Forest fires spread modeling using cellular automata approach

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Abstract. Fire modeling is used to understand and to predict possible fire behavior without getting burned. Fire models are used in different aspects of fire management: a) before fire, for risk factor calculation and this would help fire fighters to focus on areas with higher risk and develop better infrastructure, b) before fire, for fire fighter training purposes and developing a scenario for training, c) during fire, for planning fire fighting strategies and this would help fire crews position equipment on the ground so that they can minimize damage and stay safe. The paper will present how we can predict forest fire spread using cellular automata.This work on forest fire modeling is a part of a more complex integral project of Split and Dalmatia County forest fire protection. The integral forest fire protection system will be based on an information system for integrating all activities connected with early fire detection by 24 hours video and micro locations meteorological monitoring, management of forest fire fighting and post-fire recuperation of burned landscape. The module for the forest fire spread modeling is one of its modules.

1. Introduction

Numerous fire spread models have been proposed. They can be grouped into:

- Empirical (or statistical) models: these models are predicting more probable fire behavior from average conditions and accumulating knowledge obtained from laboratory and outdoor experimental fire, or historical fires.
- Semi-empirical (semi-physical or laboratory models): models based on a global energy balance and on the assumption that the energy transferred to the unburned fuel is proportional to the energy released by the combustion of the fuel, several terms of the model being fitted to laboratory fire experimental results [10]
- Physical (theoretical or analytical): Models based on physical principle, have the potential to accurately predict the parameters of interest over a broader range of input variables than empirically based models

More detailed classification is given in Figure 1.

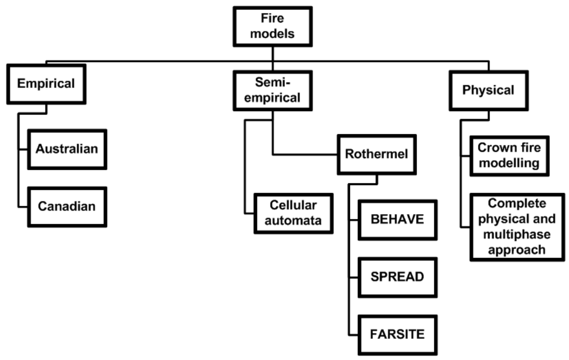

Fig. 1. Classification of forest fire models

The method described in this paper is based on cellular automata and it belongs to semi-empirical models.

Several other fire spread models are available in the market, and most commonly used among them are:

- FireGIS [5] application implements the cellular model and the evaluation procedures for use on personal computer and enables the visualization of the model's results in raster format and in a digital terrain model. FireGIS accepts GIS data inputs. Adjusted for use in ESRI ArcView.
- SPREAD [2] is a computer code intended to simulate surface forest fire behavior in heterogeneous terrain. Typical run takes a few minutes. It computes the burned area shape and evolution, as well as local results on rate of spread, flame length, fire line intensity, reaction intensity, and local times of beginning and end of propagation.
- FIRE! [8] integrates state of the art fire behavior modeling into the ArcInfo GIS environment.
- FARSITE [9] is a fire growth simulation model. It uses Rothermel's equation for calculation of local rate of fire spread and Huygens' principle for modeling the shape of fire front.

Every one of these modeling tools has parameters adjusted for specific geographic area where it was developed.

Model proposed in this paper is adjusted for the area of island Brač in Croatia and uses results achieved by running SPREAD calculations under GRASS GIS, the biggest open source GIS software, as input. This allows spread calculations to be fast enough to run faster than real time fires and leave the operator enough time to plan further activities of the field units.

2. Cellular automata and spatial modeling

Cellular automata are dynamic systems operating discrete in space and time, on a uniform, regular lattice and characterized by "local" interactions.

Celluar Automata were invented by the mathematician Stanislaw Ulam and were used by J. von Neumann, followed by A.W. Burks and E. F. Codd, to solve problem of the non-trivial self-reproduction in a logical system [3,7].
A cellular automata is defined by a grid with start states and set of rules for state transitions.
Generally, cellular automata consist of four elements, which could be considered as a *tuple (X, S, N, f)*

- X are cells which are objects in any dimensional space, we can call this cellar space. In cellar space, each cell has the form $x=(x_1, x_2, x_3, .., x_m)$,where m is the dimension of the space. All cells have some forms of neighborhood.
- S is a nonempty finite set of automaton states. Each cell can take on only one state at any one time from a set of states, $s \in S$. Strict CA also requires state variables to be discrete.
- Neighborhood Template N - the state of any cell depends on the states and configurations of other cells in the neighborhood n of that cell. In two-dimensional space, there are two well-known templates, von Neumann or 5 cell neighborhood, as shown in **Fig. 2.** and Moore , 9 cell neighborhood, as shown in picture **Fig. 3**

