Modeling Disease Spread

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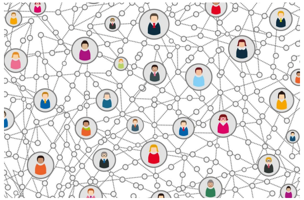
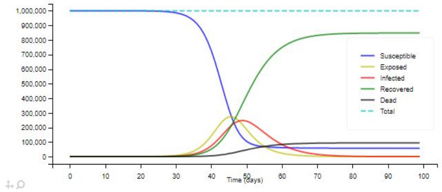
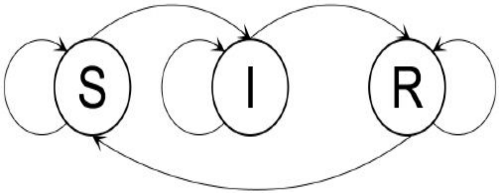
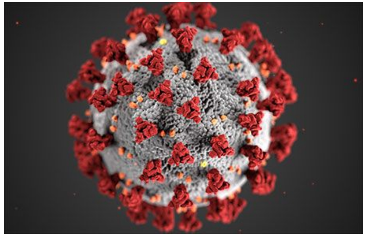


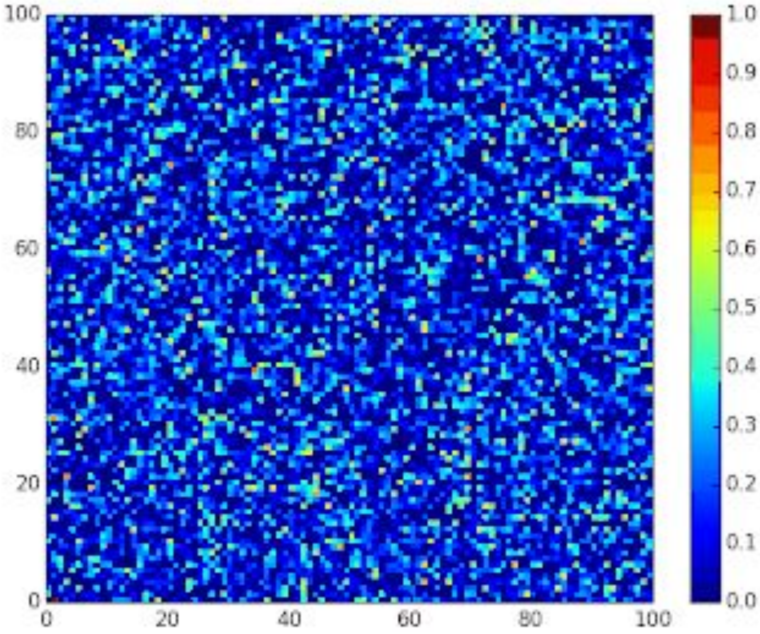






Cool visualization, not realistic though

Why **don’t** diseases wipe out populations?

