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A MODEL OF THE INFLUENCES OF A FOREST FIRE ON ITS NEIGHBOURHOODS AND RELATED RISK MANAGEMENT ASPECTS

Ioan Valentin Marcel POSEA
"Spiru Haret" University, Faculty of Juridical, Economic and Administrative Scienes, Braşov, Turnului Street, no. 7, 500152, Braşov, Romania,
Tel.: 40212421208, Fax: +40212420781, Email: sjeaposea@gmail.com

Abstract

The aim of the present paper is to produce a model for the propagation of a forest fire analyzing the influences that the fire zone has on its neighbourhoods. The model is a Moore cellular automaton type. It depends on six parameters: the medium slope of the elementary cell, the layer type, and the burning time of the fuel, the fuel type, the wind direction and speed. In order to study the influences of various parameter configurations on the system of vicinities of a fire cell we construct some special directional correlation functions. An application is elaborated based on real data.

Keywords: *mathematical modelling, cellular automata model, forest fire.*
JEL Classification: C_1

Introduction

The problem of simulating the propagation of fire in a forest is one of great importance and is extensively studied. The main models are classified as stochastic, based mainly on laboratory experimental data, or deterministic, based mainly on physical laws of conservation of energy in the system formed by the burning and the surrounding area. The deterministic models are grouped in vector models and cellular automata.

Cellular automata type models are based on ideas of J. von Neumann and S. Wolfram. From a theoretical view point, a cellular automaton is defined by the universe of the automata, the system of vicinities of a cell, the state of a cell, and the transition rule.

The type of the system of vicinities determines the type of the cellular automaton. Usually there are four types presented in Fig. 1.

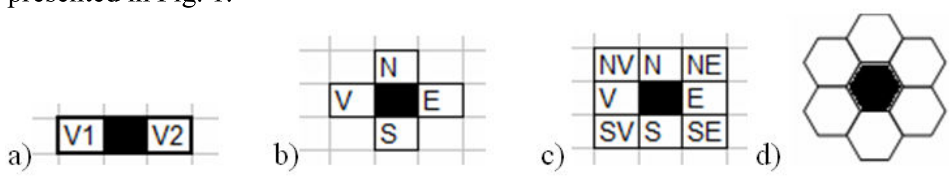

Figure no. 1 a) Linear Automaton, where V1 and V2 are neighbours of the active cell; b) J. von Neumann cellular automaton (four neighbours of the active cell); c) Moore automaton with eight neighbours; d) Hexagonal automaton (6 neighbours of the active cell)

Being a time dependent model, the associated lattice of the automaton universe generates at a given time the configuration of the machine. This configuration and the transition rules determine the evolution of the system.

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Experiment

The type of the transition rules, deterministic or stochastic gives the type of the cellular automaton. We shall consider a covering 20 x 26 grid of square subdomains (Fig. 2) of the domain *D* in study.

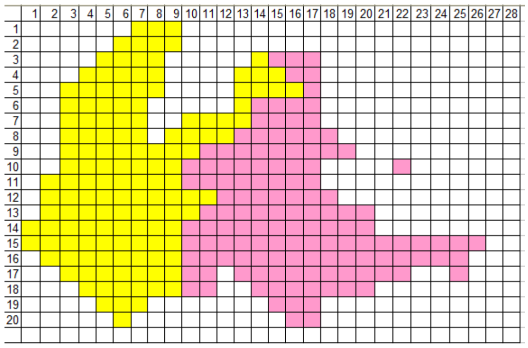

Figure no. 2. The universe of the cellular automata

We take as a cellular automaton universe all the shaded cells except the remote one which has the address (10:22). The parameters that will be used to determine the transition rule proposed by the model will be: the bedding type; the wind speed and direction and the average slope of the cell.

Each parameter will produce an index of contribution in the transition rule.

Based on the data obtained in the domain we used the following quantification of the bedding type (Fig. 3) of each cell:

- 0 – bedding less;
- 1 – irregular and interrupted bedding;
- 2 – continuous and thin;
- 3 – continuous and thick.

