From State-transition Models to DEVS Models
Improving DEVS External Interoperability using MetaDEVS - A MDE Approach

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Abstract: In this paper, the issue of the "external" interoperability of DEVS models is discussed. Scientists often need to simulate non-DEVS models using a DEVS-oriented framework, in order, for instance, to make their DEVS and non-DEVS modes interoperate. The source formalisms we propose to transform onto DEVS models are those which are based on the "family" of states and transitions. A general and model-oriented approach called MetaDEVS is presented in this article. MetaDEVS is also the name given to the DEVS metamodel we use. This metamodel allows creating platform-independent DEVS models. This paper shows how models which belong to the state and transitions "family" can be mapped onto DEVS, and more exactly onto MetaDEVS-based DEVS models, following the MetaDEVS approach. Then, the approach is applied to a concrete case: we transform Finite-State Machine (FSM) models into MetaDEVS models, using ATL, a hybrid language (which mixes both declarative and imperative rules), within the Eclipse Modelling Framework. A metamodel to describe the FSM formalism is also proposed.

1 INTRODUCTION

The study of complex systems and natural phenomenons is usually done using approaches and techniques which directly come frome the science of modelling and simulation (M&S). In the area of event-based systems, *Discrete EVent system Simulation* (DEVS) (Zeigler et al. 2000) appears to be one of the most popular formalisms used by the scientists. It has many advantages such as a good extensibility, a clear separation between models and their simulators, and strong simulation protocol and algorithms implemented on several DEVS-oriented platforms using various object-oriented languages.

However, these several platforms decrease the interoperability of DEVS models (Wainer et al. 2010), because a model has to be rewritten in order to be used on another platform than the one for which it was originally created. This illustrates that there is a lack of interoperability which can be called "internal".

Moreover, there exist other formalisms used in M&S which rely on the same concepts as DEVS such as states, and transitions. The DEVS simulation protocol can be used as an "universal simulator", enabling one to integrate a non-DEVS model within a DEVS framework. Indeed, scientists sometimes need to reuse non-DEVS models in order to simulate them with DEVS models. To do so, they have to rewrite their non-DEVS models in order to create DEVS models, and usually do a "mental translation" to reach their goal. This lack of interoperability can be called "external".

In the domain of Software Engineering, a fairly recent research area named Model-Driven Enginnering (MDE) has proposed several concepts and techniques which aim to improve the lifecycle of the models. The final code is no longer seen as the most important element of the model lifecycle, but as one of its elements. It is always the result of one or more transformations. The most important element in MDE is the model itself and every element of the process, including the transformations themselves, is considered as a model.

The main idea of MDE is to maintain a separation between the concepts and their implementation. Many MDE approaches, including the famous Object Management Group (OMG) Model-Driven Architecture (MDA), focus on metamodelling.

A metamodel describe a way to describe models using the concepts of the domain under study, regardless of the implementation. For instance, a DEVS-oriented meta-model enables one to specify

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DEVS models, which can be called Platform-Independent Models (PIMs). MetaDEVS is such a meta-model (Garredu et al., 2012).

The main idea of our work is to improve DEVS internal and external interoperability using MDE techniques and tools.

This article deals with a generic approach which can be used to transform non-DEVS models into DEVS models. To do so, both of the metamodels (source and destination) are required, beacause the transformation rules take place at the metamodel level. We already have the DEVS metamodel, it is named MetaDEVS.

This generic approach is also named after the metamodel we use : MetaDEVS.

Here, we chose to apply the MetaDEVS approach to a well-known formalism : the Finite-State Machines (FSM). In other words, we illustrate the generic approach presented here by providing transformation rules from FSM to DEVS: such a transformation is called a "Model-To-Model" (M2M) transformation.

This article starts with a background section, in which we explore the DEVS formalism, the FSM formalism, and the key concepts of Model-Driven Engineering. This section ends with a short state-of-the-art of other approaches which combine MDE and DEVS, and introduces the the MetaDEVS approach and metamodel.

Then, the third section is dedicated to the design of a metamodel for the FSM formalism.

After that, we put together in the fourth section the ideas presented in the previous sections and we present the MetaDEVS approach applied to our problem (M2M transformations), begining with the global aspects of the approach, and ending with its application to the transformation between FSM and MetaDEVS. This section is concluded by an example of such a transformation: we present a simple FSM model and show how we automatically transformed it into a MetaDEVS platform independent model.

Finally, we conclude this paper after having discussed the results of the transformation from FSM to MetaDEVS.

2 BACKGROUND

This background section is dedicated to the concepts used in the MetaDEVS approach; we start with an overview of the DEVS formalism and the two kinds of DEVS models (atomic and coupled). We also make a brief recall of the well-known FSM formalism.

2.1 Classic DEVS Formalism

Since the 1970s, formal tasks have been performed to develop the theoretical foundations of modelling and simulating discrete event dynamic systems.

One of the most popular discrete-event formalisms is the DEVS formalism (Discrete Event system Specification) (Zeigler, 1989) (Zeigler et al. 2000). The DEVS formalism may be defined as a universal and general methodology, which provides tools to model and simulate systems, the behaviour of which is based on the notion of events.

