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Homework 1

With wildfires ever increasing in frequency and climate change on the rise, a problem is wildfire prevention. The question that this project aimed to answer is the following: what is the method to preserve the most amount of trees from forest fires given a uniformly distributed forest as density varies?

Previous attempts:

- Look at highly dense patches in the forest and burn about half of the patch. However, in attempting this approach, in a highly dense forest the approach would burn the whole forest.
- The second approach was to then trim the forest to an acceptable density of about 55 percent so that fires would not burn the whole forest. However, the approach caused large amounts of highly dense forest to be removed, making it go against our goal of preserving as many trees as possible.

Our approach involved the development of a grid-based partitioning strategy within the expansive, densely wooded forest. The primary objective was to safeguard as many trees as possible while minimizing the potential spread of wildfires. We pursued this by crafting a 10 by 10 grid system, designed such that when the forest density reached 99%, only a mere one percent would succumb to random burns. Initially, we considered implementing prescribed burns to mitigate density and the risk of large-scale wildfires. However, it became evident that this approach was suboptimal for maximizing tree preservation in dense forests.

To execute our plan, we began by determining the size of each forest patch, calculated as the difference between the largest x-coordinate and the largest y-coordinate divided by the number of grid cells (forest patches) on each side. Once the grid was delineated with distinctive orange lines, we introduced a randomized ignition point for the fire within the forest. Through this process, we aimed to demonstrate the effectiveness of our partitioning technique in containing wildfires to a mere one percent of the total forest area.

Classically, whenever a forest fire has occurred, humans have been proactive to put them out as soon as possible in order to minimize the damage. However, this has an undesirable effect since the amount of wood available per cubic meter of the forest increases drastically. Such huge amounts of higher-density regions increase the probability of catching forest fire and risking further damage. Therefore, the paper argues that putting out forest fires as soon as they happen might not be the best possible way. Rather, we aim to devise an alternate strategy to minimize such losses to life and property.

Our initial approach was to consider a forest as a large undirected graph. The problem then reduces to finding the maximal sized components and trying to cut the least trees in them so that we could obtain smaller manageable regions of forest. The Gomory-Hu algorithm comes to mind (Gomory and Hu 1961). Though this algorithm may generalize to all possible distributions of trees, we've decided not to implement it due to runtime constraints. Furthermore, it is not necessary to develop an algorithm for all possible forest distributions since we are mostly interested in uniformly distributed forests.

Instead, we take motivation from our ancestors and propose an alternate trimming protocol. Ever since man started farming, has burnt "rectangular" chunks of the forests and grown crops on them.

Expected answer and intrinsic reasons:

The hypothesis was that by partitioning the total forest, the trees removed from the grid will provide barriers from the fire spreading to the whole fire. The goal was to preserve as many trees as possible. Even though making grids will require the removal of trees, the forest will be able to retain the majority of the trees even after a fire starts in a random location in the overall forest. The reasons for the hypothesis are as mentioned below:

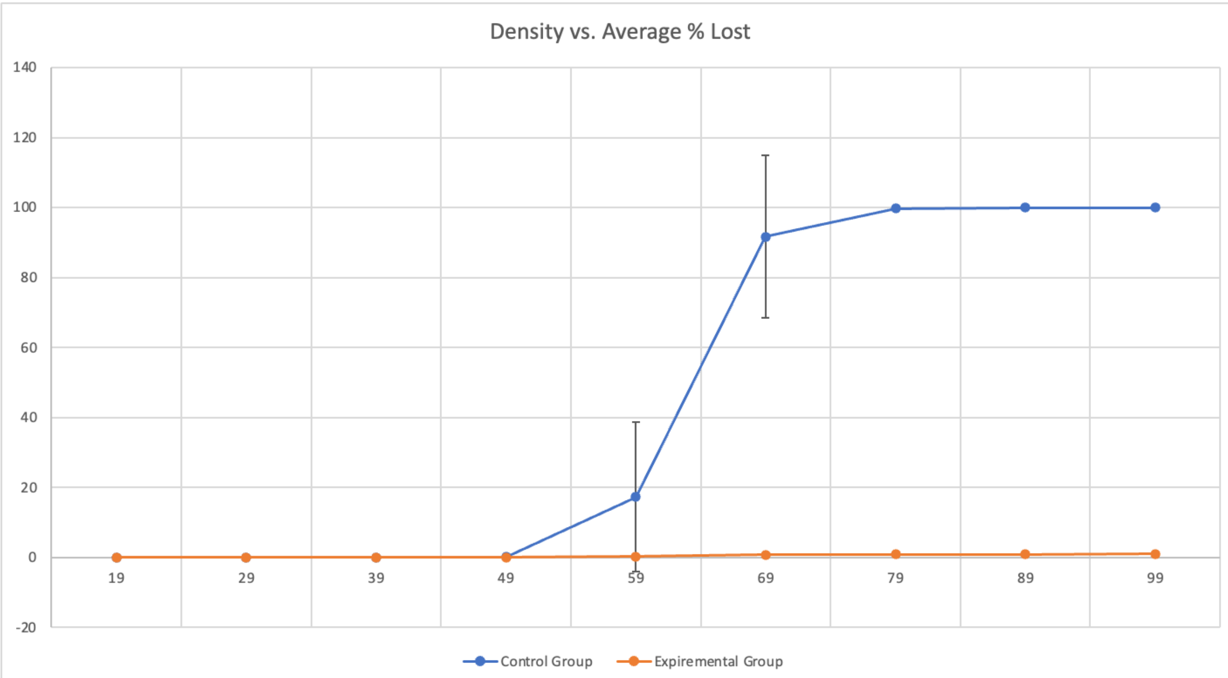
a) **Locality of burn**: If one of the grid cells does end up catching fire, the other grid cells will be safe since there are no common trees between them. The only exception to this rule is if a fire starts on the borders of two grid cells, in which the total number of trees burned can go up to two cells.

