Analysis - Simulating disease spread through Cellular Automata and the SIR model DRAFT

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Contents

1 Introduction

Since 1999, there have been 11 major disease outbreaks across the globe, eight of which involved thousands of cases. To effectively control an outbreak and ultimately stop it in its tracks, it's current and past states must be analysed so it's spread can be predicted, which is essential in influencing how governments should deal with such a threat.

This is currently being seen in how the UK government is dealing with COVID-19, where a balance between a total lockdown and total freedom needs to be struck to control how the virus spreads. This balance is essential in allowing businesses to continue operating, keeping the economy afloat and allowing people their freedoms to do what they want.

My project aims to provide a starting point for where a disease outbreak can be modelled either by cellular automata or the SIR model, which can be used in an educational environment to teach people about the spread of diseases. A user will be able to input custom parameters according to the disease they are trying to simulate and be able to introduce special events such as a partial or permanent lockdown, to be able to see how the disease spread could change. A user should also be able to compare the two different ways of simulating a disease.

Source: https://sundial.csun.edu/156361/news/a-timeline-of-outbreaks-from-2000-to-present/

2 Initial objectives

These objects represent my initial aims of what this project should be able to do. These may change later on throughout this project.

- Simulate the spread of a disease using the SIR model
- Simulate the spread of a disease using the Cellular Automata model
- Input custom parameters or use default values (from a previous disease) including infection rate, incubation period and death rate for the SIR model
- Input custom parameters or use default values (from a previous disease) relating to the number and infectivity of cells for the CA model
- Set a quarantine period or introduce a vaccine (therefore limiting disease transmission)
- Click on a graph and show statistics from that point in time
- Export graphs produced as png
- Upload past simulation results into the program to generate a graph from that previous simulation
- Be able to compare graphs of two different diseases

3 Potential user

Mr Bliss - Biology teacher at Abingdon School As this model provides a starting point for modelling disease outbreak, it's most effective use would be in an education environment, where it is used to teach people about how disease can spread and how changes in parameters such as the infection rate, recovery rate, time of infection and immunity can affect how effectively a disease is transmitted throughout a cohort.

4 How the problem was researched

To first understand how I could make this project, I had to research the two main methods of modelling disease spread, the SIR model and Cellular Automata. Once I got the basic idea of how each model worked, I further researched how I could implement these in Python, as well as looking at how to use some Python libraries to help me.

- Find out how SIR and Cellular Automata work
- Research how to implement SIR and Cellular Automata in code
- Learn how to use the Matplotlib library to draw graphs for my disease models
- Learn how to use Pandas to export data to an external file
- Learn how to use Tkinter to create a GUI interface and multiple pages
- Learn how to create, use and modify an SQL database using Sqlite3

4.1 The SIR model

The SIR model is a simple disease spread model which uses differential equations to determine the number of people in three categories, the susceptible, the infected and the recovered. The susceptible population represent those who can become infected a disease, the infected population represent those currently infected with the disease who are able to spread it to other people and the recovered population represent those who are no longer infected. In some models, people in the recovered population can be infected again.

4.1.1 Equations for the SIR model

People in each group

$S = S(t)$ - number of susceptible individuals

$I = I(t)$ - number of infected individuals

$R = R(t)$ - number of recovered individuals

The Susceptible equation

$$\frac{dS}{dt} = \frac{-\beta S(t)I(t)}{N}$$

where β is the rate at which infections occur (a positive constant)

The Infected equation

$$\frac{dI}{dt} = \frac{\beta S(t)I(t)}{N} - \gamma I(t)$$

where γ is the rate at which people recover

The Recovered equation

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

Model without vital dynamics

$$\frac{dS}{dt} + \frac{dI}{dt} + \frac{dR}{dt} = 0$$

As this model doesn't take into account vital dynamics ie. people aren't added through birth or removed through death, the sum of all the changes is constant and equal to 0

4.2 The Cellular Automata model

The basic idea of cellular automata that there there is a collection of cells with a finite set of states. Every new generation, the state of a cell can be changed depending on the state of it's neighbouring cells.

4.2.1 My implementation of CA

- Cells move randomly within a grid. Most cells will be susceptible but some will be infected
- If a susceptible cell comes in close range to an infected cell, there is a chance that that susceptible cell will be come infected
- Infected cells are only infected for a certain period of time, so after a certain number of generations the cell will no longer be infected and will be in the recovered category

5 Prototyping of code

5.1 The scientific models

5.1.1 Elementary cellular automata

My initial cellular automata model was very basic and only worked on a 1D line. The shape of each new line would be decided by looking at the previous line and applying a ruleset to it.

```
class CA:
    def __init__(self, width, generations):
        self.ruleset = [0, 1, 1, 1, 1, 0, 1, 1]
        self.width = width
        self.cells = [0] * width
        self.new_cells = [None] * width
        self.cells[int((width / 2) - 1)] = 1
        self.generations = generations
        self.cell_timeline = []

    def rules(self, a, b, c, i):
        index = int((a + b + c), 2)
        ruleset = [0, 1, 0, 1, 1, 0, 1, 0]
        self.new_cells[i] = ruleset[index]

    def draw(self):
        output = ""
        for cell_state in self.cell_timeline:
            for element in cell_state:
                if element == 0:
                    output += " " + " "
                else:
                    output += "X" + " "
            print(output)
            time.sleep(0.1)
            output = ""

    def ca(self):
        for gen in range(self.generations):
            for i in range(self.width):
                a = str(self.cells[((i - 1) % self.width)])
                b = str(self.cells[i])
                c = str(self.cells[((i + 1) % self.width)])
                # print(a,b,c)
                self.rules(a, b, c, i)
            self.cells = self.new_cells
            self.cell_timeline.append(self.cells)
            self.new_cells = [None] * self.width
        self.draw()

ca = CA(100, 100)
ca.ca()
```

The result of elementary cellular automata

```
                              x x
                             x   x
                            x x x x
                           x       x
                          x x     x x
                         x   x   x   x
                        x x x x x x x x
                       x               x
                      x x             x x
                     x   x           x   x
                    x x x x         x x x x
                   x       x       x       x
                  x x     x x     x x     x x
                 x   x   x   x   x   x   x   x
                x x x x x x x x x x x x x x x x
               x                               x
              x x                             x x
             x   x                           x   x
            x x x x                         x x x x
           x       x                       x       x
          x x     x x                     x x     x x
         x   x   x   x                   x   x   x   x
        x x x x x x x x                 x x x x x x x x
       x               x               x               x
      x x             x x             x x             x x
     x   x           x   x           x   x           x   x
    x x x x         x x x x         x x x x         x x x x
   x       x       x       x       x       x       x       x
  x x     x x     x x     x x     x x     x x     x x     x x
 x   x   x   x   x   x   x   x   x   x   x   x   x   x   x   x
x x x x x x x x x x x x x x x x x x x x x x x x x x x x x x x x
```

5.1.2 Basic SIR model

My starting block for the SIR model was a function which calculated the rate of change of the susceptible, infected and recovered population.

```
def eqns(y0, t, beta, gamma):
S, I, R = y0
dsdt = -(beta * S * I) / N # rate of change of susceptible individuals
didt = ((beta * S * I) / N) - gamma * I # rate of change of infected individuals
drdt = gamma * I # rate of change of recovered individuals
return dsdt, didt, drdt
```

5.2 External library testing TBD

5.2.1 Tkinter

My intial prototying for tkinter was done with the help of a YouTube video which focused on having multiple tkinter pages in a single file. Link: https://youtu.be/jBUpjijYtCk

This prototype allowed there to be multiple Tkinter windows which could be switched between by a button click. The way this method worked was by removeing and adding widgets depending on which page should be shown. Although this method may have worked for me, in the final project I went with destroying a Tkinter window and starting a completely new one when a user wanted to switch, as the code for this was easier to understand and write.

```
import tkinter as tk


class Gui(tk.Tk):
   def __init__(self, *args,
                  **kwargs): # *args - pass through any number of variables; **kwargs
                      - pass through dictionaries
       tk.Tk.__init__(self, *args, **kwargs) # initialising tkinter
       container = tk.Frame(self) # the frame of the window
       container.pack(side="top", fill="both", expand=True)
       container.grid_rowconfigure(0, weight=1) # 0 sets minimum size, weight shows
           priority
       container.grid_columnconfigure(0, weight=1)
       self.frames = {} # allows application to open different types of pages easily

       for F in (StartPage, PageOne): # all pages need to be listed here
           frame = F(container, self)
           self.frames[F] = frame # saving classes to dictionary, "loading it in"
           frame.grid(row=0, column=0, sticky="nsew")

       self.show_frame(StartPage) # start page is shown first

   def show_frame(self, cont):
       frame = self.frames[cont] # looks for cont in dict
       frame.tkraise() # which is then raised


class StartPage(tk.Frame):

   def __init__(self, parent,
                  controller): # parent class is Gui, controller class is main class,
                      allowing show_frame to be called
       tk.Frame.__init__(self, parent)

       label = tk.Label(self, text="Start Page")
       label.pack(pady=10, padx=10)
       button1 = tk.Button(self, text="Page 1", command=lambda:
           controller.show_frame(PageOne))
       button1.pack()


class PageOne(tk.Frame):

   def __init__(self, parent, controller):
       tk.Frame.__init__(self, parent)

       label = tk.Label(self, text="This is page 1")
       label.pack(pady=10, padx=10)
       button2 = tk.Button(self, text="Start Page", command=lambda:
           controller.show_frame(StartPage))
       button2.pack()


app = Gui()
app.mainloop()
```

The result

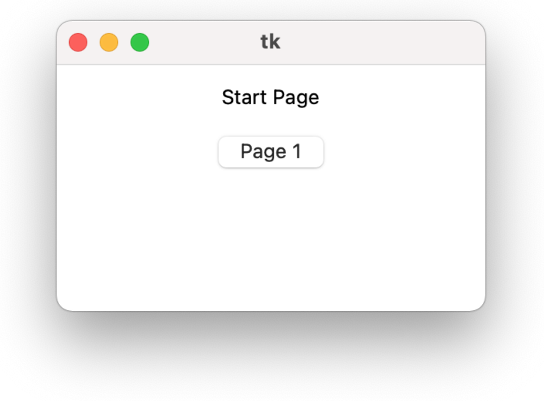


Figure 1: Start Tkinter window

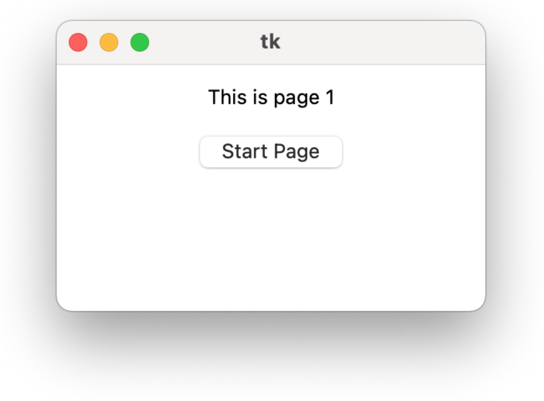


Figure 2: Page 1 Tkinter window

5.2.2 Matplotlib - FuncAnimation

The initial way I tried to update a graph with new values was by deleting the graph and plotting a new one. Funcanimation provided an easier way to do this, with the option of saving the animation as a video which was one of the objectives for my project. This prototype shows how a line graph works with funcanimate.