This formalism is based on the systems theory and the notion of the model and permits the specification of complex discrete event systems in modular and hierarchical form. Major efforts have been made to adapt this formalism to various domains and situations (Barros, 1997) (Bisgambiglia et al., 2009) (Wainer et al., 2011).

DEVS has been implemented on several platforms, such as PowerDEVS (Kofman et al., 2003), which uses C++, JDEVS (Filippi, 2003), which uses Java, DEVSimPy (Capocchi et al., 2011), based on PyDEVS (Bolduc et al., 2001), which both use Python. This leads to a lack of interoperability between DEVS models.

At this time, there is no standard and platform-independent representation of DEVS models, but there exist several approaches, which try to reach this goal.

DEVS is composed of two kinds of models: the atomic models and the coupled models.

Since they are not used in this paper, coupled models are not described here.

The smallest element in DEVS is the atomic model. It is specified as follows :

$$AM = < X, Y, S, ta, \delta_{int}, \delta_{ext}, \lambda >$$

where

- $X = \{(p,v) | p \in InputPorts, v \in X_p\}$ is the input events set, through which external events are received; *InputPorts* is the set of input ports and X_p is the set of possible values for those input ports;
- $Y = \{(p,v) | p \in OutputPorts, v \in Y_p\}$ is the output events set, through which external events are sent; *OutputPorts* is the set of output ports and Y_p is the set of possible values for those output ports;
- S is the states set of the system;
- $ta: S \rightarrow R_0^+ \cup +\infty$ is the time advance function (or lifespan of a state);
- $\delta_{int}: S \rightarrow S$ is the internal transition function;
- $\delta_{ext}: Q \times X \rightarrow S$ with $Q = \{(s,e)/s \in S, e \in [0,ta(s)]\}$ is

the external transition function;
- λ: $S \rightarrow Y$, with $Y = \{(p,v) | p \in OutputPorts,\ v \in Y_p\}$ is the output function.

The most simple transition is called the internal transition: at a given moment, a system is in a state $s \in S$. Unless an external event occurs on an input port, the system remains in the s state for a duration defined by $ta(s)$. When $ta(s)$ expires, the model sends the value defined by $\lambda(s)$ on an output port $y \in Y$, and then it changes to a new state defined by $\delta_{int}(s)$. Such a transition, which occurs because of the expiration of $ta(s)$, is an internal transition.

The other transition type is the external transition; it is triggered by an external event. In this case, it is the $\delta_{ext}(s,e,x)$ function which defines which state is the next one (s is the current state, e is the elapsed time since the last transition, and $x \in X$ is the event received).

In both cases, the system is now in a new state s' for a new duration $d' = ta(s')$ and the algorithm restarts.

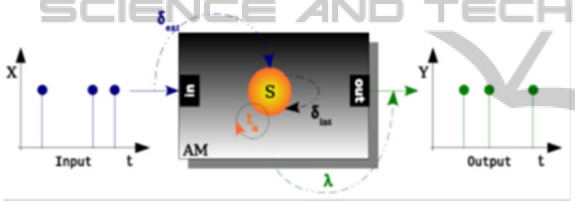


Figure 1: A DEVS atomic model.

The time advance function can take particular values. If its value is $+\infty$, the state s is *passive*: the system will remain in this state unless an external event occurs. When implementing the time advance function for a passive state, $+\infty$ will have to be translated into a keyword (or a particular value) known by the programming language.

On the other hand, if its value is zero, the state s is a *transient* state: it instantaneously triggers the $\delta_{int}(s)$ function. Figure 1 shows a representation of a DEVS atomic model.

2.2 Finite-State Machines

The Finite-State Machine is a well-known formalism based on the set theory (Glushkov, 1961) (Hopcroft et al., 1976). It is widely used for the modelling of protocols, processes, and the description of compilers, regular grammars.

A FSM (or automaton) is described as follows :

$$A = < S, \Sigma, \delta, I, F >$$

where:
- S is a finite state set;
- Σ is a finite alphabet (and ε is its « empty word »);
- δ is the set of the transitinos : $\delta \subseteq (Q \times (\Sigma \cup \{\varepsilon\}) \times Q)$;
- I is the set of the initial states : $I \subseteq Q$;
- F is the set of the final states : $T \subseteq Q$.

The most used FSM are deterministic. In this case, $Card(I) = 1$ and for a given state s and a given letter a, there exists at most one transition starting from s with the label a : $\forall s \in S, \forall a \in \Sigma, Card(\delta(s,a)) \leq 1$

2.3 Model-Driven Engineering

Model Driven Engineering is a software development generic methodology that focuses on creating and exploiting domain models. Metamodels, models and transformations are the most important concepts of MDE.

2.3.1 Models and Metamodels

The models, which describe the real world, conform to a *metamodel*, located at a higher abstraction level. The metamodel conforms to a *meta-metamodel*, or *metaformalism*, itself located at a higher abstraction level. A *metaformalism* conforms to itself (self-description).

