Parth Gupta
UT EID: pg22947

Infectious Disease Simulation

In this project, we model the spread of an infectious disease through compartmental modeling. It is important to acknowledge the assumptions and simplifications made in these simulations. The health statuses of individuals were quite simplified. The one-dimensional nature of the population (lying along a single-dimension vector) makes it difficult to accurately model the spread of disease. However, this simplified simulation still provides valuable insights into the nature of disease spreading and the power of inoculation.

Part I: Coding the Basics (39.2)

Summary:

In this portion of the project, I wrote code to track the health of one person over time. Their health begins as susceptible to illness, but still healthy. They are infected after a random number of days, and this sickness lasts for a total of 5 days. Afterwards, their health is marked as recovered, and the program ends (since they can no longer become sick).

Sample Output:

```
[pg22947@isp02 Project]$ ./part1program
Give Person 1 a name: Joe
On day 1, Joe is susceptible
On day 2, Joe is susceptible
On day 3, Joe is sick (4 more sick days)
On day 4, Joe is sick (3 more sick days)
On day 5, Joe is sick (2 more sick days)
On day 6, Joe is sick (1 more sick days)
On day 7, Joe is sick (0 more sick days)
On day 8, Joe is recovered
```

Discussion:

This first portion of the simulation, though simple, provides an interesting insight into susceptibility. The individual is given a 5% chance of being infected every day. Though this is slim, repeatedly running the program shows the individual was typically infected within 30 days, if not earlier. For example, the output provided above shows the individual infected by the third day. This time period makes sense, since a 5% chance corresponds to 1/20th; running this program many times would eventually show infection occurring, on average, around the 20th day. Given real-world flu seasons last multiple months, the probability of becoming sick within one month is concerning. This demonstrates that even diseases with very low contagion rates eventually affect susceptible individuals who have no protection (e.g. no inoculation) against the disease.

Of course, multiple assumptions are made in this simulation. The first is of the probability of infection (5%), though this is a good approximation given the percent of Americans afflicted with the flu annually.[1] Inoculation is not considered in this simulation.

We also assume an illness that lasts for five days. However, this is quite a simplification, since illnesses affect individuals differently. Additionally, the definition of "illness" is ambiguous. In this program, it is best thought of as beginning from when initial symptoms of poor health start showing. The way the main program is coded, the day on which the individual is "infected" is not the first day of their illness. This makes sense; usually, there is some time between when a person is infected with an illness, and when they begin to show symptoms (i.e. being sick).

Even accounting for assumptions, however, Part I's simulation demonstrates the susceptibility of individuals to illness if they have no protection.

[1] https://www.webmd.com/cold-and-flu/flu-statistics

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Part II: Population (39.3)

Summary:

In this portion of the project, I wrote code to visualize the health of a population. In this population, one person is sick, but cannot infect others. As such, the disease does not propagate through the population, and the simulation ends once the sick individual has recovered. Susceptibility is indicated by “?”, illness by “+”, and recovery by “-”. Inoculation is not considered.

Sample Output:

```
[pg22947@isp02 Project]$ ./part2program

Give me a population size: 20

On day 1, 1 are sick: ? ? ? + ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ?

On day 2, 1 are sick: ? ? ? + ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ?

On day 3, 1 are sick: ? ? ? + ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ?

On day 4, 1 are sick: ? ? ? + ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ?

On day 5, 1 are sick: ? ? ? + ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ?

On day 6, 0 are sick: ? ? ? - ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ?

Disease ran its course by day 6
```

Discussion:

Since this simulation did not utilize contagion, inoculation, nor random infection, it serves best as a visualization and precursor to the following parts.

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Part III: Contagion (39.4)

Summary:

In this portion of the project, I wrote code to visualize the health of a population. In this population, one person is randomly infected, but can infect his “neighbors” (people in adjacent positions to him in the Population vector). This allows the disease to propagate through the population, though the spread is limited. Inoculation is also considered, randomly selecting certain individuals to be immune from contagion. Susceptibility is indicated by “?”, illness by “+”, recovery by “-”, and inoculation by “*”.

