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ONTOLOGY-BASED SEMANTIC MODEL OF SUPPLY CHAINS FOR MODELING AND SIMULATION IN DISTRIBUTED ENVIRONMENT

Juan L. Sarli
Horacio P. Leone

Instituto de Diseño y Desarrollo (INGAR)

CONICET – Universidad Tecnológica Nacional
Avellaneda 3657
Santa Fe, 3000, ARGENTINA

Ma. De los Milagros Gutiérrez

Centro de Investigación y Desarrollo de
Ingeniería en Sistemas de Información (CIDISI)
Universidad Tecnológica Nacional
Lavaisse 610
Santa Fe, 3000, ARGENTINA

ABSTRACT

Distributed simulation becomes a suitable tool for simulating complex systems with heterogeneous models, as supply chains, mainly due to the modularity of components. High Level Architecture (HLA) is widely used as a standard to build a distributed simulation system. However, the composability of simulation models in a federation scheme is the main problem to be overcome. Most solutions propose conceptual modeling for developing federation. This work presents an ontology network to conceptualize different domains, taking into account the design of a simulation model for a supply chain in a distributed environment. The purpose of using an ontology network is the possibility of developing a conceptual model with a modular and incremental approach. The considered domains are: data model domain, federation domain, supply chain domain, and enterprise model domain.

1 INTRODUCTION

Since the beginning of the new millennium, a growing interest in building simulation models through model composition has been observed in the modeling and simulation (M&S) community (Kasputis and Ng 2000; Tolk 2006; Teo and Szabo 2008; Tolk, Bair, and Diallo 2013). Nowadays, most systems are too complex for simulating from scratch, and then this trend undergoes an increasing development because it constitutes an elegant way of simulating this type of systems. Components reuse and model construction as a puzzle are some of the major advantages of using little computation environments, which have been benefited from the advances in software engineering of component-based technology (Verbraeck 2004). The advantages of model composition allows for a good approach to simulate a supply chain (SC). A SC is one of the most popular organizational networks because it allows organizations to remain agile and competitive. This network makes it possible to provide answers for the dynamic global demand and change the structure of organizations so that they can remain agile and competitive (Arrazola 2007; Camarinha-Matos et al. 2009; Mezgár and Rauschecker 2014). Partners belonging SC set up long-term relationships, and each one performs a specific role/function to cover all stages of the value chain. Some of the benefits of using this particular configuration are that members can focus in its core skills and leave the rest to other members.

Efficient management and coordination of material, information and financial flows are key factors for the succeed of the SC. Simulation emerge as a suitable tool to find the right configuration that fit with key requirements necessary for guarantee succeed of SC (Yoo, Cho, and Yücesan 2010; Chan and Zhang 2011). In this context, simulation enables an efficient management of different flows mentioned previously. However, a SC simulation project can be highly costly in terms of money and time. Also sharing information is not easy because members are afraid to expose their in-house knowledge and processes with other organizations and the absence of a central authority (D'Angelo 2011; S. J. Taylor et al. 2013). This sort of difficulties can be solved with the use of distribute simulation. This approach provides local autonomy, privacy of information and promotes reuse of simulation models. However, the use of distributed simulation entails new problems to overcome as interoperability between different simulators and composing them in a meaningful and valid way as simulator of greater level (Page 2007).

The composability of simulation models allows save efforts in developing simulation models, but a fundamental question arises: How do combine simulation models for achieve a proper composed model? For answer this question, it is necessary to integrate component models and reach interoperability among them. There are different levels of composability: syntactic, semantic and pragmatic. Syntactic composability refers to the components connections and communication. It focuses on the implementation aspects of each simulation component and guarantees the correct and loose-coupled connections between components. Semantic composability checks if composition is semantically valid. Besides, detects if a simulation is composing in a meaningful and valid way (Weisel, Petty, and Mielke 2003; Petty, Weisel, and Mielke 2005). Pragmatic composability addresses whether components are aware of the simulation context in which they are running (Tolk 2006), in this case components know about intent of the use of data (Zeigler and Hammonds 2007).

Ontologies are used to organize the knowledge representation and to capture objects information in a particular domain (Gómez-Pérez, Fernández-López, and Corcho 2004). Ontologies in M&S can be applied to better capture the modeler's perspective (Turnitsa, Padilla, and Tolk 2010). They consider that a better differentiation between conceptualizations enable use, reuse and composability of models and interoperability of simulations. As specifications, ontologies are prescriptive; define a formal semantics for automated information processing (Hofmann, Palii, and Mihelcic 2011). Following in this way, this paper presents an ontology-based semantic model as the foundation for SC M&S in distributed environment. Focuses on the development of an ontology network centered in SC and federation domains and contribute towards semantic interoperability in distributed simulations. Besides, this approach reduces significantly time and effort need it for modeling and developing distributed simulations.