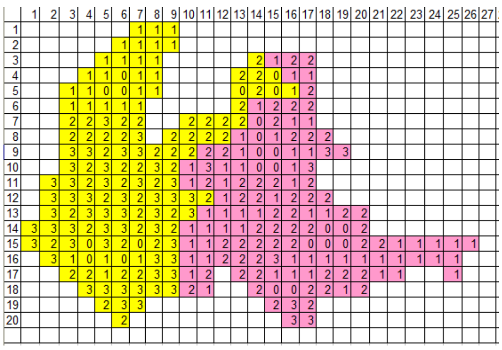

Figure no. 3. Distribution of bedding type

In order to determine the contribution of this parameter we construct a special mark correlation function. The general theoretical context is [10]:

Let us consider a point process with n points on a sample surface. Assign to each point a triplet formed by its Cartesian coordinates and the value of the specific attribute considered. We denote the set of points:

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$$P = \{p_i(x_i, y_i, m_i)\}_{i=1,2,\ldots,n} \tag{1}$$

The second order characteristics function is:

$$f(m_i, m_j) = m_i \cdot m_j \tag{2}$$

and the mark correlation function is given by:

$$k_f(h) = \frac{E\left\lfloor f(m_i, m_j) \middle| d_{ij} = h \right\rfloor}{\mu^2} \tag{3}$$

where: μ represent the mean value of the considered attribute; $E[X]$ – the mean of the random variable X, and d_{ij} – distance between points i and j.

For our purpose we shall consider a correlation function of bedding types dependent on the eight directions attached to a cell in the universe of the cellular automata (Table no. 1).

Table no. 1. Characteristics of cellular automata

Direction	N	N-E	E	S-E	S	S-V	V	N-V
θ	1	2	3	4	5	6	7	8

Using the same test function and the values of the attribute given by Figure no. 3 we construct the mark correlation function as:

$$k_f(\theta) = \frac{E\left\lfloor f(m_i, m_j) \middle| \; direction \; i \to j = \theta \right\rfloor}{\mu^2} \tag{4}$$

Using the algorithm from underneath, we obtained the results presented in Table no. 2 and Figure no. 4:

For each direction from 1 to 8
For each cell in the universe
Calculate and store the corresponding value of the test function
End for
Averaged the values of the test function
Determine the value of the correlation function
End for

Table no. 2. Experimental results

θ	1	2	3	4	5	6	7	8
$k_f(\theta)$	1,1113	1,0949	1,0897	1,1036	1,1113	1,0949	1,0897	1,1036

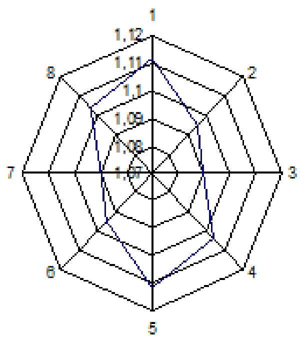

Figure no. 4. Polar graph of the correlation function

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This function presents a natural symmetry with respect to the origin. The contribution of the parameter bedding type to the model is given by the normalized values of the function $k_f(\theta)$ and will be denoted by $c(\theta)$. This value is independent of the active cell.

The parameter wind speed and direction are considered constant during the simulation and are obtained for v = 0 km/h, v = 8 km/h, v = 36 km/h, v = 58 km/h.

If we consider that the intensity of the wind is grouped in 5 categories and the direction the wind is blowing from is *a* then $b = (a+4) \bmod 8$ and the contribution of the parameter wind direction and speed is given by:

$$v(\theta) = \begin{cases} i \cdot 0{,}2 & \theta = b \\ i \cdot 0{,}1 & \theta = b \pm 1 \\ i \cdot 0{,}05 & \theta = b \pm 2 \\ 0 & otherwise \end{cases} \qquad (5)$$

The value of this function is also independent of the active cell.

A discrete quantification of the mean slope of the cells is given by Figure no. 5.

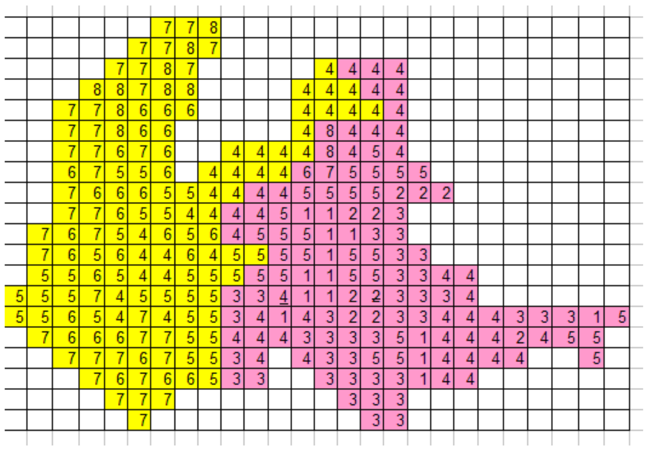

Figure no. 5. Mean slope

The contribution of the parameter slope is given with respect to the active cell.

For each active cell *a* we consider *p(a,θ)* the difference between the mean slope of the neighbour on direction *θ* and the mean slope of the active cell. The value of the contribution of this parameter is denoted by *s(a,θ)* and represents the normalized value of *p(a,θ)*.

