Complex System Report

João Domingues[1] [uc2018278415@student.uc.pt] and Tiago Conceição[1] [uc2021167993@student.uc.pt]

University of Coimbra

Abstract. This report will present a system that is based on the model agent, known as the host-parasite system. It has been developed based on a Python framework called Mesa. This system simulates how does virus spreads in a system with healthy agents, infected and dead. There were made several observations to get conclusions from the system in order to understand how can it evolve from different conditions.

Keywords: Complex Systems · Mesa · Host-Parasite System.

1 Introduction

The Host-Parasite system is an Agent-Based Model, more specifically a Probabilistic Cellular Automata, which consists of a 2D grid, in our tests squared. An Agent-Based Model consists of a system filled with agents, living in an environment, interacting with each other and the environment itself. Each agent assesses the situation it is in and makes decisions based on a set of rules and probabilities.

In order to study this system, multiple simulations were performed with the objective of studying the impact of various variables in the evolution of the system, with them being, different types of neighborhoods, initial population numbers, death, and infection probabilities.

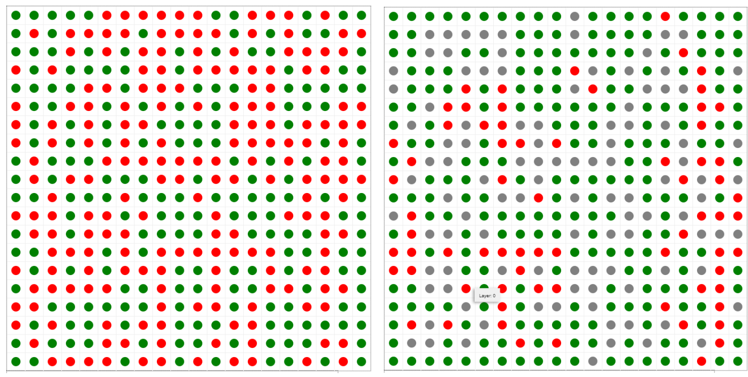
2 Methods

2.1 Model Description

The grid has dimensions 20 by 20, being 400 cells, initially, each cell can be empty or filled with an healthy agent (0), represented in green, or an infected agent (1), represented in red, randomly spread by the grid as showed in 1. As the system evolves, the cells may change states, with the possibility of being filled with a dead agent (2), represented in grey.

The parameters we defined are the probability of infection, which is calculated with the following formula:

$$probInf = numNeighbors * infect$$



(a) Grid initial state (b) Grid state after 5 step

Fig. 1: Grid States

The numNeighbors is the number of infected agents in its neighbourhood, which can be Moore (North, South, East, West and diagonals) or Von Neumann (North, South, East, West) and infect is the value given in the parameters we chose. An infected agent may die, depending on the probability of death, defined in the start of the simulation.

Our system is asynchronous, all the changes made to the state of each agent are taking into consideration the state of the system in the previous iteration. To do this we use a function from the Mesa framework, *SimultaneousActivation*.

The variables we altered in order for us to see the influence they had in the behavior of our system were the following ones:

- **Initial percentage of healthy and infected agents**: [(50%-50%), (70%-30%), (30%-70%), (90%-10%), (10%-90%)]
- **Type of neighbourhood**: [*Moore*, *Von Neumann*]
- **Probability of Death**: [5%, 20%, 50%, 70%]
- **Probability of Infection**: [5%, 10%, 20%]
- **Dead Agents can infect**: [*True*, *False*]

Finally the seed used for the tests was fixed at 125, and after some preliminary tests we noticed that the change of the seed did not influence the results enough to make a deep analysis about it, as well as different grid dimensions.

2.2 Tests

As there was an infinite number of combinations we could analyze in this work, we decided to base our work and our tests in 2 combinations considered the base ones. The comparison and analysis of the influence each variable has in the behaviour of the system will be compared to the base systems we present in the beginning.

3 Analysis

In this section, there will be presented several test analysis, with the purpose to obtain different behaviors. It will be possible to see tests with different values and probabilities, in order to achieve different system performances. This chapter will be divided into two different subsections one focused on Von Neumann and another one on Moore's neighborhood. Each analysis is made by choosing some initial values and changing some of those values to obtain different results and graphs.