This work is organized as follow. Section 2 presents the related works. Then section 3 presents the main concepts used in the development of this work. Next, the SCFHLA ontology network is presented. Finally, conclusion and future works are shown.

2 RELATED WORK

Different research efforts attempted to produce simulations from composition of simulation models in the last years (Barnett and Miller 2000; Zacharewicz, Chen, and Vallespir 2008; Snively, Leslie, and Gaughan 2013). In these research investigations, the most challenger task is build the Federation Object Model (FOM) which contains common structures and meaning of shared data for simulate an HLA federation. In other words, FOM gives semantic to HLA simulation. Besides, in HLA standard there are no guidelines to define FOM so develop it requires a significant amount of time, effort and manual labor.

The use of ontologies in M&S for knowledge representation is a good idea even though not a new, some examples are the works presented by (Benjamin, Patki, and Mayer 2006; Bell et al. 2007; Silver, Hassan, and Miller 2007; Taylor et al. 2010; Dragoicea et al. 2012). Some of them have mechanism to model validation and execution of models in web environment. These works assume that simulation models are available in a repository and that exists open source models for use in a collaborative way. But, none of these contributions employs an ontology network and in consequence, they are not take advantage of them. The primary focus of this work it is an approach to semi-automatic generation of FOM. To do that, this work use an ontology network that adopts a semantic model of SC domain presented in (Sarli and Gutiérrez 2015). The ontology network uses meta-relations and derived axioms to map concepts from SC domain to simulation domain, thus specific simulation knowledge and necessary effort to build FOM is decreased.

3 FOUNDATIONS

3.1 Ontology Definition

An ontology gives an explicit definition of the shared conceptualization of a certain domain (Gómez-Pérez, Fernández-López, and Corcho 2004). From a pragmatic perspective, ontology can be defined as a representational artifact based on four kinds of modeling components: concepts, roles, restrictions and individuals. Concept represents classes of objects. Roles describe binary relations among concepts; therefore they also give description of properties of concepts. Restrictions are used to express properties of roles, i.e. cardinality. Individuals represent instances of classes, i.e. objects. Additionally, it is possible to use axioms and rules to infer new knowledge. Axioms are logical sentences always true that express the properties of model paradigm. Rules are logical sentences that express characteristics of the domain, i.e. business rules. The component that differentiates ontology from taxonomy is the set of rules. This set has to be expressed in an appropriate logical language. Considering that the Ontology Web Language (W3C 2015a) language is the standard for implementing an ontology and this is not always enough to do some deduction, then it is needed to combine OWL with other representation formalism as rules. One of the integration approaches is the Semantic Web Rule Language (SWRL), which provides the ability to express Horn-like rules in terms of OWL concepts (O'Connor et al. 2005).

In order to extract information from OWL ontologies a query language is needed. The most powerful language is Semantic Query-Enhanced Web Rule Language, which is based on the SWRL rule language and uses SWRL's strong semantic foundation as its formal underpinning. It also contains novel set operators that can be used to perform closure operations to allow limited forms of negation as fail-true, counting, and aggregation (O'Connor and Das 2009).

3.2 Ontology Network

An ontology network is a set of ontologies related together via a variety of different relationships such as mapping, modularization, version, and dependency. The elements of this set are called Networked Ontologies (Allocca, D'Aquin, and Motta 2009). An ontology network differs from a set of interconnected individual ontologies in the relations among ontologies since in an ontology network the meta-relationships among the networked ontologies are explicitly expressed (Díaz et al. 2011). There are some models that cover both the syntactic and semantic aspects of dealing with ontology relationships in networked ontologies. In the Descriptive Ontology of Ontology Relations ontology, general relations between ontologies, such as includedIn, equivalentTo, similarTo, and versioning were defined by using ontological primitives and rules (Allocca, D'Aquin, and Motta 2009).

