# FYST13 Project Work
# Simulation of forest fire fronts

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## 1 Introduction

After reviewing different models of forest fire propagation and how they can exhibit chaotic behaviour, we used a cellular automaton acting on a 30x30 grid to model a forest, inspired by the works of Karafyllidis et al. 1997[2].

Using this automaton, we ran simulations with different values of forest density and different definitions of neighbourhoods.

This lead us to uncover the critical value of a forest density which results in its complete burning, and its dependency on the definition of the neighbourhood.

## 2 Methods

### 2.1 Models

#### 2.1.1 Deterministic/Stochastic

In this work, we studied forest fire as a deterministic process, where the burning state of a given tree is directly predictable from the burning of its neighbourhood. This is not, however, the only way to approach the problem. Since all the parameters of the system are not accessible or measurable, or a simply too complex to calculate (shape of the trees, gusts of turbulent wind), some teams have decided to embrace the unpredictability and adopt a probabilistic approach[3].

#### 2.1.2 Homogeneous/Heterogeneous forest

The first, intuitive approach to the issue of modelling the forest would be to consider it as a homogeneous inflammable plane. However, with our deterministic algorithm, this would lead to a isotropic fire front, producing a disk of burnt material. This is obviously not representative of actual forest fire propagation.

In real forest fires, the front propagates in a anisotropic way, similar to the way a piece of paper burns[7]. This behaviour arises consequentially to the fire front encountering inhomogeneities in the flammability of the forest. For instance, certain wood species might be less flammable than others, and trees themselves will not be identical and equidistant from one-another.

Therefore, we decided to insert the notion of inhomogeneity in our model, in order to see this chaotic behaviour arise. This can be seen in Figure 1.

## 2.2 Tools

### 2.2.1 Partial Differential Equations

Analytically, dispersion problems are often modelled by systems of partial differential equations (PDEs). Therefore, a naive approach to forest fire propagation would be to use such PDEs to simulate or predict the evolution of the fire front. However, multiple issues immediately arise.

First, an analytic solution to a problem with as many immeasurable and hidden variables as a forest fire is not, in practice, achievable. The precise composition and geometry of trees, ground, wind, etc. are obviously inaccessible to any observer.

Secondly, even if every variable could be measured, or at least estimated, the system of differential equations would still remain extremely complex, and therefore require immense computing power to be solved.

### 2.2.2 Cellular Automata

In this work, we used another mean of simulation, more adapted to modern computers : *cellular automata*.

Where a system of partial differential equation is very suitable to continuous processes, cellular automata use discrete time and space[6], which makes them more easily solvable by computers, which would otherwise require discretization.

**Forest** Our discrete model of the forest consist of a **30x30 grid**, each cell representing either an empty space (shown as white) or a tree (shown as green).

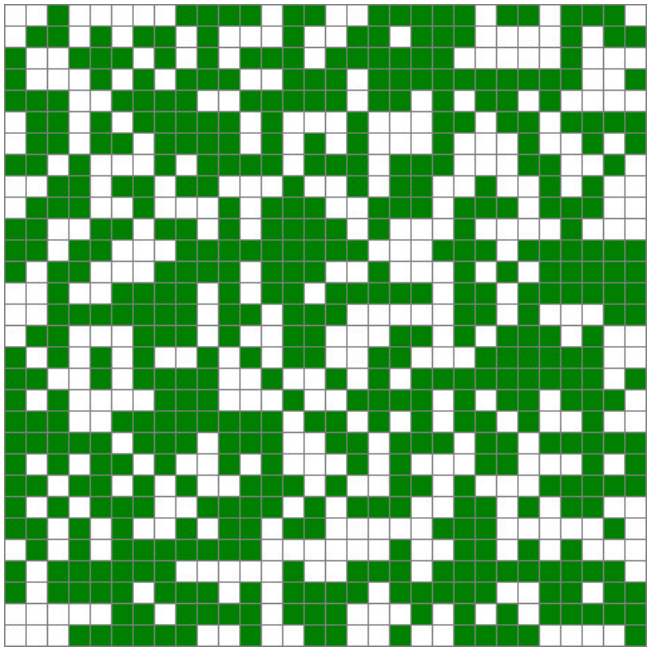

Figure 1: The forest as modelled in our cellular automata approach. Green cells are trees, white cells are empty space (not participating to fire propagation). The distribution is randomized.

This map is generated in a random fashion : each cell as a given probability (in Figure 1, this was set to 0.6) to be tree and the remainder to be empty.

**Rule** A cellular automaton is mainly described by a **rule** : a function that, given the neighbourhood of a cell at a time *t*, returns the state of that cell at time *t+1*.

In this work, we used a deterministic approach where a "tree" cell will become a "burning" cell if at least one of its neighbours is burning.

**Neighbourhood** A new question arises from this : how to define the neighbourhood of a cell in a 30x30 grid ?

This question is far from new in the field of cellular automata, and several solutions have been proposed. We will focus here on two different definitions of neighbourhoods and study their effect on the fire propagation.

