# Wildfires propagation

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**Abstract**

In areas with warm and moderate weather the occurrence of wildfires are very common mainly in the summer. These wildfires causes a great damage in the environment and if they are not controlled they could also destroy houses, industries and agriculture fields. Thereby is in the best interest to build a reliable model to study the propagation of wildfires aiming to take actions to decrease the chances of a propagation of fire.

> I'd rather fight 100 structure fires than a wildfire. With a structure fire you know where your flames are, but in the woods it can move anywhere; it can come right up behind you.
>
> Tom Watson

## 1 Introduction

In the summer there are a lot of wildfires that affects the most wooded areas, such as forests and mountains. Therefore it is in the best interest to study the propagation of wildfires aiming to protect the wild life and the forests but also protects the residential and industrial areas into zones considered of risk.

With a model capable of predict fire behaviour it will aid the firemen and the public in fire suppression, fighting wildfires and even in reducing the probability of happen fires. The construction of a realistic model it's not a easy task [4], that model has to take in account several parameters that can affect the propagation of fires, such like the temperature, the humidity, the direction of the wind and the amount of content fuel restrained in the forest. As will be described in the followings sections the author decided to simplify the parameters of the model and then built a model in a cellular automata, a 2D world.

This document is structured as follows: in the first section was described the problem covered in this document. After that was presented some approaches that was proposed and studied by other authors. In the third section were reported the approaches exhibited by the author. The following section was reserved for the analysis of the obtained results. Finally in the last section were addressed the conclusions of this work and also addressed what could be improved.

## 2 Problem

LIKE was described in the previous section, building a model of a wildfire propagation is really complex since it's necessary to deal with several parameters. Thereby is necessary have a great knowledge of a particular forest to implement its model.

The model discussed in this document was built using a cellular automata, a limited 2D world, which simplify the model by discretize the data. In that way it's possible use simple rules to each element of the data to represent a determined behaviour, deterministic or probabilistic. Other simplifications was done in the level of data. Therefore each element of the cellular automata can be represented on of the following four fields:

- **Healthy forest** - was only considered one type of tree in the forest all with the same amount of content fuel;
- **Burning forest** - a forest can burn for more than a interaction and when burning can also burns its neighbourhood;
- **Burned forest** - a field that represent one former burning field where the fire was extinguished;
- **Empty space/Obstacles** - represents empty fields on the forest like stones, clear fields and former burned fields.

# 3 State of Art

ALready have been studied and presented several models using cellular automata for the wildfire propagation. In general that models have in common the kinds of fields presents in a forest, that are: trees, empty spaces and burning areas.

One example of that kind of model are a model wherein a field ignite by a probability if a neighbour field is in flames, [1]. There are others models more complex like the Forest-fire model [2][3]. This model introduced a probability of growing trees in empty spaces.

There are still others models that concerns with the correct geometry of a fire in the form of a wave, like the model proposed by Keith C. Clarke and his team[5]. Thereby that model have in attention the direction of the wind, direction of a large and quick propagation of a fire but also the lesser and slow propagation that there is against the wind.

# 4 Methodology

WHEN studying the propagation of a fire one concern that occurs is to predict the effect of wind in the propagation. It this in mind, in the model proposed is possible change the effect of wind, to none, low and medium. It's also possible change several parameters in that probabilistic model.

Were studied three differents neighbourhoods wherein each represents one of differents conditions of the wind: none, low and medium. For simplicity was only implemented one possible direction of the wind that is northeast.

In the first model was only considered a Von Neumann neighbourhood like was described in picture 1. Wherein a burning field can ignite a adjacent forest all of them with the same probability. This neighbourhood was chosen because it resembles the propagation of a fire without wind which is circular.

The second model results of modification of the previous model, in which now the probability of ignite others fields is not static and that means that trying to ignite a field against the direction of the wind decreases the probability of ignite that field, like it's represented in the picture 2.