Concerning a support for implementing and managing ontology networks, the NeOn Project can be mentioned. NeOn has developed open service-centered reference architecture for managing the complete life cycle of networked ontologies and metadata. This architecture is realized through the NeOn Toolkit and complemented by the NeOn methodology, which is a scenario-based methodology that supports the collaborative aspects of ontology development and reuse (Suárez-Figueroa, Gómez-Pérez, and Fernández-López 2012). From a model integration point of view, within an ontology network, each ontology conceptualizes a specific domain and plays a particular role. Then, the main advantage of using an ontology network is the conceptualization of a given domain in a modular way. The networked ontology is small enough to be understandable by any person and its maintenance is easy. In addition, several ontology designers could work on different networked ontologies concurrently.

3.3 SCOR Model

The SC Operation Reference (SCOR) model is the product of SC Council organization and presents the most relevant concepts for modeling a SC. Besides, allows compare and evaluate the performance of the overall SC and its particulars activities. It is a conceptual model that provides a common terminology and facilitates understanding throughout the SC. This model helps to analyze measure, set objectives of performance, establish upgrades opportunities, identify best practices and prioritize projects in the SC management.

SCOR is organized around six major management processes: Plan, Source, Make, Deliver, Return, and Enable. In addition, it defines three hierarchical levels of processes, which are presented in Table 1.

Table 1: SCOR Processes.

#Level	Name	Description
1	Scope	Define types of process, scope and content of SC
2	Configuration	Define category of process and the operations strategy
3	Steps	Define elements of process and the configuration of individual process

At all levels, the model provide key performance indicators, which are systematically divided into five performance attributes: Reliability, Responsiveness, Agility, Costs and Asset Management (Assets).

According to SCOR model a performance attribute is a grouping of metrics used to express a strategy. An attribute itself cannot be measured; it is used to set strategic direction. SCOR metrics are organized in a hierarchical structure, describing level-1, level-2 and level-3 metrics. Relationship between these levels is diagnostic. In example, level-2 metrics serve as diagnostics for level-1 metrics. This means that by looking at the performances of the level-2 metrics it can explain performance gaps or improvements for level-1 metrics. This type of analysis is referred to as metric decomposition or root-causing (SCOR 2012).

4 SCFHLA ONTOLOGY NETWORK

This section presents the ontology network. It is based in previous work (Gutierrez and Leone 2014) and it presents a framework for supporting the semantic interoperability of simulators that belong to a federation for simulate a SC. This semantic model have four specific domains: data model domain, modeling through the Base Object Model Ontology (BOMOnto); federation domain modeling through HLA Federation ontology (HLAFed); SC domain, modeling with SC Knowledge ontology (SCK); and finally, enterprise model domain, modeling with Enterprise Model Ontology (EMOnto). Figure 1 shows the SC Federation HLA (SCFHLA) network, its main concepts and the meta-relationships between the domain ontologies. The meta-relationships are represented with dotted line, while the relationships in each domain are drawing with continuous line. The meta-relation *evaluates* links *Metric* belonging to SCK with *Federation* belonging to HLAFed and *isEvaluatedBy* is the inverse meta-relation. In other hand, *Federation* and *SupplyChain* are related through *performs* relationship. Also *Federate* and *Participant* are related through *representA* meta-relationship. The meta-relationship *isSimulatedBy* associates an EM concept belonging EMOnto ontology with *Federate* concept. A *BusinessProcess* is connected with a *CompanyProcess* through *implementedBy* relationship and an *ObjectModel* is related with *BOM* concept from BOMOnto by *similarTo* meta-relationship.

In this work, the focus is on two domains of the network: federation and supply chain. These domains it outline the main concepts of HLA federation and a SC based on SCOR model respectively. The SCK ontology facilitates modeling in terms of process, metrics, goals and relations among processes. These terms are friendly for a SC modeler, but not necessarily know federation concepts used for simulating the SC. Then, the HLAFed ontology is required for satisfy this lack of knowledge about federations in HLA. In this sense, the goal of both ontologies in the network is transform business rules of a SC in a conceptual model of objects for a HLA federation. This transformation is feasible by meta-relationships among concepts in the ontologies that paving the way. Therefore, the modeler can focus in modeling the SC concepts and rest in the ontologies to transform these concepts in federation concepts.