3.1 Von Neumann

The neighborhood considered in this subsection is the Von Neumann, this particular one in a two-dimensional square lattice, it's composed of a central cell and four other ones, the one in the front, the one in the front, the back, right and left. Several case analyses that respect the Von Neumann neighborhood were made.

Initial values of analysis:

The first case had the following details: Healthy with 90%, Infected with 10%, the Death probability with 5%, the same in the Infected probability, and with the parameter of the Recovery defined as True.

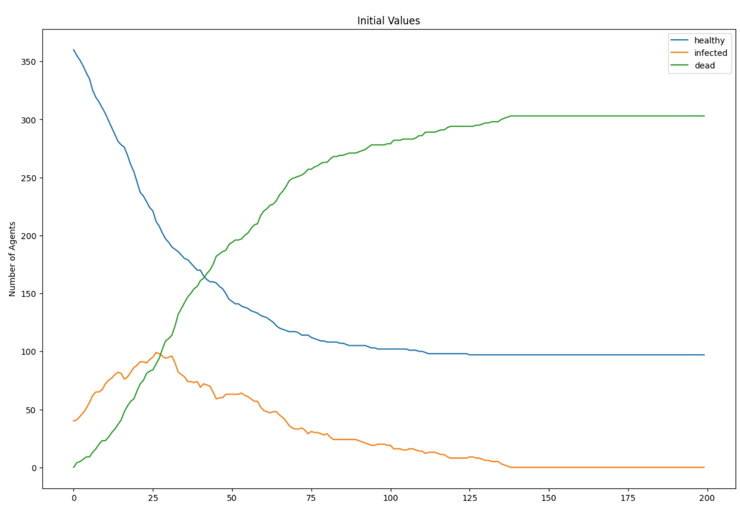


Fig. 2: Graph with Healthy - 90% / Infected - 10% / Death Probability - 5% / Infected Probability - 5% / Agent numbers - 400 / Seed Numbers - 125 / Recovery - True

According to what it is possible to acknowledge in the figure 2 with this initial data we can see that healthy people, despite being much more in the beginning than those infected, have a gradual decrease, not very steep, since the infected agents can recover, while deaths increase at quite a high rate. It is also possible to see that 25 steps in there is a peak in the infected agents, which is when healthy people decrease and the infections gradually decrease as deaths go up. At the end of some iterations, the infected will exponentially decrease after step 25 to the fixed point zero, and the deaths will exponentially increase reaching the fixed point 303, and the healthy exponentially decrease since the beginning to the fixed point, 97.

Different initial percentages of healthy and infected agents:

Then the new values that are going to be analyzed are: Healthy percentages ranging between 10%/30%/70%/50%, Infected perventages ranging between 90%/70%/30%/50% The evolution of the system is presented in 3.

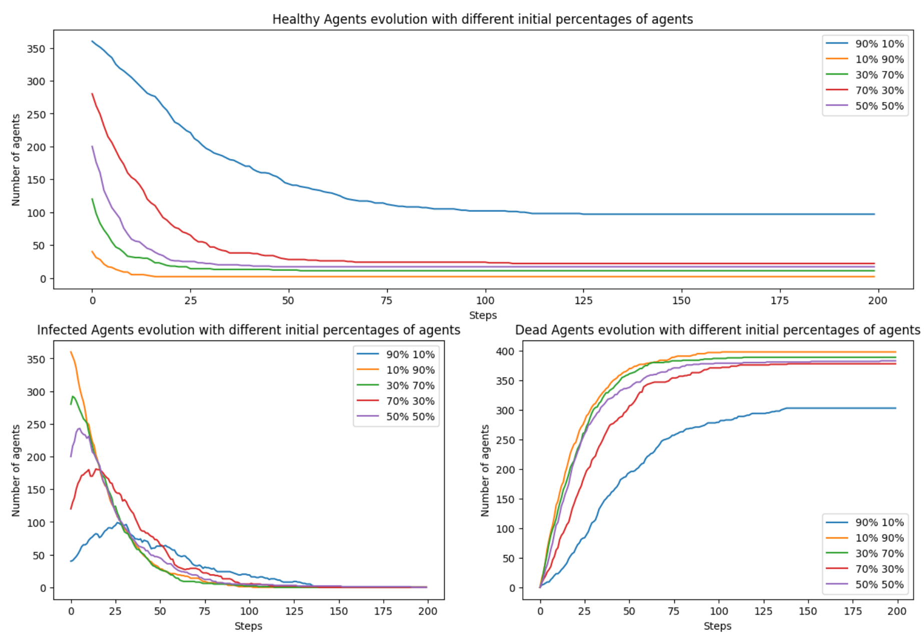


Fig. 3: Graph with the healthy and infected agents modified maintaining the other parameters

