

# Semantically Correct Representation of Multi-Model Interoperations

**Ahmed Abu Jbara, Alexander H. Levis**

System Architectures Laboratory, George Mason University, Fairfax, VA, USA  
aabujbar, alevis@gmu.edu

## Abstract

In applying Modeling & Simulation techniques to solve complex problems, different types of models are used to address the multiple aspects of the problems. While each model might be capable of answering specific questions, interoperation between models can provide more insights and allow for those models to complement/supplement each other. We call the use of multiple interoperating models to solve complex problems Multi-Modeling. In this paper we present an approach in representing Multi-Model interoperation in the form of Multi-Modeling Workflows. This kind of representation is full of syntactic and semantic challenges. In order to address these challenges we propose the definition of a Domain Specific Multi-Modeling Workflow Language and a supporting Ontology for each class of problems. We begin with domain characterization and analysis to identify the multi-modeling concepts and modeling techniques associated with a domain of interest. Once sufficient domain analysis is performed, the Domain Specific Multi-Modeling Workflow Language and the supporting Ontology are defined. For solving a specific problem in a specific domain, workflows of interoperating models can be constructed using the new language. The ontology is used to guarantee the semantic correctness of the constructed workflows with respect to the domain of interest.

## Introduction

The use of multiple interoperating models to solve complex problems is gaining more attention recently. While each model might be capable of answering specific questions, interoperation between models can provide more insights and allow for those models to complement/supplement each other. We call the use of multiple interoperating models to solve complex problems Multi-Modeling. Platforms capable of performing multi-model based simulation and analysis like the Command and Control Wind Tunnel (C2WT) (Hemingway, et al. 2011) developed by Vanderbilt University and the Service Oriented Architecture for Socio-Cultural Systems (SORASCS) (Garlan, et al. 2009) developed by Carnegie

Mellon University are already being utilized in different domains. While such platforms provide the foundations that allow interoperation between models on the syntactic levels, there is still a major challenge of improving the human interface to the Multi-Modeling process (Fishwick 2004). In our approach to address this challenge, we propose representing Multi-Model interoperations in the form of Multi-Modeling Workflows. These workflows, in addition to capturing Multi-Modeling activities, are required to represent semantically correct interoperations between models. Our approach is specific to some domain; the rationale behind this is twofold: first, problems to be solved by employing Multi-Modeling techniques are usually domain specific themselves; second, it narrows down the scope of meaningful interoperations among several modeling techniques where each technique offers unique insights and makes specific assumptions about the domain being modeled. We begin with domain characterization and analysis to identify the multi-modeling concepts and modeling techniques associated with a domain of interest. Once sufficient domain analysis is performed, a Domain Specific Multi-Modeling Workflow Language and a supporting Domain Ontology are defined. For solving a specific problem in the domain, workflows of interoperating models can be constructed using the new language. The Ontology is used to guarantee the semantic correctness of the constructed workflows with respect to the domain of interest.

In this paper we present an overview of our methodology and then focus on the use of a Domain Ontology to guarantee the semantic correctness of Multi-Modeling Workflows. Our approach is illustrated in an application from the Drug Interdiction and Intelligence domain. JIATF-South, an agency well known for interagency cooperation and intelligence fusion (Munsing and Lamb 2011), receives large amounts of disparate data regarding drug smuggling efforts. Analysis of such data using various modeling techniques is essential in identifying best Courses of Action (COAs). We apply our approach to solve a class of problems in this domain by creating workflows of model interoperations involving Social Networks, Timed Influence Nets, Organization

Structures, and Geospatial models. Then we show how the use of the Domain Ontology supports the creation of semantically correct workflows.

The rest of the paper is organized as follows. In the next section, we introduce some related concepts and approaches. Then we present a high-level overview of the proposed methodology followed by a discussion on the use of Ontologies. Finally, an illustrative example of the use of our approach is presented.

## Background

We build our approach on top of some previous efforts and we utilize some established techniques. In this section we discuss these related concepts and techniques.

