A Multiscale Network with Percolation Model to Describe the Spreading of Forest Fires

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Abstract

Fire behaves according to three interacting physical factors: fuel availability (morphological and physiological characteristics of vegetation), weather (wind speed and direction, temperature, and relative humidity) and terrain (slope and aspect) [11, 14] – FWT conditions. Fire models such as Rothermel's [15] predict fire's local behaviour using fuel model parameters as input. Fuel models, such as [1, 18] are sets of parameters that describe the characteristics that classify certain fuel types.

The field of percolation has played an important role in developing models and strategies to model fire spreading. Works [6, 8, 9] are examples of percolation frameworks to predict fire spreading, based on FWT conditions, using cellular automata (CA).

One of the existing strategies and very important structure in mitigating fire spreading is the implementation of fire-breaks [16]. These are gaps in the available combustible material that prevent the fire from advancing. In [16, 17], the authors use CA modelling to identify efficient fuel break partitions for fire containment and study the efficiency of various centrality statistics, considering GIS meteorological and landscape information data.

Laboratory experiments can be designed to simulate a small-scale fire, but with limitations. An interesting study [2] compares theory results with laboratory simulations, using matchsticks. The theory predicts that at critical percolation a fire front decelerates, whereas experiments indicate accelera tion. This discrepancy shows that percolation theory models of forest-fire propagation using simple site percolation are unlikely to be accurate. On the opposite side, large-scale experiments have their limitations in terms of reproducibility as well. Still, percolation modelling of fire-spread is of considerable importance because it describes the transition regime between extinction (spanning fires) and uncontrolled spread (penetrating fires) [2, 7].

To overcome scale limitations, some examples using Multilayer Net- works [5, 3, 13] and cellular automata with different approaches have come up with important findings. Work [4], applies multiplex networks to model fire propagation, simulating a 3-layer of possible fire development: ground, surface, and crown, where each node of the multilayer represents a group of trees. At a larger (landscape) scale, work [12] presents a network-of- networks structure, where the nodes are local land patches, with their own spreading dynamics each and, as such, presenting different spreading times.

Our work follows the line of research of the fields of percolation and complex networks. First, we define the local scale as the range in which is possible to delimit a land patch with a measurable set of characteristics, and landscape scale as the scale at which each patch of land is the element of study.

Following the works [12, 13], we present a 2-scale network structure applied to the region of Serra de Ossa, in Portugal. The nodes of the land- scape network correspond to territory division in irregular-shaped polygons, based on land characteristics. Within each polygon, SIR simulations occur on a CA, whose cells constitute the local network of the corresponding polygon. Using a classical percolation algorithm, our results for the percolation threshold, p_c 0.407, are consistent with the literature [7, 10]. We then introduce a neighbourhood of warm trees, which change this value to p_c 0.725. The landscape network is then parametrized with p_c values.

The main goal is to find an efficient fire-break structure that mitigates the spreading, to complement the efforts of civil protection forces.. Given the application geography of this model, the complexity of the problem is limited by restricting FWT conditions to those specific to that area. Still, the spatial extent to which our model can be applied strongly depends on previous land monitoring, which implies a demand for the inclusion of other areas of expertise.

As future work, after calibrating the spreading network dynamics, we intend to introduce classifications of autochthonous biomes. Afterwards, vectorial influence inherent to meteorological and orographic factors are to be considered in the simulations in addition to the existing model.

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