

A Model-driven Approach to Build HLA-based Distributed Simulations from SysML Models

Paolo Bocciarelli, Andrea D'Ambrogio and Gabriele Fabiani
Dept. of Enterprise Engineering, University of Rome "Tor Vergata", Rome, Italy

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Abstract: The analysis and design of complex systems, which very often are composed of several sub-systems, takes advantages by the use of distributed simulation techniques. Unfortunately, the development of distributed simulation systems requires a significant expertise and a considerable effort for the inherent complexity of available standards, such as HLA. This paper introduces a model-driven approach to support the automated generation of HLA-based distributed simulations starting from system descriptions specified by use of SysML (Systems Modeling Language), the UML-based general purpose modeling language for systems engineering. The proposed approach is founded on the use of model transformation techniques and relies on standards introduced by the Model Driven Architecture (MDA). The method exploits several UML models that embody the details required to support two transformations that automatically map the source SysML model into a HLA-specific model and then use the latter to generate the Java/HLA source code. To this purpose, this paper also introduces two UML profiles, used to annotate UML diagrams in order both to represent HLA-based details and to support the automated generation of the HLA-based simulation code.

1 INTRODUCTION

The analysis and design of systems in several application domains (e.g., aerospace, defence, economics, software, medical, etc.) is often based on the use of simulation techniques. Simulation-based approaches allow to analyze a system at design time, in order to assess whether or not it accomplishes both functional and performance requirements, whether or not it satisfies constraints and, ultimately, to cut or reduce the cost of experimental prototypes. Simulation execution may be carried out by use of either a local or a distributed approach.

Unlike *local simulation*, whose execution involves a single host that includes all the resources needed to complete its execution, a *distributed simulation (DS)* approach involves a set of distributed hosts interconnected by a local or geographical network infrastructure (Fujimoto, 2001). DS is mainly used to achieve scalability, aggregation and reusability (D'Ambrogio et al., 2011a).

The simulation of modern and complex systems, which very often are composed of several sub-systems, requires computational resources that might not be available on a single host. In this respect, DS is often used to enact a scalable way to simulate a co-

mplex system by partitioning the overall simulation into a set of simulation components, each executed onto an independent host (Fujimoto, 1999).

Nevertheless, the use of DS-based approaches is often limited by the non-negligible effort and the significant skills that are required to make use of DS frameworks and environments, such as the HLA (High Level Architecture) framework and its related implementation technologies.

To overcome such limitations, this work proposes a method to support the automated generation of HLA-based distributed simulations starting from system descriptions specified by use of SysML (Systems Modeling Language), the UML-based general purpose modeling language for systems engineering (OMG, 2010).

The proposed method is carried out according to principles and standards introduced in the model-driven engineering field and is specifically founded on the Model Driven Architecture (MDA), the Object Management Group's incarnation of model-driven engineering principles (OMG, 2003). Such a model-driven method makes use of model-to-model and model-to-text transformations that have been implemented by use of QVT (Query/View/Transformation) (OMG, 2008a) and MOFM2T (MOF Model

to Text Transformation Language) (OMG, 2008b), respectively. The availability of such automated transformations allows software engineers to derive the executable HLA-based simulation code with no extra effort and without being required to own specific skills of DS standards, as shown by use of an example application.

The proposed method includes two main steps:

- A *model-to-model* transformation step, to obtain a model of the HLA-based distributed simulation, starting from the system specification;
- A *model-to-text* transformation step, that takes as input the simulation model and yields as output the code that implements the HLA-based distributed simulation.

The method exploits several UML models that are created during the development of a distributed simulation. Each model represents the system from a specific point of view and at a given level of abstraction. UML models are thus used both to *represent* the system under a certain perspective and also to embody the details required to *support the model transformations* upon which the proposed method has been built.

To this purpose, this paper also introduces two UML profiles, or UML standard extension mechanisms. The first one, named *SysML4HLA profile*, is used to annotate a SysML-based system specification to support the automated generation of the HLA-based distributed simulation. The second one, named *HLA profile*, is used to annotate an UML diagram in order to represent HLA-based implementation details.

The rest of this work is organized as follows: Section 2 reviews relevant contributions which deal with the topics addressed in this paper. Section 3 briefly introduces HLA and presents the proposed HLA profile. Section 4 outlines the SysML notation and introduces the SysML4HLA profile. Section 5 illustrates the proposed model-driven method that exploits the HLAProfile and the SysML4HLAProfile to support the development of a HLA-based distributed simulation. Finally, Section 6 illustrates an example application of the proposed method.

2 RELATED WORK

This section reviews the existing literature dealing with both the use of SysML in *Modeling & Simulation (M&S)* domain and the modeling/development of HLA-based distributed simulation systems.

As regards the use of SysML in the M&S context, to the best of our knowledge, no contributions can be found that specifically address the topic faced in this paper: the generation of Java/HLA code, starting from SysML specifications. Nevertheless, several contributions are available that propose the use of SysML as a notation suitable not only for defining systems specification but also for supporting the system simulation, such as (Weyprecht and Rose, 2011; Peak et al., 2007; Paredis and Johnson, 2008).