### Modeling and Multi-Modeling

Modeling is the process of producing a model; a model is a representation of the construction and working of some situation of interest (Maria 1997). Fig. 1 represents the modeling hierarchy where a Model is obtained using a Modeling Tool that applies a Modeling Language to represent a specific situation. The model itself should always conform to the Modeling Language used to create it. We call this combination of Model, Modeling Language and Modeling Tool a Modeling Technique.

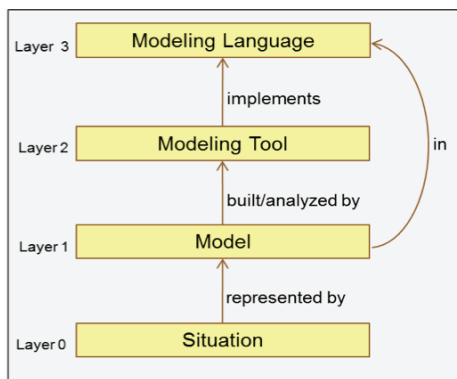


Figure 1. Modeling Hierarchy

We use multiple models because each Modeling Technique provides certain capabilities and makes specific assumptions about the domain being modeled. For example, Timed Influence Nets (Haider and Levis 2007) describe cause and effect relationships among groups at high level but have no capability of capturing social aspects among the groups of interest. Social Networks (Carley 1999), on the other hand, can describe the interactions among groups and members of the groups. In this context, a Multi-Modeling process addresses a complex problem through the use of a number of interconnected domain-specific models where each model contributes insights to the overall problem. The

interoperation between the interconnected models could serve different purposes and can happen in various forms.

### Meta-Models and Meta-Modeling

A Meta-Model is an abstraction layer above the actual model and describes the modeling language used to create the model; the model has to conform to its Meta-Model. A Meta-Model conforms itself to a higher Meta-Model (Meta<sup>2</sup>-Model) which describes the Meta-Modeling Language as shown in Fig. 2. The typical role of a Meta-Model is to define how model elements are instantiated. Meta-Modeling is defined to be the process of constructing a Meta-Model in order to model a specific problem within a certain domain.

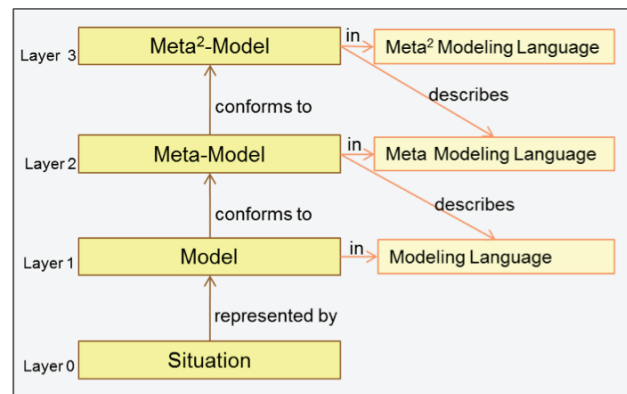


Figure 2. Meta-Models Hierarchy

### Multi-Modeling Workflows

Four layers need to be addressed in order to achieve Multi-Modeling. (Levis, Zaidi and Rafi 2012) The first layer, the Physical layer, i.e., Hardware and Software, is a platform that enables the concurrent execution of multiple models expressed in different modeling languages and provides the ability to exchange data and also to schedule the events across the different models. The second layer, the Syntactic layer, ascertains that the right data are exchanged among the models. In the third layer interoperation across models should be examined to ensure that the exchange of data is semantically correct with respect to the problem domain. The fourth layer, The Workflow layer, is where workflows of interoperating models are captured.

A Multi-Modeling workflow is itself a model of an analysis process. A formal approach to capture a Multi-Modeling workflow requires a formal Modeling Language with its own rules. Developing workflows using such approach allows for translating visual views of model interoperation into an executable implementation. There already exist generic techniques for designing and implementing workflows such as BPMN (OMG 2011) and BPEL (OASIS 2007).

