Epidemic Spread Simulation and Dashboard

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ABSTRACT

It is known that the behavior of the people is the major driving factor for the spread of COVID-19. It is important to understand how these behaviors affect the spread of the virus and which of these affect the most. A simulation allows us to understand the impacts of these behaviors and allows us to take necessary steps to mitigate/stop these behaviors, thorugh public education.

This research creates a small community, and simulates the spread of an infectious disease within that community under different conditions. With this project, we want to create a simulation that allows individual behaviors to be switched on and off, allowing us to understand which human behavior has the most impact on viral spreading. Here the behaviors were: only essential interactions, inclusion of children's parties, weekly family gatherings, and allowing mutations. The simulation also vaccinates 70% of the population to examine if the extent and the rate of spread of the virus decrease. Here we increase the performance of the existing interaction model, and incorporate an interactive user interface with data visualization to make the computations more available. This work enables increased population size, reduced runtime, interactive control, visual feedback to the user.

1 OVERVIEW

COVID-19 has played a major role in our lives for the last couple years, and I feel it is important to understand how it spreads. Given that the behavior of the people is the major driving factor for the spread of COVID. It is important to understand how these behaviors affect the spread of the virus and which of these affect the most. With this project, we want to create a simulation that allows individual behaviors to be switched on and off, which would allow us to understand the effects individually. Running simulation on a console is a barrier to most people. So, the paper aims to create a dashboard with a user interface allowing people to use it more freely and understand these behaviors.

There are 6 different scenarios that were implemented as part of this paper. The scenarios include: casual interactions, total lockdown, birthday parties, weekly family gatherings, vaccinating 70% of the population, and Enabling Disease mutations.

There are also multiple sliders to control the probability of a certain event to occur. If a person has school for on a certain day, School Going Probability affects the probability of a person going to school on a particular day. Similarly, we have options to set probabilities for Going to Work, walking a Dog, Visiting a Prayer Group, Volunteer work, Playing Sports, Filling up gas, Going to a mall, or Buying groceries. These attributes can be swichted on/off and changed to analyze the spread of the disease.

The structure of the paper is as follows: Section 2 talks about the background. Then, the experimental design is explained in section 3. Section 4 covers the implementation methodology and in section 6, the results of the simulation are explained. Section 6 talks about the future work and the conclusion is drawn in section 7.

2 BACKGROUND

A paper by Gang Xie [16] showcased the simulation of COVID 19 using a Monte-Carlo simulation process. In this paper, they modeled the simulation using both real world and hypothetical examples. This model proved to be a frontrunner in predicting the peaks of COVID-19 and thus, combating the spread of the virus. A forecasting model was developed by Hassanat et al., 2021 [5] that examined the situation and spread of COVID-19 in two cities of Saudi Arabia. In this research, they adjusted several parameters like social distancing, the walking distance of people and the infection rate on real-world data of the two cities to examine and understand the spread of the virus in these two cities.

According to a survey in Uttar Pradesh, India [6], there is a stigma that exists in the society that the virus spreads more effectively in socially backward societies. The team carried out a randomized field experiment and informed the people about the effects of the Coronavirus and how they can help avoid the spread. After the information brief and more observation after that, the people, in spite of their socio-economic conditions, were more compliant with the social distancing norms and understood the facts about prevention and transmission of the virus. They were mentally and physically healthier.

In a paper by Ravi Kiran Yedur Prabhakar [11], did a similar simulation using pandas on python. He ran the simulation for 39000 people for scenarios like Casual interactions, Lockdown, Vaccinations, Family Gatherings etc. But due to using pandas, the run time for the simulations were upwards of 6 hours to run.

3 EXPERIMENTAL DESIGN

3.1 Population Generation

Before running a simulation, we need the data to run the simulation on. For this, I generate a population database.

The population demographics of different countries are different. Population Demographics help us understand the size, status, and behavior of populations. Fig 1 is an Population demographics of United states.

The family sizes were kept similar to US demographics. Depending on the size of the family, the first two people of any family are adults. The rest of the people in the family are considered to be kids. For each person a list of attributes are assigned depending on the age.

