

COVID-19 Simulation

Introduction

The COVID-19 epidemic has spread worldwide, and many people have been infected and died because of this virus. Coronavirus can be transmitted from person to person by airborne droplets, similar to other viruses. This virus is characterized by an incubation period during which the infected person does not experience signs of the disease but may infect others. There are no drugs that can treat this virus today. Therefore, the primary means of combating this disease is a set of measures that reduces the likelihood of transmission of the virus from one person to another. Such measures include the use of masks, quarantine, blocking areas and settlements where there are outbreaks of the disease, border closures, restrictions on public places. Here we want to simulate COVID-19 and its spread in some of the aforementioned scenarios.

Theoretical Part

This problem is class of epidemic problems which can be solved by SIR-model and its modifications. SIR- model (*S*: *susceptible*; *I*: *infected*; *R*: *recovered*) can be expressed in terms of system of ODEs.

$$\frac{dS}{dt} = -b * S(t) * I(t) \quad (1)$$

$$\frac{dR}{dt} = k * I(t) \quad (2)$$

$$\frac{dI}{dt} = b * S(t) * I(t) - k * I(t) \quad (3)$$

where, k and b are constants. By solving these equations, one gets analytical solutions which can be implemented in SIR-model.

Computational Part

For COVID-19, some modifications must be made to the SIR model. Firstly, death should be included, and this model is called SIRD-model. Then incubation period should be considered. During this period, infected people continue spreading the virus but do not show symptoms of the illness. When the incubation period is over, infected people can be classified into two groups: one of the groups show symptoms, and the other does not show signs, also called asymptomatic carriers of the virus.

After including the aforementioned modifications to the SIR model, the simulation is run for seven different scenarios.

Scenario 1 (No Restriction)

The simulation area is square with side L . N people live inside this area. The position of each person is assigned according to a square lattice. Then, the velocity of each person assigned according to random normal distribution and velocity of each person $\leq V_{real}$, where

v_{real} is the average human speed in real life. *{in this project $N = 1024$; $L = 450$ meters, and $N/L^2 \sim 5000$ people/km² which is average density of European city; $v_{real} = 4$ km/hour ~ 1.12 m/s}*

The next step is to determine the duration of one iteration. It must be such that in one iteration, a person cannot cover a distance greater than d (the maximum distance between two people for one of them to get infected from another) because in this case, the agents moving toward him will slip through each other without interaction. If we choose too little time, this significantly slows down simulations. Therefore $t_{sim} < d / v_{real}$. *{in this project $d = 2m$, $t_{sim} = 1s$ }*

Then each agent assigned its status (S, I, R, D), and at the beginning, all people have status S except few people who have status I.

Finally, simulation is run, and hard-wall boundary conditions are applied. If an infected person comes in close contact with another person (i.e., the distance between them is smaller than d), the following two situations are possible in this case: 1. No action is taken to the agent if it has the status R, I or D (dead people roam freely and do not affect anything in the simulation, they are left there for computational convenience), and 2. If the person has the status S, the probability p is assigned by the random number generator. If $p < p_{infect}$ (p_{infect} is the probability of getting infected when a healthy person comes close to infected person), then the person's status changes to I, otherwise, that person's status remains S. If the person's status changed to I, counting starts for the illness time, $t_{illness}$.

Counting $t_{illness}$ continues for each infected person. If agent's status is I and $t_{illness} \geq T_{illness}$ ($T_{illness}$ is duration of illness for a person), a probability is determined p_d from the random number generator. If $p_d > p_{death}$ (p_{death} is the probability of death) the person is recovered, i.e. changes status to R; otherwise, he dies and his status changed to D.

The simulation continues until all the infected agents recover or die. *{in this project $p_{infect} = 0.4$, $T_{illness} = 250s$, $p_{death} = 0.05$. In real life $T_{illness} \sim 25$ days according to medical reports, which is computationally extremely costly. Therefore, I chose some reasonable time to run simulation}* [1],[2],[4]

It should be noted that this scenario is base of all other scenarios.

Scenario 2 (Sc1 + Introduction of hygiene)

It is well-known that hygiene reduces the probability of getting infected. Washing hands, wearing masks and using sanitisers are examples of the hygiene recommended by doctors. To simulate a hygiene situation, we reduce the probability of getting infected by dividing p_{infect} by two.

Scenario 3 (Sc1 + Isolation of infected)

Isolation involves the creation of conditions under which a sick people cannot infect others. This can be realized either by creating another simulation area where all sick people are transferred. The people are transferred to the initial simulation area after their recovery. In real life, it is not possible to detect and isolate all sick agents due to the incubation period and the possibility of asymptomatic disease. It is necessary to enter an additional parameter take these factors into account. This parameter is a binary parameter called I_S , which is 1 if person shows symptoms and 0 otherwise.

