Fire Spreading

Figure 1: Forest fire in California

Motivation

Fire only starts when three essential elements come together: sufficient fuel, sufficient oxygen and a sufficiently high temperature. If one of these elements is missing, for example due to a lack of oxygen or insufficient heat, a fire will not survive or will not even start, compare figure 2. The goal is to simulate a fire spreading over a grid depending on these three elements and states of the neighbouring cells. How long does the raging fire burn for? Has it consumed all available material? How much damage did it cause on its rampage?

Model

We consider a square grid with Neumann neighbourhoods. The states of the cells are:

1. **Fire** $\sim$ This cell is burning.
2. **Incombustible** $\sim$ This cell can not be on fire.
3. **Hot** $\sim$ This is a prerequisite or preliminary stage of fire.
4. **Vegetation** $\sim$ This cell has potential to burn.

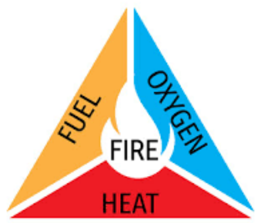

Figure 2: Fire Triangle

In order to bring in our three elements (oxygen, fuel, heat) every cell is assigned these three attributes with 5 levels each from 0 to 4. Clearly, there can be no fire with 0 fuel or 0 oxygen or 0 heat.
There are different rules, for example for spreading fire, oxygen balance, heat transmission, and so on:

1. If a cell is on fire, fuel and oxygen decrease by 1 level per step.
2. A cell increases the heat attribute by 1 level for every neighbouring cell with state hot. (E.g. 2 cells with state hot $\rightarrow$ heat of this cell $+2$ levels.)

3. If there is exactly 1 cell on fire in the neighbourhood, increase heat by 2 levels.
4. If there are more than 1 cell on fire in the neighbourhood, increase heat by 4 levels.
5. If in the neighbourhood of a cell are at least 2 cells with higher oxygen level, increase oxygen level by 1.

To Do's

Task 1

Implement the model on a small grid (e.g. 5x5). Consider a possible initialization choose a sensible number of starting fires and their locations. What happens if one side of the grid starts with a fire wall? What happens if 10% of the cells uniformly distributed are on fire at the beginning?

Task 2

Consider a condition depending on oxygen, fuel, heat when a cell is on fire and when a fire dies out.

(a) First approach: Find a threshold such that the sum of the levels in all attributes has to be bigger so that the cell starts to burn.

(b) Advanced approach: Consider a condition for every attribute individually.

(c) Stochastic approach: Add probabilities to the rules, such that the burning of a cell is depending on the probability p_b and the outgoing of a burning cell is depending on the probability p_o.

Task 3

Create a nice visualization. This visualization style should also be used for later simulations.

Task 4

Increase the width and height of the grid, try to manage it on a 100x100 grid. Test your model with approach (c) on the bigger grid and experiment with the probabilities p_b and p_o, also try different initializations depending on the number and location of the starting fires. Conduct a Monte Carlo Simulation to find out in percentages: Does the fire burn down everything or does it die out?

Task 5

A cell which was on fire and has no fuel left, is a burnt out cell. It can't be on fire again, add a rule for regeneration. Think about a sensible number of time steps for a burnt out cell to increase the fuel attribute by 1. One condition for regeneration can be that no neighbouring cell is one fire. How do the results differ with and without this rule?

Task 6

Get creative and add a new state or new rules. (One idea could be cells with state water, could it cool down the neighbouring cells?)

Programming Languages

free choice of decision, suggestions: Python, Netlogo, ...