Sample Output:

[pg22947@isp02 Project]$ ./part3program

Give me a population size: 100

How contagious is the disease (decimal): 0.5

What percent of people were vaccinated (decimal): 0

On day 1, 1 are sick: ?
? + ? ? ?
? ? ? ? ? ? ? ? ?

On day 2, 1 are sick: ?
? + ? ? ?
? ? ? ? ? ? ? ? ?

On day 3, 2 are sick: ?
? + + ? ? ?
? ? ? ? ? ? ? ? ?

On day 4, 2 are sick: ?
? + + ? ? ?
? ? ? ? ? ? ? ? ?

On day 5, 3 are sick: ?
? + + + ? ? ?
? ? ? ? ? ? ? ? ?

On day 6, 2 are sick: ?
? + + - ? ? ?
? ? ? ? ? ? ? ? ?

On day 7, 3 are sick: ?
? + + + - ? ? ?
? ? ? ? ? ? ? ? ?

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On day 8, 2 are sick: ? + + - - ? ? ? ? ? ? ? ? ? ? ? ?

On day 9, 2 are sick: ? + + - - ? ? ? ? ? ? ? ? ? ? ? ?

On day 10, 1 are sick: ? + - - - ? ? ? ? ? ? ? ? ? ? ? ?

On day 11, 1 are sick: ? + - - - ? ? ? ? ? ? ? ? ? ? ? ?

On day 12, 0 are sick: ? - - - - ? ? ? ? ? ? ? ? ? ? ? ?

Disease ran its course by day 12

[pg22947@isp02 Project]$ ./part3program

Give me a population size: 100

How contagious is the disease (decimal): 0.5

What percent of people were vaccinated (decimal): 0.5

On day 1, 1 are sick: * ? ? * * * ? ? ? * * ? * ? ? * * ? * * * * * * ? ? * * * ? * * * * ? ? * * ? ? * ? ? * ? * * * * * * ? ? ? ? * ? ? ? ? ? ? ? ? + * ? * * ? * * ? * * ? ? ? ? ? ? * * ? ? * ? * ? ? * ? ? * * ? ? * * ?

On day 2, 1 are sick: * ? ? * * * ? ? ? * * ? * ? ? * * ? * * * * * * ? ? * * * ? * * * * ? ? * * ? ? * ? ? * ? * * * * * * ? ? ? ? * ? ? ? ? ? ? ? ? + * ? * * ? * * ? * * ? ? ? ? ? ? * * ? ? * ? * ? ? * ? ? * * ? ? * * ?

On day 3, 1 are sick: * ? ? * * * ? ? ? * * ? * ? ? * * ? * * * * * * ? ? * * * ? * * * * ? ? * * ? ? * ? ? * ? * * * * * * ? ? ? ? * ? ? ? ? ? ? ? ? + * ? * * ? * * ? * * ? ? ? ? ? ? * * ? ? * ? * ? ? * ? ? * * ? ? * * ?

On day 4, 1 are sick: * ? ? * * * ? ? ? * * ? * ? ? * * ? * * * * * * ? ? * * * ? * * * * ? ? * * ? ? * ? ? * ? * * * * * * ? ? ? ? * ? ? ? ? ? ? ? ? + * ? * * ? * * ? * * ? ? ? ? ? ? * * ? ? * ? * ? ? * ? ? * * ? ? * * ?

On day 5, 2 are sick: * ? ? * * * ? ? ? * * ? * ? ? * * ? * * * * * * ? ? * * * ? * * * * ? ? * * ? ? * ? ? * ? * * * * * * ? ? ? ? * ? ? ? ? ? ? ? + + * ? * * ? * * ? * * ? ? ? ? ? ? * * ? ? * ? * ? ? * ? ? * * ? ? * * ?

On day 6, 1 are sick: * ? ? * * * ? ? ? * * ? * ? ? * * ? * * * * * * ? ? * * * ? * * * * ? ? * * ? ? * ? ? * ? * * * * * * ? ? ? ? * ? ? ? ? ? ? ? + - * ? * * ? * * ? * * ? ? ? ? ? ? * * ? ? * ? * ? ? * ? ? * * ? ? * * ?