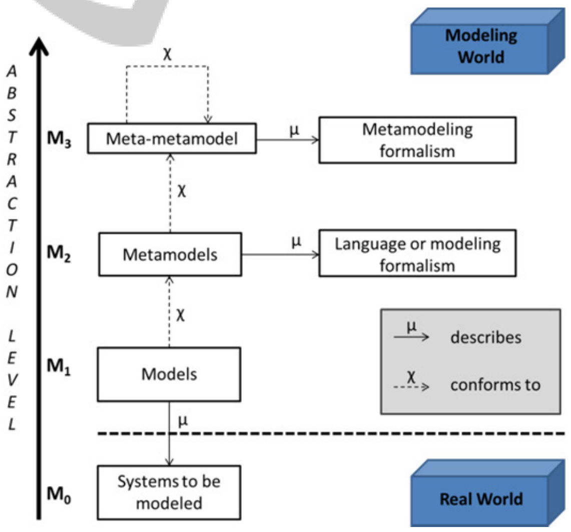


Figure 2: MDE *meta* levels.

The concepts of conformance and description are discussed in (Bézivin, 2004). Figure 2 depicts the relationships between the several abstraction levels of MDE.

Each MDE-oriented approach is located in a given *technological space* (Kurtev, 2002). The nature of the technological space depends on the metaformalism used at the top of the approach. For instance, MDE's most famous incarnation is the Model Driven Architecture, owned by the OMG, located in the object-oriented technological space, because MDA's metaformalism is the Meta-Object Facility (MOF), a subset of Unified Modelling Language (UML) (OMG, 2013). A MDE approach, which uses the metaformalism XML Schema, would be located in the XML technological space.

The purpose of a MDE approach is to list the domain concepts and express them, their attributes, their relationships, in a metamodel, without being tied to any implementation platform. Such a metamodel allows creating platform-independent models, called PIM in the MDA approach.

Those PIMs can be transformed into platform-specific models (PSMs), or even into code.

2.3.2 Transformations

The purpose of a transformation is to transform a source model into a destination model.

A "Model-To-Model" (M2M) transformation involves two models, while a "Model-To-Text" (M2T) transformation involves a source model which will be transformed into code (the code is considered as a particular model).

A transformation is made by following several transformation rules, which can be declarative, imperative, and even hybrid (mixing declarative and imperative aspects) (QVT, 2013). For the implementation of our transformation, we use a language able to express such hybrid rules: ATLas Transformation Language (ATL) (Jouault et al., 2006). This language is available as a plugin within the EMF framework (Steinberg et al., 2009).

2.4 DEVS and MDE

In this section, we will only focus on the approaches that propose a metamodel for DEVS formalism. The main drawback of many of them is that the states set has only one dimension (e.g. one state variable) and the states are only qualitatitative. However, (Cetinkaya et al., 2012) and (Garredu et al., 2012) propose metamodels that allow to handle in their atomic functions multi-dimensional states with quantitative state variables. Other approaches aim to let the programmer fill in empty code blocks (Song, 2006) (Touraille et al., 2010).

2.4.1 Existing Non-MOF DEVS Metamodels

Many approaches use XML to specify the DEVS basic elements, such as (Mittal et al., 2007) which can be considered as a "hybrid" approach as it uses SOA in order to perform the simulation. DTDs are used to describe the structure of a DEVS component.

A DEVS framework named SimStudio uses a similar specification language named DML (Touraille et al., 2010). It also has its own simulation engine called DEVS-MS. In this approach, the XML schema (and not the DTD) gives the structure of a DEVS component. This approach fully complies with OMG MDA specifications.

Two DEVS meta-models were also specified using Entity-Relationship diagrams, the meta-meta-formalism used by AToM^3 (Posse et al., 2003) (Song, 2006).

2.4.2 DEVS Meta-Models in MOF

This category refers to the metamodels located in the object-oriented technical space. The implementation of the MOD-like approaches often uses Ecore as a metaformalism. Ecore is the metaformalism used by EMF, and it is a subset of MOF. Approaches of this family are more recent than the other ones. Some examples of them are EMF-DEVS (Sarjoughian et al., 2012), MDD4MS (Cetinkaya et al., 2012) and MetaDEVS (Garredu et al., 2012). The latter is briefly presented in the following section.

2.4.3 The MetaDEVS Approach

This approach focuses on three main ideas:

- The central idea is the creation of a metamodel for DEVS named MetaDEVS. This metamodel allows creating platform-independent DEVS models, it is able to handle quantitative state variables and specify DEVS atomic functions (see 2.4.4).
- The issue of DEVS "external" interoperability. Thanks to M2M transformations, DEVS formalism can be used as a target for other formalisms. The purpose of this paper is to illustrate that.
- The issue of DEVS "internal" interoperability. This part of MetaDEVS approach is not detailed in this article : it provides a code generation method from a MetaDEVS model towards a DEVS-oriented simulation code ("Model-To-Text", or M2T approach) using templates.

To solve the external interoperability issue, we will use the MetaDEVS metamodel and the second idea mentionned above.