Acknowledging the figure 3, it is possible to observe that each graph follows completely different trends. Since it all starts with 400 agents in the first and second graph of figure, it's possible to see that they change according to the percentages assigned. In the third graph that refers to deaths, one can conclude that if the percentage of healthy people is high, fewer deaths occur, because the number of infected agents in the beginning will not be as high as in the other systems, so the infection will not be as aggressive; the opposite happens if the percentage of infected people is high.

Regarding the first graph, which corresponds to the healthy agents, one can see that over time they decrease until they reach an attractor fixed point that varies according to the percentages assigned, in the case of higher percentage of infected agents, it is noted that the fixed point is zero, because the number of healthy agents is really low, while if the number of infected agents is low, the fixed point will be much higher, 97. As far as the graph of the infected is concerned, we notice that the fixed point attractor is always zero, but each variation has some differences, like the higher the percentage of infected agents the steeper is the decrease, but the lower the percentage of infected agents, in the beginning it will start by increasing the number of infected agents.

In cases where the percentage of infected is higher, more deaths will occur and this is reflected in the last graph. For example, in the last graph with the probabilities of 90% and 10% have the fixed point of 303 and the probabilities of 10% and 90% have 398 agents has the fixed point. It is possible to see all the healthy and infected have an exponential decrease, while the other way around occurs in the deaths, making it an exponential increase. Comparing to the initial values it is possible to conclude that as long as the probability of healthy change the values will have more deaths and a reduced number of healthys.

Different death probability:

Now, the next parameter to be changed is the death probability that changes between 5%, 20%, 50%, and 70%.

With the changing probability of deaths, we acknowledge the different graphs, presented in 4. Focusing on the healthy agents the death probability of 20% follows a different trend where the healthy are at the fixed point of 273 at the 200 steps and the deaths are in 127 agents as the infections follow to zero. In the infected agents although the probabilities are different, all the values of infected have fixed point zero. An interesting aspect was the fact that when the probability of death is 5% the number of infected agents grows linearly in the beginning, reaching a maximum of 120, a behaviour completely different from the others, which makes sense since the probability of death was low they had more time to infect the healthy agents.

Looking at the figure we can see in the first graph above, it is possible to notice when changing the probabilities of death the values of healthy agents fix at certain points being those points attractors, for example in the probability with 70% and the 50% tend to a fixed point close to 352 and 343 agents respectively, much higher value than the other ones, which can be supported by the fact that a high death probability makes the agents die faster so there is harder for the infected agents to infect healthy ones. About the graph focusing on the dead agent it is possible to see that the higher death probabilities have a really close fixed points, 48 and 57, respectively.