On day 7, 1 are sick: * ? ? * * * ? ? ? * * ? * ? ? * * ? * * * * * * ? ? * * * ? * * * * ? ? * * ? ? * ? ? * ? * * * * * * ? ? ? ? * ? ? ? ? ? ? ? + - * ? * * ? * * ? * * ? ? ? ? ? ? * * ? ? * ? * ? ? * ? ? * * ? ? * * ?

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On day 8, 1 are sick: * ? ? * * * ? ? ? * * ? * ? ? * * ? * * * * * * ? ? * * * ? * * * * ? ? * * ? ? * ? ? * ? * * * * * * ? ? ? ? * ? ? ? ? ? ? ? + - * ? * * ? * * ? * * ? ? ? ? ? ? * * ? ? * ? * ? ? * ? ? * * ? ? * * ?

On day 9, 2 are sick: * ? ? * * * ? ? ? * * ? * ? ? * * ? * * * * * * ? ? * * * ? * * * * ? ? * * ? ? * ? ? * ? * * * * * * ? ? ? ? * ? ? ? ? ? ? + + - * ? * * ? * * ? * * ? ? ? ? ? ? * * ? ? * ? * ? ? * ? ? * * ? ? * * ?

On day 10, 1 are sick: * ? ? * * * ? ? ? * * ? * ? ? * * ? * * * * * * ? ? * * * ? * * * * ? ? * * ? ? * ? ? * ? * * * * * * ? ? ? ? * ? ? ? ? ? ? + - - * ? * * ? * * ? * * ? ? ? ? ? ? * * ? ? * ? * ? ? * ? ? * * ? ? * * ?

On day 11, 1 are sick: * ? ? * * * ? ? ? * * ? * ? ? * * ? * * * * * * ? ? * * * ? * * * * ? ? * * ? ? * ? ? * ? * * * * * * ? ? ? ? * ? ? ? ? ? ? + - - * ? * * ? * * ? * * ? ? ? ? ? ? * * ? ? * ? * ? ? * ? ? * * ? ? * * ?

On day 12, 1 are sick: * ? ? * * * ? ? ? * * ? * ? ? * * ? * * * * * * ? ? * * * ? * * * * ? ? * * ? ? * ? ? * ? * * * * * * ? ? ? ? * ? ? ? ? ? ? + - - * ? * * ? * * ? * * ? ? ? ? ? ? * * ? ? * ? * ? ? * ? ? * * ? ? * * ?

On day 13, 1 are sick: * ? ? * * * ? ? ? * * ? * ? ? * * ? * * * * * * ? ? * * * ? * * * * ? ? * * ? ? * ? ? * ? * * * * * * ? ? ? ? * ? ? ? ? ? ? + - - * ? * * ? * * ? * * ? ? ? ? ? ? * * ? ? * ? * ? ? * ? ? * * ? ? * * ?

On day 14, 0 are sick: * ? ? * * * ? ? ? * * ? * ? ? * * ? * * * * * * ? ? * * * ? * * * * ? ? * * ? ? * ? ? * ? * * * * * * ? ? ? ? * ? ? ? ? ? ? - - - * ? * * ? * * ? * * ? ? ? ? ? ? * * ? ? * ? * ? ? * ? ? * * ? ? * * ?

Disease ran its course by day 14

Discussion:

First, we shall discuss contagion without inoculation considered. The introduction of contagion allowed us to visualize the spread of disease throughout a population. As expected, increased probability of contagion increases the number of people affected by the illness. However, the nature of this contagion – in which the sick individual could only infect their neighbor – made it difficult for the disease to spread to the entire population. Indeed, some simulations of 100-person populations with a 100% contagion probability and 0% inoculation leave many people unaffected. A 50% contagion probability with the same population and inoculation rate generally fails to affect more than 10 individuals.

