Assignment 1 Report

Section 1 Simulation and Discussion

Problem Discussion

In this assignment, C codes have been created to simulate the growth and decline of a forest due to alternating fire and growth phases. Sensitivity studies have been performed in terms of two parameters – the growth parameter g (as the probability for an empty cell to grow a tree) and the ignition factor f (as the probability for an occupied cell to catch fire) – to study their effects on the size (number of trees) of the forest. The forest was represented by a 2D matrix with N*N (100*100 in this case) entities stored in an N*N array in the C codes. Three values were used to represent the cells' status: EMPTY (0), TREE (1), and BURN (2). The model has been simulated with up to 1000 cycles (time steps). Each cycle (time step) consists of three periods: a tree growth period, an instant ignition period (trees catch fire due to lightening) followed by a fire spreading period. The *rand()* function was used and divided by *RAND_MAX* to generate random number (r) between 0 and 1. Hence the growth probability and the ignition probability could be simulated by the possibilities of r falls into range(0, p) and range(0, f), respectively. Recursion has been used in this model to determine the extent of the fire spreading to the contiguous trees when any particular tree caught a fire.

Preliminary Tests

To test the correctness, the codes were modified to perform sample simulations with small N values for a few cycles. The forest matrix then was printed out after each of the three periods (growth, ignition, and fire spread) within each cycle for us to check if the results were correct. Figure 1 presented examples of such outputs from Cycle 1 and 5. After examination, outputs from all samples tests met our expectation. Hence, the model was then used to run the desired simulations.

Simulations and Results

In order to determine the long-term forest size, this model was then run for 1000 time steps with a 100*100 grid, an f value of 0.01 and a g value of 0.1. The step number, transient forest size (number of trees), and the cumulative average forest size at the end of each corresponding time step were printed out. Finally, the average forest size over the complete simulated period was also printed out at the very end. Please refer to the source file named *"step-wise_print-out.c"* for such outputs. Figure 2 is a graphic illustration of the transient and cumulative forest sizes over time.

As can be seen from the graph, while the transient forest size still fluctuates around ~3000, the average size of forest time over time stabilizes over time (no more than 100 time steps in this case) after a period of increasing. This means after a certain amount of time, the number of trees of a certain forest will stabilize after each cycle even if growth and fire burning are still alternating within s cycle. It shows the self-stabilization ability of a natural system, which agrees well with the real scenarios in the natural.

Figure 1: Example of selected (Cycle 1 and 5) output matrices demonstrating forest situations after: 1) the growth period; 2) the ignition period; 3) fire burns out. (N = 20, f = 0.1, g = 0.2)