b) **Ease of traversal:** It becomes possible to travel from one point in the forest to another point with "at most" one turn. This will allow easier access to put out fire in a particular grid cell in case it does catch fire. A particular care-taker could live at the intersection of such cross roads.

c) **Recursive Nature of the problem:** We argue that the rectangular structure follows a recursive nature. For example, imagine a rectangular patch that is very large. Then, it could be always partitioned again into smaller rectangular blocks without a loss of generality. Therefore, it becomes easier to build criss-cross structures into the forest, without the loss of such generality.

There are two crucial parameters to our algorithm: a) initial density of the forest. b) grid cell size. The proposed trimming possesses an inherent tradeoff: if the size of the grid cell is kept too high, then the number of trees which are available to be burnt in an area significantly increases. On the other hand, if the size of grid cells are small (hence the larger no of grid cells), then we would end up trimming a large number of trees in the forest which might not be desirable. Therefore, we aim to identify optimal values for grid size.

We perform systematic ablations with only one dimension of hyperparameter varying at a time, to provide a proper scientific analysis. All the experiments mentioned below are repeated for multiple runs (100 times). Optimal mean and standard deviation points are thus illustrated on a line plot.



group	density(%)	# runs	grid size	mean % loss	standard deviation
Control	19	100	N/A	0.013	0.018
Control	29	100	N/A	0.016	0.017
Control	39	100	N/A	0.048	0.056
Control	49	100	N/A	0.181	0.191
Control	59	100	N/A	17.326	21.359
Control	69	100	N/A	91.676	23.278
Control	79	100	N/A	99.702	0.031
Control	89	100	N/A	99.981	0.006
Control	99	100	N/A	99.998	0
Experimental	19	100	10	0.012	0.016
Experimental	29	100	10	0.015	0.02
Experimental	39	100	10	0.033	0.035
Experimental	49	100	10	0.079	0.091
Experimental	59	100	10	0.329	0.27
Experimental	69	100	10	0.784	0.27
Experimental	79	100	10	0.904	0.205
Experimental	89	100	10	0.945	0.129
Experimental	99	100	10	0.973	0.201

Metrics:
[1] Percent of trees chopped:
[2] Percent of trees lost in case of accidental burn in a grid cell.
[3] Total percent of trees lost = % trees chopped + % trees lost in case of accidental burn in a grid cell.

List of experiments:
Exp1: For a fixed initial density of the trees, variation across grid cell size.
Exp2: For a fixed grid cell size, how does tree density impact the above metrics.

Exp 1:
At 65 percent density:

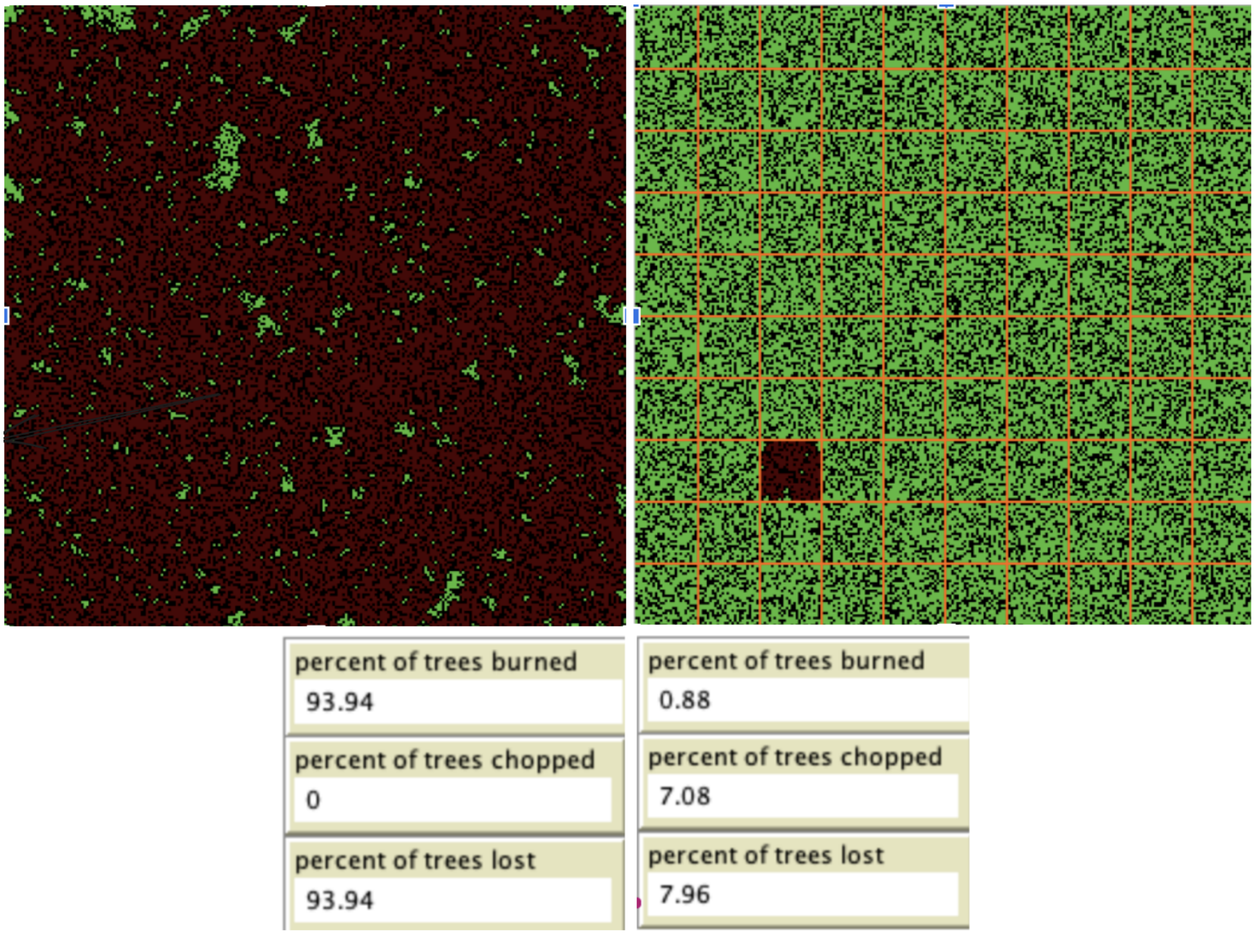
Grid Size	Percent of trees chopped	Percent burned	Total percent lost
5	3.23	3.77	7
10	7.05	0.03	7.08

15	10.73	0.34	11.07
20	14.52	0.17	14.69
25	18.23	0.12	18.36
30	21.91	0.03	21.95
35	25.22	0.01	25.23

Exp 2:
Grid size 10:

Density	Percent of trees chopped	Percent burned	Total percent lost
10	7.24	0	7.24
20	6.92	0.03	6.95
30	7.1	0.03	7.13
40	7.08	0.03	7.11
50	6.98	0.04	7.02
60	6.92	0.04	6.97
70	6.99	0.78	7.78
80	6.99	0.93	7.91
90	7.01	0.93	7.94
99	7.05	0.91	7.96

Visual Example of the Netlogo Simulation:
At 65 percent density:



On the left, we present an initial condition when the forest had a high initial density of the trees. As we can see an accidental forest fire leads to a loss of as much as 93.94% of trees. On the right, we present our proposed gridding approach. Note that the amount of trees lost while creating grids is a mere 0.8%. When the burn actually occurs in one region, only 7.08% trees are lost. Since 7.08% is much smaller than 93.94% of the trees lost earlier, this illustrates the effectiveness of our proposed approach. Note that probability that a grid cell catches fire is 1/(H*W), where H, and W are the thickness of the grid cells on the two dimensions respectively.

-> **<u>discussion: is there any particular "best" value</u>**

> The experiment will require various runs while measuring the percent of trees chopped, percent of trees lost, and the average percent of trees lost in total. This will be done by running the experiment various times to acquire the average amount of trees burnt at various densities.

The experiment shows how the utilization of partition barriers can be used to preserve the overall forest by sacrificing small isolated grid cells. This can potentially be used in human affected forests that have high unnatural densities to reduce the effects of forest wildfires. Since prescribed burns can be quite intensive in measuring density and keeping up with growing fuel, the utilization of grids is a simple and effective method to implement.

We learned that at densities around 59 and 69 are hard to predict to what span a fire can spread making it complex to predict. Via introducing a grid-based partitioning approach within the simulation, we enhance our comprehension of how small-scale mediation can affect large-scale systems. This work allows us to explore the balance between preserving ecological resources, such as forests, and managing the inherent risks, such as wildfires, in Complex Adaptive Systems.

conclusion:

We propose a novel algorithm for overcoming losses due to forest fires by gridding the forest into rectangular patches. We analyze the impact of the initial tree density and grid cell size on the total number of trees which will be lost in case of an accidental fire. We find that the proposed approach performs better than a naive baseline which might involve randomly trimming certain regions of the forest. Finally, we show that our approach is also environmentally sustainable by minimizing the number of trees lost, and also guaranteeing minimum damage in case of fire.

References

1. Gomory, R. E.; Hu, T. C. (1961). "Multi-terminal network flows". *Journal of the Society for Industrial and Applied Mathematics*. **9** (4): 551–570. doi:10.1137/0109047.