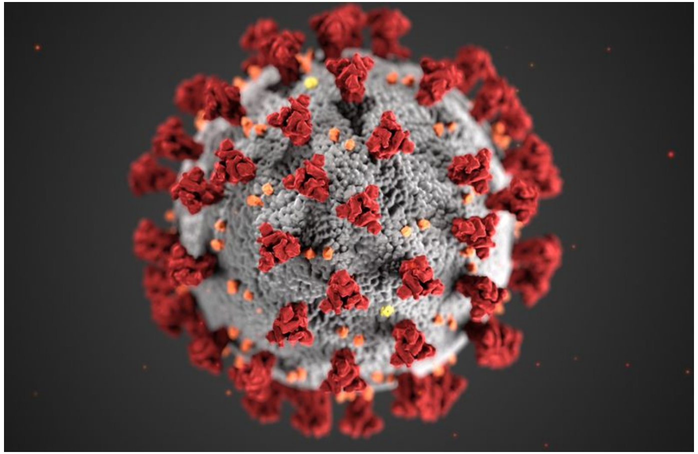


Introduction and Motivation

Motivation

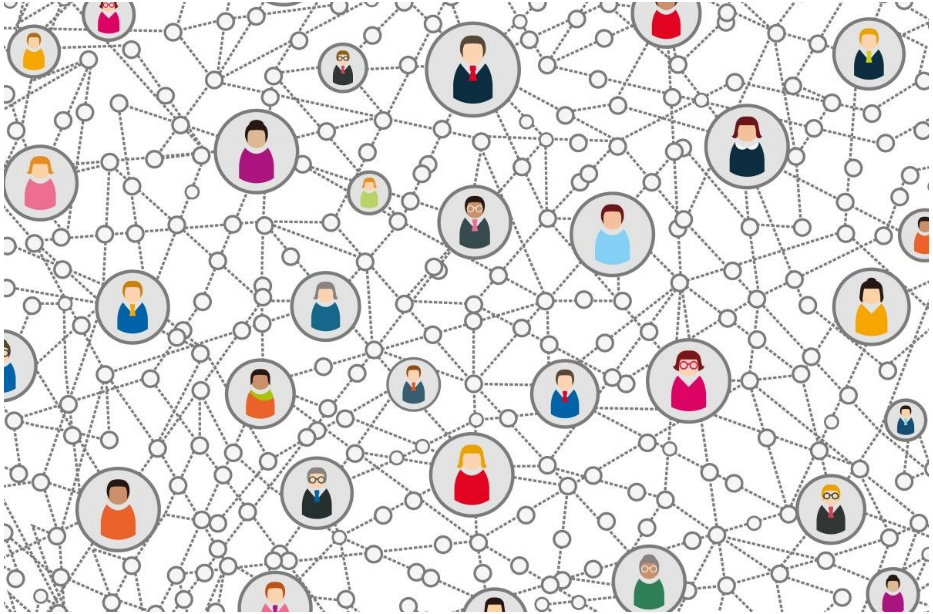
- Shared interests in data science and network science

- Current events



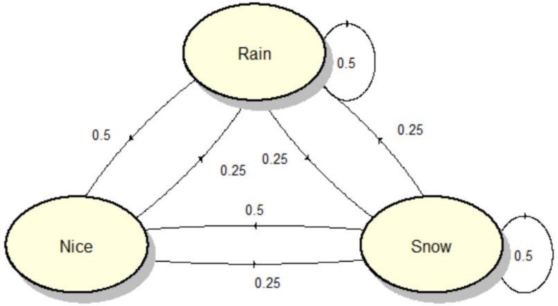
Predictions Saves Lives

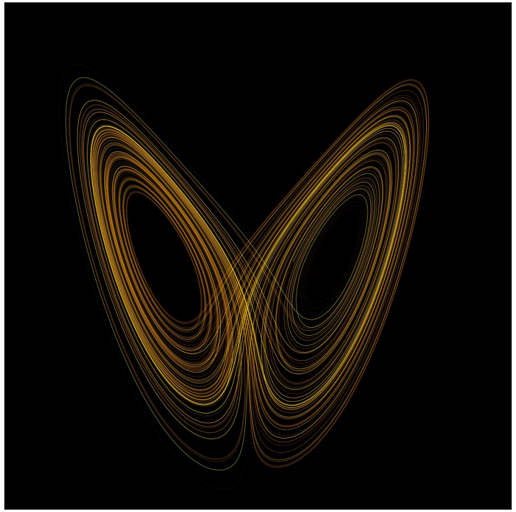
Predicting how diseases like COVID spread is indispensable in saving lives and ensuring public health.



Studying disease spread

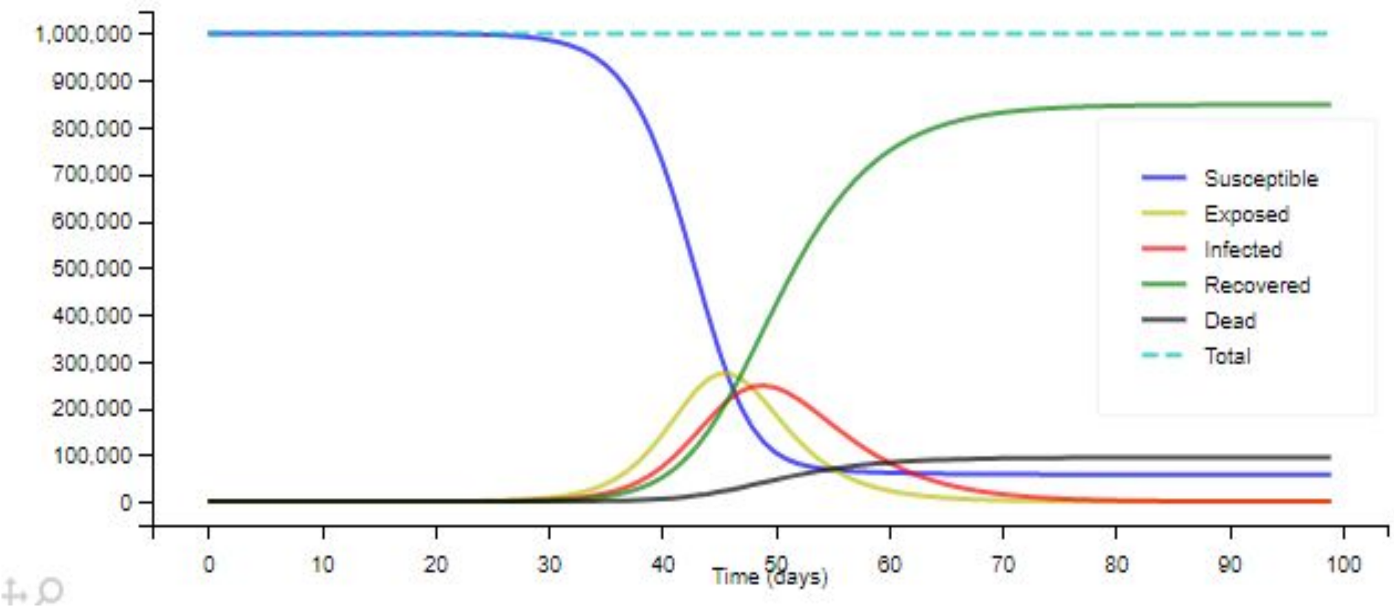
- Epidemiologists study disease spread by compartmentalizing the population into several groups(i.e SIR, susceptible, infected, recovered) and studying the rate of change of these subpopulations and how they transition into one another.
- Markov Chains/Dynamical Systems.



