OUTBREAK

Modelization and simulation of biosystems

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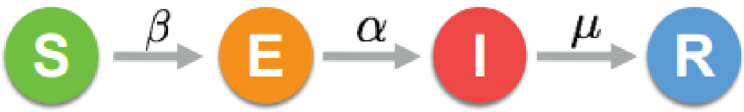
Exercise 2:

A virus called Motaba, which causes a deadly fever (98% of infected individuals die), is discovered in the African jungle. (…) The virus mutates into a strain capable of spreading like influenza, with a significant incubation period... Quarantine measures are implemented to contain the spread of the virus.

Quarantine is applied to a high fraction of individuals in the infected state (that is, after the incubation period).

The SEIR model extends the SIR model by adding an additional population compartment containing those individuals who have been exposed to the virus but not yet infective.



S: Susceptible population.
E: Exposed population.
I: Infected population.
R: Recovery population.

β: rate at which susceptible population encounters infected population.
α: rate at which exposed population becomes infective.
μ: rate at which infected population recovers.

Initial conditions:

I wanted to learn how an epidemic starts. Therefore, I have set the lowest values for the parameters exposed above for modeling the initial conditions of an epidemic. In addition, I want to simulate a global infectious disease, so the initial population (N) will be the global population, 7.8E12.

- S0: N-1
- I0: 1/N
- R0: 0
- E0: 0

On the other hand, in SEIR model we need to take into account different values time.

- **Incubation time (t_incubation):** period of time between a susceptible person gets in contact with an infected one and shows the first symptoms (infected). In this example, as it is said that incubation period is significant, I have set it to **10 days**.
- **Infective time (t_infective):** time taken by an infected person to recover from the disease. In this example I have set it to **6 days**.

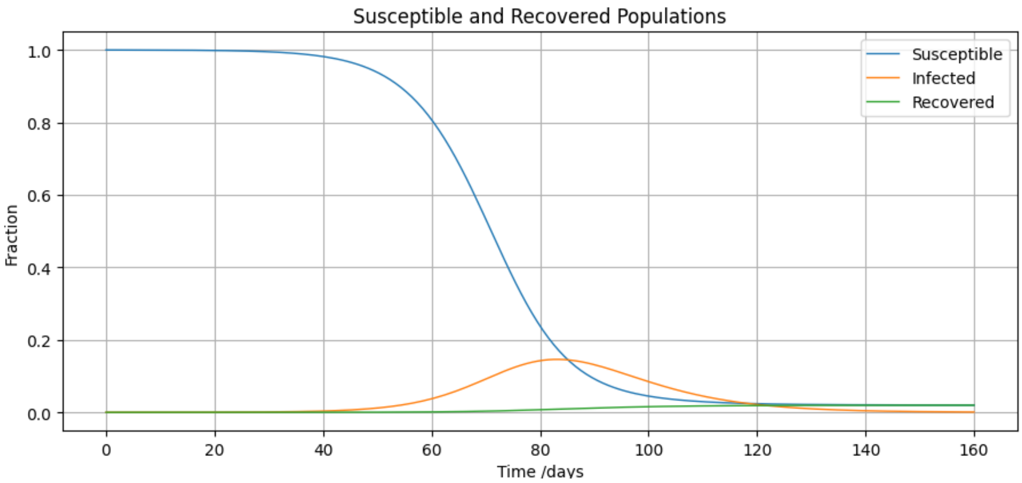
Finally, I have set rate parameters in concordance to incubation and incubation time:

- **α**: 1/t_incubation
- **β**: 4* α. As it seems to be a very infectious disease, I have multiplied the contagious by a high number (4).
- **μ**: 0.2

1. **Given a sensible set of parameters, estimate the effects of quarantine policies in the contention of the virus. What is the effect of a variable incubation period?**

