Proceedings of the 2004 Winter Simulation Conference
R .G. Ingalls, M. D. Rossetti, J. S. Smith, and B. A. Peters, eds.

XML MEDIATION SERVICES UTILIZING MODEL BASED DATA MANAGEMENT

Andreas Tolk

Virginia Modeling Analysis & Simulation Center
College of Engineering and Technology
Old Dominion University
Norfolk, VA 23529, U.S.A.

ABSTRACT

The application of the Extensible Mark-up Language (XML) enabled a new level of interoperability for heterogeneous IT systems. However, although XML enables separation of data definition and data content, it doesn't ensure that data exchanged is interpreted correctly by the receiving system. This motivates data management to support unambiguous definition of data elements for information exchange. Using a common reference model improves this process leading to "model based data management (MBDM)." The results can be used immediately to configure mediation layers integrating services into an overall service oriented architecture. For XML based services, the results of MBDM can be immediately applied in form of an auto-generated XSLT definition used to compose the service without additional modifications with other services. The paper uses the Command and Control Information Exchange Data Model (C2IEDM) – as an example for a common reference model for information exchange – and its potential use in the Global Information Grid (GIG) – as the military example for a service oriented architecture – to integrate web-enabled M&S applications as an example for applying this method.

1 INTRODUCTION

In order to support operations with rapidly changing requirements, service oriented architectures instead of the too inflexible traditional solutions are needed. As an alternative to having a system fulfilling a set of predefined requirements, services fulfilling requirements are identified, composed and orchestrated to fulfill the current users' needs in a ongoing operation. Grid Computing, System-of-Systems Engineering approaches, and the Global Information Grid are examples of this trend. Modeling and Simulation (M&S) is effected in three ways: First, M&S can be used to model and evaluate such ideas before implementing them. Second, M&S uses information technology and is therefore indirectly effected by these developments. Third, M&S must support operations in the form of M&S services. This is true for the military domain as well. The paper focuses on the third domain: How to enable the definition of operationally usable M&S services.

One of the most urgent problems that has to be solved before M&S services in service oriented architectures can become reality is *meaningful semantic data interoperability* for information exchange between the services. While the Extensible Mark-up Language (XML) enables good solutions, XML alone is not sufficient. Within the following sections, an XML based concept will be presented transferring the knowledge of heterogeneous distributed databases into the domain of XML based Mediation Services.

2 SERVICE ORIENTED ARCHITECTURES

Since its introduction, XML has been successfully applied to integrate distributed applications executed on heterogeneous information systems in various domains. The military domain, comprising among others the two domains of Joint Command and Control (JC2) – as defined in (DISA, 2003) – and military simulation systems, used for training, experimentation and support of real operations, follows this trend as well, as shown in the two following sections.

2.1 Joint Command and Control and the Global Information Grid

The main idea of JC2 is that information is obtainable by the Warfighter *Wherever he is, Whatever he does, and Whichever system he uses*. To this end, technically interoperable and conceptually composable services of all application domains have to be brought together in a distributed, heterogeneous information technology environment comprising systems using all sorts of middleware, languages, and hardware concepts. In the commercial world, this idea is supported by Grid computing. In the military world, in particular in the United States, the technical backbone actually chosen to support JC2 is the Global Information Grid (GIG), as defined in the DoD Directive 8100.1 (DoD, 2002). The GIG will be globally interconnected, end-to-end set of information capabilities, associated processes, and personnel for collecting, processing, storing, disseminating and managing information on demand to Warfighters, policy makers, and support personnel. The GIG includes all owned and leased communications and computing systems and services, software (including applications), data, security services, and other associated services necessary to achieve Information Superiority.

Current planning is that the GIG will be Internet Protocol IPv6 based, which means that the service-oriented architecture is likely to be web service-based, leading immediately to an extraordinary role of XML for interoperability. But even if the service architecture will not make use of web services, the role of XML for information exchange between the services has been identified as one of the main interoperability enablers, as XML is used to define the namespaces, the ontologies used by the communities of interest being interested in the exchange of information.

