Forest Fire Simulation in High Performance Computing

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Abstract. This work presents a research line related to the simulation of wild fires. It is being developed in San Carlos de Bariloche, Río Negro, Patagonia Argentina. Our multidisciplinary team is composed by computer scientists, physicists, atmospheric and biological scientists and electronic engineers, coming from different institutions: CONICET, Universidad Nacional de Río Negro, Centro Atómico Bariloche, Universidad Nacional del Comahue. As a result of this interaction we've developed a forest fire simulator with a visual interface that allows to test different scenarios for fire propagation. The application is tailored according to the needs of local firefighters with whom we define the main features needed to eventually use our simulator for management purposes.

Keywords: Forest fire behaviour · Simulation · High Performance Computing.

1 Introduction

Each year forest fires affect hundreds of thousands, or even millions of hectares of natural vegetation across the world. They are a real hazard in Patagonia (Argentina), as well as in the whole country and all over the world. Immediate consequences are the lost of native and exotic vegetation, death of animals, reduction of natural and forested areas, CO2 liberation into the atmosphere, etc. Some of the most important indirect consequences are the acceleration of global warming, land desertification, inundations and lost of buildings through interface zones.

Frequency and severity of wild fires had increased during last decades. A real feedback exists between big forest fires and current global warming. Climate warming causes rising temperatures, drier conditions and longer fire seasons. In turn, huge forest fires release big amount of CO2 to the atmosphere, which increases the green house phenomenon, rising global climate warming [5].

Even though great effort and work is done in this area in our country, the development of computational tools for forest fire simulation are not mature enough. Moreover, fuel types (based on typical vegetation in a region) are not developed for our landscapes.

Our team is in a constant communication with firefighters of the Departamento de Incendios, Comunicaciones y Emergencias of the Parque Nacional Nahuel Huapi (ICE-PNNH). ICE-PNNH staff contribute to the guidance on new functionalities for the simulator and requirements to be able to use it to simulate different scenarios of interest.

In this work we expose the main lines and developments of our research work.

2 Current Developments

The main goal of our work is to develop a high performance application to simulate and visualize wild fire propagation. This application can be useful in the decision-making process, for mitigation, control and eventually prevention of forest fires.

Our forest fire simulator is based on a cellular automaton (CA) often used to model the spread of a given phenomena in 2 dimensions. Within that CA the space is discretised into a grid of cells, while time is discretised into equal time steps. Then, a mathematical model for forest fire spread runs over all cells of the grid for each simulation time step.

On a previous step, a fitting procedure to real fire scars was implemented. The model parameters were estimated using genetic algorithms over millions of simulations. The best set of parameters found were used to simulate and visualize the fire propagation [3].

Besides the forest fire simulator, our research group had developed an application for calculating the Fire Weather Index (FWI) [1]. The FWI deals with the state of fine and coarse vegetation (fire fuel) in combination with weather conditions. This development was requested by the ICE-PNNH and then, the FWI assessment was included as a board that can be deployed on the simulator menu [2] [6].

At the same time, we are working in the design, implementation and testing of a new mathematical model for forest fire behaviour. This model is based on differential equations for Reaction-Diffusion-Convection processes for 2D propagation (RDC model from now on). This dynamical model aims to understand the key mechanisms driving fire propagation in the Patagonian region [2].

2.1 High Performance simulator implementation details

The core of our simulator is the CA. It was developed in parallel for NVIDIA GP-GPUs (General Purpose Graphic Processing Unit), matching High Performance Computing paradigm requirements. CUDA (Compute Unified Device Architecture) was used as programming model as well as C and C++ extension. The simulator user interface is also executed on the graphic card and execution times match real time requirements.

During simulation time, a fire behaviour model is executed within each CA cell. Previously, the fire behaviour model was implemented using a statistical model (according to [4]). This model was created by the study of different wild fires occurred in the NW Andean Patagonia.

Given that fuel models are still not available for our region and vegetation acts as fire fuel, we used land vegetation as input for our forest fire simulator. Required simulator inputs are: vegetation cover (3 kinds of vegetation are taken into account: shrubland, forest and non fuel), wind speed, wind direction, terrain altitude, slope and aspect. Simulator's inputs and outputs are raster files.

The simulator shows the area of interest, where each cell is coloured by the vegetation type. Then, the user can start fire spreading by setting one (or more) ignition points. The simulator runs and shows 10 instances of progress of the fire. When a cell is reached by the fire, it is coloured red indicating its new state. Furthermore, when user passes the mouse pointer over each cell, a label indicates how many times the fire had reached that cell (due to the 10 simulation instances). This is an indicator of cell ignition probability.

In addition, the user can set firebreaks all over the area of interest. Then, when fire reaches a cell with a firebreak, it can't propagate through that cell. Fire progress can go forward or backward. Setting firebreaks and the possibility of rewinding the fire progress, allow the user to decide where a treatment of the fuel can mitigate or halt fire spread.

As mentioned, the FWI computation was included in the simulator. Once FWI value is calculated for a specific date (using weather data as input), it is possible to calculate the fire risk for each cell (fire risk is based on the FWI value and local cell vegetation).

Different data layers describe the fire scenery (vegetation, altitude, slope, aspect, wind velocity and direction, contour lines). These data layers can be turned on and off in order to display the specific data during the simulation. Moreover, these layers can be overlapped using their transparencies.

Fig. 1 shows the execution of 10 different simulations (red, yellow and orange cells) after setting 2 ignition points. New ignition points can be set by the user during simulation. The map was zoomed and rotated in order to focus on a particular area of the map.

3 Next steps

Different goals are proposed within the scope of this project. Short term goals deal with the iterative steps needed for implementation, testing and fitting of the new RDC model. Meticulous analysis of input and output simulations of each of the RDC equations are ongoing. After model testing, using synthetic maps that will be compared with simulations, real maps will be used to validate the

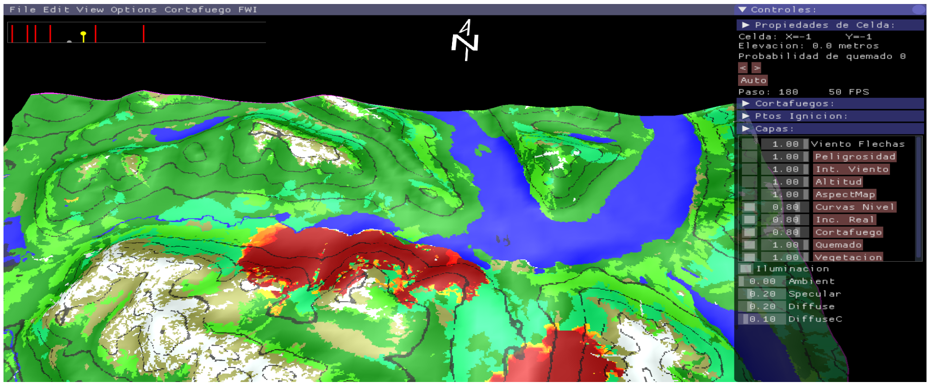

Fig. 1. Simulator's main view. Each vegetation kind is coloured with different colors. Cells in red, yellow and orange are burned. This scenery is located at the South of Lago Mascardi, Patagonia Argentina

mathematical model. This validation phase will be accomplished by fitting the model to real data, finding the best set of parameters that will be used to show simulations on the visual interface.

In a near future, internet repositories will be used for hosting the source codes and the user manual documentation of our applications.

We hope to increase the communication with different fire management institutions, municipalities and research groups, in order to work together on the requirements needed for our forest fire simulator.

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