Covid Simulation

code: https://github.com/adithyarganesh/CSC555_Covid_Simulation (https://github.com/adithyarganesh/CSC555_Covid_Simulation)

Created below is an agent based simulation modelling of how a virus can spread in a society during a pandemic. The simulation is created using the MESA library to simulate houses, grocery shops, parks and quarantine centers.

Source Code

The main libraries used for this simulation are MESA for simulation, Matplotlib for graphs, math and numpy

In [1]:
```
from mesa import Agent, Model
from mesa.time import RandomActivation
from mesa.space import MultiGrid
from mesa.datacollection import DataCollector
import math
import numpy as np
import matplotlib.pyplot as plt
```

Covid Simulation Model Class

Firstly, we create a model class where we define the elements needed in a society - Houses, Stores, Parks, Quarantine Centers, Social Distancing norms etc.

The **init** function initializes the model with a grid, predefined slots for areas and finally creates agents with a percent of infected agents.

The **get_individuals** function takes all the allocated grid positions for the agent to be in and returns the number of infected agents in the place along with the total number of agents.

the **clear_beds** function keeps track of all the beds that can be cleared at the end of each day if the agent in the quarantine center is either cured or diseased.

the **get_infections**, **get_deaths** and the **get_cures** functions return the corresponding statistics from each day.

In [2]:
```
class CovidSimulationModel(Model):

    def __init__(self, num=1000, probability=0.5, dimension=8, quarantine=False,
        self.num_agents = num
        self.grid = MultiGrid(dimension, 1, True)
        self.schedule = RandomActivation(self)
        self.healing_space = set()
        self.places = [[(i, 0)] for i in range(dimension)]
        self.quarantine = quarantine
        self.social_distance = social_distance
        for i in range(self.num_agents):
            agent = VirusAgent(i, self)
            self.schedule.add(agent)
            self.grid.place_agent(agent, (dimension-1, 0))
            infected = np.random.choice([0,1], p=[1-probability,probability])
            if infected == 1:
                agent.state = 1

        self.datacollector = DataCollector(
```

```
            agent_reporters={"State": "state"})

    def get_individuals(self, place):
        count = 0
        total = 0
        for (x,y) in place:
            temp =  self.grid.get_cell_list_contents((x, y))
            if temp:
                if temp[0].isolated != 1:
                    if temp[0].state > 0:
                        count += 1
                    if temp[0].state > -2:
                        total += 1
        return count, total

    def clear_beds(self):
        for agent in self.schedule.agents:
            agent.transition()
            if agent.unique_id in self.healing_space and agent.state <= 0:
                self.healing_space.remove(agent.unique_id)

    def get_infections(self):
        inf = 0
        for agent in self.schedule.agents:
            if agent.state >= 1:
                inf += 1
        return inf

    def get_deaths(self):
        deaths = 0
        for agent in self.schedule.agents:
            if agent.state == -2:
                deaths += 1
        return deaths

    def get_cures(self):
        cure = 0
        for agent in self.schedule.agents:
            if agent.state == -1:
                cure += 1
        return cure

    def step(self):
        self.datacollector.collect(self)
        self.schedule.step()
```

Virus Agent Class

The **init** function creates each agent with an a non-infected state and with no immunity or isolation

The `states` are mapped in the following manner:

```
 0  --> Not-infected
 1  --> Asymptomatic
 2  --> Symptomatic
 3  --> Critical
-1  --> Cured
-2  --> Diseased
```

The **move** function is called each day as the agent moves around at home/ goes to the grocery shop or the park with a list of probabilities. Here, if the agent is not currently at home, he gets back home that day.

The **home** function checks if the agent returning home has the virus or not, if he has - the remaining members

of the house get infected with the virus.

The **infect** function gets called on the agent when he is out in the park or in a grocery store. Here, based on the number of infected agents present in the same place, a probability value is generated (num. infected/ total agents). Based on this value, the user may or may not catch the virus.

Each agent undergoes the **transition** stage each day based on the stage the agent is at.

