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Filling in the Ontology Space for Coalition Battle Management Language

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ABSTRACT: The Coalition Battle Management Language is a language for representing and exchanging plans, orders, and reports across live, constructive and robotic forces in multi-service, multi-national and multi-organizational operations. Standardization efforts in the Simulation Interoperability Standards Organization seek to define this language through three parallel activities: (1) specify a sufficient data model to unambiguously define a set of orders using the Joint Command, Control, and Consultation Information Exchange Data Model (JC3IEDM) as a starting point; (2) develop a formal grammar (lexicon and production rules) to formalize the definition of orders, requests, and reports; (3) develop a formal battle management ontology to enable conceptual interoperability across software systems. This paper focuses on the third activity, development of a formal battle management ontology, by describing an ontology space for potential technical approaches. An ontology space is a notional three dimensional space with qualitative axes representing: (1) the Ontological Spectrum; (2) the Levels of Conceptual Interoperability Model; and (3) candidate representation sources that can contribute to conceptual interoperability for the Coalition Battle Management Language. The first dimension is the Ontological Spectrum, which shows increasing levels of semantic formalism using various ontology representation artifacts. The second dimension is the Levels of Conceptual Interoperability Model, which describes varying levels of interoperability that can be attained across systems. The third dimension is a survey of likely candidate sources to provide the representation elements required for interoperability. This third dimension will be further described in relation to the artifact capabilities of the second dimension and the conceptual interoperability capabilities of the first dimension to highlight what is possible for ontological representation in C-BML with existing sources, and what needs to be added. The paper identifies requirements for building the ontology artifacts (starting with a controlled vocabulary) for conceptual interoperability, the highest level described in the LCIM, and gives a path ahead for increasingly logical artifacts.

1 Introduction

The Coalition Battle Management Language (C-BML) is a language for representing and exchanging plans, orders, and reports across live, constructive and robotic forces in multi-service, multi-national and multi-organizational operations. Standardization efforts in the Simulation Interoperability Standards Organization seek to define this language through three parallel activities: (1) specify a sufficient data model to unambiguously define a set of orders using the Joint Command, Control, and Consultation Information Exchange Data Model (JC3IEDM) as a starting point; (2) develop a formal grammar (lexicon and production rules) to formalize the definition of orders, requests, and reports; (3) develop a formal battle management ontology to enable conceptual interoperability across software systems. Significant efforts are underway across these three activities. Overall C-BML standardization concepts are described in [Blais *et al.* 2005; Galvin *et al.* 2006]. General BML grammar development is described in [Schade & Hieb 2006a; Schade & Hieb 2006b; Davis & Blais 2006; Diallo & Tolk 2007]. Preliminary C-BML ontology explorations are presented in [Blais et al. 2006]. This paper seeks to contribute to the ontology development activity by describing an ontology space that identifies several dimensions for consideration and evaluation of technical approaches as the work moves forward.

2 What is Ontology Space?

To give context to development of a C-BML ontology, we define an ontology space as a notional three dimensional space with qualitative axes representing: (1) the Ontological Spectrum; (2) the Levels of Conceptual Interoperability Model (LCIM); and (3) candidate representation sources that can contribute to conceptual interoperability for the Coalition Battle Management Language. A good working definition of ontology as it relates to interoperability (for projects such as C-BML), comes from [Welty 2003]: "an artifact that represents some portion of the world in a fashion that can be processed by a machine." By applying such an artifact, the meaning of data and information that originates within one system can be made explicit, so that it may be accessed without ambiguity by another system. The origin of such data or information is not necessarily fabricated out of an information system, but may be terms and phrases that come from a community of use (such as military doctrine, command terms, and so on).

The goal of SISO products is to enhance interoperability between M&S systems, and also between C2 systems (especially for projects such as C-BML which are strongly rooted in the SISO C2/M&S community). Therefore, the goal of this paper is to show how ontology representation methods can be applied to C-BML in order to enhance the interoperability between systems that speak in the language of C-BML.

Methods for representing ontological understanding of information do not come in one form only, as the open definition of [Welty 2003] suggests – they can exist in any number of forms. In order to assess the different types of ontology products, the ontological spectrum is introduced in Section 3 below. Furthermore, in order to evaluate interoperability, to see if we have enough of it, or if more is needed (for instance), there must be a criterion. That criterion is the LCIM, introduced in Section 4 below.

If these two criteria are placed against each other, there emerges a qualitative grid showing which methods of ontology representation are suited for which levels of interoperability – both in originating systems and also in interoperability-assisting systems (examples could include, but are not limited to, central reference models and translation systems).

It is, perhaps, naïve to think that any single source of information will be sufficient to cover the entire vast domain of military (or other) modeling and simulation. As we are discussing C-BML, and its domain of representing (unambiguously) and exchanging information concerning the battlespace, this is the domain that we are looking to measure with our 2-dimensional grid described above. At each intersecting point in the grid, there will be a number of different sources of ontological information, perhaps existing in one of the forms described within the ontological spectrum, but more likely spanning two or more related levels within that spectrum, and with incomplete coverage of those levels. Each of these sources, however, will not cover all of the information required for describing all the rich information exchangeable via the C-BML method, so we can see that a third dimension presents itself – one of domain coverage.

We will cover, in the following three sections, first the ontological spectrum, then the levels of conceptual interoperability model, and finally a number of likely candidates to contribute some of the knowledge required to construct an ontological representation for C-BML. Finally, an assessment of the intersection of these three surveys gives an emerging view of the ontology space for C-BML.