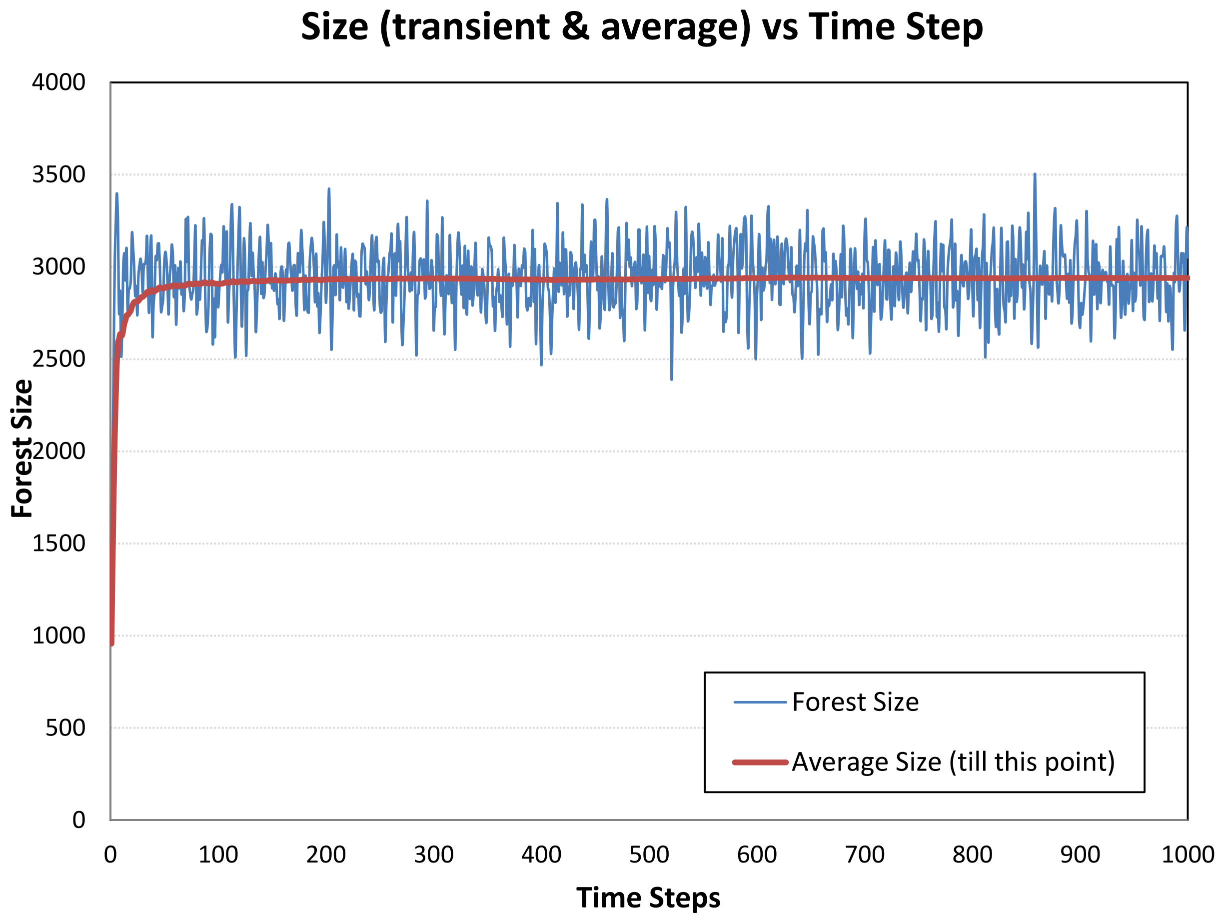
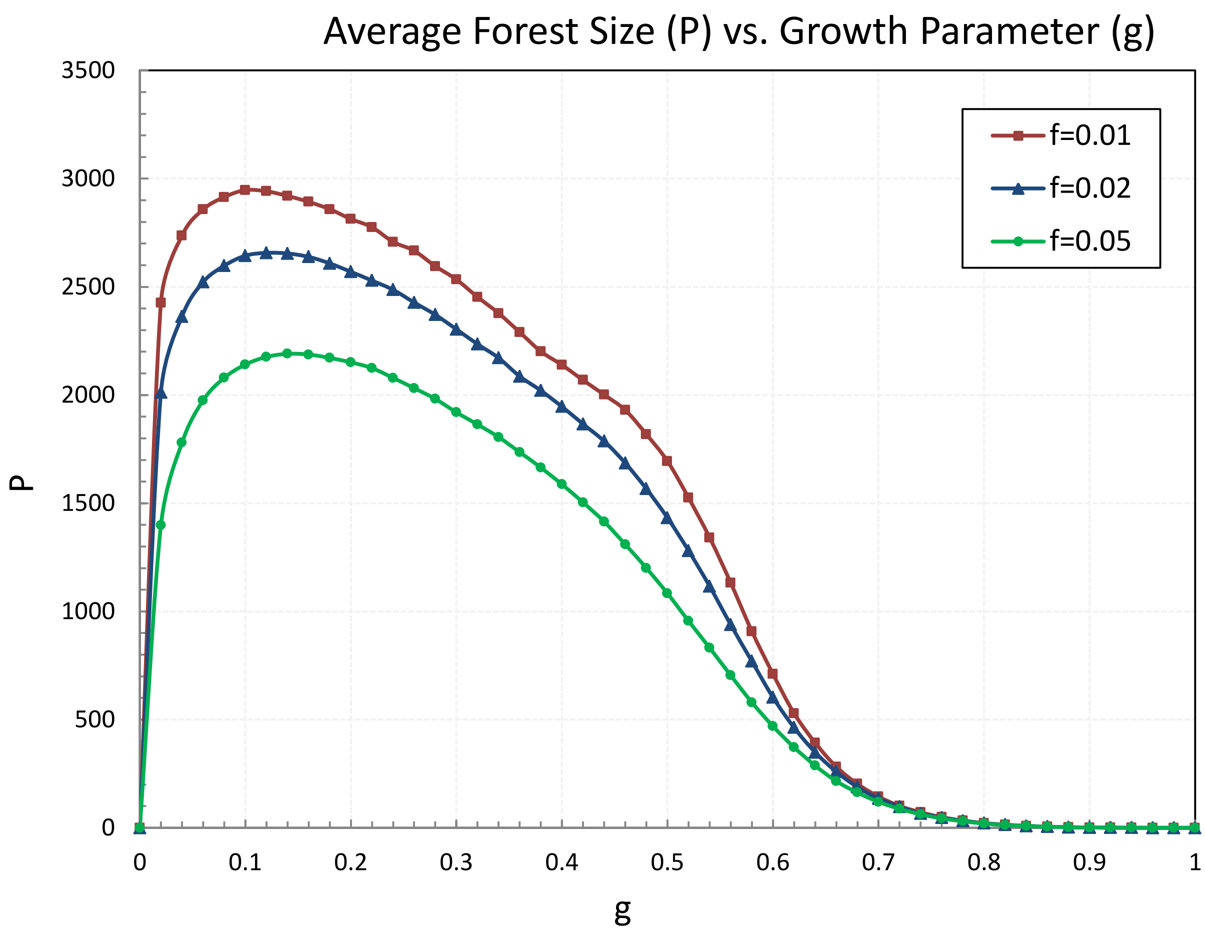


