REAL TIME FOREST FIRE SIMULATION WITH EXTINGUISHMENT SUPPORT

Anis Korchi, Aitor Moreno and Álvaro Segura
Vicomtech, Mikeletegi Pasealekua 57, 20009 San Sebastian, Spain
amoreno@vicomtech.org

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Abstract: Fires and other related disasters provoke great destruction of high valuable environments and economical losses. In this work, we present a forest fire spreading algorithm to be used in real time and interactive Virtual Simulations. The main objective is to obtain a fast, interactive and quasi-realistic Virtual Simulation to be used in the simulation of virtual scenarios where fire-fighters and controllers will be trained. The algorithm supports the main variables involved in the fire spreading (slope and wind) and the radiation effect makes the forest fires bypass rivers or firewalls. To complete the simulation, a basic model has been added to extinguish the fire using water.

1 INTRODUCTION

Fire is one of the most complex and destructive phenomena in Nature. When they are out of control, they can devastate large extensions of forest area or burn buildings provoking economical losses, environmental impacts and even human casualties (see Figure 1).

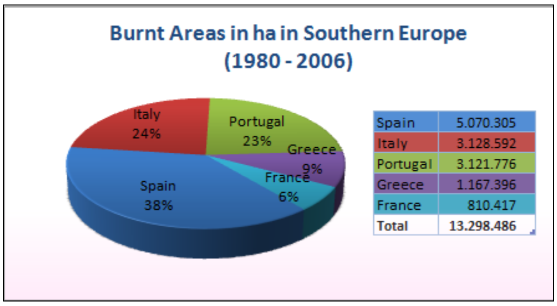

Figure 1: Burnt Areas in ha in Southern Europe between 1980 and 2006. (Forest Fires Website, 2010) (Schmuck, 2006).

The preventive measures are very important, but eventually, the fire will start. Whether in urban or in forested areas, we can stop or limit a fire by having a skilled and experienced Fire-Force, from the firemen to the management staff who will organize the available resources to fight the fire.

Emergency Training Centres are a key factor to fight against fire. One of the most suitable solution solutions to train the fire-fighters and manager is the use of Virtual Simulations, where they can safely collaborate to fight a virtual fire and check if the concepts learnt in the Training Centre have been applied correctly.

One of the main algorithmic elements in such Virtual Simulations is to simulate how fire spreads as simulation time advances. Although a simplification of the algorithms is needed in order to achieve interactive rates, it is desirable that it could deal with different types of forest fires, react to different types of terrain, slopes and changing weather conditions. The simulation should support the capability of fire to be extinguished by itself (fuel combustion) or by the fire-fighters (fire extinguish agent).

In this work, we present a fire spreading algorithm that can be implemented to be used in real time and interactive Virtual Simulations. The main objective is to obtain a fast, interactive and quasi-realistic system to be used in the simulation of virtual scenarios where fire-fighters and controllers will be trained.

2 STATE OF THE ART

There are two major models of fire simulation in wild land: empirical models and physical models.

The empirical models are made thanks to the experience of real fire, i.e., those models use statistical relationships found between the fire evolution and different parameter tested on the field (Rothermal, 1972). In this case, we can mention FARSITE (Finney, 1998), which use Huygens principle of wave propagation.

The second type, physical-based models, use convection and heat transfer mechanism, but also computational fluid dynamics methods. The main mathematical tools used here are partial differential equations and reaction diffusion systems. Fire Dynamic Simulator (FDS, National Institute of Standards and Technology (NIST)) or FIRETEC (Linn, 2002) follow this approach.

Unlike the two previous models, other research works have taken a different direction from the complex mathematical models. Their objective is to reduce computation time and to implement a real time simulation.

Gary L. Achtemeier (Achtemeier, 2003) presented the *Rabbit Model*, a collection of basic rules of fire evolution, which are implemented as autonomous agents (the rabbits). The scope of the *Rabbit Model* is limited to the evolution of forest fire.

The proposed algorithm in this work presents a forest fire spreading simulation, whose main characteristics are:

- The fire evolution is based on the terrain topology, material and weather conditions.
- The fire is allowed to cross rivers, firewall or other barriers by introducing the radiation effect.
- Very low complexity, allowing real time simulation even with standard computing power.

In the next sections, the details of the proposed method will be explained, showing some basic results of the implementation of the algorithm.

