Approaches to Modelling Forest Fire

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Abstract

There have been many efforts made towards predicting forest fires. With the increased power of computers, new approaches to forest fire prediction have emerged. As a result, a variety of methods have been developed such as cellular automata approaches and complex global mathematical solutions. Each involves two steps; implementing the model design and verifying its correctness. This review outlines current models that have been deloped, what they were designed for, the implementations that they used, and the results that were obtained for each model.

Keywords: Forest fire models, Cellular automata
CR Classification F.1.1 Cellular Automata

1 Introduction

When modelling forest fires moving over terrain, commonly occurring themes fit into three main categories; vegetation, meteorology, and topography. Differences in the models occur depending on the application of the model, whether it is being designed for a real-time simulation that is created for use during a fire emergency, or whether its purpose is to accurately predict future fires and the effects they would have on the landscape. After a model has been created verifying its correctness is a problem faced by all authors, the problem lies in being able to collect accurate data about a real forest fire.

2 Possible models to use

There are two main approaches to modelling forest fires; on a global level where the model predicts the movement of the entire fronts, or a local level where the model describes interactions between small sections of the landscape. Each model has different methods of implementation. The global level models can be described using partial differential equations [5] or fractal equations. Local models can be described by using Cellular Automata (CA) or Cell Discrete Event Systems specifications (Cell-DEVS) that is similar to the CA approach but combines the DEVS formalism. Jorba et al. [6] combined a global and local model where the local model would take into account the static and dynamic conditions, the global model then calculating a new fire line by applying an aggregation process to the local ones [6].

3 Model outlines

Zue et al. [4] decided to use fractal methods because forest combustibles such as pine needles, twigs, branches, and trunks fit a Gauss distribution on any scale. In other words quantities of branches on every tree, the twigs on each branch and the leaves on each twig are all important features in a forest fire. The self-similarity of combustibles results in the self-similarity of the fire front's shape. Forest fire spread has self replicating features in that each point of the fire can ignite the combustibles around it [4]. This allows the fire behaviour to be described by fractal geometry.

The CA approach had been chosen by Veach [3] because of the three primary attributes; the state of the cell, its neighbourhood, and the set of rules to follow. Modelling the landscape fits into this paradigm well because land can easily be cut up into discrete blocks that record the state of the topography of the land. The neighbourhood functions are represented by the spread of fire over the surface. The set of rules to follow explain how the fire moves through a cell. Mraz et al. [9] chose to use a CA approach but because they knew the exact dynamics of a system were difficult to determine, they introduced a new model, the fuzzy cellular automata (FCA) which involves fuzzy logic into the model.

Muzy and Wainer [5] developed a Cell-DEVS approach to modelling forest fires because this local approach lead to easier definitions of rule sets to their previous DEVS approach. They found that the DEVS approach was a good model when factoring in complex external influences such as; wind changes, non-homogenous fuels, and slope. However, the simulation times were too long to have any real-time simulating abilities over large areas.

Coleman and Sullivan [7] at the CSIRO developed a vector based approach to store geographical features. This was chosen because the time rasterised based data could not be stored on a large scale and still provide fine detail. Another reason for their choice was outlined by French et al. [10] who concluded that grid based models could handle heterogeneous fuel well, but produced distorted shapes of fire if the wind did not align with the grid. Heterogeneous fuel could not be handled as well by the vector approach, although they did not produce the distorted fire shapes when the wind came from an arbitrary angle.

4 Mathematics behind the models

The mathematic models designed by Rothermel [2] are used in most of the local model approaches. His prediction process has three elements: obtaining the inputs, calculating the fire behaviours, and interpreting the outputs. Problems with this model are that it was developed for homogeneous fuel beds. Adapting it to move from one cell to another was something each implementation had to consider [3].

Mraz et al. created rules with the help of local fire experts to cover five major areas which influence the spread of fire:

- Direction and speed of the wind,
- Altitude of the cells,
- Fire flammability of each cell,
- Fuel supply of each cell, and
- Weather conditions.