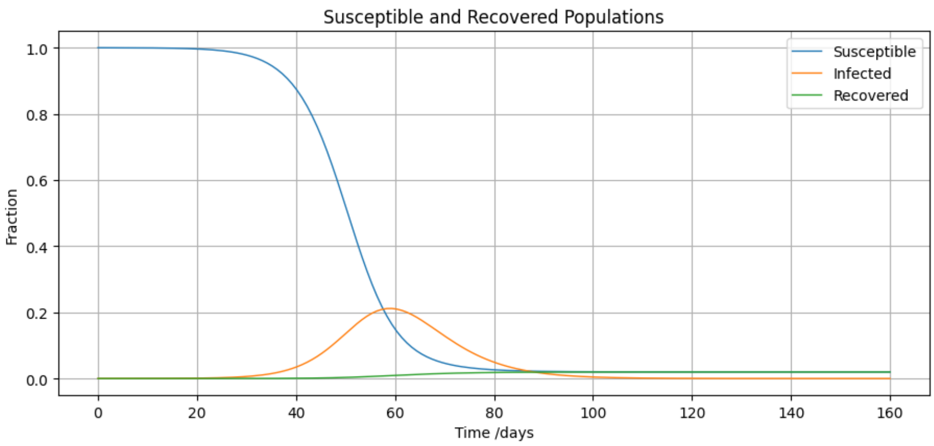
   At the outbreak case, only 2% of the population will survive to the infection. Due to its low rate of recovery (**μ**) we could omit it. However, it will mean human extinction, and as I am an optimistic person, I will take into account this value.

   Here, we can observe that, as in SIR models, susceptible population drops as infected population increases. Nevertheless, infected population increases in lower levels than in SIR models because, in this example, the recovery rate is very low (2%). Therefore, susceptible and recovered population will tend to this number. Consequently, as there are less population as time advance, there will be less people to get infected.

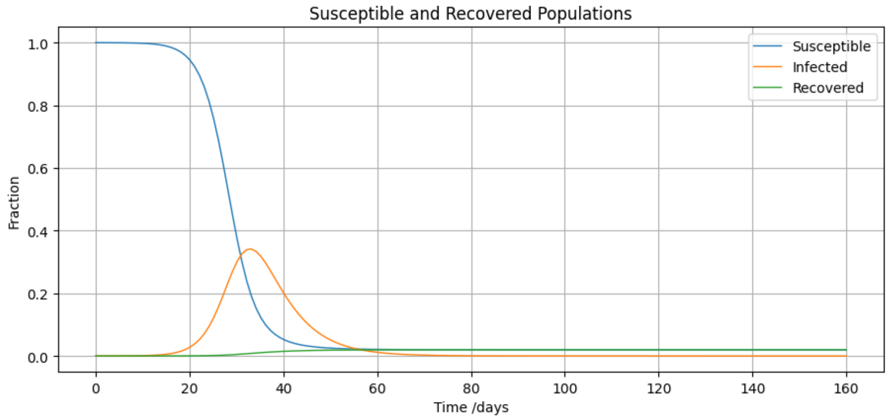


But what if we low the incubation time?

As it is explained bellow, the incubation time express the period of time between the exposed and infected state. Therefore, as we decrease this value, the speed of the system will increase. It is also important to highlight that this parameter change the maximum incidence of the disease in time but not the total incidence because the recovery rate is fixed at 2%.



Incubation time = 5 days



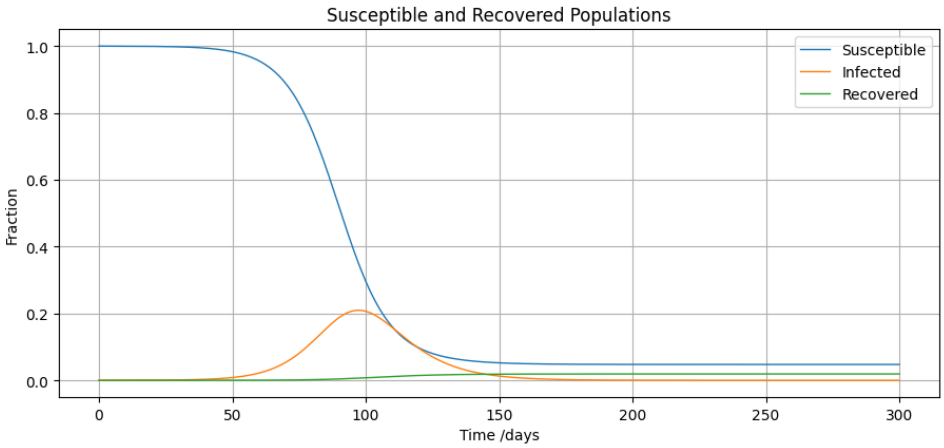
Incubation time = 1 das

But what if we use contention methods such as quarantine?
For simulating quarantine process, I have introduced a new parameter, u.