3 The Ontological Spectrum

The ontological spectrum is described by [Obrst 2006] as spanning the following six levels of semantic representation:

- *Controlled Vocabularies* enumerate all allowed terms and their meanings completely. All terms are well-defined and controlled by a common registration authority. They deal with terms.
- *Weak Taxonomies* are simple groupings of terms into like categories. Many web directories are organized along these lines, where the divisions within the taxonomy are based on gross differences in meaning, and no attempt at hierarchical structure within a category is attempted.

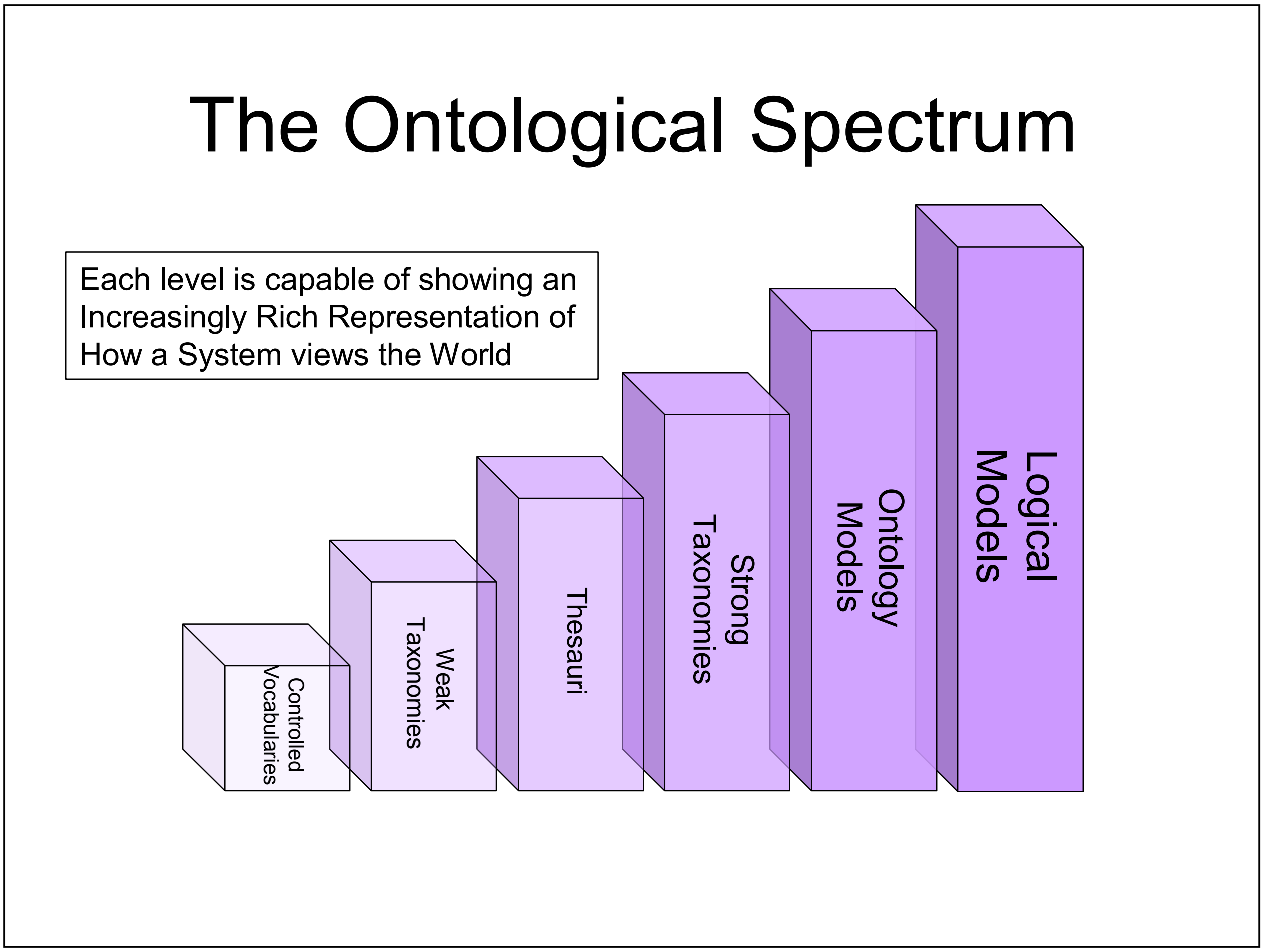


Figure 1 - The Ontological Spectrum

- *Thesauri* are controlled vocabularies arranged in a known order and structured so that equivalence, homographic, hierarchical (with regards to broader-than or narrower-than terms), and associative relationships among terms are displayed clearly and identified by standardized relationship indicators. They deal with terms.
- *Strong Taxonomies* are hierarchical structures of classifications for terms, where the hierarchy is based on the subsumption of conceptual meaning. The root node applies to all objects; nodes below the root are classifications that are more specific. Taxonomies can also be used to introduce the idea of concepts and implementing terms.
- *Ontologies* are formalized specifications of conceptualizations. Ontologies describe all the information captured in thesauri and taxonomies plus contain additional relationships and rules, such as assertions and restrictions, within the domain concept. They focus on contextual information (meaning/semantics of data), which are the concepts, but also have references to the structure/syntax of data, which are the terms.
- *Logical Models* are the strongest semantics in the ontological spectrum supporting construction of theorems and proofs. First order logic and modal logic are examples.

Existing and emerging Semantic Web standards are well-aligned with the levels of semantics in the ontological spectrum. The Semantic Web seeks to achieve unambiguous definition of information describing content of the Web to make the information more understandable, accessible and processable by machines [Daconta *et al.* 2003]. In particular, these ideas directly support the C-BML effort.