In (Weyprecht and Rose, 2011) a simulation core, implemented by use of fUML, has been proposed. This paper advocates SysML as a standardized simulation language, and model-driven techniques are introduced to generate the code of a simulation software, starting from SysML behavioral models, such as Activity Diagram. In such a paper the adoption of a model-driven paradigm is limited to the use of the Eclipse Modeling Framework (EMF), specifically the Java Emitter Templates (JET), to generate a basic source code skeleton for each needed class. Moreover, from the implementation point of view, the paper only describes a prototypal implementation of the simulation core. The implementation of a complete simulation solution is planned as a future work.

In (Peak et al., 2007) SysML is used as a notation to support the simulation-based design (SBD) of systems. By presenting several examples, such papers show how SysML is able to capture engineering knowledge needed to derive executable parametric models.

In (Paredis and Johnson, 2008) the use of SysML is proposed to support the system simulation. More specifically, such a paper introduces the use of a graph transformation approach to accomplish an automated transformation between SysML and domain-specific languages.

Differently from the above-mentioned contributions, this paper describes a model-driven method to generate a Java/HLA-based implementation of a distributed simulation software, starting from a SysML specification.

As regards the representation of distributed simulation systems, a large effort has been spent in defining UML profiles for modeling HLA federations, such as in (Topçu and Oğuztüzün, 2000; Topçu et al., 2003; Zhu et al., 2008). Similarly to such contributions, this paper proposes an UML profile to model a HLA-based simulation system that has been partially based on the HLA Object Model Template (OMT) (IEEE, 2000c). Nevertheless, this paper goes far beyond and also takes into consideration the HLA metamodel proposed in (Topçu et al., 2008), in

order to improve the expressiveness of the proposed profile. Moreover, it should be underlined that this paper contribution is not limited to an UML extension for modeling an HLA federation. This work also proposes a model-driven method to generate the implementation of a distributed simulation software, starting from the SysML specification of the system under study.

As regards the issue of implementing (or supporting the implementation of) simulation systems, several contributions can be found in literature that apply a model-driven paradigm in the modeling and simulation domain, such as (D'Ambrogio et al., 2011b; Tolk and Muguira, 2004; Jimenez et al., 2006; Haouzi, 2006)

In (D'Ambrogio et al., 2011b) a method to generate Java/HLA-based implementation of a distributed simulation software, starting from a UML representation of the system, has been proposed. On the one hand, such a contribution constitutes a starting point for this work, as the two papers share the same objective (e.g., the automated generation of the simulation implementation) and the adopted approach (e.g., the model-driven paradigm). On the other hand, this work extends the previous contribution in several ways. The proposed model-driven method is applied to the systems engineering domain thus, in this paper case, the model transformations are driven by the SysML representation of the system under study. Moreover, this paper gives a more extensive description regarding the adopted UML profiles and both the model-to-model and model-to-text transformations that constitute the method implementation, as well.

In (Tolk and Muguira, 2004) a model-driven approach is proposed in the M&S application domain. Specifically, such a contribution proposes the creation of a specific domain for Modeling and Simulation (M&S) within MDA. Differently, this paper adopts MDA techniques to the production of simulation systems treated as general-purpose software systems. This means that, in case of the system under study is a software system, the same approach can be adopted to eventually generate both the operational system and the simulation system from the same model specification. Moreover, the implementation of the proposed method is not complete in terms of both MDA compliance and software. Differently, this paper approach implements a MDA compliant process by introducing two UML profiles and a set of model model-to-model and model-to-text transformations for generating the simulation code from a SysML model specification.

In (Jimenez et al., 2006) a MDA-based develop-

ment of HLA simulation systems is also proposed. Such a contribution is limited to the definition of an initial UML profile for HLA and, differently from the contribution proposed in this paper, does not take into consideration the application of the profile for the implementation of the simulation system.

Finally, in (Haouzi, 2006) the main concepts behind the application of MDA techniques to the development of HLA systems are outlined. Such a contribution is limited to a theoretical discussion about the use of MDA-based techniques in HLA domain. Differently, this work proposes a model-driven approach to reduce the gap between the model specification and the distributed system implementation. An example application is also discussed, in order to show how the application of the proposed method allows to reduce the simulation development effort by automating the production of Java/HLA code from an initial UML-based system specification.

3 HIGH LEVEL ARCHITECTURE (HLA)

The High Level Architecture (HLA) is an IEEE standard (IEEE, 2000b; IEEE, 2000d; IEEE, 2000c; IEEE, 2000a; IEEE, 2007) that provides a general framework for distributed simulation. The standard promotes interoperability and reusability of simulation components in different contexts. The standard is based on the following concepts (Kuhl et al., 1999):

- *Federate*: a simulation program that represents the basic element in HLA;
- *Federation*: a distributed simulation execution composed of a set of federates;
- *Run Time Infrastructure (RTI)*: a simulation-oriented middleware consisting of a local component (i.e., *RTI Local*), which resides on the federate sites, and an executive component (i.e., *RTI Executive*), which is centralized.
- *RTI Ambassador and Federate Ambassador*: the interfaces that handle the communications among the federates and the RTI.

The major improvement introduced by HLA standard is an API that aims to ease the development of DS systems. Unfortunately, HLA still suffers from three main drawbacks: (i) the complexity of the API, (ii) the strictly distributed orientation of the API and (iii) the absence of a standard communication protocol between RTI Local and RTI Executive (D'Ambrogio et al., 2011a).