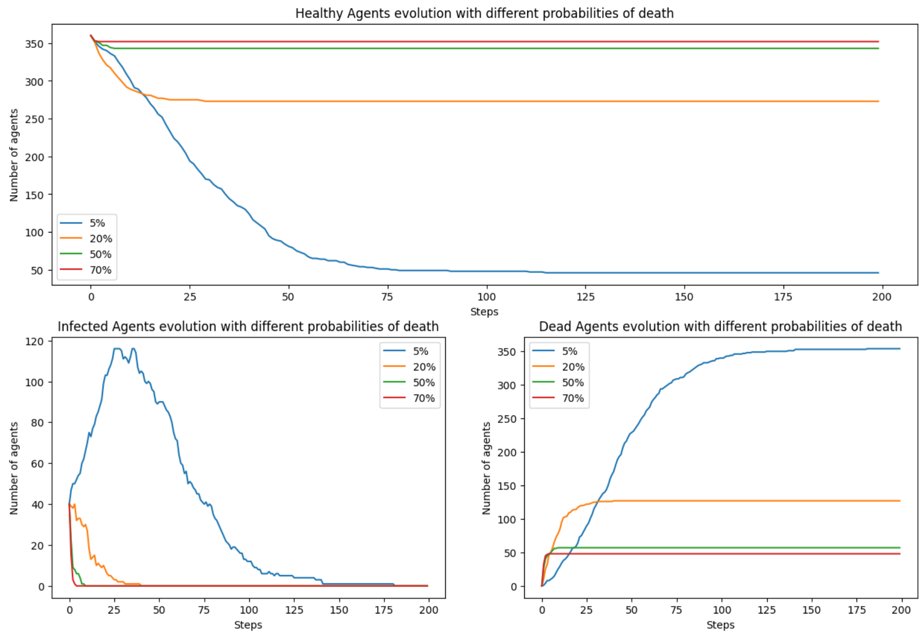


Fig. 4: Graph with death probabilities changed

Regarding the tendency of the healthy values it is possible to see that the have an exponential decrease while in the infected graph we see the opposite occuring but some steps after it decreases in an exponential way, while in the death we can see that follows a exponential increase, taking into consideration the other colors we can conclude that the color yellow follows also a exponential decrease in the healthy and infected graphs while in the death increases. The other colors don´t have the same behaviour as the colors described previously had, this ones maintain almost the same value without a big change uppward or downward.

At maintaining the probabilities defined at figure 2 and by changing the death probability like in the graphs before, it is noticeable that comparing both that the number of healthy will be higher, and the number of infected and deaths will be lower.

Different probability of infection:

The next change that needs to be done is the change of the parameter Infected probability ranging between the values of 5%/10%/20%.

Now by looking at the figure 5, when looking at the probability of 10% it is possible to see that the deaths tend to a point pretty close to the 400 agents and the healthy are almost hitting the value of zero, values significantly different from the base system, which makes sense as the infection probability increases the number of possible dead agents.

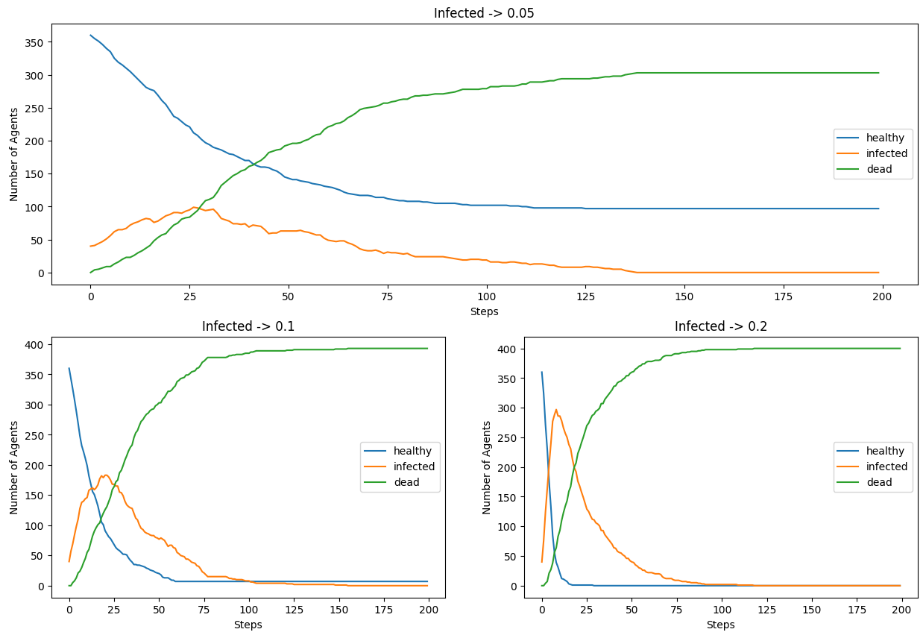


Fig. 5: Graph with infected probabilities changed

In the graph corresponding to the 2% infection probability it is more noticeable that the healthy have the fixed point in zero and the deaths hit the maximum of agents, and as we can see the infected agents increases a lot compared to the other systems, this because of the infection being so high. By looking at all graphs its possible to acknowledge that the healthys in every probability of infected decrease exponentially and the deaths the opposite.

Comparing these previous graphs with the initial graph that as the base values it is possible to conclude that the higher is the infected probability the bigger is the healthy exponential decrease and the death exponential increase, while the value of infected change according to the probability set.