The simulation in this case works in this way: when a person gets infected $t_{illness}$ starts counting as in scenario 1. However, when $t_{illness} > T_{incubation}$ ($T_{incubation}$ is incubation period), the following two situations are possible: 1. I_S is 1, and the person removed from main simulation area to another simulation area and remains there until he recovers or dies; 2. I_S

Name: Ismoil Odinaev

Course: Phys 3061

StudentID: 1155118960

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is 0, and he remains in the main simulation area continuing the spread of the virus until he recovers or dies. Finally, recovered people from the isolated simulation area are returned to the main simulation area. *{in this project $T_{incubation} = 100s$. In real life it is ~ 10 days. $\sim 20\%$ of population (200 people) have $I_S = 0$. These people are chosen randomly}* [1],[2],[3]

Scenario 4 (Sc1 + Isolation of infected + number of asymptomatic people increased)

In this scenario number of people with $I_S = 0$ is significantly increased. Here $I_S = 0$ includes not only asymptomatic carriers of the disease but also careless people who do not go to see doctors even they show symptoms. This kind of people continue spreading the virus to their families, friends, and neighbours. *{in this part number of people with $I_S = 0$ is 500 or $\sim 50\%$ of population who are chosen randomly}* [1]

Scenario 5 (Sc1 + introduction of public places)

In this case, places of the mass gathering are simulated. These places include schools, universities, mass religious gatherings or any crowded place in real life. People in these kinds of places either do not move or move very slowly.

This case can be simulated in this form: a coordinate (x_0, y_0) is assigned for the public place. In each iteration the probability p_{public} is assigned by the random number generator to each individual. If $p_{public} < P_{public}$ the person's coordinates changed to x_0, y_0 (i.e., he goes to the public place) and his velocity reduced 10 times. Velocity reduction is needed because people in public places should not quickly go away from that place and stick there for some time. The people in this public place remain there for time T_{public} (T_{public} is average time spent in this public place), and after the passage of time T_{public} , their original velocities restored and they quickly move away from that place. [1],[4]*{ in this project there is one mass-gathering place with coordinated $[x, y] = [225, 225]$; $P_{public} = 0.005$; $T_{public} = 7s$ }*

Scenario 6 (Sc1 + social distancing)

In this situation social distancing is simulated. It is sufficient to introduce a socio-psychological force similar to Coulomb's law to simulate this:

$$\vec{F} = \frac{kq_1q_2}{r^2} \hat{r}$$

which works exactly as Coulomb's force of similar charges. In this case, charges mean the degree of unwillingness of an individual to stand near each another, k – repulsion coefficient r – distance between people.

This is computationally most intensive part. Therefore, to reduce computational time if $r > d_{cut-off}$, F is regarded 0 where $d_{cut-off}$ is cut-off distance. Furthermore, Verlet algorithm is used to reduce both computational time and numerical errors. [1] *{here $k = 10$; $q_1 = q_2 = 2$; $d_{cut-off} = 25m$. It should be noted that values of q_1 , q_2 and k should be carefully chosen because when these values slightly increased, people will avoid each other altogether which is not the case in the real-life. When these values slightly decreased, effect of social distancing will be negligible. Furthermore, in real-life each person's degree of unwillingness is not same: some people follow social-distancing rules better than others. Here all people have same level of unwillingness for simplicity. Then, $d_{cut-off}$ is 25m, because at this distance $F = 0.064$ which is much smaller than $r=2$ case ($F=10$) or $r=1$ case ($F=40$). Hence, people at $r > 25m$ do not that much affect each other and their contribution to the force is very small. Finally, $t_{sim} = 0.3s$ in this part}*

Name: Ismoil Odinaev

Course: Phys 3061

StudentID: 1155118960

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P.S. For this scenario I made use of Lab3 immensely where we computed Leonard-Jonnes potential on particles. Therefore, I will not discuss here Verlet algorithm. *{mass = 70kg in Verlet algorithm}*

Scenario 7 (Sc1 + vaccinations of some people)

