The Levels of Conceptual Interoperability Model

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Keywords:
Interoperability, Conceptual Modeling, Data Federations, Net-Centric Data Strategy

ABSTRACT: *Interoperability of systems is not a cookie-cutter-function. There are various levels of interoperability between two systems ranging from no interoperability to full interoperability. In the technical domain, various models for levels of interoperability already exist and are used successfully to determine the degree of interoperability between information technology systems. However, such models are not yet established in the domain of conceptual modeling. This paper introduces a general model dealing with various levels of conceptual interoperability that goes beyond the technical reference models for interoperable solutions.*

The model is intended to become a bridge between the conceptual design and the technical design for implementation, integration, or federation. It should also contribute to the standardization of V&V procedures as well as to the documentation of systems that are designed to be federated. It is furthermore a framework to determine in the early stages of the federation development process whether meaningful interoperability between systems is possible. To this end, the scope of the model goes beyond the implementation level of actual standards, which focus on the exchange of data using standardized formats and interfaces. Another practical application of the model is, that it enhances the only recently published DoD Net-Centric Data Strategy for the Global Information Grid (GIG) and is directly applicable to derive necessary metadata to reach the DoD Data Goal to "enable Data to be understandable."

1 Introduction

The underlying idea of this paper is that interoperability goes beyond the technical implementations. In order to achieve meaningful interoperability of simulation systems on the technical level, composability of the underlying conceptual models is a necessary requirement. The proposed way to achieve this is the use of a layered approach. The application domain given here is data and meta data, as this domain is applicable to M&S as well as to C4I system. Actual approaches and standards are in general limited to the implementation level, i.e., when targeting composability they aim too short. The authors try to establish a layered model, the Levels of Conceptual Interoperability Model (LCIM), to bridge the gap between implementation focused methods and conceptual models and show, how and why these is of vital interest to the C4I community as well. The model is kept as simple as possible on purpose to facilitate discussions between all communities not limited to technical experts only.

2 A Traditional View of Levels of Information Systems Interoperability

The use of different levels or layers of interoperability is not a uniquely new idea. Within the technical domain, various models of interoperability exist. One of the matured models in this context is the "Levels of Information Systems' Interoperability (LISI)" model within the U.S. [1]. Additionally, in the international field, defined and documented within the context of the NATO C3 Technical Architecture (NC3TA) [2], the NC3TA Reference Model for Interoperability (NMI) is used. Both of them are used in the study groups of SISO dealing with interoperability between C4I systems and M&S systems.

In both cases, the idea is to establish measures of merit to evaluate the degree of interoperability between two existing systems by applying standard means. The identified layers for technical interoperability can be mapped onto each other.

LISI distinguishes the following layers:

- **Isolated Systems**
  No physical connection exists
- **Connected Systems**
  Homogeneous product exchange is possible
- **Distributed Systems**
  Heterogeneous product exchange is possible
- **Integrated Systems**
  Shared applications and shared data
- **Universal Systems**
  Enterprise wide shared systems

NMI is similar structured, using the following degrees:

- **No Data Exchange**
  No physical connection exists
- **Unstructured Data Exchange**
  Exchange of human-interpretable, unstructured data (free text)

Structured Data Exchange

Exchange of human-interpretable structured data intended for manual and/or automated handling, but requires manual compilation, receipt, and/or message dispatch

- **Seamless Sharing of Data**
  Automated data sharing within systems based on a common exchange model
- **Seamless Sharing of Information**
  Universal interpretation of information through cooperative data processing

Both examples focus on the exchange of information in form of data between the systems and the ability to invoke procedures and use the other systems functionality.

Many of the papers and proposals to increase interoperability between M&S systems are following this approach. Data consistency has been identified as a critical need to reach an interoperable solution. The definition of a common ontology and introducing standardized shared data elements has been the topic of various contributions to the interoperability discussions. An overview is given in the paper “Bridging the Data Gap” [3].

However, although the unambiguous interpretation of the meaning of the data to be interchanged between two systems is crucial and necessary to gain interoperability, it is not sufficient. This fact has been neglected in the past while problems of aggregation and disaggregation, multiple-level resolution, and not-aligned data- and object models where of the main concern. Many people now believe, that new techniques and methods using new concepts like the extensible markup language (XML) will enable the creating of a “Rosetta stone” of data interoperability solving the underlying problem.

