Agent-based Model for Wildfire Simulation

CITS4403 Project Report

Group 81 – Henry Tran (23035141)

Introduction

Agent-based Model (or we also call ABM) is the computational model to simulate self-governing agents' actions and interactions in both individuals or group of individuals viewpoints to understand the system behaviours and its outcomes. This model helps people to simulate real-life situations, such as Thomas Schelling's Model of Segregation to find how houses from different groups move to new locations with new neighbours, or Boids: Folk of Birds to understand the Boids' ability to maintain the flock.

In this paperwork, the wildfire simulation will be conducted to investigate the actions of the fire fighters in extinguishing the fire in the forest, as well as the effectiveness of the fire fighters if they can communicate with each other. The reason behind the wildfire simulation is because this is one of the most considerable problems the world is facing. Through the time, the forest coverage on Earth is decreasing due to global warming, which naturally cause the fire in the forest, reduce the forest area and would take long time to recover. Therefore, to minimise the forest reduction caused by wildfire, the fire fighters need to extinguish the fire as quickly as possible. Additionally, with the development of technology, the estimated fire spread could be detached easily. This could also be utilised to help the fighters to come and cover the fire spread as much as possible.

ABM is a well suitable model to simulate wildfire case. Since ABM includes 3 elements: agents, environment and interactions, the model can be applied in this case, with an individual fire fighter or groups of fire fighters, fires as agents, forest as an environment, and how the fire will burn the trees in the forest with the actions of fire fighters are interactions.

The wildfire simulation includes different factors that affect the complexity of the case. Firstly, the forest set up could create the challenges for this problem, if the forest coverage is large in a specified area, then the fire would be easier to burn the surrounding trees, and the fire fighters need to take more time to extinguish the fire. Secondly, the burning time (or can be understanded as the lifetime) of the fire increases the problem complexity, the longer the specific area under then fire, the more time the fire fighters have to taking the fire out. Thirdly, the interaction between fire fighters and the movement of the fire fighters towards the fire could also increase the complexity level, such as which fire in which area should be removed first so they can reduce the time of putting all the fire away.

Model Design

To better understand the wildfire model design and the rules, the previous research project from Guangjun Zhang and Yaodong Li in 2010 was used as the reference in this paperwork. The group of authors had done the wildfire simulation using a visualised software. The following initial configuration in this investigation will be mostly followed the research from Zhang and Li:

- The area of the forest will be in 2 dimensions with the size of n * n.
- The tree coverage in the forest will be 75%.
- One fire will be put randomly in the forest.
- 4 fire fighter agents will first be in 4 corners of the forest.

However, there are some modifications that added on to the initial design above. As in the research, there are 3 agents: tree (the forest coverage), the fire agent and the fighter agent. However, after consideration, fire agent and tree agent will be implemented within a big agent called Forest, as the trees are stable in the forest, and the fire's actions are just only burn the surrounding trees and "die" after it reaches its lifetime. The fire fighter agent will be remained the same.

There are 2 simulation models for 2 cases will be examined: the first case is the fire fighters individually put the fire out, and the second case is the complex case when one fire fighter spotted the fire, they will communicate its spread area to other fighters so they can come to extinguish it. Here is the full breakdown of the first agents' designs and attributes:

- Forest agent:
    - There are 4 states represent for 4 elements in the forest: 0 for no tree, 1 for tree, 2 for fire and 3 for fire fighter – the action of fire fighters will be from the fire fighter agent. The state will be updated in each timestep.
    - Creat_fire_fighters: to put 4 fighters at 4 corners of the forest.
    - Create_fire: to select randomly one tree to put the fire on the forest.
    - Ignite_tree: to track the lifetime of the fire and select randomly one tree to burn. If the fire maximum burning time reached, then the fire will be removed from the forest to mark that the tree is fully burned. As in the research paper, the authors did not mention how the fire will spread, so it is assumed in this case that the fire will burn only one more tree in the next timestep.
    - Step: to be called to repeat the rules each timestep.
- Fire_fighter agent:
    - Extinguish_fire: will be called every timestep. If there is at least one fire surrounding the fighters, they will move towards randomly one fire to extinguish it. Otherwise, the fighter just moves. As the number of steps was not mentioned in the research, then it is assumed that the fighter will move randomly one of 8 cells surrounding them.
    - Check: to check the surrounding areas of the fighter. As the vision attribute of the fighter was not mentioned in the research, then it is assumed that the fighter can check surrounding 8 cells.
    - Move: to move the fire fighter randomly. Since the way the fighter moves was not discussed in the authors' research paper, then the fighter is assumed to move randomly to 1 of 8 cells surrounding them