Figure 2: Plots showing the transient forest size and the cumulative average forest size at the end of each time step.

Finally, sensitivity analyses were performed. A graph with the average forest size P on the vertical axis and growth parameter g on the horizontal axis has been plotted under different ignition factor f. There are three curves plotted with f equals to 0.01, 0.02, and 0.05, respectively, and are shown in Figure 3. All average forest sizes are taken after 600 time steps to ensure the sizes have been stabilized. The corresponding codes are included in a separate source file named “P-g-f_study.c”.



As we can see from the graph, the average forest size (P) varies as growth parameter (g) varies under each fixed f. As g increases, P increases sharply at the very beginning till it reaches the peek, and then P decreases at a much lower pace as g continues to increase. When g=0 or g approaches 1.0, P = 0. From this graph, we can also see with the same g value, within the range we simulated, the higher the ignition factor (f), the smaller the forest size (P). What our results have shown are very realistic. With a larger f value, which means trees catch fire easily, the fire would be more intensive, and thus results in more trees been burned. In terms of g, when g is very small, which means it is very hard for trees to grow in this forest, apparently the forest size would be small. On the other hand, if g is very large (approaches 1), it means trees can grow almost as long as there is an empty cell. This would result in a forest with dense population. Trees are adjacent to each other after the growth period, which would provide connected pathways for the fire to spread. Hence, in such scenarios, the forest would be burn to the ground after the fire phase. Finally, there exists a growth parameter g that is neither too small that almost no tree could grow, or too large to provide convenient pathways for the fire to spread. This value would result in the largest forest size, and is the value we want to reach in terms of forest protection.

