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Realization Of Forest Fire Through Percolation Model – A Literature Review

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Abstract

Realization of forest fire in a realistic and scientific way is necessary for safety, security and decision making of fire fighter. Forest fire propagation is a very complex phenomenon, which depends on many environmental factors like moisture content present in the atmosphere, oxygen concentration, wind velocity etc. Percolation model is a suitable and simple theoretical approach, which can help in understanding of forest fire spread. The article presents a detail literature review on forest fire propagation using percolation model.

Introduction:

Forest fires has become a serious issue not only in view of Indian perspective but global perspective also. According to forest survey of India, in the year of 2018 alone 37,059 fires were identified using Moderate Resolution Imaging Spectro-radiometer data. Forest fire disaster of 2016 in Uttarakhand and Himachal Pradesh, massive forest fire of 2019 at Bandipur National park, Karnataka are some recent examples of from our country [1]. Massive fires develop from small flames propagation. This propagation depend on different factors:-moisture content present in the atmosphere, oxygen concentration, wind velocity, topography, age and type of trees [2]. For the purpose realistic and scientific fire fighting decision and for ensuring the safety and security fire fighters, it is essential to realise and forecast the process of forest fire accurately. For predicting the fire propagation, percolation theory can be used as a mathematical model, which is a simple model and easy to realize. With the help of this model, it is also possible to calculate the transition between extinction

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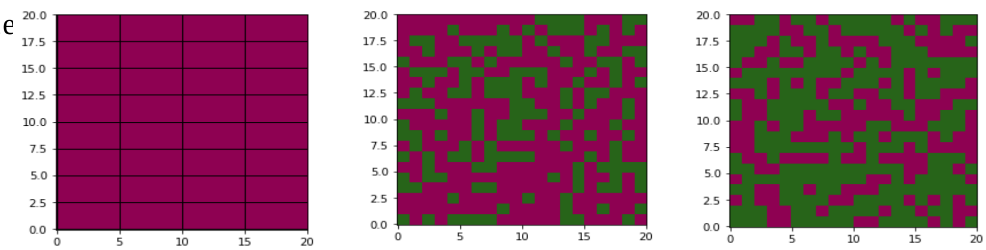
and uncontrolled spread. Here in this article, a detail literature review has been done on the general percolation theory and relate it to the forest fire spread. Thus, the article is structured is as follows:

Part I. General percolation theory
Part II. Review of forest fire model
Part III. Conclusion

Part I. General percolation theory

Broadbent and Hammersley developed the percolation theory in 1957 [3]. Percolation is considered as the movement of particles in a random network. Generally, percolation is realized in terms of random occupation of the sites on a regular lattice. Each site randomly can be assigned as "on" or "off" condition or we can say in "open" or "closed" state. In Figure 1(a) a 20 x 20 lattice size is taken with all sites as empty. Then with the help of random number generator, the lattice sites are chosen as either "open" or "closed" state. Each site state is independent of one another. In Figure 1(b) and (c), the probability of the lattice is chosen as $p=0.4$ and $p=0.6$ respectively. When $p=0.4$, the lattice is non-percolating, which means that there is no connecting path within the random network system. When $p=0.6$, the lattice is percolating giving rise to the flow of particle from top to bottom of the networking syste



(a) (b) (c)

Figure 1: A 20 x 20 square lattice is taken. (a) empty lattice sites (b) lattice sites with probability $p = 0.4$ (c) lattice sites with probability $p = 0.6$. Green sites indicate the open state.

At the onset of development of macroscopic connectivity within the system, the system is said to be in its percolation threshold (p_c) condition. In this condition, a group of connected sites will exist in the system forming a cluster (as shown in Fig. 1(c) by green sites). The

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cluster size plays an important role in determining the physical properties of the system. In the percolating condition of the system, along with the percolating cluster, many non-percolating clusters also exist in the system. Using Monte Carlo simulation, Newman calculated the p_c value for 2-D square lattice, which is equal to 0.592746 [4]. With this brief understanding of percolation theory, it is now possible to discuss about the fire propagation process in forest.

Part II. Review of forest fire model

In 1946, W. L. Fons first attempted to analyse the rate of fire spread using a mathematical model [5]. He visualized fire spread as a series of successive ignitions of fuel particles and spread rate is controlled by the distance between fuel particles and the ignition time. In 1990, Bak et al. developed a simple 2D square model to describe fire spreading in a forest [6]. Each site of the square can be either in "open" or "closed" state indicates that in each site trees can exist or can not exist with probability of p or $(1-p)$ respectively. Therefore, every site can be one of the three states: (i) the site is open (tree is existing at the site), but in non-ignited state (ii) the site is open (tree is existing at the site), but in ignited state (iii) the site is closed (already ignited or no tree is present at that site initially). The occupation probability of the site can be visualized from Figure 2, where a 10 x 10 square lattice is taken as an example.

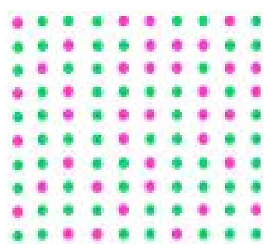

Figure 2: Green dots indicate the site is open with either ignited or non-ignited condition whereas pink dots indicate the site is closed.

The similar method of modelling was also adopted by Li et al and T. Beer [7,8]. For the simplicity in the model, they have chosen the ignited site randomly. At each time step, this will ignite its nearest neighbours and then burnout which means that this site is unable to be ignited once again. By first nearest neighbour (Von Neumann neighbourhood), it is meant the top, bottom, right and left sites of a particular ignited site. They found that near p_c (nearly equal to 0.59), the average burning time of the forest lattice is highest. Through detail

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calculation considering the first and second nearest neighbour (Moore neighbourhood), Albinet et al. [9] showed that the p_c value drops down to 0.407. In second nearest neighbour along with the neighbours of first, the diagonal sites will also be considered. The reason behind this is explained as follows. For lower values of p, the formation of ignited clusters are small, hence the fire die out quickly and burning time is small. For higher value of p, the percolation within the lattice occurs easily and hence the burning time decreases.

Vogel et al. have studied flame propagation both experimentally and theoretically with vertically oriented matchsticks [10]. The critical spacing between matchsticks and their height and are important for flame propagation. The agreement between theoretical and experimental results supports the fact that it is possible to model forest fire propagation by horizontal arrays of vertically oriented matchsticks.

Part III. Conclusion

The aim of the article was to discuss the general theory of percolation and to understand how to apply the percolation theory in understanding the forest fire propagation. From the discussion, it is understood that a forest can be generated by using Monte Carlo simulation where the distribution of trees are random. The damaging strength of forest fire depends on tree's concentration. Thus, percolation theory is appropriate in explaining the forest fire in a simple and efficient way.

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