PREDICTING WIND DRIVEN WILD LAND FIRE SHAPE USING FUZZY LOGIC IN CELLULAR AUTOMATA

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ABSTRACT

In our paper we'd like to present a practical approach for modelling a wild land fire shape using fuzzy logic and cellular automata (CA). On this way the time consuming measurements, which are used as data for statistical approach of modelling, could be exchanged with uncertain knowledge built in decision structure.

INTRODUCTION

The main goal of models for the wild land fire spread and shape simulation is to make a prediction of the area, which will be caught by fire. They are used in the domain of fire interventions and in the domain of fire spread education. In literature [2, 3, 4] we could find basic approaches used for modelling fire spread shape and size. Those are

- Physical-chemical models
- Statistical models and
- Cell models.

The last approach uses the network of cells and rule base composed of rules, which describes how the disturbance (fire) is spread through the cells under observed conditions. Bad point of approach is in determination exact rules, which are in most cases founded on iterative equations and not on experience knowledge of the system's behaviour.

Our approach is founded on cell model. Instead of crisp rules we use a concept of fuzzy logic rules. It enables us to use a descriptive and uncertain knowledge of system's behaviour provided by firemen, who have an experience with fire spread. The use of fuzzy logic enables us also to make a decision process with uncertain or approximate input data instead of exact values.

THE BASICS OF CELLULAR AUTOMATA

The cellular automata (CA) is a structure built from cells in n-dimensional space. The dimension n of space in real-life applications is usually 2 or 3. Every cell could be treated as an independent computing device which captures input data from its neighbourhood cells, calculates and changes to a new state, and this state is used as input to other cells in neighbourhood. The *"program"* of cell's behaviour is unique for all cells in the space. A generalised definition of CA [1] could be seen as in definition 1.

Definition 1: CA $\mathcal{M}$ is a quadruplet $\{A,Q,u,F\}$, where A is an n-dimensional array, Q a finite non empty set of possible stages for all cells, $u(x)$ a function which returns a neighbourhood of cell x, unique for all cells, and $F(u(x), q(x,t))$ a set of exact rules for local transitions (a cell behaviour program).

The pattern is the global state of CA and it is observed as a set of the all stages of the cells. Other main characteristics of CA are:

- Different cells could be in different states in time t.
- On the base of initial pattern and pattern's dynamics throughout processing steps we could divide the models in two groups; the patterns which change slowly are called "cold",

and the patterns which change very fast are called "gassy".

- Some self-organisation possibilities which could lead the system from initial global pattern to next possible global states known from real-system's behaviour are:

  - pattern "dies"
  - pattern becomes stable or occurs cyclically with constant period
  - pattern grows with constant speed infinitely long

Many times when we create the model of real-life system we do not know exact rules for local transitions and that is the main problem in the programming of CA's behaviour. Due to this reason we suggest a fuzzy approach for cell's state transitions.

A FUZZY CELLULAR AUTOMATA APPROACH

A fuzzy approach in the field of CA enables us to program the cell's behaviour on the base of uncertain and descriptive knowledge of the real system's behaviour. This enables us:

1. The unprecise descriptive rules are provided directly from system's behaviour expert.

2. The modelled system's dynamics is often processed as a result of parallel triggering of opposite rules.

In the phase of processing on step t we try to decide for every cell about its next stage ($t+1$) on the base of input data and cell's stage in time t. A pseudo code sequence is presented in expression (1) to explain decision process:

```
1. fuzzify(global input data); (for instance wind)
2. for all cells do:
   • fuzzify(local input data);
   • new_stage[x,t+1]=
       F(u(x),q(x,t),global_data);
   • defuzzify(new_stage[x,t+1]);
3. for all cells do: fire_stage =
new_stage;                                   (1)
```

The space dimension n of our application mentioned in [4] is 2 and the neighbourhood function used in our model is

u([x,y]) = ([x-1,y], [x+1,y], [x,y+1], [x,y-1], [x+1,y-1], [x-1,y+1], [x-1,y-1], [x+1,y+1]). (2)

The basic scheme of neighbourhood function and possible directions of spread are presented on fig.1.

