Virus Spread Analysis

1 Preface

In this work we will build a stochastic virus spread analysis (also called a Monte Carlo simulation). Once the simulation is built, different quarantine policies will be evaluated to see how these affect the spread.

2 Software

2.1 Data Structures

2.1.1 The City of Haifa

We will run our simulation on a model of the city of Haifa. In the model the city of Haifa is a rectangular grid of 64 squared Km (8000m x 8000m), where each grid cell is 50m x 50m in size. Thus, the entire grid is 160x160. Each grid cell is defined by (long, let) axis, where long ={1,…,160} and lat ={1,…,160) (see Figure 1 - Haifa Grid Model for such example).

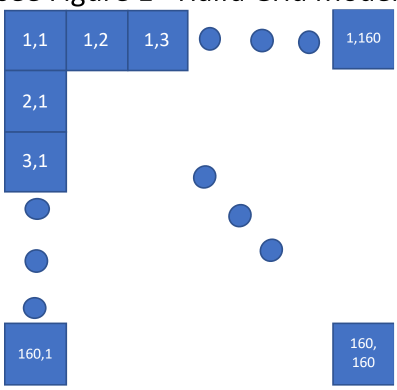


Figure 1 - Haifa Grid Model

2.1.2 Population

Haifa has a population of 300,000 people. Each person in Haifa is characterized by the following information.

Table 1 - Person Info

ID	Integer
Location	[integer, integer]
Sickness	[0,1,2]

ID is the person unique id={1,2,3,…,300,000}, Location is the person's location in the Haifa grid, and the sickness is the person's health condition: 0 – never been sick; 1 – Is sick now (thus, contagious); and 2 – recovered. In this analysis we will assume that if a person is recovered, she or he cannot become sick again – he is immune.

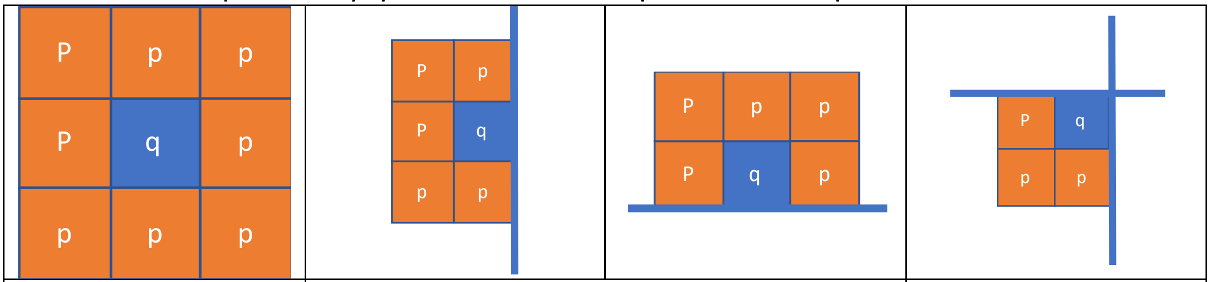
You should add other fields as you may see fit for your implementation.

2.2 Functions

2.2.1 Travel Function

The travel function receives the person's location and randomly selects hers/his next location. Each person can either stay in his current location (with a probability q) or move to an adjacent grid cell, with a probability P. Thus, q+8p=1 for regular grid cell (see Figure 2a); q+5p

=1 for the case of Figure 2b; and q+3p=1 for Figure 2c. The function receives the current location and the probability q. The function's output is the next person's location.



(a)	(b)	(C)

Figure 2 - Travel probabilities

2.2.2 Infection

The infection function receives the population and checks if any of the population *healthy* members (i.e., his Sickness filed equals 0) is located in a grid cell with a sick person (i.e., Sickness=1). The function checks how many *consecutive* timesteps this person was in the same grid cell with a sick person. The probability of a healthy person (i.e., Sickness = 0) to become sick, after staying in the same grid cell *t* time steps with a sick person, is given by the following formula:

$$p(become\ sick) = 1 - e^{-0.25 \cdot t} \tag{1}$$

2.2.3 Recovery

A sick person (Sickness=1) becomes recovered and thus stops infecting other people after two weeks of being sick (2,688 time steps).

3 Policies

In this exercise we will investigate several policies, which were evaluated by the Israeli ministry of health in the COVID-19 pandemic and see how the disease spreads under each policy. The difference between the policies is the value of q (the chances of a person to stay in its current location). There may be policies in which q assume different values for healthy and sick people. The infection and recovery rules stay the same for all policies.

3.1 No policy

In this case, no restrictions are applied on the population. Thus, **q=0.5** for all members of the population regardless of their health condition.

3.2 Full self-solitude policy

In this case, all members of the population are required to say at home. Thus, for this policy q=0.9 for all people. Make sure that the infection and recovery processes work the same as in 3.1.

