

Ontology Applied – Techniques employing Ontological Representation for M&S

Charles Turnitsa
Virginia Modeling Analysis & Simulation Center
Old Dominion University
Norfolk, VA 23529
cturnits@odu.edu

Andreas Tolk, PhD.
College of Engineering & Technology
Old Dominion University
Norfolk, VA 23529
atolk@odu.edu

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ABSTRACT: *Several papers already presented to SISO have done a lot to forward the idea that the development of formal ontologies is important to simulation interoperability, especially where semantic and conceptual interoperability is a desired result. The case for value in capturing a formal ontology has been made [Tolk and Blais, 05S-SIW-007], a definition of a formal ontology has been presented [Turnitsa and Tolk, 05E-SIW-045], a method for extracting and evaluating the apparent formal ontology of an existing data model has been presented [Turnitsa and Tolk, 05F-SIW-084] and also the value of a formal ontology within a specific domain [Goerger, Blais, Gates, Nagle, 06S-SIW-044]*

In an attempt to connect these existing ideas, and to show a way ahead out of the confusing arguments of what a formal ontology should be and how it should be captured, this paper will show a roadmap towards developing applications based on ontological research for two areas. First, a technique showing how a static information model based on a formal ontology can help in system development and system planning. Second, a technique showing how a dynamic information translation system, again based on a formal ontology, can help in system-to-system conceptual interchange. These two techniques are presented in terms of the spectrum of ontological representation strata, as well as a framework for classifying types of ontology applications. The SISO related work of C-BML, MSDL, and SEDRIS will be used as case examples.

1 Introduction

There have been few areas of information science research that have not been touched with the ideas related to ontology research in recent years. For a concise definition of what we mean by ontology research, we can borrow from Christopher Welty: “[W]hat the field of ontology research attempts to capture is a notion that is common to a number of disciplines: software engineering, databases, and AI to name but a few. In each of these areas, developers are faced with the problem of building an artifact that represents some portion of the world in a fashion that can be processed by a machine.” [1]

Modeling and Simulation is no exception, and recent workshops sponsored by SISO have seen several papers describing ongoing work in this area [2, 3, 4, 5, and 6]. The authors have tried to show [7] how ontology is of particular interest to M&S. The reason

for this is simple – as the definition above shows, ontology produces a representation of the world that a machine can process. In the case of most application domains, that world can be tested and verified outside of the system – it is just a representation. However, in the field of simulations, the synthetic environment of a simulation has reality *only within* the system. In the case of a simulation, the ontology doesn’t just serve to describe the representation of the world; it serves to describe the (simulated) world itself. Appreciating this leads us to see how ontological representation is important for design, validation, interoperability and other tasks.

Understanding the value of ontology, however, is only a part of the road to enabling its value. The other (and perhaps more challenging) part is to adapt some of the ideas of ontology research into applications. A glimpse into how this might be accomplished is the topic of this paper.

The remainder of the paper is laid out as follows:

- A brief definition of what ontology is (more formally than the definition given above)
- An introduction into the idea of the ontology spectrum
- A section discussing application types of ontology, and giving two examples – static information models and dynamic information translation systems
- Where these application types fit into M&S

2 Ontology – What it is

A commonly quoted definition for ontology is Tom Gruber’s concise statement from his 1993 work on portable ontology specifications. The statement, “formal explicit specification of a shared conceptualization” [8], is now quite common among ontology research efforts.

Taking this definition, and examining the terms within it, we can fall into the trap of thinking that an ontology can be quite a simple thing. If one wishes to derive the ontology for a particular domain space, all they would have to do is to somehow specify their conceptualization of that domain space. It sounds simple, until the details of how to specifying the conceptualization is actually attempted. Then we see that there are great difficulties for a couple of reasons:

- Concepts are elusive
- The ability to conceptualize is based in the cognitive realm, more than in the realm of spoken language
- The attributes of a concept are difficult to see, the attributes of a group of related concepts (a conceptualization) are even more difficult to see

This definition does not limit itself. It includes, in fact, any sort of formal specification of a conceptualization. This can take shape through a number of different methods, each resulting in a different *sort* of specification. These are presented in section 3, along with a view as to the order of specificity that the different sorts of specification can offer. In each case, however, there still remains the task of identifying the conceptualization of a domain, and then attempting to capture it within a specification.

The task, while difficult, is not without reward. An ontological description of a domain space can make it much easier for design, architecture, verification, validation, and interoperation of systems within that domain space [9]. These are valuable goals, and certainly of great interest to the modeling and simulation community.