For the second case, the simulation model has some adjustment to increase the complexity and more well real-life simulation. With the forest agent, there is a new variable to store the location of the first fire-spotted fighter and then share it with other fire fighters. While on the fire fighter agent, the new action called move_closer is to calculate the shortest cell to move towards to the nearest fire to that fighter. This complex rule follows the previous research that once a fire was spotted, then the fire spreading location will be shared with other fire fighters so they can cover up the fire area and reduce the spread. The second model is more complex than the first model is because there are more rules and connectivity between fire fighter agents.

For the first simulation model, it follows this rule:

1. On forest, one random fire spread to a tree if there are trees surrounding it. The age of the fire is counted.
2. If a fire reaches its maximum burning time, then the fire and the tree will be removed, and the state will be no tree
3. Each fire fighter checks around to find the fire.
4. After checking, if any tree has fire, the fire fighter moves towards it to extinguish the fire. If there is no fire, then the fire fighter moves randomly to one location surrounding them.
5. Update the forest states and fire fighter locations.
6. Repeat the process.

For the second simulation model, these are the order of actions they do:

1. On forest, one random fire spread to a tree if there are trees surrounding it. The age of the fire is counted.
2. If a fire reaches its maximum burning time, then the fire and the tree will be removed, and the state will be no tree.
3. Each fire fighter checks around to find the fire.
4. After checking, if there is no fire, then the fire fighter moves randomly to one location surrounding them. If that fire fighter first spotted the fire, then that fire fighter will move to that fire to extinguish it and let other fire fighter knows about the fire locations (this condition will be called only once).
5. The other fire fighters calculate and moves one step towards the closest fire.
6. Update the forest states and fire fighter locations.
7. Once the first fire is spotted, then from the following timesteps, all the fire fighter prioritises to move to the nearest fire.
8. Update the forest states and fire fighter locations.
9. Repeat the process.

Results and Analysis

To evaluate the performance of 2 simulation and agents' interactions, the np.random.seed(17), the size is 15*15, the forest coverage is 75% and the time the fire keep burning is 20 timesteps. These were applied to ensure that both forest agents have the same set up forest and fire spread locations. Only the fire fighter agents are different in 2 models, so the interactions between fire fighter agents with the forest agents and within fire fighters can be examined.