The approach falls into 3 parts : in the first one, we globally identify the concepts shared in common by DEVS and the state/transition formalisms. In the second one, we use a pseudo-language to express, for each concept, the transformation from the source formalisms to MetaDEVS. Those two first steps have to be achieved only once. The third part is the application of the MetaDEVS approach to a particular source formalism, and the creation of its metamodel (if it does not exist). The generic rules previously defined will be refined and adapted to the transformation context. This third step, which is the hardest one, has to be achived for every new source formalism.

2.4.4 The MetaDEVS Metamodel

This metamodel is detailed in (Garredu et al., 2012). It is fully compliant with MDE and in particular MDA specifications.

We chose to represent a state by what we call a *state variable* or *StateVar*. It takes a new value when the state changes (i.e. each new state change will lead to a change of the value of the state variable).

A state variable must be named, and must be typed. It can also be affected a literal value (initial value).

State variables and types are included in a larger set which name is *DEVSXpression*. It is one of the basis of the MetaDEVS metamodel. As a *StateVar* is a *DEVSExpression*, a *LitteralBasicValue* (LBV) is also a simpler one, in fact the simplest one because it is composed of a unique typed value. Even the *Ports* (not detailed here) have an inheritance link with DEVSXpression, but for clarity reasons (the DEVS concepts must appear clearly in order to be easily handled) they own their own package.

In spite of the differences between the four DEVS atomic functions, we can notice that every function describes a test, an action on a variable, or a message. Those descriptions follow a sort of pattern, which is often the same: a set of enumerations. We call those enumerations *DEVS Rules*.

The purpose of a rule is to represent a set of operations on specific elements. To be more accurate, these are not exactly operations but *descriptions*. A DEVS function is composed of one or several rules. A rule is always composed of a *condition* and an *action*. Table 1 sums this up.

A *Condition* is described by a test: a left member, a comparator, and a right member. It can be a test on an input port (in the case of an external transition function) or on a state variable (in every DEVS atomic function, there is a test on a state variable). There exist two kinds of *Condition*: the *StateVarComparison*, described by a StateVar, a comparator, and a DEVSXpression, and the *InputPortComparison*, described by an *InputPort*, a comparator and a *DEVSXpression*.

An *action* is in fact the *description* of an action: an output action (on a port), or a state change action (in the case of a transition function). There exist two kinds of *Action*: the *OutputAction* and the *StateChangeAction*.

Table 1: DEVS atomic functions and their associated operations.

	Test (condition)		*Description of an Action*		
	State Test	*Port Test*	*Returns Value*	*Changes State*	*Sends message*
δ_{int}	*YES*			*YES*	
δ_{ext}	*YES*	*YES*		*YES*	
λ	*YES*				*YES*
ta	*YES*		*YES*		

An *OutputAction* is described by a *port* and a *message* (a DEVSXpression), while a *StateChangeAction*, used in the transition functions, is described by the *StateVar* to be changed, and a new value (*DEVSXpression*). Finally, we present the DEVSModel package, which contains the basic hierarchy of DEVS models in MetaDEVS (see figure 3). There is a link between *DEVSXpression* and *AtomicDEVS*: an AtomicDEVS contains references to the *DEVSXpression* it handles.

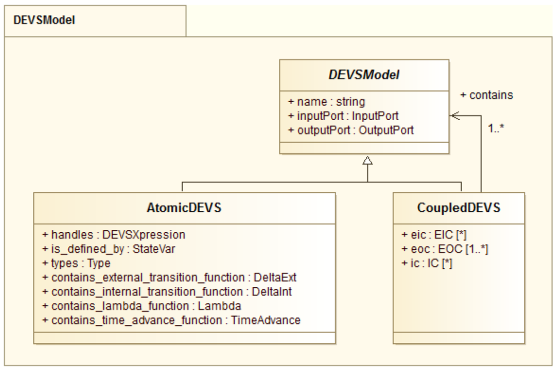

DEVSModel
DEVSModel
+ name : string
+ inputPort : InputPort
+ outputPort : OutputPort
+ contains
1..*
AtomicDEVS
+ handles : DEVSXpression
+ is_defined_by : StateVar
+ types : Type
+ contains_external_transition_function : DeltaExt
+ contains_internal_transition_function : DeltaInt
+ contains_lambda_function : Lambda
+ contains_time_advance_function : TimeAdvance
CoupledDEVS
+ eic : EIC [*]
+ eoc : EOC [1..*]
+ ic : IC [*]

Figure 3: The *DEVSModel* package.

Note that StateVar, even if it is a DEVSXpression, is the basis of the state of a model, according to the DEVS principles. Hence, it appears clearly in the metamodel.

3 A FSM METAMODEL

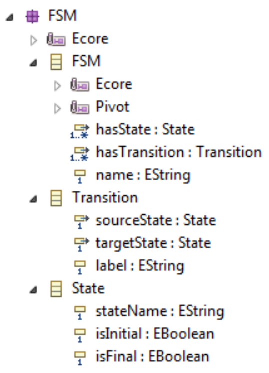
In this small section, we shortly present our proposal of a metamodel for the FSM formalism (restricted to deterministic automata).