This development led recently to the establishment of the United States Department of Defense (DoD) XML Repository, which is used to collect all relevant XML tag sets used within the responsibility of the US DoD. In addition to the DoD XML Registry, where XML tag sets are simply registered, the U.S. Department of Defense established the "DoD Metadata Registry and Clearinghouse", which objective is given on their website as follows (DoD, 2004):

> *"[The] Defense Information Systems Agency (DISA) is responsible for data services and other data-related infrastructures that promote interoperability and software reuse in the secure, reliable, and networked environment planned for the DoD's Global Information Grid (GIG). The Metadata Registry and Clearinghouse's primary objective is to provide software developers access to data technologies to support DoD mission applications. Through the Metadata Registry and Clearinghouse, software developers can access registered XML data and metadata components, COE database segments, and reference data tables and related meta-data information such as Country Code and US State Code. These data technologies increase the DoD's core capabilities by integrating common data, packaging database servers, implementing transformation media and using Enterprise data services built from "plug-and-play" components and data access components."*

The definition of the DoD Discovery Metadata Specification (DDMS) is part of this plan and a very important step towards data-driven net centric interoperability (DoD, 2003). The metadata is grouped into four categories, namely security, resource, summary content, and format.

- Security Set elements enable the description of security classification and related fields and provide for the specification of security-related attributes and may be used to support access control.
- The Resource category elements provide a way to describe aspects of a data asset that support maintenance, administration, and pedigree of the data asset.
- The Summary Content categories provide the description of concepts and additional contextual aspects of the data asset being tagged and include such elements as subject, description, and coverage.
- The Format elements provide the description of physical attributes of the asset and include elements such as file size, bit-rate or frame-rate, and mime type.

The actual version of the DDMS provides basic Summary Content elements to capture content metadata. Activities are underway to test additional Summary Content elements that provide a more robust, structured method of describing the contents of a resource. Candidates for addition to the Summary Content Category set are Person, Place, Organization, Material, and Event elements.

Furthermore, the idea of establishing common Net Centric Enterprise Services (NCES) is of interest in the context of this paper. NCES offer their functionality to all domains of all communities of interest. These services will comprise, among others:

- Services for Messaging, that is the ability to exchange information among users or applications on the enterprise infrastructure (e.g., Email, Message Oriented Middleware, AOL instant messenger, Wireless Services, Alert Services, and standardized military Message Text Formats).
- Discovery Services, which comprise the processes for obtaining information content or services that exploit metadata descriptions of enterprise IT resources stored in Directories, Registries, and Catalogs. Search engines are a subset of these services.
- Mediation Services are services that help disseminating, translating, aggregating, fusing, or integrating data and associated metadata.
- Security Services comprise capabilities that address vulnerabilities in networks, services, capabilities, or systems.
- Storage Services mean physical and virtual places to host data on the network with varying degrees of persistence (e.g., archiving, content staging).

Other services deal with application management, user support, and more. In the context of this paper, the mediation services will be of particular interest, as MBDM can be directly applied to instantiate these services using XSLT.

2.2 Extensible Modeling and Simulation Framework

While the former introduction was somehow limited to command and control systems, modeling and simulation

(M&S) is an integrated part of this. Operational requirements for embedded training, mission rehearsal, alternative course of action analyses, and after action review tools are mandating the integration of M&S services into command and control systems. This was recognized by experts of George Mason University, Naval Postgraduate School, Old Dominion University, and SAIC resulting in the establishment of the Extensible Modeling and Simulation Framework (XMSF, 2004).

XMSF is intended to contribute to the transformation of the armed forces by contributing to fulfillment of the requirements for software system support derived from future military operations. Concerning the XMSF group, the only software systems that composably scale to worldwide scope utilize Internet and web technologies. The XMSF Reports present the consensus integration of extensive inputs by over 50 experts participating in several workshops. By embracing commercial web technologies as a shared-communications platform and a ubiquitous-delivery framework, DoD M&S can fully leverage mainstream practices for enterprise-wide software development. The use of open web-based standards and technologies doesn't imply that XMSF is limited to the public Internet. The actual Working Definition for XMSF hence is:

> "*The Extensible Modeling and Simulation Framework (XMSF) is defined as a set of web-based technologies and services, applied within an extensible framework, that enables a new generation of modeling & simulation (M&S) applications to emerge, develop and interoperate.*
>
> *Current work showed that Web Services are an appropriate basis for organizing and composing the many necessary capabilities of Web/XML and Internet/Networking needed for M&S applications.*"

The XMSF group is convinced that XML, Internet technologies, and Web Services will enable a new generation of distributed M&S applications to emerge, develop, and interoperate.