Let's first consider only the cells directly in contact with the cell being studied. Then, the only choice to make is whether to include diagonal cells or to restrict ourselves to adjacent cells. Choosing the former yields the *Moore neighbourhood* definition[4], the latter the *Von Neumann neighbourhood* definition[5]. See Figure 2 for examples.

Then, we can push our study further by considering that second degree neighbours (neighbours of neighbours) also influence the propagation of fire to the current cell.

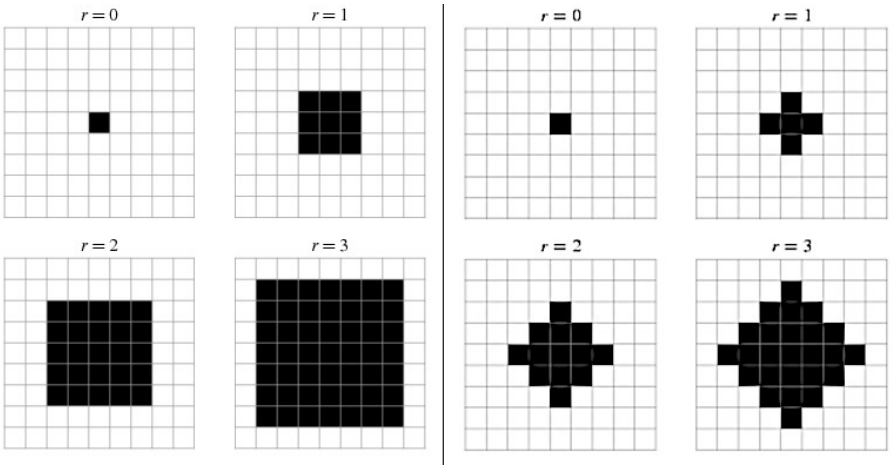


Figure 2: Examples of Moore[4] (left) and Von Neumann[5] (right) neighbourhoods of first to third degrees. From *MathWorld*.

### 2.2.3 Neural Networks

Recently, a new approach to this kind of complex problems has arose, which aims to solve them using *Neural Networks*. This method will undoubtedly prove itself to be an interesting tool in the study of forest fire propagation, but does not fit in our chaos theory approach.

### 2.3 Python code

For its simplicity of use and the extent of its libraries, we chose to program our algorithm in *Python*. The graphical user interface (GUI) was built using the *TkInter* library. The full code is available on GitHub[1].

## 3 Results

We carried out our simulations on our cellular automaton for different parameters and different definitions of neighbourhoods.

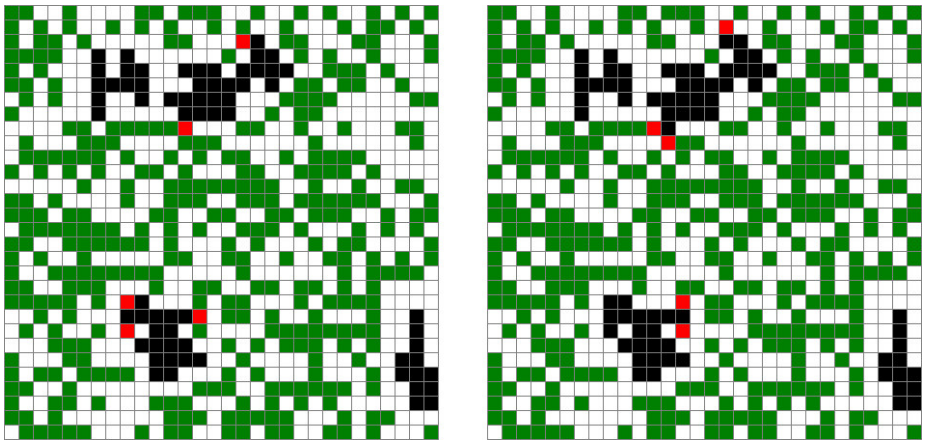

Figure 3: Example of the GUI displaying the state at the sixth and seventh iterations of a simulation with multiple fire starts. The white cells are empty, green are living trees, red are burning and black are burnt trees. The neighbourhood definition used is Von Neumann's, as is noticeable by the fact that the fire is not transmitted to diagonal cells.

The Python script and its graphical user interface (GUI) allowed us to study the fire propagation step-by-step and confirm the good integration of our approach.

An example of a simulated fire can be seen in Figure 3, where several fires were initiated and propagated through a first-order Von Neumann's neighbourhood.

## 3.1 First-degree neighbourhoods

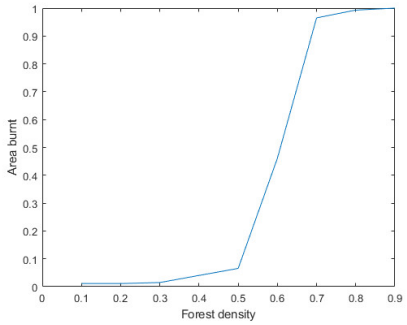


Figure 4: Area burnt for different values of the forest density. In these simulations, a burning cell in its **Von Neumann** neighbourhood was sufficient for the burning of a tree cell.