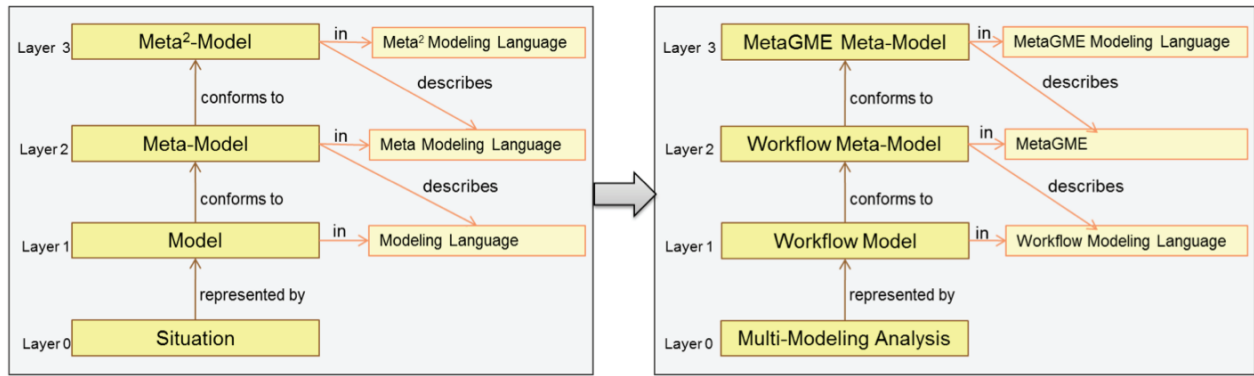


Figure. 3 Mapping the Domain Specific Multi-Modeling Workflow Language to the Meta-Models Hierarchy

The domain specific nature of our approach leads to the development of a Domain Specific Multi-Modeling Workflow Language for a selected domain. Such a language would be tailored to a problem domain of interest and would offer a high level of expressiveness and ease of use compared with a General Purpose Language (GPL) (Mernik, Heering and Sloane 2005) and can be a specific profile of an existing GPL, i.e., BPMN. Fig. 3 shows the mapping of our proposed Domain Specific Multi-Modeling Workflow Language (and its Meta-Model) to the Meta-Models Hierarchy.

### Ontologies

Ontology is the term used to refer to the shared understanding of a domain of interest. It entails some sort of a global view of a specific domain. This view is conceived as a set of concepts, their definitions and their inter-relationships; this view is referred to as conceptualization. In computer systems, ontologies can be thought of as a means to structure a knowledge base. (Uschold, et al. 1996) A Multi-Modeling Workflow Language needs a mechanism that guarantees semantic correctness of model interoperability. We propose the use of a Domain Ontology to guide interoperations between models. The use of Ontologies as a mean for representing the semantic aspects of model interoperability has been explored in (Levis, Zaidi and Rafi 2012) and (Höffner 2007). The first approach is based on comparing ontologies (for each Modeling Technique) to help identify the similarities, overlaps, and/or mappings across the models under consideration and then constructing a higher level “Meta” Ontology that determines which sets of models can interoperate. The second maintains a clear distinction between Meta-Models and Ontologies; they are different but complementary concepts, and both are needed to allow for model interoperability. We employ concepts from these two approaches in our methodology.

### Approach Overview

The focus of our approach is to provide a systematic methodology for creating and implementing Multi-Modeling Workflows that are both syntactically and semantically correct. It consists of five major steps as shown in Fig. 4.

#### Domain Identification

This is the first step which deals with characterizing a specific domain of interest, in which interoperating models are used to solve certain problems. We address the domain identification challenge by employing different techniques. We begin with an informal description of the domain in the form of statements that identify the problems to be solved, Modeling Techniques usually used in solving these problems, data sources and types, and main actors involved including domain experts, modelers and analysts.

Then, a classification of concepts applicable to the domain takes place. These concepts serve as a repository for the final step. In the final step, Concept Maps (Novak and Cañas 2006) are used to represent those concepts. Concept mapping is a representation technique to organize knowledge about a specific domain. In our approach, we consider Concept Maps as a semi-formal representation of the domain. Generating Concept Maps is an iterative process until a satisfactory domain representation is reached.

