Pandemic Model Report

TEAM 18

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Introduction

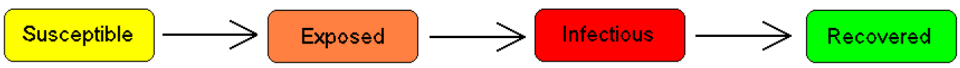
In December 2019, atypical pneumonia [coronavirus disease 2019 (COVID-19)] broke out in Wuhan, the capital of Hubei Province, mainland China. This is caused by a new type of coronavirus that is zoonotic. The epidemic has spread rapidly. So far, more than 141,326,185 cases have been reported globally and 3,021,618 people have died. It surpasses previously well-known epidemics, such as the severe acute respiratory syndrome (SARS) that broke out in 2003 and the viral hemorrhagic fever (Ebola) that broke out in 2014. To contain the epidemic, China has implemented an unprecedented intervention strategy. Such as the implementation of isolation, restrictions on travel, mandatory wearing of masks, tracking of infected persons and vaccination measures. Some of these strategies have affected the global economy on a large scale. However, as of April 2021, the spread of the atypical pneumonia virus has not been completely controlled globally.

Goals

Therefore, in the face of epidemic diseases, we need to predict the trend of transmission. At the same time, the impact of control measures such as isolation, travel restrictions, mandatory wearing of masks, tracking of infected persons and vaccination on the progress of the epidemic will be evaluated. Here we use the SEIR model, combined with data from medical research reports to predict the progress of the epidemic.

Methods

SEIR model



- S ==> Susceptible : number of susceptible
- E ==> Expose : number of expose
- I ==> Infectious : number of infectious
- R ==> Recovered or Removed : number recovered (or immune) individuals.
- We have S + E + I + R = N, this is only constant because of the (degenerate) assumption that birth and death rates are equal, N is country population.

Susceptible → Exposed → Infected → Removed, Differential Function as below:

$$\frac{dS}{dt} = -\frac{\mathcal{R}_t}{T_{\text{inf}}} \cdot IS, \qquad \frac{dE}{dt} = \frac{\mathcal{R}_t}{T_{\text{inf}}} \cdot IS - T_{\text{inc}}^{-1}E, \qquad \frac{dI}{dt} = T_{\text{inc}}^{-1}E - T_{\text{inf}}^{-1}I, \qquad \frac{dR}{dt} = T_{\text{inf}}^{-1}I$$

We need to solve the Differential equation to find the S, E, I, R, but what is "R_t", "T_inf", "T_inc" and how can we define those variables?

- R_0 & R_t ==> Reproduction number, The definition describes the state where no other individuals are infected or immunized (naturally or through vaccination)
- T_inf ==> Average duration of the infection, 1/T_inf can be treat as individual experiences one recovery in D units of time.
- T_inc ==> Average incubation period.

Dispersion parameter(k)

The definition of k is a mouthful, but it's simply a way of asking whether a virus spreads in a steady manner or in big bursts, whereby one person infects many, all at once. After nine months of collecting epidemiological data, we know that this is an overdispersed pathogen, meaning that it tends to spread in clusters, but this knowledge has not yet fully entered our way of thinking about the pandemic—or our preventive practices.

This kind of behavior, alternating between being super infectious and fairly noninfectious, is exactly what k captures, and what focusing solely on R hides. Samuel Scarpino, an assistant professor of epidemiology and complex systems at Northeastern, told me that this has been a huge challenge, especially for health authorities in Western societies, where the pandemic playbook was geared toward the flu—and not without reason, because pandemic flu is a genuine threat. However, influenza does not have the same level of clustering behavior

Configurations of program

- N ==> Total population of the area.
- S_0 ==> Initial susceptible number.
- E_0 ==> Initial Exposed number.
- I_0 ==> Initial infected number.
- Recovery ==> Initial removed number.
- confirmTime ==> Total time from infected to confirm.
- latentTime ==> Total time from infected to infectious.
- r ==> The average number of a person meet everyday. (Home quarantine will decrease it)
- T ==> Total days for simulation.
- afterDays ==> Days before government makes policies (Default value is 0 if no input.)
- methods ==> list of government policies(30% vaccine, 50%vaccine, 70%vaccine, home, mask, testing & track)

