Simulation of Forest Fire using cellular automata

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CS-302, Modeling and Simulation

In this course project we have implemented a model of Forest and natural effects on it. Our project mainly covers the model of succession of vegetation species present in the forest and the effect of fire caused due to lightning strike and the spread of fire due to that. The analysis of such a simulation is mainly to analyze the survival of forest under different conditions.

I. INTRODUCTION

Forest is characterized by the type of vegetation it has and how the vegetation undergoes changes as time passes. These changes happen due to germination of seeds due to natural factors, reproduction, adolescence and conversion from one type of vegetation to other type of vegetation. Some factors such as age and adolescence change with time. The conversion of vegetation from one vegetation to other happens due to reproduction. As reproduction in tree happens, its seeds are scattered in its neighbourhood. So the conversion of some vegetation into another depends upon the presence of adult trees in the neighbourhood. Also, the span of the neighbourhood varies according to the type of vegetation you are searching for. This happens because the seeds of different species spread with different span.

The main concern of any forest is the average life span of the forest. Other than natural death, there are many factors that cause decrease in life span. One of them is fire caused due to lightning. Once the fire is started it spreads and a tree catches fire from its neighbours depending upon the the type of the vegetation it belongs to i.e. depending upon the resistance [2] to fire.

Here both the features of fire that are succession and fire depend upon the neighbourhood at any point. So this project can be modelled as cellular automata with different rules and probabilities.

II. MODEL

This cellular automata model is defined on a L x L square lattice where $L = 50$ with extended boundaries. Each cell in the lattice corresponds to a 10m x 10m square area in the forest. It is assumed that as the forest is dense so there is no cell which doesn't contain any vegetation. There are 5 types of vegetation that are considered; they are as follows: Grass , Juvenile Pine (Softwood) , Adult Pine (Softwood) , Juvenile Hardwood , Adult Hardwood It is assumed that in each cell only a single type of vegetation exists. Here Pine corresponds to softwood tree which is more fire susceptible than hardwood. For each decision of a cell its Moore neighbourhood is considered. The age of Juvenile vegetation matters so a lattice containing the age of juvenile population which is between 1 and 10 is kept and zero is assigned to the vegetation not belonging to Juvenile.

Initially each type of vegetation has some specific fraction in the forest. The initialization of the lattice depends on these fractions. So each type of vegetation is randomly distributed but their count is dependent on their respective fractions. The survival of the forest is calculated as forest cover more than 30%. Grass is not considered in the forest cover calculation. There are two main aspects by which this model works: (1) Succession of the vegetation at each step and (2) Fire spread and initialization. The probabilities when mentioned in an array follow the correspondence of the order [Grass, Juvenile Pine, Adult Pine, Juvenile Hardwood, Adult Hardwood][1]

A. Succession

The simulation for succession is timed for n years. The basic time step for simulation is 1 year. The rules for succession are as follows:

1. If an adult pine is within 4 cells of a grass site, there is probability of 0.03 that at the next time step the site will have the state of juvenile pine instead of grass.

2. If an adult hardwood is within 1 cell of the grass site, the next time step, the site has a 0.01 probability of becoming juvenile hardwood.

3. If a site contains juvenile or adult pine with an adult hardwood neighbor there is a probability of 0.02 that at the next time step the site could have the state of juvenile hardwood.

4. After each year the age of juvenile pine and hardwood is increased. If the age crosses 10 then the tree will become adult of its corresponding vegetation.

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B. Fire Spread

Each year is divided into 100 days. On each day in a year a random cell is selected and it is struck by lightning with probability f. The cell which is struck by lightning starts burning. As this cell starts burning the neighbouring cells start burning following the below given rules: (The below mentioned fire-probability corresponds to the probability of catching fire of a cell when one of its cells is burning. And survival probability corresponds to the probability that the cell has still left the previously present vegetation after the fire has passed through the cell.)

1. Each cell sees its neighbours at each time step. If any of them is in the burning state then it starts burning with the probability of fire probability which is described according to the vegetation. Here as Hardwood is more resisting its fire-probability is least compared to other vegetation.

2. After a cell is burnt the vegetation under that cell would have survived. So for each type of vegetation a survival probability is assigned to know that with what probability the cell should have survived the fire.

3. Grass succeeds all type of vegetation. If any cell has not survived the fire then in the next succession step the cell will contain grass.