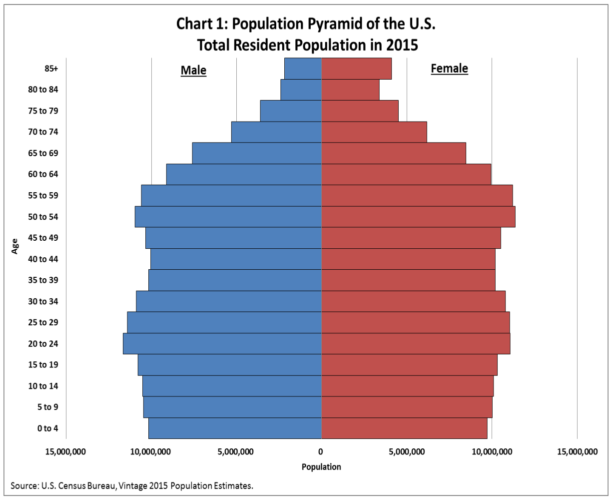

Figure 1: Population Demographics of United States. The Simulated Population follows similar demographics.

For storing the generated population Neo4j is used, one of the most popular graph databases. Each and every attribute, family and people are implemented as nodes and connections are established if a person belongs to a certain family or does a certain attribute.

Initially, nodes for all the attributes are created. There are 3 different types of schools (grad school, middle school, high school) are there 6 unique schools for each type. Similarly, there are multiple workplaces, dog walking parks, malls, gas stations etc. Each of these places are denoted as a node in the graph database.

Once the places for different attributes are created, we then create families. Each family has a size, and attributes like do they were a mask, do they have a dog, do they have a car etc. For each family a park, a gas station, and grocery store are assigned where they would walk the dog, fill up a car and buy groceries. This is with an assumption that attributes like wearing a mask, owning a dog, etc are a attributes that belong to the whole family, rather than individuals. We have assigned arbitrary values of 9 and 7 for the quantity of groceries and gasoline respectively. These quantities decrease by 1 per day and the day it becomes 0, one adult from the family would go to replenish these items. These values are same for every member of the family.

Then the actual people that belong to the family are created. If there are one 1 or 2 people, then both of them are considered to be adults. If more than 2 people are present, 2 are meant to be adults, and the rest are assigned using the US population demographics. People above 18 years are classified as adults and those who are 18 and below, are classified as children. Children between the age of 0 and 4 are classified as toddlers. Children between 5 and 11 attend grade school and children between 12 and 15 and between 16 and 18 attend middle school and high school respectively.

After the age is assigned, the rest of the attributes are assigned. Depending on the age, a school(Grade school, Middle school, or High School) or a Work Place. Along with these, other attributes like playing sports, Working for a voluteer group, Being part of a prayer group, and going to a mall are randomly assigned.

3.2 Simulating Epidemic Spread

All the parameters are built from the ground up. The previous state of the people is not considered in the project. We are trying to simulate the state of the spread of the virus everyday with respect to each person in the population. The simulation is run for the first 100 days of the year. Every day, every contagious person's activities are tracked and the virus is spread using various factors and probabilities. This way the spread of the virus is closer to real life.

On day one, 10 people are exposed to the virus. This is the seed population for the virus to grow. There is an incubation period of 2-14 days, for COVID-19 according to the CDC [4]. According to an article by Cristina Cicogna, M. D. [2], a person infected with COVID-19 is contagious 2 to 3 days before showing symptoms. So, in the simulation exposed person can't spread the disease for the 2 days [2]. The simulation is run according to this. To the people who are exposed, we assign a random number between 2 to 14 for them to show symptoms. From the start of the contagious period till the end of the incubation period, these people are drivers of the virus and are not quarantined. Once the incubation period ends, these people are quarantined. It can take 2 - 6 weeks to recover from the virus [12]. There is also the possibility of people recovering due to no symptoms. However, they are expected to quarantine nonetheless for a span of 2 weeks. In the simulation, these numbers are randomly assigned to the exposed and infected people. The people who are quarantined are not allowed to go out until they are completely recovered. They will not be drivers of the spread of the virus.

The decision to wear masks plays a key role in the spread of the virus. Studies have shown that there is conflicting evidence that the probability of the spread of the virus if one of the two individuals (the infected and the healthy) who come in contact with each other do not wear a mask. However, the probability of transmission of the virus is high [10] [13]. In this simulation, joint probabilities of people's mask wearing attributes are considered and the virus is spread accordingly.

