Water based shields deployment on terrain during wildfire spread: a modelling approach using distributed information through autonomous agents

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THE ODD PROTOCOL: OVERVIEW, DESIGN CONCEPTS, DETAILS
ODD is a schedule to describe the features of the model in an organized synthetic manner.
The Overviews information is distributed among the agents, the patches, with a set of properties describing the initial state of the system and the rules of interaction. The rules of interaction are combined with the types of patches so the system evolves its state, with other interactions that may appear depending on the virtual landscape at hand, while the system moves to some state to be examined as possible critical or final state. Each agent will have its own performance task, with a coupling between agent types that may bring to a change of state of the system or a sudden transition.
The Design concepts: the model aims at studying basic aspects of this complex system (i.e. interaction, prediction, emergence, adaptation, stochasticity) and recognizing typical properties (i.e. connectivity, non-equilibrium, nonlinearity, self-organization, co-evolution).
The Details: initialisation, input data, submodels. The model is initialized by designing the virtual landscapes and the agents. No recorded data are used to start the model, some estimations are made from personal experience and literature survey. The virtual landscape represents a square-based open-domain, the agents are the patches they are made of. The landscape models a terrain with some tree density over a plain and a hill. The agents model the nature of the terrain with different characteristics and the response to environmental actions, such as flame front advancement and relief effect. The input data of the landscape are the geometry (square-based area), hill placement in the plain, no solid boundaries, the input data of the agents are the position (placement on the landscape) and the characteristics (type and nature). The sub-models deal with the actions of the agents and the effects of the environment. The actions of the agents involve response to fire (fuel availability, water cooling, block of spreading), the effects of the environment involve spreading, fire fend, slopes, humidity). Some behaviors of the system are expected to emerge by reaction or adaptation to inputs, some characteristic thresholds might appear to mark a difference in the behavior observed in the model; a metric is to be devised to analyse data, compare results and explain outputs. Furthermore, several runs are always needed to take into account, at least in a basic form, stochastic effects linked to the system. Proper control rules will be designed and applied in the NetLogo interface to manage any operation needed and visualize results.

NETLOGO MODELS, VIRTUAL LANDSCAPE, AGENTS, INTERACTIONS
The virtual landscape models a square whose outer boundaries are never crossed because what happens is always entirely inside or at the boundaries (so called "wrapped off" world), where space is continuous and time is discrete. The landscape is made of square patches of same side, whose overall length is set in advance by means of a coordinate controller. In this study, the box results in a total of 251 by 251 patches, with each patch covering a space that can be the same or different from the space covered by the neighboring patches, depending on what characteristic the patch is assigned with. Should a real landscape be modelled, maps in 3D could be imported, with real scales and dimensions to be uploaded in the NetLogo model. Here we simply adopt unit length for the square patches side and for the square height modelling of the hill in the plain.

Several agents-sets are employed as patches describing the landscape, with colours differentiating them: trees (green), scattered trees (blue), ground without trees (yellow), flame front (red), burned tree (dark red), base layer (brown). A variable degree of combustibility is assigned to the agent-set, from a minimum (less combustibility, e.g. scattered trees and ground without trees) to a maximum (high combustibility, e.g. trees), associated to the colours. Variability is assigned through constant values that define a probability of success to the event describing the combustion activation of the patches.

Two specific properties are assigned to the patches that may enhance fire spreading: elevation and humidity. The former is assigned to the hill only, the latter is associated at random to all the landscape. Elevation is scale coloured (brown) in 100 unit-heights, the latter is associated at random to all the landscape. Elevation is scale coloured (brown) in 100 unit-heights, with the peak of the hill placed at 30 unit-length along the base plane coordinates (-30, 30) from the centre of the world (0,0). Wind can further enhance the flame front spread up to the highest elevation of the neighbouring patches. Humidity is assigned through the parameter of humidity, that is set in advance and that can also be varied, to represent the wind and the availability of humidity. The latter is assigned a strength variability, that is set in advance and that can also be varied, to represent the wind and its variability.

Table: Results of simulations

<table>
<thead>
<tr>
<th>World id</th>
<th>Average over 100 runs</th>
<th>Standard deviation over 100 runs</th>
<th>Setup of possible barriers to fire spreading</th>
</tr>
</thead>
<tbody>
<tr>
<td>4b-2</td>
<td>62.01 %</td>
<td>0.6 %</td>
<td>No water barrier No ground barrier</td>
</tr>
<tr>
<td>4b-3</td>
<td>72.92 %</td>
<td>0.56 %</td>
<td>No water barrier Yes ground barrier</td>
</tr>
<tr>
<td>4b-4</td>
<td>62.01 %</td>
<td>0.53 %</td>
<td>Yes water barrier Yes ground barrier</td>
</tr>
<tr>
<td>4b-5</td>
<td>75.72 %</td>
<td>3.94 %</td>
<td>Yes water barrier No ground barrier</td>
</tr>
<tr>
<td>4b-6</td>
<td>75.41 %</td>
<td>1.46 %</td>
<td>Yes water barrier Yes ground barrier</td>
</tr>
<tr>
<td>4b-7</td>
<td>80.23 %</td>
<td>0.18 %</td>
<td>No water barrier Yes ground barrier</td>
</tr>
</tbody>
</table>

Plan views at setup-hilltop fire reach-end of run

% burned patches vs time ticks advancement

Evolution trend and final value

World id: 4b-2 one run
World id: 4b-3 one run
World id: 4b-4 one run
World id: 4b-5 one run
World id: 4b-6 one run
World id: 4b-7 one run

World id: 4b-2 one run
World id: 4b-3 one run
World id: 4b-4 one run
World id: 4b-5 one run
World id: 4b-6 one run
World id: 4b-7 one run