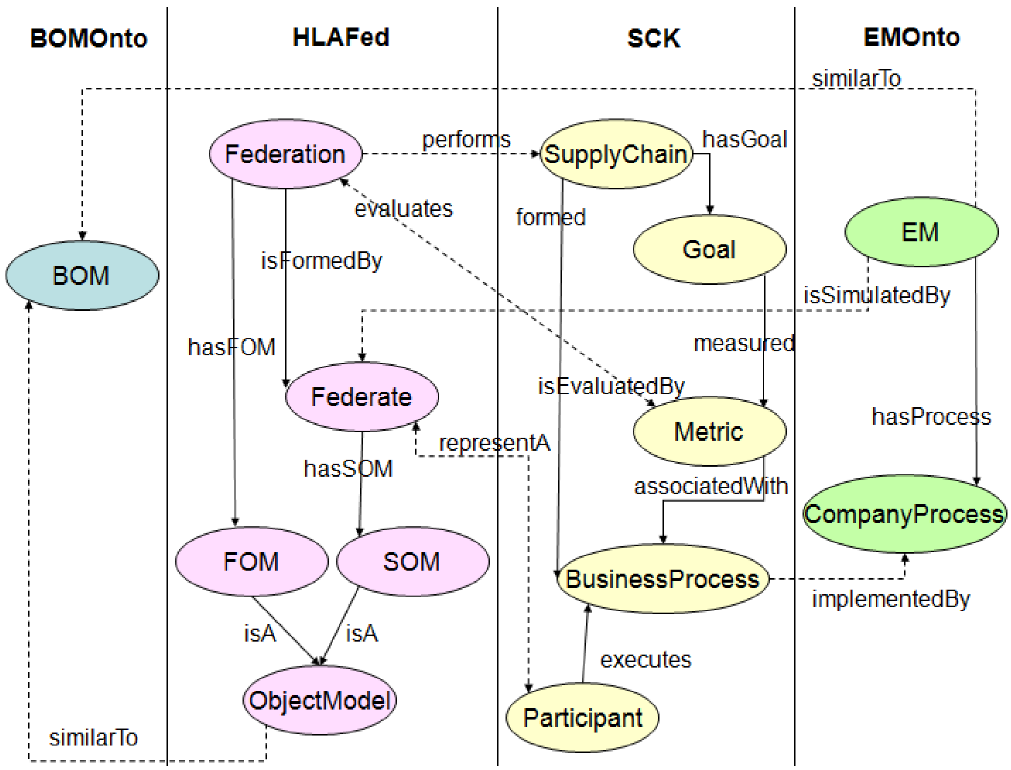

Figure 1: SCHFLA network.

4.1 SCK and HLAFed Ontologies

Figure 2 presents SCK ontology. The main concept is *SupplyChain*, representing a SC model. A SC is conforming by processes related to each other, and then *BusinessProcess* concept is models process. *BusinessProcess* is an abstract concept that encapsulates common attributes to all types of process defined in SCOR. This concept has three sub concepts: *Process*, *SubProcess*, and *Task*. *Process* models a scope process of SCOR, *SubProcess* represents a configuration process, and finally *Task* defines a step process of SCOR (defined in Table 1). According to SCOR, a process can be decomposed in sub processes and each one can be decomposed in tasks. Then, for modeling this decomposition the relationship *hasSubprocess* is defined. In order to represent relation among participant of a SC the *Relation* concept is defined. It represents information and material flow among processes. A SC can be modeled as a set of processes and his relations, therefore the *formed* and *contains* relationships are defined between *SupplyChain* and *BusinessProcess*, and *SupplyChain* and *Relation* respectively.

A SC has a purpose, a goal that seeks to achieve so SCK define a *Goal* concept for that. The goals of a SC have associated certain performance attributes that set the strategic direction of the SC, in some way, defines that evaluate for reach the goal of a SC. The concept *PerformanceAttribute* is modeled for this reasons. Conforming to SCOR model a performance attribute cannot be measured by himself, then is necessary establish some key performance indicators for disclose their performance. The indicators frequently are named metrics and a *Metric* concept is defined for this purpose. A metric uses certain information about processes for realize his calculations and obtain an evaluation of a performance attribute. Metrics are organized in a hierarchy, similar to processes, and each level have different needs of information for calculate his value.

A metric needs a formula to determine its calculation. Then, SCK define the *Formula* concept that has variables which can be atomic or complex. *Variable*, *AtomicVariable* and *ComplexVariable* are defined to represent these concepts. A formula stores the result of its calculation, his equation and unit. Too, a formula is composed for a set of variables and each of them measures a particular resource. An atomic variable measures a certain property of resource, whereas a complex variable measures an aggregate feature of a resource.