If the model allows for Quarantine, the **quarantine** function gets invoked and based on the number of beds available in the quarantine center and the severity of the virus on the agent, he/she may get quarantined.

All these functionalities are called in the **step** function by the model each day until the the entire population are immune to the virus.

In [3]:
```
class VirusAgent(Agent):

    def __init__(self, unique_id, model):
        super().__init__(unique_id, model)
        self.state = 0
        self.immunity = 0
        self.isolated = 0

    def move(self):
        if self.pos != (7, 0):
            self.home()
        else:
            movement = np.random.choice([1,2,3], p=[0.1, 0.2, 0.7])
            x = 7
            if movement == 1:
                x = np.random.choice([0,1])
            elif movement == 2:
                x = np.random.choice([2,3,4,5,6])
            y = self.model.random.randrange(self.model.grid.height)
            self.model.grid.place_agent(self, (x, y))

    def home(self):
        self.model.grid.place_agent(self, (7, 0))
        probability = 1
        if self.state >= 1:
            family = [elem for elem in range(math.floor(self.unique_id/4)*4, mat
            for member in family:
                if self.model.schedule.agents[member].state >= 0 and self.model.
                    self.model.schedule.agents[member].state = max(self.model.sc

    def infect(self, places):
        if self.state >= 0 and self.pos != (7, 0):
            for place in places:
                n, total = self.model.get_individuals(place)
                probability = 0.1 if self.model.social_distance else 0 if n == 0
                if self.pos in place:
                    self.state = max(self.state, np.random.choice([0,1], p=[1-pr
                if self.immunity == 1:
                    self.state = 0

    def transition(self):
        if self.state == 1:
            self.state = np.random.choice([1,2], p=[0.75, 0.25])
        elif self.state == 2:
            self.state = np.random.choice([2, 3, -1], p=[0.75, 0.10, 0.15])
        elif self.state == 3:
            self.state = np.random.choice([3, -1, -2], p=[0.75, 0.20, 0.05])
        if self.state == -1:
            self.immunity = 1
```

```
50
51     def quarantine(self):
52         if self.state == 2:
53             self.isolated = np.random.choice([0,1], p=[0.80, 0.20])
54         elif self.state == 3:
55             self.isolated = 1
56         if self.isolated == 1:
57             self.model.healing_space.add(self.unique_id)
58
59     def step(self):
60         if self.unique_id not in self.model.healing_space:
61             self.move()
62             self.infect(self.model.places)
63         if len(self.model.healing_space)<100 and self.model.quarantine:
64             self.quarantine()
65
```

The **simulate** function that tracks the metrics for each model run on simulation and plots graphs on several parameters.

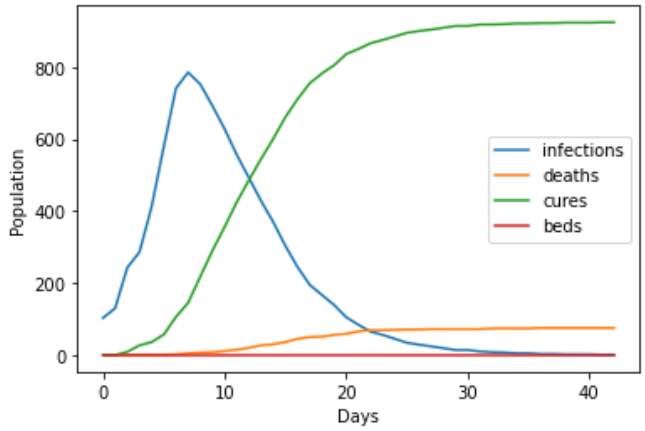
In [4]:

```
def simulate(model):
    days = 0
    infections = []
    cures = []
    deaths = []
    beds = []
    while(model.get_infections() != 0):
        infections.append(model.get_infections())
        deaths.append(model.get_deaths())
        cures.append(model.get_cures())
        beds.append(len(model.healing_space))
        model.step()
        days += 1
        model.clear_beds()

    print("Days for survival", days)
    print("Casualties", model.get_deaths())
    print("Cures", model.get_cures())
    print("Max Quarantine Beds used", max(beds))

    plt.plot(infections)
    plt.plot(deaths)
    plt.plot(cures)
    plt.plot(beds)
    plt.xlabel('Days')
    plt.ylabel('Population')
    plt.gca().legend(('infections','deaths', 'cures', 'beds'))
    plt.show()