#### Domain Analysis

Once satisfactory Concept Maps that represent the domain of interest and its supporting Modeling Techniques are ready, the Domain Analysis (DA) process starts. The process goes into two parallel, but complementary, paths. On the outer path, UML class diagrams derived from the concept maps are produced to capture the structural aspects of the domain and its supporting Modeling Techniques. A mapping between these class diagrams follows to produce consolidated diagrams that include interoperations between

the Modeling Techniques. On the inner path, Ontologies based on the concept maps of the Domain and the Modeling Techniques are constructed to capture the semantic aspects. These Ontologies are represented using the formal OWL (W3C 2004) standard.

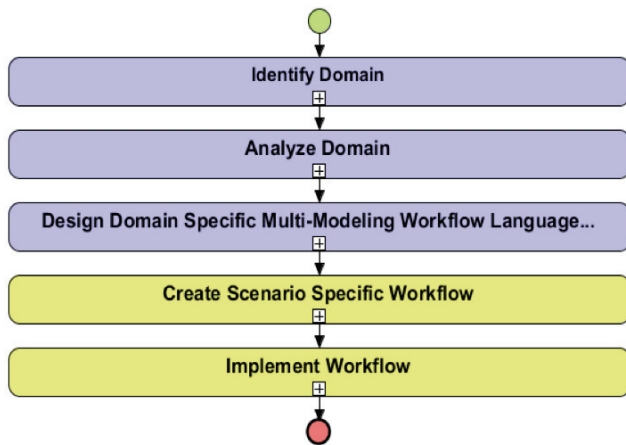


Figure 4. Overview of the proposed methodology

### Domain Specific Workflow Language

In the third step of our methodology, the UML class diagrams obtained from the Domain Analysis step are used as the basis for a Meta-Model that defines the Domain Specific Multi-Modeling Workflow Language. The Generic Modeling Environment (GME) (Ledeczki, et al. 2001), a configurable toolkit for creating domain-specific modeling languages and program synthesis environment developed by Vanderbilt University, is used to create the Meta-Model of the Multi-Modeling Workflow Language. This Meta-Model is then translated into a GME configuration that allows the use of GME itself to create workflows of specific scenarios. Since the Meta-Modeling paradigm in GME is based on the UML standard, the process of transforming the domain UML class diagrams to GME is straightforward. In general, we propose the use of a profile of BPMN as the basis of a new Domain Specific Multi-Modeling Workflow Language.

### Multi-Modeling Workflow Creation

After defining the domain specific Multi-Modeling Workflow Language and having its GME modeling paradigm interpreted, GME can be used to create workflows for specific situations of interest. In this fourth step of our methodology Subject Matter Experts (SMEs) are capable of visually capturing Multi-Modeling activities in the form workflows.

### Workflow Implementation

The final step is to implement our workflows in an appropriate platform. In order to achieve this, an interpretation of the workflow to an executable form is

required. For this purpose, a GME interpreter is required. One example platform that can be used to execute our workflows is the SORASCS (Garlan, et al. 2009).

## Using Ontologies for Semantic Guidance

The semantic concepts identified in the domain identification process and then captured using Ontologies in the Domain Analysis step should be utilized in obtaining a Domain Ontology that guarantees constructing semantically correct Multi-Modeling Workflows. Since our workflows are meant to capture interoperations between models, the semantic concepts captured in these Ontologies should be mapped and matched so that they can be used effectively. The research community in the area of semantics has already provided several approaches for such mapping and matching process. These approaches range from manual to automatic and semi-automatic in between. In (Niles and A. Pease 2001) and (Kotis and Lanzenberger 2008) a set of Upper Ontology and Ontology Matching techniques are described. A previous research conducted at the System Architectures Laboratory in George Mason University has provided a systematic way of transforming initial pseudo Ontologies of a specific domain into an Enriched Ontology (Levis, Zaidi and Rafi 2012). We employ these techniques in obtaining an Upper Enriched Ontology for the domain of interest.