Each process in the SC has an owner responsible of its execution. Each participant has a role that determines their SC functions. The concepts *Participant* and *Role* are defined to represents this situation respectively. A role is specialization in three subclasses: *Source*, *Make*, and *Deliver*, conceptualizing the most typical roles used in the SC modeling .The *Source* role defines interactions for obtain goods and/or services. Furthermore, *Make* role has interactions to transform raw materials into finished goods. Finally, *Deliver* role execute actions to deliver intermediate o finished goods and services.

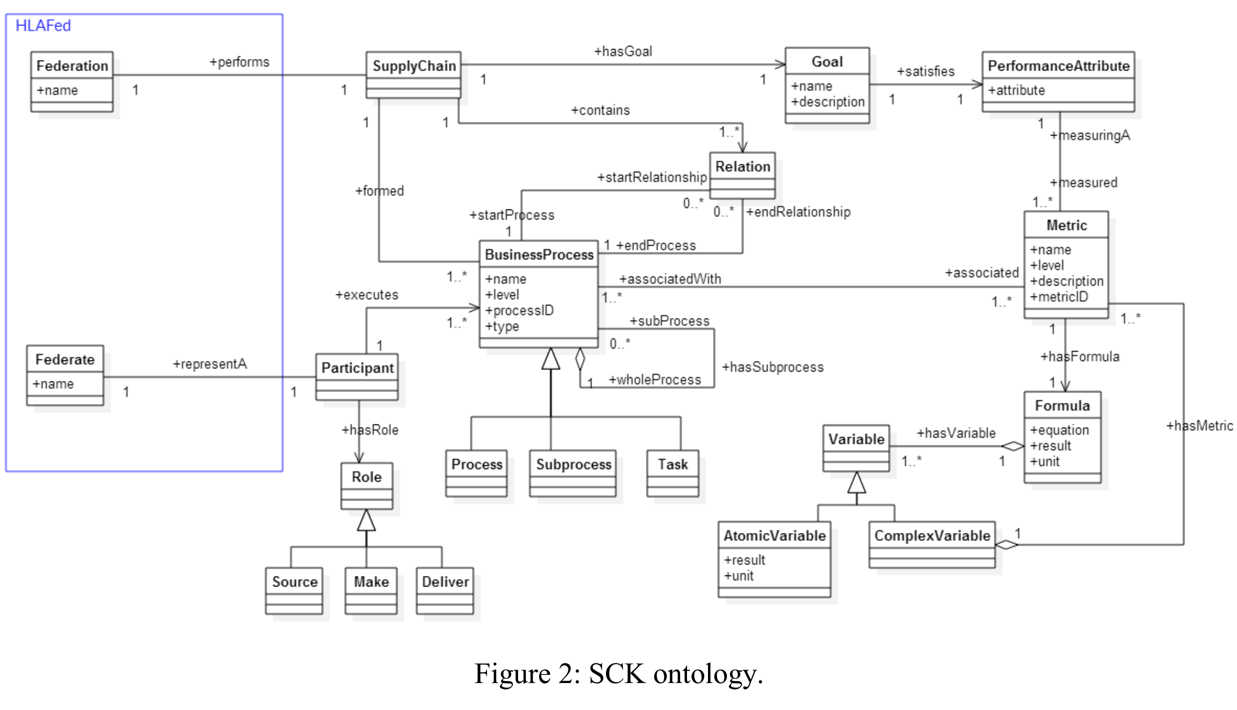

Figure 2: SCK ontology.

Figure 3 presents HLAFed ontology. This ontology conceptualizes HLA simulation concepts. The *Federation* and *Federate* are some of the main concepts. Each federation must have an initiator, which is responsible for constituting the federation and invite to join the rest of participants. The initiator is represented with the *Administrator* concept.

Both a federation and a federated have object models defined as *ObjectModel*, specialized in *FOM* and *SOM* (Simulator Object Model). The object model has objects and interactions for manage and use the services provided by a HLA implementation used to simulate. In this case, object and interactions for management are represented for *MOMObject* and *MOMInteraction* concepts respectively. Also, object model has objects and interactions defined by user provided by the simulation models members of the federation. Moreover, a federated owns some objects on which it performs read/write operations to represent state. These objects are called *ObjectClass*. The interactions of explicitly send messages between federates are called *InteractionClass*.

An object owned by a federate has certain attributes to determine state and properties (i.e.: data type, ownership, update type). In the ontology, *Attribute* and *Property* are modeled for this purpose. Interactions have different types of parameters to send messages, and they store information to be sent to another federated member. As a consequence, the concept *Parameter* is defined.