The only recently published DoD Net-Centric Data Strategy [4] focuses on the establishment of metadata standards instead of looking for standardized shared data elements. Establishment of metadata standards allows a much more open use of data within the systems as not the data itself have to be standardized, but the interpretation of the data in the given context. The approach therefore is comparable to the establishment of a data federation as proposed in [3], as the problem to define a standard common federated object and related mapping rules equals the problem to establish a standard description in form of standardized metadata.

The following simple model shows that these efforts are necessary, but not sufficient. While in the world of state-of-the-art C4ISR many problems are solved by the new techniques, M&S system deal *per definition* with the agile component of the battlefield. In order to reach “meaningful interoperability,” not even the standard methods of software engineering for dynamic systems are sufficient. *“Meaningful interoperability” of simulation systems requires composable models on the conceptual level.*

To cope with the problem, the conceptual models of the M&S systems have to be aligned. The problem is that actual solutions are targeting the implementation level, while alignment on the conceptual level is what is really needed. While the next chapter introduces the model of conceptual levels of interoperability, the following chapters deal with the implications of these findings.

3 The Levels of Conceptual Interoperability

This section introduces the Levels of Conceptual Interoperability Model (LCIM). Similar to the technical approaches, five levels of interoperability are defined. The focus lies on the data to be interchanged and the interface documentation, which is available. The layers are defined as follows:

- **Level 0 - System Specific Data**
  No interoperability between two systems. Data is used within each system in a proprietary way with no sharing. The component (or application) is a black box.
- **Level 1 – Documented Data**
  Data is documented using a common protocol,

such as the Object Model Template defined by the HLA and is accessible via interfaces. The component is a black box with an interface.

- **Level 2 – Aligned Static Data**
  Data is documented using a common reference model based on a common ontology, i.e., the meaning of the data is unambiguously described. This is also possible by using metadata standards as proposed in [4] or by using standard reference models, such as the Realtime Platform Reference Federation Object Model (RPR-FOM). The component is a black box with a standard interface.
- **Level 3 – Aligned Dynamic Data**
  The use of the data within the federate/ component is well defined using standard software engineering methods such as UML. This shows the use of data within the otherwise unknown "black box behind the interface," also known as white box.
- **Level 4 – Harmonized Data**
  Semantic connections between data that are not related concerning the execution code is made obvious by documenting the conceptual model underlying the component. It is not only a white box; because beyond the implemented parts of the concept the important relations that are NOT captured in the implementation are captured.

The following figure displays the five levels of conceptual interoperability.

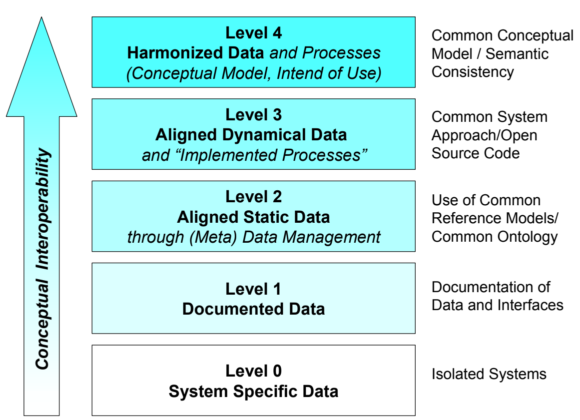

Figure 1: *LCIM*

The following subsections will elaborate every level in a little bit more detail. *(Refer to the annex of this paper for recent developments.)*

3.1 System Specific Data (LCIM Level 0)

The initial level of data interoperability is the proprietary use of data within the systems. Data are seen as a resource of the system, not meant to be shared with other users.

In particular, data being hard-coded in the source code of the system belong to this group. Fortunately, more and more systems are using input files or databases to initialize the values of their parameters, however, in legacy systems many of these parameters are still hidden in the code. This is in particular true for hard-coded behavior of components, thresholds, etc.

However, even when using input files or databases, the data is often system specific, and often poorly documented. Comma separated lists and excel spreadsheets with meaningless column names are more often the rule than the exception. In particular, systems that have been developed as prototypes or demonstrations and than were taken over into the use phase show this syndrome. In addition, little changes in the system during exercises or experiments are often to be documented and improved later, which then never happens.