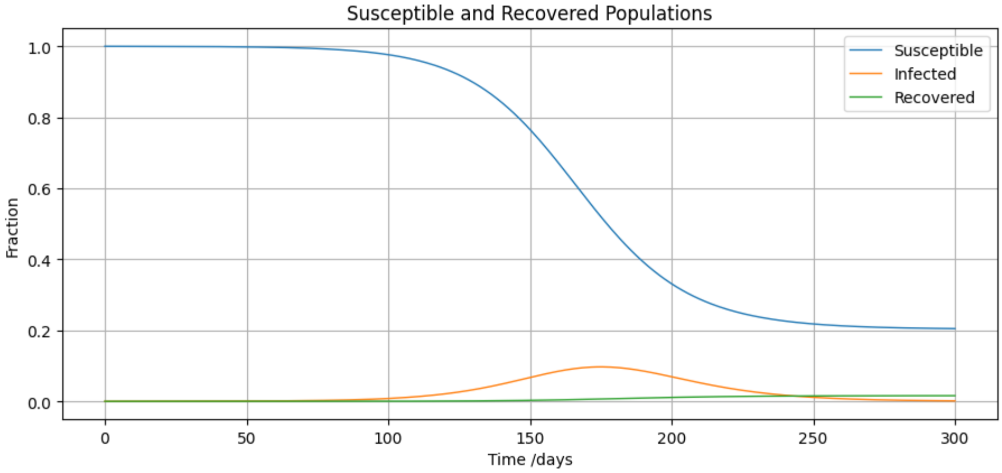
u: indicate the effective quarantine. For u=0, represents the absent of quarantine and in contrast, u=1 means a perfect isolation since the encounter between an infected and susceptible person.

In outbreak example, I will consider u as the number of days between the mentioned encounter and the first quarantine day. That means that if the encounter sudden at day 0 and the susceptible person starts its quarantine on day 7, u value will be 0.3.

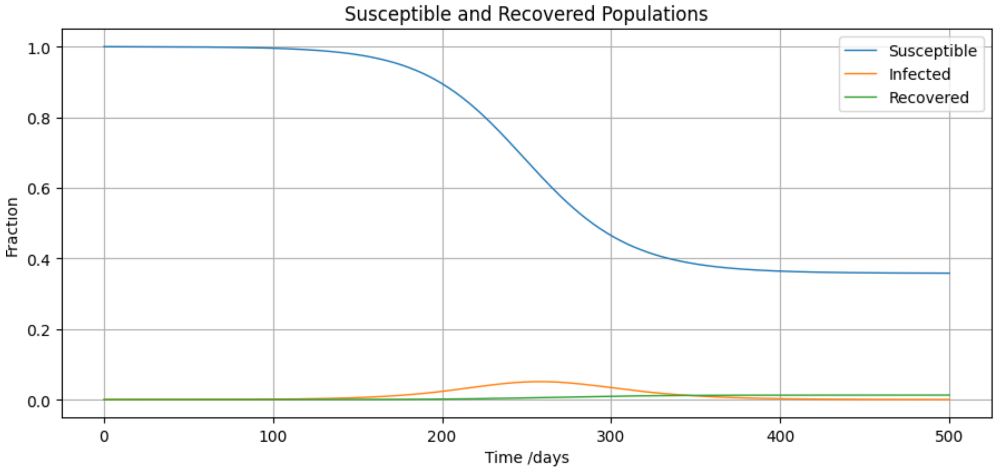
Now I will plot some examples varying the initial time of quarantine.



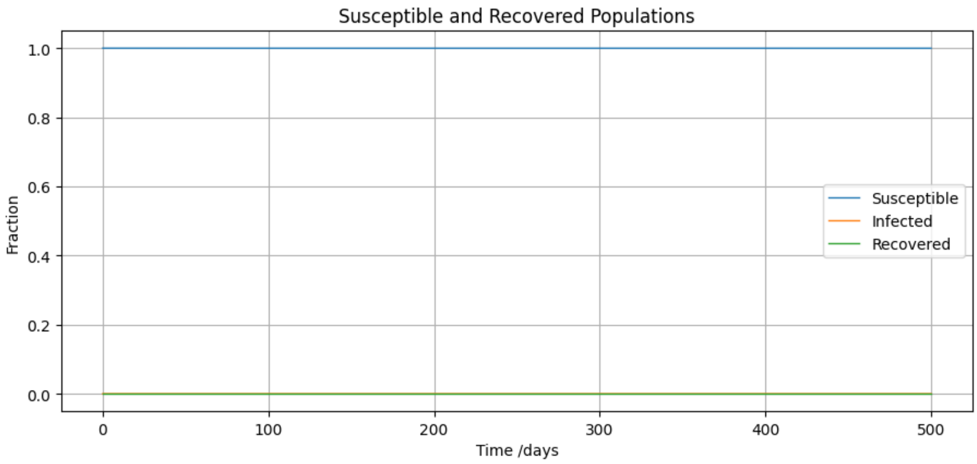
u = 0.2 (day 8)



u = 0.5 (day 5)



u = 0.6 (day 4)