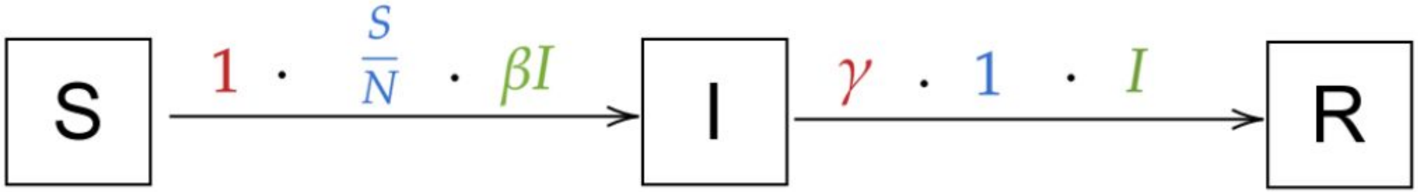


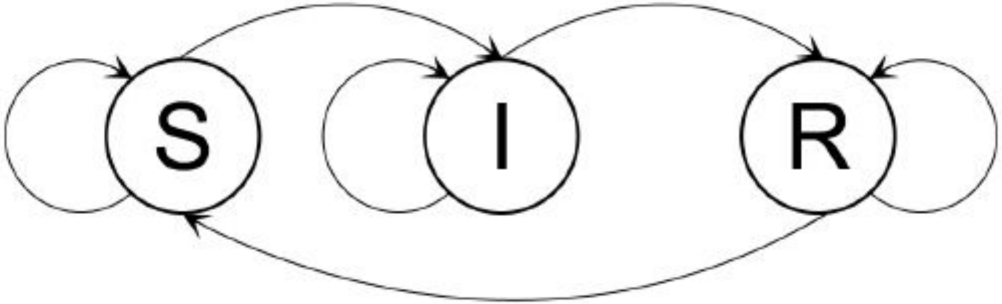
Problem Statement

How can we model the trajectory of COVID?



Summary of Basic SIR Model





Understanding the Model

S

S is the number of **Susceptible** people in the population. *S(t)* is the number of susceptible individuals on day *t*.

$$\frac{dS}{dt} = -\beta \cdot I \cdot \frac{S}{N}$$

I is the number of **Infected** people in the population. *I(t)* is the number of infected individuals on day *t*.

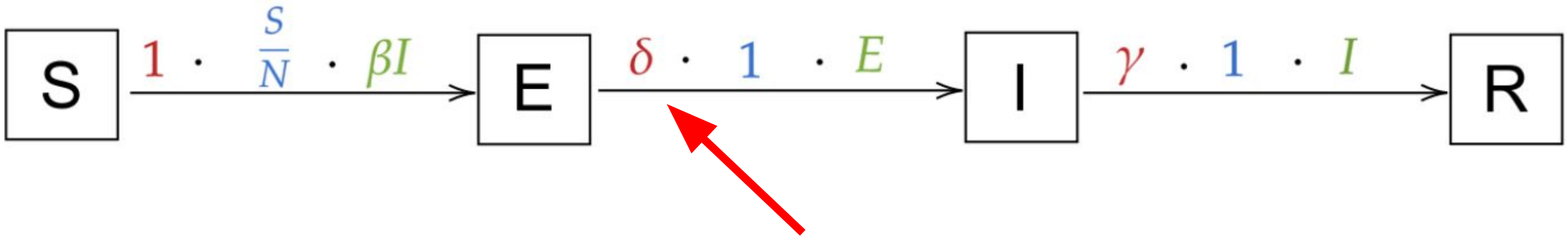
$$\frac{dI}{dt} = \beta \cdot I \cdot \frac{S}{N} - \gamma \cdot I$$

R

R is the number of **Recovered** people in the population. *R(t)* is the number of recovered individuals on day *t*.