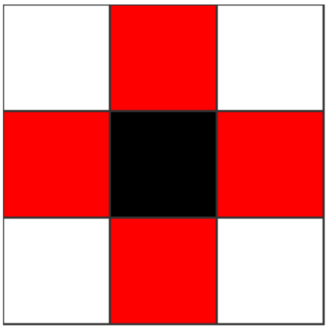


Figure 1: **Neighbourhood of the first model**

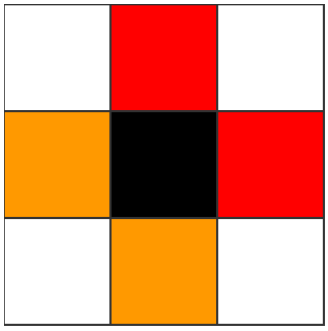


Figure 2: **Neighbourhood of the second model**, the oranges zones represent the reducing of the inflame probability

The last model is a derivation of the previous model in which now the range of neighbourhood is bigger according the direction of the wind. That was proposed with the intention to simulate the propagation of fire between obstacles when exists wind and also increase the speed of this propagation.

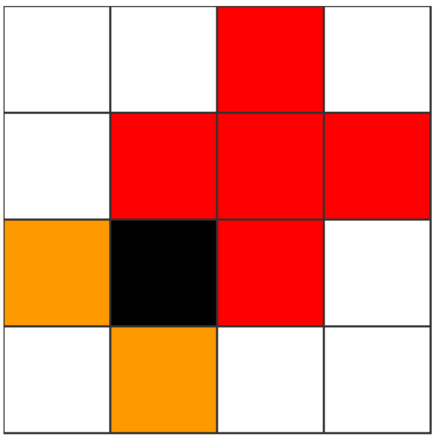


Figure 3: **Neighbourhood of the third model**, the oranges zones represent the reducing of the inflame probability

# 5 Results and discussion

THE space used in these experiments was a 2-D limited world, in which each field is represented by a square in a world with 250 squares by the width and 150 squares by the height. These world is limited and by that is considered that when a fire exits the world it disappears.

All the performed experiments was executed with the following parameters, that result after some tuning.

- Initial inflame probability: 80%
- Reducing the inflame probability, when against the wind: 20%
- Number of interactions burning a field: 3

Was performed two differents kinds of experiments, the first experiment compares the three models mentioned before with different densities of forest fields vs empty fields. In the other experiment, the three models were tested with the inclusion of reforestation, in that way a empty field can became a forest field.

For simulation purposes all the experiments was performed with the exactly the same initial world and with the same initial point of fire. It is worth mentioning that being a cellular automata the evaluation of the results is based a lot in a visual inspection. Hence the need of other way to observe the evolution of these cellular automata, because of that the author presents graphics that show the evolution of the simulated world. These graphics presents the burning area, burned area, forest area and empty (obstacles) fields.

## 5.1 First Experiment

Like mentioned before in the first experiment were compared the tree model described before in two different worlds. The difference between these two worlds were in the density in the forest vs empty spaces.

- **Forest with a density of 90%**

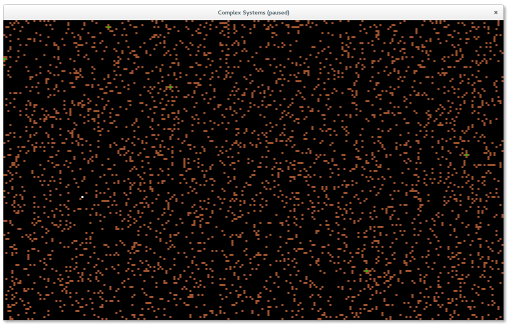



Figure 4: **Burned area in a forest with density of 90% with the first model of neighbourhood**

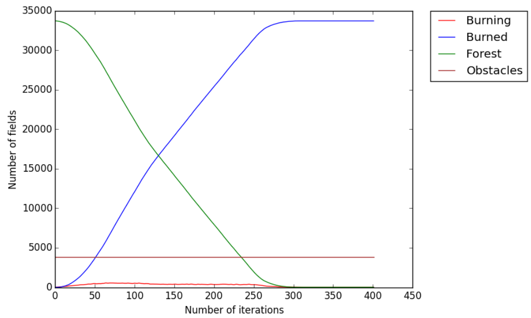



Figure 5: **Evolution of the types of fields in the wildfire** of the previous picture

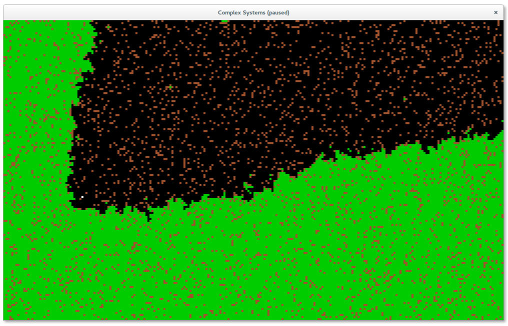



Figure 6: **Burned area in a forest with density of 90% with the second model of neighbourhood**