Estimation of model parameters

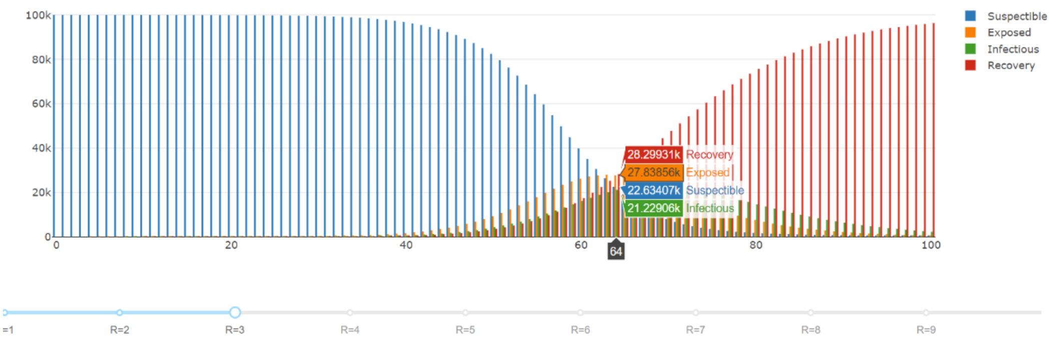
In order to apply the SEIR model, we need to estimate the parameters β, σ and γ, where β is the product of the people exposed to each day by infected people (k) and the probability of transmission (b) when exposed (i.e., β= kb) and σ is the incubation rate which is the rate of latent individuals becoming symptomatic (average duration of incubation is $1/\sigma$). Because the incubation period of the SARS-CoV-2 has been reported to be between 2 to 14 days (2,10,11,12), we chose the midpoint of 7 days. γ is the average rate of recovery or death in infected populations.

Algorithm Implementation

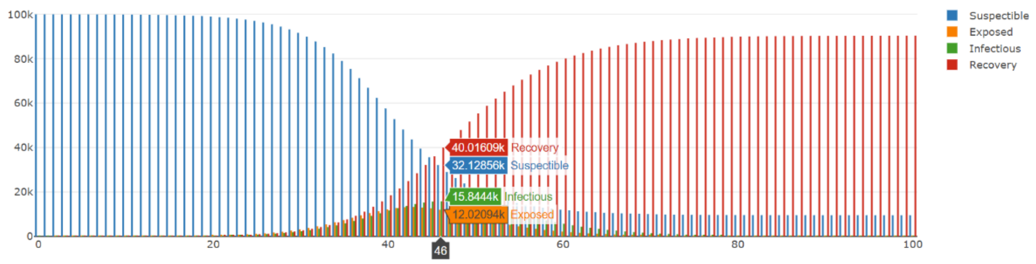
Predict the spread of the epidemic

Through the SEIR model, based on the SEIR data of the previous day, infer the SEIR data of the next day. SEIR data obtained at different times in days units by iteration. Simulate the spreading trend of different viruses without epidemic prevention measures in an area with a population of 100,000.

For example, SARS virus, R0 is set to 3, the result is as follows.



For example, for the Covid-19 virus, R0 is set to 4, the result is as follows.



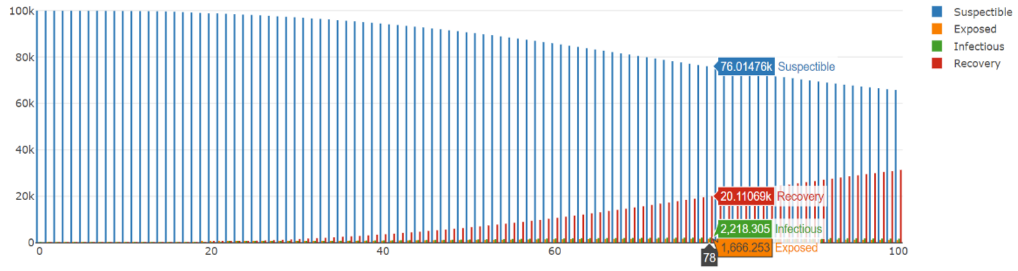
Analysis: We can know the spreading trend of the virus from the two pictures. Since SARS and Covid-19 are both coronaviruses, the two trends are very similar. Since the R0 of Covid-19 is greater than the R0 of SARS, it can be seen that Covid-19 spreads faster, with the number of infections peaking at 46 days, while the number of SARS infections peaking at 64 days.