It works for both line graphs and scatter graphs

```
import matplotlib.pyplot as plt
from matplotlib.animation import FuncAnimation
from itertools import count
import random

x_full = [[229, 29, 52, 90, 78], [228, 29, 52, 90, 79], [229, 28, 53, 89, 79],
    [228, 27, 52, 90, 78], [227, 28, 51, 89, 79], [227, 27, 50, 88, 78], [226,
    28, 51, 88, 79], [227, 29, 51, 89, 79], [227, 30, 51, 90, 79], [228, 30, 51,
    90, 79], [229, 30, 50, 89, 78], [228, 30, 49, 90, 79], [228, 30, 50, 89, 78],
    [228, 31, 50, 88, 78], [229, 32, 49, 87, 78], [230, 33, 50, 87, 77], [230,
    34, 50, 88, 76], [231, 35, 51, 87, 75], [232, 36, 50, 87, 74], [232, 37, 51,
    86, 74]]
y_full = [[37, 23, 94, 195, 90], [37, 22, 93, 194, 89], [36, 22, 94, 195, 88],
    [36, 22, 95, 194, 88], [35, 22, 94, 195, 88], [36, 22, 95, 196, 89], [35, 21,
    94, 197, 90], [34, 20, 94, 196, 91], [34, 20, 94, 197, 90], [35, 19, 94, 196,
    90], [35, 18, 95, 197, 89], [35, 18, 94, 198, 88], [35, 19, 93, 197, 89],
    [35, 20, 94, 196, 90], [34, 20, 95, 196, 90], [33, 19, 95, 195, 90], [33, 19,
    96, 196, 91], [33, 20, 95, 196, 90], [32, 20, 94, 195, 90], [31, 19, 93, 194,
    91]]

x_vals = []
y_vals = []

index = count()

def animate(i):
    x_vals.append(next(index))
    y_vals.append(random.randint(0,5))
    plt.plot(x_vals, y_vals)
```

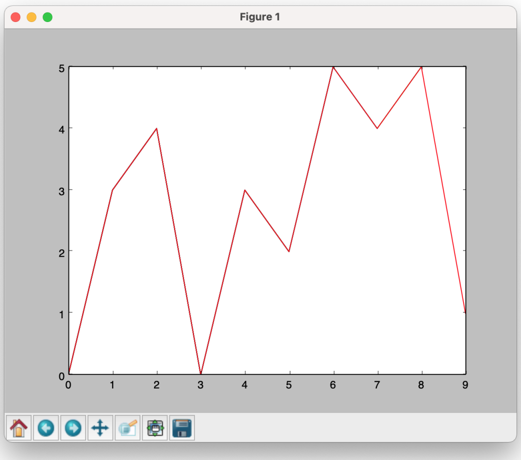


Figure 3: Graph 1

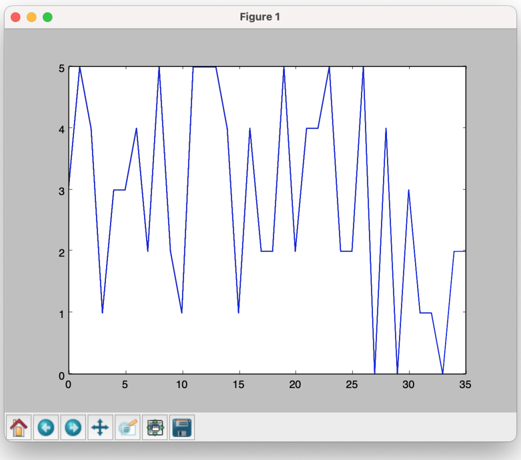


Figure 4: Graph 2

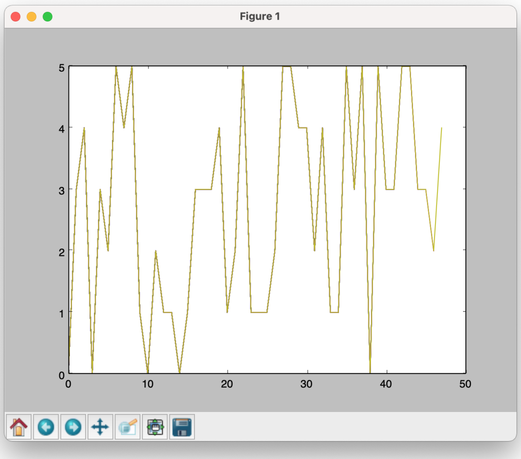


Figure 5: Graph 3

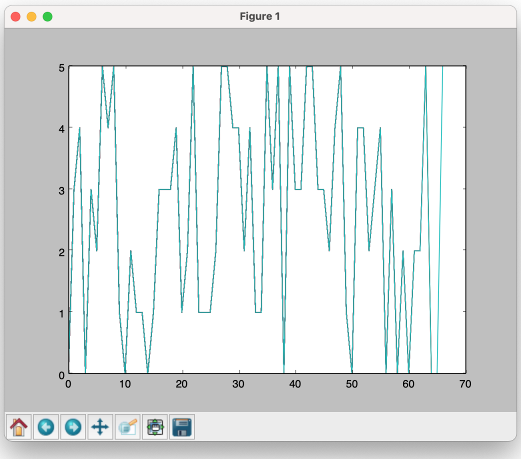


Figure 6: Graph 4

```
ani = FuncAnimation(plt.gcf(), animate, interval=10) # get current figure,
    function, interval
plt.show()
```

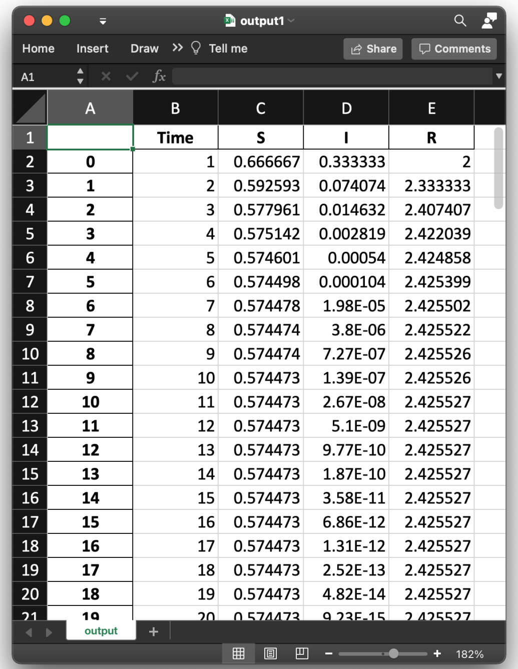
The result

5.2.3 Pandas

I used Pandas to help export the data generated using the SIR model. This allowed me to generate an excel file with appropriate column names, which could possibly be used later for data analysis

```
def export_to_excel():
data = {'Time': timearray,
        'S': solver_result[0],
        'I': solver_result[1],
        'R': solver_result[2]}

df = pd.DataFrame(data, columns=['Time', 'S', 'I', 'R'])
name = "output" + str(f) + ".xlsx"
df.to_excel(name, sheet_name='output')
```



	Time	S	I	R
0	1	0.666667	0.333333	2
1	2	0.592593	0.074074	2.333333
2	3	0.577961	0.014632	2.407407
3	4	0.575142	0.002819	2.422039
4	5	0.574601	0.00054	2.424858
5	6	0.574498	0.000104	2.425399
6	7	0.574478	1.98E-05	2.425502
7	8	0.574474	3.8E-06	2.425522
8	9	0.574474	7.27E-07	2.425526
9	10	0.574473	1.39E-07	2.425526
10	11	0.574473	2.67E-08	2.425527
11	12	0.574473	5.1E-09	2.425527
12	13	0.574473	9.77E-10	2.425527
13	14	0.574473	1.87E-10	2.425527
14	15	0.574473	3.58E-11	2.425527
15	16	0.574473	6.86E-12	2.425527
16	17	0.574473	1.31E-12	2.425527
17	18	0.574473	2.52E-13	2.425527
18	19	0.574473	4.82E-14	2.425527
19	20	0.574473	9.23E-15	2.425527

5.2.4 Pygame

One of the options I considered to simulate and show my Cellular Automata simulation was Pygame. With Pygame I would be able to easily create cells which could move randomly in a set space, and using Pygame's collision method I could detect if cells touched. In the end I decided against this method as although it may have been easier, using Matplotlib graphs would grant me extra flexibility, for example if I wanted to export position data of each cell I would already know how to do that with Matplotlib. The prototype I tested was made with the help of a YouTube video covering Pygame: https://youtu.be/NjvIooRpuH4

```
import pygame
import time

pygame.init()

black = (0,0,0)
white = (255,255,255)
red = (255,0,0)

gameDisplay = pygame.display.set_mode((800,600))
pygame.display.set_caption('Test')
```

```python
clock = pygame.time.Clock()

carImg = pygame.image.load('unnamed.jpg')

def text_objects(text, font):
    textSurface = font.render(text, True, black) # what to render, anti-aliasing,
        colour
    return textSurface, textSurface

def message_display(text):
    largeText = pygame.font.Font('freesansbold.ttf', 115)
    TextSurf, TextRect = text_objects(text, largeText)
    TextRect.center = (800/2, 600/2)
    gameDisplay.blit(TextSurf, TextRect)

    time.sleep(2)

    game_loop()

def crash():
    message_display('You crashed')

def car(x,y): # car object
    gameDisplay.blit(carImg, (x,y)) # drawing carImg to x,y

def game_loop():

    x = (100)
    y = (100)
    x_change = 0

    gameExit = False

    while not gameExit: # user controls
        for event in pygame.event.get():
            if event.type == pygame.QUIT:
                gameExit = True

            if event.type == pygame.KEYDOWN:
                if event.key == pygame.K_LEFT:
                    x_change = -10
                elif event.key == pygame.K_RIGHT:
                    x_change = 10

            if event.type == pygame.KEYUP:
                if event.key == pygame.K_LEFT or event.key == pygame.K_RIGHT:
                    x_change = 0

            print(event)

        x += x_change

        gameDisplay.fill(white)
        car(x,y)
        if x > 800 or x < 0: # boundaries
            crash()

        pygame.display.update()
        clock.tick(60)

game_loop()
pygame.quit()
```

5.3 SQL database TDB

6 Interview with target user

Q1. How could such a tool like this be used in the classroom?

A1. As a comparator of diseases; To be able to decide the best method to restrict a disease; To possibly predict the start of a second spike

E1. I will try to implement a feature where the parameters of two diseases could be entered, and a graph could be calculated and shown for both, which would allow a user to compare the spread of the two diseases.I will also add features that a government may try and implement to restrict a disease. This could include a lockdown feature or a vaccine introduction which would allow a user to see how the spread of a disease could change.

Q1. How could such a tool like this be used in the classroom?

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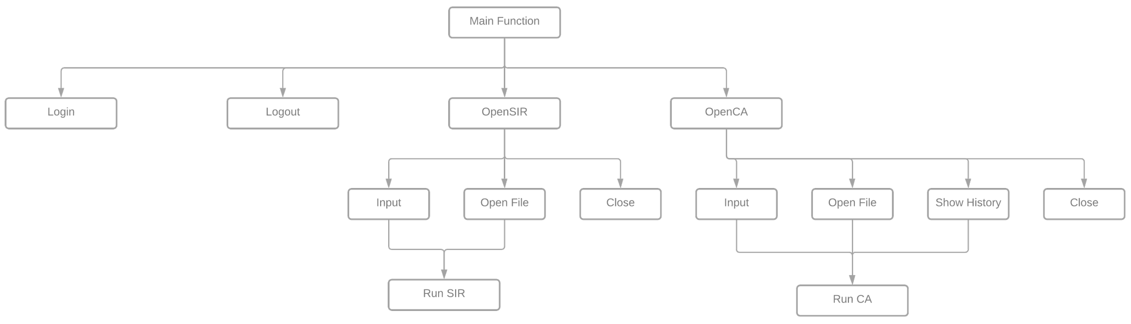
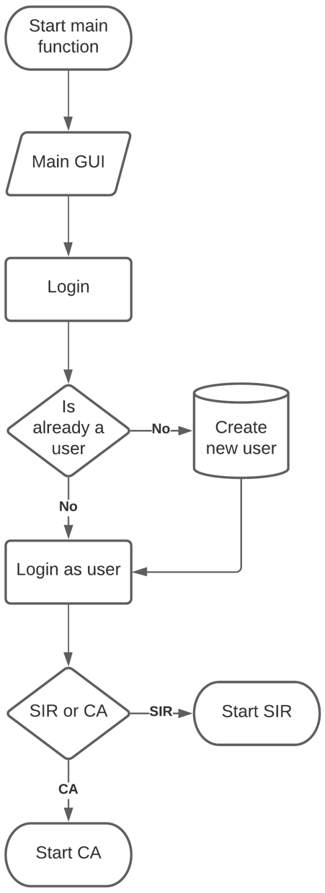
7 Documented design