I should note that this is partially due to the way the code is written. If a sick individual can infect a neighbor, the code randomly chooses a neighbor to infect. However, if the chosen neighbor has already recovered from illness, then that neighbor will not be infected. If the randomized process works out to where the recovered neighbor is repeatedly chosen to be infected, the sick individual will not "pass on" their illness. Additionally, illness which begins at the "ends" of the population cannot propagate beyond the "ends", limiting the spread of disease.

From these simulations, we gather that limiting the ability for sick individuals to "interact" with and potentially infect large groups of people stifles the spread of disease. It demonstrates the importance of keeping contagious people away from susceptible populations. As such, it supports the idea of "staying home from work" when ill to prevent infecting coworkers. The limited exposure of sick people to susceptible people in this simulation is an important assumption in this part; Part IV will do away with such an assumption.

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Part III also involved simulations incorporating inoculation. Inoculation proved to be extremely effective at reducing the number of individuals affected by the illness, and subsequently the number of days the disease lasted in the population. Even the introduction of just 10% inoculation rate to a 100-person population with a 100% contagion probability would occasionally reduce the affected population to just two individuals. While results varied depending on the location of the initially infected individual, the inclusion of randomly distributed inoculated individuals significantly curtailed the spread of disease.

Certain assumptions about vaccinations made in this simulation do conflict with reality. First, the vaccinated members of the population were chosen randomly, scattered throughout the population. In reality, inoculation occurs in groups within populations. A woman who gets vaccinated is more likely to have a vaccinated husband and children, whereas a father who does not get vaccinated is less likely to have vaccinated children. Urban areas with many medical resources and outreach campaigns (e.g. universities) are likely to have higher rates of inoculation than rural areas with limited resources. Inoculation is therefore not randomly distributed across society but varies across pockets of the population.

Additionally, vaccination does not always work. Measures of vaccine effectiveness by the CDC show fluctuations between 40% and 60% effectiveness.[2] While this is significant, the assumption that inoculation entails no chance of illness is unrealistic. This assumption, along with the limited way contagion occurred in this simulation, likely made inoculation appear more effective than true.

[2] https://www.cdc.gov/flu/professionals/vaccination/effectiveness-studies.htm

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Part IV: Spreading (39.5)

Summary:

In this portion of the project, I wrote code to visualize the health of a population. In this population, one person is randomly infected, but can infect multiple other people who are randomly distributed across the population. This allows the disease to propagate through the population quite a bit. Inoculation is also considered, randomly selecting certain individuals to be immune from contagion. Susceptibility is indicated by “?”, illness by “+”, recovery by “-”, and inoculation by “*”.

Sample Output:

```
[pg22947@isp02 Project]$ ./part4program

Give me a population size: 100

How contagious is the disease (decimal): 0.5

What percent of people were vaccinated (decimal): 0.5

On day 1, 1 are sick: * * ? ? ? ? ? ? * * * * ? ? ? * ? ? ? ? * ? * * * ? * ? ? * ? ? * * * ? ? * * * ? ? ? *
* ? * * * * ? ? ? * * ? ? ? ? * ? * * ? ? ? * ? * * * * * * ? * * * ? ? * + ? * * ? ? * ? ? ? ? * * * ? * ? ? *

On day 2, 1 are sick: * * ? ? ? ? ? ? * * * * ? ? ? * ? ? ? ? * ? * * * ? * ? ? * ? ? * * * ? ? * * * ? ? ? *
* ? * * * * ? ? ? * * ? ? ? ? * ? * * ? ? ? * ? * * * * * * ? * * * ? ? * + ? * * ? ? * ? ? ? ? * * * ? * ? ? *

On day 3, 2 are sick: * * ? ? ? ? ? ? * * * * ? ? ? * ? ? ? ? * ? * * * ? * ? ? * ? ? * * * ? ? * * * ? ? ? *
* ? * * * * ? ? ? * * ? ? ? ? * ? * * ? ? ? * ? * * * * * * ? * * * ? ? * + ? * * ? ? * ? ? ? ? * * * + * ? ? *

On day 4, 6 are sick: * * ? ? ? ? ? ? * * * * ? ? ? * ? ? ? ? * ? * * * ? * ? + * ? ? * * * ? ? * * * ? ? ?
* * ? * * * * ? ? ? * * ? ? + ? * ? * * + ? ? * ? * * * * * * ? * * * ? ? * + ? * * ? ? * ? ? ? + * * * + * ? ? *

On day 5, 20 are sick: * * ? ? ? ? ? + * * * * + ? ? * ? ? ? ? * ? * * * ? * ? + * ? ? * * * + + * * * + ?
+ * * ? * * * * ? ? + * * + ? + + * ? * * + + ? * ? * * * * * * + * * * ? ? * + + * * ? + * ? ? ? + * * * + * +
? *

On day 6, 29 are sick: * * ? ? ? ? ? + * * * * + ? + * + + ? ? * ? * * * ? * + + * + ? * * * + + * * * + ?
+ * * ? * * * * ? ? + * * + ? + + * ? * * + + ? * + * * * * * * + * * * + ? * - + * * ? + * + + ? + * * * + * +
+ *

On day 7, 46 are sick: * * ? + ? + + + * * * * + + + * + + + ? * + * * * + * + + * + + * * * + + * * * + +
+ * * + * * * * + ? + * * + + + + * + * * + + + * + * * * * * * + * * * + + * - + * * + + * + + + + * * * + * +
+ *

On day 8, 48 are sick: * * + + ? + + + * * * * + + + * + + + + * + * * * + * + + * + + * * * + + * * * + +
+ * * + * * * * + + + * * + + + + * + * * + + + * + * * * * * * + * * * + + * - + * * + + * + + + + * * * - * +
+ *
```