Web-based technologies applied within an extensible execution framework are enabling a new generation of modeling and simulation applications to emerge, develop, and interoperate in the commercial world. A bridge is needed between these emerging commercial technologies/standards and defense systems. An extensible XML-based framework can provide a bridge between forthcoming modeling and simulation requirements and open/commercial Web standards.

XMSF proofed to be feasible and applicable within various prototypes, among these a commercial-off-the-shelf based viewer for High-Level-Architecture (HLA) federations – which was successfully integrated into the Joint National Training Capability (JNTC) Network of the J7/Training Directorate and the Distributed Continuous Experimentation Experiment (DCEE) of the J9/Experimentation Directorate of the US Joint Forces Command (JFCOM), – and an XMSF prototype of the US Army's Battle Management Language (BML) called XBML – which is currently evaluated by the NATO Modeling and Simulation Group (NMSG) for coalition application as well as by the Defense Modeling and Simulation Office (DMSO) and JFCOM for use within the prototypical experiments leading towards the GIG, called Horizontal Fusion. Both XMSF prototypes were shown during the I/ITSEC 2003 in Orlando, Florida.

In particular the XBML project as described in (Hieb et al. 2004) contributed to the idea of MBDM in general, and in particular in using the NATO Command and Control Information Exchange Data Model (C2IEDM) as the reference model for Joint Command and Control (JC2); some details will be given in section 5 of this paper.

In summary, showing the necessity for additional metadata for the application domain and the use of DDMS in the domain setting up a repository supporting the Warfighter with reusable, composable, and orchestrated solutions for training, education, experimentation, and support of operations, are the main objectives of this paper: How to apply XML based Mediation Services utilizing Model Based Data Management. These are new ideas not yet applied in the XML Repository or the DDMS, but necessary to be dealt with on the long term.

3 DATA ENGINEERING

The real potential of service oriented architectures lies in the possibility to compose services and to orchestrate their execution enabling new functionality compositions to fulfill the current often changing user requests "on the fly."

To this end, information must be exchangeable between all composed services. In order to do this in a meaningful manner, i.e., not simply exchanging bits and bytes but ensuring the interpretation of data in a consistent way leading to the same information, knowledge, and ultimately awareness within the services and their users, each service has to know *what* data is located *where*, the *meaning* of data and its *context*, and into what *format* the data have to be transformed to be used in respective services composed into a distributed application within the overall system. To generate the answers to these questions is the objective of data administration, data management, data alignment, and data transformation, which can be defined as the building blocks of a new role in the interoperability process: *Data Engineering* (Tolk, 2003). The composing terms are defined as follows:

- Data Administration is the process of managing the information exchange needs that exist between the services, including the 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 is planning, organizing and managing of data by defining and using rules, methods, tools and respective resources to identify, clarify, define and standardize the meaning of data as of their relations.
- Data Alignment ensures that the data to be exchanged 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 of the embedding systems to match the information exchange requirements including the adjustment of the data formats as needed.

In XML environments, and in particular when using web service architectures, these data engineering processes are supported by the respective web-based standards: As every service defines its information exchange needs using XML, many translation problems are solved already by having agreed on this common standard. As the definitions are furthermore published using universal description, discovery, and integration (UDDI) registries, data administration can be directly supported as well. The application of XSLT for data transformation will be dealt with explicitly in a later section. The main intellectual process in the chain of data engineering is the data management process, in which data elements are identified, described, and equivalent expressions of information are mapped to each other.

Within XML environments, data management really becomes tag set management. The challenges are not trivial. They are closely related to problems to be solved in heterogeneous, distributed database environments. In their work on heterogeneous data federations published in (Spaccapietra et al., 1992; Parent and Spaccapietra, 1998), the authors identify the following four classes of conflicts to be solved by data management, which are applicable to semantic XML tag set management as well:

- Semantic Conflicts occur when concepts of the different local schemata do not match exactly, but have to be aggregated or disaggregated. They may only overlap or be subsets of each other, etc.
- Descriptive Conflicts describe homonyms, synonyms, and different names for the same concept, different attributes or slot values for the same concept, etc.
- Heterogeneous Conflicts result from substantially different methodologies being used to describe the concepts.
- Structural Conflicts results from the use of different structures describing the same concept.

Spaccapietra et al. concluded that a generic meta data model comprising only objects and attributes for values and references is needed to support efficient data management. Their model can be mapped surprisingly well to XSLT structures.