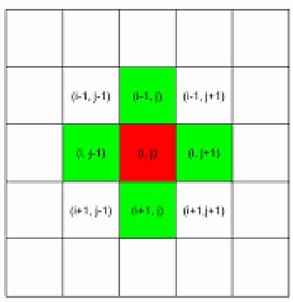

Fig. 2. Van Neumann's Neighborhood

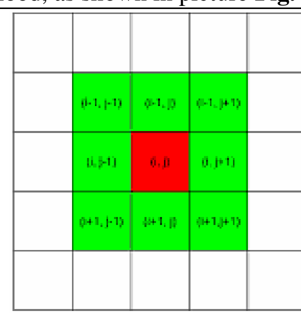

Fig. 3. Moore's Neighborhood

- f is state transition function rule

$$f \in F \qquad \textbf{(1)}$$
$$S_c^{t+1} = f(S_c^t, S_{n(c)}^t)$$

The transition rule will take the previous state of a cell and the status of neighborhood $S_{n(c)}^t$ as input ant return the status S_c^{t+1} at time t+1
Also cellular automata can be implemented with rules of different range. Range of 1 means that only the nearest cells are considered as neighbor cells, and higher range means that more nearby cells are considered, as shown in **Fig. 4**
Cellular automata can also be implemented with rules of different range. Range of 1 means that only the nearest cells are considered as neighbor cells, and higher range means that more nearby cells are considered, as shown in **Fig. 4.**

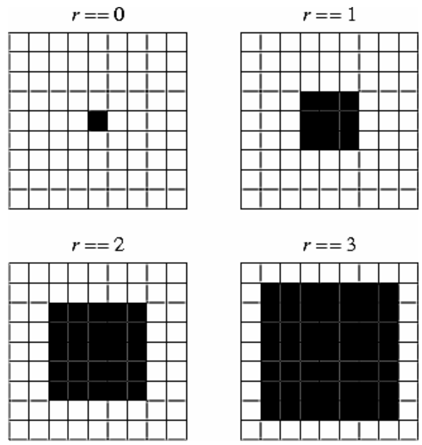

Fig. 4. range of cellular automata

3. Fire spread modeling using cellular automata

Landscapes can be represented as cellular automata. Thus, it is possible to apply cellular automata formulations to a number of landscape diffusion processes such as forest fires [5].

The most common approach for fire modeling has been to simulate fire growth as a discrete process of ignitions across a regularly spaced landscape grid of cells. Each cell represents a fixed surface area and has attributes that correspond to environmental features such as vegetation cover and topography. Computational methods are used to automate the application of fire shape models to non-uniform conditions by assuming local uniformity.

We can assign a numerical value to each cell following this convention:

- A burning cell has a value of 3
- A burnt cell has a value of 2
- A growing cell has a value of 1, and
- The state where it can be ignited has a value of 0

We can use the following rules for cell evolution:

- A cell that is in an ignitable state remains in an ignitable state unless at least one neighbor is burning. In this case the cell becomes burning in the next step.
- A burning cell becomes a burnt cell in the next step.
- A burnt cell becomes a growing cell in the next step.
- A growing cell becomes an ignitable cell in the next step.

4. Cellular automata fire spread model implemented on island of Brač

In order to implement cellular automata model on specific area we need to obtain input data required by the model. In our case we need a matrix grid where each cell has assigned value that represents parameters that affect forest fire. Each cell represents a tree or no tree – can or can not burn. Probability that a cell holds a tree is calculated from vegetation characteristics, obtained in GIS format.

4.1 CORINE Land Cover

CORINE Land Cover [6] is a project which is being coordinated by the European Environment Agency.

Main aims of the CORINE (Coordination of information on the environment) program of the European Commission are:

- to compile information on the state of the environment with regard to certain topics which have priority for all the Member States of the Community;
- to coordinate the compilation of data and the organization of information within the Member States or at international level;
- to ensure that information is consistent and that data is compatible.

CORINE Land Cover (CLC) is based on a simple 3-level hierarchy classification system consisting of 44 land cover classes.

CORINE Land Cover maps are created by analyzing satellite images of earth surface. Project includes nearly all European countries, except Croatia. There are some speculations that Croatia will join the project in the future.

Anyway, Corine Land Cover map for island Brac already exists and it is available in vector shape format which was imported into the GRASS GIS location of island Brac.

GRASS GIS is the biggest open source GIS software project. It consists of many modules. GRASS can import and export all main different formats, can convert raster to vector and vice versa.

We converted imported vector data into a raster consisting of matrix which cells hold the CORINE code of land use.

Than we used the export module to convert raster data in matlab workspace file.

Loading the .mat file into a matlab workspace created variables shown in Table 1.