These follow a different set of mathematical rules outlined by Anderson [1]

5 Methods of implemenation

Veach et al. [3] implemented their model by writing a piece of software called BURN. At the time the limiting factor was memory constraints that lead to large scale models being unsuitable. To begin each simulation BURN read the inputs from five files: terrain, moisture, wind, elevation, and ignition. BURN's solution to moving between different fuel beds was to assume that a fire only occurred in the centre of a cell, and did not spread continuously across the cell. This meant that a fire would jump from one cell to another and not pass in a homogeneous fashion through cells. This doesn't happen in the real world but for the model it did not lose accuracy when looking at the overall fire situation. Similar modelling techniques were used by Muzy et al. [5] in the Cell-DEVS model. When a cell is on fire, the cell worked out the direction of the fire and the time it would take to reach each neighbour. A record would be kept of these times and the cell would delay its next event until a message to a neighbour needed to be sent. An advantage to the CA and Cell-DEVS approach is the ability to easily add new rules into the model. This would allow simulation of rain or fire fighters into the model that other more global models could not.

The local and global model by Jorba et al. was defined by Andre and Veigas [8]. The goal of this model was to calculate the next position of the whole fire line by considering the current fire line. The model first disintegrated the fire line into sections then used Rothermel's model to calculate the maximum speed of the fire front. Anderson's method of fire propagation is then used to calculate the distance travelled in each direction from the fire front. Once a new section of the fire front has been generated each section is blended together with the sections beside them. The simulation overall involve several processes that require complex calculus. This leads to large amounts of computing time required that can only come from a parallel or distributed solution [8].

The choice by Coleman and Sullivan to use a vector based approach lead to quite a unique solution to the problem. They defined the fire front by a doubly linked circular list. Each node defines a point on the map for display purposes, an angle to the next point, and the distance to the next point. To calculate the fire spread for each point of the old perimeter four steps were taken:

- Determining fuel type and calculating rate of forward spread;
- Calculating the propagating ellipse parameters;
- Identifying the points on each propagating ellipse that meet specific criteria;
- Adding the identified points on the propagating ellipse to the new fire perimeter [7].

6 Results

Zhu et al. solution of modelling the fire front using a fractal technique was successful when comparing it to a real fire. Photographs of the real fire were taken after a period of 48 hours and the total burnt area was 51.18km^2. The results of a simulated propagation were 55.09km^2. The error of the simulation was 7.4%. They also noted that the shape of the real fire was similar to the simulation giving more evidence that forest fire fronts have fractal and self replicating features. The time taken to simulate the fire was not mentioned because the model was not meant to produce a fast simulation but a more accurate one.

Mraz et al. initial method of verification for their implementation was to compare their FCA against a simple example of how wind affects the spread of fire. They used experiments designed by Fons [1] and also a real example of a fire. They came to the conclusion that the FCA approach gave good results and followed closely to the actual shapes of the real fire. Muzy et al. Cell-DEVS approach modelled the environment correctly, but suffered from a large number of cell to cell messages that were a result of the asynchronous nature of the Cell-DEVS approach. They outlined new methods of modelling the environment that would eliminate these problems but they did not implement them.

Veach et al. did not compare any actual fires or statistical ones because at the time of the paper BURN had not been completed and was still in its implementation stage. They concluded that their CA approach to the problem had positive results because it provided a global perspective from a local model. They also concluded that the success of the simple simulation and the ease of adding new rules to the model made it a good solution for more sophisticated fires by progressively adding in new rules.

The product that Coleman and Sullivan produced was called SiroFire. It was tested by modelling two weather scenarios with two geographic databases with simple and complex detail respectively, giving four different simulations altogether. The simulations were of a six hour fire and were completed in 7.06 minutes on a Pentium 66MHz. The reliability of SiroFire against actual fires is not easy to validate. One example of comparison showed that SiroFire gave a good indication of the perimeter of a fire in a complex terrain given certain conditions. It demonstrated that it was practical to implement a sophisticated fire spread model application on a desktop computer [7].

7 Conclusion

All the local level models that used the Rothermel and Anderson algorthims were able to use the predicting techniques to simulate a landscape with heterogeneous fuel properties and a variety of meteorological conditions. When the models are compared with real world examples the algorithms can be assessed for their adequacy under certain conditions and whether new algorithms need to be created to better suit the changing conditions. Using any of the current models, fire fighters can also run simulations under different weather and fuel conditions and be assured, to some degree of accuracy, of what could happen, allowing them to be better prepared. No model is perfect however and care must be taken when relying on a models results.

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