There are numerous representation schemes for ontologies, various formats for capturing ontological information, and a variety of ways to display ontologies. This is a very active research field, and only a few standards are seeing widespread adoption.

4 Levels of Conceptual Interoperability

The integration of information systems is an effort that can take place at a number of different levels, based on the information exchange requirements among multiple systems. Efforts have been made to describe the level of integration that can be achieved between systems, such as the Levels of Information Systems Interoperability [C4ISR 1998] and the NATO Model for Interoperability [NATO 2003]; but these have concentrated on the technical aspects of integration, as well as the socio-informatics aspect of having integrated systems being part of an enterprise. In order to achieve true information visibility across systems, however, there must be a higher, conceptual level of exchange than is possible with a technical coupling alone; that is, the information itself must be integrated. To support the understanding and study of such interoperability efforts, the Virginia Modeling, Analysis, and Simulation Center (VMASC) defined the Levels of Conceptual Interoperability Model (LCIM).

4.1 The Model

The LCIM is a model, which in its current form consists of seven different layers, that represents a hierarchy of capability for representing the meaning (increasingly conceptual in nature, as the model layers are ascended) of information passed between systems. A similar hierarchical structure exists within the ISO Open System Interconnection (OSI) model, but the chief difference is that the ISO/OSI seven layer model has a number of different hierarchical layers, where each new layer targets a different perspective for exchange. With the LCIM, each new hierarchical layer shows an increased capability for information exchange through added formalization in the representation of conceptual meaning in the information being exchanged. However, the focus of providing meaningful representation between systems remains the same.

Tolk and Muguira presented the first version of the LCIM during a Simulation Interoperability Workshop [Tolk and Muguira 2003]. Other scientists and researchers have subsequently refined the model and contributed to its current form. In particular [Page 2004] suggested defining composability as the realm of the model and interoperability as the realm of the software implementation of the model. In addition, that work introduced the notion of integratability when dealing with the hardware and configuration side of connectivity. Following this categorization, we recommend the following distinctions when dealing with interoperation:

- Integratability applies to the physical/technical realms of connectivity between systems, which includes hardware and firmware, protocols, etc.
- Interoperability applies to the software and implementation details of interoperations; this includes exchange of data elements based on a common data interpretation.
- Composability applies to the alignment of issues on the modeling level. The underlying models are purposeful abstractions of reality used for the conceptualization being implemented by the resulting simulation systems.

[Figure 2] shows the current LCIM including the ideas described in [Page 2004] and added layers for modeling/abstraction, simulation/implementation, and network/connectivity. The currently used LCIM version distinguishes between the following levels:

- Level 0: Stand-alone systems have No Interoperability.
- Level 1: On the level of Technical Interoperability, a communication protocol exists for exchanging data between participating systems. On this level, a communication infrastructure is established allowing the exchange of bits and bytes; the underlying networks and communication protocols are unambiguously defined.
- Level 2: The Syntactic Interoperability level introduces a common structure to exchange information; i.e., a common data format is applied. On this level, a common protocol to structure the data is used and the format of the information exchange is unambiguously defined.
- Level 3: If a common information exchange reference model is used, the level of Semantic Interoperability is reached. On this level, the meaning of the data is shared; the content of the information exchange requests are unambiguously defined.
- Level 4: Pragmatic Interoperability is reached when the interoperating systems are aware of each other's methods and procedures. In other words, the use of the data – or the context of its application – is understood by the participating systems; the context in which the information is exchanged is unambiguously defined.
- Level 5: As a system operates on data over time, the states of that system changes along with the assumptions and constraints that affect its data interchange. At the Dynamic Interoperability level, interoperating systems are able to comprehend and take advantage of the state changes that occur in the assumptions and constraints that each other makes over time. Simply stated, the effect of the information exchange within the participating systems is unambiguously defined.

- Level 6: Finally, if the conceptual models – i.e., the assumptions and constraints of the "purposeful abstraction of reality" – are aligned, the highest level of interoperability is reached: Conceptual Interoperability. This requires that conceptual models be fully documented based on engineering methods enabling their interpretation and evaluation by other engineers and potentially by machines as well. In other words, we need a "fully specified but implementation independent model" as requested in [Davis and Anderson 2003], and not just a text describing the conceptual idea.

A detailed description of each layer, and what is expected of systems interoperating at such a layer, is provided in the following subsections.

4.2 Technical

Technical Interoperability refers to a state where the interoperating systems have a technical connection (in which the exchange of digital signals is possible) with each other (perhaps over a network). Systems that have attained only the technical level are most likely connected via a network, using a compatible method for exchanging digital data, but there is no predefined