Section 2 Literature Review/Survey

In reality, the occurrence and spreading of forest fire are complicated. They highly depend on the environment conditions and the site conditions, such as the vegetation, which provides the combustible source for the reaction; the oxygen in the air, and the heat source responsible for the initiation and the self-sustainability of the combustion reaction [1]. When simulating the effects of fire on the long-term forest size, the model described in this assignment report simplified the environmental conditions. However, it has taken into consideration three key aspects that were demonstrated as most important in the literature [2-7]. When this model simulates the decline and growth of a forest with periodic fires, it has considered the ignition factor, the spreading parameter (related to the vegetation population and distribution) and a factor that measures the easiness of plants regrowth. Though highly simplified, this model is capable of showing how these three key factors affect the forest size, and the results are in line with other more sophisticated stochastic models presented in literature. In Almeida and Macau's stochastic cellular automata model [2] for wildland fire dynamics under flat terrain and no-wind conditions, they analyzed the dynamics of the fire both qualitatively and quantitatively. Via simulation, they concluded that since the proportion of vegetation cells across the lattice determines the spatial distribution of available fuel along the lattice. A higher value for the connection factor of vegetation across the lattice provides fire propagates with more facility. Hence, from their plots, it can be seen that as vegetation density increases, the decline of forest due to fire also increases. When the vegetation density is low, its increase will result in a larger forest size, while when the forest is densely populated with vegetation, increasing the vegetation density would actually result in more serious decline of the forest. As for the spreading factor, which models the probability of the fire spreads from a burning cell to a neighboring vegetation cell, it appears that there is a positive correlation between the spreading of the fire and the spreading factor. The observations we can derive from their plots agree with what were shown in my model. Also, their plot of forest size over the simulated time, though more sophisticated, generally agrees with my plot (Figure 2). In another paper [3], authors discussed the application of Cellular Automata (CA) models as suitable tools to model the behavior of fire front because of their intrinsic features. They indicated the communication between constituent cells in a CA model is limited to local interaction. Each individual cell is in a specific state which changes over time depending on the states of its local neighbors. They pointed out that the evolvement of cells in a forest fire model with given transition rules, which are characterized by an ignition probability for the cell, which, in their model, depends only on the number of burning cells in its neighborhood. The general evolving states of their model illustrated in their paper agree with my model's results if we print out the states of the forest matrix at the end of each time step. Similar to Almeida and Macau's paper [1], they also indicate that the diffusive fire spread requires a continuous pathway or clusters of vegetation cells. The effects from vegetation distribution and multiple fire spreading factors are widely discussed in the literature [4][5] and have been verified by data from real cases[6][7]. Overall, the observations we can get from my simplified Cellular Automata model show good agreement with the literatures.

In the end, I think the Cellular Automata methodology provides a good tool to simulate the dynamics of a real wildfire that burst due to their inherent similarities. Such modeling tool could help predict the spreading and decline of forest fire, and can help us with the estimation of consequences of the fires. Also the CA method has wider applications of simulating complex dynamical systems whose evolution depend on the local interactions of their neighboring parts. Traffic flow simulation is an example.

Reference

[1] Pyne S J, Andrews P L and Laven R D 1996 Introduction to wildland fire (New York, USA: John Wiley and Sons)

[2] Almeida, Rodolfo Maduro, and Elbert EN Macau. "Stochastic cellular automata model for wildland fire spread dynamics." *Journal of Physics: Conference Series*. Vol. 285. No. 1. IOP Publishing, 2011.

[3] Quartieri, Joseph, et al. "A cellular automata model for fire spreading prediction." *Latest Trends on Urban Planning and Transportation* (2010): 173-178.

[4] Karafyllidis, Ioannis, and Adonios Thanailakis. "A model for predicting forest fire spreading using cellular automata." *Ecological Modelling* 99.1 (1997): 87-97.

[5] Ghisu, Tiziano, et al. "An Improved Cellular Automata for Wildfire Spread."*Procedia Computer Science* 51 (2015): 2287-2296.

[6] Russo, L., D. Vakalis, and C. Siettos. "Simulating the wildfire in Rhodes in 2008 with a cellular automata model." *Chem. Eng. Trans* 35 (2013): 1399-1404.

[7] Alexandridis, Alex, et al. "A cellular automata model for forest fire spread prediction: The case of the wildfire that swept through Spetses Island in 1990." *Applied Mathematics and Computation* 204.1 (2008): 191-201.

Collaboration Statement

I have discussed the assignment with Peijun Wu, and also had a very brief conversation over the assignment with Bangtian Zhou. I have instructed Jiayao Zhang with C programing technics. All codes that I turned in are completely my own work. I have not shared or viewed any other people's codes.

Reference has been listed on Page 7.