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Large Forest Fire Spread Prediction: Data and Computational Science

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Abstract

The accurate prediction of forest fire propagation is a crucial issue to minimize its effects. So, several models have been developed to determine the forest fire propagation beforehand. Such models require several input parameters that, in some cases, cannot be known precisely in a real emergency. So, a Two-Stage methodology was developed to calibrate the input parameters to improve the quality of the prediction. This methodology was based on Genetic Algorithms which require the execution of many simulations. Moreover, when the fire is large some input parameters cannot be considered uniform among the whole fire and extra models must be introduced. One of these non-uniform parameters is wind. So, in this work a wind field model is introduced. This model implies more computation time and response time is the main constraint. The prediction must be provided as fast as possible to be useful, thus it is necessary to exploit all available computing resources. So a Hybrid MPI-OpenMP application has been developed to reach a response in the shortest possible time. This work focuses on reducing the execution time of a worker in a MPI Master/Worker structure analyzing the simulation software parts which compose the Fire Simulator System.

Keywords: error function, forest fire, simulation

1 Introduction

Natural hazards are significant problems that every year cause significant losses around the world. Floods, tsunamis, hurricanes, earthquakes or forest fires are some of these hazards. A good prediction of the behavior of the hazards is a crucial point to fight against them to minimize the damages. In the particular case of forest fire, many researchers from different disciplines have developed models to represent this phenomena in order to be able to provide a prediction of the future behavior of an emergency [13][2]. These models need several input parameters and in many cases such parameters are difficult to determine or even estimate in a real emergency occurrence. Thus, a methodology based on the observation of real fire propagation

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was developed in order to calibrate the input parameters according to real observation data. Such tuned parameters are then used on the next prediction step to drive the forecast [1]. The developed methodology took the fire behavior during a recent past time interval ($t_{past} - t_{current}$) and then, it searches for the values of the input parameters (wind speed, wind direction, moisture contents of the death fuel, moisture contents of the live fuel, vegetation features, and so on) that best reproduce this observed behavior. To carry out this search previous works rely on Artificial Intelligence techniques such as Genetic Algorithms (GA) [6], Case-based Reasoning [14], and also on statistical methods as the one described in [3]. The values of the parameters that best reproduce the behavior of the fire were then used as input parameters to predict the propagation during the near future time interval ($t_{current} - t_{future}$). This scheme requires the execution of many independent scenarios in an iterative way. Such parallel structure responds naturally to a Master/Worker programming paradigm using MPI [11]. The Master process generates the individuals of each generation, distributes the individuals among the Workers, waits for the results of each individual, ranks the individuals according to their results and generates the population for the next iteration. The Workers receive the individuals, evaluate the propagation, evaluate the error function corresponding to each individual and return these error values to the Master. This Master/Worker approach clearly provides better performance in terms of execution time since the workload caused by the execution of the huge number of fire spreads simulations is distributed among the available execution nodes. However, when fires are large the parameters are not uniform along the whole terrain and they present an spatial distribution. One of such parameters is the wind. Therefore, a model must be introduced to estimate the wind along the terrain. Next section describes how the prediction model works when coupling both models wind field model and forest fire propagation model. Section 3 shows the analysis performed to determine the performance scalability problems denoted by the worker process and the proposed improvements in terms of OpenMP [5] parallelization are also reported. Section 5 shows some experimental results and finally, in section 6 the main conclusions are reported.

2 Coupling wind field and forest fire propagation models

As we have previously mentioned, we rely on the Two-Stage prediction scheme to forecast fire spread evolution, which aims on calibrating the input parameters needed by the fire simulator to provide better quality results. Previous works [7] considered these parameters uniform along the whole evaluated map. That is, a single value for each parameter was obtained in the calibration process and used in the prediction stage without considering the dimensions of the fire. This assumption was acceptable when the methodology was applied to non-very large forest fires providing great improvements in the prediction quality but it becomes unfeasible when dealing with large scale forest fires that could burn hundreds or even thousands of hectares. It is well known that wind speed and wind direction have a great impact in fire propagation and, furthermore, their values vary according to the topography of the terrain. Therefore, it is mandatory to incorporate a wind field model in the above described Two-Stage prediction method to consider the influence of the topography in the wind values that will be fitted into the fire simulator when dealing with large forest fires. So, in the Calibration process the meteorological wind parameters of each scenario must be used to calculate the wind field corresponding to that particular scenario and then the propagation simulator must consider the wind speed and direction particular for each cell of the map. It implies that each worker process requires the calculation of the effective wind field for a given scenario before the fire spread simulation itself could be executed. This worker modification implies a significant increase in