In summary, a lot of valuable functionality exists that is driven by data that is not sufficiently documented. The utility of these systems is therefore limited to the original users, and if the data cannot be lifted to the next level, the utilization is furthermore limited to the original application.

3.2 Documented Data (LCIM Level 1)

As soon as all the hidden data are known and the data are documented in an unambiguous manner, the first interoperability level deserving this name is reached.

Systems with documented data can at least principally be federated, as the documentation of data is the necessary requirement for interface definitions.

Based on the documentation of data, system builders can establish mapping layers to interconnect the data with external sources, such as the Runtime Infrastructure of High Level Architecture federations, the data replication mechanisms of actual C4I systems, or future sources such as the GIG.

3.3 Aligned Static Data (LCIM Level 2)

Many interoperability papers and articles of the recent past focus on the alignment of data and/or object models as one of the necessary requirements for interoperability. The development of a common ontology, common or shared reference models, and standardized data elements is the main mean.

This is without a doubt a necessary requirement, but it is not sufficient. LCIM Level 2 insures that everybody has the same thing in mind when talking about it. The use of standardized references to talk about information elements to be exchanged is solving three of the four conflicts that have to be taken care of when merging different data sources. The four classes are (following the schema defined in [5] and already introduced to SISO in [3]):

- **Semantic Conflicts**:
  The 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**:
  There are homonyms, synonyms, different names for the same concept, different attributes or slot values for the same concept, etc.
- **Heterogeneous Conflicts**:
  The methodologies being used to describe the concepts differ substantially, e.g., one concept is described in the Unified Modeling Language (UML), the other in the relational data model description methodology IDEF1X.
- **Structural Conflicts**:
  Different structures are used to describe the same concept, e.g., in one local schema an attribute is used, in the other schema a reference to another concept is used to describe the same part of the view of "reality".

Reference models on LCIM Level 2 avoid descriptive conflicts (as the reference models used to refer to them are unambiguous, i.e., using individual terms for individual concepts of the ontology), heterogeneous conflicts as long as the underlying describing methods are equally mighty in capturing the concepts, and structural conflicts. Furthermore, reference models help to deal with the challenge of semantic conflicts. The solution proposed in [3] and other papers dealing with this problem is to use high-resolution reference models and explicit aggregation functions, which have to be included in the reference standard.

However, even when using the common ontology, or the common reference model including all mapping standards, this is not sufficient for conceptual interoperability. The reason is that the same object with the same meaning can be used completely differently – or, what can be worse in practice, slightly differently – in the participating simulation systems. This dynamical aspect is coped with in the next section.

3.4 Aligned Dynamic Data (LCIM Level 3)

The mature discipline of system science describes a system from three different viewpoints:

- A **Static View** of the system, its sub-systems and components,
- A **Functional View** focusing on the interfaces and the data flow between the components,
- A **Dynamical View** looking at the state change of the overall system over time (temporal and causal behavior)

These views where directly supported by some earlier object-oriented design patterns, e.g., as supported by Rumbaugh et al's view of object-oriented modeling and design [6]. LCIM Level 2 is supporting interoperability in the static as well as in the functional view; however, the dynamic behavior of the system is not covered.

It seems to be obvious that two systems with the same components, the same interfaces, and the same data to be exchanged via these interfaces between these components can easily instantiate different behaviors. Although similar or even identical when looking at the information exchange, the systems can be quite different. The same is true for a federate within a federation. Just to agree on the way to exchange data in a given way (e.g. using DIS protocols or the HLA) using an agreed template (like PDU's or the FOM) doesn't ensure the interoperability of the underlying simulators or simulations.

The effects are well known. In the DIS world, the resulting problems were often referred to as "fair fight" problems. The differences in the simulators beyond the level of interoperability reachable by DIS led to the advantage of one opponent leading to very strange effects during the execution. The constructive view and some implications are given in [7], where the term "structural variances" is defined.

The recommended way to overcome these problems is to make the behavior of the components visible to the integrator. There are many ways to do this. One of the most promising solutions is to use the "lingua franca" of computer engineers to cope with this issue, the Unified Modeling Language. Another option is the use of the Extensible Markup Language (XML), in particular the Simulation Reference Markup Language (SRML) [8], to deal with this issue.