```

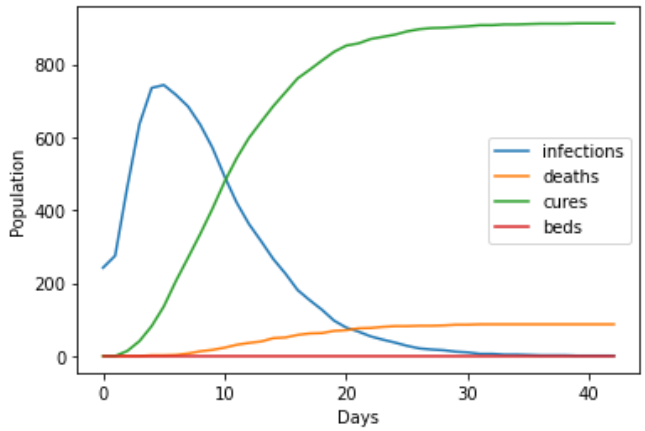
If the quarantine parameter in the model is set to `True`, the simulation for **Adding Quarantine Centers** task is implemented. If both quarantine and social distancing parameters in the model is set to `True`, the **Enforcing Social Distancing Norms** task is implemented. If both arent mentioned, **Basic implementation** task runs.

In [5]:
```
1 simulate(CovidSimulationModel(probability=0.1))
2 simulate(CovidSimulationModel(probability=0.25))
3 simulate(CovidSimulationModel(probability=0.50))
```

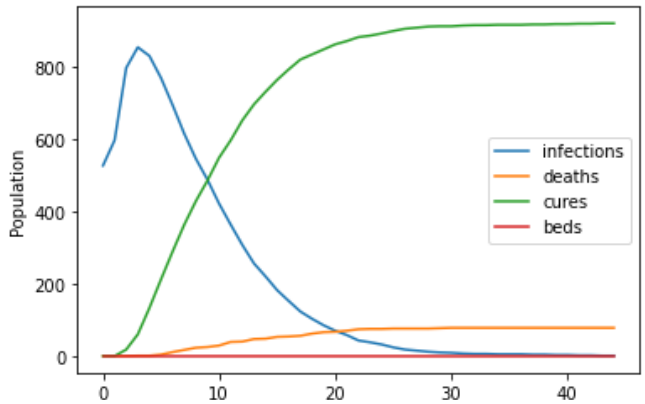
```
Days for survival 43
Casualties 75
Cures 925
Max Quarantine Beds used 0
```




```
Days for survival 43
Casualties 88
Cures 912
Max Quarantine Beds used 0
```




```
Days for survival 45
Casualties 78
Cures 920
Max Quarantine Beds used 0
```



Basic Simulation

1. When does the simulation stabilize?

   It can be seen that the simulation stabilizes when the cures, infections and death become a flat line and when there are no infected agents in space. We notice that on average we get the following values

Probability	Days	Deaths	Cures
0.1	44	78	877
0.25	43	80	919
0.5	41	86	917

```
        Above table has been generated after taking the mean of the values a
fter 30 such simulations
```

2. Time taken to stabilize

   We see that as the percent of initially infected people increases, the number of days before the curve stabilizes tends to decrease as each day the agent goes through the transformation. And if lots of agents are already affected by the virus, they may undergo the transformation to the final state of diseased/ cured sooner. Corresponding values have been tablulated above.

3. When was the infection at its peak?

   When the initial infection was less, the peak new cases was between days 5 and 10. However, when the number of initially infected agents increased, we notice that the peak new cases in a day was hit much sooner. We also notice that the peak gets reached in 3 to 4 days as the percent of initial infections increases.