Result of the first simulation model

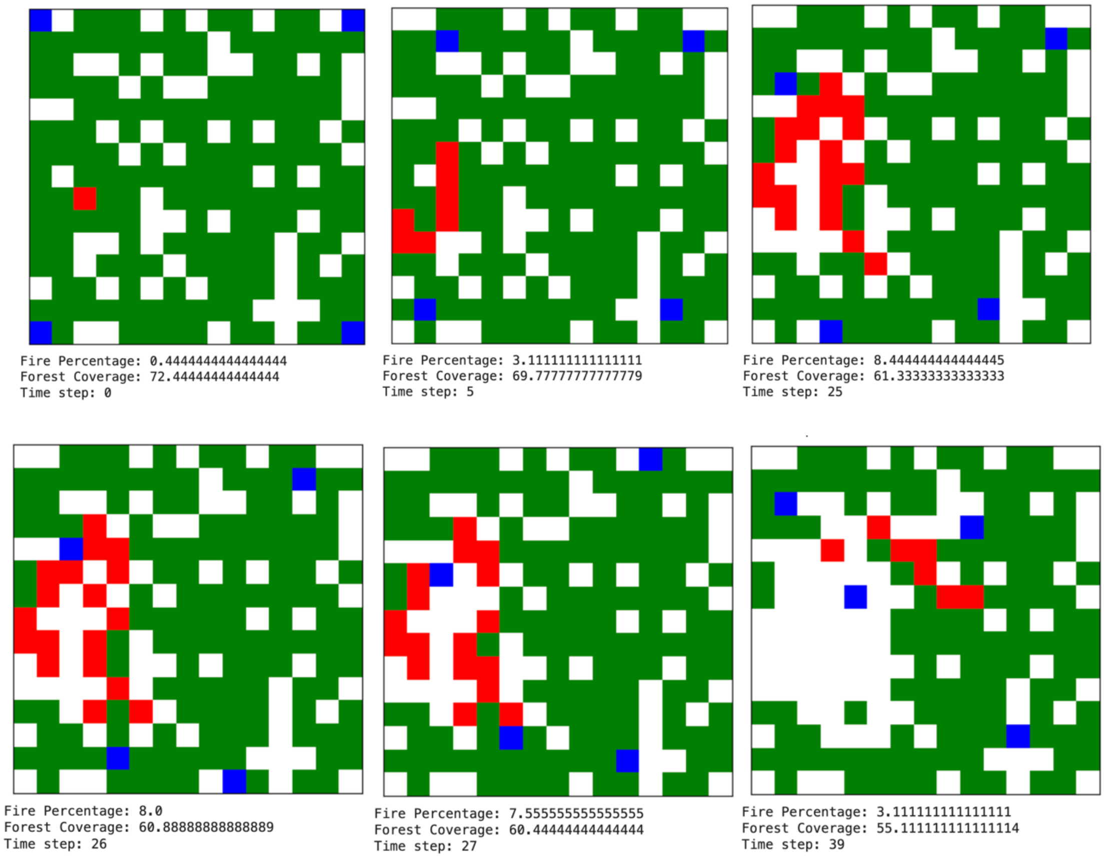

Figure 1: The visualisation outcomes of the first simulation model

With the first simulation model, the fire fighter agents individually extinguished the fire and only interact with the forest agent. On the figure 1, it demonstrated the movement of the fire fighters, the spreads of fire in 6 different timesteps. When the simulation went to the timestep 25th, the fighter was first spotted the fire. One timestep after, the fighter extinguished the fire, which implies that fire fighter agent interacted with the forest agent, and the fighter put out another in the following timestep. However, the fighters just move randomly, they did not know about where the fire was.

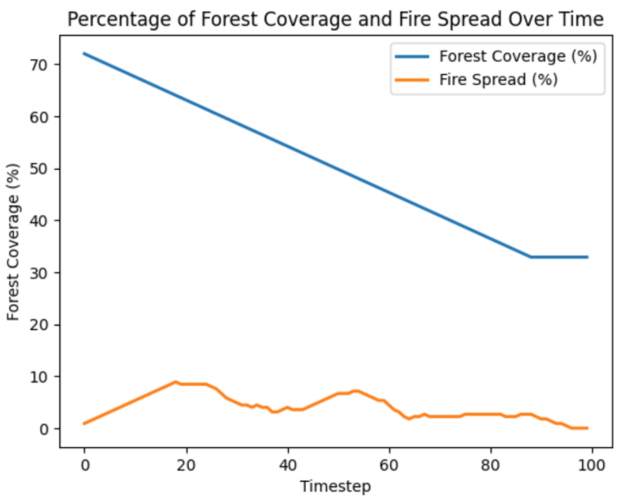

Figure 2: The percentage of forest coverage and fire through 100 timesteps of the first simulation model

Figure 2 represents the percentage of the forest coverage and the percentage of the fire within 100 timesteps. Through the time, the forest coverage decreased, from 75% at the beginning, to estimated 35% at around close to timestep 90th. The fire spreads to around 10% of the forest at timestep 20th, after the fire fighters extinguished the fire in some locations and move randomly again, then the fire spread to around 10% of the forest again. From around timestep 90th, even though the forest coverage did not decrease, but the fire did not spread anymore and gradually reduced through each timestep and become 0% at timestep near 100th. The reason behind this fire reduction is because when the fire reached it maximum fire time, and did not have any surrounding trees to burn, then it just extinguished itself.

From the first simulation, when reference to real-life situation, it can be seen that if only fire fighter extinguishes the fire by themself, the forest will lose a lot of trees as the fire keeps spreading.