In any case, the documentation of the use of the data within the system and the resulting state change of the system as the result of this information exchange is necessary to reach the third level of the LCIM.

It is perceived that in particular the simulation system producing industry will have reservations against this "open source" like view of the world, however, if we do not learn how to cope with behavior representations of components, we will never be able to reach the next level of interoperability. Fortunately, the requirement already has been formulated within the context of Verification & Validation (V&V). V&V will not be possible without a proper documentation of the behavior of the system and its sub-components. In particular when dealing with non-linear, highly interrelated, complex systems, the behavior presentation is vital to V&V as well as to interoperability on the dynamic level.

3.5 Harmonized Data (LCIM Level 4)

Unfortunately, even when having well defined information exchange definitions (LCIM Level 2) and perfectly documented use within the system (LCIM Level 3) there is still room for not interoperable solutions.

The reason lies in the foundation of modeling and simulation. A simulation system is an executable form of a model. A model is a subset of reality. When doing the modeling, parts of the real world and its relations are left out. This, however, leads to interoperability problems if these not modeled relations are necessary to ensure interoperability.

The only instance of the M&S development process coping with this issue is the conceptual model. The conceptual model describes which part of the real world is modeled under which constraints, and sometimes even more important, which parts are not modeled.

Why this can lead to interoperability problems is visualized using the following example: Two models are used to model a future tank. Both models are using a common reference model to define attrition (e.g. by probability of hit (Ph) and probability of kill (Pk) for given constraints). They are also in agreement about modeling reconnaissance (e.g. by infra-red spectrums of the tank). The introduction of a new type of armor will influence both models, as the new armor reduces the probability to be killed and influences the infrared spectrum of the tank. The semantic interrelation of Pk and infrared can only be coped with on this fourth level of interoperability.

While this example seems to be trivial, please extrapolate it to the actual use of high-resolution models to evaluate future weapon systems. Only with the use of a very appropriate conceptual model, can the consistency can be checked. To the knowledge of the author, the tool support to evaluate this kind of interoperability can only be described by the adjective "limited." Only the conceptual model can deal with this issue. It cannot be solved by technical solutions.

3.6 LCIM and Metrics

The LCIM allows the federation developer to define metrics for the degree of conceptual alignment of models. Generally, the higher this alignment is, the easier is the integration of these models into a federation. However, not all simulation application domains require the same degree of alignment.

If the integration of a model into a federation is needed only to provide the data produced by the model, i.e., a sequential model is applied for the execution, and the processes of this model do not interact with other processes, there is no need for alignment above LCIM Level 2. The initialization of models, the correlation of terrain and positions, the calculation of the impact of a single point in time, etc. can serve as examples.

Training and testing environments, such as computer assisted exercises and functionality training with the system-in-the-loop, require fair fights and fair testing. It is often the case that the likelihood of the values of the parameters and data to be exchanged are known. The main objective of the federation is to deliver a simulated test bed or training environment producing outputs to react on and accepting inputs to react. In this environment, alignment on LCIM Level 3 will often be sufficient.

Finally, if the federation is used to evaluate parametric variations of potential solutions, or if the system is used to find quasi-optimal solutions to real-world problems, LCIM Level 4 is necessary. The application domains analysis, experimentation, and course-of-action analysis fall into this category.

The metrics on each level can be furthermore refined by applying additional methods, which already are accepted and successfully applied in sub-domains, e.g., the data alignment metrics for (C4I) data models and (M&S) object models as proposed in [9].

4 Implications for Conceptual Models

While the first levels of interoperability in the LCIM can be supported by engineering methods (data modeling and object modeling, metadata modeling, system modeling using UML, software-engineering and re-engineering, etc.), conceptual modeling is still considered to be an art and is hardly supported by methods and tools.

In order to support the view on data interoperability given in this paper, the documentation and publication of conceptual models based on standardized methods, which may have to be enhanced to be able to cope with all related issues, is mandatory.

In order to cope with effects above LCIM Level 3, the conceptual model has to examine the semantic relations between participating attributes, even – or better said in particular – when they are not interrelated by shared code later on.