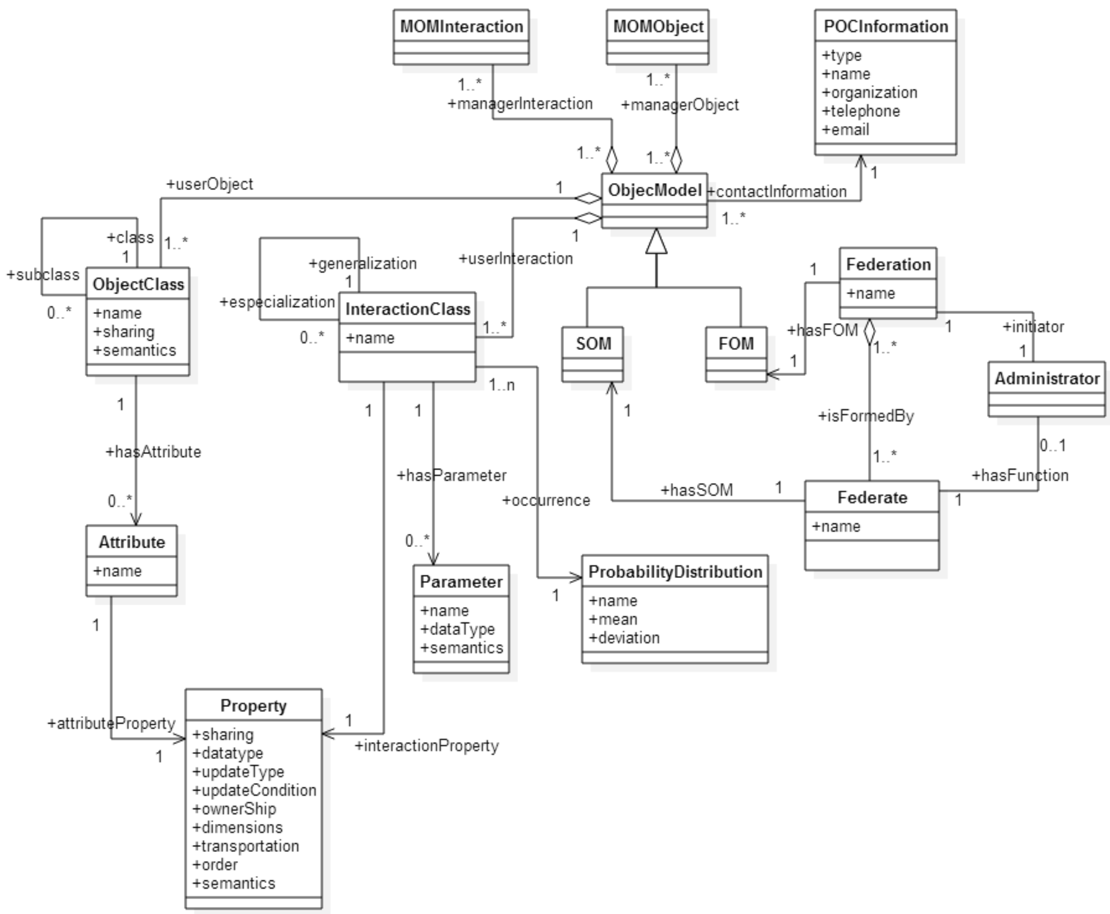

Figure 3: HLAFed ontology.

4.2 SCK and HLAFed Implementation

Both SCK and HLAFed are implemented using Protégé 4.3 version tool (Stanford 2016).
To implement these ontologies, it is necessary to transform class diagrams of Figure 2 and 3 into domain ontology and interconnecting them. The following criteria are applied in this task:

- The classes from class diagram are transformed into OWL classes from Protégé.
- The relationships from class diagram are mapped in Object Properties from Protégé.
- The attributes from class diagram are translated into Data Properties from Protégé.

Also, some rules are added to ontologies so as to restrain the open world conception and have a suitable model of reality. Figure 4 presents the following rule implemented in SWRL: *If a metric is of level two then his formula has only atomic variables.*

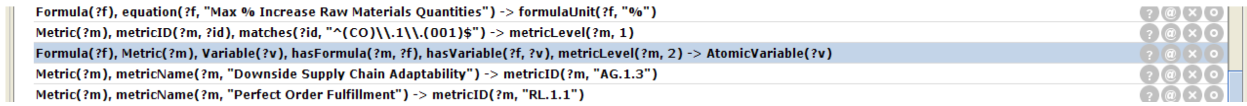

Figure 4: A rule implemented with SWRL.