As long as the XML schemas that have to be mapped to each other are relatively simple, the task of data management is easy to accomplish. Some current works are already evaluating solutions without a human in the loop, i.e., automatically generated solutions based on the use of intelligent software agents and other technologies (Su et al., 2001). As long as addresses and packing lists have to be mapped, approaches like the referenced one are valuable and should be supported. However, information structures like the Air Task Order (ATO) comprising all air operations of interest within a period of 24 hours, or the Operational Order of a US Army Battalion are too complex to be mapped automatically. Therefore, an alternative approach is necessary.

4 MODEL BASED DATA MANAGEMENT

The two preceding sections describe two apparently contradicting requirements to be solved to enable service-oriented architectures supporting military operations: on the one side, independently developed and published services should be composed and orchestrated in meaningful ways; on the other side, the data structures used to describe military operations are too complicated to be handled, managed and mapped automatically. In other words: How can the information exchange between services be managed ensuring semantic consistency without knowing the services at definition and implementation time?

The traditional way chosen in the recent decades to couple Command and Control Systems facing the same problem was limited to individually designed point-to-point interfaces. Of the several approaches to design configurable interfaces, none was generally accepted so far. However, the use of meta data and meta data models to support configurable mappings is found in many proposals presented during recent workshops and symposia. Therefore, before demonstrating the use of a special reference model in the following section, the general idea to use a reference model for data management and capture the mappings to this data model in the meta data model will be discussed first.

However, before going into the meta model and mapping details, a general motivation will be given. As pointed out before in various papers dealing with interoperability between n systems, the problem of mapping is an n^2 problem: Every time a new system is introduced, the mapping process must done for every potential partner. The use of a common reference model agreed to by all participating systems reduces this effort to an n problem: The alignment must only be done with the reference model, not with each participating partner. If this reference model is used by the data management process, a common information hub is gradually created which increases with each new system.

It should be pointed out that this is a gradually increasing evolutionary process and not a “big bang” solution.

Furthermore, the underlying work of data management and alignment has to be done anyhow; the use of a common, continuously growing and improving reference model only facilitates the conservation of knowledge and supports re-use and continuity.

Before showing what rules should be applied for the extension and modification of the reference model, a general meta model for information modeling for services is introduced. The idea is to use properties describing the data and information, i.e., data in context. The atomic information is stored in the property values, i.e., pure and factual single data points. The properties can be grouped into property concepts, structuring data into a minimal context. Finally, using the idea of relations between these minimal concepts, associated concepts can be established allowing for description of more complex information structures. In summary, the following elements are defined:

- Property values are the allowed values for a specifying characteristic. Of particular interest are enumerations. Within XML, these are the allowed values within the documents. Within relational databases, these are enumeration values for attributes.
- Propertied concepts are a collection of specifying characteristics for an entity in the domain of knowledge. In ontologies using data models to structure its information, this can be mapped to tables and their attributes. Within XML, this is the collection of XML tag sets.
- Associated concepts are semantic entities in which data is given in a broader context. Within data models, these are the views or replication domain sets. In the XML world, this can be mapped to XML documents satisfying the XML schema. In recent publications, such as (Pohl, 2004), similar ideas are referred to as domain-specific ontology layers above the propertied concepts, as these constructs are needed to provide the domain-specific context of the data.

Model Based Data Management (MBDM) uses this information model to cope with the information comprised in the reference data model – in other words: establishing a common information exchange language to be spoken and understood by all participating services.

In practice, the information exchange requirements of the service, i.e., what data has to be provided in what structure as input data for the service and what data has to be expected in what structures as a result of the service execution, have to be mapped to respective data sets of the reference model with the same meaning. Assuming that the resolution of both sides are similar (if this is not the case, it is likely that the wrong reference model is used for the given purpose), the following cases within the mapping process can be observed:

