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Scientific Computation (COE 322)

Infectious Disease Simulation

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Description

In this simulation of a disease spreading through a population, I observe the changes that the change in population, days of infection, probability of vaccination and infection have on the overall days until the disease is eradicated. I also took note of the maximum amount of people vaccinated or infected on a given day. The code for the simulation originates from a single person and is then scaled to be the size of a city, which can then be used to optimize the precautions taken in a real-life scenario to reduce the devastation of disease. A proper example of how this simulation can be used is by inputting a population of 950,000, days of infection as 14, 50% chance of contracting said disease, and 55% as vaccinated. This disease would theoretically be eradicated in 40,000 days, this example is covid-19 if people kept interacting without social distancing and other precautions. I am encompassing the concepts of a disease with a single person, population and infecting or vaccinating people randomly. It also includes the probability of transferring the disease by direct contact and the effect of vaccines on individuals and the overall state of the population.

Data Tables

The tables of data gathered from the simulation present different outcomes for the same amount of population, days of infection, probability of infection, and probability of vaccination. I annotate the key portions of the disease such as the total amount of days the infection is live, the day the infection has the most infections and the amount, as well as the day the vaccines reaches its height and the amount. Something to note from the results is once the vaccinations peak, they remain constant throughout the simulation thus reducing the spread of the disease. Due to this, the probability percentages are extremely important, and this is shown when both thresholds are low since the vaccine trumps over the infection. Alternatively, when the probability values are larger the disease reaches its height before the vaccine and does its damage before the vaccine can effectively protect the population.

The first table is the baseline for the changes in the other data, this is the basic effects of the inputs and the outputs. Trial is the number of attempts with the following values, Population is the amount of people within the experiment, Days of In is the days the infection lasts for one person, In Prob is the threshold for infection per person, Vacc Prob is the threshold for vaccinating per person, Total days is the total days the infection lasts within the population.

BASE

Trial	Population	Days of In	In prob	Vacc Prob	Total days	Max In	Day	Max vacc	Day
1	100	5	0.6	0.6	9	35	3	63	4
2	100	5	0.6	0.6	8	50	4	49	3
3	100	5	0.6	0.6	8	57	3	42	3
4	100	5	0.6	0.6	8	51	4	48	3
5	100	5	0.6	0.6	8	51	4	48	4
6	100	5	0.6	0.6	8	51	4	48	3
7	100	5	0.6	0.6	9	44	4	54	4
8	100	5	0.6	0.6	11	38	4	60	3
9	100	5	0.6	0.6	9	43	4	55	2
10	100	5	0.6	0.6	8	52	4	47	5

This table shows a double in population and its effects can be observed within the increase of total days to be about 1.5x, while maximum infections and vaccinations increase linearly to the population. There is not much of change when increasing a population which means it only corralates with increasing the rest of the values, so no real change is observed except for the totals days of infection.

CITY GROWTH

Trial	Population	Days of In	In prob	Vacc Prob	Total days	Max In	Day	Max vacc	Day
1	200	5	0.6	0.6	11	106	4	92	3
2	200	5	0.6	0.6	12	103	4	95	5
3	200	5	0.6	0.6	8	93	4	105	4
4	200	5	0.6	0.6	9	92	4	106	3
5	200	5	0.6	0.6	8	103	4	96	3
6	200	5	0.6	0.6	10	90	4	107	3
7	200	5	0.6	0.6	13	115	4	82	3
8	200	5	0.6	0.6	10	102	4	96	3
9	200	5	0.6	0.6	9	109	5	89	6
10	200	5	0.6	0.6	8	97	4	102	4

When I double the days the infection lasts within an individual, the total days increase linearly and the maximum infections now overtake the vaccines compared to the original. Because the infection lasts longer, the disease will last longer and it has more opportunities to infect and deny the vaccine from spreading.