Result of the second simulation model

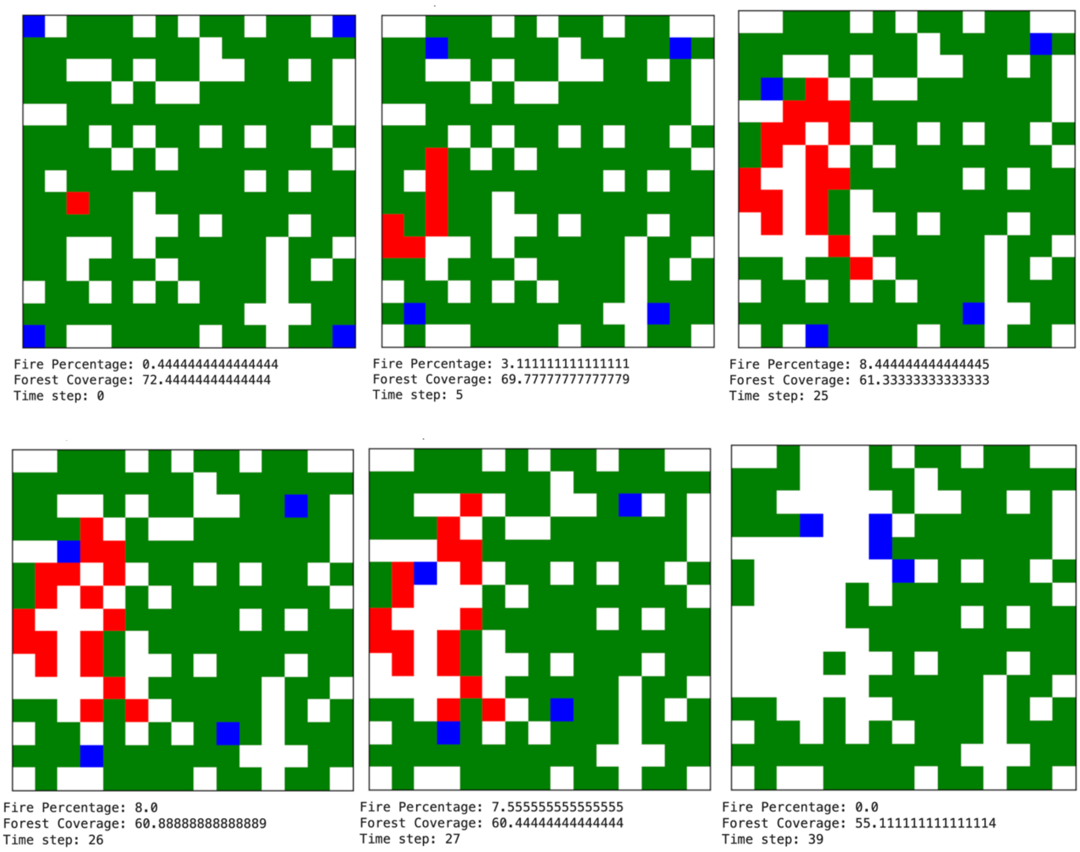

Figure 3: The visualisation outcomes of the second simulation model

In contrast to the first simulation model, on the second one, the fire fighter agents collectively extinguished the fire, so this is the interactions between each fire fighters agent with the forest agent and the interactions within the group of fire fighters agent. On the figure 2, similar to figure 1, it showed the movement of the fire fighters, the spreads of fire in 6 different timesteps. When the simulation went to the timestep 25th, the fighter was first spotted the fire. One timestep after, the fighter extinguished the fire, which implies that fire fighter agent interacted with the forest agent. Additionally, the fire fighter in the bottom left of the forest, from timestep 25th to 27th, moved one cell closer to the fire each timestep. The same movements recorded for 2 other fighters, moved from the left to the fire on the right. This signified that when the first fighter spotted the fire, they communicate with other fire fighters in the forest to support extinguishing the fire. When all the fighters knew about the fire came towards the fire, the fire should be removed within smaller number of timestep and all the fire extinguished in timestep 39th, while in the first simulation, there were still some fire spreading in the same timestep.

