarity and alignment are particular problems.

4.1 Similarity

Reference [11] addresses some first thoughts on the need to cope with similarities in data mediation. The current approach is based on the use of common data models, such as the C2IEDM. However, applying data models requires possible associations to be captured explicitly in the model. If two different types of units can be used for the some tasks, both need to have a relationship with these tasks. If two units are affected in the same way, we need explicit relationships. Such relationships come about when predefined relationships are violated by real-world considerations. An artillery unit may suddenly be responsible for military police activities; navy personnel may need to take over army tasks and vice versa; many other examples are possible. To cope with this challenge, we need to be able to define similarity concepts allowing the generalization of data model results, such as

- Similarity of units based on their defining properties (similar weapon systems, task structures, etc.)
- Similarity of units based on executable tasks (who can become active concerning a military tasks to be conducted during an operation)
- Similarity of units based on the effect of a task who will be affected by a task executed in an area, whereby the task can cover the complete PMESII spectrum (Political, Military, Economic, Social, Infrastructure, and Information domain).

While ontologies will help in this area [11,12], we are just beginning to understand their use. Furthermore, the use of an ontology is only the agreement to use a special container; subject matter experts are needed to fill the container.

4.2 Business object and service alignment

In the general application case, aligning the structure of the information also is required. In [5], we introduced associated concepts grouping atomic information together into objects comprising information dealing with a higher business object, such as all information required for an attack order. Composite Web services generally will require such more complex business objects, which imply a need for data alignment so that all information necessary can be provided.

Several options are possible to resolve this sort of problem, for example, using the latest value exchanged earlier to fill in the missing parameters, or to explicitly ask the providing system for additional information, etc. The problem is well known in the process of setting up a federation; however, it has not been dealt with in more detail in the context of Web services for distributed simulation systems.

5. Conclusions

The approach described in this paper helps to solve problems at the technical level of interoperability by simplifying the process of interfacing multiple, interoperating software systems, using a common data model (C2IEDM) with Web services. However, it also generates a new sort of challenge; interoperability problems don't stop with the exchange of bits and bytes, they only begin there. The Levels of Conceptual Interoperability Model [13] shows that challenges on the technical level and syntactical level are well understood. The XBML project is coping with the semantic level, which also is supported by the approach discussed in this paper. The M&S community can and must help the broader information technology community to understand the need for composable services. The approach described here is a first step along that path.

Acknowledgments

Work described in this paper was supported in part by the U.S. Defense Modeling and Simulation Office (DMSO) and the U.S. Joint Forces Command (JFCOM).

The authors express appreciation to their colleagues, industry partners, and students Saikou Diallo, Kevin Dupigny, Michael Hieb, David Perme, Bill Sudnikovich, Bo Sun, and Chuck Turnitsa for their support in implementing and documenting the ideas described in this paper.

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