A FSM model must have one initial state, and at least one final state. Two states cannot have the same identifier. A transition involves one source state and one target state. Two transitions with the same source state cannot have the same label. A state cannot be both initial and final.

The metamodel we propose is shown in figure 5. Some of the constraints mentioned above are not shown here: they are expressed with OCL.

This metamodel is a screenshot of the EMF Ecore editor; it is an equivalent view as a classic UML class diagram, and can be used for very simple metamodels. To create a FSM model, three very simple steps have to be followed:

- create the model and give it a name
- create the model's states. Each state has an identifier (string). A state can be initial or final. The default value of the attributes *isInitial* and *isFinal* is set to *false*.
- create the transitions between the states. Each transition has a source state, a target state, and a label. The label symbolizes the letter read by the automaton.



```
FSM
  Ecore
  FSM
    Ecore
    Pivot
    hasState : State
    hasTransition : Transition
    name : EString
  Transition
    sourceState : State
    targetState : State
    label : EString
  State
    stateName : EString
    isInitial : EBoolean
    isFinal : EBoolean
```

Figure 4: The FSM metamodel (EMF screenshot).

4 DEVS EXTERNAL INTEROPERABILITY

We have presented in 2.4.4 an overview of the MetaDEVS approach. In this section, we focus on a part of this approach: the issue of the external interoperability of the DEVS formalism. We and provide a general and practical method, based on MDE and M2M transformations, to transform any formalism based on states and transitions onto DEVS formalism, described in our case by the MetaDEVS metamodel.

This method starts from the need scientists have to simulate non-DEVS models within DEVS-oriented platforms, in order to take advantage of the DEVS simulation algorithms, to simulate their models with DEVS models, and also to reuse those previous models without rewriting them into DEVS terms. This method lies on the fact that DEVS and other formalisms share concepts in common. Those formalisms can be untimed (e.g. Finite-State Machines) or timed (e.g. Timed Petri Nets). Moreover, it has been formally proved (Vangheluwe, 2000) that for every model based on discrete-events, and even every model based on states and transitions, a DEVS model exists.

4.1 M2M Transformations in DEVS Context

In this section, we detail the transformation process from a language which belongs to the state-transition family, towards DEVS concepts, in particular those handled by the MetaDEVS.

4.1.1 Overview of a M2M Transformation towards DEVS

If we apply to DEVS the ideas exposed before, we obtain the basis of the MetaDEVS approach regarding the DEVS external interoperability. The transformation from a non-DEVS model into a DEVS model is described at the M2 (metamodel) level, then executed at the M1 (model) level. Figure 5 shows the basis of the approach.

Note that both of the metamodels, which will be used to illustrate such a transformation (MetaDEVS and the FSM metamodel), conform in our case to EMOF (Ecore).

4.1.2 Concepts

Here, we look deeper into the definition of a transformation. As we said before, the proposed

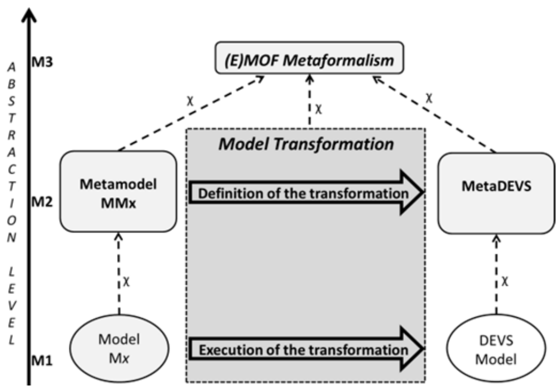


Figure 5: A basic M2M transformation towards DEVS.

method is made possible by the sharing of some key concepts between DEVS and other formalisms based on states and transitions.

Those concepts are the *model*, the *state* (and the notion of initial state), the *transition*, and sometimes, the *port*. They are shown in table 2, which also gives the DEVS "incarnation" of those concepts.

Table 2: General concepts shared by DEVS and formalisms based on states and transitions.

SOURCE	***TARGET***
Model	AtomicDEVS or CoupledDEVS
State	One or more LitteralBasicValue linked to one or more StateVar
Port	InputPort or OutputPort
Transition	DeltaInt or DeltaExt

4.1.3 Generic Rules

The definition of a transformation always starts with rules. As, at this stage, we do not know what will exactly be the source formalism, we need to make our rules be as generic as possible. A rule usually looks for an element in the source model (optional), then creates an element in the target model.

A rule can take arguments, call another rule, or be called by another one. We use this mechanism ("coupled" rules) to reuse most of the rules we created: for instance, a rule, which creates a *LitteralBasicValue* in the target model, will always have the same form, whatever the source formalism is ("immutable" rule). On the other hand, the rule that calls it behaves as an "intermediate rule". It will change every time the source formalism changes.

We write our rules with a pseudo-language, close to the OMG QVT specification.