Number of intervals of time for complete combustion of fuel in each cell (corresponding to the number of steps in the algorithm in which a cell can be considered to burn) denoted by *t(i,j)* is quantized in this model using the bedding type and fuel model and is given in Figure no. 6.

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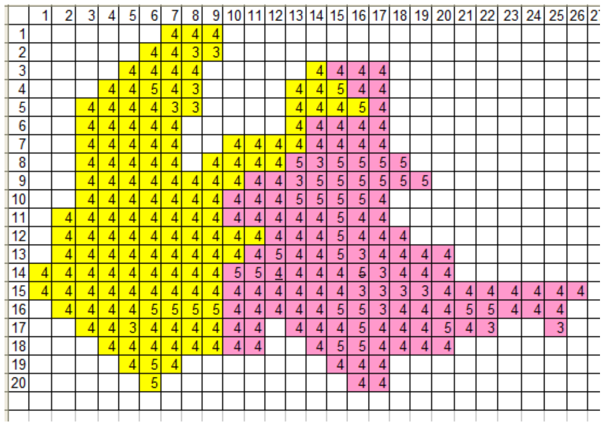

Figure no. 6. Time intervals for complete burning

In order to define the transition rules we consider seven different types of states for a cell and for each we attach a colour:

- ST0 – no fuel in the cell; attached parameter is *0* and the colour is green;
- ST1 – cell unaffected by fire; the value of the attached parameter is smaller than *1* and the colour is white;
- ST2 – weak influences on the characteristics of the cell; the parameter takes values between *1* and *2,* attached colour being yellow;
- ST3 – moderate influences on characteristics of the cell; parameter takes values between *2* and *3.5* and the colour is orange;
- ST4 – state of major influence on cell characteristics, igniting combustible material imminent. The attached parameter values are between *3.5* and *5*, with brown colour;
- ST5 – burning cell, considered active cell; value of the parameter is *5* and red colour attached (Figure no. 7);
- ST6 – cell total burned; without parameter attached and black colour.

p(8)	p(1)	p(2)
P(7)	ca	p(3)
P(6)	P(5)	P(4)

Figure no. 7. Parameters of the system of vicinities of the active cell

The algorithm used is (Figure no. 8):

For all ca
If ca(i,j) is in ST5 then
For $\theta = 1$ *to 8*
$p(\theta) = p(\theta) + c(\theta) + v(\theta) + s(ca, \theta)$
if $p(\theta) \geq 5$ *then* $p(\theta) = 5$
Next
t(ca)=t(ca)-1
if $t(ca) < 0$ *then ca(i,j) is ST6*

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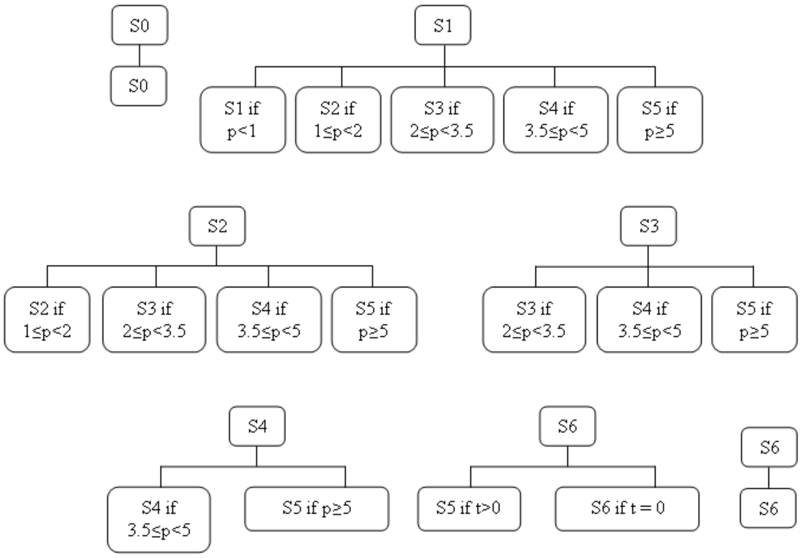

Figure no. 8. The algorithm

Considering two starting active cells, the evolution of the model in 1, 3, 5 and 10 time intervals is presented in Figure no. 9.

Figure no. 9. Evolution of the model

Conclusions

In this paper we propose a model that can estimate the performance of a fire depending on wind speed and terrain slope. In this respect, it is determined a model of cellular automaton type for simulating of litter fire for U.B. V Noua.

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Mathematical modelling offers a number of advantages. After simulation, we can see how the fire spreading from one cell to another.

In terms of fire risk management, especially global warming interested reflected by increasing the annual and monthly average temperatures. For this purpose, in the mathematical modelling we have considered these aspects, as well as other characteristic issues.

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