As stated earlier we use OWL as the standard language to represent our Ontologies. Since we are using GME to create Multi-Modeling workflows, and since our final Domain Ontology is captured in OWL, there should be a way to allow communication between GME and the Domain Ontology while creating workflows for specific problems. This communication is required to make sure that interoperations captured in any workflow are semantically correct. Checking the domain Ontology for the correctness of workflow interoperations requires the capability of querying the Ontology for such information. The SPARQL (W3C 2008) Ontology Query Language is used for this purpose.

GME allows for different types of extensions to the environment (Ledeczki, et al. 2001). Utilizing these GME extensibility features and in order to address the semantic guidance issue, we implemented a GME Add-on extension. This Add-on reacts to GME events, and in case of creating any connection that represents interoperation between models, the OWL ontology is queried on the semantic validity of this connection. SPARQL queries are passed to a Fuseki (Fuseki 2011) SPARQL server that utilizes Jena (Jena 2011) SPARQL query engine to query the ontology. Based on the query result, our GME extension could allow or disallow any interoperation connection. Figure 5 shows an overview of this process.



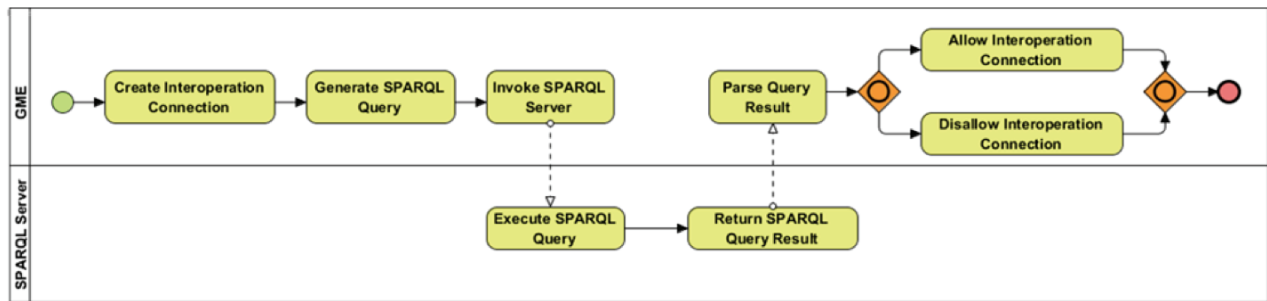


Figure. 5 Overview of the Semantic Guidance Process

## Application: JIATF-South

In this section we present an application of our approach to a decision making problem in the Drug Interdiction domain. JIATF-South (Joint Interagency Task Force - South) is a Drug Interdiction agency well known for interagency cooperation and intelligence fusion (Munsing and Lamb 2011). The agency usually receives disparate data regarding drug trafficking activities from different sources. Quick and effective analysis of data is essential in addressing drug trafficking threats effectively. A typical case begins with JIATF-South receiving information from the DEA (Drug Enforcement Administration). This prompts the deployment of UAVs (Unmanned Airborne Vehicles) that subsequently detect and monitor a suspect vessel until JIATF-South can sortie a Coast Guard cutter to intercept. If drugs are found, jurisdiction and disposition over the vessel, drugs and crew are coordinated with other agencies. COAs (Courses of Actions) identified by JIATF-South are fully dependent on efficient analysis of received data.