As stated, this paper aims to propose a method to support the code generation of a distributed

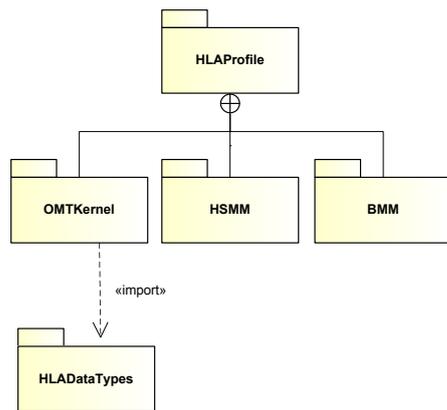


Figure 1: Package structure of the UML profile for HLA.

simulation software. The first step consists of the definition of an UML profile that extends UML in order to represent a HLA-based simulation model. To this respect, the next section presents the proposed HLA profile.

3.1 HLA Profile

The proposed UML profile for HLA (briefly denoted as *HLAProfile*) has been defined in order to model concepts, domain elements and relationships defined by the HLA metamodel (Topçu et al., 2008). For the sake of brevity, the structure of such a metamodel is not discussed in this work; a complete description of the HLA metamodel can be found in (Topçu et al., 2008). The *HLAProfile* includes several stereotypes. In order to manage its complexity it has been organized in several packages, as shown in Figure 1.

3.1.1 HLADatatypes Package

This package includes the datatypes of the several attributes used to specify the stereotypes included in the *OMTKernel* package. Its structure is shown in Figure 2. This package contains the following enumerated types:

- **PSKind:** specifies the publish/subscribe capabilities of a federate. It can assume the following values: *Publish*, *Subscribe*, *PublishSubscribe* or *Neither*;
- **UpdateKind:** specifies the policy for updating an instance of a class attribute. It can assume the following values: *Static*, *Periodic* or *Conditional*;
- **DAKind:** specifies whether ownership of an instance of a class attribute can be released or acquired. It can assume the following values: *Divest*, *Acquire*, *DivestAcquire* or *NoTransfer*;

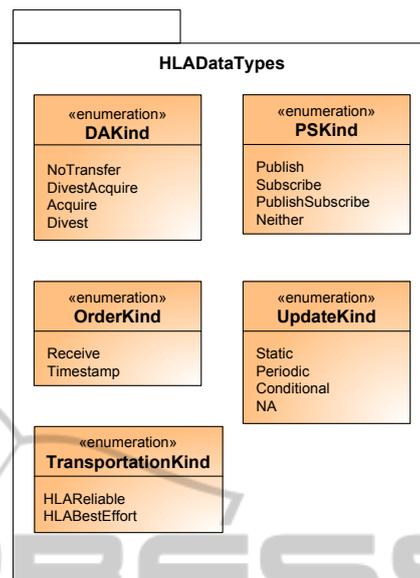


Figure 2: HLADatatypes package structure.

- **TransportationKind:** specifies the transportation type. It can assume the following values: *HLAReliable* or *HLABestEffort*;
- **OrderKind:** specifies the order of delivery. It can assume the following values: *Receive*, *TimeStamp*.

3.1.2 OMTKernel Package

This package includes the stereotypes defined in the HLA OMT specification. The provided stereotypes and the related associations are shown in Figure 3.

- **Federate:** represents a federate within a federation. Extends the UML Component metaclass;
- **ObjectClass:** identifies an Object Class. Extends the UML Class metaclass;
- **InteractionClass:** represents an interaction. Extends the UML Component metaclass and is specified by the following tagged values:
 - Dimension: represents the association of a class attribute with a set of dimensions;
 - Transportation: specifies the transportation type to be used;
 - OrderKind. specifies the order of delivery.
- **HLADimension:** represents a specific dimension for an attribute of an ObjectClass or an InteractionClass. Extends the UML Class metaclass and is specified by the following tagged values:
 - DataType: identifies the datatype for the federate view of the dimension;

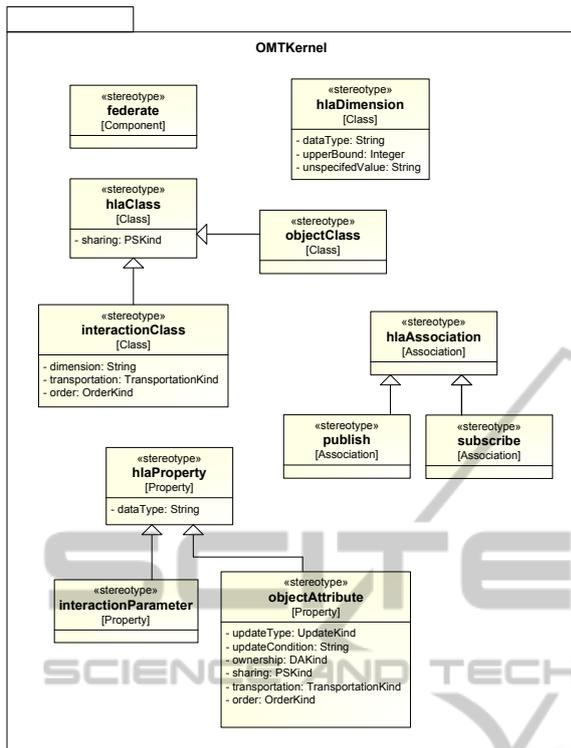


Figure 3: OMTKernel package structure.