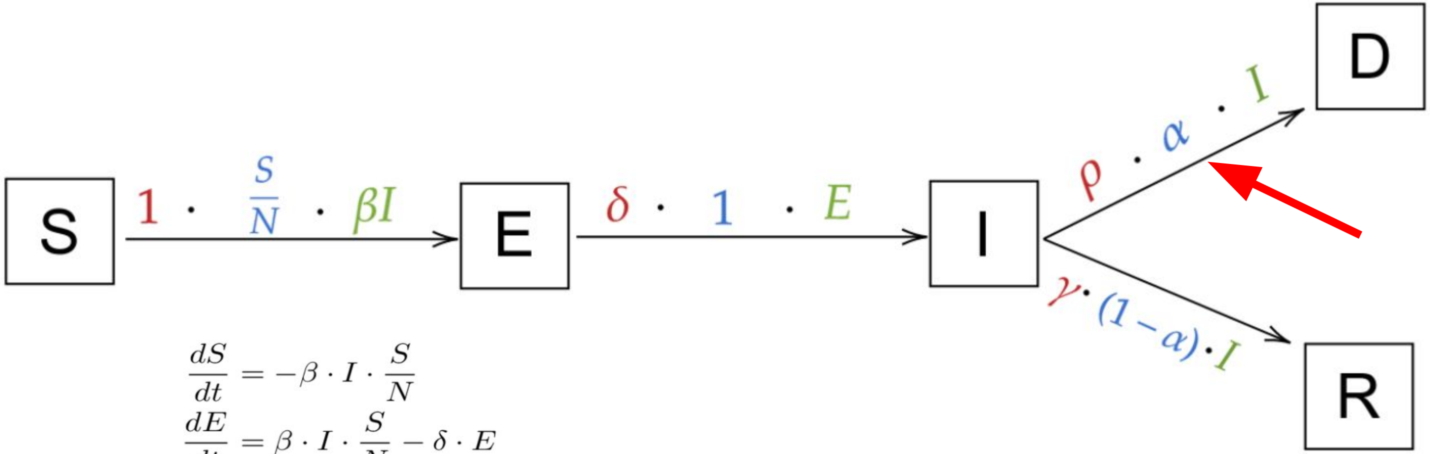
$$\frac{dR}{dt} = \gamma \cdot I$$

SEIR Model, incorporating new state: Exposed



$$\frac{dS}{dt} = -\beta \cdot I \cdot \frac{S}{N}$$
$$\frac{dE}{dt} = \beta \cdot I \cdot \frac{S}{N} - \delta \cdot E$$
$$\frac{dI}{dt} = \delta \cdot E - \gamma \cdot I$$
$$\frac{dR}{dt} = \gamma \cdot I$$

SEIRD Model, incorporating new state: Dead



$$\frac{dS}{dt} = -\beta \cdot I \cdot \frac{S}{N}$$
$$\frac{dE}{dt} = \beta \cdot I \cdot \frac{S}{N} - \delta \cdot E$$
$$\frac{dI}{dt} = \delta \cdot E - (1-\alpha) \cdot \gamma \cdot I - \alpha \cdot \rho \cdot I$$
$$\frac{dR}{dt} = (1-\alpha) \cdot \gamma \cdot I$$
$$\frac{dD}{dt} = \alpha \cdot \rho \cdot I$$

Other models

SIS, SEIS (no immunity/recovery, therefore after infection, you become susceptible again, i.e. common cold)

SIRS, SEIRS (temporary immunity)

MSIR, MSEIS (maternally derived immunity, does not immediately enter susceptible state after birth, i.e. Measles)

SICR (carrier state: not infected but can still spread, i.e tuberculosis)

Tweaking Parameters

Parameter Overview

- **N:** total population
- **S(t):** number of people susceptible on day t
- **E(t):** number of people exposed on day t
- **I(t):** number of people infected on day t
- **R(t):** number of people recovered on day t
- **D(t):** number of people dead on day t
- **β:** expected amount of people an infected person infects per day
- **D:** number of days an infected person has and can spread the disease
- **γ:** the proportion of infected recovering per day ($\gamma = 1/D$)
- **Ro:** the total number of people an infected person infects ($R_0 = \beta / \gamma$)
- **δ:** length of incubation period
- **α:** fatality rate
- **ρ:** rate at which people die (= 1/days from infected until death)