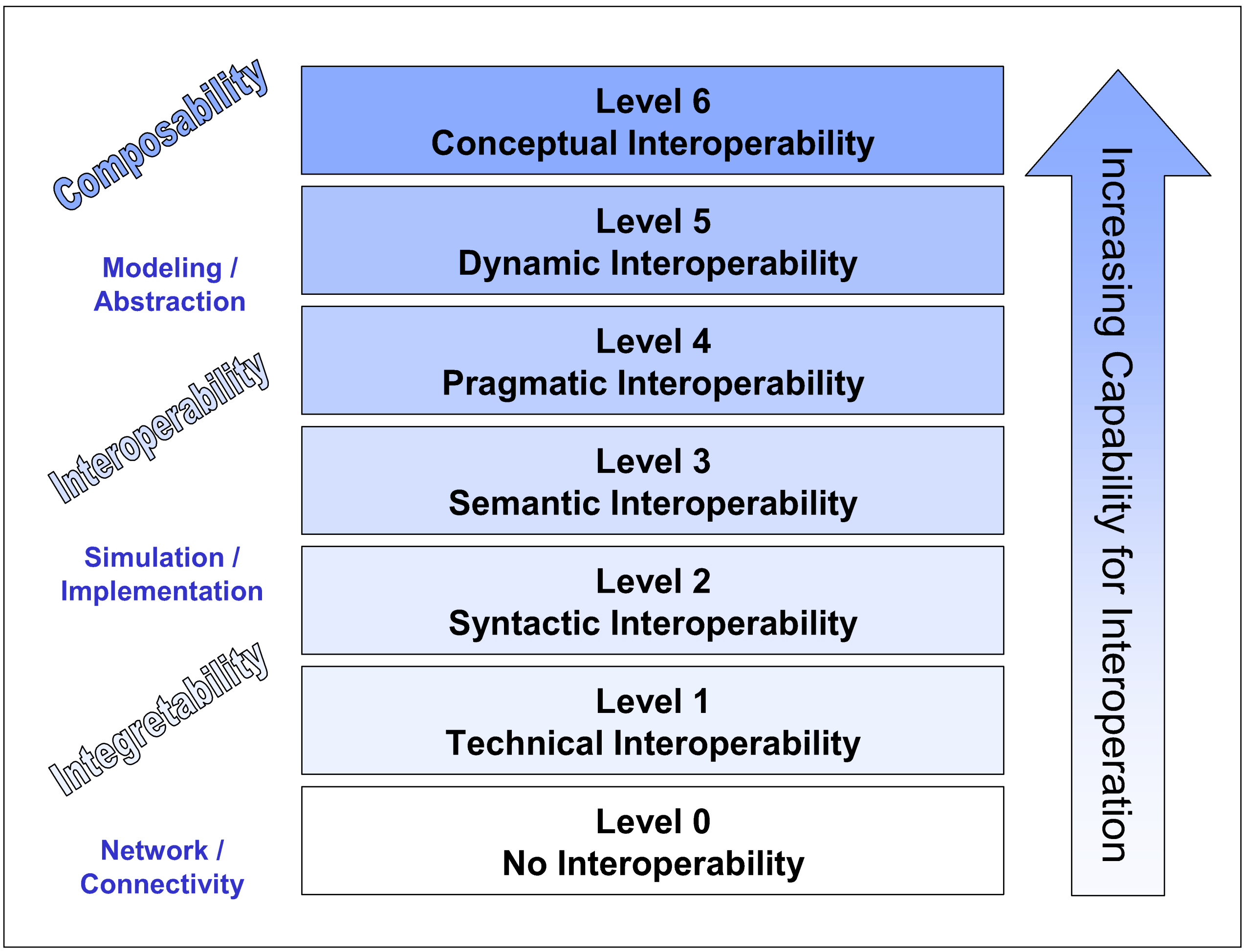


Figure 2 - Levels of Conceptual Interoperability Model

structure or protocol for the exchange of such data. An example of a technological method whereby technical interoperability is achieved is TCP/IP, or a similar network protocol that allows for the exchange of digital data.

The LCIM owes its origins to the challenge of bringing together federations of simulation systems, which is the focus of the original work done at VMASC. However, the model has proven to be useful in a general sense to many system-of-system integration efforts, and has been referred to in the final report on System-of-Systems Interoperability evaluations conducted by the Carnegie Mellon University [Morris et al., 2004].

4.3 Syntactic

Syntactic interoperability is the next level up from the simplest of technical connections. At this layer, there is a basic syntax agreed to by systems for data exchange. By syntactic understanding, the intention is to refer to a system's ability to exchange the right forms of data, and in the right order. Syntax for communications (linguistics) is the proper ordering within an agreed upon format. An accepted alphabet and the means for forming words out of that alphabet is a good example [Crystal, 1997]. Systems interoperating at this level have the capability to exchange data within the correct protocol, and to form elements into the correct format to satisfy that protocol, but there is not yet an agreed upon meaning for those elements.

Technologies and methods that have the capacity to accommodate syntactic interoperability include the High Level Architecture, CORBA, SOAP, XML tagging, and various other service connecting technologies that would mandate a particular sequence and ordering of connectivity, without mandating any level of understanding of the data being passed across the connections.

4.4 Semantic

The semantic level of interoperability is the first within the LCIM to deal with meaning. Meaning here refers to the connection that exists between a data element (as a symbol, or word) and what it represents to the system that uses it. In natural language, semantics refers to the shared meaning of words that allow for their use within sentences to express communication. This of course assumes that the basic type of building blocks to construct the symbols and the ordering of those symbols already exist – and this is what is prescribed in the syntactic level.

Systems that are interoperating at this level exchange data elements that have a shared meaning (as defined above). Following the example of using natural language communications we can see that the semantic level is where we can begin to construct sentences not only following syntax rules for proper order, but with the meaning of the words being known, so that those sentences are also semantically (or meaningfully) correct [Crystal, 1997].

4.5 Pragmatic

The ability for systems to enjoy a shared meaning for an exchange data element is limited by the fact that such an element can have different aspects, based on the context within which the employing system uses the element. Context here is defined as both the state that the system is in at the time the element is being employed, as well as a specification of the particular system process that employing the element. If any of these things change (either the system state, or the particular process), then the meaning of the element might be different. At the pragmatic level of interoperability, this context is understood, and will lead to the specific-aspect meaning of a data element being employed.

When systems operate at the pragmatic level they will have a method of referencing each other's context, and an indication of how an exchanged information element will be employed, to know the particular meaning of the element for a particular case of interchange. To enable existing systems to operate at this pragmatic level of interoperability, there must be some way for the systems involved to represent the specifics of meaning – in short, some sort of ontological representation method.