Before moving on to the ontological spectrum, it should be pointed out that there is a great mistake made by many who encounter the idea of an ontology. That mistake is in assuming that the methods for capturing an ontology are limited to Resource Description Framework (RDF), Web Ontology Language (OWL), or any of the derivatives of these methods (such as RDFS, OWL-S, and so on). While both systems are very capable of specifying a conceptualization (which makes them suited for ontological description), they are not the only such methods.

3 The Ontology Spectrum

The Ontology spectrum is a view into the world of formal methods that are used to capture some understanding of a domain space – a representation of meaning for all of the objects and processes within that space. In other words, the spectrum presents types of ontologies, and it does so by introducing them in an order that reveals their increasing complexity, and also increasing strength for capturing the semantic meaning of a domain space. In its original form, it comes from a presentation [10] given to the Ontolog community¹ by Dr. Leo Obrst, of MITRE’s Center for Innovative Computing and Informatics. As presented, it reveals four broad strata of ontology methods:

- Taxonomies
- Thesauri
- Conceptual Models
- Logical Theories

This same spectrum has been adopted and modified for presentation to SISO in [12]. As presented there, it contains five levels, and in somewhat different order from the original Obrst model. The five levels presented in [12] are (in order of complexity):

- Controlled Vocabularies
- Thesauri
- Taxonomies
- Ontologies
- Logical Models

Within this paper, we will concentrate on definitions of the first four, so that we can see how they are each valuable towards ontological representation for M&S applications.

¹ Ontolog is the Open, International, Virtual Community of Practice on Ontologies located at <http://ontolog.cim3.net/>

3.1 Controlled Vocabularies

Controlled vocabularies are just that – a vocabulary that is shared by all systems and data models operating within the domain that the vocabulary applies to. An example would be a common database (or data warehouse), or even a federated database that is shared among all systems across the domain. In this way, all terms used by systems throughout the domain are the same. This ensures the alignment of terms, but not necessarily the concepts behind those terms.

In building a controlled vocabulary, a project undertaken by the Oregon Graduate Institute, and the United States Department of Agriculture Forest Service led them to come up with a set of criteria to use for evaluating each part of such a vocabulary [13]. These are listed here, as their value should be easy to see.

- Are the terms currently used?
- Who are the users?
- Do the terms match interoperability needs?
- Are the terms well documented?
- Can the terms map to other controlled vocabularies?
- Can the terms be encoded in a machine-processable form (XML)?
- Can the terms be maintained?
- Do the terms support the correct level of detail?
- What format are the terms in currently?
- Are the terms appropriate to the domain?

Controlled vocabularies can take several forms, the first of which is just an agreed-to set of terminology. Such an effort is being undertaken within the realm of bio-informatics, especially the specific area of protein modeling and protein analysis [11]. In this case, a domain specific standards organization (similar to SISO) is tasked with getting industry, academia, and government partners to devise a common vocabulary to enable meaningful data interchange. One published source of standardization that deals with the formulation of controlled vocabularies is found in [22].

Controlled vocabularies are also possible when one considers the use of enterprise-wide data models, federated databases, and standardized metadata models. In this way, the database (or data model) provides a preset list of available terms, and even associations between those terms (leading to complex terms). If all applications within a domain rely on such a model, then at the term level there is agreement between those applications.

Whichever route is taken to employ a controlled vocabulary, it is important to realize that it is an *ontology* [12], as it captures meaning (at the term level) within a domain, and allows applications to share that meaning. It lacks, however, the structure (especially the subsumption structure) of higher forms such as thesauri and taxonomies.

3.2 Thesauri

Thesauri are a collection of terms, ordered within a hierarchy, and the ordering is based on the subsumption of terms. This (subsumption) means that within the hierarchy, each node (term) is either a parent of other nodes, a child of another node, or both. Parents are more general in meaning, children are more specific in meaning, so that the root node is the most general node of all, and that the leaf nodes are the most specific. This growing specificity is based on the terms themselves, not necessarily the concepts behind the terms.

Many thesauri are based on the ISO standard 2788 [14] and more modern versions presented by BS 5723 [19] and from ANSI Z39 [15]. These forms suggest a thesaurus that captures terms, and then categorizes them with three basic sub-sumption relations. These three are broader-term (BT), narrower-term (NT), and related-term (RT). The relationship between a parent and child would obviously be captured with the two (opposite) relation indicators of BT and NT, while the relationship between siblings would be captured with the RT indicator.