III. RESULTS

A. Change in Vegetation fraction

For this experiment the required variables are: Probability of Lightning = 0.1 , Probability of catching fire: [0.4, 0.1, 0.1, 0.05, 0.05] , Probability of surviving fire: [1.0, 0.3, 0.8, 0.1, 0.2]

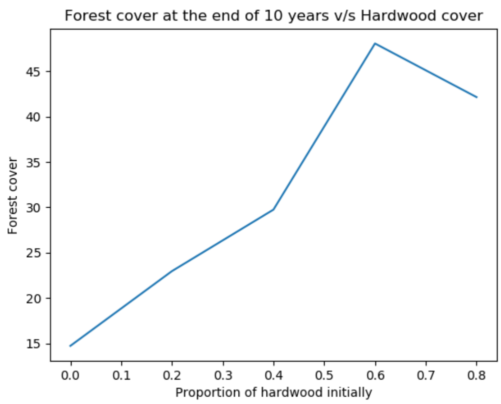

FIG. 1: Plot of Forest cover with changing Hardwood initial fractions

Fig 1. shows the variation in forest cover at the end of 10 years with different initial hardwood fractions. Initially, as the hardwood fraction increases in the forest the forest cover at the end of 10 years is more. This is because the fire-probability of hardwood is least compared to other type of vegetation. Here initially we see a non-linear growth because there are two factors which contribute to increase in forest cover. The fire-probability and the conversion of other types of vegetation into Hardwood. So up to an initial fraction of 0.6 the forest cover after 10 years increases. But a decrease is seen after that. This is because, as the fraction of the hardwood increases it decreases the fraction of other vegetation so the conversion from other vegetation to hardwood decreases significantly. And also the survival probability of hardwood is very less so a burnt hardwood is converted to grass. But the burnt grass is very less probably converted to pine as the pine fraction was initially less because of more hardwood.

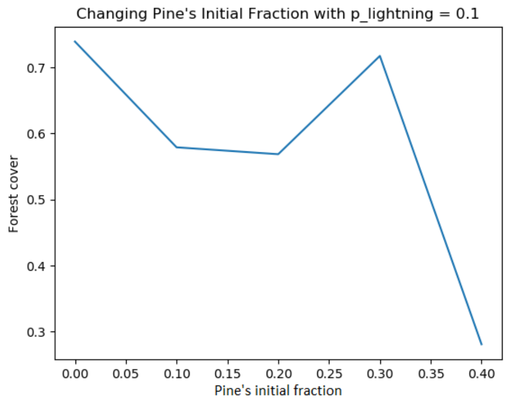

FIG. 2: Plot of Forest cover with changing Hardwood initial fractions

Fig 2 shows the variation in forest cover at the end of 10 years with different initial pine fractions. Initially, when the fraction increases the fraction of trees having more fire susceptibility increases, so after 10 years the forest cover decreases. One more factor which plays important role is the conversion from Pine to hardwood. This is the main reason of the local optima at 0.3. At this value there is maximum conversion from pine to hardwood which makes the forest less susceptible to fire so the forest cover increases. At 0.4 the fraction is so high that it decreases the fraction of Adult hardwood significantly that the conversion rate is decreased. Now as the Pines are not converting to hardwood the forest remains more susceptible to fire and hence the forest cover decreases at the end of 10 years.

B. Change in Probabilities of catching fire

For this experiment the required variables are: Probability of Lightning =0.1 , Probability of surviving fire: [1.0, 0.3, 0.8, 0.1, 0.2]

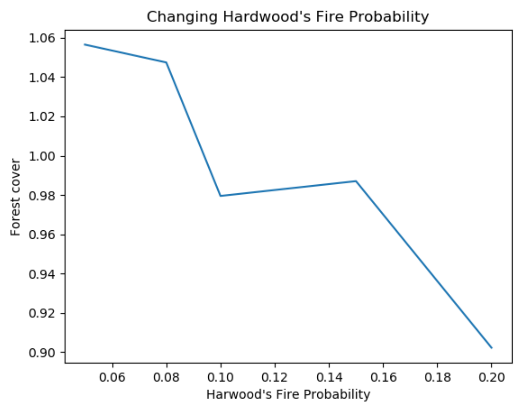

FIG. 3: Plot of forest fraction vs probability of catching fire for hardwood

Fig 3. shows the variation in forest fraction at the end of 10 years with different probabilities for catching fire by hardwood. Initially at value 0.05 the forest fraction is more than 1 which tells us that the forest has become more dense than before. As the probability of catching fire increases therefore more hardwood catch fires and as a result current forest cover is less than the initial forest cover. But an anomaly is seen at the values between 0.10 and 0.14. This is because of the stochastic model. We can see that this anomaly is not so significant i.e. forest cover doesn't increase much as compared to the decrease due to increase in fire probabilities.