Herd immunity occurs when the q% of the population contract the disease

$$q = 1 - \frac{1}{R_0}$$

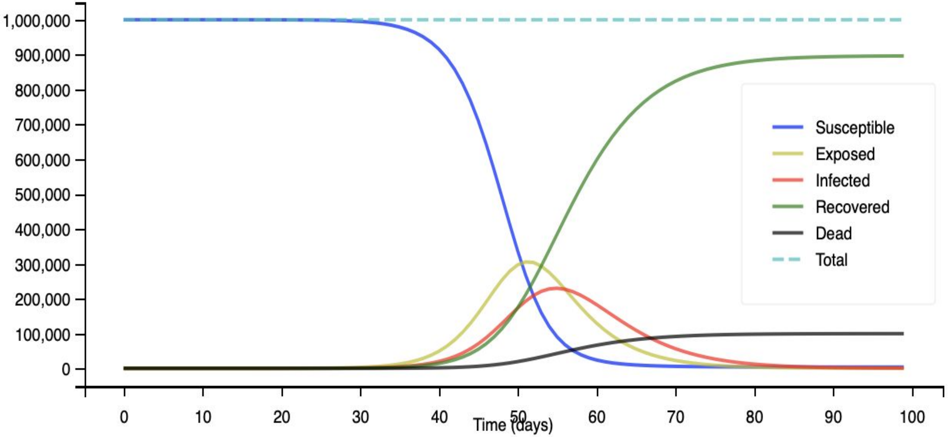
q is also the **critical immunization threshold**

Effects of changing alpha

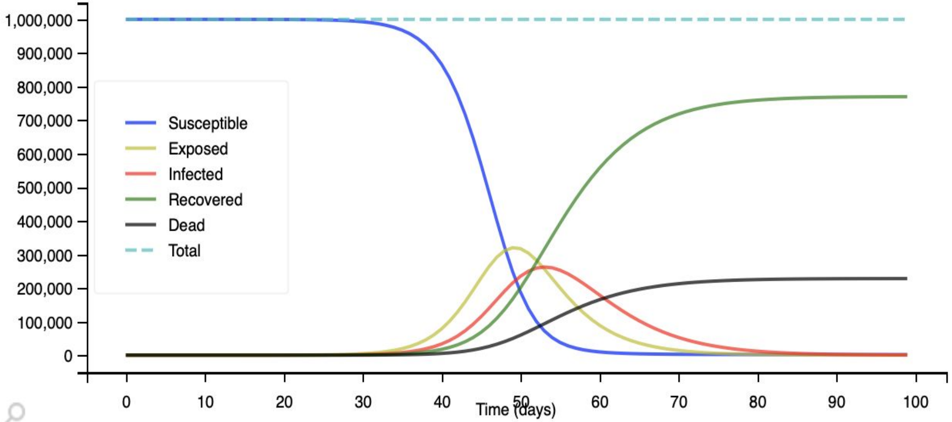
- **α** is the **fatality rate** which represents the proportion of people who get the disease and die
- **α** can be set at different levels: for example, you could program in α to have a dependency on age

```
alpha_by_agegroup = {"0-29": 0.01, "30-59": 0.05, "60-89": 0.2, "89+": 0.3}
```