General technologies and methods that could be developed to support pragmatic interoperability include ontology specification mechanisms (such as OWL), Unified Modeling Language (UML), and perhaps the Model Driven Architecture [Miller and Mukerji 2003]. A specific case for using a core ontological representation that can accommodate all of the required specific meaning definitions for system-to-system interchange is given in [Doerr, et.al, 2003]. An example of early results of such an application is given in [Tolk *et al.*, 2005].

4.6 Dynamic

The previous level of interoperability assumed that the means of specifying context and the aspect of meaning within that context are sufficient to describe all the understanding that a target system needs to know, in order to make sufficient understanding of the data. However this makes the assumption that the possible contexts (the state of the system and state of processes within that system) will be static enough to have a knowable list of aspects of meaning. For a dynamic system (that is, a system with an unknowable number of permutations of context), it is not likely to be possible to enumerate all potential aspects of meaning for data elements. In this case, it is required that meaning can be defined and described between systems, just as context must be definable and describable. Interoperability at this level is referred to as Dynamic Interoperability.

Pragmatic interoperability (level 4) assumes that a source system will be able to provide the data required by a target system, and that the parameters and characteristics of that data are well understood. But what if the necessary view or description of those parameters and characteristics change? Rather than having a single ontology to convey understanding of all data elements within a data model, there exists the need to have a system, or method for conveying the particular instance of an agile ontology to an interoperating system.

An example of a method for capturing and describing a dynamic system would be a complete UML representation. The Object Management Group is currently working towards modeling specifications for a specialized method that can be used for this purpose [MOF 2002]. Not only are the data and system elements modeled, but there is also the idea of dynamism as seen through the changes to the relationships between system and data elements over time, as the topology of the overall system changes with internal state variation.

4.7 Conceptual

We now reach the final level described within the LCIM; namely, Conceptual Interoperability. This level defines communications between systems that entails full sharing of strong semantics as described in the Ontological Spectrum. True conceptual interoperability or communication is only available when complete understanding of the concepts inherent within the target and source data models is shared, or shareable, between the data models. This understanding implies not only the data, and their meaning, but also the associated relationships, defining parameters, and composing assumptions behind that data; in short, the full logical formalism describing the shared concepts.

Currently there are a couple of approaches that begin to define, in a rigorous fashion, a system and its underlying assumptions and concepts. One such method is in the relatively new extension of UML, the Systems Modeling Language (SysML). SysML is a method that is intended to allow enterprise architects to have the ability to define all of the interoperating systems within their architecture [SysML, 2005].

5 Candidates for C-BML Ontology

In [Turnitsa and Tolk 2006] the contributing layers of a total C-BML architecture were presented [Figure 3 - Five Layers of BML]. The connection between the traditional BML triangle components of Protocol, Representation and Doctrine was shown to have gaps (filled by a grammar and an ontology), and this view has been repeated within the findings of the original SISO C-BML study group, and also the ongoing SISO C-BML product development group. The interrelation of all of the five layers was also described in [Turnitsa and Tolk 2006], showing how the overall architecture not only requires all five layers, but also that the successful representation of any one of those layers within the architecture is reliant on the surrounding layers.

In satisfying the requirement for an ontological representation within C-BML, there are several candidate sources of information that might prove to be useful. These are described in brief here, with a short description of the source and what role it can play within the ontological spectrum for C-BML. It is not likely that any one of these sources will be sufficient for completely satisfying the requirement for an ontological representation. It is also equally unlikely that any ontological representation that satisfies one community of use will be sufficient for additional communities. In order to answer these open questions, more research will be needed, but candidate sources presented here may serve as a starting point.

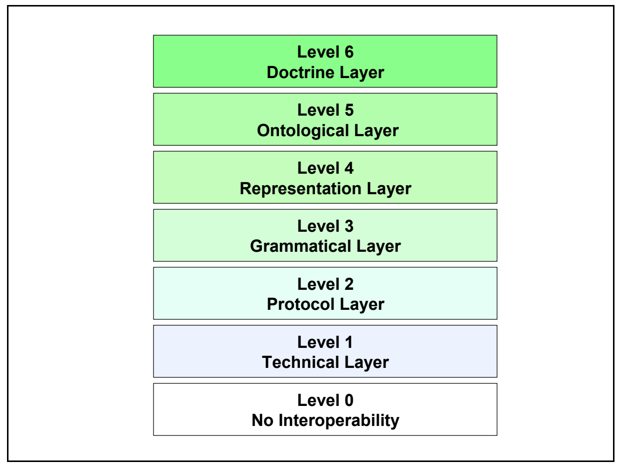


Figure 3 - Five Layers of BML

5.1 JC3IEDM Defined Enumerations

The JC3IEDM, under constant development by the Multilateral Interoperability Programme (MIP), has been identified by the C-BML PDG (and a parallel Joint Battle Management Language project funded by the U.S. Department of Defense) to provide the underlying data structure needed for the Representation layer of the BML architecture. Not only is the model very good at representing the sorts of things required for C-BML tasking and reporting, but it has international support and has been in continuous development and refinement for over 20 years. Earlier SISO workshop papers [Turnitsa *et al.*, 2004] give a good overview of the C2IEDM (precursor to the JC3IEDM, following the same principles), and its role within C-BML [Tolk and Blais 2005].