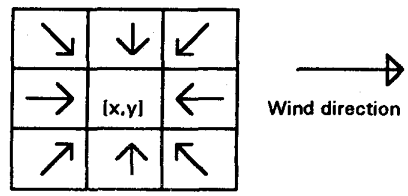

Figure 1: Basic scheme of neighbourhood function and spread directions

From interpretation view of fire spread we could presume, that the spread of disturbance (fire) is more or less accelerated in the direction of wind. The acceleration of spread depends on input data. Every cell is determined with an internal data structure presented in expression (3).

```
struct cells
{ int fire_stage;       /* q(x,t) */
  int inflammability; /* q(x,t)   */
  int next_fire_stage;/* q(x,t+1)*/
} cell[max_x,max_y];                 (3)
```

First variable represents the stage of fire in one cell in time t (inference step index), the second one the inflammability stage of the cell, and the third one a temporary location in decision process for determination of the *fire_stage* in the time $t+1$. All input variables are normalised in expected intervals. The last input variable used in the decision process is *wind_speed(t)*, which represents the speed of wind. In the sense of fire spread, greater wind speed means greater fire spread and smaller wind speed vice versa.

Fuzzifying input data

In ordinary logic every cell x in time t could be in exactly one state q, ($q \in Q$). In fuzzy logic the cell could be at the same time in more states, described with their values and membership functions. From our application's point of view [4], we have used two parameters state description. First one is *inflammability* of the cell's inside property and second one is *fire_stage* in time t. On fig.2 we could see an example of fuzzification process for both input variables:

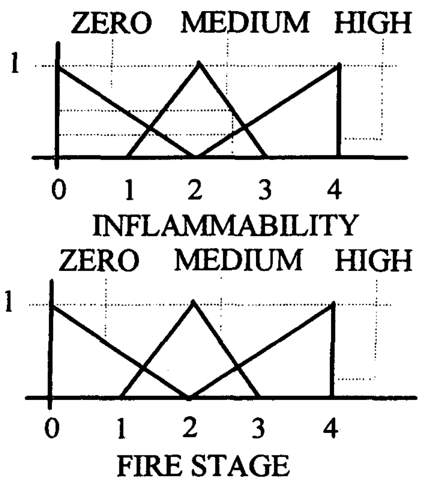

Figure 2: Fuzzy sets *inflammability* and *fire stage*

From the figure we could found out that if *inflammability* = 2.5 (it could be calculated or estimated from the real system), then $\mu(t,i)_{BigInflamm}$ = 0.25, and $\mu(t,i)_{MediumInflamm}$ = 0.5. These expressions represents the membership values for different terms of *inflammability*. Explanation: the *Inflammabilty* 2.5 belongs to class "*Medium Inflammability*" with membership 0.5 and to class "*High Inflammability*" with a membership 0.25. In the same way other input variables are fuzzified. Those are:

- *fire_stage* = {*zero, medium, high*};
- *inflammabilty* = {*zero, medium, high*};
- *wind_speed* = {*zero, medium, high*};

Every exact input value could belongs to more terms (descriptive classes) with calculated membership from interval [0,1], which depends on definition of membership functions. The phase of decision making as the next step uses terms as input variables.

Fuzzy decision process

In expression (4) we could see an example of a fuzzy rule from the application [4]. It's used to determine the fire state in the cell [x,y] (expression depends on 2-D model) in time $t+1$, on the base of input data which are neighbourhood cells's states and cell's [x,y] fire state in time t.

```
if (cell[x,y].fire_stage = "medium")
AND (cell[x,y].inflammabilty = "high")
AND (wind_speed = "high")
AND (cell[x-1,y].fire_stage = "high")
then (cell[x,y].next_fire_stage =
"high").                                    (4)
```

Logic interpretation of the presented rule is: *if fire in cell is medium and if the cell's inflammable stage is high and if speed of wind is high and the fire in left neighbour cell is high then the fire in cell on the next step will be high.*

The rule set consists of 288 rules. They are all of them are of the same type as an example in expression (4). They describe how the disturbance is carried from neighbour cells to central one.

After the sequence of iterations over all rules we get an output variable's value. It means in the sense of fuzzy logic that membership functions of output terms are assigned with max. function during iterations. It's presented with the same three terms as the *fire_stage* variable is. The last step of the algorithm (see expr. (1)), which has to be done is defuzzification process of the output variable. In our experiments the COG method was used [5,6].

RESULTS

In present section we'd like to present results of the simulation compared to statistical method's results. The last mentioned method is widely use in practice. The shape of the fire is found on two semi ellipses. The coefficients of them depend on the wind speed (global dynamic variable) and on a constant, which depends on inflammability of the area. Fire statistics over real fire data show us that a ratio between the length (direction of wind) and width of the fire spread shape is between 1:1 (no wind, equally inflammable area) and 1:6 (strong wind in the height of flames, equally inflammable area). The results of our method show similar ratios. On Fig. 3, we can see our method's shape (grey shape) compared to statistical result (2 semi ellipses), on Fig. 4, we can see statistical shape compared to real fire spread shape, and on Fig.5 we can see the results of our method compared to real data. The real and statistical data are resumed from [2].