4. Deaths by the virus

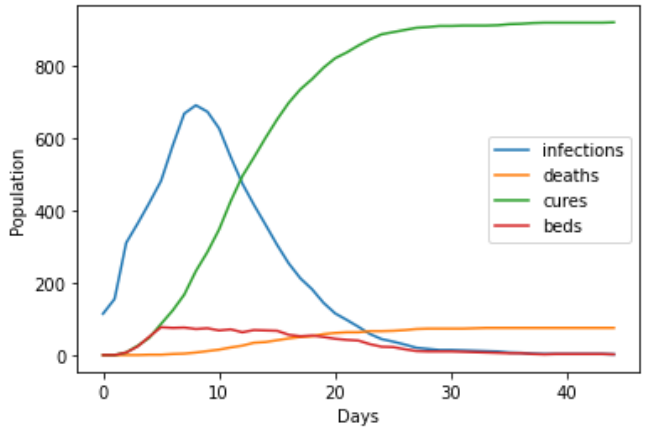
   Since there are only 7 places the agents go to, there is a good chance that he/she gets affected. This makes the chance of death high. From mltiple runs of the simulations, we notice that on average there is a death rate of about 0.08 percent as mentioned in the table above.

5. Graphs

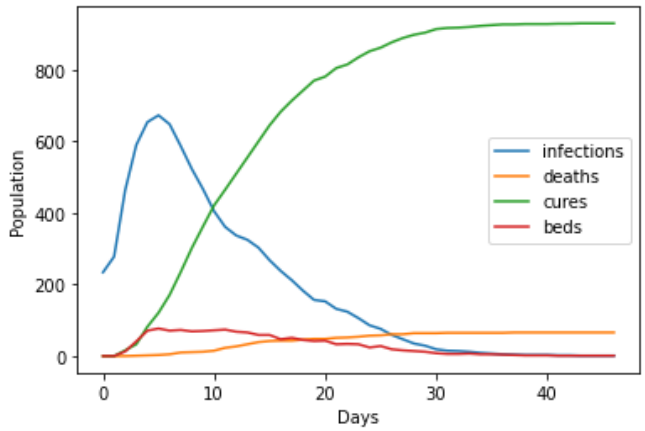
   Please find above the graphs for the probability values 0.1, 0.25 and 0.5 along with the metrics above the description

In [13]:
```
1 simulate(CovidSimulationModel(probability=0.1, quarantine=True))
2 simulate(CovidSimulationModel(probability=0.25, quarantine=True))
3 simulate(CovidSimulationModel(probability=0.50, quarantine=True))
```

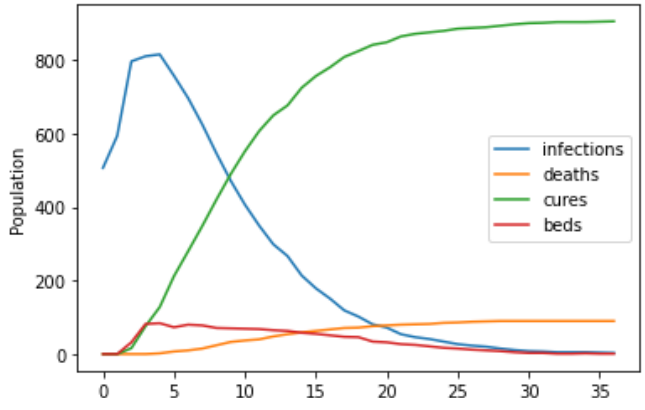
```
Days for survival 45
Casualties 76
Cures 920
Max Quarantine Beds used 77
```




```
Days for survival 47
Casualties 66
Cures 931
Max Quarantine Beds used 77
```




```
Days for survival 37
Casualties 90
Cures 909
Max Quarantine Beds used 84
```



Adding Quarantine Centers

1. When does the simulation stabilize?

   It can be seen that the simulation stabilizes when the cures, infections and death become a flat line and when there are no infected agents in space. We notice that on average we get the following values

Probability	Days	Deaths	Cures
0.1	44	76	889
0.25	42	79	917
0.5	41	81	918

   Above table has been generated after taking the mean of the values a fter 30 such simulations

2. Time taken to stabilize

   Just like the previous case, we see that as the percent of infected people increases, the time to stabilize the virus decreases. Since we are working with a smaller dataset, we donot see a drastic decrease in the number of days. However, we can conclude that there is an appreciable increase in time as the initial infected percentage decreases. Values are mentioned in the table above.