The first rule to set up is the one that browses the source model in order to recreate its hierarchy (if the source formalism has one) into the target model. This rule is particular, because it is at the top of the transformation definition, and does not create (directly) anything in the target model. Its pseudo-code has the following form :

```
rule createHierarchy(s : SMM!Model)
if s.containsModels()
 createCoupledDEVS(s);
else
 createAtomicDEVS(s);
```

where *SMM* is the source metamodel, *Model* the meta-element which designates a model in the source formalism, and *s* its current instance (i.e. the source model). *Dev* is the instance of AtomicDEVS which is being created.

The rules called by this first rule will create elements in the target model. In this paper, we will assume that the source formalism does not have the ability to specify a hierarchy. Hence, we will focus on the second rule.

The rule `createAtomicDEVS()` has the following (simplified) form :

```
rule createAtomicDEVS(s : SMM!Model)
to dev : DEVS!AtomicDEVS
dev.name=s.name;
dev.handles = collectLBV(s);
DEVS!DeltaInt;
DEVS!DeltaExt ;
DEVS!Lambda ;
DEVS!TA ;
dev.InputPort=collectInputPorts(s)
dev.outputPort=collectOutputPorts(s)
```

We suppose here that the source model is named (attribute *name*). Then the four DEVS behavioral (atomic) functions are each one instantiated once. Finally, the rule calls two rules in order to collect the source model's input and output ports. Then, those rules will be in charge with the creation of the two kinds of ports in the target model, by calling port creation rules. This combination of rules is not detailed here.

The four atomic functions have now to be filled in. To do so, the first step is to collect all the values handled by the source model. We propose once again a combination of two rules, one will collect each value handled by the source model and then call the other one which will create the corresponding *LitteralBasicValue* in the destination model, passing as parameter the retrieved value. Those rules have the following form:

```
rule collectLBV(s : SMM!Model)
 foreach (s.handledValues)
     createLBV(s.valeursManipulées)

rule createLBV(m : value)
to lbv : DEVS!LitteralBasicValue
   lbv.isAlwaysTyped=<manually>
   lbv.(int/str/char/…)val=m.value
```

Note that the harvest of the values depends on the source formalism; we suppose here that it is done with "handleValues" and that the type is verified. Also note that in the second rule, the value type is not known, and will be manually filled. It is possible to write a function which does it automatically.

Finally, the values must be linked to the target model, using a reference in the target model (see rule `createAtomicDEVS()`):

```
   dev.handles = collectLBV(s)
```

The second step is to create the *StateVar*(s) handled by the target atomic model. The number of *StateVar* depends on the nature of the source metamodel, for instance, a FSM will be transformed into a DEVS atomic model that will have only on state variable. The initial value of the *StateVar* will be chosen among the previously created LBVs.

The third step is to create some very important and immutable rules: the rules, which will be in charge with the creation of the two *Condition* kinds (StateVarComparison and InputPortComparison), and the two *Action* kinds (*OutputAction* and *StateChangeAction*). Those "immutable" rules will be called during the filling of the DEVS atomic functions in the target model.

We give an example of each kind of rules, the `createSVC()` rule creates a *StateVarComparison*, and the rule `createSCA()` creates a `StateChangeAction()`(used in the transition functions).

```
   rule   createSVC(s:   SMM!State,   sv:
   DEVS!StateVar)
   to sv : DEVS!StateVarComparison
      left_member <- sv,
      right_member<-select(DEVS!LBV,
      s.value)
      rule  createSCA(t:  SMM!Transition,
      sv: DEVS!StateVar)
      to sv : DEVS!StateChangeAction
      state_to_be_changed <- sv
      new_value<-select(DEVS!LBV,
      t.targetState)
```

The fourth step consists in filling the atomic functions. For instance, the *DeltaInt* function needs to be filled in with *Rules*, composed of a *StateVarComparison* and a *StateChangeAction*.

```
   rule createDintRule(t:SMM!Transition
   , sv: DEVS!StateVar)
   to sv : DEVS!DeltaIntRule
      tests <- createSVC(t.source,sv)
      changes_state <- createSCA(t,sv)
```

The three other functions are not detailed here. The major difficulty with MetaDEVS approach is to create the rules of the fourth step, by taking into account the specifications of the source metamodel, in order to find the best way to represent it in DEVS terms.

4.2 From FSM Models to MetaDEVS Models

In this section, we apply the generic rules to a concrete case: the transformation of a FSM model into a MetaDEVS model, using the part of the MetaDEVS approach dedicated to the M2M transformations.

4.2.1 Discussion

First of all, we need to think about the basic requirements of the transformation, by asking ourselves a few questions, which are common to all the MetaDEVS transformations: they must be linked to the ideas presented in 4.1.2.

Those questions are: what DEVS concepts are not represented in the source metamodel (FSM)? How can we translate them into DEVS terms without modifying the behaviour of the input model? How does the destination model have to behave?

4.2.1 Proposal

A FSM evolves by reading letters. Even if it doesn't have any input, the resulting DEVS model needs to read those letters on its input port. Hence, we need to create an input port in the destination model.

If we reason even further, we notice that reading a letter which arrives on an input port will trigger, in DEVS terms, an external transition function. A first proposal for the basic behaviour of the target model can be the following one: while nothing happens on the input port, stay in the current state for an infinite time.