During the recent SCS-SISO Panel discussion on Priorities for M&S Standards [10], Zeigler stated explicitly in his presentation that to ensure interoperability between systems *standardization must be aimed at the modeling level,* i.e., the standardized level must be higher than the programming level standards applied actually. For "meaningful interoperability," the sharing of standardized data via standardized protocol, such as the Distributed Interactive Simulation (DIS) protocol or the High Level Architecture (HLA) standard, is necessary, but not sufficient. The coordination of the underlying conceptual models, the harmonization of the operational ideas simulated, is the real crux to create interoperable solutions. Instead of only standardizing the information exchange requirements, the underlying modeled cause-effect-chains must be coordinated.

Concerning the authors, Platform Independent Models (PIM) as defined in the Model Driven Architecture (MDA) are promising candidates to fulfill this requirement. It should be possible to enhance software engineering standards, such as the UML, on which the MDA is based, to cope with the special interests of M&S in a way that a coherent approach, as depicted in the paper "Avoiding another Green Elephant" [11] to ensure interoperability from the first ideas on the design board.

It should be clear by now that interoperability on LCIM Level 4 only can be reached be aligned conceptual models. This means that even open source solutions, assuming well-documented code, can only ensure LCIM Level 3 interoperability. Without the blueprint of the conceptual model documented in a standardized manner, composable models and interoperable systems cannot be purposefully engineered. This blueprint can be drawn by engineers, but the design must be done by the experts in the domain.

5 Implications for the DoD Net-Centric Data Strategy

There is another operational domain that is highly influenced by the findings gained with the reference model, namely the integration of M&S functionality into operational C4ISR systems to enable decision support. The authors are convinced that the integration of M&S functionality into operational systems will enable the next order-of-magnitude improvement in IT support for Joint Command and Control (JC2). It is said that a picture says more than 1,000 words. It is assumed by the authors that an executable simulation will say more than 1,000 pictures. While recent C4I systems supported the decision maker with orders and data streams, the actual C4I world is supporting a common operational picture (COP), which increased JC2 efficiency measurably. However, it is still hard to capture the commanders intend within a COP. What needed is the agility of M&S systems.

Recent C4I systems used the Common Operating Environment (COE) of the U.S. DoD or NATO as the underlying C4I framework. Future system will use the Global Information Grid (GIG) [12].

To ensure data usability, data mining, metadata administration, etc., the U.S. DoD only recently established the Net-Centric Data Strategy [4]. However, there are much more standards to be taken into account, such as the ISO 11179 standard for the specification of data and metadata elements [13] and related standards being dealt with in the so-called Diffuse Project, a project dealing with data, metadata, repositories, behavior representation, etc. under aegis of the European community.

Furthermore, these standards are focusing again on the component and interface level, i.e., they can only support interoperability up to LCIM Level 2. In order to support decision support by simulation systems, a new set of behavior description is needed to increase this level at least up to LCIM Level 3, or may be on the long term to Level 4.

Within the following sub-sections, we will deal with all these aspects and will give some hints on how to solve related problems.

5.1 The Global Information Grid

As already mentioned in earlier papers, such as [11], one of the main shortcomings of C4ISR/Simulation interoperability is the de facto limitation to interface solutions, as both communities came up with their own concepts for data, architectures, procedures, infrastructures, etc. The new era of web-service based IT can change this, as the C4ISR as well as the M&S community are reorienting themselves in the light of the maturing of these techniques. One of the leading edge projects the authors are both involved in is the Extensible M&S Framework (XMSF) [14]. Other projects have been presented in recent SIW as well; a short overview is given in [11].

The C4ISR community is actually looking towards the definition and prototypical implementation of the Global Information Grid (GIG). The GIG will become the backbone of future C4ISR application and will not be limited to U.S. DoD applications. What makes the GIG so interesting is not only the technology, but also a paradigm shift in data dissemination. Information management and distribution will be radically changed. Instead of pushing data to consumers, the pull principle will be applied. In addition, data will be made available in the moment it is obtained, i.e., in raw form. As soon as value added products of these data are available, they will be posted as well. The network becomes a general infosphere, a pool from which everybody can draw what he needs.