- Extension of property values: the property values of the model to be mapped exceed the property values of the reference model. The reference model must be extended to comprise these additional property values in respective properties.
- Enhancement/refinement of property values: the resolution of the model to be mapped is higher than the resolution of the reference model. The resolution of the reference model has to be increased in order to be able to cope with these higher detailed values.
- Different grouping of property values: although the property values are the same they are used to describe different propertied concepts. This is a semantic conflict, as the "specifying characteristics" are specifying different concepts in both models. This conflict must be resolved by enhancement/refinement of the affected propertied concepts.
- Extension of propertied concepts: a propertied concept of the model to be mapped comprises additional properties. If this doesn't lead to an enhancement/enrichment, the number of properties has to be increased to cope with these information elements.
- Enhancement/refinement of propertied concepts: the resolution of the model to be mapped is higher than the resolution of the reference model. The resolution of the reference model has to be increased. The use of sub-categories is a special form of refinement, in particular when new categories are introduced in the process of enhancement/refinement.
- Different grouping of propertied concepts: although the propertied concepts are the same they are used to describe different associated concepts, which means, they describe different semantic concepts, such as fields necessary to describe an action like an attack, etc. This is a semantic conflict on a higher level. The reference model should be used as the standard.
- Extension of associated concepts: if the reference model has more propertied concepts in the associated concept, the models to be mapped have to be enhanced. If the model to be mapped has more propertied concepts, it must be decided if these are model specific issues or if the semantic concepts of the reference model have to be extended.
- Enhancement/refinement of associated concepts: these conflicts can be solved by increasing the resolution of the reference model by splitting the propertied concepts into new, higher resolution propertied concepts.

To summarize the idea of MBDM, the reference model can be interpreted as the common language. If a model which wants to use this language has a higher resolution, the language must be refined to cope with this new information exchange requirement. The extension and enhancement rules allow this. XML is an appropriate technical mean to capture the models as well as the mapping results.

It is worth mentioning that this doesn't imply any internal details on how services have to handle their information. The reference model is for external information exchange and is not forcing the service implementation to use special methods or structures, as long as these data are aligned with the information exchange requirements.

5 THE COMMAND AND CONTROL INFORMATION EXCHANGE DATA MODEL

It would go beyond the scope of this paper to give an introduction to the Command and Control Information Exchange Data Model (C2IEDM), which is currently defined as Version 6.1. The complete documentation is available online at the MIP website (MIP, 2004). In addition, a tutorial was presented by Dr. Loaiza during the recent C2IEDM workshop (Loaiza, 2004). A short overview including the history can be found in (Tolk, 2004).

To give a very rough overview, the C2IEDM utilizes the concepts of categories and subcategories to model existing information exchange request–such as orders and reports –in military operations and a set of extension rules allowing for extension of the model without having to modify the existing kernel. Table 1 shows the hub concepts of the C2IEDM from which the more detailed concepts are derived by subcategorizing and adding attributes to the sub-concepts.

What is much more of interest in the scope of this paper is the use of the C2IEDM as a common reference model for military services–which includes M&S services–within service oriented architectures, such as the GIG. This general idea is described in more detail in (Pohl, 2004). In the keynote address during the C2IEDM workshop dealing with the applicability of this approach to increase of M&S solution–and in particular to increase Command and Control and M&S interoperability–the slide depicted in Figure 1 was used to show the potential of this solution within the Defense Modeling & Simulation Office (DMSO) and the Defense Information Systems Agency (DISA).

The idea is simple: applications of C2IEDM within the Multilateral Interoperability Program (MIP) of NATO have already proven, that the C2IEDM is mighty and flexible enough to cope with the information exchange requires of the strategic, operational, and tactical systems. To do so, the C2IEDM was used as a reference model and enhanced as described within section 4 of this paper.

Furthermore, the author is convinced that there should be no fundamental difference between data describing a real world military operation and the data describing its simulation. In Germany, the Army Office already uses the C2IEDM to manage the information exchange needs of its simulation models (Zimmermann, 2003). Finally, the XBML project described in (Hieb et al., 2004) uses the C2IEDM exactly for the purpose of exchanging data between tactical systems generating operational orders and the simulation systems executing these orders.

Table 1: C2IEDM Hub Concepts

Concept	Definition
OBJECT-ITEM	An individually identified object that has military significance. Examples are a specific person, a specific item of materiel, a specific geographic feature, a specific coordination measure, or a specific unit.
OBJECT-TYPE	An individually identified class of objects that has military significance. Examples are a type of person (e.g., by rank), a type of materiel (e.g., self-propelled howitzer), a type of facility (e.g., airfield), a type of feature (e.g., restricted fire area), or a type of organization (e.g., armored division).
CAPABILITY	The potential ability to do work, perform a function or mission, achieve an objective, or provide a service.
LOCATION	A specification of position and geometry with respect to a specified horizontal frame of reference and a vertical distance measured from a specified datum. Examples are point, sequence of points, polygonal line, circle, rectangle, ellipse, fan area, polygonal area, sphere, block of space, and cone. LOCATION specifies both location and dimensionality.
ACTION	An activity, or the occurrence of an activity, that may utilize resources and may be focused against an objective. Examples are operation order, operation plan, movement order, movement plan, fire order, fire plan, fire mission, close air support mission, logistics request, event (e.g., incoming unknown aircraft), or incident (e.g., enemy attack).

