Applications of Cellular Automata: Wildfire Spread simulation

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1 Abstract

2 Introduction

A brief summary of what you did and what you found.

By implementing a 6-state based model of fire spread across a variable-height terrain with wind and areas of varying flammability, we have been able to simulate the spread of real forest fire across a simulated environment, dictated by the specification given to us.

By using a reduced state set and cell properties, we can model complex relationships between the properties of an area in a forest fire to create a stochastic state transition function for each cell in the next time step.

Attempting to relate our simulation to the real world values of forest fires across a similar terrain, we have gradually improved the weighting of various factors to generate a suitable fire spread.

3 Introduction and Background: Literature Review

As the issue of simulating the spread of the wildfire is to be implemented through cellular automata, consulting existing research into this field can give us a valuable insight into how best to proceed. Considering what properties are being modelled and the ways in which transitions between state are decided can give us a grounding in this specific problem area.

Considering the evidence existing papers have used to justify their results can provide a good metric for the accuracy of our results. Because this project seeks to show the effect of wildfires in relation to a municipality and surrounding area,the real world implications are obvious, and should be considered throughout our research into this domain.

There are two notable papers in this field whose outcomes seem to overlap strongly with our intentions. Both of these papers consider simulating real world forest fires using cellular automata. Using the deeper understanding of the problem space that the authors of these papers have will allow us to consider global properties which we may have been unaware.

3.1 Paper 1: A CA model for forest fire spread prediction (Alexandridis, Vakalis, Siettos, & Bafas, 2008)

3.1.1 Background

This paper seeks to provide a comprehensive model for modelling wildfires using a cellular automata, designed to include the most impactful properties when considering the spread of wildfire. By comparing their results against that of the 1990 Spetses island wildfires, and iteratively changing constants in their transition functions, the authors simulated forest fire spread to a high degree of accuracy - their final results occupying $5.4km^2$, with the actual fire occupying $5.9km^2$.

3.1.2 Context

The authors states several key criteria which affect the spread of wildfire across a terrain.

- Spread and shape of a forest fire front

- The fuel type (type of vegetation)

- Humidity

- Wind speed and direction

- Forest topography (slope and natural barriers), fuel continuity (vegetation thickness)

- Spotting which is a phenomenon where burning material is transferred by the wind or other reasons such as the fling of flaming pinecones to areas that are not adjacent to the fire front.

Each parameter is given a weighting and a probablistic model is used for each parameter to calculate the total chance of a cell being set on fire in the next time step $(t+1)$.

The chance of fire, p_{burn}, is given as:

$$p_{burn} = p_h(1 + p_{veg})(1 + p_{den})p_w p_s$$

where:
p_h = constant probability that a cell adjacent to a burning cell containing a given type of vegetation and density will catch fire at the next time step under no wind and flat terrain
$p_{den}, p_{veg}, p_w, p_s$ = the density of vegetation, the type of vegetation, the wind speed and the slope, respectively.

3.1.3 Implementation

The CA has four necessary states:

$State = 1$: The cell contains no forest fuel. This state may describe the cells corresponding to parts of the city with no vegetation, rural areas with no vegetation etc. We assume that cells that are in this state cannot be burned.

$State = 2$: The cell contains forest fuel that has not ignited.

$State = 3$: The cell contains forest fuel that is burning.

$State = 4$: The cell contained forest fuel that has been burned down.

3.1.4 Conclusion

The use of additional parameters such as humidity to predict the spread of the forest fire, along with their use of real world GIS values gives rise to a greater accuracy of results (in relation to the real world spread of forest fires) when compared to the default criteria to be implemented.

To meet the criteria given, the insights regarding the weighting of different parameters and the use of a probabilistic model to calculate the chance of a cell burning offer a credible starting point.

3.2 Comparison between literature, insight and relevance to this implementation

The two papers discussed above implement the idea of 'fuel' in different ways. (Alexandridis et al., 2008) structures fuel as a property of the states, whereas **Jacob's Paper** provides different states for different levels of fuel.

The advantage of moving the fuel state into an attribute of the cell is the greater precision of fuel that can be stored, while also maintaining a smaller amount of states. By limiting fuel state to discrete variables, the forest fire spread will lose valuable resolution which can be maintained with a different data structure.

4 Methodology

> - A short summary (IN YOUR OWN WORDS) of how the CA approach can be applied to model a forest fire. This should assume that the reader is a non-expert in modelling or Computer Science in general. You should explain in English (as opposed to simply using code), how you have extended the model you have been given in order to investigate the features mentioned. You can

also use simple flow or state transition diagrams to support you description. You can also refer to relevant python code included in an appendix. It is expected that in extending/developing your model you will have to make some assumptions about how to implement particular behaviours, and also in terms of the parameters (values) you choose to use e.g. to represent different fuel resources/burning times. You are not expected to become experts in this area but you should at state justify any assumptions you make.

Cellular Automata is a term to describe the simulation of a discrete number of cells and interactions across a cell space (grid). Each cell can have one state at any one time step. Cells can change state. The permitted changes from any one state to another state is determined by a transition function. The transition function can consider global properties, such as the current time step, as well as local properties, such as the cell's current state, as well as its neighbourhood - a set of cells near the cell.

By representing small sections of the terrain as cells, cellular automata can be used to simulate the spread of the fire across the grid. By constructing the states of the CA to the functional states of the areas of terrain, transition functions which take additional parameters along with the cells can be used to map the flow of fire.

After consulting existing literature, the following functional states were devised:

0. Burnt out

1. Burnable grass

2. Dense Forest

3. High Flammable Scrub

4. On fire

5. Buildings

6. Water

State	Valid transition states
Burnt Out	Burnt out
Burnable grass	Burnable grass, On fire
On fire	On fire, Burnt out
Buildings	Buildings, On fire
Water	Water

Figure 1: Valid state transitions for each of the states in the CA.

The transitions between states are calculated with a set of parameters for each cell, which

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are stored in an 5-parameter list for each cell in a grid equal in width and height to the cell grid.

0. Height - Scalar value

1. Wind/Magnitude - East to West

2. Wind/Magnitude - North to South

3. Flammability

4. Humidity

5. Fuel

Given the parameters, a probability is derived: the chance of the current cell setting on fire in the next time step. This is consistent with the method of (Alexandridis et al., 2008).

If at least one cell is on fire in the cell's neighbourhood, the chance of catching fire is calculated by the using a weighted sum of probabilities, dependent on the wind magnitude, the flammability of the cell that is on fire, and the difference in height compared to the neighbourhood.

This can be represented as the following equation:

5 Results

In this section you should describe what simulations you carried out under which conditions (e.g. parameter sets mentioned above, wind direction,...) and how long the simulation was run for. You should use fully labelled diagrams (e.g. screenshots or where appropriate, line graphs) to display your results and you should also describe your results in text. Additional results can be included in an appendix

- Wind Direction - East to West

- Wind Direction - North to South

- Wind Direction - North East

- Wind Direction - South West

- Resolution - 50 x 50

- Resolution - 200 x 200

- Resolution - 400 x 400

6 Discussion of model and conclusions

7 Conclusion

References

Alexandridis, A., Vakalis, D., Siettos, C., & Bafas, G. (2008). A cellular automata model for forest fire spread prediction: The case of the wildfire that swept through spetses island in 1990. *Applied Mathematics and Computation*, *204*(1), 191 - 201. Retrieved from `http://www.sciencedirect.com/science/article/pii/S0096300308004943` doi: https://doi.org/10.1016/j.amc.2008.06.046