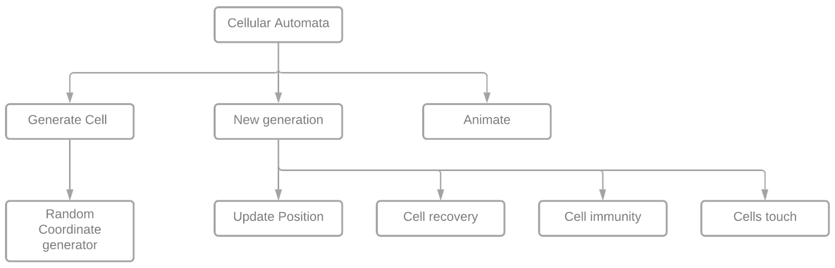
7.1 Main function structure diagram



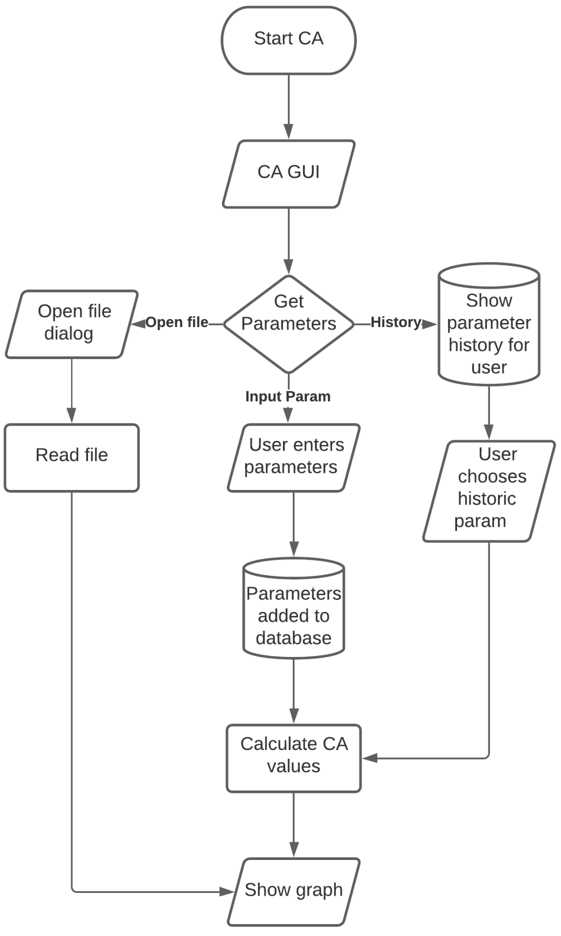
7.2 Main function flowchart



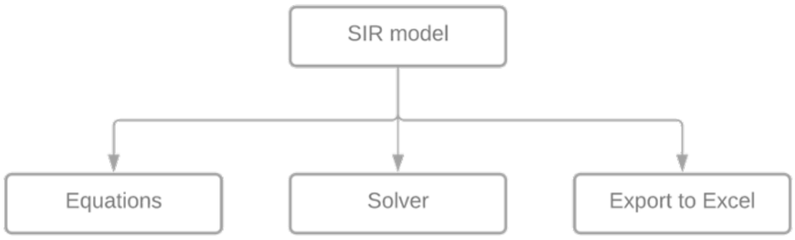
7.3 Cellular automata structure diagram



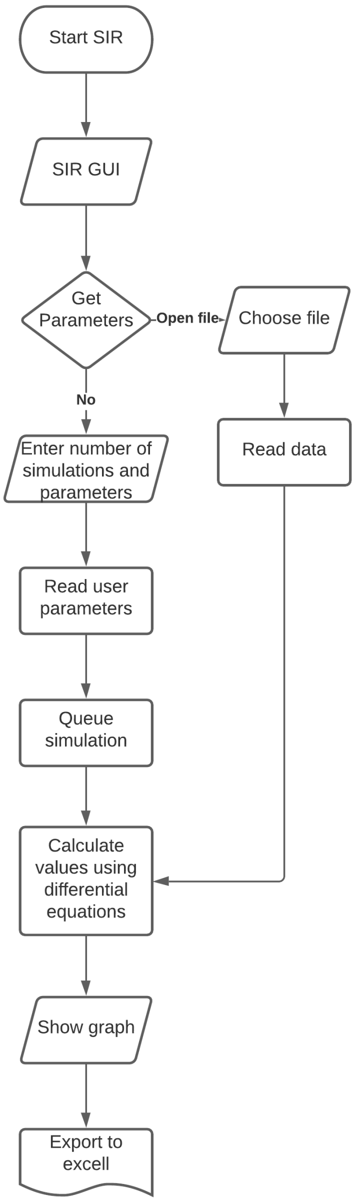
7.4 Cellular automata flowchart



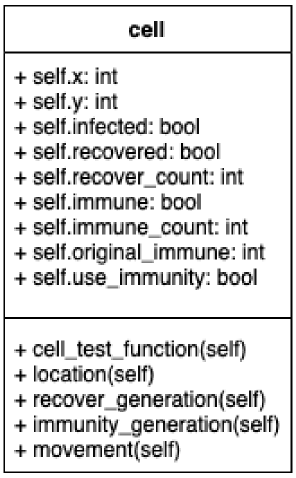
7.5 SIR Model structure diagram

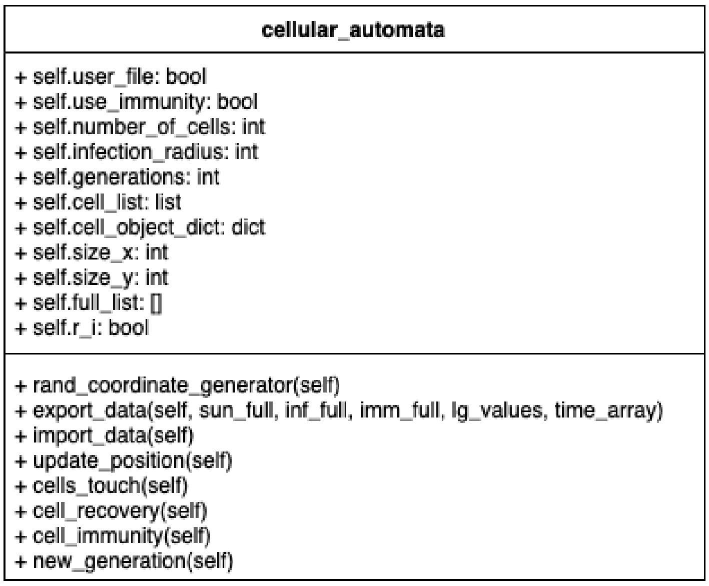


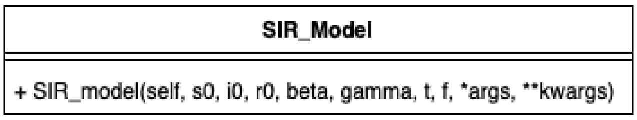
7.6 SIR model flowchart

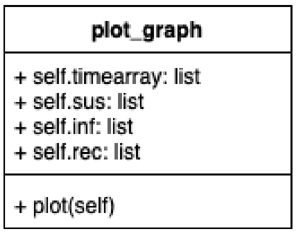


7.7 Cellular automata and SIR model UML charts

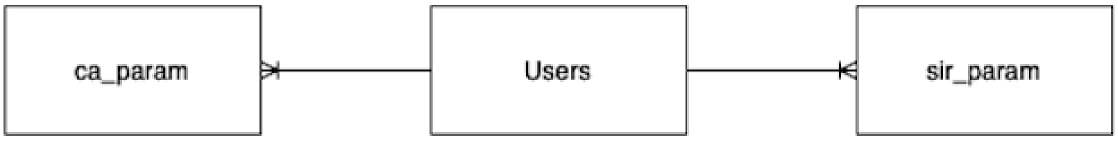

cell
+ self.x: int
+ self.y: int
+ self.infected: bool
+ self.recovered: bool
+ self.recover_count: int
+ self.immune: bool
+ self.immune_count: int
+ self.original_immune: int
+ self.use_immunity: bool
+ cell_test_function(self)
+ location(self)
+ recover_generation(self)
+ immunity_generation(self)
+ movement(self)




SIR_Model
+ SIR_model(self, s0, i0, r0, beta, gamma, t, f, *args, **kwargs)



7.8 SQL Entity relationship diagram



7.9 SQL queries used

Creating a new table

```
CREATE TABLE users (username text PRIMARY KEY, see_all integer)

CREATE TABLE ca_param (
    user string,
    no_cells integer,
    generations integer,
    size_x integer,
    size_y integer,
    infection_radius integer,
    no_infected integer,
    recovered_can_be_infected integer,
    days_until_recovered integer,
    use_immunity integer,
    days_of_immunity integer
    )

CREATE TABLE sir_param (
    user string,
    sus0 integer,
    inf0 integer,
    rec0 integer,
    beta integer,
    gamma integer,
    time integer
    )

INSERT INTO users VALUES (:username, :see_all), {'username': 'admin', 'see_all': 1}
```

This code sets up a clean database containing 3 tables, users, ca_param and sir_param. In the users table there are two columns, one containing the username and another containing a value to decide whether that user can see the history of all calculations performed and not just the calculations performed by that user. THIS WILL BE UPDATED. The ca_param and sir_param table contain columns to record the user doing the calculation and the parameters the user entered.

Inserting a new user into the user table

```
INSERT OR IGNORE INTO users VALUES (:username, :see_all),{'username': in_user,
    'see_all': 0}
```

Entering parameters from the Cellular Automata model

```
INSERT INTO ca_param VALUES (
    :user, :no_cells, :generations, :size_x, :size_y,
    :infection_radius, :no_infected, :recovered_can_be_infected,
    :days_until_recovered, :use_immunity, :days_of_immunity),
    {'user': in_user, 'no_cells': up[0], 'generations': up[1], 'size_x': up[2],
        'size_y': up[3],
        'infection_radius': up[4], 'no_infected': up[5], 'recovered_can_be_infected':
            up[6],
        'days_until_recovered': up[7], 'use_immunity': up[8], 'days_of_immunity':
           up[9]}
```

This query will be passed the user, in_user, and a list of the parameters entered, up. This will be added into the ca_param table.

Entering parameters from the SIR model

```
INSERT INTO sir_param VALUES (:user, :sus0, :inf0, :rec0, :beta, :gamma,
    :time),{'user': in_user, 'sus0': up[0], 'inf0': up[1], 'rec0': up[2], 'beta':
    up[3], 'gamma': up[4], 'time': up[5]
    }
```

Similar to function above except for the SIR model

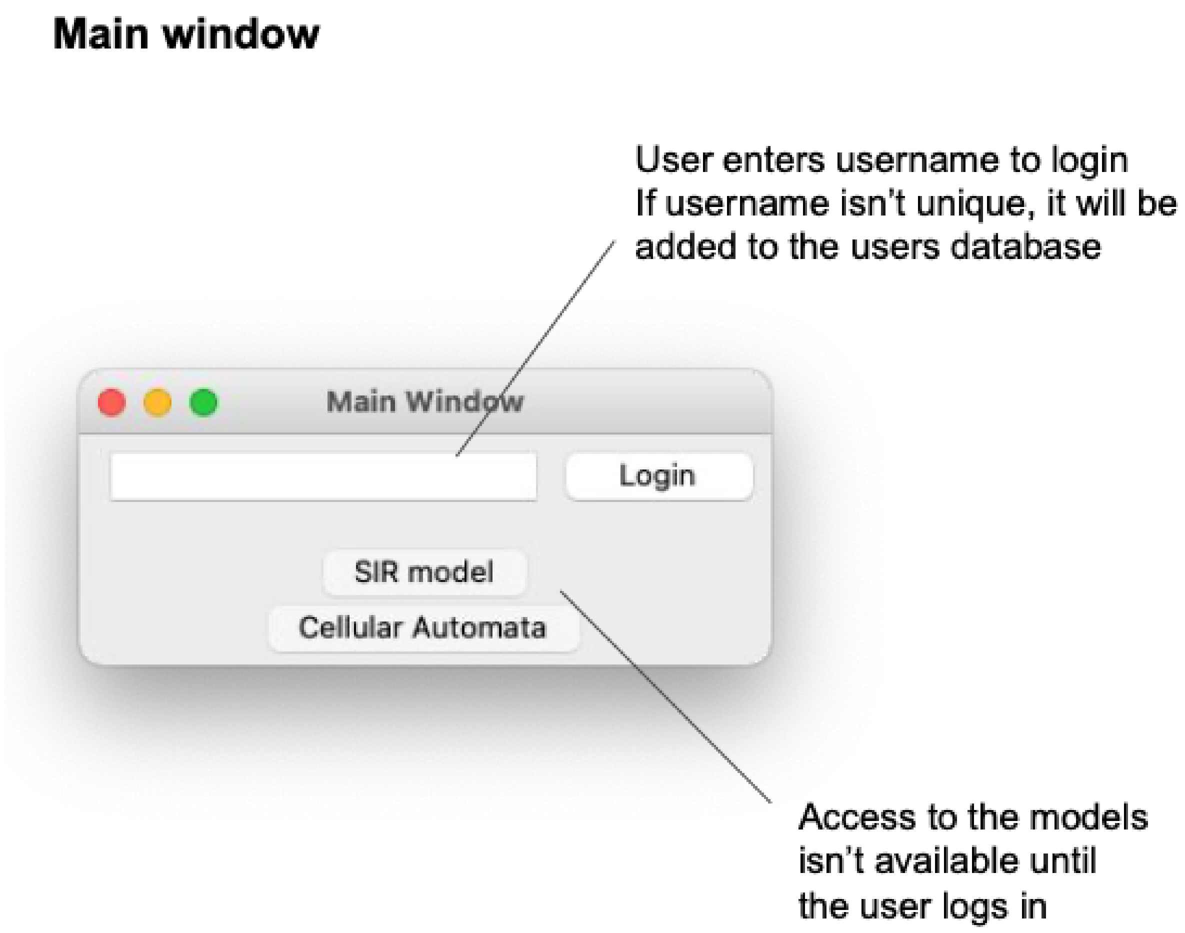
Return history from Cellular Automata model

```
SELECT * FROM ca_param WHERE user=:curr_user, {'curr_user': in_user}
```

Return history from SIR model

```
SELECT * FROM sir_param WHERE user=:curr_user, {'curr_user':in_user}
```