Within the ontological spectrum, the first time that semantic relations (other than those supporting the structure of a hierarchy) are introduced is with some of the defining documents [14] of a thesaurus. The two types of relationships are (1) a disjunction between homonyms is made possible, and (2) an open form for categorization is made possible. The first is enabled by *qualifiers*, which are applied to a term to distinguish it from identical terms with the same meaning. An example might be between Tank (storage) and Tank (AFV). The term in both cases is Tank, but they each have a *qualifier* (either storage or AFV) that helps to distinguish them from each other.

The second type of semantic relationship, categorization, is made possible with *node labels*. *Node labels* exist within child nodes (nodes that are related to a “parent” with an NT relation), and exist to give character to the specificity of the narrowed definition. An example might be a group of child nodes that are more narrowly defined than the parent node “truck”. Some of the child nodes might have the *node label* “role”, and their narrower definition is based on the intended use of such a truck. Other child nodes might have the *node label* “manufactured-by” which have a narrower definition based on who built the truck. Both are valid narrowing relationships from the parent, but of course, knowing the nature of the relationship will help the user of the thesaurus.

It has been suggested in recent work [16] that a thesaurus based on concepts rather than terms might be useful. In fact, this is one of the core ideas of the component based ontology system presented in [2, 3] and a refined version in [7]. Having a structure based on concepts, rather than terms, however useful it might prove to be [17], takes us out of the realm of thesauri and into the realm of taxonomies.

3.3 Taxonomy

Taxonomies are hierarchical collections, just like Thesauri, yet they base their subsumption on the concepts behind the terms. In both cases, of course, they are used to classify information, so they are a simplified form of ontology. With a taxonomy, being based on concepts, each introduction of a child underneath a parent necessitates the greater specificity of the child through the introduction of one or more concepts (or a refining of concepts) that the parent did not have. It is worth noting that the difference in placement of taxonomies in this spectrum differs from the original Obrst spectrum due to the fact that we are talking about *strong* taxonomies here. An additional class, *weak* taxonomies, is possible, where there is a hierarchical categorization, but it is not based on subsumption. This (a *weak* taxonomy) is lower in the spectrum (in strength of semantics) than a thesaurus.

The main difference between a taxonomy and a thesaurus is in the difference between concepts (which taxonomies are based on) and terms (which thesauri are based on). When we mention concepts in this paper, we define them as “a commonly accepted idea that is universal to all things said to exhibit it” [7]. That may sound a little circular, but any attempt to further define it necessarily loses some of the value of what a concept is.

Terms are words or symbols that we use to refer to objects or processes. These terms have, underneath them, concepts that give them meaning. The concepts that are understood to be within the terms are the same concepts that are understood to be within what the terms are referring to (real world, or imagined world, objects and processes). While concepts (by definition) are universal, and universally understood, terms are not. There may be different terms that exist for the same referred to object, and there may be the same term that exists, but it points to different objects. Taxonomies, with this distinction, help to solve that problem with terms misaligned to their underlying concepts. A concise introduction to some of these distinctions is given in [18].

Just as there are certain published standards guiding the formation of thesauri, there are also similar works describing the development of Taxonomies. As the identified chief difference between a thesaurus and taxonomy is the difference between being based on terms (thesaurus) and concepts (concepts), it might be helpful to explore this difference from the point of view of development. If one was going to develop a knowledge clarification system based on several languages, so that there were necessarily more than one term for each referred-to object, then it would have to be based on the underlying concept behind those several terms. In this case, the knowledge clarification system is based on concepts, rather than terms. To this end, the several published standards that deal with developing thesauri for multi-lingual systems deal with what we are referring to as a taxonomy. These standards include ISO 5964, and BS 6723 [20, 21].

Controlled vocabularies help to solve the problem of shared information representation (ontological understanding) within a domain by ensuring that all participants within the domain are using the same model for terms and relationships among those terms. Thesauri help to solve this problem by creating a categorized, hierarchical model based on the terms used. Taxonomies take this one step further and base it on the information inside the terms, or the concepts. In both cases of Thesauri and Taxonomies, it is helpful to understand that having a published and accessible hierarchical model is to support the sharing of information representation among the domain participants. Some standards work assisting with this is being undertaken in the UK with the British Standard 8723 [23] activity. Specifically that activity is dealing with structured vocabularies for information retrieval. It builds on the work presented in earlier BS5723, and BS6723 by modernizing the approach, and also by supporting vocabulary interoperability, based more on conceptual meaning than just terms.