Different value of the Recovery:

For now, the last test done was necessary to change the parameter of Recovery defined as False.

As it is possible to observe in figure 6, the changes seem not very obvious, but when looking closely, it is possible to acknowledge that compared with the 2 the healthy have a steeper decrease and the gap that divided both healthy and infected is smaller, relatively the deaths, these ones have more significant growth. The values make sense since the values tend to stabilize to a determined fixed point as is possible to acknowledge that healthy will be attracted to the point close to 46 agents while the deaths will tend to 354. Regarding to the behavior of the healthy they decrease exponentially while in the deaths they increase.

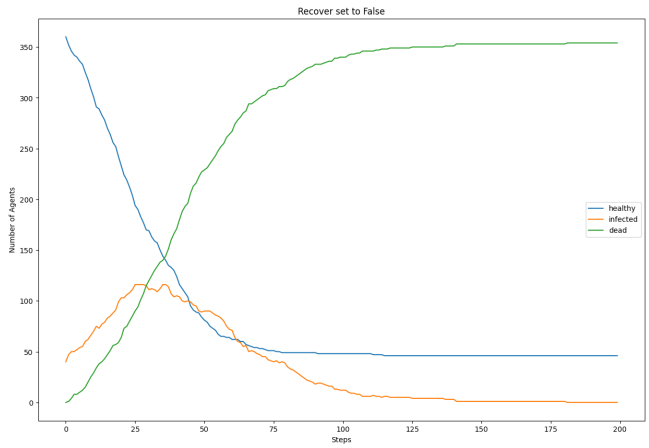


Fig. 6: Graph with Recovery changed

Different value of the neighborhood:
The final variation made was using the Moore's neighbourhood.

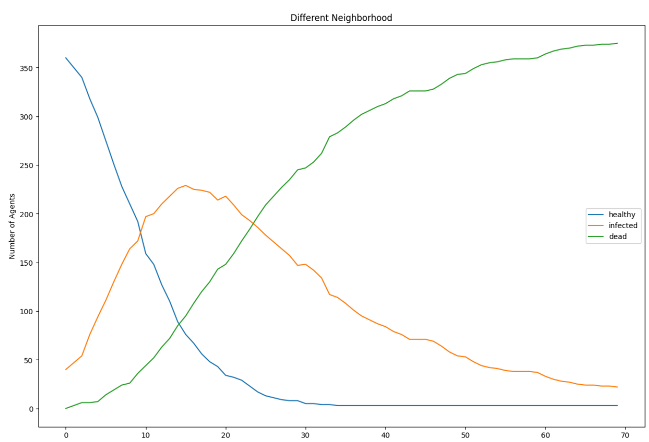


Fig. 7: Graph with the neighborhood changed

As it is possible to conclude from the graph the healthy agents have an exponential decrease, while the infected increase right by the first step and fall around in the 24 steps ending the simulation with still some infected and the rest of the agents dead. It is also important to mention that all of the parameters tend to attract to a certain fixed point, namely the healthy ones go straight to the value zero, and the infected agents seem to be tending to that same value even though they are not there yet and the dead agents to 400. This behavior is quite similar to the base system except for the fact that the number of infected agents grows much more, in the beginning, intercepting the healthy agents at one point, something normal since the probability of infection may be way higher since the considered neighborhood is the double.

Comparing this graph with the one with the initial values it is possible to conclude that, by changing the neighborhood, the healthy and dead agents, follow an more rapid exponential decrease and a more rapid exponential increase, respectively, all that before the 40 steps, making it different from the graph 2 obtained. And the number of infected agents grows to a higher value than in the base system, and takes much longer to get to the fixed point. This happens because by having a Moore neighborhood the agent has 8 different neighbors which makes the calculation of the probability of infection to be higher in most cases, compared to the Von Neumman.

3.2 Moore

The second case we selected is the one presented in 8.