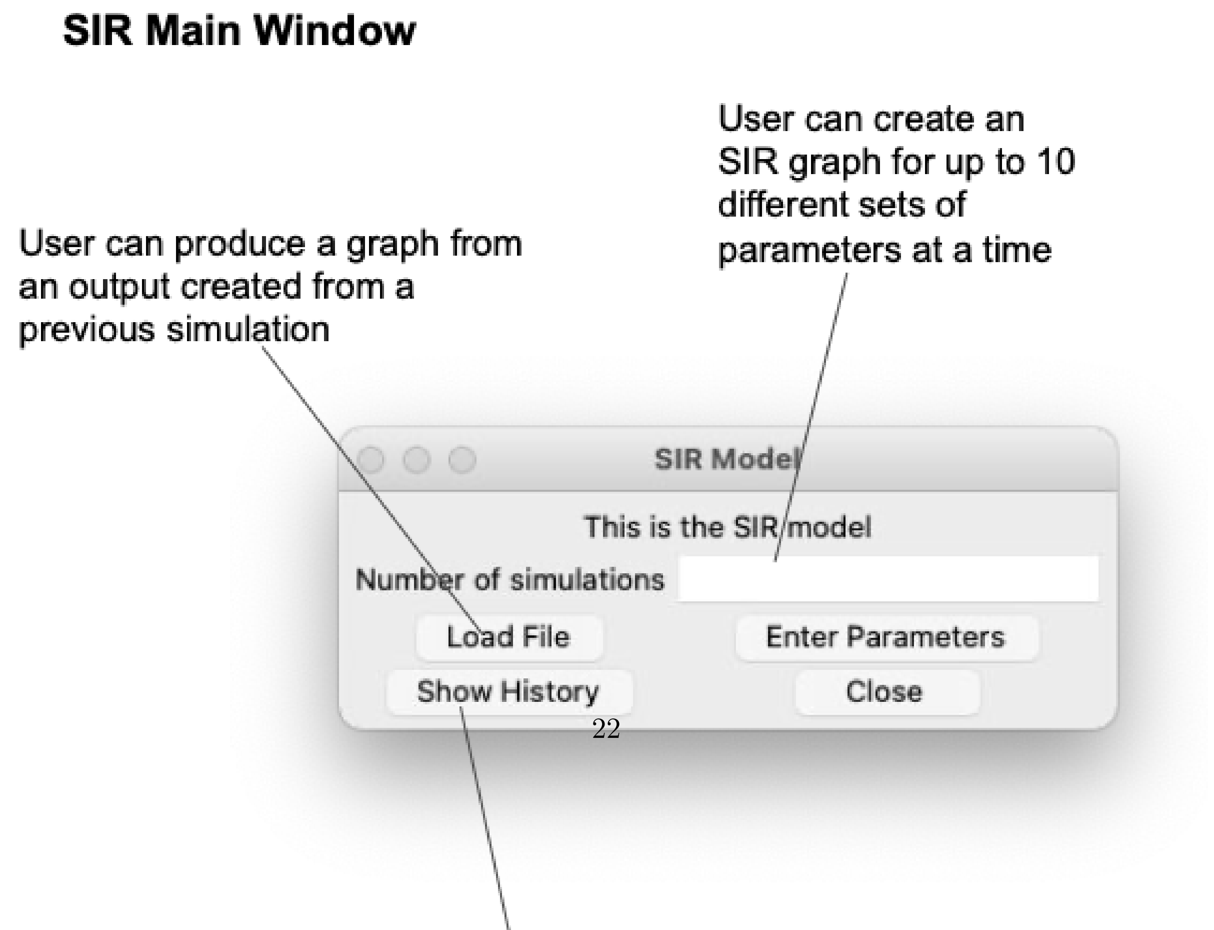
7.10 UI design



Main window

User enters username to login
If username isn't unique, it will be added to the users database

Access to the models isn't available until the user logs in



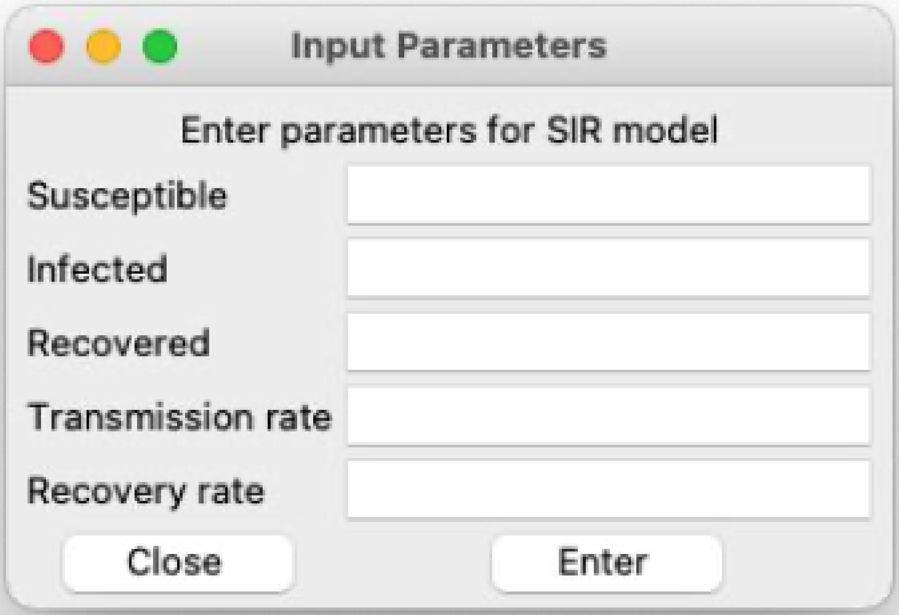
SIR Main Window

User can produce a graph from an output created from a previous simulation

User can create an SIR graph for up to 10 different sets of parameters at a time

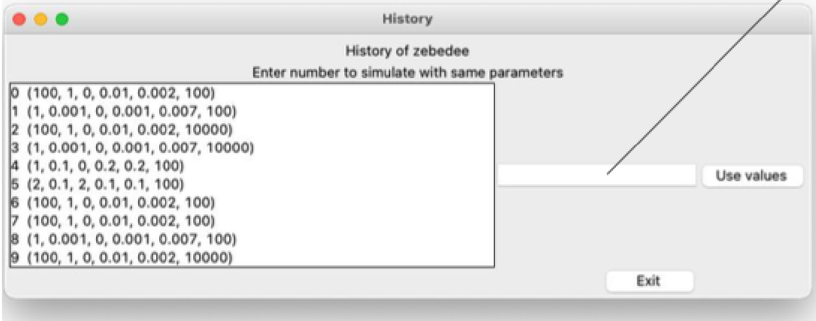
This is the SIR model

SIR Input Parameters Window



SIR History Window

User can scroll though the history of values used and choose a set to use

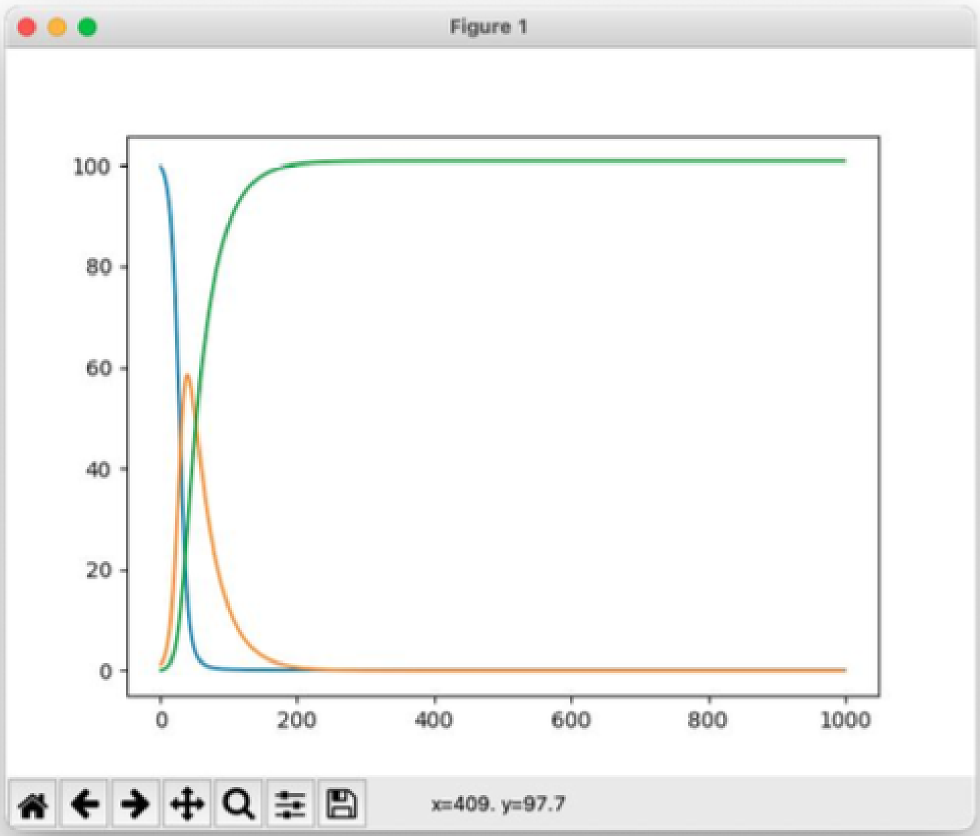


History of zebedee

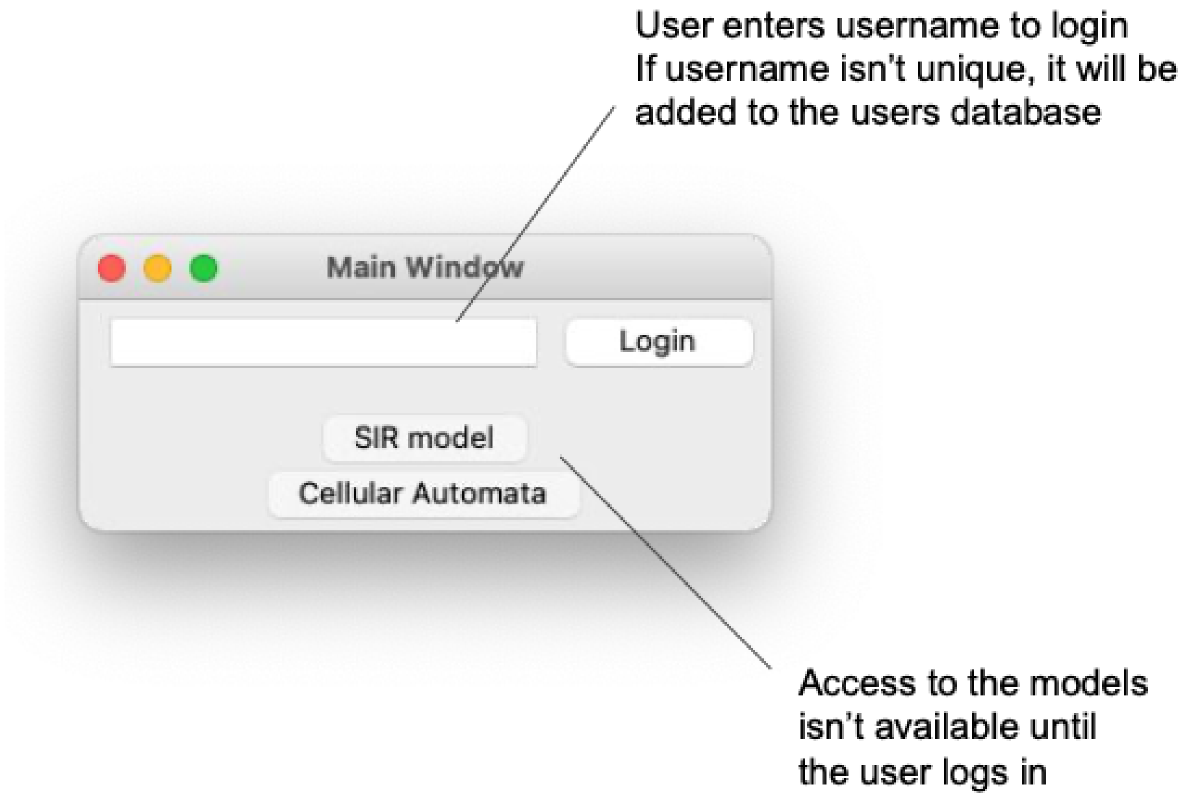
Enter number to simulate with same parameters

```
0  (100, 1, 0, 0.01, 0.002, 100)
1  (1, 0.001, 0, 0.001, 0.007, 100)
2  (100, 1, 0, 0.01, 0.002, 10000)
3  (1, 0.001, 0, 0.001, 0.007, 10000)
4  (1, 0.1, 0, 0.2, 0.2, 100)
5  (2, 0.1, 2, 0.1, 0.1, 100)
6  (100, 1, 0, 0.01, 0.002, 100)
7  (100, 1, 0, 0.01, 0.002, 100)
8  (1, 0.001, 0, 0.001, 0.007, 100)
9  (100, 1, 0, 0.01, 0.002, 10000)
```