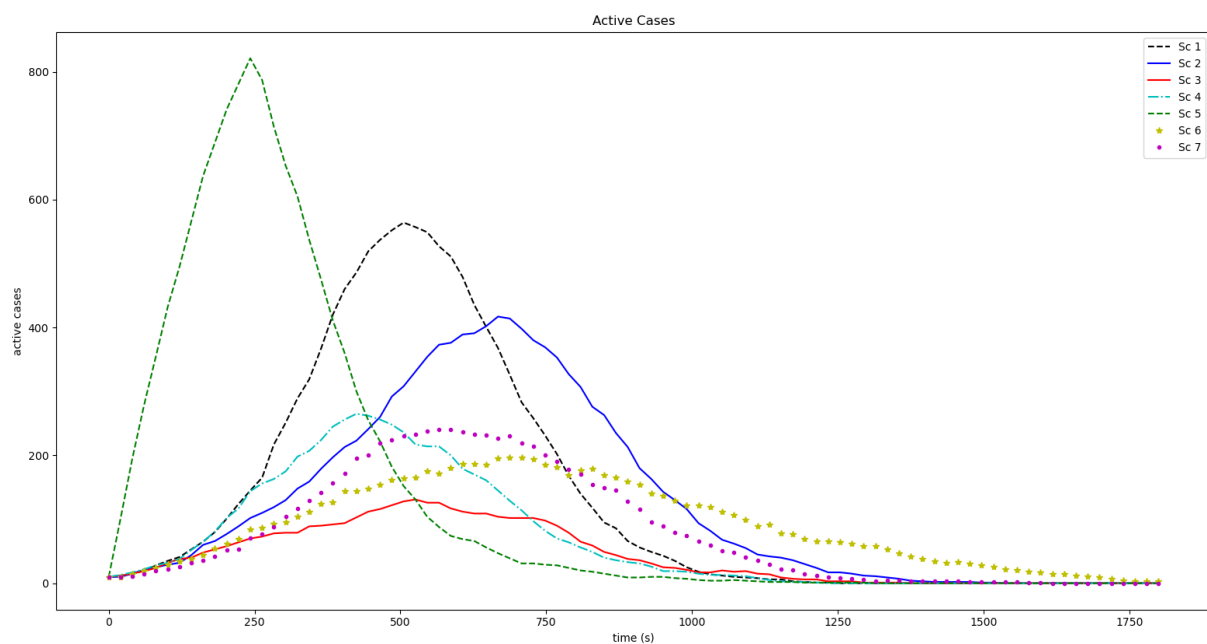
In this situation a proportion of people are assigned status R at the beginning of simulation. The rest is exactly same as Scenario 1. *{~30 % of population or 308 people are vaccinated in this part who are chosen randomly}*

Results and Discussions

In each scenario there are 10 people whose status is I at the beginning of simulations. These people are chosen randomly. Simulation run for 1800s for each scenario. At the end of each simulation number of people with status I is 0. Results of each simulation is presented in chart below.

	Total # of dead people	Total # infected people
Scenario 1	44	959
Scenario 2	41	892
Scenario 3	23	605
Scenario 4	46	771
Scenario 5	45	1022
Scenario 6	32	646
Scenario 7	23	583

The chart above alone cannot explain the simulation. Graph of # active cases vs time complete picture.



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StudentID: 1155118960

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From the graph, we can see that Scenario 5 (Sc5) is the worst possible scenario, where we have one open public place. We have the largest peak (~800 people), and the time when the peak is reached is the earliest (~250s). A large peak means hospitals will be overcrowded, and there may be a shortage of medical supply. This scenario also has the largest total # of infected people. (1022 people). Therefore, public places should be shut down to decrease transmission of the virus and relieve the burden on doctors.

Scenario 1 is better than Sc5, but it should be avoided as well. It still has a large peak (~580 people) and creates an unnecessary burden for hospitals. The total number of dead 44 (4.3% of the population), and the total number of infected 959 (~94%).

Sc2 is even better than Sc1, where people observe hygiene. The total number of dead 41 (4% of the population), and the total number of infected 892 (~87%). It has a smaller peak (~400 people), and it comes later (~700s) compared to Sc1 (~500s) which gives healthcare workers more time to prepare.

Sc3 is significantly better than Sc1 or Sc2, where infected people who show symptoms are isolated. Although it peaked earlier than Sc2, its peak is much smaller (~100 people). The total number of infected and dead is significantly less as well, with a total number of the infected 605 (~59% of the population) and dead 23 (2.24% of the population).

Unfortunately, if the number of careless people who do not contact doctors and continue spreading the virus increases in society (Sc4), they will undo the work done by the government and doctors to some degree. The peak reaches earlier (~450s) and has a larger value (~220 people) than Sc3 and, as a result, creates an unnecessary burden for both government and hospital. Subsequently, the total number of infected (771 people) and dead (46 people) is larger as well.

The number of infected people vs time in Sc6 is better than in any other scenario. Peak is reached latest as well (~750s) with moderate peak size (~200 people). The total number of infected and dead is one of the lowest as well (646 people ~ 63% of the population) and (32 people ~ 3.1% of the population) respectively.

Finally, Sc7 is not as successful as Sc6. Although the total number of people is less in this case (583 people), the peak is larger (~250 people) and reached earlier (~570s). Furthermore, the small number of total infected people is due to 30% of the population being vaccinated at the beginning of the simulation. This means we had ~700 susceptible people at the beginning, not ~1000.

To conclude, one may ask which method is better and which one to implement. My scientific reply is their combinations would be the best scenario. Both individuals and government should take responsibility. Individuals must observe hygiene (Sc2), follow social-distancing rules (Sc6), and take vaccines (Sc7) while government should isolate infected people (Sc3), close mass-gathering places (Sc5), and provide vaccines (Sc7).

Name: Ismoil Odinaev

Course: Phys 3061

StudentID: 1155118960

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Appendices

Appendix 1

The code is provided for this article and since the code is long, there is README file to explain the code.

Appendix 2

References

1. Y. Vyklyuk, M. Manylich, M. Škoda; Modeling and analysis of different scenarios for the spread of COVID-19 by using the modified multi-agent systems – Evidence from the selected countries; Results in Physics; Dec/2020
2. <https://covid19.rs/homepage-english/>
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