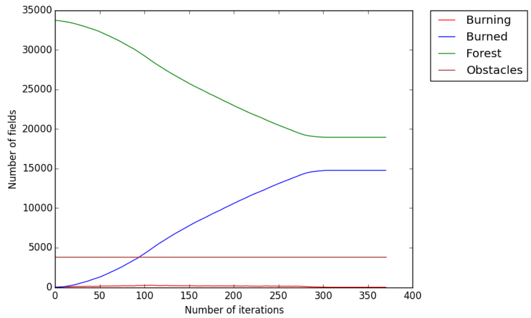



Figure 7: **Evolution of the types of fields in the wildfire** of the previous picture

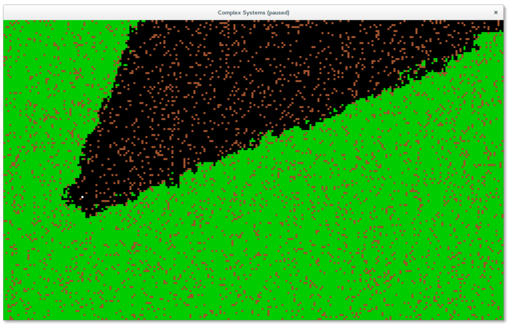



Figure 8: **Burned area in a forest with density of 90% with the third model of neighbourhood**

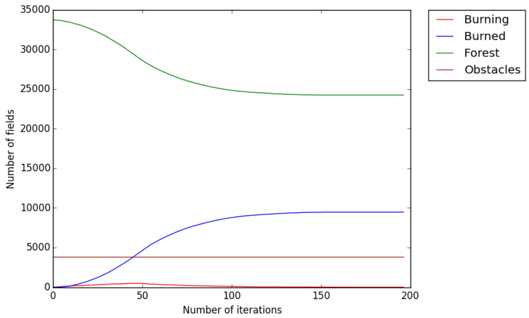



Figure 9: **Evolution of the types of fields in the wildfire** of the previous picture

- **Forest with a density of 70%**

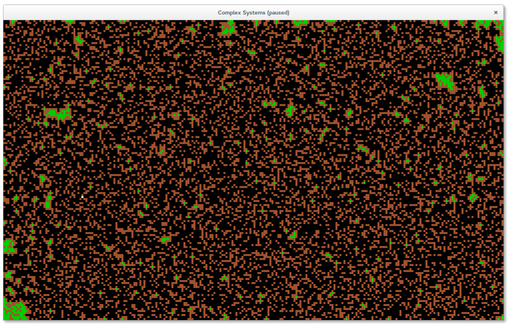



Figure 10: **Burned area in a forest with density of 70% with the first model of neighbourhood**

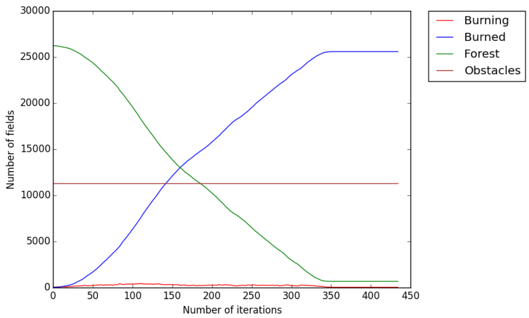
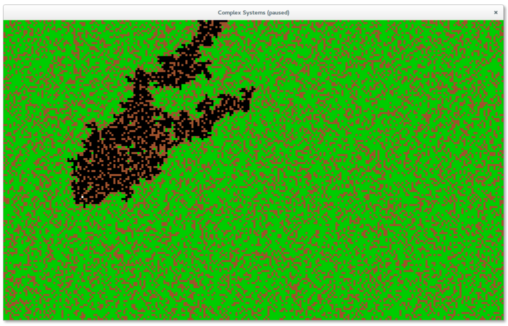



Figure 11: **Evolution of the types of fields in the wildfire** of the previous picture