The documentation for the model, presented by the MIP [Multilateral Interoperability Programme 2006], is accompanied by several annexes. One of these, Annex E, is a listing of all the enumerated domain values for the JC3IEDM. These values are cross-indexed by the named domain that they serve, and also by the particular attribute within an entity that they supply meaning for. Along with the listed values, a definition and outside referential source is given for each term. Finally, for technical assistance, the physical value and enumeration codes from a recommended instance of the data model are included to ensure consistency.

The information provided by these enumerations, as well as their organization, satisfies several artifact types from the ontological spectrum. A controlled vocabulary is immediately apparent, but also some others. A simple taxonomy is satisfied, if it is understood that the enumerations can be organized into the general spaces of the JC3IEDM, such as OBJECT_TYPE, OBJECT_ITEM, ACTION_TASK, ACTION_EVENT, etc. Additionally, the combination of the enumerations with the listed domain that they can satisfy provides a synonym relationship (in a morphological sense), and the relationships of the data model when combined with the domain listings give broader-than and narrower-than relationships, thereby meeting the criteria for thesaurus-level semantics. But, as all of the domain values are organized at the term level, and all relationships are at that level, none of the more expressive artifacts of the ontological spectrum are satisfied by the JC3IEDM enumerations.

5.2 Swedish Defence Conceptual Modeling Framework-Ontology

The Swedish Defence Research Agency has published a conceptual model dealing with the defense domain, covering command and control, modeling and simulation, operations, and other aspects. The conceptual model, as presented, does not have an extensive glossary of terms, but does give an in-depth description of a taxonomical structure of such an information repository, as well as explaining how such a repository would be employed. The method employed to categorize the information in taxonomical format is based on the upper level categories of SUMO (the Suggested Upper Merged Ontology) project. Categorical organization at this level, while at first appearing to be more in the realm of metaphysics than in the realm of defense modeling and simulation, is important to capture the many nuances that can exist between representation of information within one system and another system (for instance, is a tank a weapon system, or is it equipment for a unit).

5.3 Joint Warfare Simulation Object Library

The Joint Warfare Simulation Object Library (JWSOL) is a collection of classes and objects, derived from object-oriented analysis and design techniques, designed to represent the domain of joint operations in terms of three categories – *agent*, *physical* and *event* [Conwell 1995]:

- *Agent* includes all actors within the domain – primarily humans and organizations – that are capable of pursuing goals.
- *Physical* includes military assets such as equipment and materiel, physical infrastructure (military and civilian) and the environment.
- *Event* includes military events, civilian events, and environmental phenomena. Also included in the *Event* category are agreed-to environmental objects such as shipping lanes, borders, and airways.

The categories are related to each other, and also to a top-level node (command and control), as can be seen in the high level taxonomy of [Figure 4 - JWSOL Top Level Taxonomy].