Mass gatherings also effect the spread of an epidemic disease adversely. There are many studies that talk about the adverse effects of social gatherings on the number of COVID-19 cases [3] [9]. To demonstrate the effects of social gatherings the experiment includes Birthday Parties for children, and weekly family gatherings.

To demonstrate how parties can affect the spread of the virus, we have considered children's birthday parties. The assumption here is that only the children over the age of 4 can have birthday parties. The parents are not involved in these parties directly however, once the children go back home, the other members of the family are infected based on a probability. Every person who comes to these parties is susceptible and is made infectious and contagious if that person is chosen based on a probability of getting picked. This 2 way, we have another way in which the virus is spread. Using this, we can examine how having birthday parties can make people infectious and if they accelerate the process.

We are also introducing relationships between families. Each family is friends with five other families and all the five families have this one family as their friend. This is a connected component that helps in understanding how the virus gets spread when families meet each other for gatherings. A motive of this research is to understand if seasons effect the spread of the virus. For example, let's assume that two families that are friends with each other meet for a barbecue every week in summer. This increases the number of people that are vulnerable to the virus. This is another interaction that the paper keeps track of.

A pod is a container for different people based on the activity they perform. The people in the population belong to specific pods, for example, the volunteering pod, the school-going pod or the work-going pod. We have assumed that a person that belongs to a certain pod would be strongly connected to everyone else in that pod. A single person may belong to multiple pods. Thus, if a person belongs to multiple pods, the people who belong to these pods are also strongly connected. This way, if a person is contagious and comes in contact with people in the two pods, the people in both pods have a higher probability of contracting the virus.

3.3 Experiments

We have performed the simulation on many scenarios to check how the spread of the virus would take place under several conditions. Below are the scenarios involved in the simulations.

3.3.1 Casual Interactions. In this scenario, the population takes part in all the activities. The population behaves with no regard to the ongoing pandemic. However, they do not have any parties or regular family gatherings. This simulation spreads the virus through the general activities performed by people. Thus, the simulation does not amplify the spread of the virus which might be caused due to these gatherings. This is a base scenario for our experiment.

3.3.2 Only Essential Interactions. In this scenario, the population takes part in only a limited number of activities that are completely essential. This is to simulate the state of a lockdown, where the town in completely closed down, except for essential activities. The activities that people can take part in include dog walks, visits to gasoline stations and grocery stores and volunteering in several organizations. People do not go to work or school. People also do not take part in any religious activity(Church, Temple, Mosque etc.) or play sports of any kind. This is a base scenario for our experiment.

3.3.3 Allowing Birthday Parties. As mentioned above, we have examined how children's birthday parties can take part in spreading the virus. The basis for taking up children's birthday parties is that, these parties might have been partly responsible for the spread of the virus. According to the research[7] [15], there was an increase in the number of people diagnosed with COVID-19 in the group that had birthday parties when compared to the group that did not have any birthday parties.

This is additional criteria that can be selected along with a base scenario. To implement this, we have assumed that each child between the ages 4 and 19 belongs to groups of friends. Each group consists of 20 people. The simulation is run similar to the base scenario with the addition of birthdays. On a birthday, all the children who belong to the respective group(s) get together to celebrate the birthday and the virus spreads among the children in the respective groups based on a probability.

3.3.4 Allowing Family Group Gatherings. Another situation that the paper deals with is when families have weekly meetings with their friends. This is additional criteria that can be selected along with a base scenario. So all the activities from the base scenario are included. Due to the inclusion of these family gatherings, the spread of the virus is amplified [14]. Thus, a higher number of people get the virus than in 3.3.1.

To implement this, we have created a network of friends in the Graph Database. Each family belongs to a group of friends. Each group has 5 families. These groups meet once every week. It will be the same group meeting every week.

3.3.5 Vaccinating 70% of the Population. To demonstrate and extend President Biden's goal of vaccinating 70% of the adult population of the United States [1], this research considers 70% of the families who wear masks and 70% of those who do not. Once the vaccination is completed, these people are allowed to go about their daily activities and also take part in the birthday parties scenario (3.3.3). The research aimed to show the results of interactions only after getting vaccinated.