In summary, the C2IEDM has been identified as a very promising hub to evolve from in order to come to a common reference model in the military domain, and in particular in command and control. The joint and combined nature of C2IEDM is of particular interest for projects as the Joint National Training Capability (JNTC). The advantage of the C2IEDM is not only that it is academically and scientifically sound and well documented, it is also accepted and has been agreed to by the operational specialists and warfighters of the participating nations. Together with its flexibility and extensibility, the C2IEDM is highly recommended for use by the author to initiate a common reference model for information exchange.

How is this related to XML and MBDM? The relation to MDBM is obvious: it is recommended to use C2IEDM as the hub for the common reference model. In order to be able to follow the recommendations of this paper, an XML schema for C2IEDM is needed. Unfortunately, the transformation from (relational) database models can be done following several methods leading to ambiguous results.

Therefore, it must be decided first if the XML schema is needed for unambiguous tag set definition only, or if data

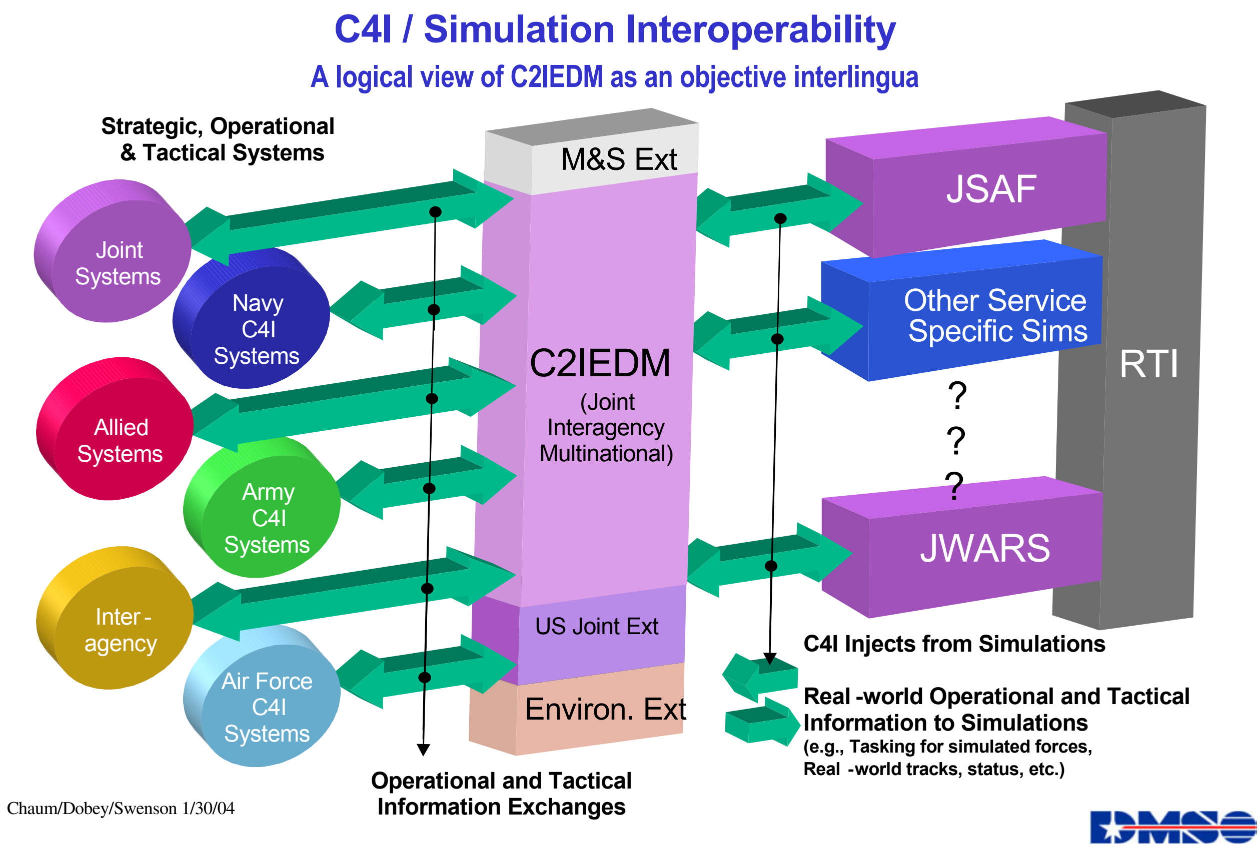

Figure 1: C2IEDM as a General Information Exchange Hub

replication mechanisms should be replaced by XML based protocols, such as web service use, etc. Second, it must be decided if the logical or the physical model is used to generate the tag set. Third, the tag set can be generated automatically or by hand, and finally, the documentation or the data of the information resource dictionary of the tool describing the C2IEDM may be used. All ideas have been successfully applied; however, no standard has been established so far. The works of the Institute of Defense Analysis (IDA) in Alexandria, VA, and the Naval Postgraduate School in Monterey, VA, are groundbreaking in this domain, but other organizations are working on this issue as well.

Anyway, in order to be able to use C2IEDM as a common reference model for MBDM, the following requirements have to be ensured by policy and procedures:

1. The C2IEDM must be established as a common hub for information exchanged;
2. The way to generate XML models must be established as a common method;
3. The way the C2IEDM must be extended and enhanced must be agreed to over the borders of the participating communities of interest.

The author believes that the technical challenges are not as hard to overcome as cultural gaps between the potential users of the model.

6 USING MODEL BASED DATA MANAGEMENT TO INTEGRATE XML BASED SERVICES INTO MILITARY SYSTEM

So far, the methods recommended are only of limited directly applicable use. However, if the various parts are combined in a meaningful way, Model Based Data Management can be directly applied to generate software layers needed to solve the discrepancy between the need for well define information alignment between service in a completely open and arbitrary service oriented environment where services may be composed in ways never expected by the service developers. The idea to use data management to configure a data mediation layer is already coped with in (Krusche and Tolk, 2000).