SYMPTOMATIC

Trial	Population	Days of In	In prob	Vacc Prob	Total days	Max In	Day	Max vacc	Day
1	100	10	0.6	0.6	15	53	6	46	4
2	100	10	0.6	0.6	14	54	5	45	2
3	100	10	0.6	0.6	13	45	4	54	4
4	100	10	0.6	0.6	13	45	4	54	4
5	100	10	0.6	0.6	14	49	5	50	4
6	100	10	0.6	0.6	13	50	4	49	4
7	100	10	0.6	0.6	13	63	4	36	4
8	100	10	0.6	0.6	15	47	6	52	3
9	100	10	0.6	0.6	13	46	4	53	2
10	100	10	0.6	0.6	15	50	6	49	6

This data set the infection threshold is lowered to 0.1 and the vaccine threshold is increased to 0.9 to represent both extremes. Because of this the disease spreads to 90% of the population which keeps the total days of infection and maximum vaccinations low (vaccinations are only applied the first day). When the disease is able to run rampant, it infects a large amount of people but also dies out as quickly as it hits achieving immunitiy through natural means.

VACCINE SHORTAGE, CONTAGIOUS

Trial	Population	Days of In	In prob	Vacc Prob	Total days	Max In	Day	Max vacc	Day
1	100	5	0.1	0.9	6	91	2	8	1
2	100	5	0.1	0.9	7	92	3	7	1
3	100	5	0.1	0.9	7	89	3	10	1
4	100	5	0.1	0.9	7	89	3	10	1
5	100	5	0.1	0.9	6	92	2	7	1
6	100	5	0.1	0.9	7	91	3	8	1
7	100	5	0.1	0.9	7	89	3	10	1
8	100	5	0.1	0.9	7	88	3	11	1
9	100	5	0.1	0.9	7	94	3	5	1
10	100	5	0.1	0.9	7	90	3	9	1

Alternatively, the vaccine threshold is increase to 0.9 and the infection threshold is now 0.1, which affects the total days in the same manner as the previous example. Because most people are vaccinated before the disease can spread, it dies off quickly but this time immunity for the public is achieved through medicine. The majority of the vaccinations are applied by the second day of the virus, thus limiting its effects of the population.

VACCINATION INCENTIVES, WEAK VIRUS

Trial	Population	Days of In	In prob	Vacc Prob	Total days	Max In	Day	Max vacc	Day
1	100	5	0.9	0.1	6	2	2	95	3
2	100	5	0.9	0.1	9	4	3	94	2
3	100	5	0.9	0.1	6	5	2	92	3
4	100	5	0.9	0.1	6	4	2	93	2
5	100	5	0.9	0.1	6	2	2	95	2
6	100	5	0.9	0.1	16	2	2	95	2
7	100	5	0.9	0.1	6	3	2	94	2
8	100	5	0.9	0.1	6	3	2	94	2
9	100	5	0.9	0.1	11	2	7	96	2
10	100	5	0.9	0.1	8	4	4	94	2

The table below shows how increased thresholds for both factors leads to less people being affected overall in the population. Neither the infection or vaccination win over the other, meaning that immunity is reached through herd immunity, only about hald the population is affected. It is also important to note that the total days the infection stays active is increased by more than 3x the original, meaning that it spreads slowly and little by little but it still spreads.

WEAK DISEASE, NO ATTENTION

Trial	Population	Days of In	In prob	Vacc Prob	Total days	Max In	Day	Max vacc	Day
1	100	5	0.95	0.95	28	35	5	25	14
2	100	5	0.95	0.95	35	37	5	29	24
3	100	5	0.95	0.95	23	29	6	34	22
4	100	5	0.95	0.95	36	27	5	39	19
5	100	5	0.95	0.95	22	28	5	40	20
6	100	5	0.95	0.95	31	24	5	39	26
7	100	5	0.95	0.95	26	37	5	26	23
8	100	5	0.95	0.95	20	29	5	35	15
9	100	5	0.95	0.95	30	33	5	29	22
10	100	5	0.95	0.95	28	38	5	31	17

This last table represents real life enviornments in which the populations are able to match cities and towns. Because the populations are so large, it takes massive amounts of time to fully eradicate the disease. I was unable to find the data for the other factors because it takes to long to compute and measure the simulation. After messing around with it I infer that high thresholds allow for the disease to stay hidden especially among a large population

REAL CITIES

Population	Days of In	In prob	Vacc Prob	Total days
500	5	0.95	0.95	32803
1000	20	0.95	0.95	32828
10000	100	0.95	0.95	32931
25000	20	0.95	0.95	32853
50000	100	0.95	0.95	32944

Person Class (Jose)