There is no internal transition and no temporized state in the basic FSM formalism. However, a DEVS atomic model needs its *DeltaInt* function not to be empty. What particular transitions in the source model may correspond to *DeltaInt* in DEVS terms? If the basic transitions in the target model are, as we said, triggered by letters read by the input port, we can assume that all the states of the target model have an infinite duration. If we do so, we will never know when a word has been recognized.

To solve this, a possible solution is to assign, to every final state:

- a lifespan with value below infinity, but above the "arrival frequency" of the letters on the input port;
- an internal transition function, the target state of which is not important: our purpose is to trigger *Lambda*;
- a *Lambda* rule which, when the lifespan of the state expires, send a message on the output port in order to warn that the word has been recognized (so, we also need an output port in the target model).

This helpful global reasoning is to be applied for each MetaDEVS M2M transformation.The general rules presented above have to be specialized and adapted to the current case: this is the last step (not shown here) of MetaDEVS, it is illustrated by table 3 sums our discussion up and can be seen as a specialization of table 2.

Table 3: MetaDEVS approach applied to FSM: a guideline for the M2M transformation rules.

SOURCE	***TARGET***
FSM	AtomicDEVS
State List	Several **StringValue** in only one StateVar (DEVSid="FSMState")
State List	TimeAdvanceRule > "arrival frequency" if final state, else equals to infinity
-	1 InputPort and 1 OutputPort
Transition	DeltaExtRule based on the name of the state and the input letter read
Transition	Create as much as LambdaRule as there are transitions towards final states
-	Create as much as DeltaIntRule as there exist final states

4.3 Example

Let us take the following FSM as an example It is able to recognize the words described by the regular expression: `mi[[ui]*[m]*]*`.

Let us call it the "MIU" automaton. It is composed of three states, the first is the initial state, and the last is the final state.

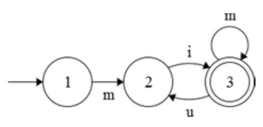
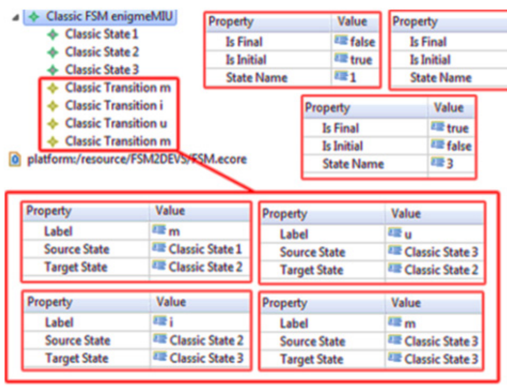


Figure 6: The automaton designed following the FSM metamodel specifications.

Figure 7 shows an EMF screenshot of the corresponding instance created within the FSM



Classic FSM enigmeMIU
- Classic State 1
- Classic State 2
- Classic State 3
- Classic Transition m
- Classic Transition i
- Classic Transition u
- Classic Transition m

platform:/resource/FSM2DEVS/FSM.ecore

Property	Value
Is Final	false
Is Initial	true
State Name	1

Property	Value
Is Final	false
Is Initial	false
State Name	2

Property	Value
Is Final	true
Is Initial	false
State Name	3

Property	Value
Label	m
Source State	Classic State 1
Target State	Classic State 2

Property	Value
Label	u
Source State	Classic State 3
Target State	Classic State 2

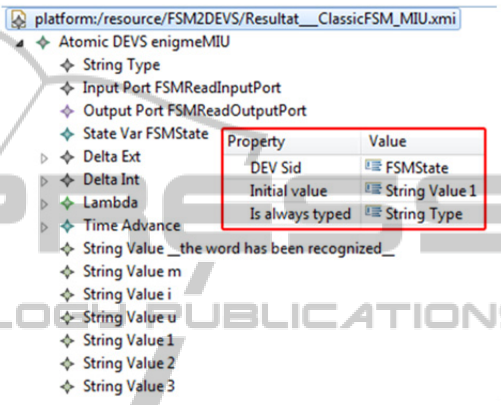
Property	Value
Label	i
Source State	Classic State 2
Target State	Classic State 3

Property	Value
Label	m
Source State	Classic State 3
Target State	Classic State 3

Figure 7: EMF screenshot of the "MIU" automaton.

metamodel presented in 3. The transformation definition was implemented within EMF using ATL language. The rules are based on the ones we previously presented.

The result of the automatic transformation is partially shown here. The resulting model is an *AtomicDEVS* model, with an *InputPort*, an *OutputPort*, a StateVar named "FSMState", seven *StringValue* : "m", "i", "u", "1", "2", "3", "word recognized", and the four behavioral atomic functions (figure 8).