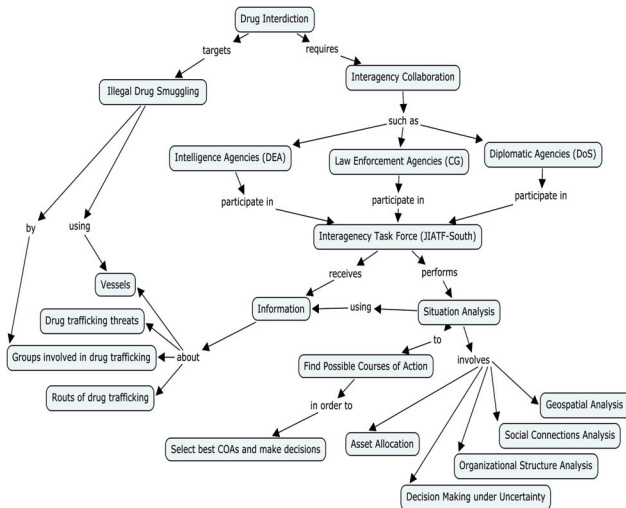


Figure 6. Concept Map

Analysts at JIATF-South are trained to use various Modeling Techniques to analyze data and then to identify possible COAs. By applying our approach, analysts should be capable of creating visual workflows of Multi-Modeling activities.

We first begin with an informal description of the domain. After identifying related concepts, we construct Concept Maps to capture the relations between the concepts. Concept Maps are generally constructed to answer specific questions in the domain of interest. Fig. 6 shows a concept map that addresses the question: How does JIATF-South perform Drug Interdiction? The same applies to other aspects of the domain and the Modeling Techniques. The resulting concept maps are then used to perform extensive domain analysis. In this step, we construct UML class diagrams to represent the constructs of the domain and the Modeling Techniques. Parallel to that, we identify semantic concepts and relations and capture them in our Domain Ontology. Fig. 7 shows a visualization of an example high level Domain Ontology. Solid lines represent the hierarchy of the ontology classes while dashed lines represent relations between classes.

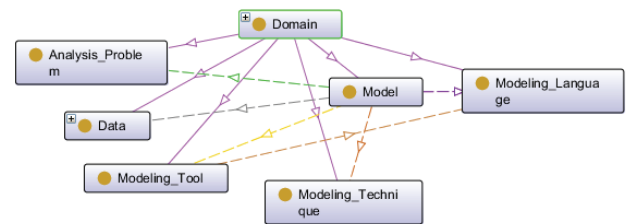


Figure 7. Example of High Level Domain Ontology

After that, using GME, a Meta-Model for our domain's Workflow Multi-Modeling Language is defined. A workflow in the selected domain has two types of activities, operations and interoperations. Operations are those activities performed on a specific model using the Modeling Tool that supports its Modeling Language. Interoperations are those activities that involve interoperations across models through their Modeling Tools. Once the GME Meta-Model of our Domain Specific Multi-Modeling Workflow Language is interpreted and registered as a new Modeling Paradigm in GME, we begin using the GME environment to create workflows that capture specific domain scenarios. Fig. 8 shows an example of an interoperation between a GIS model and a Timed Influence Net model captured using the Domain Specific Workflow Language.

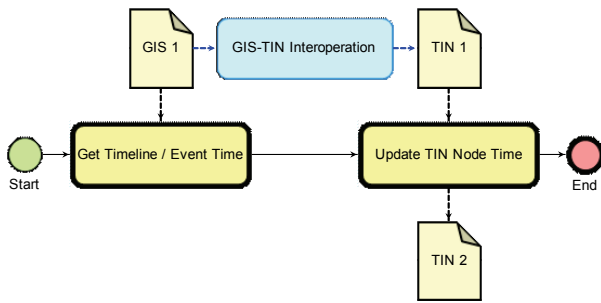


Fig.8 Model interoperation between models

The example shown in Fig. 8 represents an interoperation where the time of an event in the GIS model is used to update the time of a node in a Timed Influence Net. Adapters in our language, such as the “GIS-TIN Interoperation” rounded box in Fig. 8, capture the low level details of the interoperation as shown in Fig. 9.



Fig. 9 Interoperation Adapter

The enforcement of semantic rules captured in the domain Ontology takes place on the Interoperation Adapter level. Whenever a connection between two models on this level is created, the GME Add-on we developed is triggered to check the semantic correctness of the connection. The extension formulates a SPARQL query based on the models being connected, sends the query to the SPARQL query server and then parses the returned result to determine the validity of the connection. Based on the query result, the connection is allowed or disallowed.