- UpperBound: specifies the upper bound that the federation requirements allow;
- UnspecifiedValue: specifies a default range.
- **HLAProperty:** Defines the abstract concept of *properties* that is specialized by ObjectAttribute and InteractionParameter stereotypes. Extends the UML Component metaclass and is specified by the following tagged value:
 - DataType: datatype of attributes or parameters.
- **ObjectAttribute:** represents an object class attribute. Extends the UML Property metaclass and is specified by the following tagged values:
 - UpdateType: specifies the policy for updating an attribute;
 - Ownership: indicates whether ownership of an instance of a class attribute can be released or acquired;
 - Sharing: specifies the publish/subscribe capabilities of a federate with respect to an attribute;
 - Dimension: represents the association of a class attribute with a set of dimensions;
 - Transportation: specify the type of transportation;
 - Order: specify the order of delivery;

- **InteractionParameter:** represents an interaction class attribute. Extends the UML Property metaclass.
- **HLAClass:** represents an abstraction of object class and interaction class. Extends the UML Class metaclass and is specified by the following tagged values:
 - Sharing: represents the information on publication and subscription capabilities;
- **HLAAssociation:** represents an abstraction that is specialized by publish and subscribe stereotypes. Extends the UML Association metaclass;
- **Publish:** represents the association between a Federate and a published element. Extends the UML Association metaclass;
- **Subscribe:** represents the association between a Federate and a subscribed element. Extends the UML Association metaclass.

3.1.3 HSMM Package

This package includes the stereotypes derived by the *HLA service* and *HLA method* concepts, according to the HLA Services Metamodel. Such stereotypes, summarized in Table 1, are defined to model the events defined in the HLA Behavioral Metamodel.

3.1.4 BMM Package

This package includes the stereotypes derived by the HLA Behavioral Metamodel that provides the UML extensions needed to model the observable behavior of the federation, as summarized in Table 2.

4 SYSTEM MODELING LANGUAGE AND HLA

SysML (System Modeling Language) (OMG, 2010) is an UML profile provided by OMG for modeling complex systems in the systems engineering domain. As discussed in Section 1, simulation-based techniques should be introduced during the development of complex systems, in order to conduct an *early assessment* of the system behavior, and thus to determine whether or not the system meets the user requirements.

Unfortunately, the development of distributed simulations starting from SysML specifications requires a non-negligible effort, and SysML does not provide any information that can support such development process.

Table 1: HSMM stereotypes.

Stereotype	Extension	Description
hlaService	Interface	Defines an interface implemented by components acting the role of federate
hlaMethod	Operation	Defines an operation provided by an interface

Table 2: MSC stereotypes.

Stereotype	Extension	Description
action	Message	Identifies a request for executing an operation by a federate
initialization	Message	Identifies messages exchanged to setup the distributed simulation infrastructure
message	Message	Identifies a communications between two federates

Table 3: SysML4HLA stereotypes.

Stereotype	Extension
federate	Block (UML Class)
objectClass	Block (UML Class)
interactionClass	Block (UML Class)

To this respect, this paper proposes an UML profile for extending SysML, in order to enrich a SysML diagram with information needed to support the automated generation of the HLA-based distributed simulation implementation.

4.1 SysML4HLA Profile

This section introduces the *SysML4HLA profile*, an UML profile specifically introduced to annotate a SysML model in order to make such specification suitable to drive a model-driven method for generating the HLA code that implements the distributed distributed simulation. SysML4HLA provide stereotypes that extend the `block` element of SysML, which in turn is an extension of UML *class* metaclass. These stereotypes have been introduced to represent the basic elements of an HLA simulation: federates, objectClasses and interactionClasses. The proposed SysML4HLA profile is shown in Table 3.

5 MODEL-DRIVEN METHOD TO SUPPORT A HLA-BASED DISTRIBUTED SIMULATION

This section illustrates how the UML profiles introduced in sections 3.1 and 4.1 are used to generate the Java/HLA code that implements the distributed simulation software. The proposed method, shown in Figure 4, is founded on model-driven principles and standards and exploits the SysML4HLAProfile and the HLAProfile to enact the automated code generation of the HLA-based simulator.

At the first step, the system under study (and that is going to be simulated) is initially specified in terms of UML diagrams annotated with the SysML profile (e.g., block definition diagrams, sequence diagrams, etc.). According to the model-driven terminology (OMG, 2003), such a model constitutes the platform independent model (PIM) of the system. At this step, the system engineer in charge of producing the system model, is not concerned with any detail regarding the simulation model. The focus is on the specification of an UML-based system design model, starting from the system requirements.

At the second step, the SysML4HLAProfile is used to annotate the PIM in order to enrich such a model with information needed to derive the HLA simulation model. Specifically, the HLA profile allows to specify both how the system has to be partitioned in terms of federation/federates and how system model elements have to be mapped to HLA model elements such as *object class* and *interaction class*.

The third step takes as input the marked PIM and the HLA profile, and carry out the *SysML-to-HLA model-to-model* transformation, in order to automatically obtain an UML model, annotated with the stereotypes provided by the HLA profile, which represents the HLA-oriented simulation model. The latter, according to the model-driven paradigm, constitutes the platform specific model (PSM).

Finally, at the fourth step, the Java/HLA-based code of the simulation model is generated by use of the *HLA-to-Code model-to-text* transformation. This step requires the choice of a specific HLA implementation (e.g., Pitch, Portico, etc.) that provides the HLA services in a given programming language (e.g., Java, C++, etc.)¹.