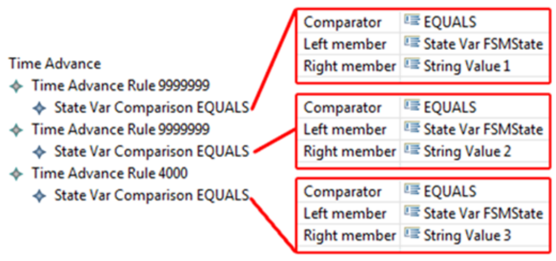
platform:/resource/FSM2DEVS/Resultat__ClassicFSM_MIU.xmi
- Atomic DEVS enigmeMIU
  - String Type
  - Input Port FSMReadInputPort
  - Output Port FSMReadOutputPort
  - State Var FSMState
  - Delta Ext
  - Delta Int
  - Lambda
  - Time Advance
  - String Value _the word has been recognized_
  - String Value m
  - String Value i
  - String Value u
  - String Value 1
  - String Value 2
  - String Value 3

Property	Value
DEV Sid	FSMState
Initial value	String Value 1
Is always typed	String Type

Figure 8: The target model generated by the execution of the transformation.

The initial state has been preserved by the transformation.

If we look at the *TimeAdvance* function, we can see it is conform to our proposal made in 4.2.1. The final state as a lifespan which is below infinity (we assume that it is above the "arrival frequency" of the letters). The two other states have an infinite lifespan. Figure 9 shows a screenshot of this function.



Time Advance
- Time Advance Rule 9999999
  - State Var Comparison EQUALS
- Time Advance Rule 9999999
  - State Var Comparison EQUALS
- Time Advance Rule 4000
  - State Var Comparison EQUALS

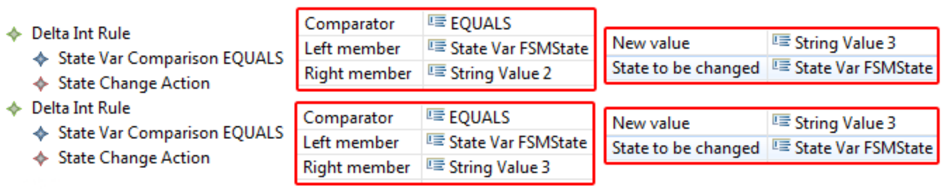
Comparator	EQUALS
Left member	State Var FSMState
Right member	String Value 1

Comparator	EQUALS
Left member	State Var FSMState
Right member	String Value 2

Comparator	EQUALS
Left member	State Var FSMState
Right member	String Value 3

Figure 9: The generated *TimeAdvance* function.

The DeltaInt function also conforms to our expectations. It takes into account the two transitions which are fired towards the target state (from state 2 to state 3, from state 3 to itself). This function is shown on figure 10.



- Delta Int Rule
  - State Var Comparison EQUALS
  - State Change Action
- Delta Int Rule
  - State Var Comparison EQUALS
  - State Change Action

Comparator	EQUALS
Left member	State Var FSMState
Right member	String Value 2

New value	String Value 3
State to be changed	State Var FSMState

Comparator	EQUALS
Left member	State Var FSMState
Right member	String Value 3

New value	String Value 3
State to be changed	State Var FSMState

Figure 10: The generated *DeltaInt* function.

According to our expectations, the generated *Lambda* function definition follows the *DeltaInt* specifications, and describes an *OutputAction* which will be triggered if the lifespans of the states 2 or 3 expire (not shown here).

Finally, the *DeltaExt* function definition shows that the transitions of the source FSM model and the generated *MetaDEVS* model match: the four FSM transitions are preserved, they have been turned into four *DeltaExt* rules (state “1” to state “2”, state “2” to state “3”, state “3” to state “2”, state “3” to state “3”).

This example shows that with what we know about the source possible formalism, we can establish generic rules in order to transform non-DEVS models onto DEVS formalism, represented by the MetaDEVS metamodel. This approach for M2M transformations is a part of a larger approach also named MetaDEVS. The generic rules, expressed with a pseudo language, were applied to a concrete case: a transformation between a simple FSM and MetaDEVS. The results are those we expected. The FSM model has now become a DEVS model, fully specified without any code line.

The implementation was made within the EMF framework, where both of the metamodels we used were designed. We also used the ATL plugin. The approach we followed is fully compliant with MDE/MDA.

5 CONCLUSIONS

In this paper, we have proposed a MDE-oriented approach, based on M2M transformations, in order to increase the external interoperability of DEVS formalism. This approach, named MetaDEVS, is based on a DEVS target metamodel named MetaDEVS. This model allows specifying DEVS models without any reference to any simulation platform. In other words, the MetaDEVS metamodel is able to specify platform-independent models.

Our approach is based on the concepts, which are shared by DEVS, and other formalisms based on states and transitions. It has been validated by a transformation definition between FSM and MetaDEVS. The generated MetaDEVS model is ready to be connected to a letter generator (i.e. used in a coupled MetaDEVS model).

Another part of the MetaDEVS proposes a solution to the “internal” interoperability of DEVS models: having shown that MetaDEVS was a solution to describe DEVS models in a platform-independent way, we propose a method to generate object-oriented code directly from MetaDEVS models, using a template-driven approach (M2T transformations).

However, the power of expression of MetaDEVS is still limited, as long as it does not allow the specification of complex conditions (complex logical structures with Boolean operators), nor complex actions (incremental structures, loops…).

The next step is to increase the ability of MetaDEVS to specify complex functions, always in a platform-independent way.

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