MATH 2121: Final Project Report

Professor Benjamin Seibold

Jihye Lee

May 3, 2024

COVID-19 2D Grid Spread Simulation: An Agent-Based Model

Introduction

In late December 2019, COVID-19 was first detected in Wuhan, China. Initially mistaken for a novel strain of flu, the virus quickly gained attention due to its rapid spread and high mortality rate. In just three months, COVID-19 escalated to a global pandemic, declared by the World Health Organization (WHO) on March 11, 2020. This marked the fifth documented pandemic since the 1918 flu pandemic and the first in over a century. Despite this, many people initially underestimated the importance of social distancing and other mitigation measures.

The pandemic's early stages showed the difficulties of controlling a highly infectious disease in a globalized world. As scientists and public health officials raced to understand the virus, various strategies were employed to curb its transmission. Measures such as lockdowns, travel restrictions, and limitations on public gatherings became common worldwide. At the same time, the impact of individual behavior on the spread of the virus became increasingly evident.

Agent-based models like the one presented in this project offer valuable tools for understanding the dynamics of disease spread. By simulating agents' movements and interactions within a defined space, the model provides a visual representation of how factors such as social distancing, quarantine, and infection probabilities affect the trajectory of an outbreak. The model draws inspiration from notable works in the field, such as a video titled "Simulating an Epidemic" by the YouTube channel 3Blue1Brown, which explored the impact of key variables such as the R0 value (basic reproduction number) and interventions such as quarantine and travel restrictions on the spread of an epidemic.

By experimenting with different scenarios, researchers and policymakers can use agent-based models to gain insights into the potential outcomes of various strategies and make more informed decisions to manage and mitigate the effects of pandemics. This project's simulation of

COVID-19 spread within a 2D grid serves as a valuable contribution to understanding and visualizing the complex interplay between individual behavior and disease transmission.

Methods

This project employs an agent-based model to simulate the spread of COVID-19 within a two-dimensional grid, representing a confined environment. The model begins with an initial population of 500 agents randomly distributed across the grid. Each agent moves randomly at a constant speed and alters its direction slightly at each timestep, simulating the wandering behavior of individuals. Agents interact with one another when they occupy the same grid cell, and the probability of infection transmission is determined by the presence of infected or quarantined agents in the cell.

Infected agents continue to move freely around the grid for six days, potentially spreading the virus during this asymptomatic phase. After this period, the agents transition to quarantine, remaining stationary within the grid with a 0.0001 probability of spreading the virus. Upon completing the quarantine period, agents gain immunity and can no longer be infected or transmit the virus.

For simplicity, all agents in this model are assumed to have the same age and health conditions. This simplifies the model and focuses on understanding the spread of the virus in a homogeneous population. Although this assumption may not reflect real-world demographics, it allows for a clearer analysis of disease dynamics without introducing additional variables related to age-specific behaviors or susceptibilities.

The model runs over a specified number of timesteps, representing hours, to simulate the progression of the outbreak over time. Key parameters such as the speed of agents, infection probability, duration of infection, and quarantine periods can be adjusted to explore different scenarios and their impacts on the spread of the virus. Throughout the simulation, data is collected to track the number of susceptible, infected, quarantined, and immune agents at each timestep. This data is used to visualize the dynamics of the epidemic and understand how different interventions and parameters affect the trajectory of the outbreak.

The simulation outputs graphs showing the spatial distribution of agents at various points in time and trends in the number of agents in each status category (susceptible, infected, quarantined, and immune) over the duration of the simulation. These visualizations provide insights into how the disease spreads and how interventions can alter its course.

Results and Discussion

Data was collected from 1,000 simulations for each movement speed to assess the impact of different speeds on the spread of the virus.

In the No Movement simulation, agents have a movement speed of 0, effectively acting as a control group. This scenario serves as a baseline for comparison with other experiments involving varying speeds. In this setup, initially infected agents go into quarantine after six days, and once the quarantine period ends, they gain immunity. Figure 1 shows the number of infected agents dropping to zero by the six-day mark, coinciding with a rise in the number of agents in quarantine, matching the initial number of infected agents. By day 20, the number of quarantined agents decreases to zero, while the number of immune agents increases, marking the end of the simulation.

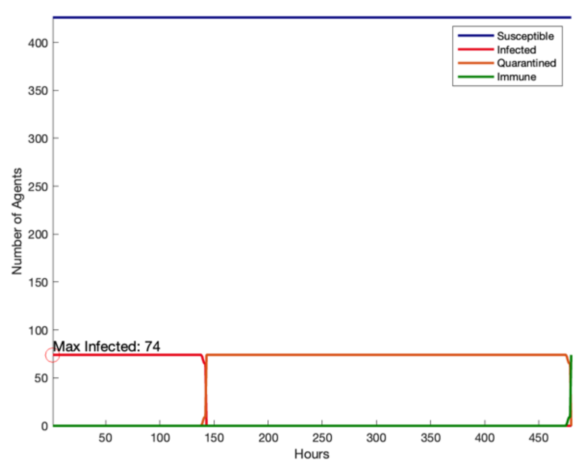

Figure 1

In the slow movement speed (v = 0.0125) simulation, agents move slowly across the grid, resulting in longer durations spent within each cell. This slower movement increases the time agents spend near one another, leading to a higher chance of disease transmission. Figure 2 shows a steep rise in infected agents, indicating rapid infection spread due to the extended contact time. The average maximum number of infected agents is 162, and the model runs for an average of 66.5 days.