¹it should be noted the implementation of *HLA-to-Code* transformation provided in this work makes use of Portico and Java. Nevertheless, the model-driven approach at the basis of the proposed method allows to use different HLA implementations or programming languages. All such cases can be easily dealt with by revising the specification of the

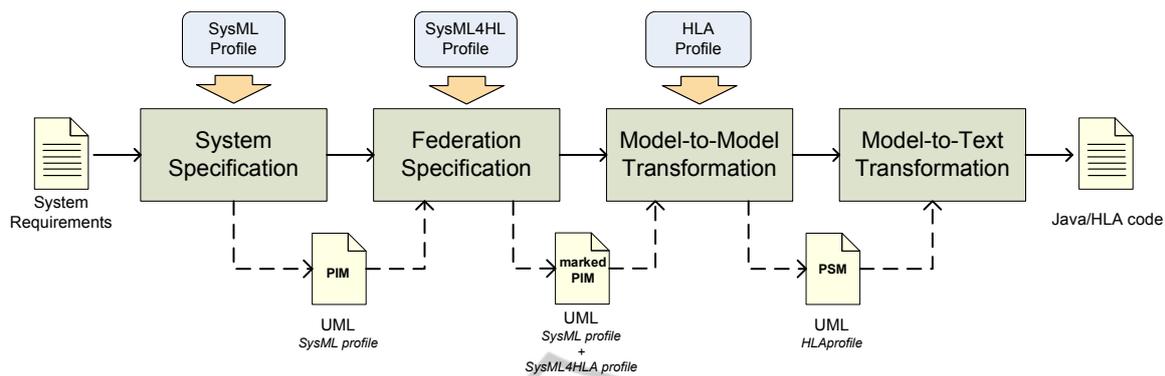


Figure 4: Model-driven method to automate the generation of Java/HLA code.

The following subsections describe the SysML-to-HLA transformation and the HLA-to-Code transformation, respectively.

5.1 SysML-to-HLA Transformation

The SysML-to-HLA model transformation takes as input a UML model representing the system under study and yields as output an UML model that specifies the HLA-based distributed simulation. The input model is annotated with stereotypes provided by both SysML and SysML4HLA profiles, while the output model makes use of the HLA profile.

Specifically, the source model consists of the following SysML diagrams:

- a *Block Definition Diagram*, that defines the static structure of the system to be developed in terms of its physical components;
- a set of *Sequence diagrams*, that show the interactions among system components.

The target model is specified by the following UML diagrams:

- *Structural model*, constituted by a component diagram, that shows the partition of the simulation model in terms of federates;
- *Behavioral model*, constituted by a set of sequence diagrams that show the interactions among the federates and the RTI;
- *Publish/Subscribe diagram*, constituted by a second component diagram, that shows how federates publish or subscribe HLA resources (i.e., *object classes* and *interaction classes*).

As stated in Section 1, the model transformation has been implemented by use of QVT-Operational mapping language (OMG, 2008a), which is provided by the Object Management Group (OMG) as the

HLA-to-Code model-to-text transformation.

standard language for specifying model transformations that can be executed by available transformation engines (Eclipse, 2010; IKV++, 2008). The following subsections 5.1.1, 5.1.2 and 5.1.3 specify, by use of natural language, the mapping rules defined to generate the structural model, the behavioral model and the Publish/Subscribe diagram, respectively.

5.1.1 Structural Model

Rule 1: Depending on its SysML4HLA stereotype (i.e., the role played in the source model), a *block* element in the SysML diagram can be mapped to a *federate element*, an *objectclass element* or an *interaction class element* in the target model.

According to such rule, the main *block element* in the *block definition diagram* stereotyped as <<Federate>>, represents a HLA federate and is thus mapped to an UML *component element*, stereotyped as <<Federate>>. Other *blocks element*, stereotyped as <<Objectclass>> or <<InteractionClass>> and connected by a *composition* relationship with the *block element* represent federate elements, which are mapped to UML *class elements*, stereotyped as <<Objectclass>> or <<InteractionClass>>, respectively, and nested to the federate component.

Rule 2: Attributes of classes representing federate elements in the source model are mapped to class attributes in the target model. Such attributes, associated to the related class in the target model generated according to rule 1, are stereotyped as <<objectAttribute>> and <<interactionParameter>>.

Rule 3: Each UML *class element* in the source model is mapped to an *interface element* in the target model, stereotyped as <<hlaService>>. The related class methods in the target model are mapped to corresponding methods in the source model, stereotyped as <<hlaMethod>>.

Rule 4: Federate component in the target model

generated according to rule 1 is associated to the interfaces generated according to rule 5 by an `implements` association.

Table 4 summarizes the mapping rules.

5.1.2 Behavioral Model

The sequence diagrams in the source model specify the interactions between model elements representing federates (i.e., block elements stereotyped as `<<federate>>`) and/or model elements representing federate elements (i.e., block elements stereotyped as `<<ObjectClass>>` or `<<InteractionClass>>`). The behavioral view of the target model is obtained according to the following rules.

Rule 1: Each UML sequence diagram in the source model is mapped to a sequence diagram in the target model. Such diagrams specify the behavioral view of the target model.

Rule 2: In order to represent interactions between federates and the HLA RTI, each sequence diagram contains an UML component named RTI.