The impact of control measures on the progression of the epidemic

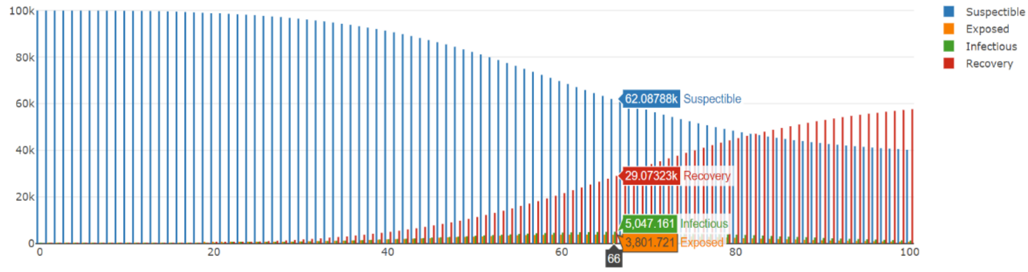
According to the SEIR model, the impact of control measures on the corresponding parameters, such as wearing a mask to reduce β1 and β2 (the probability of E and I being transmitted to S), isolation and stay-at-home reduce the value of k (the number of people E and I contact each day), Detection of human infection with the virus and tracking of close contacts, reducing the ConfirmTime (reducing T_inc) and reducing the number of S by vaccination, have obtained new prediction results.

For the control measures for the spread of the Covid-19 virus, we can change the parameters according to different measures to get the spread trend chart in this case (set the control measures from the 20th day).

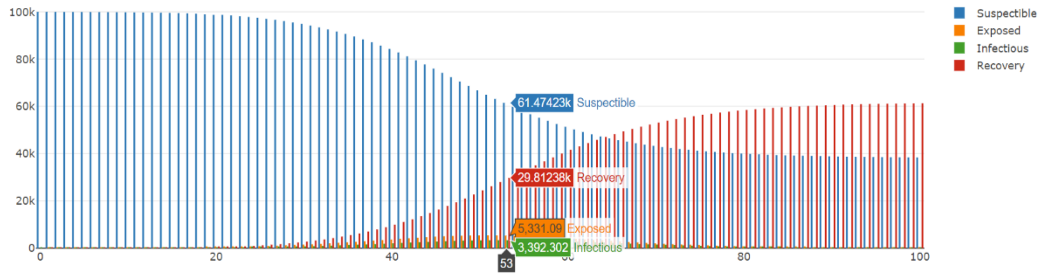
stay-at-home



wearing a mask



Detection and tracking

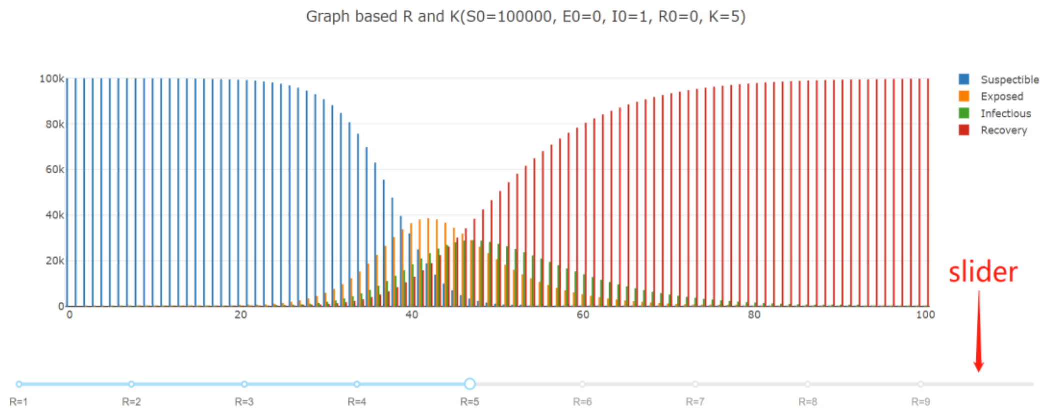


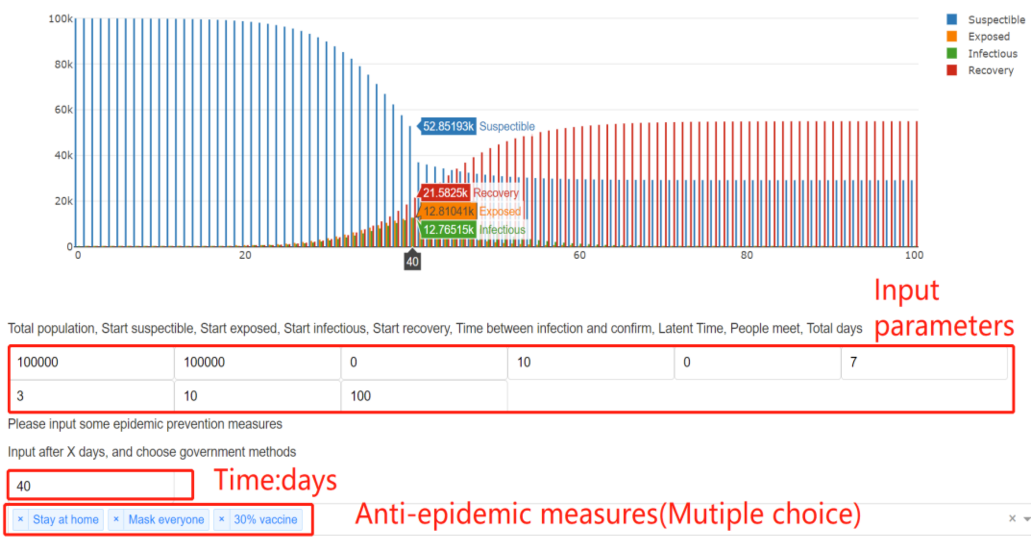
Analysis: Through comparison, it can be seen that the quarantine policy is the most effective way to control the spread of the epidemic, and the number of infected people does not have a significant peak, indicating that there is no outbreak of the epidemic. Both the detection and tracking policy and the mask-wearing policy have effectively reduced the peak number of infected persons, but the former peak appears earlier than the latter peak. The detection and tracking policy has a delay. This shows that in the early stages of the implementation of the policy, wearing masks more effectively restrained the spread of the epidemic.