4.3 Ontology Network Workflow

The Figure 5 presents a process that describes how to use SCFHLA ontology network. The process is composed with three components a Modeling Tool, SCFHLA and a Runtime Infrastructure (RTI) implementation of an HLA standard.

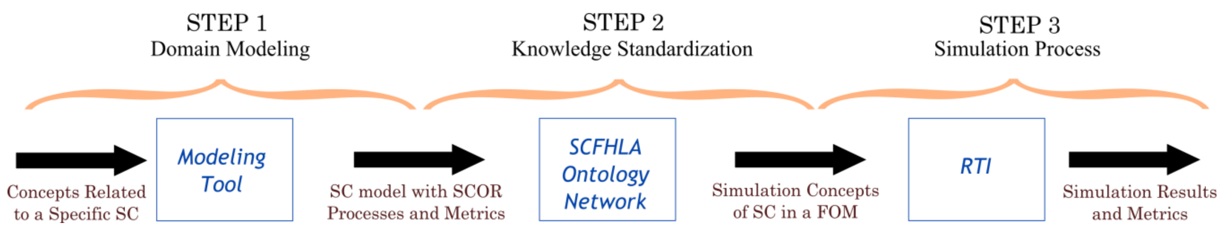

Figure 5: Process for make use of SCFHLA.

The first step in the process is denominated *Domain Modeling*. Modeling tool receives concepts related to a specific SC as input from end user. Then, the output of this step is a SC model with SCOR concepts like performance attributes, metrics, process and goals. The second step is denominated *Knowledge Standardization*; here the input is the output of the first step. SCFHLA ontology network uses the input to instantiate SCK concepts, through the meta-relations and derived axioms can relate to HLAFed concepts. The participants of a SC are mapped to federates, the relations between processes are mapped to interactions classes and variables of metrics are mapped to objects classes. With this information and with transformation rules to map instances of HLAFed on a document with extensible markup language (W3C 2015b) format, the FOM can be generated automatically. Then, SCFHLA provides as output the FOM in an xml archive. Finally, the third step is denominated *Simulation Process*; here an RTI implementation takes as input the FOM and simulates the SC with the respective simulation components. The simulation components need to be consistent with SCOR processes to gather information needed to calculate SCOR metrics. Once the SC simulation is finished, metric with calculated values are provided as output.

As a small example, the following situation is summed: Two companies collaborate in a fruit juice SC, a factory and a supplier. In this SC, the supplier is responsible for supplying fruit to the factory, and this relation is named "send raw materials". Companies are interested in determining if the time of "send raw materials" is relevant in order fulfillment time. The time needed by the supplier to send supplies to the factory and the time needed to complete an order are measured as Delivery Cycle Time and Order Fulfillment Time SCOR metrics respectively. In the modeling tool, the above explained situation must be modeled with two processes: On the one a source process with a source stocked product strategy for supplier and on the other hand a make process with a make to stock strategy for factory. The relationship "send raw materials" can be modeled with a relation denominated deliver supplies. In SCFHLA, the processes and relation from modeling tool are instantiated in SCK concepts (*process*, *subprocess* and *relation*) and related in the following HLAFed concepts: The supplier and factory are modeled as *federates*, relation deliver supplies is modeled as *interaction class*; in both cases instances are named with same name used above. Also, to analyze status of deliver supplies interaction an *object class* named state order is instantiated. The FOM is generated as output of SCFHLA and then to explain how FOM is composed, interaction deliver supplies is shown in Figure 6.

```
<interactionClass name = "DeliverSupplies"
    sharing = "PublishSubscribe"
    dimensions = "NA"
    transportation = "HLAreliable"
    order = "TimeStamp"
    semantic = "interaction between supplier and factory">
    <parameter name = "ItemID"
        dataType = integer
        semantics = "item identifier"/>
    <parameter name = "deliveryDate"
        dataType = date
        semantics = "delivery date of the order"/>
    <parameter name = "quantity"
        dataType = integer
        semantics = "quantity of supplies to deliver"/>
</interactionClass>
```

Figure 6: Extract of a FOM.

An RTI implementation like poRTIco (Portico 2016) can simulate the federation composed by supplier and factory using the FOM generated for SCFHLA. Given the interest of SC in the relation between delivery time and order fulfillment time, simulation obtains as result the Delivery Cycle Time and Order Fulfillment Time SCOR metrics with calculated values. Finally, Figure 7 shown the example presented before.