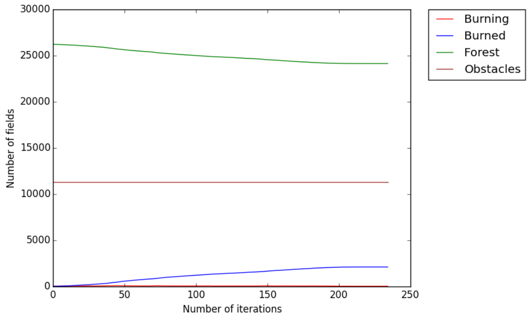
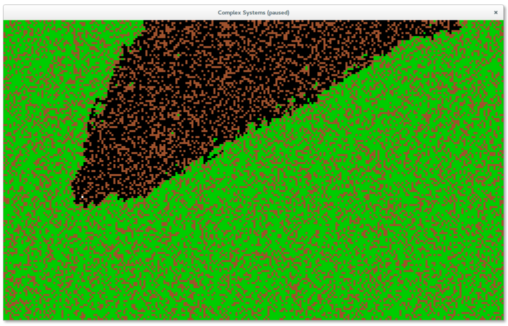



Figure 12: **Burned area in a forest with density of 70% with the second model of neighbourhood**

Figure 13: **Evolution of the types of fields in the wildfire** of the previous picture



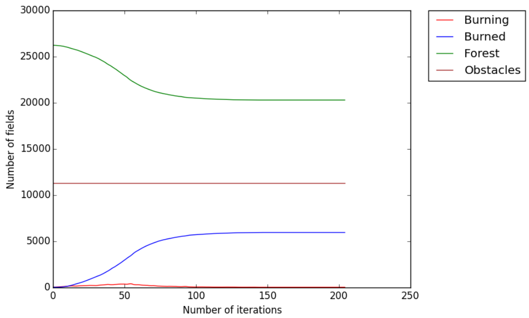



Figure 14: **Burned area in a forest with density of 70% with the third model of neighbourhood**

Figure 15: **Evolution of the types of fields in the wildfire** of the previous picture

Like it can be observed in the previous figures a alterations in the density of the forest can lead to changes in the propagation of a wildfire. In these simulation was possible to see how a propagation of fire in a forest with no wind or with weak wind can burn a large part of forest (4, 6) if the density of the forest is high. However changing the density leads to a lesser burned area and this area burns more slowly (10, 12). Which can indicates can clean some areas in a forest and even preserve some empty spaces it could prove beneficial to preserve the wild life and to aid to control the propagation of a wildfire.

In other hand, changing the density of the forest with a medium wind will not lead to many changes in the propagation of a wildfire, like it can be observed in 8 and 14.

## 5.2 Second Experiment

In this experiment the model was tested with a continuous evolution. In that way was added a probability of grow a tree (forest field) in a empty space. When a fire is extinguished or it go out of the windows it appears a new burning field in a random position.

This experiment was done with the idea of simulate what sometimes happens in a real scenario. Wherein there are wildfires in a previously burned zone some years ago, and the forest environment has not yet completely recovered of that fact whereby there are still some marks, obstacles.

Were considered the following parameters for these experiments: the probability of grow a tree from a empty space was 0.005%, a burned area became a empty space after 10 interactions and the density of forest was set to 70%, the other parameters remain the same as those described above.

Unlike it happens in the previous experiment, in this only are present graphics. This is due to first the evolutionary characteristic of this experiment that will not converge to any state. And second because in the first experiment that images were also presented to show how a fire with different neighbourhoods progresses.