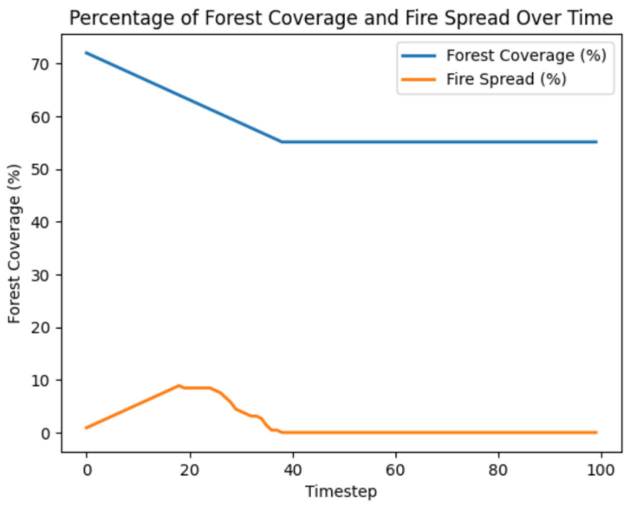

Figure 4: The percentage of forest coverage and fire through 100 timesteps of the second simulation model

Figure 4 shows the proportions of the forest coverage and the fire within 100 timesteps of the second simulation model. Within only 40 timesteps, the forest coverage decreased from 75% at the beginning to around 55% at some timesteps before the timestep 40th, while the fire spread to around 10% of the forest at timestep 20th, then was put out from the fire fighters gradually to 0% within the same number of timesteps. When compared to the first simulation model, these show an improvement that the time spent to extinguish the fire is shorter and the forest coverage was protected better with smaller percentage of tree deduced.

Parameter changes

There are some cases the burning time of the fire is extremely long.

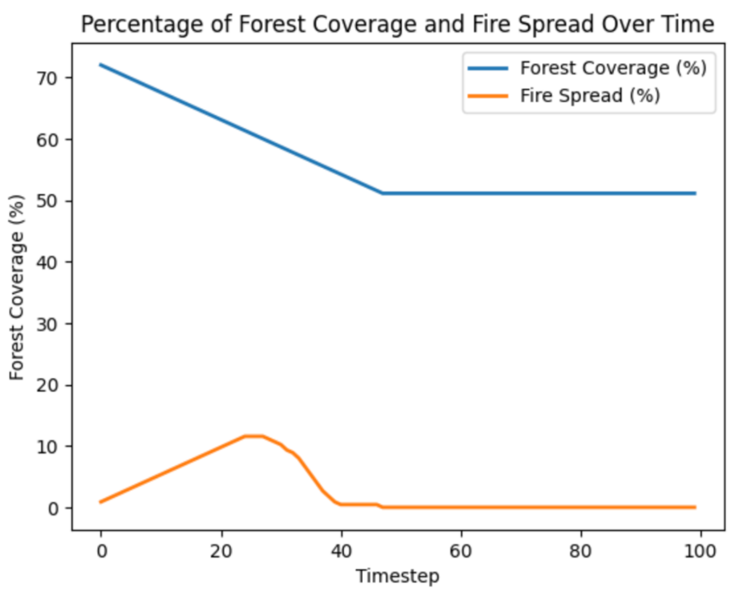

Figure 5: The percentage of forest coverage and fire through 100 timesteps of the second simulation model with the fire burning time of 70 timesteps

Figure 5 illustrates the percentages of the forest coverage and the fire within 100 timesteps of the second simulation model with the burning time of the fire extended to 70 timesteps. Looking at figure 4 of the fire burning time in 20 timesteps, the shapes of the fire percentage are identical, but the figure 5 shows a smoother decrease in the percentage of fire, compared to the one in figure 4. As the burning time of the fire was shorter in figure 4, the number of locations burned in the forest decreased by the combination of maximum burning time and the remove from the fire fighters. In figure 5, the fire decreased mainly from the extinguishment of the fire fighters. Additionally, the burning time on figure 5 is a little longer, by around 5 timesteps compared to figure 4, and the percentage of forest coverage closed to 50% on figure 5, while it is estimated 55% on figure 4. Therefore, it can be seen when the fire burning time is longer, the fire fighters have to work more, and the forest coverage also decreases faster.