Rule 3: Each sequence diagram in the target model represents the behavior of a federate interacting with its component and/or other federates. The diagram must contain the following messages:

- a self message named *createRTIAmbassador*, stereotyped as `<<initialization>>`;
- a message exchanged between federate and RTI, named *createFederationExecution*, stereotyped as `<<initialization>>`;
- a self message named *createFederateAmbassador*, stereotyped as `<<initialization>>`;
- a message exchanged between federate and RTI, named *enableTimeRegulation*, stereotyped as `<<initialization>>`;
- a message exchanged between federate and RTI, named *joinFederation*, stereotyped as `<<initialization>>`;
- *main flow* according to rules 3 and 4;
- a message exchanged between federate and RTI, named *leaveFederation*, stereotyped as `<<message>>`;

Rule 4: messages included in the source sequence diagram exchanged between a federate and one of its component (i.e., an element stereotyped as `<<federate>>` and an element stereotyped as `<<ObjectClass>>` or `<<InteractionClass>>`, respectively) are mapped to self messages of the federate, stereotyped as `<<action>>`.

Rule 5: messages included in the source sequence diagram exchanged between two federates

are mapped to messages between federate and RTI (and vice-versa). Such messages are stereotyped as `<<messages>>`.

5.1.3 Publish/Subscribe Diagram

The publish/subscribe diagram is generated starting from the block definition diagram, according to the following rules:

Rule 1: Blocks in the source model are mapped to UML classes and components, according to the same rule 1 specified in 5.1.1;

Rule 2: Each composition association between a block *A* stereotyped as `<<federate>>` and a block *B* stereotyped as `<<objectclass>>` or `<<interactionclass>>` is mapped to two different associations between the corresponding elements *C* and *D* in the target model, stereotyped as `<<publish>>` or `<<subscribe>>`, respectively. *C* and *D* are generated from *A* and *B* by applying rule 1.

Rule 3: Each composition association between a block *A* stereotyped as `<<federate>>` and a block *B* stereotyped as `<<objectclass>>` or `<<interactionclass>>`, where a composition association between *A* and *B* does not exist, is mapped to an association between the corresponding elements *C* and *D* in the target model, stereotyped as `<<subscribe>>`. *C* and *D* are generated from *A* and *B* by applying rule 1.

Rule 4: Each composition association between blocks *A* and *B*, both stereotyped as `<<objectclass>>` or `<<interactionclass>>`, where *A* and *B* do not share a composition association with the same block *C*, is mapped to an association between the corresponding elements *D* and *E* in the target model, stereotyped as `<<subscribe>>`. *D* and *E* are generated from *C* and *B* by applying rule 1.

Figure 5 summarizes the above-mentioned mapping rules.

5.2 HLA-to-Code Transformation

The HLA-to-Code model-to-text transformation takes as input an UML model representing the HLA-based simulation system and yields as output the code that constitutes its implementation.

The code generation makes use of Portico (Portico, 2010), an open source implementation of the HLA RTI, and Java as the language for implementing federates and ambassadors. The model-to-text transformation has been implemented by use of Acceleo (Eclipse, 2011), the model-driven Eclipse plugin for code generation.

Table 4: Structural model: SysML to HLA element mapping.

SysML		HLA	
Element (Stereotype)	Diagram	Element (Stereotype)	Diagram
Block (Federate)	BDD	Component (Federate)	Component Diagram
Block (ObjectClass)	BDD	Class (ObjectClass)	Component Diagram
Block (Interaction Class)	BDD	Class (Interaction Class)	Component Diagram
Attribute	BDD	Attribute (objectParameter or interactionParameter)	Component Diagram
Class	BDD	Class (hlaService)	Component Diagram
Operation	BDD	Operation (hlaMethod)	Component Diagram
Attribute	CDD	Attribute (hlaDimension)	Component Diagram

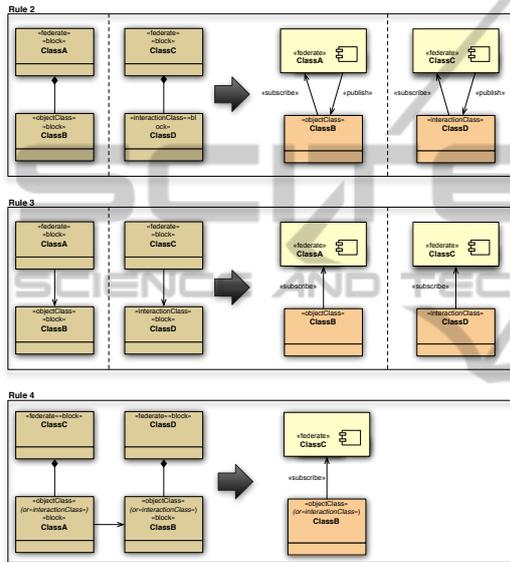


Figure 5: P/S Diagram generation rules.

The implementation of the proposed transformation includes the following *templates*:

- *generateFederate*: for each element in the HLA model stereotyped as <<federate>>, generates a java class that implements the corresponding federate;
- *generateObjIntClass*: for each UML class in the HLA model stereotyped as <objectClass>> or <<interactionClass>>, generates a tag in the XML file in which classes representing objectClass and interactionClass are serialized. In other words, such file constitutes the representation of the FOM (Federate Object Model). Moreover, this template creates, in each class generated by the *generateFederate* template, the method for publishing and subscribing resources, according to the *P/S diagram* of the HLA model.
- *generateAmbassador*: generates a set of java classes constituting the implementation of the required federate ambassadors.