3 PROPOSED METHOD

The proposed algorithm main goal is to simulate how the fire spreads in a forest environment under different circumstances. In order to explain the method, the field where the fire will be must be defined.

3.1 Introduction and Field Definition

The forest fire simulation method is based on a divided field in autonomous cells. The field is regularly divided in a grid of square cells and is defined by its geometrical information (origin, size and height map).

Every square cell contains all the necessary information to support the fire spreading, being divided in two main categories: *i)* passive information, which will be used to initialize the field and *ii)* runtime information, which will be modified or calculated during the simulation.

The passive information of each cell corresponds with the geometrical data (position, size and height of the cell in the field) and the characterization of the cell, i.e., type of cell, which will determine the nature of the cell (dry grass, tall trees…), and the starting quantity of combustible.

The fire-spreading algorithm is a step-by-step process, i.e., every time that the algorithm is run; a new state of the fire evolution is calculated.

Thus, the runtime information will be calculated during each simulation step, and includes: the quantity of combustible, the power or intensity of the fire and the state of the fire.

3.2 Main Considered Physical Variables

The objective is to reduce the algorithmic complexity and the processing time while keeping a correct behaviour of the spreading of the fire. To reach this goal, among the whole set of variables and physical parameters which can influence the fire behaviour, we have chosen the most significant ones.

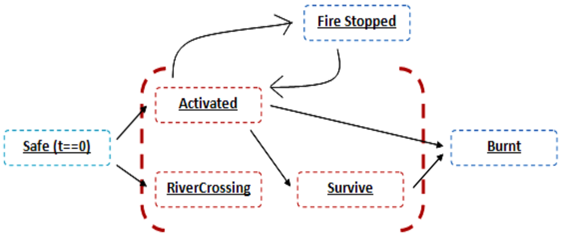

Figure 2: The different states of a cell and the available transitions.

The most relevant external parameters are the wind and the slope (Weise, 1996). Other variables, although necessary for precise simulations or predictions have been discarded.

3.3 The States of the Fire Evolution

All the cells in the field have an internal state which corresponds with the state of the fire that exists in such cell. The different states are *Safe, Activated, Burnt, Survive, RiverCrossing and FireStopped* (See Figure 2).

When a cell is in the *Safe* state, there is no fire in it. The *Activated* state indicates that there is an active fire in the cell.

The *Burnt* state is the final state of a cell after being completely consumed by the fire. The *Survived* state is pseudo-final state, when the cell is burnt, but still has residual heat. Even being completely consumed by the fire, the cell can irradiate some heat to others cells. Eventually, the cell will pass to the *Burnt* state.

The *RiverCrossing* state is a hidden state used in the computation of the fire spreading through a river or firewall, using the radiation effect.

Finally, the *FireStopped* state represents an intermediate state of a cell, when some external fire extinguisher has stopped the fire.

3.4 Fire Spreading Algorithm

The algorithm that defines how the fire spreads in wild land is based on the cells' initial data of the whole field (combustible, states ...).

Following a similar approach to Gary L. Achtemeier in the "Rabbit Model" (Achtemeier, 2003), we define the fire spread as a displacement of *mice*. The combustible on the field is considered as the mice's food (*cheese*). Thus, the basic concept is that when a mouse eats a cheese, it is equivalent to when a combustible unit is burnt by the fire.

A fire is started by positioning a mouse in a square cell, changing its corresponding internal state to *Activated*. The added mouse will interact with the neighbour cells and will follow some rules.

Every mouse is born in a square with a given power to eat a quantity of cheese per simulation step (fire intensity), which changes depending on the type of the cell. When a mouse eats a quantity of cheese, its power is increased in the same amount, which simulates how the fire intensity is continuously growing while there is available combustible.

If there is no cheese remaining, the mouse dies. When a mouse dies, up to 8 new mice can be born, since there are 8 potential neighbour squares. The algorithm uses the local slope and wind in order to determine which neighbours will be the destiny of the new born mice.

The mouse will give birth to all the squares which are in an area of +/- 45° of the wind angle. If there is no wind (or it is too slow), the mouse will give birth to other mice in all the 8 neighbours.

Also, the mouse will always try to give birth to other mice in squares that are in higher altitude. This behaviour tries to simulate the fact that the fire goes up if there is a slope. Only if there is not a non-burned square at a higher altitude, the mouse can go down (it has no option to go up).

Every square cell has a parameter named *Fire Power*, which is in fact the sum of the mice's power of the cell. Similarly, the *Fire Power* of a given cell will be stronger or more intense with a higher number of mice.