3.3 Sick people quarantine policy

In this case, all sick people are required to stay at home. Thus, for sick people (Sickness = 1), q=0.9. For all other members of the population (i.e., Sickness =0 or 2), q=0.5. Make sure that the infection and recovery processes work the same. Healthy people may still move next to sick people and interact with them (thus, may be infected by walking into a grid cell with a sick patient).

3.4 Red-Zones Policy

For *any* 40x40 grid cell with more than 20 sick people in it (see Figure 3 for example for 40x40 regions), *all* member of the population (healthy, sick and recovered) within this region are required to stay in quarantine, thus their q is set to q=0.9. All other people may still move with q=0.5 and walk into the quarantined region. Once they enter the region, their q changes to q=0.9.

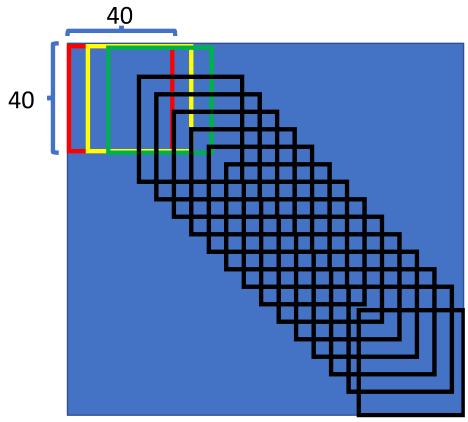


Figure 3 - Red Zones

4 Simulation

1. Initiate your simulation by randomly placing the 300,000 members of the population on the 25,600 (160x160) grid cells. Use a uniform distribution for that.
2. Select a *single* random member of the population and infect him/her (change its Sickness field from 0 to 1).
3. For each time step perform the following *for all population members*:
    a. On all *healthy* people run the **infection** function and change their health status if required.
    b. On all *sick* members of the population run the **recovery** function.
    c. Record the number of sick members of the population, S(t).
    d. For all members of the population run the **travel** function using the proper *q* for the policy used. Reposition all members of the population in their new computed location.
    e. Advance the time step in 1
    f. If the timestep *t*<16,000 timesteps.
        i. Go to 3.a. above.
        ii. Else report S(t) and terminate

5 Your report

You should submit a digital copy of your code (see Section 5.1 below) and the answers to the questions in Section 5.2 in a pdf file. All code and pdf files should be zipped into one file for submission.

5.1 Coding

1. You may code in *any* programming language of your choice (Matlab, Python, C, R, etc.).
2. You are required to submit your code.
    a. The code should be well documented.
    b. You should add a readme.txt file which explain how to run your code. **If we are not able to run your code – your grade will be affected**.

5.2 Questions

Run your simulation for the four policies above (Sections 3.1 through 3.4) for 16,000 time steps and answer the following questions:

Question 1

Plot (on the same graph) the number of sick people vs. time for the four policies.

Question 2

What policy would you use to handle the pandemic? Explain by reffering to two aspects, mortelaty (you can use Israel recorded statistics of rate of mortality out of people infected) and hospital capacity (what are the resources required to treat the pandemic in each scenario).

Question 3

If you could change policy over time, what policies would you apply in what order? For example, in Israel, the ministry of health applied 4.1, and then 4.2 and now 4.3 is applied. In the Sweden, 4.2 has been enforced throughout the pandemic, UK on the other hand choose to use 4.1. You should consider the results you have obtained in question 1 above (the number of sick people versus time for all four policies) to support your suggestion.

Question 4

The World Health Organization (WHO) is not sure if reinfection is possible. To evaluate a situation where reinfection is indeed possible, change the recover function, so sick people condition is changed to "healthy" rather than "recovered" after 2,688 time steps of the person being sick.

Then, run the simulation for *only one* of the policies above. You should select the policy to use by the following logic: Take the ID of all members of the team and sum the fourth digit of the ID number till you get a 1-digit number. To illustrate, let us assume that the team consists of two students. The first student's id is 333**7**6567 and the second student's id is 345**6**78999. The sum of the fourth digits is 13, which sums to 1+3 = 4. Following your one-digit number and Table 2 you should use Policy 4.4.

Once you have obtained the results of the reinfection analysis, compare them with the results you obtained for the same policy in question 0 above. Would the fact that we do not know if reinfection is possible, change your answers to questions 2 and 3 above?

Table 2 - Policy Selection

Your One-digit	Policy
1	3.1
2	3.2
3	3.3
4	3.4
5	3.1
6	4.2
7	4.3
8	3.4
9	4.3

Bonus Question

Let assume that any increase over 0.5 of 0.1 in q cost the country of Israel 1 NIS per time stamp per person. Every sick person cost the country 10 NIS per time stamp. Every mortality (use the mortality you found in q2) cost the country 100 NIS. Calculate what is the most cost-effective way out of the above scenarios (4.1 – 4.4)? Try to find if the combinations of scenarios you suggested in q.3 is more cost effective? If not try to suggest a different combination.