The very foundation of this code is based on the person class in which we only need four functions in order to produce a working main code provided by the textbook. I provide a functional status string function that returns a string of the current status of the person, by going through four if statements checking its status. Next is the update function that decreases the amount of days for recovery from infection as long as the person is infected until he is recovered. Next is the infect function which is provided in the textbook, but it functions to make the person sick by the amount of days inputted in the main function. Lastly is the stable check, which runs until the state of person is recovered, which then breaks the loop in the main code.

```
public:
    string status_string(){
    if(state==-1){
        condition= "recovered";}
    else if(state==-2){
        condition= "vaccinated";}
    else if(state>0){
        cout << "sick (" << to_string(state) << " to go)" << endl;
        condition= false;}
    else if(state==0){
        condition= "susceptible";}
    return condition;}

    int update(){
    if(state>1){
        state = state -1;
    }
    else if(state==1){
        state = state -2;
        }
    return state;}

    void infect(int n) {
    if (state==0){
        state = n;}
    }

    void vacc() {
    if (state==0){
        state = -2;}
    }

    bool is_stable(){
    if(state==-1){
        return true;}
    else {
        return false;}
    }

    int new_state(){
        return state;}
};
```

```
On day 1, Jose is susceptible
On day 2, Jose is susceptible
On day 3, Jose is susceptible
On day 4, Jose is susceptible
On day 5, Jose is susceptible
On day 6, Jose is susceptible
On day 7, Jose is susceptible
On day 8, Jose is susceptible
On day 9, Jose is susceptible
On day 10, Jose is susceptible
On day 11, Jose is susceptible
On day 12, Jose is susceptible
On day 13, Jose is susceptible
On day 14, Jose is susceptible
On day 15, Jose is sick (5 to go)

On day 16, Jose is sick (4 to go)

On day 17, Jose is sick (3 to go)

On day 18, Jose is sick (2 to go)

On day 19, Jose is sick (1 to go)

On day 20, Jose is recovered
```

The output from the main code is above, it runs until the person is beaten by bad luck. Once he is finally infected the disease lasts as long as the input provided and then ends when the person is fully recovered and the program updates you all the while.

Population Class (Austin)

In this class, we use elements from the previous code such as the state of the person and a vaccination process that we can then call within the population. We initialize the start of this code by defining a vector that will act as our population and be the any size that we input. Next is a function to record the number of days that pass, then a random infection which takes a random person and infects them at the beginninf of the code. Then two functions that count the number of people vaccinated and infected which output at every given day, they function by checking that each person in the vector has the correct status then adding to the count.

I then call back to the update function in the person class to update every individual in the population, then is a function that provides a string of the status of the population. This is extremely similar to the individual, but here it runs through a for loop to inlude each person in the vector. The key parts of the code are the next two functions, which work in the same style. Interaction works to decide whether or not to infect the neighbors if an infected person, it decides this through luck and the threshold that we input in the main function. The vaccine talk functions in the same way, but instead it applies the value of the vaccine to a single individual by calling back to the vaccinate in the person class.

The main is structured so that it first asks for the inputs and then it sets up the population and randomly selects the first infected person. It then runs through a while loops using the various processes previously described and ends when the disease is eradicated from the population. It also outputs the status as its all happening and provides a summary of the data that it produces.

```
public:
    Population() { };
    Population (int npeople) : npeople(npeople){
    people = vector<Person>(npeople);
    };

    int num_days(int i) {
    totdays = i;
    return totdays;
    }

    void random_infection() {
        randn = rand() % people.size();
        return people[randn].infect(totdays);
    };

    int inf_count(){
    Icount=0;
    for(int i=0;i<people.size();i++){
        if(people[i].new_state()>0){
            Icount++;}
        }
        return Icount;};

    int vacc_count(){
    Vcount=0;
    for(int i=0;i<people.size();i++){
        if(people[i].new_state()==-2){
            Vcount++;}
        }
        return Vcount;};

    void updatePop(){
    for(int i=0;people.size()>i;i++){
        people[i].update();}
    }
    void popn_status() {
    for (int i = 0; i < people.size(); i++) {
        if (people[i].new_state() > 0) {
            cout << "+";
        }
        else if (people[i].new_state() == 0) {
            cout << "?";
        }
        else if (people[i].new_state() == -1) {
            cout << "-";
        }
        else if (people[i].new_state() == -2) {
            cout << "*";
        }
    }
    };

    void interaction(float prob) {
    for (int i = 0; i < people.size(); i++) {
        float bad_luck = ((float)rand() / (float)RAND_MAX);
        if (bad_luck > prob && (i - 1) > 0 && (i + 1) < people.size()) {
            people[i - 1].infect(totdays);
            people[i + 1].infect(totdays);
        }
    }
    }
    void Vaccine_talk(float Vprob) {
    for (int i = 0; i < people.size(); i++) {
        float good_luck = ((float)rand() / (float)RAND_MAX);
        if (good_luck > Vprob && (i - 1) > 0 && (i + 1) < people.size()) {
            people[i].vacc();
        }
    }
    }
};
```