Output

Based on the above algorithm, we used python's dash library to make a web page, which dynamically and intuitively showed the spreading trend of different epidemics in different situations in the form of charts.

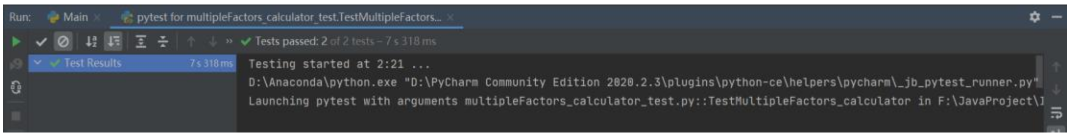
On this page, you can use the sliding bar to adjust parameters, enter parameters or select different epidemic prevention policies to obtain virus transmission images and data. The image can be freely selected to enlarge in a specific range, and the number of S\E\I\R people can be obtained by hovering the mouse on the image.



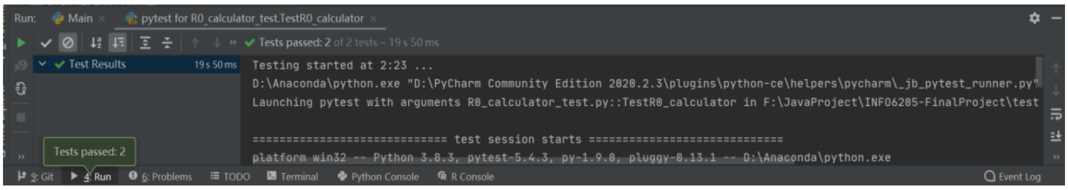


Unit test

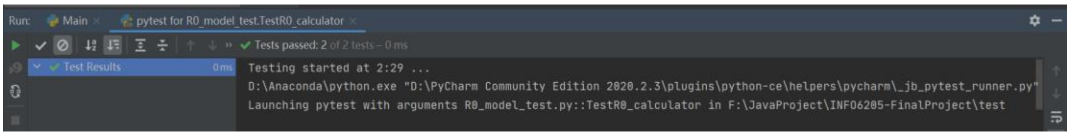
Test 1:



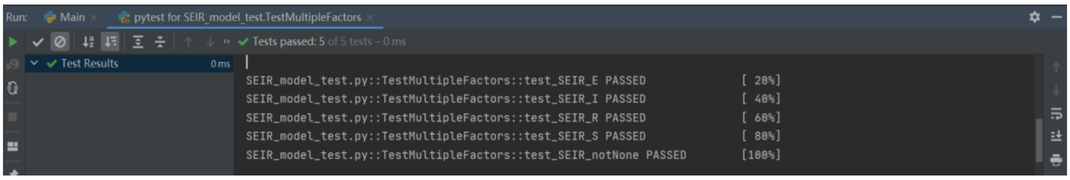
Test 2:



Test 3:



Test 4:



Conclusion

The covid-19 model was built to visualize the spread of the virus. It is intuitive to see that the epidemic is spreading fast, the peak number of infected people is high, and the situation is severe. However, it can also be seen that the current prevention and control measures have effectively controlled the epidemic to a certain extent from reducing the number of contacts, reducing the probability of transmission, and shortening the transmission time. The government should adopt appropriate prevention and control measures according to different development stages of the epidemic, and gradually restore the economy on the basis of controlling the epidemic.

At the same time, it is even more necessary for the government to correctly disseminate relevant information, raise the public's awareness of protection, and correctly guide the public to protect.

Condolences for those who lost their lives in the epidemic, and pays tribute to the frontline workers of epidemic prevention.

Reference

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