Coupling of physical models and social models : multi-modeling and simulation with VLE

Couplage de modèles physiques et sociaux : multi-modélisation et simulation avec VLE.

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Abstract
With the increasing of complexity, the coupling of models became a need. The modeler needs more and more to build several models within the same model which several aspects of his system which are in interaction. The main objective of the paper is to show how DEVS formalism and its extensions within the VLE application (Virtual Laboratory Environment) can answer this problem. DEVS offers a formal framework for the modeling of system and an operational framework of simulation. The proposed work shows how one can translate the formalisms such as the spatial differential equations or multi-agents models in DEVS. This operation requires a translation of the concepts of theses formalisms to concept of state, event and hierarchisation of the processes. The principle will be illustrated on a system of fire control of forrest by firemen. This system integrate at the same time of the physical aspects of process and process of coordination.

Résumé
Avec l'augmentation de la complexité, le couplage de modèles est devenu une nécessité. Le modélisateur a de plus en plus besoin de réunir au sein du même modèle plusieurs aspects de son système qui sont en interaction. L'article a pour objectif de montrer comment le formalisme DEVS et ses extensions au sein de l'application VLE (Virtual Laboratory Environment) peut répondre à ce problème. DEVS offre un

cadre formel pour la modélisation de système et un cadre opérationnel de simulation. Le travail exposé ici montre comment on peut transposer des formalismes tels que les équations différentielles spatialiées ou les modélisations multi-agents en DEVS. Cette opération nécessite une traduction des concepts du formalisme en notion d'état, d'événement et de hiérarchisation des processus. Le principe sera illustré sur un système de lutte contre un incendie de forêt par des pompiers. Ce système intégre à la fois des aspects de processus physiques et de processus de coordination.

Keywords
Multi-modeling, Discrete Event Specification, Multi-agents

1 Introduction

The activity of modeling is confronted today with the problem of coupling of heterogeneous models. Since we build a multi-facets model of a complex system where social aspects (negotiation between autonomous entities, for example) and of the spatial-temporal aspects (of the physical processes as the propagation of fire of forrest) are related to the global model, the question of the coupling appears. Since the Seventies, a community is built around the concept of multi-modeling with B. Zeigler and P. F. Fishwick. One of the used tools by this community is the DEVS formalism (Discrete Event Specification) [ZEI76]. The principal interest of DEVS is to abstract from other formalism by unifying the points of view on the modelled system. The central idea is to consider the system through a state graph controlled by the events. Several extension of DEVS, mapping or wrapping of formalisms were proposed [WAI01][BAR96] and allow now to propose a unifying framework for the modeling of complex systems where entities evolves in a continuous environment, where physical phenomena come to interact with these discrete entities and where the entities can also have social relations within complex network.

The goal of this article is to show how a system such as a squad of fireman which fights against a fire of forrest. The system and the propagation of the fire can be modelled with DEVS framework and its derivatives. It should be noted that a first side, this system uses a subsystem at continuous time and modelled continuous space with spatial differential equations and another side, the firemen are agents plunged in a hierarchical communication network (for the synchronization of the firemen) and interaction with the subsystem "fire of forrest".

This example will be developed within the framework of VLE application (Virtual Laboratory Environment) [DUB04]. Initially, we will show how to model within DEVS framework and VLE of the spatial differential equations and how to manage the disturbances due to the actions of the firemen. This first part will be the opportunity to present Cell-DEVS [WAI01], an extension of DEVS for the cellular automata, and QSS [KOF01][KOF02], a numerical method for integration of differential equation based on the concept of event. In the second time, the translation between the concepts of agent (physical or social environment, agent...) and DEVS will be clarified through an XML application to specify the multi-agents model and another extension of DEVS : DS-DEVS [BAR96].

2 DEVS framework and VLE application

A DEVS atomic model is define as a structure $M = \langle X, Y, S, \delta_{int}, \delta_{ext}, \lambda, ta \rangle$ where :
X is the set of input values
Y is the set of output values
S is the set of sequential states
$\delta_{int} : S \rightarrow S$ is the internal transition function
$\delta_{ext} : Q \times X \rightarrow S$ is the external transition fct
$\lambda : S \rightarrow Y$ is the output function
$ta : S \rightarrow \mathbb{R}_0^+$ is the time advance function
$Q = \{(s, e) | s \in S, 0 = e = ta(s)\}$
Q is the set of total states,
e is the time elapsed since last transition

A DEVS coupled model define how to couple atomic models in order to build a new model. The property of closure under coupling guaranties that a DEVS coupled model is equivalent to an atomic one in a upper hierarchical level. Hierarchical decomposition and modularity are fundamental in the DEVS formalism.