The following are outputs from the code which show the inputs for population, the days the infection will last, the threshold needed to break for an infection or vaccine per person. The long string of values represents an individual and their status along with a summary of infected, vaccinated, and total days to the right of that. The states are ? is susceptible, they have not been infected or vaccinated, * is vaccinated they can no longer be infected, + is infected they stay in this state based on your input, lastly is – which is recovered and can no longer be infected. The two examples below show how a change in population can change all the results.

```
Population of Austin: 50
Days of infection: 5
Threshold of infection 0 < i < 1: 0.95
Threshold of vaccination 0 < v < 1: 0.95
?????????????????????*????????*??????+????????????  |  1, 2 people are infected, vaccinated on day 0
????+*+?????????????**????????*????+?+????+?+?????  |  6, 4 people are infected, vaccinated on day 1
????+*+?+?+?????????**???+?++?*+?+?+?+????+?++?+??  |  15, 4 people are infected, vaccinated on day 2
????+*+?+?+?????+?+?**???+?++?*+?+?+?+????+?++?+??  |  17, 4 people are infected, vaccinated on day 3
????+*+?+?++?+??+?+?**???+?+++*+?+?+*-*??+++++?+??  |  21, 6 people are infected, vaccinated on day 4
????-*-?+?++?+?++?+?**???+*+++*+?+?-*-*??+-+-+?+??  |  17, 7 people are infected, vaccinated on day 5
????-*-?-?-+?+*++?+?**+*?-*--+*-?-?-*-*??+-+--?-??  |  9, 9 people are infected, vaccinated on day 6
????-*-?-?-+?+*+-?-?**+*+-*--+*-?-?-*-*??+-+--?-??  |  8, 9 people are infected, vaccinated on day 7
????-*-?-?--?-*+-?-?**+*+-*---*-?-?-*-*??-----?-??  |  3, 9 people are infected, vaccinated on day 8
???*-*-?-?--?-*--?-?**+*+-*---*-?-?-*-*??-----?-??  |  2, 10 people are infected, vaccinated on day 9
???*-*-?-?--+-*--?-?**-*+-*---*-?-?-*-**?-----?-*?  |  2, 12 people are infected, vaccinated on day 10
???*-*-?-?--+-*--+-?**-*--*---*-?-?-*-**?-----?-*?  |  2, 12 people are infected, vaccinated on day 11
???*-*-?-?--+-*--+-?**-*--*---*-?-?-*-**?-----?-*?  |  2, 12 people are infected, vaccinated on day 12
???*-*-*-?--+-*--+-?**-*--*---*-?-+-*-**?-----?-*?  |  3, 13 people are infected, vaccinated on day 13
??**-*-*-?----*--+-?**-*--*---*-+-+-*-**?-----+-*?  |  4, 14 people are infected, vaccinated on day 14
??**-*-*-?----*----+**-*--*---*-+-+-*-**?-----+-*?  |  4, 14 people are infected, vaccinated on day 15
??**-*-*-?----*----+**-*--*---*-+-+-*-**?-----+-*?  |  4, 14 people are infected, vaccinated on day 16
??**-*-*-+----*----+**-*--*---*-+---*-**?-----+-*?  |  4, 14 people are infected, vaccinated on day 17
??**-*-*-+----*----+**-*--*---*------*-**?-------*?  |  2, 14 people are infected, vaccinated on day 18
?+**-*-*-+----*-----**-*--*---*------*-**?-------*?  |  2, 14 people are infected, vaccinated on day 19
?+**-*-*-+----*-----**-*--*---*------*-**?-------*?  |  2, 14 people are infected, vaccinated on day 20
