AN OBJECT-ORIENTED ENVIRONMENT APPLIED TO A SEMI-PHYSICAL MODEL OF FIRE SPREAD ACROSS A FUEL BED

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ABSTRACT

This paper presents an application of the DEVS formalism (Zeigler 1990) to a fire spread across a fuel bed. Its main contribution is to show the sturdiness and the contribution of the DEVS formalism applied to a semi-physical non stationary two dimensional fire behaviour model based on a meshed spread domain. For that we make a comparison between a real case simulation results of a C non object oriented simulation and a DEVS one. Then we show how our model can take easily into account the evolutions of the physical model and realise numerous formal extensions.

Keywords : Simulation methods : Discrete-event simulation. Modelling methodology : DEVS models, cell. Application : fire spread.

INTRODUCTION

In a previous study (Balbi et al. 1998) we have developed a model calculating the fire spread rate, the flame front position and the temperature distribution in a complex fuel under no wind condition. This semi-physical bidimensional model is based on a diffusion reaction equation. The model is solved by a numerical method that provides us a discrete equation which gives each grid node temperature of an uniformly meshed study domain.

Our semi-physical model was firstly implemented with a C non-object oriented program. Despite the good results, the developed code proved complex, and showed some problems related to the evolutions of the fire spread model.

Therefor we aimed to have a modelling method that :

- take easily into account the evolutions of the model principle and field conditions (wind influence, non-homogenous vegetation, slope influence …);
- locally specify the fire propagation;
- model and simulate a complex discrete event system;
- give formal extension possibilities (dynamical environment, GIS connection …) in order to have in the long term a real time simulator.

To circumvent these difficulties, we decided to apply an object-oriented modelling approach based on DEVS (Aiello et al. 1998) and further extensions to our propagation fire model. To facilitate the implementation, we have chosen to use the Java language.

The literature presents other approaches based on discrete event simulators. Actually most of the simulators (Barros and Ball 1998, Vasconcelos et al. 1995, Ameghino et al. 2001) using DEVS formalism employ the stationary one-dimensional model of Rothermel (Rothermel 1972) and give fire behaviour by propagation algorithm. We show here the robustness of DEVS formalism applied to a more physical model propagation which give the flame front position at any step time.

Since the forest fire spread model and the simulation process have already been detailed elsewhere (Muzy et al. 2001), we make here a short presentation of its principle and numerical resolution. Then, the DEVS modelling and the simulation results will solely be provided after.

I - FOREST FIRES : POSITION OF THE PROBLEM AND NUMERICAL EQUATION

Phenomenon Description and Existing Models

In the view of elaborating a real time simulator, we have developed a semi-physical model. Indeed, facing with the important data volume to take into account, it is necessary to have a simple model doing a globalisation of the phenomena. A previous study was concerned with actual forest fire. Indeed, before modelling great scale fire, we must determinate the influence of the mechanisms involved in fire spread. To this end, we have in a first stage modelled fire spread across a 1 m² pine needles litter without wind and slope.

Numerical Study

The study domain is meshed uniformly with cells of 1 cm². The physical model is solved by the finite differences method which leads to the following algebraic equation :

$$T_{i,j}^{k+1} = a(T_{i-1,j}^{k} + T_{i+1,j}^{k}) + b(T_{i,j-1}^{k} + T_{i,j+1}^{k}) + cQ\left(\frac{\partial \sigma_v}{\partial t}\right)_{i,j}^{k+1} + dT_{i,j}^{k}$$

where T_{ij} is the temperature of a grid node. The coefficients a, b, c and d depend on the considered time step and mesh size**.**

II - DEVS MODELLING OF A FOREST FIRE SPREAD

The numerical resolution of our semi-physical model which needs to mesh the spread domain leads naturally to define the atomic models (C elements) associated to the cells which are constituting the mesh. This gives rise to the following behavioural model :

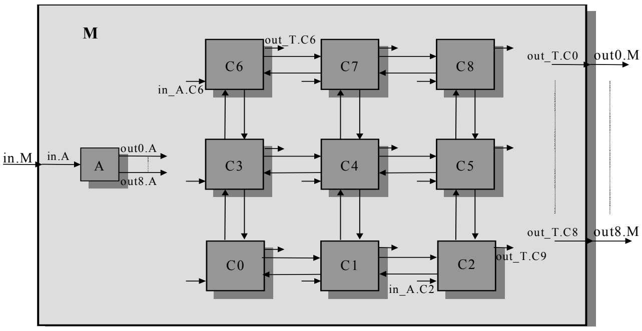

Figure 1 : Fire Spread Object Oriented Model

Each C element on Fig. 1 is linked to its cardinal neighbouring elements. These links allow to take into account the thermal exchanges between the different cells. The A element is directly linked to the C elements. It allows to initiate the fire spread in specifying the ignition zone. The interconnections between these Atomic Models are represented by the Coupled Model M.