VLE is a platform of multi-modeling and simulation of complex systems based on DEVS formalism. DEVS modeling defines a state graph from atomic models bringed together within coupled models in order to create hierarchy of models. Its models are controlled by events generated by the atomic models. DEVS offers a modular and hierarchical vision of dynamic systems being translated in VLE in form of XML applications [DUB02]. Its formalizations are implemented through the concept of « abstract simulator » [ZEI76].

3 Modeling of spatial differential equations with QSS

We will show that it is possible to generalize the use of DEVS formalism, QSS1 and QSS2 with the partial differential equations with the derivative, which allows the integration of the problem.

3.1 Brief presentation of quantification integrators

Parallel to the traditional methods appeared new techniques of numerical resolution of differential equations based on the quantification of the output values rather than on the discretization of time. Thus, Kofman proposes through QSS1 and QSS2 two methods of numerical resolution of first order differential equations. For the presentation of these two methods, let us consider the following system :

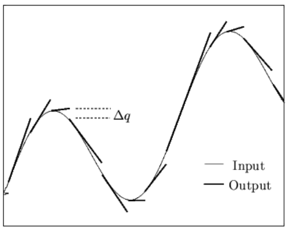

FIG. 1 – QSS2 in [KOF02])

$$(\mathcal{S}) \begin{cases} \dot{x}_1(t) &= f_1(x_1(t),\ldots,x_n(t)) \\ \dot{x}_2(t) &= f_2(x_1(t),\ldots,x_n(t)) \\ \vdots & \\ \dot{x}_n(t) &= f_n(x_1(t),\ldots,x_n(t)) \end{cases} \quad (1)$$

The global idea is to approximate the functions $x_i(t)$ by constant piecewise functions (for QSS1) or of the affine piecewise functions (for QSS2) then to encapsulate each x_i in an atomic DEVS model. At an instant denoted t, each model has like state variable a constant for QSS1 or a affine function for QSS2. Lastly, it's appropriate for the models to compute an internal transition when their states moves away too much the theoretical curve to integrate. (see figure 1).

3.2 Another extension of DEVS : Cell-DEVS

The extension named Cell-DEVS was born from the following observation : many models use discrete spaces and use formalisms such as the cellular automata. Wainer and Giambiasi in [WAI01] developed Cell-DEVS. This extension must be able to describe and simulate models as a multidimensional cellular automata and discrete events. The dynamics of the cells is time-lag i.e. that the state of cell will be modified according to the state of its neighbour cells, but it will be known by neighbour cells after a certain time. The basic idea is to provide a simple mechanism of definition of the synchronization of the cells. As for any proposal for an extension, the authors offer at the same time the extension of the formalism which is summarized with the addition of variables and their semantics, and the abstract simulator.

3.3 Application of partial derivative equations

Let us consider the example of the equation of diffusion of heat on a bar [FLE00] for illustration of QSS and Cell-DEVS :

$$\frac{\partial T(t,x)}{\partial t} = K\frac{\partial^2 T(t,x)}{\partial x^2} \quad (2)$$

where K is the coefficient of diffusion.

We make an approximation of $T(t, x)$ by its values in various points of the bar after having chosen a space step δx. Denoted $T_i(t)$ these values, the equation 2 becomes :

$$\frac{\partial T_i(t)}{\partial t} = K \frac{T_{i-1}(t) - 2T_i(t) + T_{i+1}(t)}{(\Delta x)^2} \tag{3}$$

for all i from 1 to N, using, by example, an approximation of the second derivative in three points.

One of the traditional approaches (the explicite method) would now consist to approximating $\frac{\partial T_i(t)}{\partial t}$ by $\frac{T_i(t + \Delta t) - T_i(t)}{\Delta t}$. But the equations form at this level a system of first order differential equations in $T_i(t)$. It is thus possible to solve them using a QSS method.