3. When was the infection at its peak?

   With the quarentine in place, we actually notice that on average for an initial infected value of 0.1, the peak is reached only between 10 and 15 days and with an increase in this value to 0.5 the peak is reached between 5 and 10 days.

4. Deaths by the virus

   We notice that the deaths are not affected by the addition of quarantine. Considering the fact that we are running the simulation on 1000 agents, we could maybe say 76 deaths when 0.1 are affected is low in comparison to 82 when 0.25 of the population is affected. When scaline this up, the difference may prove to be huge.

5. Graphs

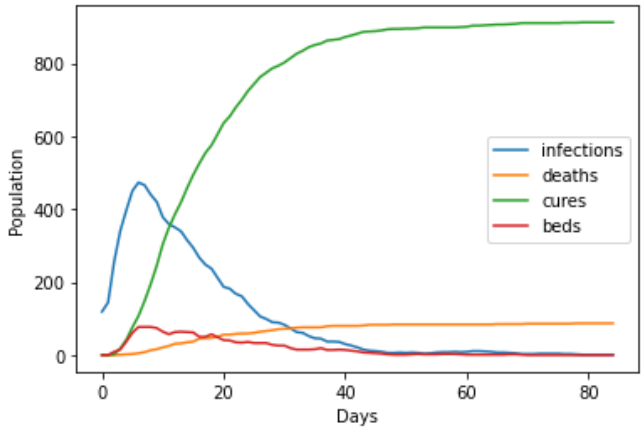
   Please find above the graphs for the probability values 0.1, 0.25 and 0.5 along with the metrics above the description

6. Quarantine center fill-up

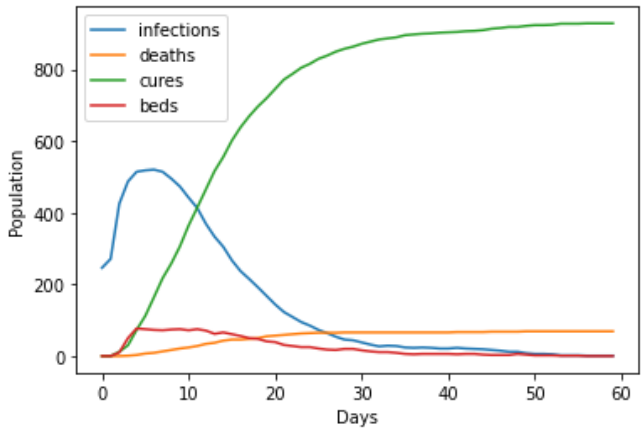
   The Quarantine center doesnt seem to fill up for all the cases as the probability of an agent being in a critical stage is low. But we notice a steady increase in the number of occupied beds in the quarantine center to slowly increase as the number of initial infected agents increases.

In [11]:
```
simulate(CovidSimulationModel(probability=0.1, quarantine=True, social_distance=
simulate(CovidSimulationModel(probability=0.25, quarantine=True, social_distance
simulate(CovidSimulationModel(probability=0.50, quarantine=True, social_distance
```