3.4 Ontology

Ontologies are similar to strong taxonomies, with the addition of more types of relations between nodes (terms) than just the subsumption relations. Ontological models are, as with a strong taxonomy, concentrating on the concepts behind the terms, rather than being based on the terms themselves. Also, with an ontology, it is possible to also capture (and to base relations on) attributes and properties rather than just terms and relations. Again, there is some difference here from the original Obrst model. In that (the original) version of the spectrum, ontologies are split between weak and strong models. A weak ontology is identified as a conceptual model (similar to the sort of model that can be derived from the unified modeling language) and in many cases can be the same as a taxonomy [24], and a strong ontology is identified as a logical model.

A representation of knowledge at this level (strong ontology) is similar, in its core form, to a taxonomy. It is a hierarchical structure based on concepts. The additions to this that we see at the strong ontology level of the ontological spectrum are the establishment of relations that are outside of the normal parent-child-sibling relations common to the subsumption (hierarchical) structures common to thesauri and taxonomies. At the strong ontology level, other relations – relations based on semantic links between concepts – are introduced.

4 Uses for Ontology

Just as there are a number of different ways to represent the knowledge of a domain, as seen in the four strata of the ontology spectrum presented in section 3, there are a number of forms that products of these strata can take, and each form can serve a different use. There is a very nice assessment of those uses in [25], which presents a sort of taxonomy of ontologies. The four uses are listed here.

- Ontology-Based Search
- Neutral Authoring
- Ontology as Specification
- Common Access to Information

Each of these uses has been adopted already, to a greater or lesser extent, and each is valuable in some way to the M&S application area. Following is an overview of all four, and a brief assessment of their value to M&S.

4.1 Ontology Based Search

The first one of these – ontology based search – is far and away the most mature. It is already being adopted by most internet portals as a way to base information searches on concepts. Ontology based search is also the basis for such successful search and retrieval mechanisms as library categorization methods (Dewey decimal system, library of congress system, etc.).

Ontology based search is seemingly of limited use to the M&S community, when compared to the other three use areas, when operational data is considered. One possible area where ontological-based search may prove to be valuable to M&S would be in an M&S knowledge repository. Such a repository has been presented within the NATO Modeling and Simulation Group, as the Pathfinder Integration Environment knowledge base project. This project (MSG-027) has been reported on in [26].

Of the different strata within the ontological spectrum, all support ontology based search, except for controlled vocabularies. The reason for this, of course, is that searching is based (somewhat) on the use of free search, so more information other than just an enumerated set of vocabulary terms (no matter how enriched by association into complex terms) is required.

4.2 Neutral Authoring

Neutral Authoring is a method whereby ontologically organized content, capturing the knowledge of a domain, is kept separate from any of the applications operating in the domain space. That content, however, is used to enable meaningful exchange or sharing between systems. The distinction between these two terms (exchange and sharing) is important [25], and will be made clear below.

- Exchange of data is data that is originated in a form native to the application originating it, and it is delivered to another application in that form, but its meaning is made clear to all applications involved.
- Sharing of data is data that is transformed into a standardized format and then delivered to another application in that standardized form. All applications involved in sharing understand what is meant by the standardized form.

This use is gaining ground, and is already found in some application areas such as those where domain ontologies are employed to enable or enrich information exchange. The Battle Management Language effort is one area in M&S (and also C4ISR) where such a use is already anticipated and early results are proving successful [27].

The various strata of the ontological spectrum can all be employed by applications making use of neutral authoring; however controlled vocabularies are very useful for information sharing, while taxonomies and thesauri are very useful for information exchange. A strong ontology system may be too rich for such a use. One of the assumptions for neutral authoring is that the major difference between the applications is at the format and term level – the meaning behind the term (the concepts) is not in disagreement between applications [25].

4.3 Ontology as Specification

This use area is predicated on having an ontology for a domain space already developed. That developed ontology would then serve as a model that developers and architects would reference when building or federating applications to operate within the domain.

Such a use is based on having the ontology in a human readable form. This may change with the development of applications that can assist with the traversing and tracing of relations and meaning within a large, complex ontology. Because of this required suitability for human-readable product, this use is limited to controlled vocabularies, thesauri, and taxonomies from the ontological spectrum. A strong ontology (logical model) may be too complex to assist with any undertaking where other than a machine understanding is undertaken.

One of the areas where ontology as a specification has proven useful is where ontological meaning is specified as part of a model to be used for development. The use of the Object Management Groups Unified Modeling Language, as well as extensions such as the Meta Object Facility and XML Metadata Interchange allow models (and meta-models) done in the extended UML world to serve as ontological specification for application development [28].