3.4 DEVS formalization

We can model the problem by 50 interconnected Cell-DEVS cells. A cell has a outport S which sends the new temperature before the evaluation of its function of internal transition to its neighbours. It also has two input ports G and D to receive the temperature of the neighbours by activation of it function of external transition. In our case, the delay of sending of the state of the cell is null. The neighbours thus are immediately informed of the change of state.

3.5 Application of the spreading of fire of forrest

The same work can be made on a differential equation system managing the evolution of temperature during the spreading of fire of forrest. It is necessary to generalize with two dimensions and it then misses nothing any more but the interaction with the agent “fireman”. However the system being already essentially DEVS-compliant, this management of the global system is natural. Remain to see the influences on the state of a cell in particular. In the case of QSS1 : the disturbance takes the form of an external event to a cell, specifying to it to take such value or, to decrease by such other, . . . All these cases being, for the cell, only one operation : it must modify its value. The difference with function of an internal or external transition is that the computed value changes arbitrarily. It is thus appropriate to :

- recompute the slope by the new value,
- update the QSS1 engine by calling of a special function which consists in computing the constant, then σ (period of validity of the state) in agreement with the new slope,
- generate a function of external transition in the neighbours, to spread the new value to them.

4 The coupling with a multi-agent modeling : Cell-DEVS and DS-DEVS

As we saw before, DEVS is a formalism describing a static graph. However, SMAs, where the relations between agents are able to change dynamically, requires a dynamic structure. Works to introduce this type of structure was proposed [BAR96][UHR01] to be integrated in DEVS. The formalization of F. Barros called DS-DEVS for Dynamic-Structure DEVS, is more satisfactory since it preserves all the properties of DEVS, i.e. the modularity and the hierarchical decomposition. DS-DEVS is represented in the form of a coupled model thus which can couple itself with other models DEVS. It makes it possible to modify connections between its models and to add or remove its DEVS models in running of simulation on internal or external events.

A multi-agents model of the spatiotemporal systems is defined by physical and social environments, agents and objects. We carried out a XML specification describing this type of system, where the agents, mainly reactive, is decomposed in several entities :

- the sensors and the affectors placed in the physical and social environments,
- a brain centralizing information of the sensors and sending orders to the affectors.

An agent can be associated to a role if it makes a part of a social environment with an aim to realize networks of accouintances. The physical environments are divided into several classes with the following attributes : discrete or continuous spaces, dimension, size of spaces, associated dynamics...

We produced a tool for translation of XML applications to compatible XML applications for VLE where the environments are represented in the form of coupled models, the graphs of links of the social environments are managed using DS-DEVS. The agents are represented in the form of atomic models or if they have a complex dynamics in coupled models. DEVS brings here the possibility to us of defining dynamic each entity of the multi-agent system in different formalisms like the ordinary differential equation systems, the Petri nets, automata and so on.

The example proposed in this article is an toy example of multi-agent system. It defines a unit of several firemen fighting against the spreading of fire of forrest. In this example, we can define two types of environments :

- physical : the forrest and the dynamics of spreading of fire are represented in the form of a system of spatial differential equations specified with Cell-DEVS and QSS1.
- social : the coordination between the firemen is primary to improve the capacity to extinguish the fire. This coodination is carried out through graph of links specified using a model of the DS-DEVS class.

To define this model in VLE, we use three different XML applications :

- to describe the multi-agent system in the concepts relating to the formalism,
- a second to describe the dynamics of the fireman agent in the form of atomic or coupled models,
- a last for the description of the model of space.

After the translation in DEVS, these three XML applications build a coupled model composed of Cell-DEVS, DS-DEVS and QSS1 models. The phase of translation aims to leave free to the modeler to express in the concepts of the formalism of its choice and VLE is given the responsability to translate its formalism in DEVS.

5 Conclusion and perspectives

This article presents a possible way to federate within the same formal and operational tool of the models of simulation : DEVS and VLE. The models can at the same time to use mathematical models for the physical environments and the social models (modelled by multi-agent systems, by example).
The work of integration isn't finished. It is imperative to continue the integration of the most exotic formalisms. Moreover, a reflexion must be carried out on the experimental frames which are integrated with DEVS and which would make it possible the experimental plans to make a part of the model. A beginning of answer exists now in VLE with the concept of state port.

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