

Simulating and Analyzing the Spread of Diseases

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Why did I choose this project?

- 1 Combines Computer Science, Mathematics, and Biology.
- 2 Both practical and interesting applications.
- 3 Pure curiosity of how CDC or WHO create their disease models, and if it's possible to create a simplistic model for common use.

Objectives

- ① Implement the SIR Model Differential Equations into Python.
- ② Graph and analyze the spread of different diseases using Python and the SIR model.
- ③ Demonstrate the real world uses of this program, and simplify it as much as possible for common use.

Materials used for the program

- ① The SIR Epidemic Model¹
- ② Python 3.7.2
 - ① Matplotlib
 - ② Numpy
 - ③ Scipy

¹Mathematical Theory of Epidemics (1927), W.O. Kermack and A. G. McKendrick

SIR Model

- 1 System of differential equations to simulate diseases.
- 2 Three main variables represent the three possible groups of people.
 - 1 S is the number of susceptible individuals.
 - 2 I is the number of infected individuals.
 - 3 R is the number of recovered individuals with immunity.
- 3 I_0 is our starting number of infected individuals.
- 4 R_1 would be our starting number of immune individuals.
- 5 N is the total population.
- 6 β is the transmission rate.
- 7 γ is the recovery rate.

$$\frac{dS}{dt} = -\frac{\beta IS}{N} \quad (1)$$

$$\frac{dI}{dt} = \frac{\beta IS}{N} - \gamma I \quad (2)$$

$$\frac{dR}{dt} = \gamma I \quad (3)$$

There were three significant steps for writing the program.

- 1 Find and import libraries
 - 1 Matplotlib
 - 2 Numpy
 - 3 Scipy
- 2 Implement the SIR model
- 3 Graph out data using Matplotlib

```

# The total population
N = 1000
# The initial number of infected and recovered individuals
I0, R0 = 1, 0
# Basic Reproduction Rate (R_0)
R = 2.5
# Contact rate (Beta) and recovery rate (Gamma)
gamma = 1/7
beta = (gamma*R)

# Set S0 to our total number of susceptible individuals
S0 = N - I0 - R0
# Create a vector of our initial conditions
y0 = S0, I0, R0

# The SIR model differential equations.
def deriv(y, t, N, beta, gamma):
    S, I, R = y
    dSdt = -beta * S * I / N
    dIdt = beta * S * I / N - gamma * I
    dRdt = gamma * I
    return dSdt, dIdt, dRdt

# Time grid in Numpy representing our total time simulated
t = np.linspace(0, 160, 160)
# Integrate the SIR equations over the time grid
ret = odeint(deriv, y0, t, args=(N, beta, gamma))
S, I, R = ret.T

# Matplotlib data for graphing the three curves
fig = plt.figure(facecolor='w')
ax = fig.add_subplot(111, axisbelow=True)
ax.plot(t, S, 'b', alpha=0.5, lw=2, label='Susceptible')
ax.plot(t, I, 'c', alpha=0.5, lw=2, label='Infected')
ax.plot(t, R, 'g', alpha=0.5, lw=2, label='Recovered')
ax.set_xlabel('Time (days)')
ax.set_ylabel('Number of People')
ax.set_ylim(0, 1000)
ax.yaxis.set_tick_params(length=0)
ax.xaxis.set_tick_params(length=0)
ax.grid(b=True, which='major', c='w', lw=2, ls='-')
legend = ax.legend()
legend.get_frame().set_alpha(0.5)
for spine in ('top', 'right', 'bottom', 'left'):
    ax.spines[spine].set_visible(False)
plt.show()

```

Flu Model (Spanish Flu)

Begin with the reproduction number of the disease (Denoted R_0).

$$R_0 = \frac{\beta}{\gamma} \quad (4)$$

For the 1918-1919 Flu Epidemic this is estimated to be 2-3, but this doesn't provide us with values for β or γ .

Flu Model (Spanish Flu)

General recovery period for the Flu is one week, so there is a $\frac{1}{7}$ recovery chance per day.

$$\beta = R_0 \times \gamma \quad (5)$$

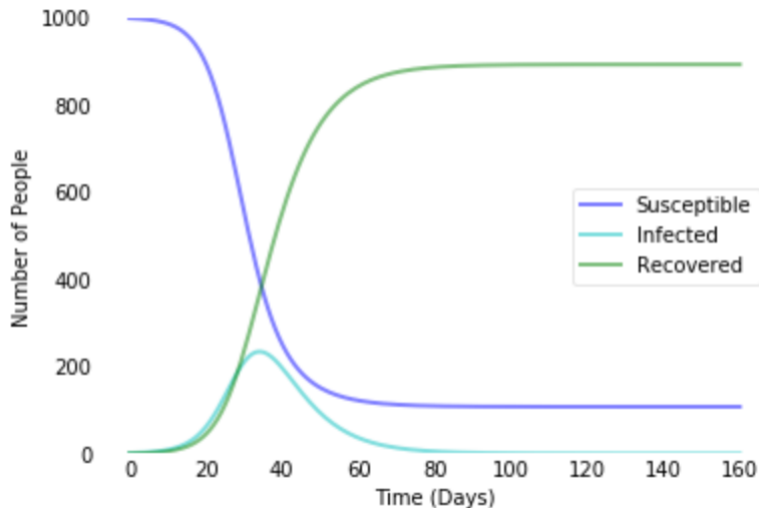
$$\beta = 2.5 \times \frac{1}{7} \quad (6)$$

$$\beta = 0.36 \quad (7)$$

We also have this equation solving implemented into the program itself.