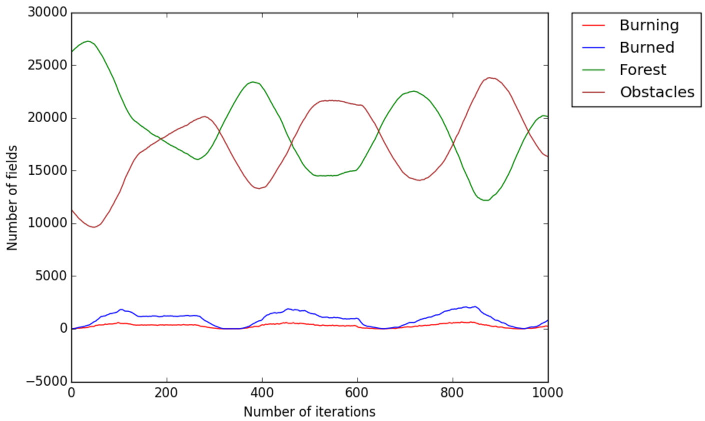



Figure 16: **Evolution of a forest with the first model of neighbourhood**

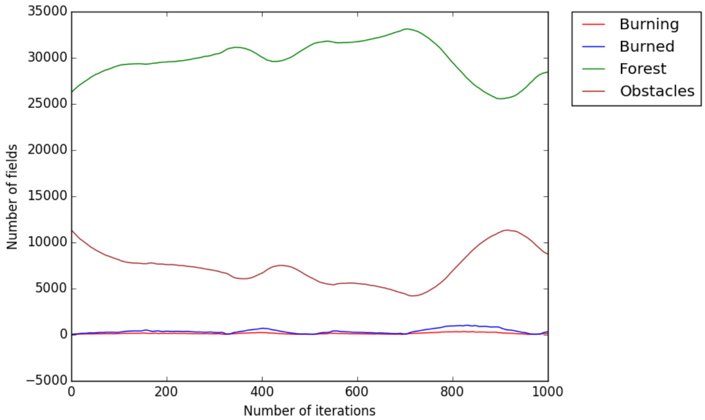



Figure 17: **Evolution of a forest with the second model of neighbourhood**

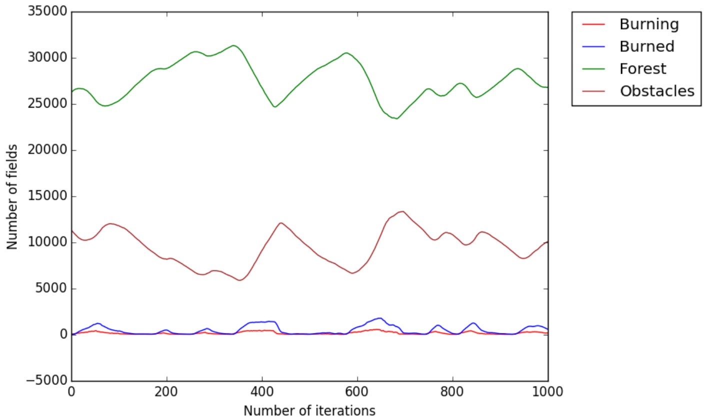



Figure 18: **Evolution of a forest with the third model of neighbourhood**

Like it can be observed in the previous graphics (16, 17 and 18) in general the results can be analysed by the occurrences of fires. Although these occurrences are constant, when a fire is extinguished it arise another fire. The propagation of these fires is spaced in time that occurs because the forest not recovered of the previous fire and because of that a new fire has little success. Also a season with peaks of fires is followed by a great increase of the empty spaces followed by the increase of forest. That is what happen in a real scenario wherein a fire caused the appearance of empty spaces that decrease the occurrence of fires of great dimensions and after a while it arise trees in these spaces.

## 6 Conclusion

WAS observed how the three proposed models act in different worlds with different densities of trees. Wherein a forest with a highest number of obstacles provokes a slowly propagation of a fire and in general the area of that propagation is lesser, this if the wind during that fire is absent or weak. Whereby the author concludes that adding empty spaces to a forest for these conditions it helps to control the occurrences of greats fires, like it is observed in the evolution model proposed in the second experiment.

However by other side the alterations of the density, this if the density of trees were bigger than the density of empty spaces, will not affect significantly the propagation of that fire.

In the future will be interesting to test this model with differents types of trees, to vary the amount fuel content, and also include others obstacles that will vary other parameters, like for example the inclusion of rivers or lakes that will affects locally the humidity of the adjacent fields. It would be interesting also explore other neighbourhoods and see how they will affect the model. The author also think that use a continuous model instead of a celular automata will increase the robustness of the proposed model.

## References


[1] Forest fire cloud – predict, analyze and visualize. http://forestfirecloud.com/.

[2] Forest-fire model. https://en.wikipedia.org/wiki/Forest-fire_model.

[3] A implementation of the forest-fire model. http://aryannayra.com/randomstuff/forestfire.html.

[4] Wildfire modeling. https://en.wikipedia.org/wiki/Wildfire_modeling.

[5] Keith C Clarke, James A Brass, and Philip J Riggan. A cellular automation model of wildfire propagation and extinction. *Photogrammetric Engineering and Remote Sensing*, 60(11):1355–1367, 1994.