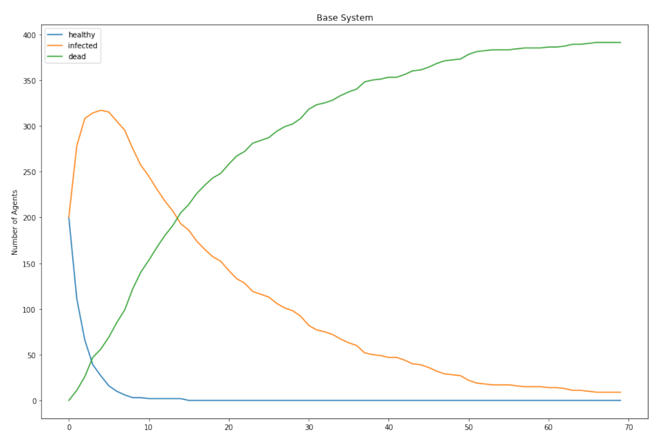


Fig. 8: Graph with Healthy - 50% / Infected - 50% / Death Probability - 5% / Infection Probability - 10% / Agent numbers - 400 / Seed Numbers - 125 / Infected can recover - False

As we can see the behaviour is very close to the one we were expecting. The death probability is quite low, so the number of dead agents takes some time to grow, presenting an exponential increase, approximating to a fixed point, 400. The infection probability can be high as well as low, depending on the number of infected agents in the neighborhood, since the number of healthy agents decreases exponentially and really fast, reaching its fixed point, 0, we can assume that the probability of infection is very high for almost all the agents. The number of infected agents decreases exponentially since the beginning, reaching the fixed point, 0, quite early in the evolution.

Here we will make the comparisons of the behavior of the system, taking into consideration the different values each parameter can take.

Different initial percentages of healthy and infected agents:

First, we started by analyzing the influence of different initial conditions, by this, we mean different initial percentages of healthy agents and infected agents, 9.

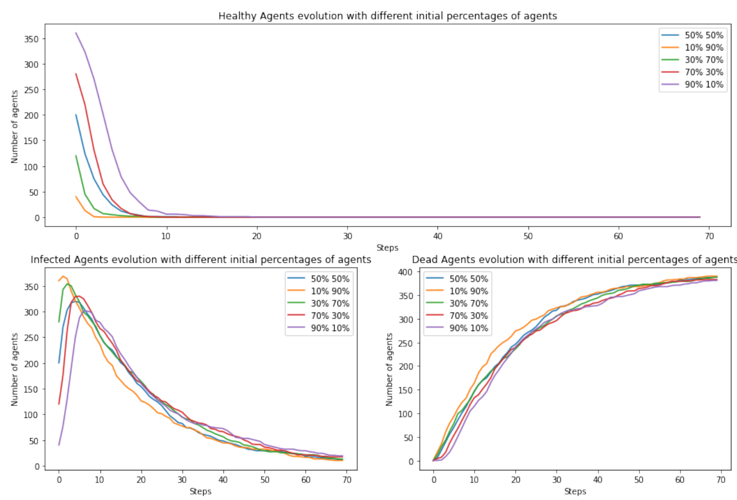


Fig. 9: Graph with varying percentages of Healthy and Infected Agents/ Death Probability - 5% / Infection Probability - 10% / Agent numbers - 400 / Seed Numbers - 125 / Infected can recover - False

As we can see the number of healthy agents is exponentially decreasing since the beginning of the system. In all of the variations, it has only one fixed point, 0, an attractor. The systems that start with a lower percentage of healthy agents reach the fixed point faster than the others, which makes sense since there are lesser healthy agents to infect.

As for the number of infected agents, we can notice that all of the variations start by increasing, the ones with fewer infected agents at the start have a bigger increase, and they all start to decrease at the same time, more or less. They have only 1 fixed point as well, 0, as we can see not all of the variations have reached it but are tending to it and they all have an exponential decrease behavior.

The dead agents all have practically the same behavior with minor differences, with 1 fixed point, 400, which they are all tending to and have an exponential increase.

Different probabilities of death:

Focusing on different probabilities of death, 10, the behavior is very much the one expected.

First taking into consideration the healthy agents, we can see that contrary to the previous analysis, the fixed points change based on the probability of death. All of the variations have the exact same behavior, decreasing at the same rate but systems with a higher death probability, 50%, and 70%, have higher fixed points, 61 and 81, respectively, while the ones with death probability 5% and 20% have fixed points, 0 and 4, with all the fixed points being attractors. What all the variations have in common is that they have an exponential decrease.