4.4 Common Access to Information

Common Access to Information is a richer method of exchanging data than that already presented in the use type of Neutral Authoring, in 4.2. One of the main differences between this use, and that found in 4.2 is that Neutral Authoring makes the assumption that the meaning behind terms is shared, and that once that meaning is understood, differences in terms and formats can be worked out. Common Access to Information, on the other hand, makes no such assumption. Its goal is to make not terms known from one application to another within a domain, but the meaning of those terms, at the concept level.

One of the more common applications of this type comes from information science – the ontological organization and revealing of meaning of a body of knowledge. In this case that ontology product is usually for the use of knowledge workers or ontology authors [25]. One area where this is done is for library cataloging efforts and knowledge organization efforts – web portals, knowledge bases, dictionaries, human readable taxonomies, *etc.*

The automated system application of Common Access to Information is similar to the ideas for Neutral Authoring. An additional layer to support this be a reader and writer (for each application within the domain) to the independent ontological representation, and those readers and writers would have to be able to dynamically map between the presented concept-based meaning and relationships from the ontological representation, to the application that the reader and writer are serving, and back again. This would be a relatively new approach, and the systems that can support this are not yet available.

The strata from the spectrum that support Common Access to Information type uses are taxonomies and ontologies. The reason why these layers, and not thesauri and controlled vocabularies, is because of the reliance on concept based representation. Both thesauri and controlled vocabularies are based on term based representation, which does not help with Common Access to Information.

5 Ontology Application Types for M&S

We have seen the multiple strata of the ontological spectrum, and have defined them with reference to potential implementations and standards that support each individually. We have seen a framework for ontology application use types, addressed the potential current types of application within each frame, and also pointed out which strata from the spectrum are appropriate candidates for representation within those frames. Now we will take a look at some actual (and proposed) applications for M&S that tie all of this together.

We will divide these types into two broad categories, one of which is already largely in use with several application and development areas within the M&S community. The second is an area where more research is needed, but the way ahead can be seen. The first is the application type of static information models, where a static ontological representation is a key part of the application. The second is the application type of dynamic information systems, which is an ontological representation that supports a dynamic re-configuring of meaning to support a shifting domain. Both are addressed below.

5.1 Static Information Models

Capturing the ontological meaning of a domain into a static model can, as we have seen in section 3 above, take several different forms, each with more or less semantic meaning. The use that such a representation can be put to also varies, and can take several forms as we see in section 4 above. We would like to present several ongoing efforts from the M&S community that combine these forms and use types to build a static model of ontological representation.

5.1.1 C-BML

C-BML (Coalition Battle Management Language) is a project that has the aim of unambiguously conveying information between a C2 system as a source, and either another C2 system, M&S system or robotic system as a target. It accomplishes this by relying on the BML idea of separating the effort into a number of different layers, each of which contributes to the overall success [27]. Those layers include (among others) a protocol describing the means of the interchange, a representation describing the terms of the interchange, and a doctrine describing the meaning of the interchange. Of interest to us here is the connection between meaning and terms (or between Doctrine and Representation), which has been identified as the Ontology Layer [6].

Currently the approach of having a Controlled Vocabulary (3.1) as a Neutral Authoring (4.2) is supported within the Representation layer, as a Common Reference Model. This model can be accessed via atomic, composite, and aggregate levels, which gives great control to the accessing application in terms of how they would like their information combined [30]. Underneath the representation layer, the data model used is the C2IEDM, or Command and Control Information Exchange Data Model [32]. gives, in some instances, a thesauri-like structure, so the strata achieved

By basing the C-BML ontological representation on a data model, or a controlled vocabulary, the emphasis is currently on representation of terms, rather than concepts. The planned ontology research that is part of the C-BML standardization effort [31] should result in a concept based ontological representation that can tie the unambiguous meaning of the doctrine layer, to the terms from the representation layer. At this point, the strata achieved by such an effort will be either a taxonomy (3.3) or an ontology (3.4).

5.1.2 MSDL

MSDL (Military Scenario Definition Language) is an effort to describe all of the aspects that are part of a military scenario [33]. This includes the environment, entities, orders, and effects. It has grown out of a simple representation that has been used in the Military Simulation Development Environment, and is being standardized within SISO to be valuable to a broad area of applications.