α = 0.2
20% death rate



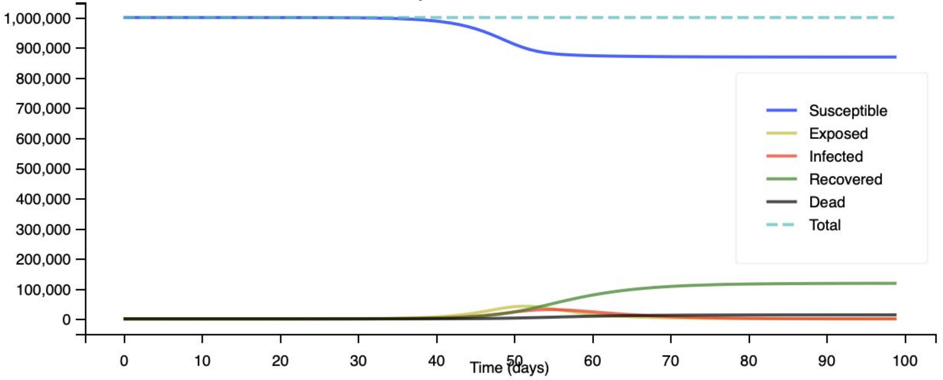
α = 0.4
40% death rate



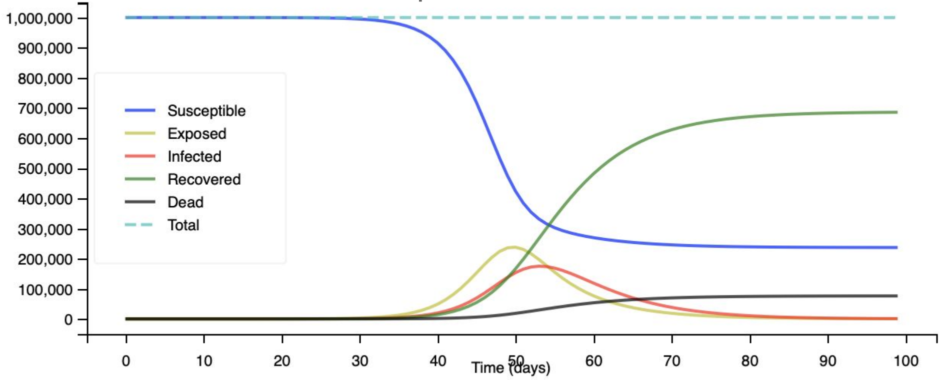
Effects of changing beta

- Beta is which is the **transmission rate** which is number of people an infected person infects per day
- Very important parameter from a public health standpoint since measures such as social distancing can decrease this variable

Start: β = 1
End: β = 1/40



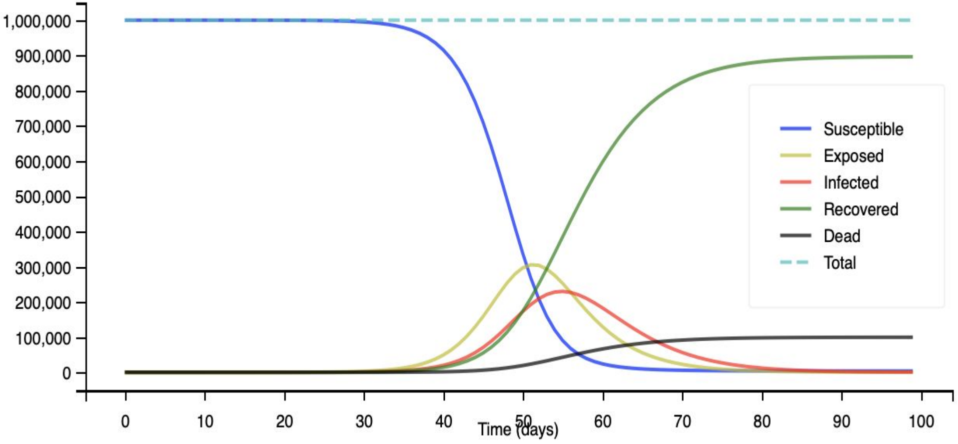
Start: β = 5/4
End: β = 1/8



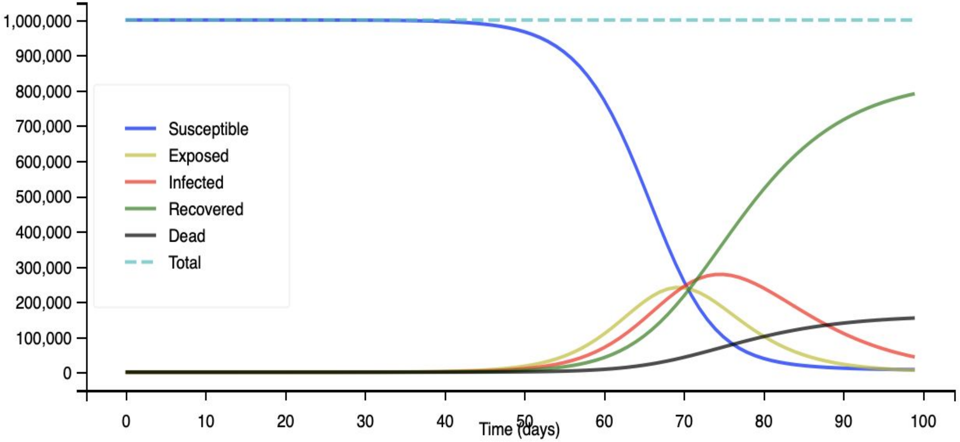
Effects of changing gamma

- **Γ** = 1/D, which represents the **proportion of people that recover daily**
- D = how long the infection lasts