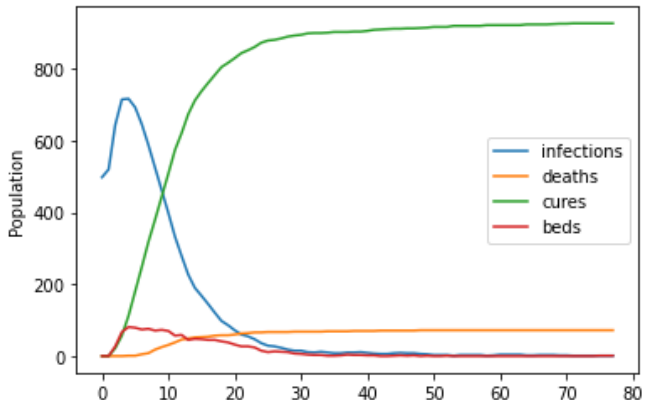
```
Days for survival 85
Casualties 87
Cures 913
Max Quarantine Beds used 77
```




```
Days for survival 60
Casualties 69
Cures 929
Max Quarantine Beds used 77
```




```
Days for survival 78
Casualties 73
Cures 927
Max Quarantine Beds used 81
```



Enforcing Social Distancing Norms

1. When does the simulation stabilize?

   It can be seen that the simulation stabilizes when the cures, infections and death become a flat line and when there are no infected agents in space. We notice that on average we get the following values

Probability	Days	Deaths	Cures
0.1	74	79	916
0.25	75	82	914
0.5	66	82	914

```
        Above table has been generated after taking the mean of the values a
fter 30 such simulations
```

2. Time taken to stabilize

   Unlike the previous cases, we see that the stabilization time is much higher. We could thus say that social distancing may indeed help reach a virus free world but it does so by flattenning the peak across multiple days.

3. When was the infection at its peak?

   With the quarentine and social distancing in place, we see that on average for an initial infected value of 0.1, the peak is reached between 10 and 15 days and with an increase in this value to 0.5 the peak is reached between 5 and 10 days just like the previous situation with just quarantine. This is because of our tiny population and regions.

4. Deaths by the virus

   We notice that the deaths are also not affected by social distancing as the average number of fatalties is aroung 79 for initial probability of 0.1 and it tends to increase with a higher initial infected percentage. All values are tabulated above.

5. Graphs

   Please find above the graphs for the probability values 0.1, 0.25 and 0.5 along with the metrics above the description

6. Improvements in the situations?

   We could argue that with the addition of social distancing, we notice a much lower peak but a broader graph. This is mainly because we were able to prevent overcrowded quarantine centers with agents rushing to the quarantine centers but instead spreads the time at which each agent is affected so that resources can be efficiently managed.

Conclusions

Interesting findings

If one looks at the three tables generated for the 3 situatuations (Basic, Quarantine and Social Norms) we can justify that a similar number of agents reach a cured/ fatal stage but there is a huge difference in time taken to reach the final state. There is lesser unpredictability in the Graph with social distancing incorporated as the slope is much lesser than that determined in basic simulation and a broader graph helps the government manage resources.

From Dr. Fauci's comments that "social distancing may decrease deaths in the country", we notice that that is not the case in our simulation. The reason for that is mainly because we start with about a 100 agents infected and we place on average a minimum of 30 of them in 7 areas. This makes a large number of asymptomatic individuals present in these hotspots negating the affect of quarantine and social distancing. When we change the probability of symptomatic agents to quarantine at home, the new generated graphs showed a decrease in daily deaths.

Impacts of quarantine and Social distancing

We could make a case that quarantine and social distancing definitely helps. In our simulations, since we have just 7 areas the agent may go to and since we have simplified the case of when he/she might get affected, we do not see a big difference in the time taken to reach a COVID free state. However, with social distancing in place as lesser people catch the virus sooner, there is a safe and efficient way in which the government could manage the situation.

Other things to note about quarantine and social distancing is that the beds occupied are filled more gradually when social distancing is added.

2 influential factors in spreading the virus

1. The population of the region
2. How strictly the rules are followed

Changes to society

1. Minimal outdoor movement
2. Increased virtual events so that there as lesser crowds
3. More stricter social distancing norms

Ref: https://mesa.readthedocs.io/en/master/tutorials/intro_tutorial.html (https://mesa.readthedocs.io/en/master/tutorials/intro_tutorial.html)