MSDL as it currently exists consists of an enriched controlled vocabulary (3.1). There is currently progress being made in organizing and categorizing the elements of MSDL so that it can become aligned with the thesaurus (3.2) or taxonomy (3.3) strata of the ontological spectrum. Migrating to either the taxonomy (3.3) or ontology (3.4) strata of the spectrum would require basing the elements of MSDL on concept, rather than just terms. Such an effort is planned by the MSDL Standard Product Development Group.

5.1.3 SEDRIS

SEDRIS (the Synthetic Environment Data Representation and Interchange Specification) has been the object of interest of a group that is representing the domain ontological meaning that is shown through the SEDRIS data representation formats. This group has presented a view of how an ontology could be developed to support making that ontological meaning known and portable between applications [29]. Their effort discusses several different ontology representation methods (Description Logics, OWL - Web Ontology Language, and a migration from the former to the latter).

This effort is really dealing with exposing the apparent ontology that resides within the SEDRIS DRM (Data Reference Model). As SEDRIS already has a number of other constructs that support transport of information between systems, the ontology work can be said to be of the Ontology as Specification category discussed above in 4.3. As more applications can make use of ontological data during their exchange, I believe that either a Neutral Authoring (4.2) or Common Access to Information (4.4) method might arise.

As the method described in [29] is based on Description Logics and also OWL, the two strata of Taxonomies and Ontologies can be supported. The early report from the paper suggests that the higher level of semantic meaning from the Ontology strata is possible.

5.2 Dynamic Information Systems

One of the aspects of M&S that makes applying ontological representation both crucial, as well as difficult, is that a simulated environment is a dynamic world. As the entities and processes within that environment exist and interact with each other, the nature of ontological meaning shifts. This is true of the real world, and as we saw in the introduction, the rules of a simulated environment are not just referents to a real world – they define a world in themselves. So, for instance, a truck in a simulated environment can be a vehicle that transports goods, but if the truck is destroyed on a road, it now is an obstacle. The ontological representation of truck, and the other elements of the domain that the term truck (and the concepts behind it) are related to, will necessarily change.

In order to support such a dynamic domain view, an ontological representation must be able to adapt. It should be based on concepts, as they are universal and won't change, yet the relations between various terms that those concepts give meaning to will shift as time (and the context of all the entities with each other) changes within the simulated environment. There is currently no real agreement over whether a dynamic domain would be best served by an ontological representation that is large enough to encompass all of the changes within a static structure, or if the ontological representation would have to be dynamic. If the latter is the case, then there must also be some level of awareness (via agents or services) between the ontological representation and the domain that it is describing. If the former is the case, then the number of possible rules concerning relations between terms could prove to be challenging.

6 The Future of Ontology and M&S

As described within section 5, the example application areas within M&S (and this is not an exhaustive list) are currently based on static ontological representations. Several of the ontological representations within these application areas are in the process of undergoing current development (C-BML, MSDL, SEDRIS, *etc.*). As those representation are developing, they are growing into new ontology application types (see section 4), and also into increased semantic meaning by achieving higher strata within the ontological spectrum (see section 3).

As the need for accurate and precise ontological representation for a dynamic simulation system becomes real, research will have to be done into systems that can not only be aware of the concepts behind terms, the relations between terms, but also operate in a mode where those combinations of terms, concepts, and relations can change over time. Once such systems are developed, then the appropriate level of ontological representation will be made clearer. In the meantime, more research into earlier stages (such as representing terms by their concepts, and understanding the relations and rules between terms in a domain space) is needed.

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9 Authors' Biographies

CHARLES D. TURNITSA is a Ph.D. candidate at the Virginia Modeling Analysis and Simulation Center (VMASC) of the Old Dominion University (ODU). He received his B.S. in Computer Science (1991) from Christopher Newport University (Newport News, Virginia), and his M.S. in Modeling & Simulation (2006) from ODU. His Ph.D. research under Tolk focuses on the domain of dynamic and fractal ontology models for M&S interoperability.

ANDREAS TOLK is Associate Professor in the Faculty for Modeling, Simulation, and Visualization at the Engineering Management Department of the College of Engineering and Technology at Old Dominion University (ODU) of Norfolk, Virginia. He has over 16 years of international experience in the field of Applied Military Operations Research and Modeling and Simulation of and for Command and Control Systems. He is affiliated with the Virginia Modeling Analysis & Simulation Center (VMASC). His domain of expertise is the integration of M&S functionality into real world applications based on open standards. He received a Ph.D. (1995) and an M.S. (1988) in Computer Science from the University of the Federal Armed Forces in Munich, Germany.