The actual implementation prototypes are evaluating the applicability of the Joint Tactical Radio System (JTRS) as the main GIG transportation layer, comprising ground based, airborne, and satellite components; however, the innovation interesting for distributed simulation system developers is the fact that the communication will be Internet Protocol (IP) based. Actually, it is planed to use IP version 6. Furthermore, by working on end-to-end information assurance, the transportation layer is considered to be "black," i.e., unclassified information can be distributed via the same net classified information is using.

The following section deals with the first management and procedure aspects to enable this concept in the light of data interoperability. While the GIG already will support M&S by opening a new era of data availability and obtainability to feed defense simulation systems with real data, the actual proposals are only targeting data interoperability on LCIM Level 2 by introducing metadata, tag set, and name space management, which is necessary, but not sufficient in the light of agile and dynamical components, such as M&S functions, which require behavior representation.

5.2 The DoD Net-Centric Data Strategy

The DoD Net-Centric Data Strategy [4] defines the core of the actual DoD Data Vision as follows:

"The core of the net-centric environment is the data that enables effective decisions. In this context, data implies all data assets such as system files, databases, documents, official electronic records, images, audio files, web sites, and data access services…"

The data vision comprises also the objective to make data available as soon as possible using the push principle. It is furthermore predicated on several key elements:

- Communities of Interest (COI) are established to address organization and maintenance of data. These COI are responsible for the data, there is no central node for standardization, but coordination and alignment will be the guiding principles.
- Metadata, which provide a way to describe data assets and the use of registries, catalogs, and shared spaces, which are mechanisms to store data and information about data, will be established by the COI. Only the structure and the standards will be coordinated.
- GIG Enterprise Services (GES) are provided to enable data tagging, sharing, searching, and retrieving. Net-Centric Enterprise Services (NCES) will provide limited functionality until GES will be able to take over the responsibility.

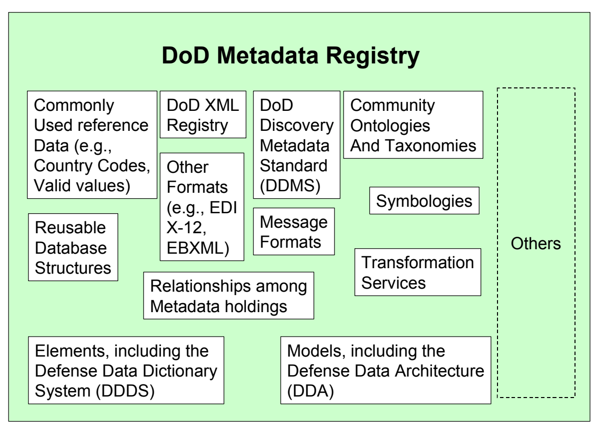

Figure 2: *Contents of the DoD Metadata Registry [4]*

The DoD Metadata Registry schematically shown in Figure 2, which is based on the already mentioned ISO 11170 specification for metadata registries, plays a central role. The actual plan incorporates the variety of existing metadata resources such as the DoD XML Registry, the Defense Data Dictionary Systems, and others. Many of these interim solutions have been evaluated for supporting M&S interoperability, in particular for C4ISR/Simulation Interoperability.

Mediation is the key GES capability. It relies on the availability of metadata. Mediation resolves differences in the name, structure, and representation of data. This, however, is exactly the methodology in sum detail evaluated in [3] and referred to as Aligned Static Data on the LCIM Level 2. Even the resolved differences can be found in [3] as well as in sub-section 3.3 of this paper.

If the GIG wants to support the M&S functionality to be integrated for decision support "on the fly" in case of need, more powerful behavior representation methods than those to be actually established in the DoD Metadata Registry will be needed. Among the candidates needing a closer examination are

- The Web service description language (WSDL),
- The DARPA Agent Markup Language (DAML), and
- The Simulation Reference Markup Language (SRML).

This list is neither complete nor exclusive. What is important is the necessity to include behavior representation of agile, dynamic systems.

5.3 Supporting the DoD Data Goals

There are seven DoD Data Goals included in the Net-Centric Data Strategy [4]:

- Goal 1: Make Data Visible
- Goal 2: Make Data Accessible
- Goal 3: Institutionalize Data Management
- Goal 4: Enable Data to be Understandable
- Goal 5: Enable Data to be trusted
- Goal 6: Support Data Interoperability
- Goal 7: Be Responsive to User Needs

The LCIM supports goals 1, 2, 3, 4, and 6. Much of this support is obvious, so we focus on goal 4, as the necessity for enhanced conceptual modeling to enable data to be understandable may not visible to the decision makers and designers of future systems without further explanation.