D = 4



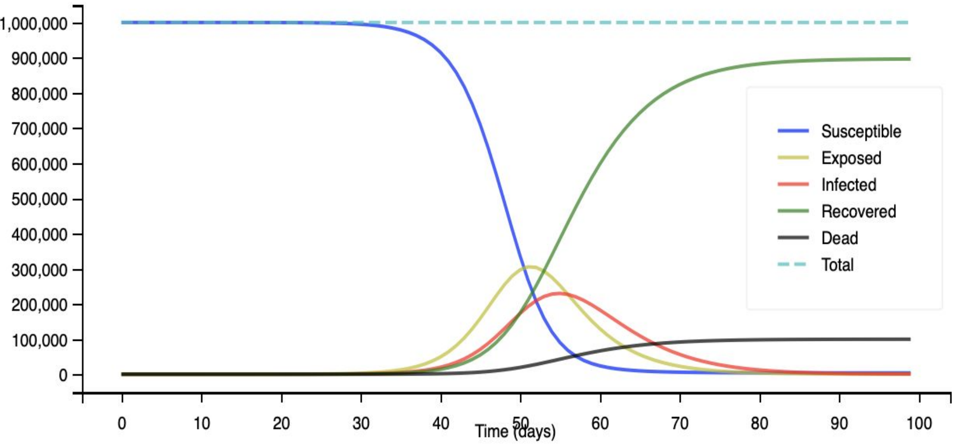
D = 7



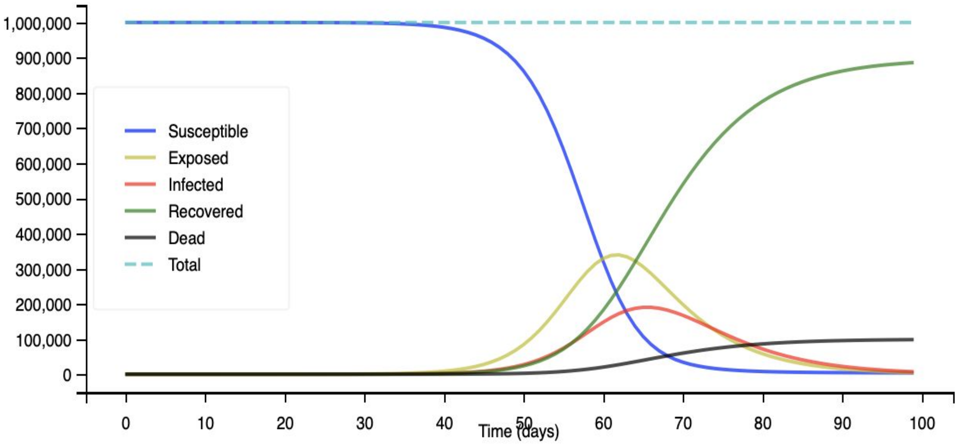
Effects of changing delta

- Δ = 1/T
- T = number of days
- Δ = incubation period (How long it takes to show symptoms)