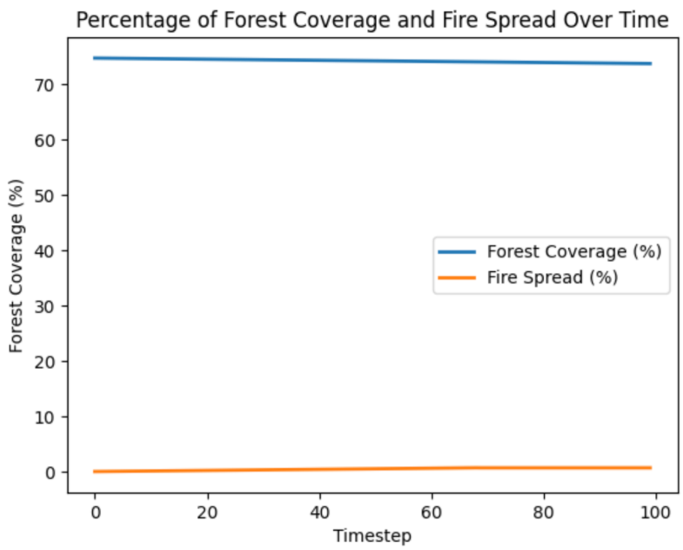

Figure 6: The percentages of forest coverage and fire through 100 timesteps of the second simulation model with the fire burning time of 70 timesteps and the size of the forest is 100

Figure 6 demonstrates the combination changes in size and fire burning time variables. The percentage of the forest coverage slightly reduces, and the rate of fire spread also goes up very little. This implies that the larger the forest, the more fire fighters needed to faster spot the fire and extinguish them.

Insights for real-life cases

From 2 simulation models, when reference to real-life situation, there are some key insights:

- The connection between fire fighters helps decreasing the spread of fires and preventing the forest coverage lost. This is because of the fire location informed by the first fire fighter. Therefore, if a fire spotted and reported to other fire fighters, this could reduce the travelling time to the fire as they will go with the shortest path.
- The longer the burning time, the more fire the fighters must extinguish. In this case, the plan of having more fire fighters should be implements

- With the larger the forest, the harder for the fire fighters to spot the fire, which makes the fire keeps burning more trees and reduces the forest coverage. The implementation of more fire fighters in larger area helps to find the fire faster.

Conclusion

In short, with the application of 2-dimension Agent-based Model, it supports human in simulating one real-life problem of how to extinguish the wildfire. ABM is a well suitable model, it strongly shows the interactions between different agents, which are the fire and the fighters in real life. For the purpose of preserving the forest lost as much as humans can from the fire, a well-prepared plan is needed, including the significant numbers of fire fighters in an area, in order to spot and extinguish the fire as fast as possible. Also, the communication development is required so the fire fighters can faster locate the fire positions and save more time moving to the fire.

The model developed has some limitations. First of all, the vision and movement parameters for the Fire fighter agent were missed. Because of lacking parameters, then the fire fighters' movements were not really similar to real fighters. Second, for the second simulation model, if the first fire fighter spotted the fire, some of the fire in the fire fighters' vision ability should be reported, not all fire in the map. The reason is because one fire fighter could not see all the fire locations on the map. These are the 2 improvements needed in this AB simulation model.

The model could be developed to better simulate more extreme situations closer to the real life. Firstly, the winds and the temperature are two parameters which can be put into the simulation model. With the combination of these 2 factors, the simulation model would replicate the case closer to reality. For example, if the wind goes up north, then 3 cells about the one fire will be burned, or if the temperature is higher, the burning time of the fire will be longer and the spread will be more intense, by burning more surrounding trees. Secondly, with the Fire fighter agent, it could be improved by adding the survival status. For instance, if there are 6/8 cells surrounding the fighter are fire, the fighter would be burned, or after extinguishing numbers of fire, they could be removed. In short, adding winds, temperatures for the forest and the survival status for the fire fighters make the Agent-based model better to simulate closer to real-life wildfire cases.

Reference

Zhang, G. and Li, Y. (2010). Agent-based modeling and simulation for open complex systems. doi:https://doi.org/10.1109/car.2010.5456783.