This is additional criteria that can be selected along with a base scenario. To implement this, we used masks as a main screening criteria. the families as a whole are vaccinated at once and not individuals. Based on the mask wearing preferences of the families, 70% of the families are randomly selected and are vaccinated before the start of the simulation. These people are immune to the virus and are removed from the initial set of people. The rest of the people take part in the base scenario.

3.3.6 Allowing of Mutations in the Virus. Everytime a virus spreads from one person to another, it has a chance mutate. This would affect multiple things, like the death rate and the infection rate. Mutations can also mean that the people who are immune to one strand of the virus, are not immune to the others. But the later scenario is not implemented during this research.

To implement this, we introduce a mutation every 10-14 days [8] of the simulation. This changes the incubation period, infection rate and death rate of the virus.

4 IMPLEMENTATION

4.1 User Interface

We wanted the final Population generator and the Epidemic simulator to be available to be used easily by everyone. An interactive user interface is important for usability. The UI was implemented using Angular 12. I also used Python 3.9 along with the flask framework to create a REST API framework An API framework is required for the UI to be able to interact with the backend, which is the Population generator, and Epidemic simulation scripts. Figure 2 gives a view of part of the Dashboard.

Population can be generated by moving the Total population slider to the appropriate position and clicking on "Create Population". Once a population is created we can run a simulation on them. We need to first pick a Scenario:

(1) **Casual Interactions:** The population takes part in all the activities.
(2) **Total Lockdown:** The population takes part in limited activities like dog walking, Filling gas and Grocery Shopping.