SIR Typical Output



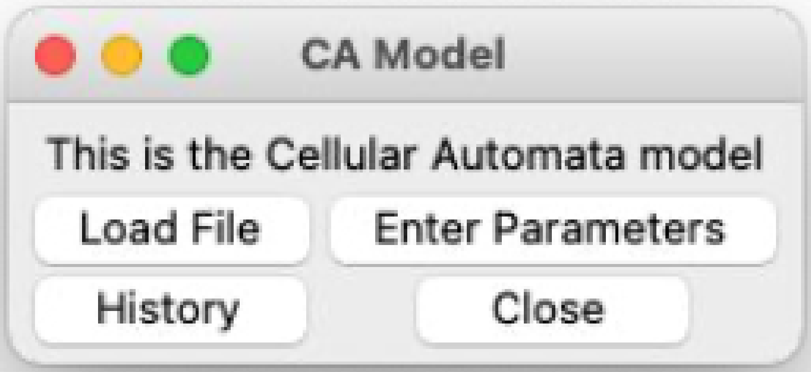
Main window



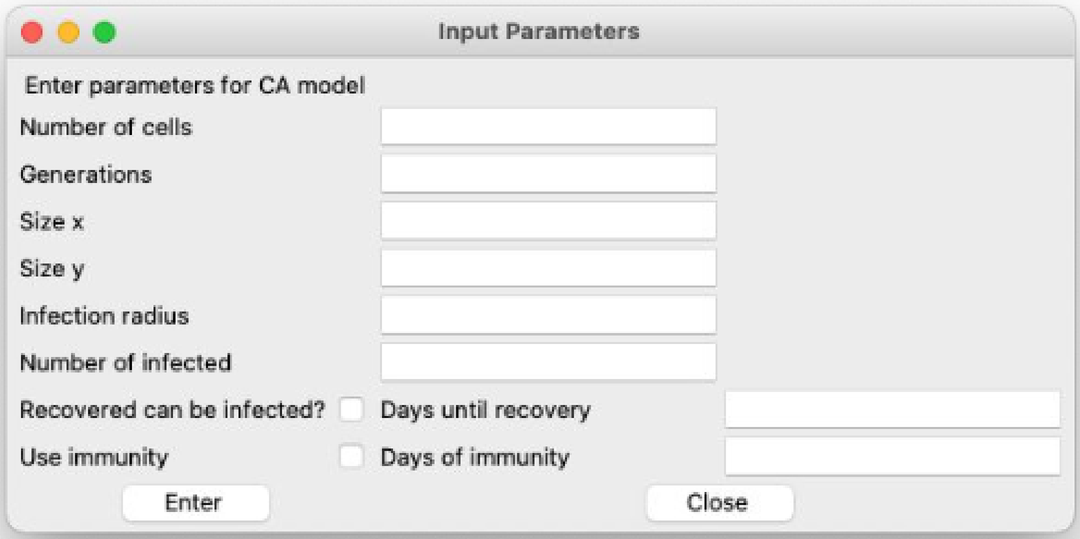
User enters username to login
If username isn't unique, it will be added to the users database

Access to the models isn't available until the user logs in

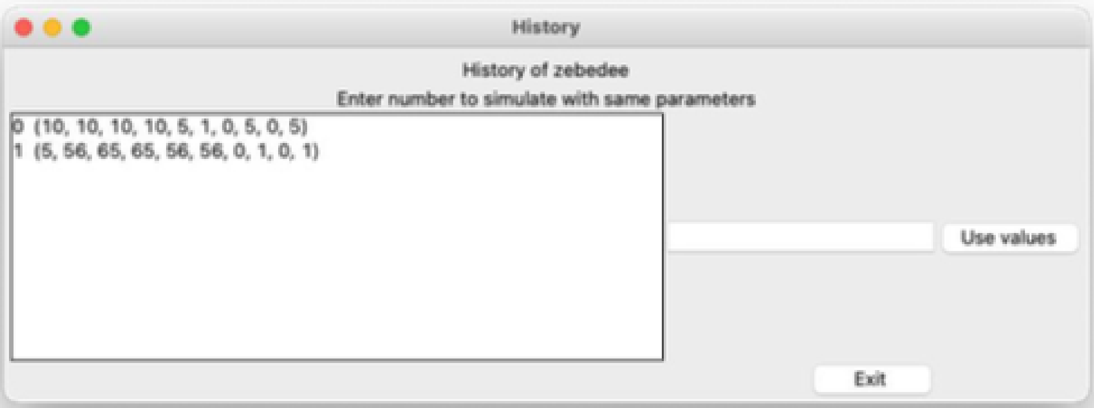
Cellular Automata Main Window



Cellular Automata Input Parameters Window



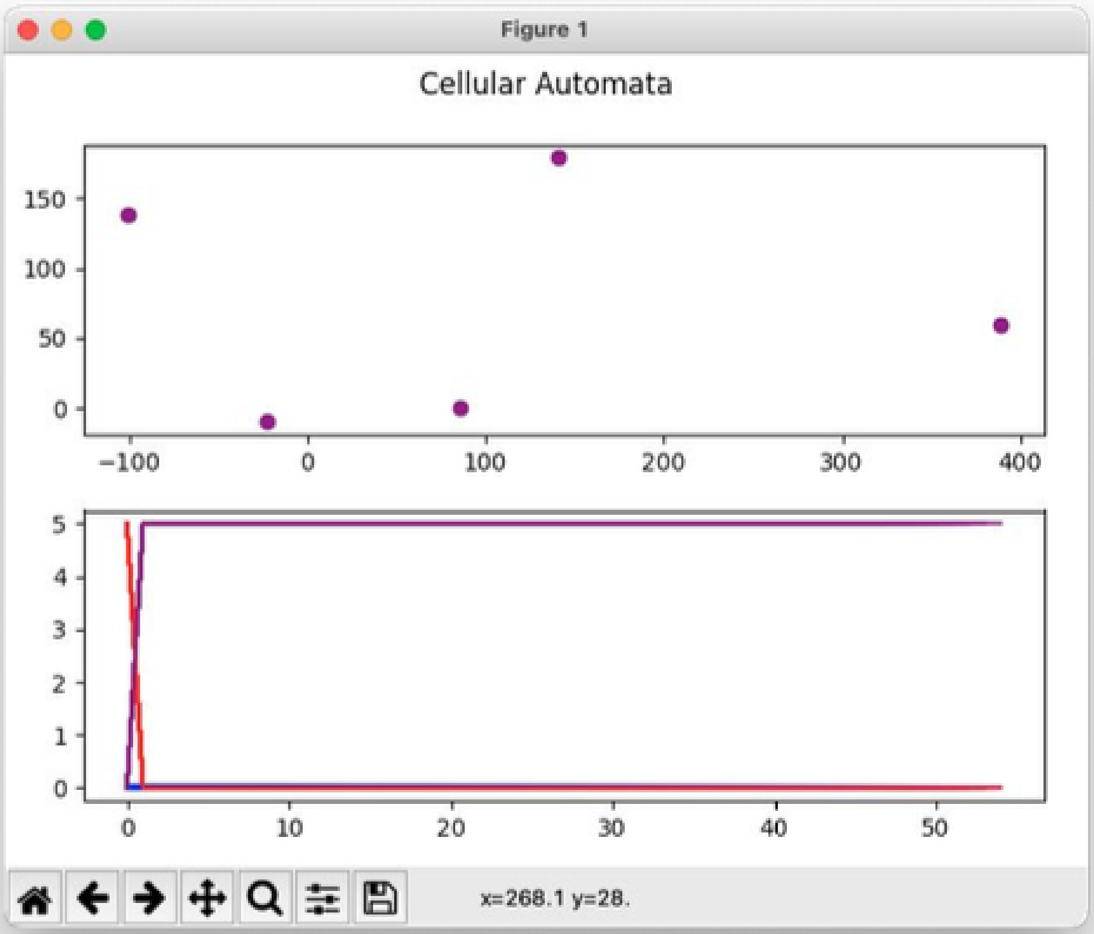
Cellular Automata History Window



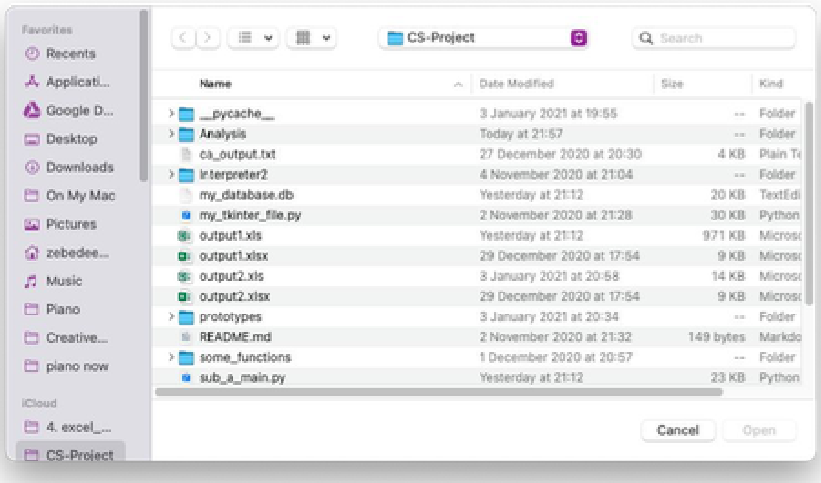
History of zebedee
Enter number to simulate with same parameters

```
0  (10, 10, 10, 10, 5, 1, 0, 5, 0, 5)
1  (5, 56, 65, 65, 56, 56, 0, 1, 0, 1)
```

SIR Typical Output



CA and SIR Open File Window



Name	Date Modified	Size	Kind
__pycache__	3 January 2021 at 19:55	--	Folder
Analysis	Today at 21:57	--	Folder
ca_output.txt	27 December 2020 at 20:30	4 KB	Plain Te
Interpreter2	4 November 2020 at 21:04	--	Folder
my_database.db	Yesterday at 21:12	20 KB	TextEdi
my_tkinter_file.py	2 November 2020 at 21:28	30 KB	Python
output1.xls	Yesterday at 21:12	971 KB	Microsc
output1.xlsx	29 December 2020 at 17:54	9 KB	Microsc
output2.xls	3 January 2021 at 20:58	14 KB	Microsc
output2.xlsx	29 December 2020 at 17:54	9 KB	Microsc
prototypes	3 January 2021 at 20:34	--	Folder
README.md	2 November 2020 at 21:32	149 bytes	Markdo
some_functions	1 December 2020 at 20:57	--	Folder
sub_a_main.py	Yesterday at 21:12	23 KB	Python