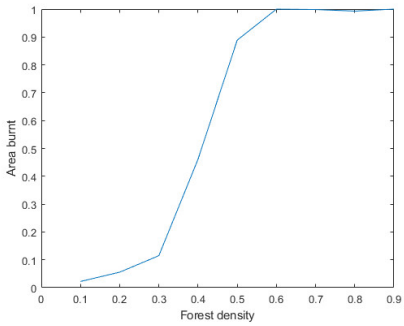


Figure 5: Area burnt for different values of the forest density. In these simulations, a burning cell in its **Moore** neighbourhood was sufficient for the burning of a tree cell.

We ran simulations on randomly distributed forests with several values of the number of trees and with a single fire start. We call *forest density* the ratio of the number of trees to the total number of cells in the grid and *area burnt* the ratio of the number of burn trees to the number of trees generated. In order to achieve sufficient precision in our measurements, ten simulations were run for each value of the forest density, and the results were averaged.

Figure 4 shows that, using Von Neumann's definition of the neighbourhood, there exists a critical value of the forest density, estimated at 60%, above which forest fires will tend to propagate so much that they totally burn the forest.

We also notice, by comparing Figures 4 and 5, that this **critical density** is affected by the definition of neighbourhood used. Indeed, where the critical density was around 60% for simulations with Von Neumann's neighbourhood, it is only around 40% with the more inclusive Moore definition (it includes diagonal cells).

### 3.2 Second-degree neighbourhoods

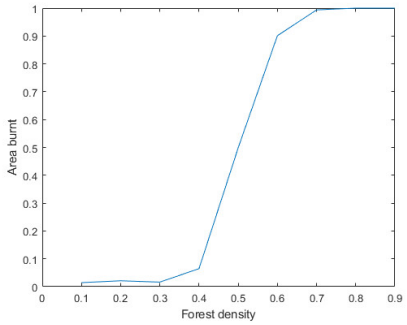


Figure 6: Area burnt for different values of the forest density. In these simulations, a burning cell in its **second degree Von Neumann** neighbourhood was sufficient for the burning of a tree cell.

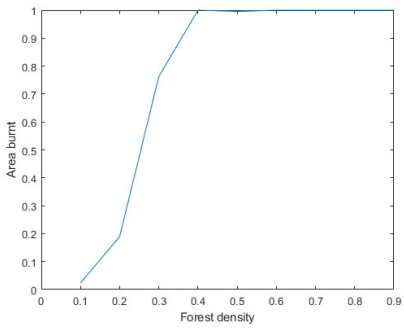


Figure 7: Area burnt for different values of the forest density. In these simulations, a burning cell in its **second degree Moore** neighbourhood was sufficient for the burning of a tree cell.

We also studied what happens when we extend the notion of neighbourhood to the second degree. Then, a tree cell will catch fire at step *n+1* if three or more of its neighbours or neighbours neighbours are on fire at step *n*.

The Moore and Von Neumann definitions extend intuitively to the second degree, as can be seen in Figure 2.

Our simulations then confirmed what could have been naively expected : the more inclusive definition of neighbourhoods lead to a lowering of the critical forest density. For a second degree Von Neumann neighbourhood, Figure 6 shows that the critical density fell to approximately 50%, and for a second degree Moore neighbourhood, Figure 7 shows that it falls to around 25%.

## 4 Conclusion

In this work, we researched the different ways to model forest fire propagation, before finally settling on using a cellular automaton. With this method, we simulated forests of randomly distributed trees on a grid, and propagated fire through it with variations of our algorithm (using different definitions of a cell's neighbourhood) and with varying forest density.

From the results of those simulations, we concluded to the existence of a critical value of the forest density, determining the final outcome of the fire, and its dependency on the type of neighbourhood used.

A follow-up to this work could consist in confronting its results to actual forest fire data, or to similar experimental data such as paper-burning experiments[7].

This paper was produced as student work for the *Chaos in Science and Technology* class at Lund University. All relevant computer code will shortly be made available on the class GitHub repository[1].

# References


[1] Chaos project (cellular automata) files. Contribute to LundInChaos/Cellular-Automata development by creating an account on GitHub, May 2019. original-date: 2019-03-26T20:26:22Z.

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[4] Eric W. Weisstein. Moore Neighborhood. http://mathworld.wolfram.com/MooreNeighborhood.html.

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[7] Jun Zhang, Y.-C. Zhang, P. Alstrm, and M.T. Levinsen. Modeling forest fire by a paper-burning experiment, a realization of the interface growth mechanism. *Physica A: Statistical Mechanics and its Applications*, 189(3-4):383–389, November 1992.