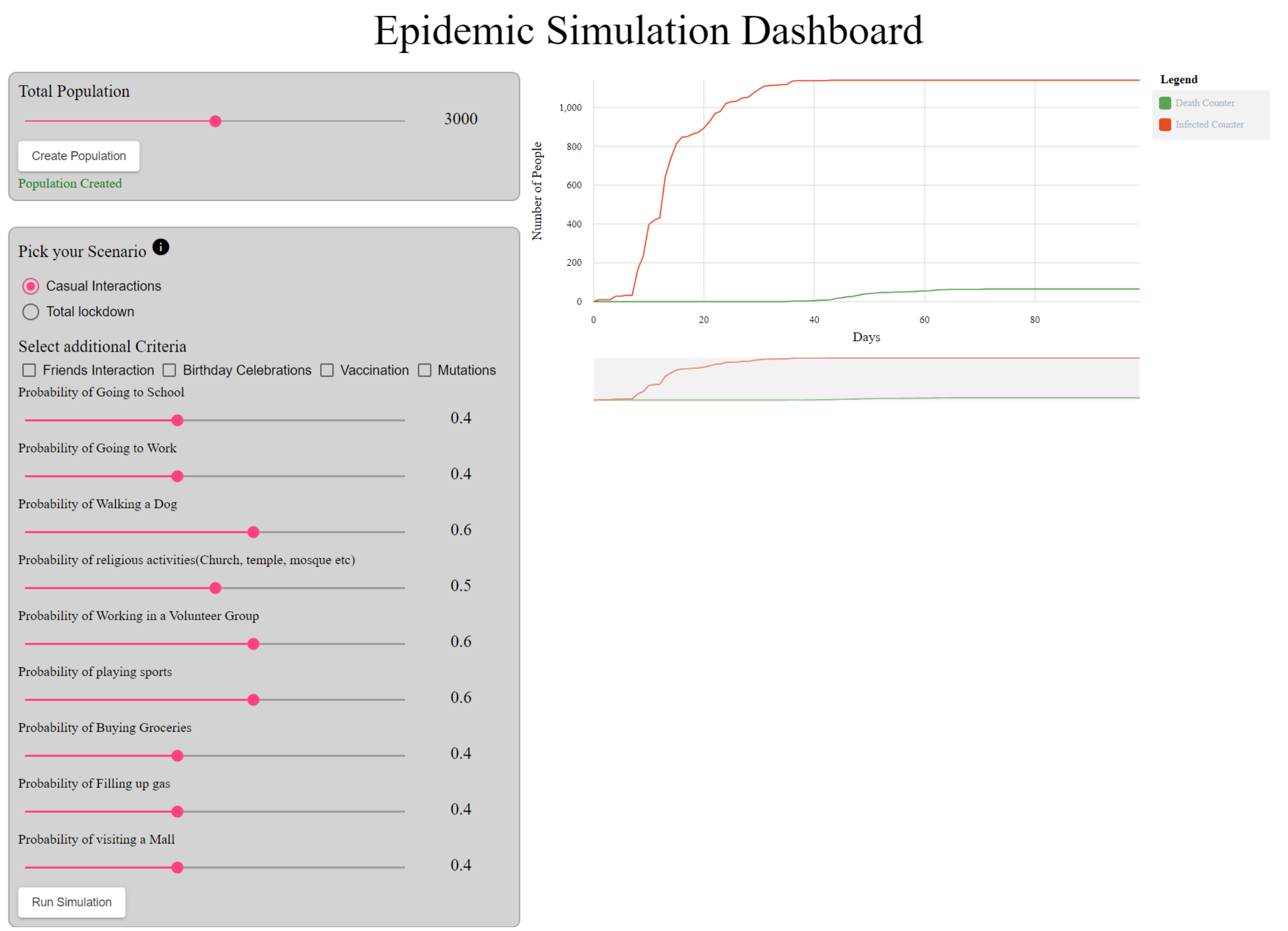

Figure 2: View of the Epidemic Simulation Dashboard. Scenario, criteria and probability selection are on the left and the results are on the right,

All other activities like Going to school, work, malls, etc are removed.

We can also select additional sub scenarios for each scenario.

(1) **Friends Interaction:** Groups of family's are created. These groups meet every week.
(2) **Birthday Celebrations:** Allows children between the age of 4-18 to celebrate birthdays.
(3) **Vaccination:** Vaccinates 70% of the population, which removes them from the set of people that can be infected.
(4) **Mutations:** Allows mutations to occur, every 10 - 14 days which increase the death rate, and infection rate, and decrease the incubation period.

There are also additional sliders using which various probabilities can be controlled.

(1) Probability of Going to School
(2) Probability of Going to Work
(3) Probability of Walking a Dog
(4) Probability of religious activities(Church, temple, mosque etc)
(5) Probability of Working in a Volunteer Group
(6) Probability of playing sports
(7) Probability of Buying Groceries
(8) Probability of Filling up gas
(9) Probability of visiting a Mall

with all the options selected, we can run a simulation for it to be displayed to on the right half of the Dashboard.

4.2 Population Generation

The programs are written in Python 3.9. The database of choice was Neo4j. We wanted a database that scales for high populations and also has the properties of a Relational Database. A Graph database in the the form of Neo4j was perfect for these reasons. The number of people to be included in the population is given as a parameter is selected in the UI and passed a parameter. Each person in the family has particular interests in performing an activity.

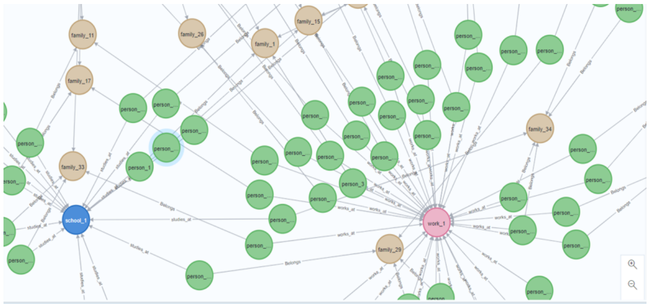

Figure 3: Snapshot of Graph Representation of the Population. Green Nodes represent people, Brown nodes represent families etc.

The program initially generates Nodes for each of the activities. There are 3 different types of schools (grade school, middle school, high school) are there 6 unique schools for each type. Similarly, there are multiple work places, dog walking parks, malls, gas stations etc. Each of there places are denoted as a node in the graph database.

Once the Nodes for different attributes are created, the program then creates families. Each family has a size, and attributes like do they were a mask, do they have a dog, do they have a car etc. Each of these attributes are connected to their respective Nodes. Once the Families are created, people in the family are generated. As mentioned in 4.2 the demographics of the population are similar to US population. Each of the person is assigned different attributes depending on age, using probabilities. They are assigned different actions depending on the attributes and the day of the week. These values are then used in simulating different scenarios.