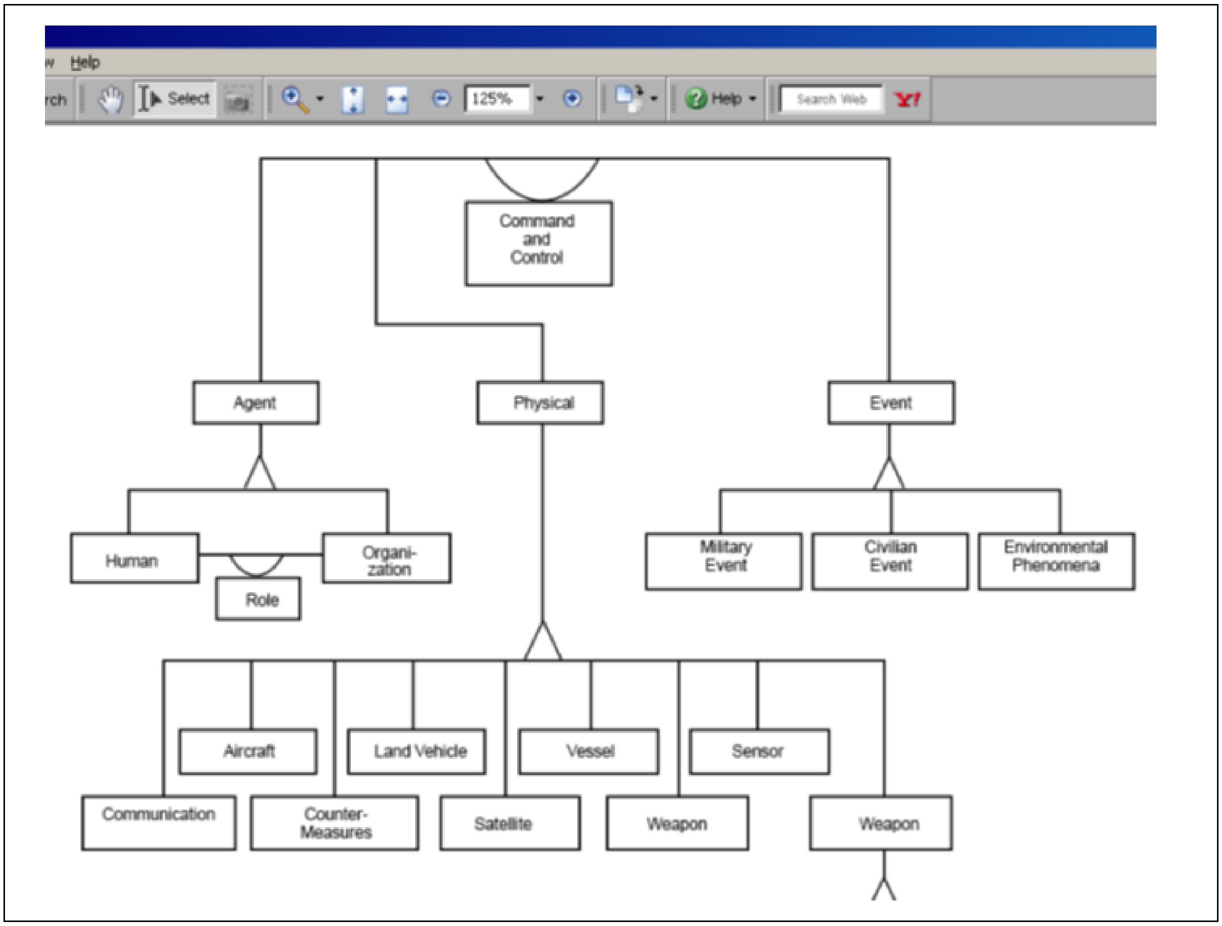


Figure 4 - JWSOL Top Level Taxonomy

The decisions that went into organizing the JWSOL were based on ontological and epistemological considerations based on the organization goals of the knowledge being represented. The contextual perspective was that of the Commander in Chief of a Joint Operation. The knowledge itself is presented in the form of a Strong Taxonomy (by the terms of the Ontological Spectrum), but could easily satisfy any of the lower forms (Thesaurus, Weak Taxonomy, Controlled Vocabulary).

One of the weaknesses of the JWSOL for C-BML is that of its perspective. C-BML, as a standard being developed under the umbrella of SISO, is intended to support international interoperability of simulations, C2 systems, and robotic forces. Because of this, there will be a need to accommodate national perspectives and national terminologies (and the epistemological connection between such terminologies and the conceptualization found within the layers of C-BML). Some of these things are not supported by the JWSOL, a fact that is also true of the JC3IEDM.

5.4 NATO Glossary of Terms and Definitions

The NATO Glossary of Terms and Definitions, also known as NATO publication AAP6 [NATO 2005], is a glossary of terms common to NATO operations and systems, provided in English and French. It was prepared by the NATO Standardization Agency to give a reference of terms in the two official languages of NATO, along with their definitions.

The glossary is a good example of a very rich controlled vocabulary; however, it does not rise above that level in the Ontological Spectrum. It is the reference for many of the terms within both the JC3IEDM and the NATO C2 Conceptual Model, so as a complementary artifact it might be quite useful for C-BML.

5.5 NATO C2 Conceptual Model

The Systems Analysis and Studies Group of NATO Research and Technology produced a conceptual model dealing with a number of issues pertinent to C2. Many of these issues, of course, are in the same domain as C-BML. The product of the study group, "Exploring New Command and Control Concepts and Capabilities," [NATO RTA] presents a conceptual model of the C2 domain, as well as some assessment of each area.

The conceptual model concentrates mainly on factors contributing to command and control – leadership, communications, makeup of units, personal characteristics of team members, etc. It has a very good glossary of terms concerning the various factors in these areas, as well as presenting a very good hierarchy, giving a taxonomical approach towards organizing the factors. It exhibits some of the features of a weak taxonomy, and some of the features of a strong taxonomy, but in trying to fulfill the role of the latter, it is incomplete. From the ontological spectrum, some of the features of a thesaurus are notoriously lacking – terms of equivalence, and relationships of broader-than and narrower-than definition. The terms of equivalence would certainly be helpful where an underlying concept might be portrayed in either of the official NATO languages – English or French. A portion of the hierarchy can be seen in figure 4.

NATO C2 Conceptual Model Hierarchy

- C2 Approach
  - Command Approach
  - Control Approach
  - Leadership
  - Command Skills
  - Control Skills
- Quality of Acton
- Decision Making
- Quality of Decisions
- Entity Characteristics and Behavior
  - Behavior
  - Individual Cognitive Abilities
  - Personality and Values
  - Physical Abilities
  - State
- Sensemaking
  - Mental Models
  - Quality of Awareness
  - Quality of Shared Awareness
  - Quality of Plan
  - Quality of understanding

(continued)

Figure 5 - NATO C2 Conceptual Model Hierarchy (partial listing)

As a potential source of ontological information for C-BML, the NATO C2 Conceptual Model is a very good candidate in the knowledge area of command and control structure. It is somewhat weaker in terms of exhibiting effects and tasks on the battlefield, but is not meant to address those areas of the domain.

5.6 Environment, Tasks and Symbology

Finally, in our survey of likely sources of information that might contribute to a C-BML ontology representation, mention should be made of a number of smaller (in terms of domain narrowness) sources that can contribute to an overall representation. The areas under consideration here are specific groupings of knowledge concerning a specialized region of the C-BML domain.

In the domain area of environment, to include terrain, features, weather, and environmental effects, the various products of SEDRIS are useful. The main useful tool, for our purposes, is the Environmental Data Coding Specification (EDCS). This is a taxonomical organization of terms designed to describe any of the features that can be found within an environment (natural effects, man-made effects, and so on).

The United States Department of Defense, and each of its constituent parts, has published enumerations of possible tasks. These lists provide a very good overview of the sorts of activities that a directed entity (such as a military unit) can be commanded to perform. From the U.S. perspective, perhaps the most useful to C-BML would be the Universal Joint Task List (UJTL). As mentioned, the services that make up the Department of Defense each have their own similar documents, such as the U.S. Army Universal Task List. These exist for almost all military organizations from allied nations, and could each serve as a controlled vocabulary (perhaps as a weak taxonomy) for the tasks of that organization/nation. Often such an enumeration will be accompanied by a description that can be used to help with disambiguation of terms.

Similar to the categories of tasks mentioned above, there are also categories of representational symbology for many of the military organizations that will be served by C-BML. An example is the US Military Standard 2525B. While this may seem like a small aspect of the overall battlespace representation that will be required of C-BML, visualization is quite important in representing information to a human user in a standardized and agreed upon (unambiguous) fashion.