An A element owns an input port (in.A) through the one the data which allow to determine the ignition place are received, as well as a set of output ports (out0.A à out8.A) which are corresponding to the C elements number. This component allows to request only the concerned elements by the ignition.

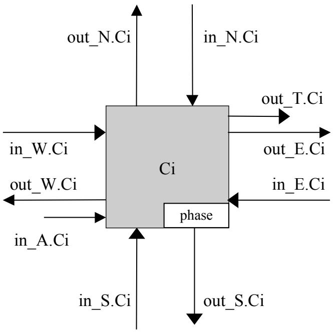

Figure 2 : C Elements Details

The C elements (Fig. 2) are defined by the following characteristics :

- Four input ports and four output ports allow the information exchange between the element and its neighbours :
  - in_N.C • out_N.C
  - in_S.C • out _S.C
  - in_E.C • out _E.C
  - in_W.C • out _W.C
- An input port is used for the element ignition : in_A.C ;
- An output port gives the temperature value of the element : out_T.C.

Let see the simplified temperature curve of a point of the domain and its associated phases :

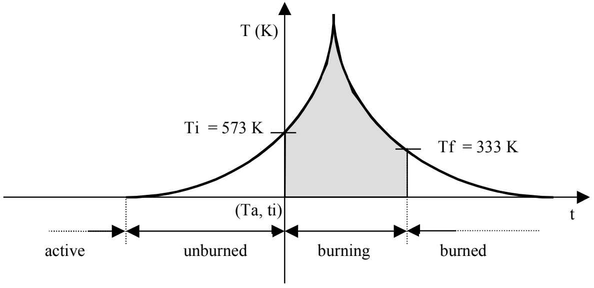

Figure 3 : Simplified Temperature Curve of a Point of the Domain

So the C element has phases *active*, *unburned*, *burning* and *burned* with corresponding sigmas of *0, 1, 1* and *infinite* (Fig. 3). We consider that above a threshold temperature T_i, the combustion occurs and above a T_f temperature, the combustion is finished. So we voluntary neglect the end of the real curve to save simulation time.

III - SIMULATION RESULTS

Experimental conditions :

- Combustion table of 30 cm long and 60 cm wide;
- Homogenous fuel bed of pine needles;
- Windless and slopeless conditions.

We make here a comparison between the sequential code (already validated against experimental data) and the DEVS application. The white point represent the front realised with a sequential code. A first observation of the circular wave fronts gives us the same results :

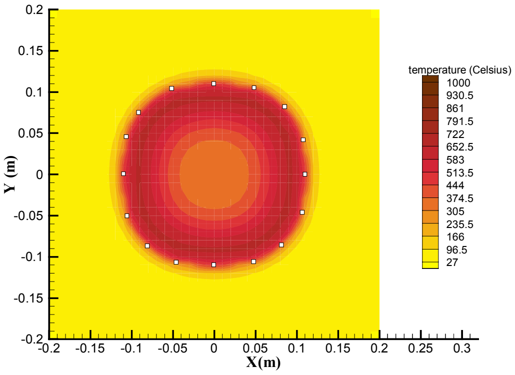

Figure 4 : Front Comparison of a Sequential and an Object-oriented Approach Simulation at t=30s.

At the time t=50s, we can see a difference of the widths of the fronts (Fig. 5). This can be explained by the end combustion assumption. Indeed the fire front cools more quickly.