This uses the default open file window on Mac or Windows

8 The code

8.1 Main Function

```
# pylint: disable=unused-variable
import tkinter as tk
from tkinter import ttk
from scipy.integrate import odeint
import numpy as np
import matplotlib.pyplot as plt
import pandas as pd
import random
import time
from matplotlib.animation import FuncAnimation
import matplotlib
import csv
import json
from tkinter import filedialog
from tkinter import messagebox

import sub_SIR_model as my_sir
import sub_CA_model as my_ca
import sub_sql_functions as my_sql

current_user = "None"


class gui_Main_Window:
    """GUI of main window where user must login before they can choose SIR or CA model
    """

    def __init__(self, master):
        self.master = master
        self.frame = ttk.Frame(master, padding=5)

        # self.lbl_name = ttk.Label(self.frame, text='This is the main page')
        self.e_user = ttk.Entry(self.frame)
        self.btn_login = ttk.Button(self.frame, text='Login', command=self.login)
        self.btn_SIR = ttk.Button(self.frame, text='SIR model', command=self.openSIR,
            state=tk.DISABLED)
        self.btn_CA = ttk.Button(self.frame, text='Cellular Automata',
            command=self.openCA, state=tk.DISABLED)

        self.frame.grid(row=0, column=0, sticky='nsew')

        # self.lbl_name.grid(column=1, row=0, columnspan=3, sticky='n')
        self.e_user.grid(column=1, row=0, sticky='n')
        self.btn_login.grid(column=2, row=0, sticky='n')
        self.btn_SIR.grid(column=1, row=1, columnspan=2, sticky='s')
        self.btn_CA.grid(column=1, row=2, columnspan=2, sticky='s')

        self.master.columnconfigure(0, weight=1)
        self.master.rowconfigure(0, weight=1)

        self.frame.columnconfigure(1, weight=1)
        self.frame.rowconfigure(1, weight=1)
        if current_user != "None":
            self.pers_login()

    def pers_login(self):
        """If a user closes an SIR or CA window, this function ensures that they stay
            logged in"""
        self.btn_SIR['state'] = tk.NORMAL
        self.btn_CA['state'] = tk.NORMAL
        self.e_user.destroy()
        self.btn_login.destroy()
        self.lbl_name = ttk.Label(self.frame, text=f'Hello {current_user}')
        self.lbl_name.grid(column=1, row=0)
        self.btn_logout = ttk.Button(self.frame, text='logout', command=self.logout)
        self.btn_logout.grid(column=2, row=0)

    def openSIR(self):
        self.master.destroy()
        root2 = tk.Tk()
        root2.title('SIR Model')
        # root2.geometry('1400x900')
        new_window = gui_First_SIR_Window(root2)
        root2.mainloop()

    def openCA(self):
        self.master.destroy()
        root2 = tk.Tk()
        root2.title('CA Model')
        new_window = gui_First_CA_Window(root2)
        root2.mainloop()

    def login(self):
        """Gets username from user that was entered into username box, calls
            enter_username sql function with it and assigns it to the current user
            global variable
        """
        username = str(self.e_user.get())
        my_sql.enter_username(username)
        global current_user
        current_user = username

        self.btn_SIR['state'] = tk.NORMAL
        self.btn_CA['state'] = tk.NORMAL
        self.e_user.destroy()
        self.btn_login.destroy()
        self.lbl_name = ttk.Label(self.frame, text=f'Hello {current_user}')
        self.lbl_name.grid(column=1, row=0)
        self.btn_logout = ttk.Button(self.frame, text='logout', command=self.logout)
        self.btn_logout.grid(column=2, row=0)

    def logout(self):
        """Logs out user, setting global current_user to none and disabling SIR and CA
            button until they log in again"""
        print('logout')
        self.e_user = ttk.Entry(self.frame)
        self.btn_login = ttk.Button(self.frame, text='Login', command=self.login)
        self.e_user.grid(column=1, row=0, sticky='n')
        self.btn_login.grid(column=2, row=0, sticky='n')
        self.btn_SIR['state'] = tk.DISABLED
        self.btn_CA['state'] = tk.DISABLED
        current_user = "None"


class error:
    """Class for producing error box"""
    def __init__(self, err_type, message):
        tk.Tk().withdraw()
        title = err_type + " error"
        messagebox.showerror(title, message)


# ---------------------------------------

class gui_First_SIR_Window:
    """GUI where user can enter how many graphs they want to make, and whether they
        want to manually enter parameters, chose a file or use past parameters in
        history"""

    def __init__(self, master):
        self.master = master
        self.frame = ttk.Frame(master, padding=5)

        self.lbl_name = ttk.Label(self.frame, text='This is the SIR model')

        self.lbl_num_sim = ttk.Label(self.frame, text='Number of simulations')
        self.e_num_sim = ttk.Entry(self.frame)
        # self.num_sim.insert(0, 1)
        self.btn_open_file = ttk.Button(self.frame, text='Load File',
            command=self.open_file)
        self.btn_input_param = ttk.Button(self.frame, text='Enter Parameters',
            command=self.input)
        self.btn_history = ttk.Button(self.frame, text='Show History',
            command=self.show_history)
        self.btn_close = ttk.Button(self.frame, text='Close', command=self.close)

        self.frame.grid(row=0, column=0, sticky='nsew')

        self.lbl_name.grid(column=0, row=0, columnspan=2, sticky='n')
        self.lbl_num_sim.grid(column=0, row=1)
        self.e_num_sim.grid(column=1, row=1)
        # self.num_sim.grid(column=0, row=1)
        self.btn_open_file.grid(column=0, row=2)
        self.btn_input_param.grid(column=1, row=2)
        self.btn_history.grid(column=0, row=3)
        self.btn_close.grid(column=1, row=3, sticky='s')

        self.master.columnconfigure(0, weight=1)
        self.master.rowconfigure(0, weight=1)

        self.frame.columnconfigure(1, weight=1)
        self.frame.rowconfigure(1, weight=1)

    def close(self):
        self.master.destroy()
        main_win = tk.Tk()
        main_win.title('Main Window')
        new_window = gui_Main_Window(main_win)
        main_win.mainloop()

    def open_file(self):
        """Allows user to open file containing results from previous simulation and
            converts the values into python lists so they can be used by the
            my_sir.plot_graph function"""
        print("file dialog")
        filename = filedialog.askopenfilename()
        print(filename)
        df = pd.read_excel(filename)
        timearray = df['Time'].values.tolist()
        susceptible = df['S'].values.tolist()
        infected = df['I'].values.tolist()
        recovered = df['R'].values.tolist()

        self.master.destroy()

        plot = my_sir.plot_graph(timearray, susceptible, infected, recovered)
        plot.plot()

    def input(self):
        """Checks that user as entered a value between 1-10 for the number of
            simulations. IF the user has not, it will produce an error and ask user to
            enter a value between 1 and 10."""
        try:
            int(self.e_num_sim.get())
            if 1 <= int(self.e_num_sim.get()) <= 10:
                self.number_of_simulations = int(self.e_num_sim.get())
                print(self.number_of_simulations)

                # self.number_of_simulations = 1
                self.master.destroy()
                root3 = tk.Tk()
                root3.title('Input Parameters')
                input_window = gui_SIR_Param(root3, self.number_of_simulations)
                root3.mainloop()
            else:
                err = error("Entry", "Please enter an integer between 1 and 10")
        except ValueError:
            err = error("Entry", "Please enter an integer between 1 and 10")

    def show_history(self):
        self.master.destroy()
        root3 = tk.Tk()
        root3.title('History')
        history_window = gui_SIR_history(root3)
```

```
class gui_SIR_Param:
    """GUI for entering parameters for the SIR model"""

    def __init__(self, master, num_sim):
        self.param_list = [[], [], [], [], []]
        self.counter = 0

        self.number_of_simulations = num_sim
        self.master = master
        self.frame = ttk.Frame(master, padding=5)
        self.frame.grid(row=0, column=0, sticky='nsew')

        # label variables
        self.lbl_name = ttk.Label(self.frame, text='Enter parameters for SIR model')
        self.s_name = ttk.Label(self.frame, text='Susceptible')
        self.i_name = ttk.Label(self.frame, text='Infected')
        self.r_name = ttk.Label(self.frame, text='Recovered')
        self.tr_name = ttk.Label(self.frame, text='Transmission rate')
        self.re_name = ttk.Label(self.frame, text='Recovery rate')
        self.btn_enter = ttk.Button(self.frame, text='Enter', command=self.enter_param)
        self.btn_close = ttk.Button(self.frame, text='Close', command=self.exit)

        # button variables
        self.e_s = ttk.Entry(self.frame)
        self.e_i = ttk.Entry(self.frame)
        self.e_r = ttk.Entry(self.frame)
        self.e_tr = ttk.Entry(self.frame)
        self.e_re = ttk.Entry(self.frame)

        # gridding label variables
        self.lbl_name.grid(column=0, row=0, columnspan=2, sticky='n')
        self.s_name.grid(column=0, row=1, sticky='w')
        self.i_name.grid(column=0, row=2, sticky='w')
        self.r_name.grid(column=0, row=3, sticky='w')
        self.tr_name.grid(column=0, row=4, sticky='w')
        self.re_name.grid(column=0, row=5, sticky='w')

        self.e_s.grid(column=1, row=1, sticky='w')
        self.e_i.grid(column=1, row=2, sticky='w')
        self.e_r.grid(column=1, row=3, sticky='w')
        self.e_tr.grid(column=1, row=4, sticky='w')
        self.e_re.grid(column=1, row=5, sticky='w')

        self.btn_enter.grid(column=1, row=6, columnspan=1)
        self.btn_close.grid(column=0, row=6, columnspan=1)

        self.master.columnconfigure(0, weight=1)
        self.master.rowconfigure(0, weight=1)

        # weight elements for resizing
        self.frame.columnconfigure(0, weight=1)
        self.frame.rowconfigure(0, weight=1)
        self.frame.rowconfigure(1, weight=1)
        self.frame.rowconfigure(2, weight=1)
        self.frame.rowconfigure(3, weight=1)
        self.frame.rowconfigure(4, weight=1)
        self.frame.rowconfigure(5, weight=1)
        self.frame.rowconfigure(6, weight=1)

    def enter_param(self):
        """Appends values user has entered to the main parameter list. If the number
            of simulations is more than 1, it will remove values in the input boxes so
            user can enter parameters for next simulaion."""
        self.counter += 1

        self.param_list[0].append(float(self.e_s.get()))
        self.param_list[1].append(float(self.e_i.get()))
        self.param_list[2].append(float(self.e_r.get()))
        self.param_list[3].append(float(self.e_tr.get()))
        self.param_list[4].append(float(self.e_re.get()))

        self.e_s.delete(0, 'end')
        self.e_i.delete(0, 'end')
        self.e_r.delete(0, 'end')
        self.e_tr.delete(0, 'end')
        self.e_re.delete(0, 'end')

        if self.counter == self.number_of_simulations:
            self.submit_param()
            self.counter = 0

    def submit_param(self):
        """Creates queue object from my_sir function and calls the run simulation
            function
        """
        # print(self.param_list)
        self.master.destroy()

        pass1 = True
        for sub_list in self.param_list:
            for value in sub_list:
                if value < 0:
                    pass1 = False
                    err = error("Value", "Negative numbers cannot be used for any of
                        these inputs")

        if not pass1:
            root3 = tk.Tk()
            root3.title('Input Parameters')
            input_window = gui_SIR_Param(root3, self.number_of_simulations)
            root3.mainloop()
        else:
            queue = my_sir.QueueSimulation(self.number_of_simulations,
                self.param_list[0], self.param_list[1],
                                         self.param_list[2],
                                         self.param_list[3], self.param_list[4],
                                         1000, current_user)

            queue.run_simulation()
    def exit(self):
        self.master.destroy()
        sir_win = tk.Tk()
        sir_win.title('SIR')
        sir_main = gui_First_SIR_Window(sir_win)


class gui_SIR_history:
    """GUI history window which shows history of values entered for the user
        currently logged in
    """

    def __init__(self, master):
        self.master = master
        self.frame = ttk.Frame(master, padding=5)
        self.frame.grid(row=0, column=0, sticky='nsew')
        self.user_history = my_sql.sir_return_history(current_user) # user_history is
            a list of tuples
        print(self.user_history)

        self.lb_history = tk.Listbox(self.frame, width=50)
        for i in range(len(self.user_history)):
            to_insert = str(i) + " " + str(self.user_history[i][1:])
            self.lb_history.insert(i, to_insert)

        self.lbl_title = ttk.Label(self.frame, text=f"History of {current_user}")
        self.btn_exit = ttk.Button(self.frame, text="Exit", command=self.exit)
        self.lbl_text = ttk.Label(self.frame, text="Enter number to simulate with same
            parameters")
        self.e_sim_num = ttk.Entry(self.frame)
        self.btn_use = ttk.Button(self.frame, text="Use values", command=self.use)

        self.lbl_title.grid(column=1, row=1, columnspan=3)
        self.lbl_text.grid(column=1, row=2, columnspan=3)
        self.lb_history.grid(column=1, row=3)
        self.e_sim_num.grid(column=2, row=3)
        self.btn_use.grid(column=3, row=3)
        self.btn_exit.grid(column=2, row=4, columnspan=2)

    def exit(self):
        self.master.destroy()
        sir_win = tk.Tk()
        sir_win.title('SIR')
        sir_main = gui_First_SIR_Window(sir_win)

    def use(self):
        """User enter number and set of parameters are retrieved from the database"""
        sim_number = int(self.e_sim_num.get())
        sim_param = list(self.user_history[sim_number][1:])
        print(sim_param)

        queue = my_sir.QueueSimulation(1, [sim_param[0]], [sim_param[1]],
            [sim_param[2]], [sim_param[3]],
                                 [sim_param[4]], sim_param[5], current_user)
        queue.run_simulation()


# ---------------------------------------

class gui_First_CA_Window:
    """GUI window where user can enter parameters manually, load file generated or
        show history of previously used parameters and choose one for the ceccular
        automata model
    """

    def __init__(self, master):
        self.master = master
        self.frame = ttk.Frame(master, padding=5)

        self.lbl_name = ttk.Label(self.frame, text='This is the Cellular Automata
            model')
        self.btn_open_file = ttk.Button(self.frame, text='Load File',
            command=self.open_file)
        self.btn_input_param = ttk.Button(self.frame, text='Enter Parameters',
            command=self.input)
        self.btn_show_history = ttk.Button(self.frame, text='History',
            command=self.show_history)
        self.btn_close = ttk.Button(self.frame, text='Close', command=self.close)

        self.frame.grid(row=0, column=0, sticky='nsew')

        self.lbl_name.grid(column=0, row=0, columnspan=2, sticky='n')
        self.btn_open_file.grid(column=0, row=1)
        self.btn_input_param.grid(column=1, row=1)
        self.btn_show_history.grid(column=0, row=2)
        self.btn_close.grid(column=1, row=2, sticky='s')

        self.master.columnconfigure(0, weight=1)
        self.master.rowconfigure(0, weight=1)

        self.frame.columnconfigure(1, weight=1)
        self.frame.rowconfigure(1, weight=1)

    def open_file(self):
        # enter file stuff
        print("Opening file dialog")
        file = filedialog.askopenfile(mode="r")
        lines = [line.rstrip('\n') for line in file]
        file.close()

        if lines[-1] == "":
            del lines[-1]

        self.master.destroy()

        ca = my_ca.cellular_automata(0, 0, 0, 0, 0, 0, False, 0, False, 0, True, lines)
        ca.new_generation()
        self.master.destroy()
    def input(self):
        self.master.destroy()
        root3 = tk.Tk()
        root3.title('Input Parameters')
        input_window = gui_CA_Param(root3)

    def show_history(self):
        self.master.destroy()
        root3 = tk.Tk()
        root3.title('History')
        history_window = gui_CA_history(root3)

    def close(self):
        self.master.destroy()
        main_win = tk.Tk()
        main_win.title('Main Window')
        new_window = gui_Main_Window(main_win)
        main_win.mainloop()


class gui_CA_Param:
    """GUI interface for inputting cellular automata parameters manually
    Need to make some entry boxes dependent on checkboxes
    """

    def __init__(self, master):
        self.master = master
        self.frame = ttk.Frame(master, padding=5)
        self.frame.grid(row=0, column=0, sticky='nsew')

        # label variables
        self.l_lbl_name = ttk.Label(self.frame, text='Enter parameters for CA model')
        self.l_no_cells = ttk.Label(self.frame, text='Number of cells')
        self.l_gen = ttk.Label(self.frame, text='Generations')
        self.l_size_x = ttk.Label(self.frame, text='Size x')
        self.l_size_y = ttk.Label(self.frame, text='Size y')
        self.l_inf_rad = ttk.Label(self.frame, text='Infection radius')
        self.l_no_inf = ttk.Label(self.frame, text='Number of infected')
        self.l_r_i = ttk.Label(self.frame, text='Recovered can be infected?')
        self.l_d_r = ttk.Label(self.frame, text='Days until recovery')
        self.l_use_imm = ttk.Label(self.frame, text='Use immunity')
        self.l_d_i = ttk.Label(self.frame, text='Days of immunity')

        # bool values for checkbuttons
        self.b_r_i = tk.BooleanVar()
        self.b_u_i = tk.BooleanVar()

        # entry and checkbutton variables
        self.e_no_cells = ttk.Entry(self.frame)
        self.e_gen = ttk.Entry(self.frame)
        self.e_size_x = ttk.Entry(self.frame)
        self.e_size_y = ttk.Entry(self.frame)
        self.e_inf_rad = ttk.Entry(self.frame)
        self.e_no_inf = ttk.Entry(self.frame)
        self.cb_r_i = ttk.Checkbutton(self.frame, variable=self.b_r_i)
        self.e_d_r = ttk.Entry(self.frame)
        self.cb_use_imm = ttk.Checkbutton(self.frame, variable=self.b_u_i)
        self.e_d_i = ttk.Entry(self.frame)

        self.btn_enter = ttk.Button(self.frame, text='Enter', command=self.enter_param)
        self.btn_close = ttk.Button(self.frame, text='Close', command=self.close)

        # grid label variables
        self.l_lbl_name.grid(column=0, row=0, columnspan=2, sticky='n')
        self.l_no_cells.grid(column=0, row=1, sticky='w')
        self.l_gen.grid(column=0, row=2, sticky='w')
        self.l_size_x.grid(column=0, row=3, sticky='w')
        self.l_size_y.grid(column=0, row=4, sticky='w')
        self.l_inf_rad.grid(column=0, row=5, sticky='w')
        self.l_no_inf.grid(column=0, row=6, sticky='w')
        self.l_r_i.grid(column=0, row=7, sticky='w')
        self.l_d_r.grid(column=2, row=7, sticky='w')
        self.l_use_imm.grid(column=0, row=8, sticky='w')
        self.l_d_i.grid(column=2, row=8, sticky='w')

        # grid entry variables
        self.e_no_cells.grid(column=2, row=1, sticky='w')
        self.e_gen.grid(column=2, row=2, sticky='w')
        self.e_size_x.grid(column=2, row=3, sticky='w')
        self.e_size_y.grid(column=2, row=4, sticky='w')
        self.e_inf_rad.grid(column=2, row=5, sticky='w')
        self.e_no_inf.grid(column=2, row=6, sticky='w')
        self.cb_r_i.grid(column=1, row=7, sticky='w')
        self.e_d_r.grid(column=3, row=7, sticky='w')
        self.cb_use_imm.grid(column=1, row=8, sticky='w')
        self.e_d_i.grid(column=3, row=8, sticky='w')

        self.btn_enter.grid(column=0, row=9, columnspan=2, sticky='s')
        self.btn_close.grid(column=2, row=9, columnspan=2, sticky='s')

        # grid main column and tow
        self.master.columnconfigure(0, weight=1)
        self.master.rowconfigure(0, weight=1)

        # weight elements for resizing
        self.frame.columnconfigure(0, weight=1)
        self.frame.rowconfigure(0, weight=1)
        self.frame.rowconfigure(1, weight=1)
        self.frame.rowconfigure(2, weight=1)
        self.frame.rowconfigure(3, weight=1)
        self.frame.rowconfigure(4, weight=1)
        self.frame.rowconfigure(5, weight=1)
        self.frame.rowconfigure(6, weight=1)

    def enter_param(self):
        """Gets values that were input, creates a cellular automata object and calls
           the new_generation function to start the cellular automata function
        """
        # should call CA function in this
        no_cells = int(self.e_no_cells.get())
        generations = int(self.e_gen.get())
        size_x = int(self.e_size_x.get())
        size_y = int(self.e_size_y.get())
        inf_rad = int(self.e_inf_rad.get())
        no_inf = int(self.e_no_inf.get())
        rec_inf = self.b_r_i.get()
        days_rec = int(self.e_d_r.get())
        use_imm = self.b_u_i.get()
        days_imm = int(self.e_d_i.get())

        self.master.destroy()

        arguments = [no_cells, generations, size_x, size_y, inf_rad, no_inf, rec_inf,
            days_rec, use_imm,
                     days_imm, False]

        my_sql.ca_enter_param(current_user, arguments)


        ca = my_ca.cellular_automata(*arguments) # arguments sent as separate
            parameters

        ca.new_generation()

    def close(self):
        self.master.destroy()
        main_ca = tk.Tk()
        main_ca.title('CA')
        new_window = gui_First_CA_Window(main_ca)
        main_ca.mainloop()


class gui_CA_history:
    """GUI history window which shows history of values entered for the user
        currently logged in
    """

    def __init__(self, master):
        self.master = master
        self.frame = ttk.Frame(master, padding=5)
        self.frame.grid(row=0, column=0, sticky='nsew')
        self.user_history = my_sql.ca_return_history(current_user) # user_history is a
            list of tuples
        print(self.user_history)

        self.lb_history = tk.Listbox(self.frame, width=50)
        for i in range(len(self.user_history)):
            to_insert = str(i) + " " + str(self.user_history[i][1:])
            self.lb_history.insert(i, to_insert)

        self.lbl_title = ttk.Label(self.frame, text=f"History of {current_user}")
        self.btn_exit = ttk.Button(self.frame, text="Exit", command=self.exit)
        self.lbl_text = ttk.Label(self.frame, text="Enter number to simulate with same
            parameters")
        self.e_sim_num = ttk.Entry(self.frame)
        self.btn_use = ttk.Button(self.frame, text="Use values", command=self.use)

        self.lbl_title.grid(column=1, row=1, columnspan=3)
        self.lbl_text.grid(column=1, row=2, columnspan=3)
        self.lb_history.grid(column=1, row=3)
        self.e_sim_num.grid(column=2, row=3)
        self.btn_use.grid(column=3, row=3)
        self.btn_exit.grid(column=2, row=4, columnspan=2)

    def exit(self):
        self.master.destroy()
        main_ca = tk.Tk()
        main_ca.title('CA')
        new_window = gui_First_CA_Window(main_ca)
        main_ca.mainloop()

    def use(self):
        """User enter number and set of parameters are retrieved from the database"""
        sim_number = int(self.e_sim_num.get())
        sim_param = list(self.user_history[sim_number][1:])
        print(sim_param)
        sim_param.append(False)
        ca = my_ca.cellular_automata(*sim_param)
        ca.new_generation()


# ---------------------------------------


root = tk.Tk()
root.title('Main Window')
root.geometry("300x100")

window = gui_Main_Window(root)
# window = gui_First_CA_Window(root)
current_user = "zebedee"

root.mainloop()
```