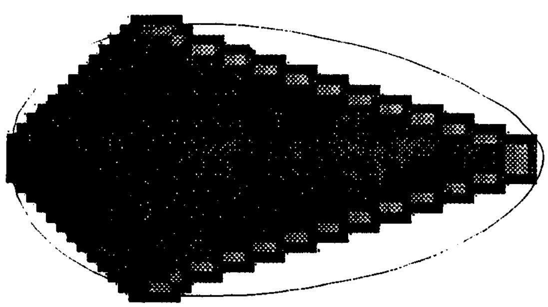

Figure 3: Statistical approach results compared to Fuzzy CA

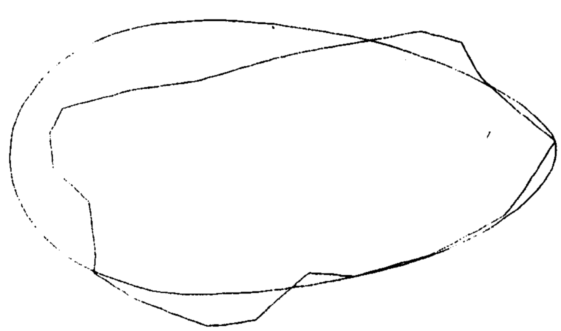

Figure 4: Statistical approach results compared to real data

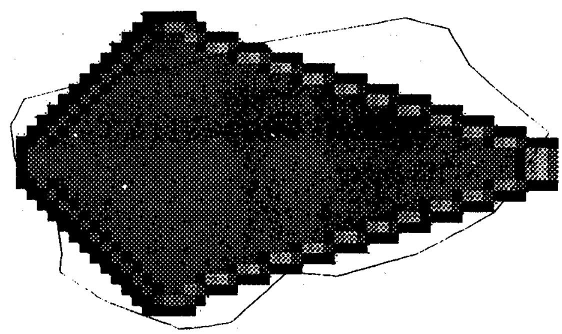

Figure 5: Fuzzy CA approach compared to real data

The results presented in Fig.4 and 5 show us that statistical method gives us a little better results in comparison to our results. The main reason for that is a lack of data on the change of wind (speed and direction) not mentioned in the source data [2]. The second disadvantage of statistical method is in a big number of experiments which have to be done on specific area to get coefficients of semi ellipses. We suppose that in the case of randomly chosen place of wild fire (in that case we don't have specific statistical data) our method can give us better results than statistical approach.

CONCLUSION

We have built a relative simple cell network, with fuzzy rule based spread of disturbance. Fuzzy logic enables us to use a descriptive uncertain knowledge about simulated system's behaviour. Proposed modelling approach could be also used in the field of healing wounds, the spread of diseases, social appearances etc. The only bad point of processing fuzzy rules is increased processing time. Our main intention in future is to build an universal application for cell space behaviour modelling. It will be built with improvements in the sense of:

- optimised speed of processing fuzzy arithmetic operations

- graphic interface to provide interactive work with decision details
- the target platform have to be a high speed performance workstation
- fuzzy logic alternative approaches built in (fuzzification, operators,..)
- distributed processing of cell's stage transition on more platforms

REFERENCES

[1] Adamatzky A.I.: *Hierarchy of fuzzy cellular automata*, Fuzzy sets and Systems 62, 1994, 167-174

[2] Anderson, H.A.: *Predicting Wind Driven Wild Land Fire Size and Shape*, USDA Forest Service, Intermountain Research, USA Ogden, Research Paper INT 305, 1983, USA

[3] Grm B., Stevanović B., Mraz M.: *Wild land fire spread simulation and mathematical models* (MORS's final project report), 1995, Slovenija

[4] Mraz M., Zimic N., Virant J.: *Computer aided predicting wind driven wild land fire size and shape using fuzzy logic*, 9th International Symposium Computer Science for Environment Protection, Berlin, 1995, 726-732

[5] Virant J.: *Using fuzzy logic in modern systems*, Didakta, Radovljica, 1992, Slovenija

[6] Zimermann H.J.: *Fuzzy Sets Theory and Applications*, Kluwer Acad. Press, 1992