6 EXAMPLE APPLICATION

This Section presents an example application that shows how the proposed model-driven method effectively exploits the UML profiles discussed in sections 3.1 and 4.1, in order to support the simulation of a system by generating the HLA/Java code, starting from its SysML specification.

The proposed example application deals with the development of an automobile, in particular a Hybrid gas/electric powered Sport Utility Vehicle (SUV) (OMG, 2010).

6.1 System Specification

The first step of the method discussed in Section 5 includes the definition of the system model by use of the SysML notation. For the sake of brevity, this example only takes into account the diagrams needed to derive the HLA simulation model and, consequently, the code of the simulation program. Specifically, the SysML automobile model includes the following diagrams:

- *Block definition diagram*, to specify the structural view of the system. The diagram shows the automobile components (e.g., Vehicle, BrakingSystem, Chassis e and Power Control Unit) and their relationship;
- A set of *sequence diagrams*, to specify the behavioral view of the system. Such diagrams describe the interactions between system components.

6.2 Federation Specification

At the second step, the SysML model is refined and annotated with stereotypes provided by the HLAprofile. This step, that constitutes a PIM *marking*, adds to the SysML model the information needed to map each SysML domain element to the corresponding HLA domain element and makes the PIM model ready to be automatically processed by

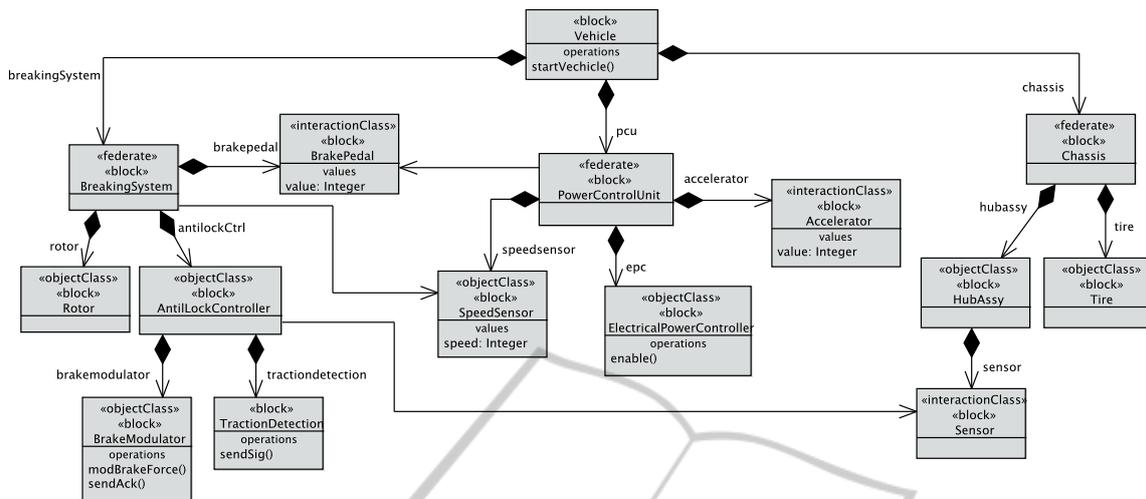


Figure 6: Source model: block definition diagram.

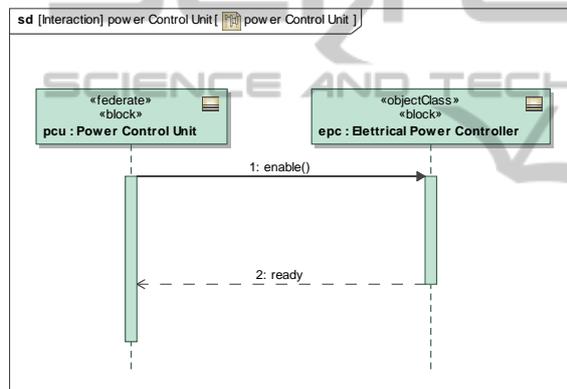


Figure 7: Source model: sequence diagram (interaction between PowerControlUnit and ElectricalPowerController).

the model-driven transformations included in the next steps. As an example, figures 6 and 7 show the BDD and a SD that specifies the interactions between the PowerControlUnit component and the ElectricalPowerController component, respectively.

6.3 SysML-to-HLA transformation

The UML model annotated with SysML and HLA profiles is given as input to the SysML-to-HLA model-to-model transformation, to generate the HLA-based simulation model. As discussed in Section 5.1, the HLA model is composed by a set of UML sequence diagrams, and two UML component diagrams. The set of SDs specifies the behavioral view of the HLA simulation model, the first component diagram describes its structural view, while the other

one shows the publish/subscribe association among federate, objectClass and interactionClass HLA elements.

As an example, figures 8 and 9 depict the UML component diagram showing the structural view and the UML sequence diagram corresponding to the one shown in Figure 7, respectively. For the sake of readability, in such diagrams the adopted stereotype/attributes have not been completely specified.

The component diagram in Figure 8 shows the structure of the simulation model in terms of federate objectClass and interactionClass elements. The diagram also shows the interface elements, stereotyped as hlaServices, that allow each federate to communicate with RTI in order to enact the interactions among federates.