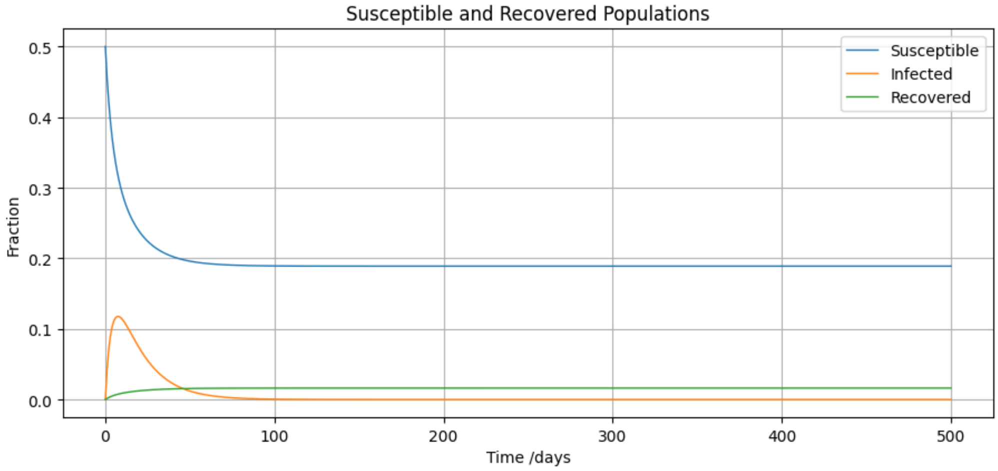


u = 0.8 (day 2)

As we have observed, quarantines are a good contention method. If doctors can diagnosticate the disease just 2 days before symptoms appeared, the final population will double its number (from 2%, recovered population, to 4%, recovered population and protected population)

It is also remarkable the last plot. If people who got in contact with infected people starts quarantine since this moment, the epidemic won't happen.

As I said, this is the model of the star of an epidemic, so it is obvious that if there is just one person infected and starts its quarantine early, there won't be epidemic. **But what if we increase I0 to 1/N?**

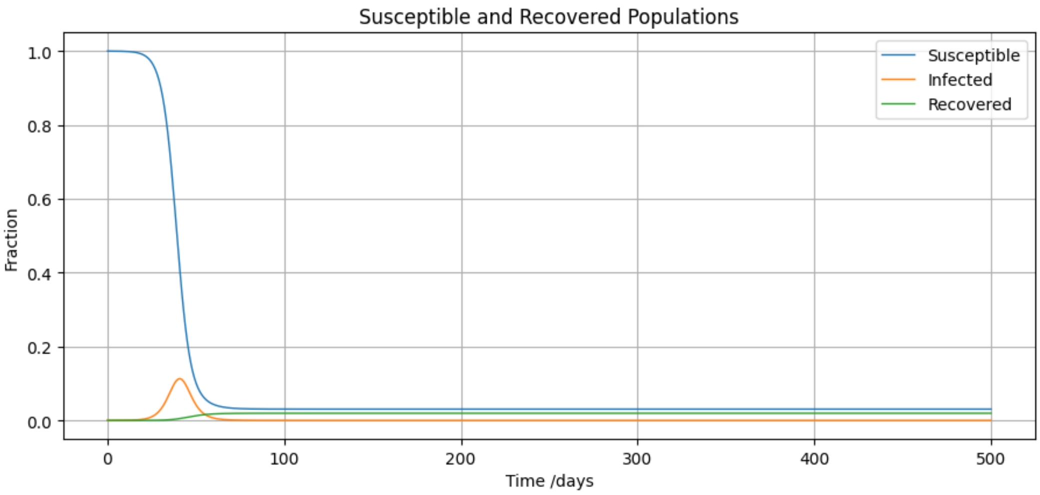


u = 0.8 (day 2)