6 Conclusion – The Three Dimensional Ontology Space for C-BML

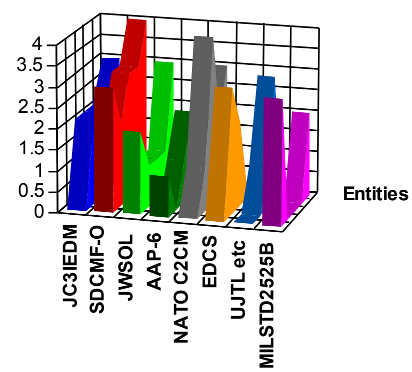
The different products evaluated for this work suggested a few results. First, there is a wide divergence among the products in terms of their structure (as related to the Ontological Spectrum). The allowed richness based on this structure will have a necessary dampening effect on how much interoperability will be available, (via the LCIM). Second, there is a wide difference in the products in terms of the data they address. While the Swedish Defense Conceptual Modeling Framework provides broad subject matter coverage, and has adopted methods and techniques that should reach, at least, the Strong Taxonomy, if not Ontological Model level of richness in the Ontological spectrum, it is not complete. And it is not clear how much coverage will be possible within such a framework for extra-national entities (whether coalition, or opposition force). More research (see the following section) is required of these products by the C-BML PDG.

In terms of what can be shown, perhaps a look at our existing candidate products, vs. the metrics described will give a good start. Rather than include the LCIM as well as the ontology spectrum as axis, it appears to be more useful to measure the value of each product, with regards to the richness allowed within the ontological spectrum, for different sub-domains for C-BML. The sub-domains evaluated are listed below.

- Entities – these are the directed movers within a C2 view, or within a simulation. Most commonly, these will be either weapon platforms (in a high-resolution view), or units (in a high-aggregation view).
- C2 Messages – these are the tasks and reports that are expected to be directed towards, and generated from friendly entities within the battlespace.
- Battlefield Effects – these are descriptions of effects and affects within the battlefield domain. These can be kinetic or non-kinetic, intentional or not, directed or accidental.
- Environment – this is a representation of not only terrain, but also weather, socio-political constraints, spatial-temporal context, and other aspects dealing with the synthetic battlefield space being generated within a simulation, or represented within a C2 system.
- Symbology – a shorthand way of describing the methods for graphically describing all of the above (but most notably entities).

The different products are given a ranking from the ontological spectrum, ranging from 0 (not represented within the particular product), to 6 (represented as a full logical model). Within our sample range of products none of the sub-domains scored higher than a 4 (strong taxonomy), and most were at the level 2 or 3 (weak taxonomy and thesauri, respectively) range in the best of cases. Note, that at this stage in our work

Ontology Space for C-BML



	Entities	C2 Msgs	Battlefield	Environment	Symbology
JC3IEDM	3	2	2	2	0
SDCMF-O	4	3	3	2	3
JWSOL	3	1	1	1	2
AAP-6	1	2	1	0	1
NATO C2CM	3	2	4	1	0
EDCS	0	0	2	3	0
UJTL etc	0	3	1	0	0
MILSTD2525B	2	0	0	0	3

(again, refer to section 7 below), we do not evaluate whether the sub-domain is in regards to a single nation or organizations perspective, or if the sub-domain has a multi-national, multi-organizational perspective.

7 Future Work - Improving Conceptual Representation

Establishment of standards for C-BML is extremely challenging since it has to span multiple Services, organizations, and countries. For long-term success, and to achieve ultimate goals for Network-Centric Operations, it is important to push the standard as far as possible toward the upper levels of the three dimensions of the Ontology Space. This means attaining higher levels in the Ontological Spectrum through strongly formalized semantics, Conceptual Interoperability through formalized engineering models, and broad yet detailed and widely applicable representations of battlespace concepts. These goals present significant technical difficulties to the C-BML community, but the effort to achieve the highest levels possible will have high pay-off even if the highest level in each dimension is not achieved.

7.1 Attaining higher levels in the Ontological Spectrum

While JC3IEDM has been selected for the underlying data model for C-BML, there have been few attempts to formalize the semantics of the model. Formalization of semantics for conceptual level interoperability will require logical constructs that relate and support battlespace concepts, spatial-temporal reasoning, causal relationships, and reasoning under uncertainty.

7.2 Accommodating Improved Conceptual Representation within C-BML

The best way to improve the conceptual representation within the C-BML will be to first level the various sub-domains. This may mean introducing further products as source material, or to research the contributing material as part of the C-BML PDG work. Once the various sub-domains have equivalent coverage, then it must all be improved to reach a sufficiently high level of the ontological spectrum, in order to support higher levels of interoperability out of the LCIM.

7.3 Source data requirements for Improved Conceptual Representation

A complete representation of the battlespace is probably not possible, and probably not desired if the information system is to have the agility to deal with the dynamics of the constantly evolving modern battlespace. It is certainly not likely to be found in only one, or even in only a few, sources of descriptive information. More likely, repositories of concepts and composite concepts will be linked through shared relations that will allow the variety of domains to evolve independently from each other while retaining overall semantic interrelationships.

7.4 Exposing the implicit connection between ontological representation and the LCIM

The relationship between the ontological representation richness, as described by the ontological spectrum and the LCIM is a research idea currently being worked on by the authors. The findings of this relationship, along with a clear relationship between ontology representation products and the supported levels of conceptual interoperability between systems will be included in the follow on work to this paper, to be presented at a future SISO workshop.

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