As already pointed out before, the use of XML to describe the information exchange requirements of a service principally enables any composition of services. The use of common reference models to unambiguously define the tag sets – e.g. using the C2IEDM – ensures the semantic consistency of data exchanged. Together, these ideas can be used to be applied to instantiate mediation services as needed within service oriented architectures using services with various data interpretations.

Generally, mediation services will navigate between individual service interpretations of data, i.e., they translate data from one interpretation into another. If a common reference model is used, mediation services can utilize the data modeling results, which map individual data interpretations to the standardized data elements of the reference model. Thus, mediation services can be applied using mediation schemas to navigate from the individual service interpretation to the standard and vice versa. Within XML environments, this idea can be directly implemented by XSLT configurations.

This works as follows: the data manager uses C2IEDM – or better said its agreed XML representation – to map the data elements of a service to a standardized data element (or a group of standard data elements). If necessary, the reference model has to be extended and enhanced following the rules sketched in section 4 of this paper. After this work is accomplished, a mapping or mediation schema from one internal XML dialect into the C2IEDM XML description is documented which can be used to define the XSLT schema translating between both variants. If the appropriate tool for data management is used, the results can be directly applied to generate the XSLT schema automatically. As these XSLT schemas can be composed as well, a translation layer from one service A to another service B can be generated by combining the mapping of A to C2IEDM with the layer of C2IEDM to B.

In summary, the method described here can gradually instantiate an enhanced and extended C2IEDM, which can become the basis for the common language between the services in an open service oriented architecture, as envisioned in a more general sense in (Pohl, 2004).

7 SUMMARY

The methods outlined in this paper are technically mature enough to be applied. First prototypes demonstrated the feasibility and efficiency of the recommend parts of the solution. What is currently missing is the community-wide will to agree to such a common way to do business. The cultural gaps and not the technical gaps are the main obstacles. However, the work described in this paper has to be done for each integration and interface project anyhow, it is just a question if the community can and will agree on common standards and procedures. As commercial industry partners are supporting more and more of the methods recommended to combine in this paper, the author sees no reason not to follow such a common path into a future of homogenous, requirement-driven support for the Warfighter using heterogeneous IT systems combined into a service oriented architecture based on a common computer grid.