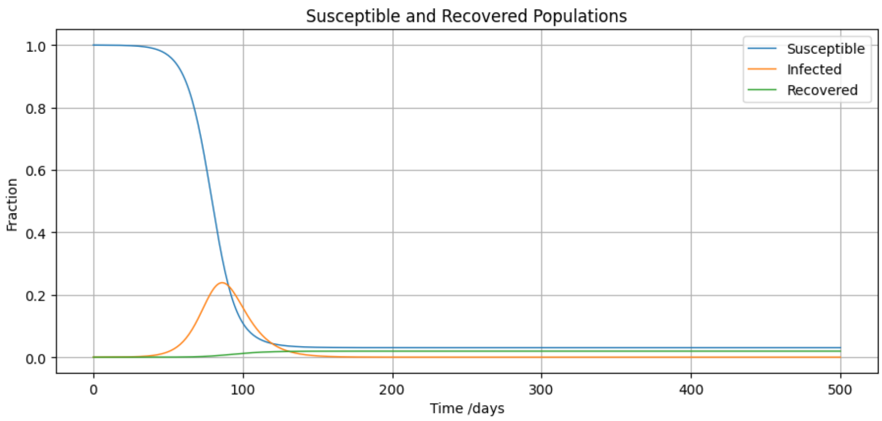
In this case, epidemic will happen but in less than 100 days it will be under control. Therefore, we can affirm that quarantine is such a good contention method.

As the incubation time is set at 10 days, a long incubation period, the variation of quarantine days is low. **But what if the incubation time is 2 days?**

As u is a percentage of the incubation time, it won´t matter if we change the incubation period, because it is proportional. We will only observe changes in the speed of the system.



Incubation time = 2 days, u = 0.1



Incubation time = 10 days, u = 0.1

2. **A time D after the epidemics started, a vaccine that immunizes susceptible individuals is obtained. If V individuals are vaccinated per unit time, what is the final death toll of Motaba?**

Generate a vaccine will increase the number of recovered population. I suppose D is day **55** and we will able to immunize **0.05%** of the population (N) per day since the vaccine has been created.

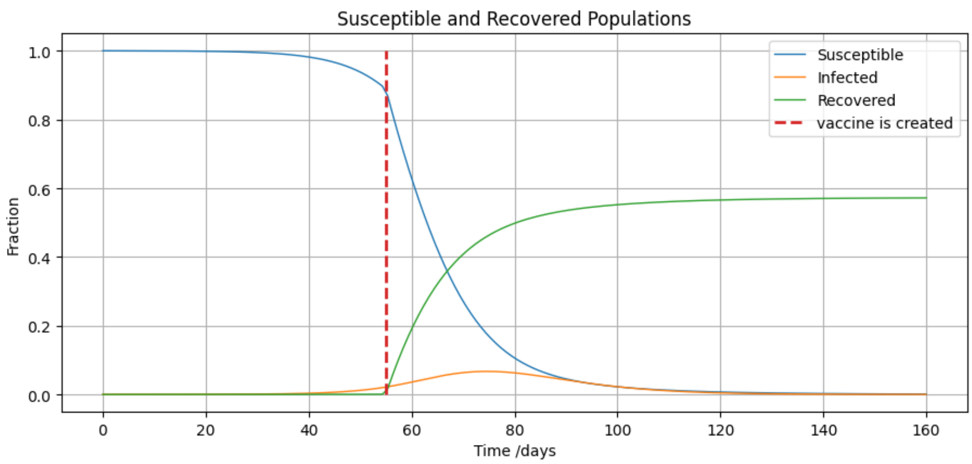
Initial condition:

- **S0**: N-1
- **I0**: 1/N
- **R0**: 0
- **E0**: 0
- **Incubation time:** 10 days.
- **Infective time:** 6 days.
- **α**: 1/10
- **β**: 4* α
- **µ**: 0.2

For modeling this situation, we must modify our equations:

- $\frac{ds}{dt} = -\beta * s * i - s * vacune$ we need to eliminate the susceptible vaccinated
- $\frac{de}{dt} = \beta * s * i - \alpha * e$
- $\frac{di}{dt} = \alpha * e - \mu * i$
- $\frac{dr}{dt} = (\mu * i) + s * vacune$ and add them to the recovered population.

Here are the plotted results:



We can observe that at D Day (55) susceptible dramatically drop, but not o turns into infected (because infected population doesn't increase). They move to the recovered population which highly increase after day 55.

The final recovered population is 57,18% which means 4.46E12 people has survived to the outbreak.

The final dead toll is 3.33E12.