4.3 Epidemic Simulation

We have implemented Epidemic simulation for 2 different Scenarios

(1) **Casual Interactions:** The Graph database is queried for people by this program and 10 random people are initially infected. The date of infection, the incubation period, the contagious period, the recovery date and the removal date are calculated for the initially infected and saved. The people who are in the infected set will not be contagious again. The infected people are added to a queue. The attributes of these people in the queue are compared with those of the people who are healthy on that day. If the conditions are met, the newly infected are derived and they are added back to the queue. Until the queue is empty, the infection metrics of day the of infection, the incubation period, the range of contagious dates, the date of recovery and the date of removal are calculated. This process is done for each day of the simulation period.

(2) **Total Lockdown:** Similar to Casual Interaction simulations with the exception that only Grocery Shopping, Filling up Gas, Walking Dog and Volunteer work are the only activities allowed. The rest are not checked.

After selecting the scenario, There are 4 other epidemic criteria to choose from:

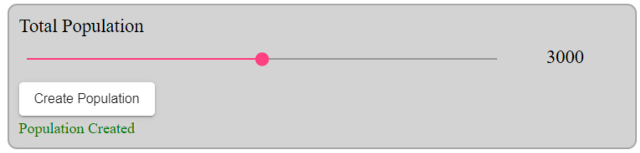

Figure 4: Snapshot of population generation section. We can move the slider to create the desired amount of population

Figure 5: Snapshot of epidemic simulation section. Sliders for each option can be moved independently to generate a unique scenario.

(1) **Vaccination:** Before running the epidemic simulation, 70% of the mask wearing families are vaccinated. The vaccinated people are treated similar to the people recovered from the disease and can't catch the disease.

(2) **Mutations:** For every mutation, a random number between 10-14 is chosen. On the chosen day, the the death rate, and infection rate increases and the incubation date deceases by a small value.

(3) **Family group Interaction:** Groups of families are created in the Graph Database. There is an extra activity during the situation, where all the families in the group meet.

(4) **Family group Interaction:** Children of age between 4 - 18 celebrate birthdays in this scenario. Everyday the program checks if any children have their birthdays on the that day. if yes, they celebrate their birthday with 20 other friends(selected randomly).