ACKNOWLEDGMENTS

The research work underlying this paper was funded by the Defense Modeling and Simulation Office (DMSO) and General Dynamics – Advanced Information Systems (GD/AIS). The work described in this paper is part of the XMSF initiative conducted by the Naval Postgraduate School, George Mason University, Old Dominion University, and SAIC, and supported by sponsors in government and industry.

REFERENCES

Defense Information Systems Agency (DISA). 2003. The Joint Command and Control Strategy. The Pentagon, Washington, D.C.

Department of Defense (DoD). 2002. DoD Directive 8100.1: Global Information Grid (GIG) Overarching Policy. The Pentagon, Washington, D.C.

Department of Defense (DoD). 2003. Department of Defense Discovery Metadata Specification (DDMS) – Version 1.0. Deputy Assistant Secretary of Defense, The Pentagon, Washington, D.C.

Department of Defense (DoD). 2004. DoD Metadata Registry and Clearinghouse. Available online via <http://xml.dod.mil/mdreg/user/index.cfm> [accessed August 18, 2004]

Hieb, M., Tolk, A., Sudnikovich, W. and Pullen, M. 2004. Developing Battle Management Language into a Web Service. In *Proceedings of the 2004 Spring Simulation Interoperability Workshop*, Washington, D.C.

Krusche, S. and Tolk, A. 2000. Information Processing as a Key Factor for Modern Federations of Combat Information Systems. In *Proceedings of the NATO IST Panel Symposium on New Information Processing Techniques for Military Systems*. NATO Document No. RTO-MP-049. Available online via <http://www.rta.nato.int> [accessed August 18, 2004]

Loaiza, F. 2004. C2IEDM Tutorial. In *Proceedings of the 2004 C2IEDM Workshop*, Fairfax, VA. Available online via <http://www.vmasc.odu. edu/c2iedm/ws2004.html> [accessed August 18, 2004]

MIP. 2004. Multilateral Interoperability Programme website. Available online via <http://www.mip-site. org> [accessed August 18, 2004]

Parent, C. and Spaccapietra, S. 1998. Issues and approaches of database integration. *Communications of the ACM* 41(5): 166-178

Pohl, J. 2004. The Evolution of Intelligent Computer Software and the Semantic Web. In *Proceedings of the 16th International Conference on Systems Research, Informatics and Cybernetics; Intelligent Software Systems for the New Infostructure*, Baden-Baden, Germany, ISBN 1-894613-41-4

Spaccapietra, S., Parent, C. and Dupont, Y. 1992. Model Independent Assertions for Integration of Heterogeneous Schemas. *Very Large Database (VLDB) Journal* 1(1): 81-126

Su, H., Kuno, H. and Rundensteiner, E. 2001. Automating the transformation of XML documents. In *Proceeding of the third international workshop on Web information and data management; Session: Web Information Integration*, 68-75

Tolk, A. 2003. Common Data Administration, Data Management, and Data Alignment as a Necessary Requirement for Coupling C4ISR Systems and M&S Systems. *Journal on Information & Security* 12(2): 164-174

Tolk, A. 2004. Moving towards a Lingua Franca for M&S and C3I – Developments concerning the C2IEDM. In *Proceedings of the 2004 Euro Simulation Interoperability Workshop*, Edinburgh

XMSF. 2004. Extensible M&S Framework website. Available online via <`http://www. movesinstitute. org/xmsf`> (accessed August 18, 2004)

Zimmermann, B. 2003. Integrated Army Modelling and Simulation Data Network. In *Proceedings of the NATO M&S Group Conference on C3I and Modelling and Simulation Interoperability*. NATO Document No. RTO-MP-123. Available online via <`http://www.rta.nato.int`> [accessed August 18, 2004]

AUTHOR BIOGRAPHY

ANDREAS TOLK is Senior Research Scientist at the Virginia Modeling Analysis and Simulation Center (VMASC) of Old Dominion University in Norfolk, VA. He holds a M.S. in Computer Science and a Ph.D. in Applied Operations Research, both from the University of the Federal Armed Forces of Germany in Munich. He is interested in the application of open standards to establish common IT infrastructure for command and control and simulation systems to enable all military application domains, in particular the support of real operations. He is a member of SCS and SISO. His e-mail address is <`atolk@odu.edu`>.