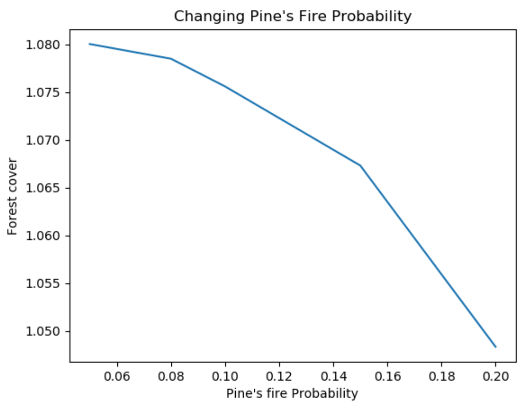

FIG. 4: Plot of forest fraction vs probability of catching fire for pine

Fig 4. shows the variation in forest fraction at the end of 10 years with different probabilities for catching fire by Pine. Here the simulation is considered as if decreasing the fire probability and going towards becoming hardwood. So as the fire probability decreases the forest cover increases. Here the forest fraction remains more than 1 because the fire-probability of hardwood is 0.05 (as this is very less to spread fire) which remains constant.

C. Change in Probabilities of surviving fire

For this experiment the required variables are: Probability of Lightning =0.1 , Probability of catching fire: [0.4, 0.1, 0.1, 0.05, 0.05]

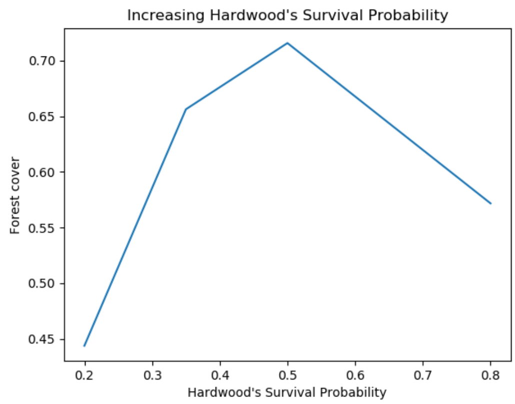

FIG. 5: Plot of forest fraction vs probability of surviving the fire for hardwood

Fig 5. shows us the variation in the forest fraction with changing the surviving probability of Hardwood. As the survival probability increases the forest cover increases because the count of the cells that have survived the effect of fire has increased. An anomaly is seen at the large value of survival probability because this would create a very unnatural condition i.e. 80% of the burnt hardwood doesn't burn to the extent that it would be succeeded by grass and thus it decreases the number of pines and hence the conversion of hardwood from pines decreases.

Fig 6. shows us the change in forest fraction after 10 years as we decrease the survival probabilities. As we decrease the survival probability for pines the forest fraction decreases because more trees won't survive after fire has passed through them.

IV. CONCLUSIONS

From the above mentioned experiments with different constants used in the simulation we conclude the following points:

1. If the forest has more than 40% of resistant trees that are hardwood in our model with survival and fire probabilities mentioned [1], then after a long

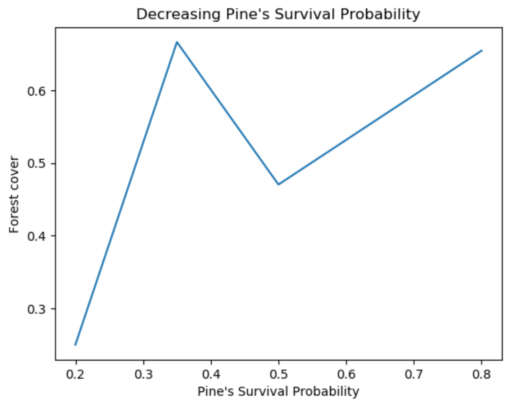

FIG. 6: Plot of forest fraction vs probability of surviving the fire for pine

time the forest would survive. So a measure to save the forest is to maintain the proportion of resistant trees.

2. The inverse follows for susceptible trees i.e. the proportion of the susceptible trees (Pine) should be less than 30%. So to maintain the forest the proportion of susceptible trees should be maintained under 30%.

3. The resistance of the resistant trees matter so to maintain the forest, the resistant trees should not have fire catching probability more than 10%

4. Similarly the susceptible trees would not have fire probability more than 20%.

5. The survival probabilities for the hardwood should be greater than 20% and that for pine should be greater than 40%

Here the percentage of tree proportions can be controlled by human interventions. But the fire catching probability and survival probability are natural and cannot be controlled by human interventions. For such conditions the solution is to check these probabilities using some samples of the forest. With these obtained values of constants we can run the simulation of this model and we can obtain the different value of proportions and that proportion should be maintained. This is very difficult process but this is very less frequent as the fire catching and survival probabilities are natural parameters and natural parameters are a part of evolution and hence this process is not required frequently.

This model can be extended by increasing the number of species in the forest with having the respective probabilities for each kind of vegetation.

[1] https://ics.wofford-ecs.org/additional-projects (Modelling succession)

[2] Forest - fire model with resistant trees - Gustavo Camelo-Neto and S. Coutinho