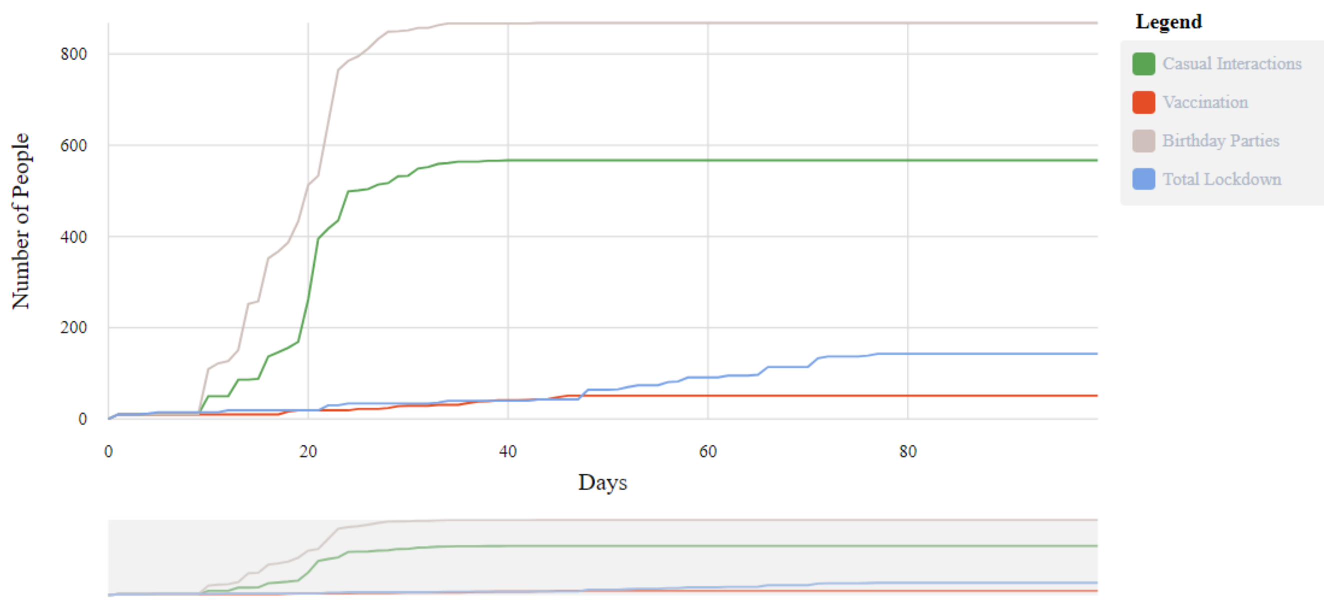

Figure 6: Snapshot of epidemic simulation graph. Only Base scenarios with no additional criteria, and Vaccination and Birthday Celebrations with Casual Interactions were used.

5 RESULTS

Figure 4 shows that we can create a population of up to size 5000. This is create a population like we spoke about in section 4.2. The generated population is stored as Nodes in Neo4j.

Figure 5 shows the various options that can be used to run a simulation. Different scenarios and criteria can be used in either independently or in tandem to generate an epidemic and view the results. This helps the end user understand how much each of these activities affect the spread of an infectious disease.

By choosing different options, there are 20 different possibilities to choose using the scenarios and criteria. Below are some of the few interesting observations. All of these experiments were run with the same probability values.

Figure 6 shows graphs for the Casual Interactions and Total lockdown. Both these scenarios were run with all other criteria like Birthdays, vaccination, mutations turned off. It is clear that enforcing a lockdown would help is restricting the number of cases.

In the lockdown scenario, the total number of infected people is less compared to Casual Interactions . This is due to the fact that the people do not come in contact with each other except for a few essential activities. As mentioned earlier, only essential activities like Grocery Shopping, Filling gas etc are available for people to take part in and this has a massive say in how people behave and contract the virus.

Figure 6 also shows that birthdays increase the number of cases dramatically. It is also observed that enabling family gatherings has a similar effect. This is due to the fact that in both these scenarios an additional activity is added where the number of cases can soar upwards.

Figure 6 also demonstrates that vaccinating 70% of the population decrease the spread dramatically. This makes sense as 70% of the population is made immune and cant participate in the epidemic spread, keeping the number of cases in check.

In Yedur's[11] Implementation, he ran the code for 36000 and it took about 4 hours. As my implementation in on the UI, I restricted the run time 1 min and are able to run the simulation for 4000 people. Also I added the ability to run the simulation with multiple scenarios/ criteria together unlike his implementation.

6 FUTURE WORK

This simulation currently is slow to be put on the UI. Making the code more efficient or changing the design is required so it can be run for a greater number of people.

Masks are key in this simulation for spreading the virus. This research does not consider social distancing norms or hygiene into consideration while spreading the virus. Making use of these two parameters could make the simulation more accurate.

In the real world depending on the size and population of the town, the number of schools, parks, malls etc vary. But, currently the number of schools, parks, malls etc are fixed in the simulation, irrespective of the population. This needs to be changed, to make the simulation more realistic.

Once person gets vaccinated, or is contracted by a disease he is considered immune to the disease. But when a virus mutates there is a probability that even people that are immune, get the virus. This was not considered a part of the simulation, and could be improved.

7 CONCLUSION

We examined how, using general everyday activities, the spread of the an infectious virus can be simulated and the effect of different behaviors can be studied in a small community. We have also created a Front end dashboard for easy simulation of epidemic spread.

We have studied the impact of different scenarios on the spread of an infectious disease in a small community. Code was written to create a small community and assign different interests and social activities to the people in the community. The population distribution is modeled to match that of the United states.

Using the generated population, I then built a epidemic simulator that tracks the virus based on several Scenarios, criteria and probabilities. The simulator generates a JSON file that is in the format understood by the FrontEnd UI.

The Angular UI has options to pick and choose which scenarios and criteria to select. It also has the capabilities to adjust the Probabilities of various activities to occur.

This paper is a study of the affects of different activities on the spread of an infectious disease. By changing the probabilities and enabling different scenarios, the number of the infected cases can be seen in the graph. By comparing these scenarios, the end user can understand the affect a particular activity had on the spread of a disease.

This paper was also a study of the concept of the small world community, and how people are connected to each other in an interdependent web of mutual responsibility. It is hoped that the results of this work will help with community education, and can help to save the lives.

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