Δ = 1/5



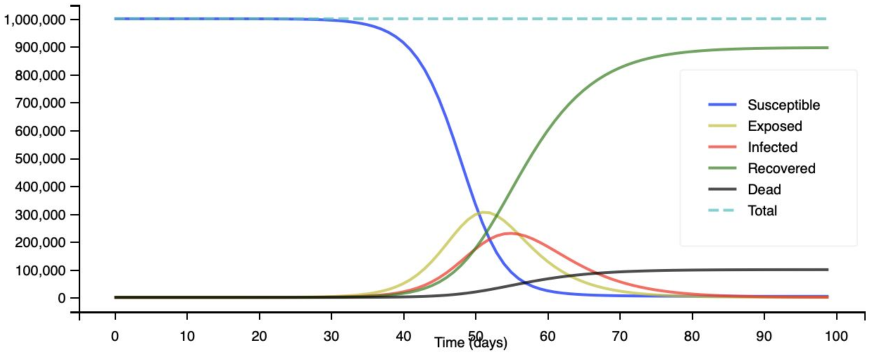
Δ = 1/7



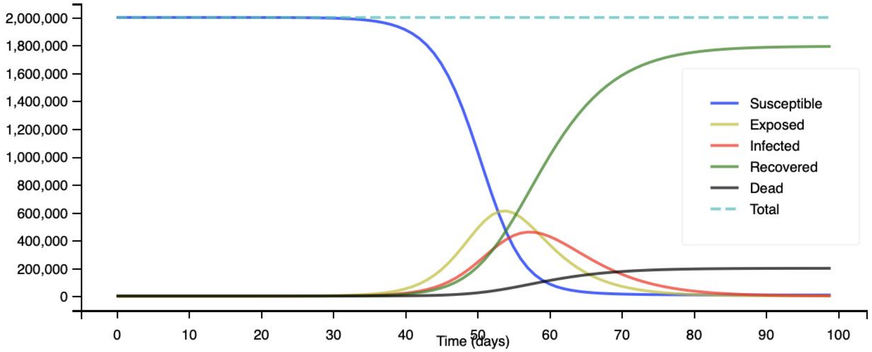
Changing N

- N : Number of total people

N = 1,000,000



N = 2,000,000



Simulating COVID

Our Parameters

N: 350,000,000

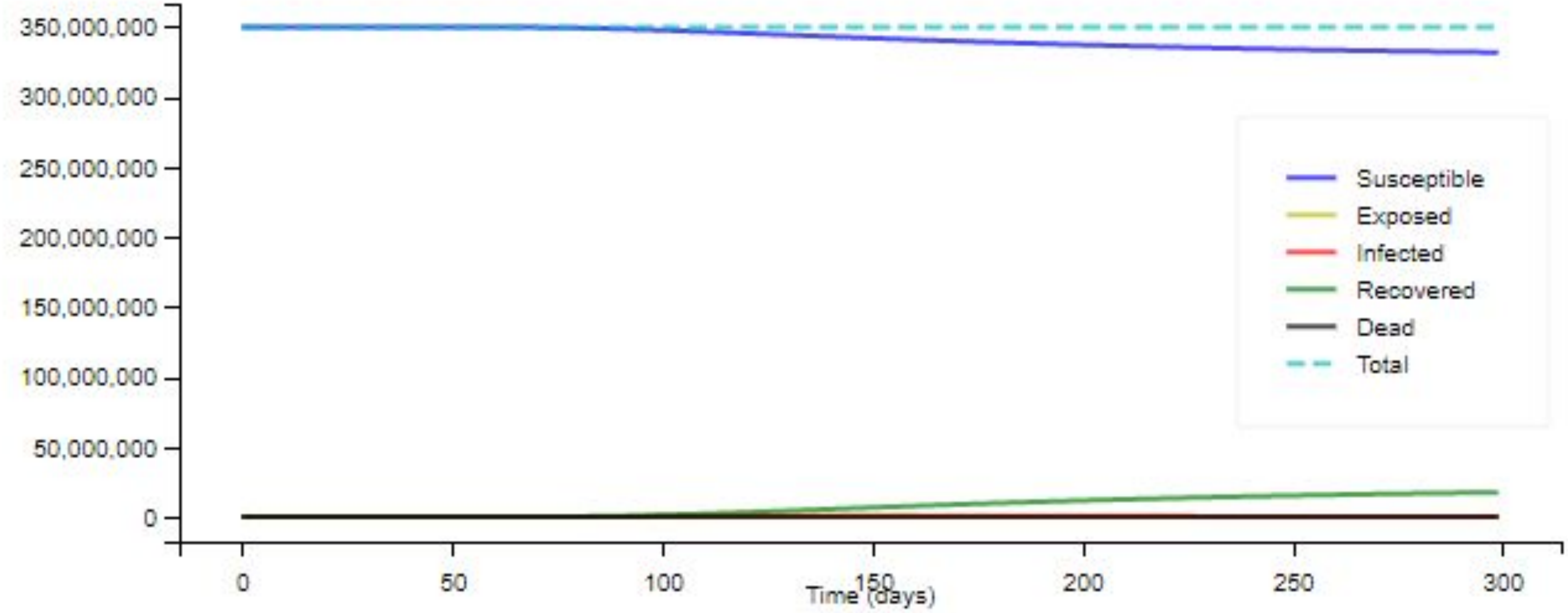
Alpha: 0.02

Gamma: 1 / 6

Beta 0.833 to 0.158 over time

Delta: 1 / 4

COVID Model



350,000,000
300,000,000
250,000,000
200,000,000
150,000,000
100,000,000
50,000,000
0
0
50
100
150
200
250
300
Time (days)
Susceptible
Exposed
Infected
Recovered
Dead
Total

Challenges

- Finding accurate values for parameters
  - What region? What time frame?
  - How to extract parameters from data?
  - How to fit parameters to data?
  - The parameters change continuously

- What combinations of parameters are most realistic?

Future Work

- Getting more accurate parameters
    - Data Fitting

- Incorporating rate of change of the parameters (second derivatives?) into the model
- Exploring more combinations of parameters

- Exploring different states
    - birth/death
    - asymptomatic/symptomatic
    - Vaccine state

References

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