The definition of *Goal 4: Enable Data to be Understandable* given in [4] is the following:

"Users and applications can comprehend the data, both structurally and semantically, and readily determine how data may be used for their specific needs."

In order to understand data in the sense of initialization data or data to be exchanged during the execution of a simulation system, the M&S community has to reach at least LCIM Level 3. This can be done by additional agreements (the federation agreement of Distributed Continuous Experimentation Environment actually is nearly 40 pages long) or by adapting additional standards and documentation rules. It is assumed that M&S will use metadata registries as well, however, the model introduced in section 2 of this paper implies that these repositories have to be mightier than those under consideration for the GIG are right now. In order for an M&S application to comprehend the data, more is needed than data and metadata management as envisioned in the Net-Centric Data Strategy. As M&S applications will use the GIG data in the future, improvements are necessary.

The situation is even more complicated when thinking about M&S components as resources to be found within the GIG. It is assumed that M&S functionality will be included to support the Warfighter of the future with decision support capabilities, such as after action review, alternative courses of action analyses, and much more. To enable the Warfighter (and the software that supports him) to comprehend the M&S functionality, the constraints, requirements, etc., these components have to be described unambiguously, and this is a new class of data (which may be comparable to web service definitions, but the research of using M&S functions as web services is still in its infancy).

To summarize, the LCIM can support understanding the data goals better and fulfilling them effectively and efficiently. The introduction of M&S functionality will introduce new requirements concerning the data and the Net-Centric Data Management. However, analyzing the requirements for IT support for future military operations, C4I systems have to become as agile as today's M&S systems are, hence, the lessons actually learned in the M&S domain will be applicable – and don't have to be re-learned – in the C4ISR domain.

6 Implications for SISO

The Simulation Interoperability Standards Organization (SISO) is dedicated to the promotion of modeling and simulation interoperability and reuse for the benefit of diverse M&S communities, including developers, procurers, and users, world-wide. Therefore, the issues dealt with are of direct concern for SISO. Various forums directly have to become involved in the application and enhancement, among them

- Validation, Verification, and Accreditation
- Command, Control, Communications, Computers, and Intelligence
- Research, Development, and Engineering
- Communications, Frameworks, and Infrastructure
- Distributed Simulation Development Process

There are legions of open standards being more or less applicable to problems and sub-problems, which have to be analyzed concerning the applicability for M&S. A list of these standards can be detailed and mapped on to the LCIM. The first set of standards concern the lowest levels of LCIM, examples of annotation or data levels are

- Resource Description Framework (RDF)
- Specification and Standardization of Data Elements (ISO 11179)
- Specification for a data descriptive file for information interchange (ISO 8211)
- XML Metadata Interchange (XMI)

Next to follow are the tools needed to facilitate searching:

- Dublin Core Metadata for Resource Discovery
- Global Information Locator Service (GILS)
- Open Archives Initiative (OAI)
- Open Information Model (OIM)

The last set of standards strike at the most difficult problem of assigning meaning and facilitating sharing

- Ontology Inference Layer (OIL)
- OWL Web Ontology Language

This list is neither complete nor exclusive.

A common thread running through all these example technologies is the need to add value to and precisely define the meanings of terms in order to support a machine reasoning paradigm enabling automated supported for the search of interoperable solutions. In can be argued that most of these technology ideas are trying to bridge the gap between the LCIM's levels 2 and 3, which is the step from interoperability (exchanging of data) to composability (using the data in the same context). This gap today is bridged by the great flexibility of the human mind with its limitless capacity to apply the required ontology to the material at hand and reason towards a valid representation. The common theme in the LCIM is that a shift away from platform dependent data level solutions toward a platform independent (PIM), model level view of the world is needed to achieve automatic assurance of working solutions or machine support when looking for applicable components; in other words the shift from technical interoperability towards conceptual composability is needed.