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On day 9, 44 are sick: * * + + ? + + + * * * * + + + * + + + + * + * * * + * + - * + + * * * + + * * * + + + * * + * * * * + + + * * + + - + * + * * - + + * + * * * * * * + * * * + + * - + * * + + * + + + - * * * - * + + *

On day 10, 31 are sick: * * + + + + + - * * * * - + + * + + + + * + * * * + * + - * + + * * * - - * * * - + - * * + * * * * + + - * * - + - - * + * * - - + * + * * * * * * - * * * + + * - - * * + - * + + + - * * * - * - + *

On day 11, 21 are sick: * * + + + + + - * * * * - + - * - - + + * + * * * + * - - * - + * * * - - * * * - + - * * + * * * * + + - * * - + - - * + * * - - + * - * * * * * * - * * * - + * - - * * + - * - - + - * * * - * - - *

On day 12, 4 are sick: * * + - + - - - * * * * - - - * - - - + * - * * * - * - - * - - * * * - - * * * - - - * * - * * * * - + - * * - - - - * - * * - - - * - * * * * * * - * * * - - * - - * * - - * - - - - * * * - * - - *

On day 13, 1 are sick: * * - - + - - - * * * * - - - * - - - - * - * * * - * - - * - - * * * - - * * * - - - * * - * * * * - - - * * - - - - * - * * - - - * - * * * * * * - * * * - - * - - * * - - * - - - - * * * - * - - *

On day 14, 1 are sick: * * - - + - - - * * * * - - - * - - - - * - * * * - * - - * - - * * * - - * * * - - - * * - * * * * - - - * * - - - - * - * * - - - * - * * * * * * - * * * - - * - - * * - - * - - - - * * * - * - - *

On day 15, 0 are sick: * * - - - - - - * * * * - - - * - - - - * - * * * - * - - * - - * * * - - * * * - - - * * - * * * * - - - * * - - - - * - * * - - - * - * * * * * * - * * * - - * - - * * - - * - - - - * * * - * - - *

Disease ran its course by day 15

Discussion:

The ability for sick people to reach many other susceptible people dramatically increased the number of people affected by illness. Oftentimes, the only people unaffected by illness were those inoculated.

However, when an overwhelming majority of the population was inoculated, herd immunity could be seen. The disease spread was very limited, if at all. This demonstrates the importance of herd immunity, as it provides protection to those who could not be inoculated (e.g. young children). As Part I showed, remaining completely unprotected from a disease means eventual infection. As such, herd immunity is crucial.