Focusing on the infected agents, when the probability of death is higher, 70% and 50%, the number of infected agents increases in the first steps, until a certain moment where they decrease abruptly, in an exponential way, while the variations with less probability of death, 5% and 20%, its behavior is always decreasing in an exponential way. All of the variations have only one fixed point, 0, and all tend to it, the only difference is the lower the probability of death the more time it takes for the system to reach the fixed point, and this time it takes is higher and higher as the probability of death grows.

Finally taking the dead agents into consideration, we can see that the behaviors are quite different. When the probability of death is lower, its growth, even though all have an exponential increase, is slower than when the probability of death is higher, which makes sense as a higher probability of death makes the infected agents die more quickly. As for the fixed points each variation has only 1 fixed point, when the probability of death is 5% and 20% it is 400 but when the probability of death is 50% or 70%, it is 339, 319 respectively. This also makes a lot of sense since the high probability of death makes the agents die much more easily and they do not have time to infect other agents, so they never tend to the maximum of agents in the world, contrary to the other two variations.

Different probability of Infection:

As for the different probabilities of infection, are presented in 11. The value multiplied to get the probability of infection is lower than the one in the base system, 5%, so the maximum value of infection, which depends on the neighborhood, is $0.05 * 8 = 0.4$, a very small value. We were expecting a much slower decrease in the number of healthy agents because as we can see the behavior of all the state variables is practically the same as in the base system and the trajectory, and fixed points are all the same, the only difference is the fact that it takes more time for the healthy and infected agents to get to 0, and the dead agents to get to the maximum value.

Different neighbourhood:

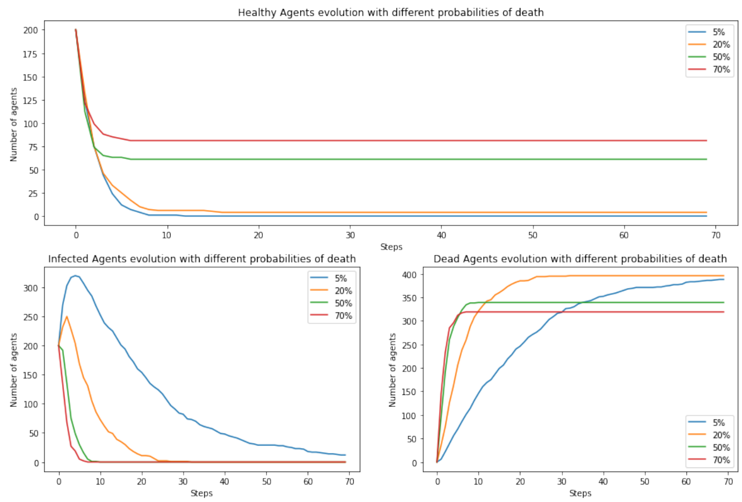


Fig. 10: Graph with Varying Probability of Death / Healthy - 50% / Infected - 50% / Infection Probability - 10% / Agent numbers - 400 / Seed Numbers - 125 / Infected can recover - False

Additionally, we considered a different neighborhood from the one used in the base system, Von Neumann, to see what influence it would have in the number of infected agents, 12. It is possible to notice that the difference is not as noticeable as we thought it would be. The number of healthy agents takes a little bit more time to decrease, to a minimum, when the neighborhood is Von Neumann since the maximum probability of infection is 0.4 instead of 0.8 when using the Moore neighborhood. In terms of trajectory and fixed points is exactly the same as the ones in the base system.

Infected agents can recover:

Finally, we analyzed the influence the infected agents having the possibility of recovering and the results it showed are displayed in 13. We can notice that, contrary to all the other systems, the number of healthy agents grows instead of decreasing, which makes sense since this agents can recover and its probability of recovery increases as the time goes on. The number of infected agents decreases rapidly from the initial value, since the infected agents are recovering the infected agents can always change state, either die or recover, so it is normal its decrease is more rapid. The trajectory of the healthy agents is exponentially increasing, with an attractor fixed point of 346, as well as the dead ones, which have an attractor fixed point of 54, while the infected agents have a trajectory of exponentially decreasing and an attractor fixed point of 0.