8.2 CA Model

```
# pylint: disable=unused-variable
# pylint: enable=too-many-lines

import matplotlib.pyplot as plt
import random
from matplotlib.animation import FuncAnimation
import json


class cell:
    """Each cell will be a class instance of this class. Gives each cell its own
        attributes"""
```

```
def __init__(self, x, y, infected, d_r, d_i, u_i):
    self.x = x
    self.y = y
    self.infected = infected
    self.recovered = False
    self.recover_count = d_r # default - can be changed - time until infected cell
        recovers
    self.immune = False
    self.immune_count = d_i
    self.original_immune = d_i
    self.use_immunity = u_i
    # self.infection_rate = i

def cell_test_function(self):
    return self.x, self.y, self.infected

def location(self):
    # print(self.x, self.y)
    return self.x, self.y

def recover_generation(self):
    self.recover_count -= 1
    if self.recover_count <= 0:
        self.recovered = True
        self.infected = False
        self.recover_count = 10
        if self.use_immunity:
            self.immune = True

def immunity_generation(self):
    if self.immune:
        self.immune_count -= 1
        if self.immune_count <= 0:
            self.immune = False
            self.immune_count = self.original_immune

def movement(self):
    def nothing():
        pass

    # mvmt = 5
    mvmt = random.randint(0, 50)

    def north():
        self.y -= mvmt

    def northeast():
        self.x += mvmt
        self.y -= mvmt

    def east():
        self.x += mvmt

    def southeast():
        self.x += mvmt
```

```
            self.y += mvmt

        def south():
            self.y += mvmt

        def southwest():
            self.x -= mvmt
            self.y += mvmt

        def west():
            self.x -= mvmt

        def northwest():
            self.x -= mvmt
            self.y -= mvmt

        instructions = {
            0: nothing,
            1: north,
            2: northeast,
            3: east,
            4: southeast,
            5: south,
            6: southwest,
            7: west,
            8: northwest
        }

        rand = random.randint(0, 8)
        instructions[rand]() # like a switch case condition - for constant time
            complexity
        # print(self.x, self.y)


class cellular_automata:
    """Main class to run function"""

    def __init__(self, no_cells, generations, size_x, size_y, infection_radius,
        infected, r_i, d_r, immunity, d_i,
                    user_file, *uf_param):
        """Creates list of how every many cells the user inputs so a list will look
            like ['cell1','cell2','cell3'...]. Each
        element in that list will then be used as a dictionary key where the
            definition will be a class instance of cell. Each
        class instance will be created with a random x and y coordinate, and an
            infected status.
        r_i : recovered can be infected
        d_r : days until recovery
        """
        self.user_file = user_file
        self.use_immunity = immunity
        self.number_of_cells = no_cells
        self.number_of_infected = infected
        self.infection_radius = infection_radius
        self.generations = generations
        self.cell_list = []
        self.cell_object_dict = {}
        self.size_x = size_x
        self.size_y = size_y
        self.full_list = []
        self.r_i = r_i # recovered can be infected

        if len(uf_param) != 0:
            self.uf_param = uf_param
            self.lines = list(uf_param)[0]

        for i in range(no_cells):
            self.cell_list.append(("cell" + str(i)))

        infected_counter = 0
        for element in self.cell_list: # creates user inputted number of infected
            cells first, then creates normal cells
            infected_counter += 1
            infected_status = False
            if infected_counter < self.number_of_infected:
               infected_status = True
            rand_x, rand_y = self.rand_coordinate_generator()
            self.cell_object_dict[element] = cell(rand_x, rand_y,
                                                 infected_status, d_r, d_i,
                                                 self.use_immunity) # creates a
                                                     dictionary of cell objects

    def rand_coordinate_generator(self):
        """Generates random coordinates for cells being generated"""
        rand_x = random.randint(0, self.size_x)
        rand_y = random.randint(0, self.size_y)
        return rand_x, rand_y

    def export_data(self, sus_full, inf_full, rec_full, imm_full, lg_values,
        time_array):
        """Should export data in a format that it can be analysed and reused
        gen_imm empty when not using immunity, but shouldn't be a problem"""

        filename = "ca_output.txt"
        with open(filename, 'w') as file:
            file.write(str(sus_full) + "\n")
            file.write(str(inf_full) + "\n")
            file.write(str(rec_full) + "\n")
            file.write(str(imm_full) + "\n")
            file.write(str(lg_values) + "\n")
            file.write(str(time_array) + "\n")

    def import_data(self):

        if self.lines[-1] == "":
            del self.lines[-1]

        result = [json.loads(item) for item in self.lines]
        # print(result)
        return result
```

```
def update_position(self):
    """For each cell object, movement function will be called to see where the
       cell will move, and the x coordinate list and y coordinate list will be
       returned of the new generation"""
    loc_x = []
    loc_y = []
    infected = []
    recovered = []
    immune = []

    for cell_obj_name in self.cell_list: # for each cell object name ie. 'cell1',
       'cell2' etc, use the name as a dictionary key and run movement function
       and get location
       self.cell_object_dict[cell_obj_name].movement()
       loc_x.append(self.cell_object_dict[cell_obj_name].location()[0])
       loc_y.append(self.cell_object_dict[cell_obj_name].location()[1])
       infected.append(self.cell_object_dict[cell_obj_name].infected)
       recovered.append(self.cell_object_dict[cell_obj_name].recovered)
       immune.append(self.cell_object_dict[cell_obj_name].immune)

    # print(infected)
    # print(recovered)
    # print(immune)
    # print("------------")

    # self.collect_data() # this function could be moved into the new generation
       class function

    return loc_x, loc_y, infected, recovered, immune

def cells_touch(
       self): # need to change to put all infected in a list, THEN compare
           susceptible otherwise not proper
    """If another cell in in a certain radius of an infected cell, it will become
       infected. To be changed"""
    infected_locations = [] # list of tuples of infected cells
    recovered_obj = []
    susceptible_obj = []
    for cell_name in self.cell_list:
       if self.cell_object_dict[cell_name].infected:
           infected_locations.append(self.cell_object_dict[cell_name].location())
       elif self.cell_object_dict[cell_name].recovered:
           recovered_obj.append(self.cell_object_dict[cell_name]) # holds
              recovered both with and without immunity
       else:
           susceptible_obj.append(self.cell_object_dict[cell_name])

    def touch(cell_obj):
       sus_x, sus_y = cell_obj.location()
       for infected_tuple in infected_locations:
           if (sus_x - infected_tuple[0]) ** 2 + (
                  sus_y - infected_tuple[1]) <= self.infection_radius ** 2: #
                     equation of a circle
```

```
                # self.cell_object_dict[cell_name].infected = True # need to chance
                    for chance
                # PROBLEM
                cell_obj.infected = True
                # print(f'{cell_obj} has been infected')
                # cell is infected, LISTS ARE NOT UPDATED

    if self.r_i: # if recovered can be infected - doesn't change immunity status
        but is currently dependent on it - CHANGE
        for recovered in recovered_obj:
            if not recovered.immune:
                touch(recovered)
    for susceptible in susceptible_obj:
        if not susceptible.immune:
            touch(susceptible)

def cell_recovery(self):
    """Cells automatically recover after a certain period of time"""
    for cell_name in self.cell_list:
        cell_obj = self.cell_object_dict[cell_name]
        if cell_obj.recovered == False and cell_obj.infected == True:
            cell_obj.recover_generation()
        elif cell_obj.recovered == True and cell_obj.infected:
            cell_obj.recover_generation()

def cell_immunity(self):
    for cell_name in self.cell_list:
        cell_obj = self.cell_object_dict[cell_name]
        if cell_obj.recovered == True and cell_obj.immune == True:
            cell_obj.immunity_generation()

def new_generation(self):
    """Main definition for running program. For the number of generations to
        simulate, call self.update_position() to get new coordinate lists"""

    # coordinates = []

    sus_full = []
    inf_full = []
    rec_full = []
    imm_full = []

    lg_values = [[], [], []]

    time_array = list(range(0, self.generations))

    if not self.user_file:
        # if user chosing own file will not need - put in function later
        for i in range(
                self.generations):

            if i % 50 == 0:
                print("Generating generation " + str(i))

            x_list, y_list, infected, recovered, immune = self.update_position()
            # check if cells touch here, then can adjust objects if need
            self.cells_touch() # adjusts the objects, not any list

            # recovery function
            self.cell_recovery()

            # immunity function
            if self.use_immunity:
                self.cell_immunity()

            gen_sus = []
            gen_inf = []
            gen_rec = []
            gen_imm = []

            # puts cells in list depending on their status and whether immunity is
                used
            if self.use_immunity:
                for inf in range(len(self.cell_list)):
                    if infected[inf]: # if True
                        gen_inf.append([x_list[inf], y_list[inf]])
                    elif immune[inf]:
                        gen_imm.append([x_list[inf], y_list[inf]])
                    elif recovered[inf]:
                        gen_rec.append([x_list[inf], y_list[inf]])
                    else:
                        gen_sus.append([x_list[inf], y_list[inf]])
            else:
                for inf in range(len(self.cell_list)):
                    if infected[inf]: # if True
                        gen_inf.append([x_list[inf], y_list[inf]])
                    elif recovered[inf]:
                        gen_rec.append([x_list[inf], y_list[inf]])
                    else:
                        gen_sus.append([x_list[inf], y_list[inf]])


            sus_full.append(gen_sus)
            inf_full.append(gen_inf)
            rec_full.append(gen_rec)
            if self.use_immunity:
                imm_full.append(gen_imm)

            lg_values[0].append(len(gen_sus))
            lg_values[1].append(len(gen_inf))
            lg_values[2].append((len(gen_rec) + len(gen_imm)))


    # self.export_to_excel() # will soon be redundant
    if not self.user_file:
        self.export_data(sus_full, inf_full, rec_full, imm_full, lg_values,
            time_array) # WORKING NOW

    # if using own values, assign them here
```

```
        if self.user_file:
            sus_full, inf_full, rec_full, imm_full, lg_values, time_array =
                self.import_data()
            self.generations = len(time_array)
            print("Imported data!")

        fig, axs = plt.subplots(2)
        fig.suptitle('Cellular Automata')

        # animate_graph = Anim(self.generations, sus_full, inf_full, rec_full,
            imm_full, self.use_immunity, time_array, lg_values)

        def animate(i): # need to adjust to work with two graphs
            #
                https://stackoverflow.com/questions/42621036/how-to-use-funcanimation-to-update-and-a

            axs[0].cla()

            x_sus_full = [cell[0] for cell in sus_full[i]]
            y_sus_full = [cell[1] for cell in sus_full[i]]
            x_inf_full = [cell[0] for cell in inf_full[i]]
            y_inf_full = [cell[1] for cell in inf_full[i]]
            x_rec_full = [cell[0] for cell in rec_full[i]]
            y_rec_full = [cell[1] for cell in rec_full[i]]

            axs[0].scatter(x_sus_full, y_sus_full, color='blue')
            axs[0].scatter(x_inf_full, y_inf_full, color='red')
            axs[0].scatter(x_rec_full, y_rec_full, color='purple')
            if self.use_immunity:
                axs[0].scatter([cell[0] for cell in imm_full[i]], [cell[1] for cell in
                    imm_full[i]], color='gray')

            # plots line graph
            axs[1].plot(time_array[0:i], lg_values[0][0:i], label="Susceptible",
                color="blue")
            axs[1].plot(time_array[0:i], lg_values[1][0:i], label="Infected",
                color="red")
            axs[1].plot(time_array[0:i], lg_values[2][0:i], label="recovered",
                color="purple")


        ani = FuncAnimation(plt.gcf(), animate, frames=self.generations, interval=100,
            repeat=False)

        # ani.save('video.mp4', writer='ffmpeg', fps=30, dpi=250)

        plt.tight_layout()
        plt.show()
```