3.5 Radiation Effect

The *radiation effect* is added to support the fact that a fire can cross a river, firewall or other barriers like roads. It is based on the heat radiation.

In the proposed algorithm, a fire is stopped when it encounters a barrier. Depending on the *Fire Power* in the area, and considering the width and type (streets, road, river [...]) of the barrier, it can be overridden.

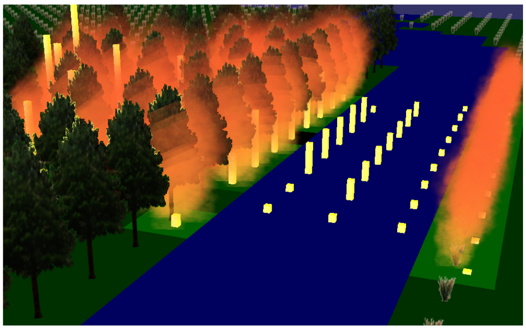

Figure 3: The Fire has bypassed successfully a river. The sticks in the water represent the *Fire Power* and it can be seen that it is being reduced gradually. In the presented case, the fire reached the opposite bank, spreading it.

The fire is able to bypass the river only if the existing vegetation is composed of trees or any other high vegetation. The main idea is the difference of size: the more a tree is high, the more the wind can spread heat/radiation to the other side of the barrier (see Figure 3).

As the fire is stopped when the power is zero or negative, there are not too many possibilities to reach the other side of the barrier if it is wide enough.

4 FIRE EXTINGUISHER MODEL

The proposed method allows trying to extinguish an ongoing forest fire. Its main purpose is to allow the fire-fighters to interact with the fire evolution and see the consequences of their decisions on the field.

This model is conceptually the antagonist of the fire spreading algorithm, where the *Fire Power* amount is replaced by *Fire Extinguisher Agent* amount (e.g., water). When, a given quantity of *water* is thrown into a cell, the same quantity of *Fire Power* is decreased.

Thus, as long as there is *water* in a cell, its *Fire Power* will be equal to zero and the fire will be stopped (changing to the state *FireStopped*).

A cell being in the state *FireStopped* still has food (combustible), therefore, the fire in that area could be restarted due to the surrounding burning areas.

5 RESULTS

A C++ implementation of the algorithm has been done to test the algorithm behaviour and outputs.

The tests have been performed using a field of 2.25 hectares, choosing a tile side size equals to 3 meters, which is half the distance of possible spread of fire when there is no wind (Breton, 2008).

To simplify the tests, the wind is uniform and constant in the entire field and during all the simulation.

The first test is to run the fire simulator without any external factor which can influence the fire spread (Wind, Slope). The fire evolves in a circular way, as expected (see Figure 4, top-left).

To test the wind effect, another test is performed with a uniform wind blowing from North-West to South-East.

The slope tests have been divided in two, one to test how the fire can evolve towards higher positions (see Figure 4, top-right) and to test how the fire avoids go towards lower positions (see Figure 4, bottom-left and right).

6 CONCLUSIONS AND FUTURE WORK

In this paper, a pedagogical real-time fire simulation algorithm has been presented. Its main purpose is to be integrated into interactive Virtual Simulations where fire-fighter and managers can train their skills.

Although the forest fire spreading is a very complex phenomenon, we tried to simulate the most common characteristics of its behaviour by simplifying the model. Only two main physical variables have been used in the algorithm: direction of the wind, and the slope.

For the future work, a comprehensive comparison between different algorithms should be done. These tests will try to measure analytically the efficiency and other related factors. Also, a graphical comparison of the output should be done, since the ultimate objective is to be integrated in a VR environment. In this case, user tests will be done in order to validate the algorithm output.

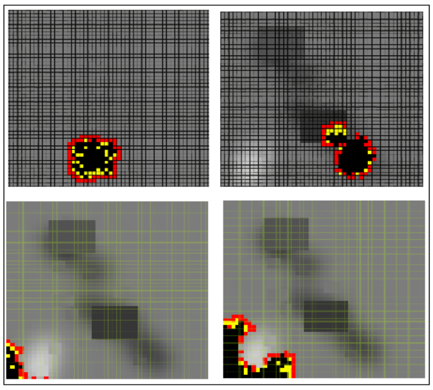

Figure 4: Some results of the Fire Spreading algorithm. Grey level shows the height map of the field.

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