## Conclusion

We have shown in this paper an approach that allows for semantically correct representation of Multi-Model interoperations. The approach is domain specific and requires the definition of a Domain Specific Multi-Modeling Workflow Languages and a Domain Ontology. Our proposed approach can be viewed as a two phase process. In the first phase Domain Identification and Domain Analysis take place to generate the new Domain Specific Multi-Modeling Workflow Language and its supporting Domain Ontology. In the second phase, the new language can be used to create workflows of specific Multi-Modeling scenarios. Such workflows can be reused in addressing similar future problems. In the case of introducing a new modeling technique in the domain, the first phase can be revisited to update the language Meta-Model.

## References

- Carley, K. On the Evolution of Social and Organizational Networks. Steven B. Andrews and David Knoke (Eds.) special issue of *Research in the Sociology of Organizations* 16 .1999.
- Fishwick, Paul A. *Toward an Integrative Multimodeling Interface: A Human-Computer Interface Approach to Interrelating Model Structures.* Simulation. 2004.
- Fuseki. 2011. [http://jena.apache.org/documentation/serving\\_data](http://jena.apache.org/documentation/serving_data).
- Garlan, D., K. M. Carley, B. Schmerl, M. Bigrigg, and O. Celiku. *Using Service Oriented Architectures for Socio-Cultural Analysis.* Software and Knowledge Engineering. 2009.
- Haider, S., and A. H. Levis. *Effective Course-of-Action Determination to Achieve Desired Effects.* IEEE Transactions on Systems, Man, and Cybernetics, Part A: Systems and Humans 37, no. 6 (2007): 1140 - 1150 .
- Hemingway, G., H. Neema, H. Nine, J. Sztipanovits, and G. Karsai. *Rapid Synthesis of High-level Architecture-Based Heterogeneous Simulation: a Model-Based Integration Approach.* Simulation. Volume 88 Issue 2. 2011.
- Höfferer, P. *Achieving business process model interoperability using metamodels and ontologies.* 15th European Conference on Information Systems. 2007.
- Jena. 2011. [http://jena.apache.org/about\\_jena/about.html](http://jena.apache.org/about_jena/about.html).
- Kotis, K., and M. Lanzemberger. *Ontology Matching: Current Status, Dilemmas and Future Challenges.* International Conference on Complex, Intelligent and Software Intensive Systems. 2008.
- Ledeczki, Akos, et al. *The Generic Modeling Environment.* Workshop on Intelligent Signal Processing. 2001.
- Levis, Alexander H., Abbas K. Zaidi, and Mohammad F. Rafi. "Multi-modeling and Meta-modeling of Human Organizations." 4th International Conference on Applied Human Factors and Ergonomics. 2012.
- Maria, A. *Introduction to Modeling and Simulation.* Proceedings of the 29th Winter Simulation Conference. 1997.
- Mernik, M., J. Heering, and A. M. Sloane. "When and how to develop domain-specific languages." *ACM Computing Surveys (CSUR)* 37 (2005): 316–344.
- Munsing, Evan, and Christopher Lamb. *Joint Interagency Task Force - South: The Best Known, Least Understood Interagency Success.* National Defense University Press. 2011.
- Niles, I., and A. Pease. *Towards a standard upper ontology.* International conference on Formal Ontology in Information Systems. 2001.
- Novak, Joseph D., and Alberto J. Cañas. *The Theory Underlying Concept Maps and How to Construct and Use Them.* Technical Report, IHMC CmapTools. 2006.
- OASIS. *Business Process Execution Language.* 2007. <https://www.oasis-open.org/committees/wsbpel/>.
- OMG. *Business Process Model and Notation (BPMN).* 2011. <http://www.omg.org/spec/BPMN/>.
- Uschold, M., M. Gruninger, M. Uschold, and M. Gruninger. "Ontologies: Principles, Methods and Applications." *Knowledge Engineering Review* 11 (1996): 93-136.
- W3C . *SPARQL.* 2008. <http://www.w3.org/TR/rdf-sparql-query/>.
- W3C. *OWL.* 2004. <http://www.w3.org/TR/owl-ref/>.