Name	Dimensions	Size	Data type
map_data	821x2016	13241088	double array
map_eastern_edge	1x1	8	double array
map_name	1x16	32	char array
map_northern_edge	1x1	8	double array
map_southern_edge	1x1	8	double array
map_western_edge	1x1	8	double array

Table 1. variables exported from GRASS

map_data is a matrix of corine codes. It is data that will be taken into account.
We converted corine codes into density of burnable cells using following asumptations:

– The cells with corine family code 100 are nonburnable cells, and are automatically asigned value 0.
– Cells of corine family code 200 are cells with short grass, vineyards, and we assumed that about 30% of them are burnable.
– Cells with family code 300 are forest, and we assigned them burnability of 70%.

We assigned following numbers to represent the state of cell:
0 – the cell is unburned and can not burn.
1 – the cell is burning
2 – the cell represents a tree that is not burning, but has a tension to burn if fire occurs in neighboring cells.
The rules used in simulation are:

1. Unburned cell becomes a burned if one of the neighbor cells is burning 2➔1
2. Burning cell becomes unburnable in the next step 1➔0
3. If there are wind conditions one cell of range 2 in the direction of wind is taken into calculation as neighbor cell.

To automate this process we created a MATLAB script file corinetrans.m which must be called after loading .mat file.

4.2. Results of simulation:

Example 1: No wind conditions:

The first example describes simulation started in forest with high density without wind conditions. Pictures below show results after 7, 14 and 30 time steps. The shape of fire is elliptical. After 14 steps the east side of fire front has reached the area with lower flammability (forest with lower wood density, or some form of agricultural land). In the last picture we can see that fire spread was slower for that area than for the forest.

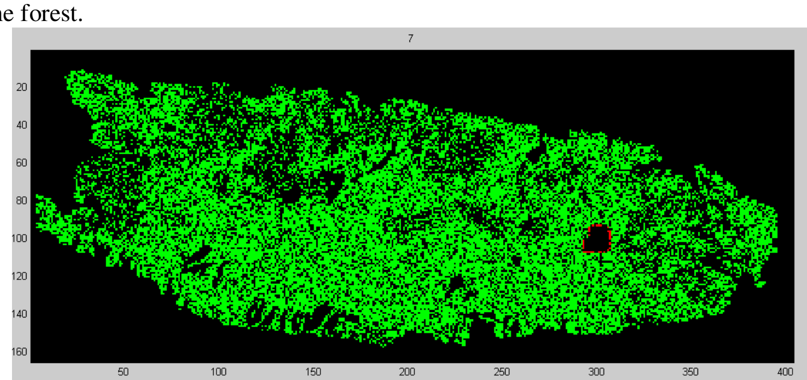

Fig. 5. Shape of forest fire after 7 time steps

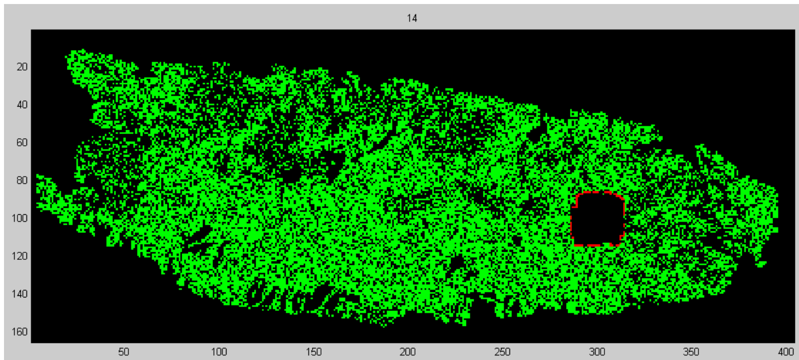

Fig. 6. Shape of forest fire after 14 time steps

Example 2:

In this example the fire was started in the area with lower flammability. The shape of fire front is irregular and the velocity of fire spread is slower. There are areas in the middle of fire shape that are unburned. We can conclude that the intensity of fire was lower than in the example before.