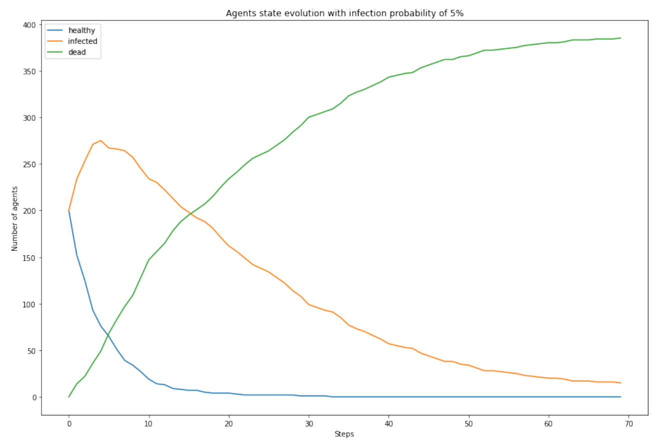


Fig. 11: Graph with Healthy - 50% / Infected - 50% / Death Probability - 5% / Infection Probability - 5% / Agent numbers - 400 / Seed Numbers - 125 / Infected can recover - False

4 Conclusions

Based on the obtained results and the analysis performed for each variation, we concluded that each variable has a certain weight in the evolution of our system, some have more obvious variations of behavior, some less notorious ones. Nonetheless, it is possible to affirm that our system is not autonomous, as it does not depend on time, discrete since it has a countable number of states, three as mentioned before, and dynamic as its state is uniquely specified by a set of variable, presented previously, and its behavior is described by a certain set of rules, defined in the beginning. We can conclude as well that our system is stable in some cases, such as the ones where the fixed point to the healthy and infected agents is 0, if we perform any kind of perturbation to it the system will always end up tending to the fixed points.

Analyzing the graphs, we can affirm that in its majority the systems are fixed, since whatever difference there is in the parameters, the evolution of the number of agents usually behaves the same way in all of the variations, with exponential growths or exponential decreases. The number of infected agents will normally always have a fixed point of 0, since either the agents die or recover from the infection.

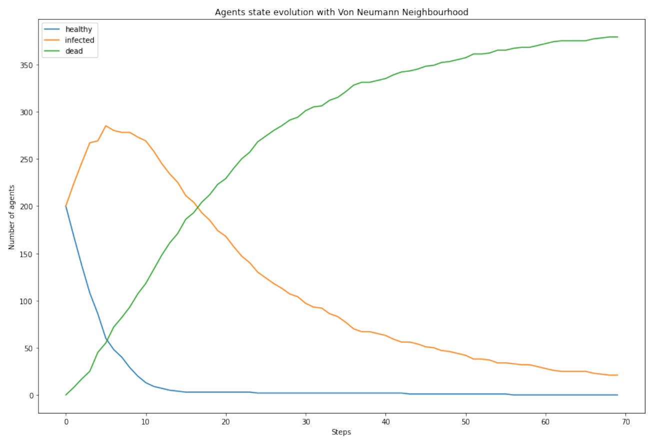


Fig. 12: Graph with Von Neumann Neighbourhood / Healthy - 50% / Infected - 50% / Death Probability - 5% / Infection Probability - 10% / Agent numbers - 400 / Seed Numbers - 125 / Infected can recover - False

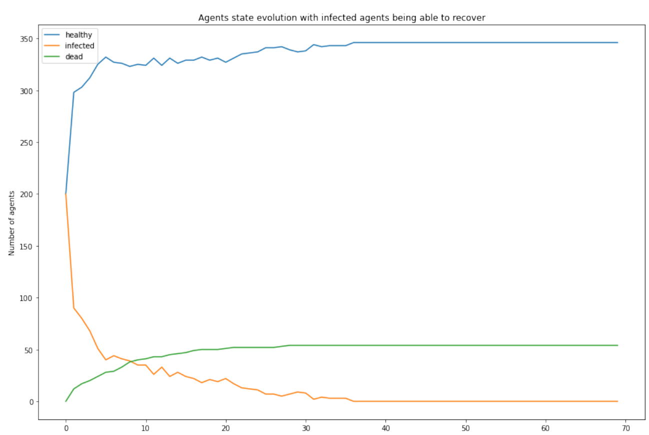


Fig. 13: Graph with Healthy - 50% / Infected - 50% / Death Probability - 5% / Infection Probability - 10% / Agent numbers - 400 / Seed Numbers - 125 / Infected can recover - True