8.3 SIR Model

```
import matplotlib.pyplot as plt
import pandas as pd
import sub_sql_functions as my_sql
```

```
class QueueSimulation:

    def __init__(self, n, s_list, i_list, r_list, b_list, g_list, t, current_user):
        self.n = n # number of simulations to be run
        self.parameters = []
        for i in range(n):
            self.parameters.append([s_list[i], i_list[i], r_list[i], b_list[i],
                g_list[i], t, i + 1])
            my_sql.sir_enter_param(current_user, [s_list[i], i_list[i], r_list[i],
                b_list[i], g_list[i], t])
        print(self.parameters)

    def run_simulation(self):
        sir_model = SIR_model()
        for i in range(self.n):
            sir_model.SIR_model(*self.parameters[i])
        plt.show()


class SIR_model:

    def __init__(self):
        pass

    def SIR_model(self, s0, i0, r0, beta, gamma, t, f, *args, **kwargs):
        """
        :param s0: number of susceptible people
        :param i0: number of infected people
        :param r0: number of recovered people
        :param beta: transmission rate of an individual
        :param gamma: recovery rate of an individual
        :param t: how long the simulation should run for
        :param f: how many graphs should be calculated simultaneously
        """

        plt.figure(f) # names the graph
        N = s0 + i0 + r0 # total population

        timearray = list(range(1, int(t))) # creates time array

        def eqns(param):
            # e = random.uniform(0, 1)
            e = 0
            S, I, R = param
            dsdt = (-(beta * S * I) / N) + (e * R) # rate of change of susceptible
                individuals
            didt = ((beta * S * I) / N) - gamma * I # rate of change of infected
                individuals
            drdt = (gamma * I) - (e * R) # rate of change of recovered individuals
            return dsdt, didt, drdt

        def solver(): # solves differential equations in eqns
            param = (s0, i0, r0)
            solver_result = [[], [], []]
            for time in timearray:
                eqns_results = eqns(param)
                x, y, z = (param[0] + eqns_results[0]), (param[1] + eqns_results[1]),
                    (param[2] + eqns_results[2])
                solver_result[0].append(x)
                solver_result[1].append(y)
                solver_result[2].append(z)
                param = (x, y, z)
            return solver_result

        solver_result = solver()

        # print(solver_result)

        def export_to_excel(): # exports calculated results to excel
            data = {'Time': timearray,
                    'S': solver_result[0],
                    'I': solver_result[1],
                    'R': solver_result[2]}

            df = pd.DataFrame(data, columns=['Time', 'S', 'I', 'R'])
            name = "output" + str(f) + ".xls"
            df.to_excel(name, sheet_name='output')

        export_to_excel()
        plt.plot(timearray, solver_result[0], label="S(t)")
        plt.plot(timearray, solver_result[1], label="I(t)")
        plt.plot(timearray, solver_result[2], label="R(t)")


class plot_graph:

    def __init__(self, ta, s, i, r):
        # deconstruct file here
        self.timearray = ta
        self.sus = s
        self.inf = i
        self.rec = r

    def plot(self):
        plt.plot(self.timearray, self.sus, label="S(t)")
        plt.plot(self.timearray, self.inf, label="I(t)")
        plt.plot(self.timearray, self.rec, label="R(t)")
        plt.show()
```

8.4 SQL Functions

```
    import sqlite3
    import os.path


    def initial_setup():
```

```
    """Sets up clean database with users table and ca_param table. Users table
        contains username and
    whether user can see all parameters previously used, and ca_param table
        contains the history of
    parameters used as well as the user who executed them"""
    conn = sqlite3.connect('my_database.db')
    c = conn.cursor()
    # c.execute("DROP TABLE users")
    # c.execute("DROP TABLE ca_param")
    c.execute("CREATE TABLE users (username text PRIMARY KEY, see_all integer)")

    c.execute("""CREATE TABLE ca_param (
               user string,
               no_cells integer,
               generations integer,
               size_x integer,
               size_y integer,
               infection_radius integer,
               no_infected integer,
               recovered_can_be_infected integer,
               days_until_recovered integer,
               use_immunity integer,
               days_of_immunity integer
               )""")
    c.execute("INSERT INTO users VALUES (:username, :see_all)", {'username':
        'admin', 'see_all': 1})

    c.execute("""CREATE TABLE sir_param (
               user string,
               sus0 integer,
               inf0 integer,
               rec0 integer,
               beta integer,
               gamma integer,
               time integer
               )""")

    conn.commit()
    conn.close()


def enter_username(in_user):
    """If new username entered, it will create a record in the users table for
        that user, if username
    entered already exists nothing happens. Username is returned"""
    conn = sqlite3.connect('my_database.db')
    c = conn.cursor()
    c.execute("INSERT OR IGNORE INTO users VALUES (:username, :see_all)",
             {'username': in_user, 'see_all': 0}) # don't add if duplicate username
    conn.commit()
    conn.close()
    return in_user


def ca_enter_param(in_user, up):
    """Inserts new parameters entered by the user into the CA parameter database"""
    conn = sqlite3.connect('my_database.db')
    c = conn.cursor()
    c.execute("""INSERT INTO ca_param VALUES (:user, :no_cells, :generations,
        :size_x, :size_y,
                                        :infection_radius, :no_infected,
                                            :recovered_can_be_infected,
                                        :days_until_recovered, :use_immunity,
                                            :days_of_immunity)""",
              {'user': in_user, 'no_cells': up[0], 'generations': up[1], 'size_x':
                  up[2], 'size_y': up[3],
               'infection_radius': up[4], 'no_infected': up[5],
                   'recovered_can_be_infected': up[6],
               'days_until_recovered': up[7], 'use_immunity': up[8],
                   'days_of_immunity': up[9]})
    conn.commit()
    conn.close()


def ca_return_history(in_user):
    """Returns entered parameter history depending on current user"""
    conn = sqlite3.connect('my_database.db')
    c = conn.cursor()
    c.execute("SELECT * FROM ca_param WHERE user=:curr_user", {'curr_user':
        in_user})
    # conn.close()
    return c.fetchall()


def sir_enter_param(in_user, up):
    """Inters new parameters entered by the user into the SIR parameter database"""
    conn = sqlite3.connect('my_database.db')
    c = conn.cursor()
    c.execute("""INSERT INTO sir_param VALUES (:user, :sus0, :inf0, :rec0, :beta,
        :gamma, :time)""",
              {'user': in_user, 'sus0': up[0], 'inf0': up[1], 'rec0': up[2],
                  'beta': up[3], 'gamma': up[4], 'time': up[5]
               })
    conn.commit()
    conn.close()

def sir_return_history(in_user):
    conn = sqlite3.connect('my_database.db')
    c = conn.cursor()
    c.execute("SELECT * FROM sir_param WHERE user=:curr_user",
        {'curr_user':in_user})
    return c.fetchall()
```