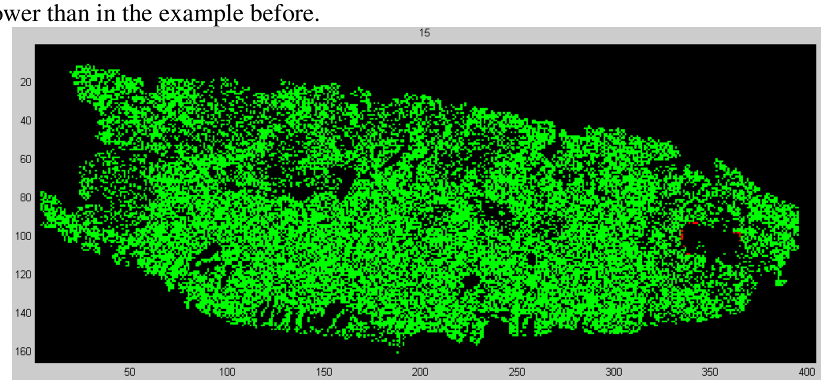

Fig. 7. Shape of forest fire after 15 time steps

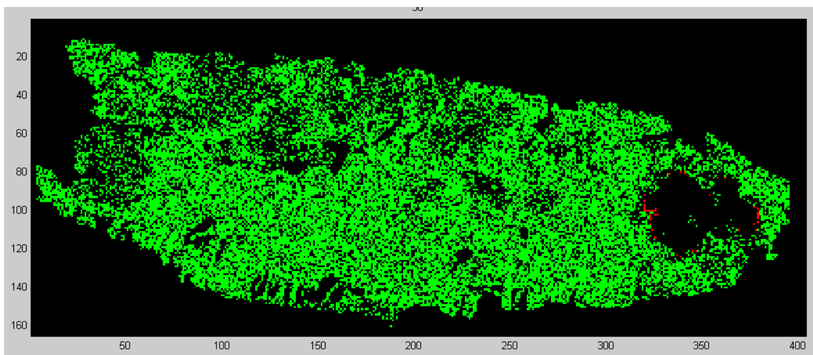

Fig. 8. Shape of forest fire after 30 time steps

Example 3:

Example with South-East wind:

The start point of fire is inside a forest area with higher density of trees. The shape of fire is typical for windy conditions, the fire moves faster, accelerated by the wind.

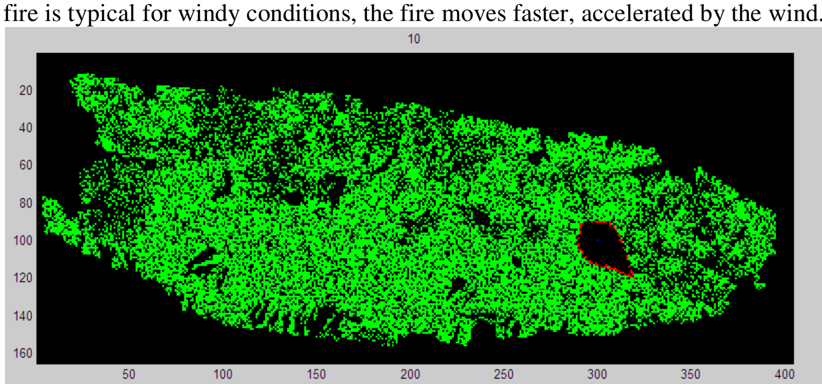

Fig. 9. Shape of forest fire started under strong wind conditions

Example 4:

This example shows the result of a simulation on a larger grid, that is higher resolution grid.

The blue spot represents the starting point of a fire. The wind is north. The picture shows the results after 100 time steps. Larger number of steps is required because the total number of cells is larger, and neighborhood is of range of 1, so the propagation will be slower, that is for one time step, smaller area will be affected.

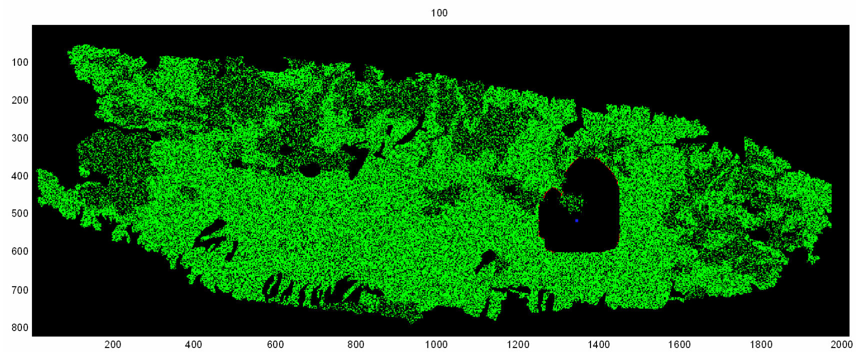

Fig. 10. Shape of forest fire simulation on a larger grid

5. Conclusion

Fire models are useful in every aspect of fire protection activity – before fire, during fire and after fire. Different approaches to fire modeling and fire behavior prediction can be used, but in practice, most commonly, rough, simple models are used. In this paper cellular automata model has been applied to area of island Brač. Among input parameters, only vegetation characteristics and wind conditions are taken into account. The results have shown that this approach is fast and satisfactory enough for practical use. Shape of the fire front achieved in the simulation is similar to shape of fire front developed in forest fires on the same area taken place in the past.
Future work on expanding input parameters can be done, considering that fire behavior is a complex process controlled by many parameters, such as air temperature and humidity, fuel bed, fuel wetness, but here, only vegetation density and wind conditions have been taken into account. Combination of cellular automata model together with other computational methods would give more accurate results.

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