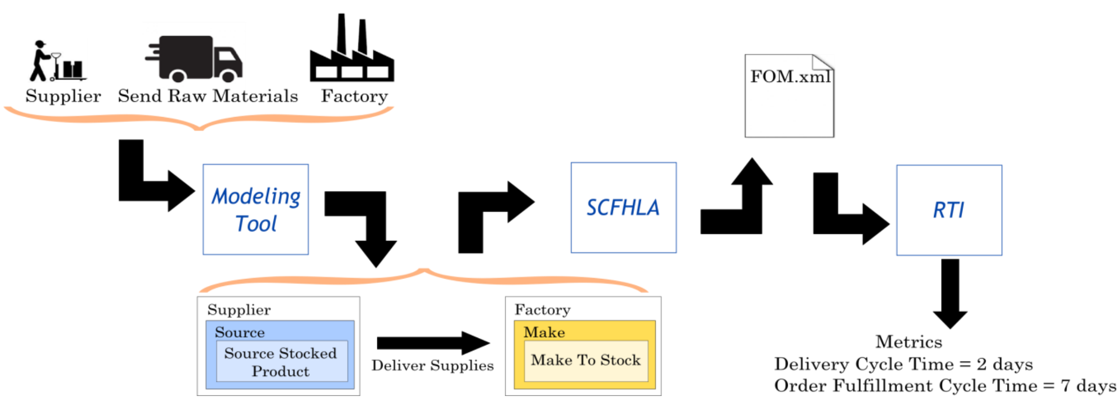

Figure 7: Use of SCFHLA in an example.

5 CONCLUSION AND FUTURE WORK

This work has shown a preliminary ontology network whose purpose is to conceptualize the SC simulation domain in a distributed environment. The modularizations provided by this network helps in focusing the attention on a particular domain and incrementally building a more general model by relating different ontologies. The concepts related to SC simulation domain were presented. This work is mainly focused on describing two particular domains: federation and SC. Therefore, SCK ontology conceptualizes not only the artifacts proposed in SCOR model but also relationships and restrictions among concepts that are not present in SCOR, resulting in an improvement in the use of such a reference model.

HLAFed ontology presents the main concepts needed to build a federation model according to the HLA standard. Note that the data model conceptualization is represented in a different domain (BOMonto), making modular and incremental development easier. Through an ontology network, it is possible to add a new ontology and relate it with the existing ones.

The developed ontologies have been implemented using Protégé. Some SWRL rules were executed to validate the ontology coverage.

Current research work is aimed to adding new concepts and relationships to improve SCFHLA. At the same time, expert knowledge on the modeling domain is being captured and translated as SWRL rules with the aim of providing the basis for a tool that are an expert in guiding users. In addition, a web based tool for supporting the generation of a SC federation is meant to be developed by using the ontology network presented in this paper.

Furthermore, the definition of transformation rules for mapping HLAFed concepts in a FOM and rules to transform SCK concepts in simulation models constitute some of the issues that are subjected to the authors' future work. Also, all the information needed to generate the simulations models is contained in concepts business process, task, metrics, formula and variable of SCK. To perform this task, a SCOR simulation framework is being developed in DEVSJAVA (Arizona State University 2012) to create SCOR processes, tasks, and metrics. This is an important contribution to develop SC simulation development so as to save time and effort in building simulation from scratch.

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AUTHOR BIOGRAPHIES

JUAN LEONARDO SARLI is a System Information Engineer and now is a PhD fellow working with Dr. Horacio Leone and Dra Maria de los Milagros Gutierrez in the Instituto de Desarrollo y Diseño (INGAR) of the Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET). His research interests include simulation on SC applied to cloud computer environments. His email address is juanleonardosarli@santafe-conicet.gov.ar

MARIA DE LOS MILAGROS GUTIÉRREZ is a Professor in the System department of Universidad Tecnológica Nacional Facultad Regional Santa Fe. Received her Ph.D. in System Engineering from UTN - FRSF. Her research interests include conceptual models for interoperability and intelligent systems focusing on applications in distributed simulation and e-learning. Her email address is mmgutier@frsf.utn.edu.ar

HORACIO P. LEONE is a Professor in the System department of Universidad Tecnológica Nacional Regional Santa Fe and an Independent Researcher in CONICET. Received his Ph.D. in Chemical Engineering from UNL - FIQ. His research interests include software engineering, software architecture, chemical processes. His email address is hleone@santafe-conicet.gov.ar.