6.4 HLA-to-code Transformation

At the last step of the method shown in Figure 5 the HLA-to-code model-to-text transformation is carried out. Such a transformation takes as input the HLA model produced in the previous step and yields as output the Java/HLA code which implements the HLA-based distributed simulation. It should be noted that the proposed method does not generate the *complete* code that implements the HLA-based distributed simulation. The model-driven method should be considered as a *supporting tool*. More specifically, the HLA-to-code transformation allows to generate a template of the Java classes that contains the class structure (i.e., constructor, method and attribute declarations, exception management, etc.) and most of the HLA-related code (i.e., data types definition, RTI interaction methods, etc.), but the code

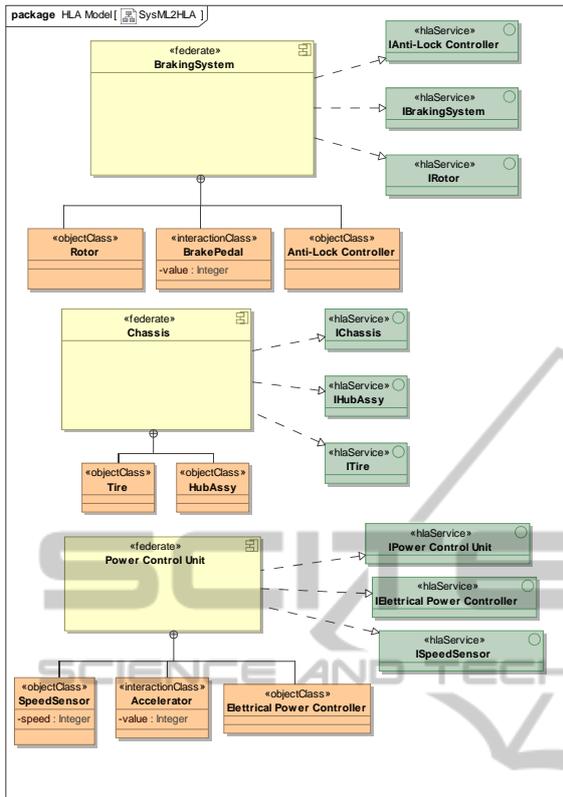


Figure 8: Target model: structural view.

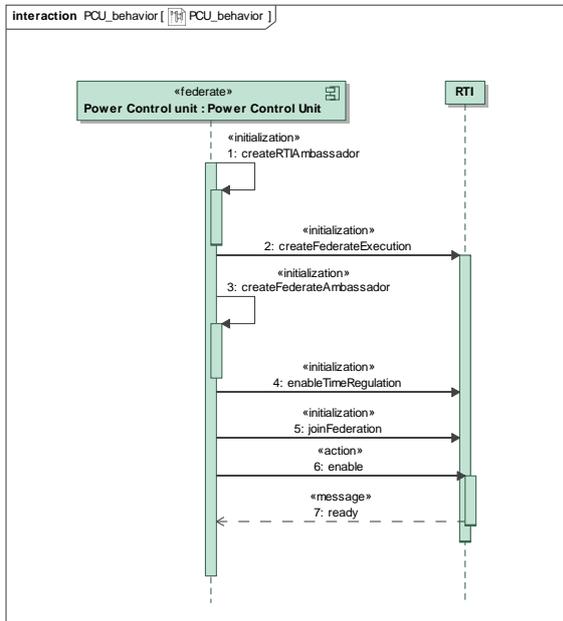


Figure 9: Target model: sequence diagram (interaction between PowerControlUnit federate and RTI).

implementing the federate simulation logic has to be

added manually.

```

1
2 import hla.rti1516.*;
3 ...
4 import org.portico.impl.hla1516.types.DoubleTime;
5
6 public class BrakingSystem{
7 ...
8 public void runFederate() {
9 // create the RTIAmbassador
10 rtiamb = RtiFactoryFactory.getRtiFactory().
    getRtiAmbassador();
11 // create the federation
12 try{
13 File fom = new File("FOM.xml");
14 rtiamb.createFederationExecution("
    ExampleFederation",
15 fom.toURI().toURL());
16 log("Created Federation");
17 }
18 catch(FederationExecutionAlreadyExists exists) {
19 { log("Didn't create federation, it already
    existed");
20 }
21 }
22 catch(MalformedURLException e) {
23 log("Malformed Url");
24 }
25 // create the federate ambassador
26 fedamb = new BrakingSystemAmbassador();
27 this.federateName = "BrakingSystem";
28 //join the federation
29 rtiamb.joinFederationExecution(federateName,"
    ExampleFederation",
30 fedamb, null);
31 log("Joined Federation as " + federateName);
32 /******
33 * place here simulation logic
34 *****/
35 // resign from the federation
36 rtiamb.resignFederationExecution(ResignAction.
    DELETEOBJECTS);
37 log("Resigned from Federation");
38 ...
39 }
40 }
    
```

Listing 1: Java/HLA code generated by HLA-to-code model-to-text transformation (portion).

As an example, a portion of the code that implements the BrakingSystem federate is shown in Listing 1. A comment acts as placeholder to indicate where the code that implements the federate simulation logic has to be placed.

7 CONCLUSIONS

This paper has introduced a model-driven approach to support the code generation of a HLA-based simulation from a SysML specification of the system to be simulated. The approach has introduced two different UML profiles. The first one, named *HLA profile*, is used to annotate an UML diagram in order to represent HLA-based details. The second one, named *SysML4HLA profile*, is used to annotate a SysML-based system specification to support the subsequent automated generation of the HLA-based distributed simulation code. The proposed approach is founded on two transformations that automatically map the source SysML model into a HLA-specific

model and eventually into the Java/HLA source code, as illustrated by an example case study dealing with the automotive domain.

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