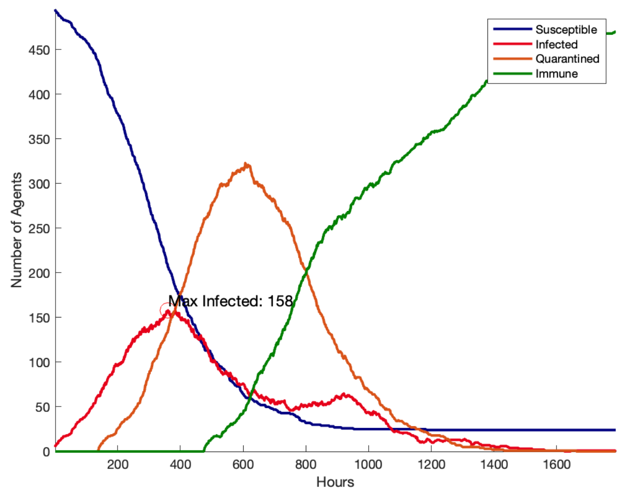

Figure 2

In the normal movement speed (v = 0.025) experiment, agents move twice as fast as in the slow movement speed scenario, resulting in shorter durations spent within each cell compared to the previous simulation. As the duration of contact decreases, so does the number of infected agents. Figure 3 displays a more evenly distributed graph. The average maximum number of infected agents is 113.8, and the model runs for an average of 75.7 days.

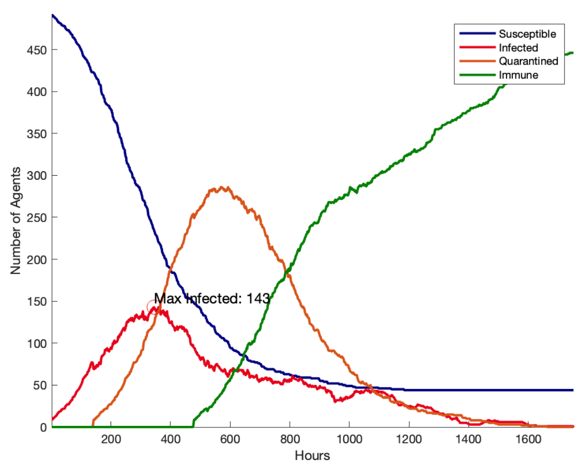

Figure 3

In the fastest movement speed (v = 0.05) experiment, agents move twice as fast as in the normal movement speed scenario. This results in even shorter durations within each cell, further reducing the number of infected agents. Figure 4 shows a more evenly distributed graph. The average maximum number of infected agents is 66.8, and the model runs for an average of 110.4 days.

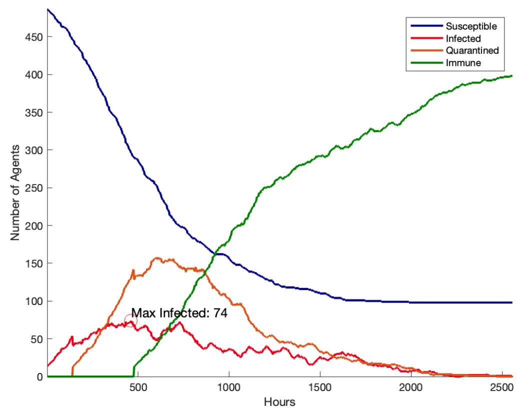

Figure 4

Conclusion

The experiments demonstrate the importance of social distancing and movement speed in controlling the spread of the virus. Although a longer duration for the virus may be observed in faster movement scenarios, the overall infection rate is lower due to the reduced duration of contact between agents. This underscores the significance of social distancing measures in managing outbreaks and limiting the number of infections, ultimately protecting public health. The results suggest that measures that limit movement and contact can be effective strategies in controlling the spread of infectious diseases like COVID-19. Furthermore, the varying movement speeds in the simulations illustrate that even slight changes in movement speed can significantly impact the trajectory of an outbreak. This emphasizes the need for flexible and adaptable public health strategies that can be tailored to the specific circumstances of an outbreak.

Understanding how movement speed affects the spread of the virus can help guide more targeted interventions, such as travel restrictions, curfews, and other forms of social distancing.

By employing these strategies effectively, communities can better protect vulnerable populations and prevent healthcare systems from becoming overwhelmed. The insights gained from these experiments highlight the critical role of responsible movement management in combating the spread of COVID-19 and future pandemics.

Work Cited

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