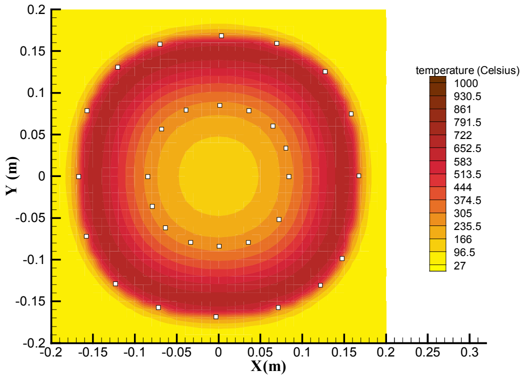

Figure 5 : Front Comparison of a Sequential and an Object-oriented Approach Simulation at t=50s.

The results between DEVS implementation results, and the previous code ones are equivalent. But the use of an object-oriented approach enables us to take easily into account the semi-physical model behavioural evolutions, for example for the wind and slope effects (Marcelli et al. 2000). In the non-homogenous vegetation case, the spread equation coefficients values are modified. These variations can be taken into account by a simple modification of the object parameters associated to the atomic component functions.

The disadvantage is the simulation time that is longer with DEVS application.

CONCLUSION

DEVS formalism revealed its sturdiness by its application to a semi-physical non stationary two dimensional fire behaviour model. The main advantage of this formalism application will be for the future modifications of the computer and physical models.

But, despite good results, the calculation time is too long to be efficient in a real fire case.

Thus we project in a first time to optimise and specify our object-oriented environment, and to use C++ language. In a second time we aim to activate only the cells adjoining the flame front.

Another solution to save substantial simulation time will be the application of the Dynamic Structure Discrete Event Specification Formalism developed by Barros (Barros 1996). This formalism will be very interesting to formally model and simulate real case fire.

We project too, to exploit the potentiality of the object-oriented environment of Aiello (Aiello 1997), for real case evolution. This with the application of its structural view concept for GIS integration, and its temporal hierarchy as a function of wind and slope.

REFERENCES

Aiello, A. 1997. "Un environnement orienté objet de modélisation et de simulation à événements discrets de systèmes complexes", *Thèse de Doctorat en Informatique, soutenue à l'Université de Corse*.

Aiello, A.; P.A. Santoni; J.F. Santucci; J.H. Balbi; P. Bisgambiglia. 26-28 May 1998 . "Mise en œuvre d’un environnement orienté objet appliqué à la propagation des feux de forêt*", Proceedings of the Nîmes 98, Complex Systems Intelligent Systems and Interfaces*.

J.H. Balbi, J.H. ; P.A. Santoni ; and J.L. Dupuy. 1998."Dynamic modelling of fire spread across a fuel bed", *Int. J. Wildland Fire*, pp.275-284.

Barros, F. 1996. "Dynamic Structure Discrete Event Specification Formalism*", Transactions for the Society for Computer Simulation*. No 1, pp. 35-46,.

Barros, F. and G.L. Ball. 16/20 November 1998. "Fire modeling using dynamic structure cellular automata", *III International Confer. On Forest Fire Research, 14th Conference on Fire and Forest Meteorology*, VOL I, PP. Luso, 879-888.

Marcelli, T.; A. Aiello; P.A. Santoni. Du 13 au 16 juin 2000. "Un environnement de modélisation et de simulation orienté objet : application à la propagation de feux de litières en présence d’effets combinés de pente et de vent". *Congrès "Environnement et Identité en méditerranée" Programme de coopération scientifique Interreg II BILAN ET PERSPECTIVES : Corti*.

Muzy, A.; T. Marcelli; A. Aiello; P.A. Santoni; J.F. Santucci; J.H. Balbi. 6-8 june 2001. "Application of D.E.V.S. formalism to a semi-physical model of fire spread accross a fuel bed", *Advanced Technology Workshop.* France, Corsica, Aiacciu.

Rothermel, R.C. 1972. "A mathematical model for predicting fire spread in wildland fuels", United States Department of Agriculture, Forest Service Research paper INT-115.

Vasconcelos, Maria J.; José M. C. Pereira and Bernard P. Zeigler. 1995. "Simulation of fire growth using discrete event hierarchical modular models". *EARSeL Advances in Remote Sensing*, 4 (3), pp: 54-62.

Zeigler, B.P. 1990. "Object-Oriented Simulation with Hierarchical, Modular Models, Intelligent Agents and Endomorphic Systems", *Academic Press*.

Ameghino, J.; A. Tróccoli; G. Wainer. 2001. "Models of complex physical systems using Cell-DEVS". *Proceedings of Annual Simulation Symposium. Seattle, WA. U.S.A.*