Flu Model (Spanish Flu)

Using a total population of $N = 1000$, a time of 160 days $T = 160$, and $I_0 = 1$ we can graph our model.

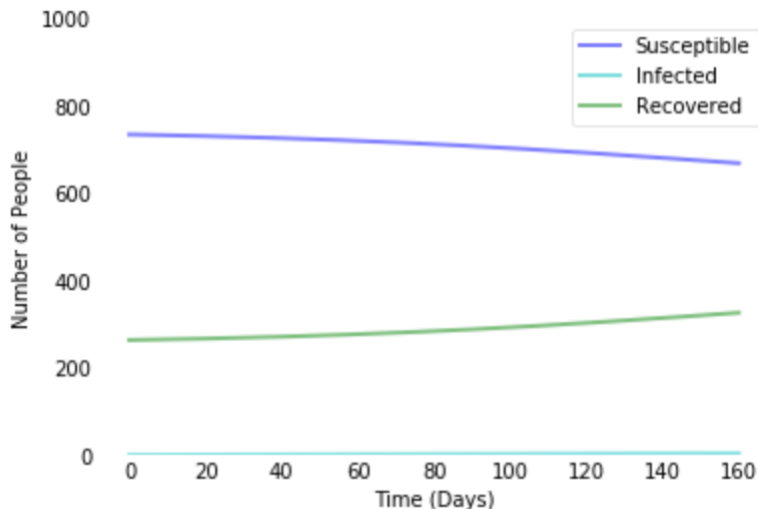


Flu Model (Seasonal)

The seasonal flu has immunizations unlike the time when the Spanish flu happened, so we must take this into account. Using the statistic that 46.8% of Americans get their flu vaccinations, and that the vaccine works around 50% of the time, we can assume that 23.4% of our 1000 person population has immunity.

Flu Model (Seasonal)

We can graph the seasonal flu now as well, assuming the same $N = 1000$, $T = 160$, and $I_0 = 1$. And our different $R_0 = 1.5$ and $R_1 = 264$.



Analysis: Seasonal Flu VS Spanish Flu

Using the graphs and data we can analyze these two scenarios and easily see and show the differences between them. For example we can already see two key differences between the 1918-1919 Epidemic and a standard Seasonal outbreak.

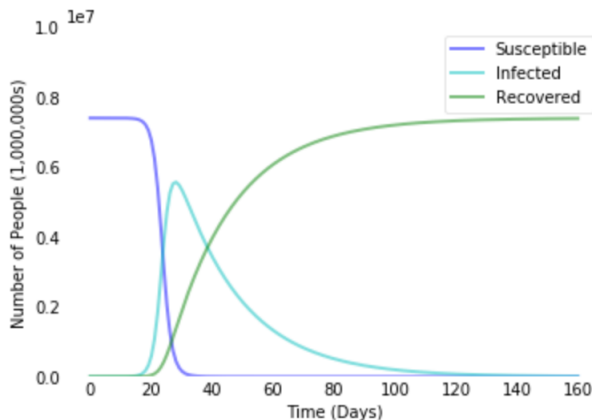
- 1 β of the 1918-1919 Epidemic is significantly higher than that of the Seasonal Flu, and it had no immunizations.
- 2 Noticeable spike in infected individuals in the Spanish Flu.
- 3 Modern flu with immunizations is significantly less severe than what occurred during the 1918-1919 outbreak.

Real World Applications

- ① People who are in or near an outbreak area and would like to know more about their situation.
- ② Predicting the spread of new or future diseases or outbreaks.
- ③ Possible use by official sources (CDC, WHO, etc.) for public information.
- ④ People who don't know or understand calculus could easily use this program to understand disease or epidemic situations better.

Measles

Population (N) of Washington State is 7.406 Million. $\gamma = \frac{1}{21}$ and $R_0 = 15$. The program automatically calculates β . And $I_0 = 1$. This disaster scenario assumes that nobody in Washington State is vaccinated at the time of outbreak.



Possible Errors

- 1 The SIR Model lacks vital dynamics.
- 2 The SIR Model also doesn't account for factors like autoimmune diseases, age, locations, or incubation periods.
- 3 R_0 will always be an average as diseases are constantly changing.
- 4 γ will always be an agreed upon average upper bound for recovery time.

Conclusion

- 1 The program is functional and accurately simulates the spread of diseases.
- 2 The graphs are useful for visualizing and analyzing the data, especially for the common person.
- 3 The program also has many possible real world applicatons from government to household use.
- 4 The program still needs a proper interface, but that is just aesthetics and can be improved in the future .

- ① Mathematical Theory of Epidemics (1927), W. O. Kermack and A. G. McKendrick
 - <https://royalsocietypublishing.org/doi/abs/10.1098/rspa.1927.0118>
- ② <https://www.python.org/>
- ③ <https://matplotlib.org/>
- ④ <http://www.numpy.org/>
- ⑤ <https://www.scipy.org/>
- ⑥ https://en.wikipedia.org/wiki/Mathematical_modelling_of_infectious_disease
- ⑦ https://en.wikipedia.org/wiki/Basic_reproduction_number

Questions?