This shift is going to be a difficult shift to make since the ideas are relatively new. However, the Model Driven Architecture (MDA) and the approach recommended in [11] is a promising candidate to become the crutch needed to move toward this paradigm shift. The MDA advocates a platform independent model view of the solution space and encapsulates all transformations of the solution in terms of models which once validated are then transformed into platform specific solutions. Implementation driven solutions are replaced by model driven methods that consider the conceptual level much more intensely.

It is likely that specific M&S enhancements will be necessary to ensure applicability, like identifying specifics for M&S components when being used as web services, etc. In order to reach this, R&D in this direction has to be aligned, and SISO is the place to do this, e.g. in form of discussions and study groups.

7 Summary

The Level of Conceptual Interoperability Model (LCIM) is applicable to discuss many SISO relevant issues. In particular, the LCIM shows that the actual approach of the Net-Centric Data Strategy is necessary but not sufficient for M&S applications.

Generally speaking, ***meaningful interoperability of simulation systems on the implementation level***, such as needed within federations or components within a wider system of systems approach, such as the GIG, ***requires composability of the underlying conceptual models!***

Actual approaches, such as the Distributed Interactive Simulation (DIS) protocol or the High Level Architecture (HLA) are mainly targeting at the implementation level, therefore they fall short when aiming at composability. We cannot fix conceptual problems with implementation-driven solutions. The LCIM was developed to enable the evaluation and discussion of conceptual discrepancies.

The implications, however, are not only of academic interest. In order to improve the interoperability within federations of simulation systems as well as in order to ensure the integration of future M&S systems into the GIG – or into GIG like structures within the M&S domain –, the requirements stated in this paper must be met by future enhancements of the DoD Metadata

Registry and related projects. Furthermore, the validation of conceptual model composability should become a step in the next iteration of the Federation Development and Execution Process (FEDEP), as only this requirements ensures meaningful interoperability within the resulting federation or system of systems. First steps into this direction have been made.

SISO can – and must – play a central role to align the efforts of the M&S community to support these processes.

8 References

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The following section has been published as section 2 of paper 04S-SIW-009:
"Composable Mission Spaces and M&S Repositories - Applicability of Open Standards,"
Andreas Tolk,
to be presented on the 2004 Spring Simulation Interoperability Workshop,
Washington, D.C., April 2004:

Levels of Conceptual Interoperability

During the Fall Simulation Interoperability Workshop 2003, Tolk and Muguira introduced a model dealing with the various levels of interoperability [Tolk & Muguira, 2003]. Using this model, Tolk and Muguira showed that **meaningful interoperability on the implementation level requires composability on the conceptual level.** This circumstance was already pointed out before in slightly different wording, when Ziegler stressed that **meaningful interoperability cannot be achieved by standards targeting the implementation level** [Zeigler, 2003].

While the view on the various levels of conceptual interoperability given in [Tolk & Muguira, 2003] was very data centric, the author developed the model further in order to cope more efficient with dynamic issues. The improvements have been influenced by ongoing studies at the University of the Federal Armed Forces in Munich, Germany, dealing with the applicability of linguistic research results to cope with issues like ontology driven interoperable solutions. A good overview on these efforts is given in [Hofmann, 2003]. Hofmann introduced a pragmatic level above the semantic level, meaning that the receiver of the information not only understand its meaning (semantic level), but also knows what to do with it. Together with the findings summarized in [Tolk & Muguira, 2003], this led to the definition of the enhanced version of the Levels of Conceptual Interoperability Model (LCIM).

- On level 0, *no connection* is established at all.
- On level 1, the *technical* level, physical connectivity is established allowing bits and bytes to be exchange.
- On level two, the *syntactical* level, *data* can be exchanged in standardized formats, i.e., the same protocols and formats are supported.
- On level 3, the *semantic* level, not only data but also its contexts, i.e. *information*, can be exchanged. The unambiguous meaning of data is defined by common reference models.
- On level 4, the *pragmatic/dynamical* level, information and its use and applicability, i.e. *knowledge*, can be exchanged. The applicability of information is here defined in an unambiguous form.
- On level 5, the *conceptual* level, a common view of the world is established, i.e. an *epistemology*.[1] This level not only comprises the implemented knowledge, but also the interrelations between these elements.

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[1] Epistemology in this context deals with the theory of knowledge, especially with reference to its limits and validity. It is a typology of the ontology, i.e., a way to formalize the knowledge about a given domain.