?+**-*-*------*-----**-*--*---*------*-**?-------*?  |  1, 14 people are infected, vaccinated on day 21
?+**-*-*------*-----**-*--*---*------*-**?-------*?  |  1, 14 people are infected, vaccinated on day 22
?-**-*-*------*-----**-*--*---*------*-**?-------*?  |  0, 14 people are infected, vaccinated on day 23
```

```
Population of Austin: 100
Days of infection: 5
Threshold of infection 0 < i < 1: 0.95
Threshold of vaccination 0 < v < 1: 0.95
????????????????????????????*????*???????????????????????????????????+??????????????????????????????  |  1, 2 people are infected, vaccinated on day 0
??????+?+???????????????????*????*+?+??????????*??+?+???????????????++?+??+?+???????????????????????  |  11, 3 people are infected, vaccinated on day 1
??????+?+?????????????++++??*????*+?+???*???+?+*??+?+??????+?+??????*++*+??+?+?????*????????????????  |  19, 7 people are infected, vaccinated on day 2
??????+?+??*????????+?++++??*??+?*+*+???*???+?+*??+?+??????+?+?+?+??*++*+??+?++?+??*????????**??????  |  25, 11 people are infected, vaccinated on day 3
??????+*+??*???+?+?+?++++??*??+?*+*+???*???+?+*??+?+????+?+?+?+?+??*-+*+??+?++?+??*????????**??????  |  27, 12 people are infected, vaccinated on day 4
??????-*-??*???+?+?+*++++??*??+?*-*-???*???+?+*??-?-?++++?+?+?+*+?+*--*-*?-?-+?+??*????????**??????  |  21, 15 people are infected, vaccinated on day 5
????+?-*-??*???+?+?+*----??*??+?*-*-???*???-?-*+?-*-?++++?-?-?+*+?+*--*-*?-?-+?+??*???????+?**??????  |  16, 16 people are infected, vaccinated on day 6
????+?-*-?**???+?+?-*----??*?+-+*-*-???*?+?-?-*+?-*-?++++?-?-?-*-?+*--*-*?-?--?-??*?+?+??*+?**?+????  |  16, 18 people are infected, vaccinated on day 7
????+*-*-?**???-?-?-*----??*?+-+*-*-?***+++-?-*+?-*-?+++-?-?-?-*-?+*--*-*?-?--*-??*?+*+??*+?**?+??*?  |  15, 24 people are infected, vaccinated on day 8
????+*-*-?**???-*-?-*----??**+-+*-*-?***+++-?-*+?-*-?----?-*-?-*-?-*--*-*?-?--*-??*?+*+??*+?**?+??*?  |  11, 27 people are infected, vaccinated on day 9
??+?-*-*-?**?**-*-?-*----??**+-+*-*-?***+++-?-*-?-*-?----?-*-+-*-?-*--*-*?-?--*-*?*?+*+??*-?**+++?*?  |  12, 30 people are infected, vaccinated on day 10
??+?-*-*-?**?**-*-?-*----??**---*-*-?***+-+-?-*-?-*-?----?-*-+-*-?-*--*-*?-?--*-*?*?-*-*?*-?**+-+?*?  |  6, 31 people are infected, vaccinated on day 11
??+?-*-*-?**?**-*-?-*----??**---*-*-?***----?-*-?-*-?----?-*-+-*-?-*--*-*?-+--*-*?*?-*-*?*-+**+-+?*?  |  6, 31 people are infected, vaccinated on day 12
??+?-*-*-?**?**-*-?-*----??**---*-*-+***----*-*-?-*-?----?-*-+-*-?-*--*-*+-+--*-*?*?-*-*?*-+**+-+?*?  |  8, 32 people are infected, vaccinated on day 13
??-?-*-*-?**+**-*-?-*----+?**---*-*-+***----*-*-?-*-?----?-*---*-?-*--*-*+-+--*-*?*?-*-***-+**---?*?  |  6, 33 people are infected, vaccinated on day 14
??-?-*-*-?**+**-*-?-*----+?**---*-*-+***----*-*-?-*-+----?-*---*-?-*--*-*+-+--*-*+*+-*-***-+**---?*?  |  9, 33 people are infected, vaccinated on day 15
??-?-*-*-?**+**-*-?-*----+?**---*-*-+***----*-*-?-*-+----?-*---*-?-*--*-*+-----*-*+*+-*-***--**---?*?  |  7, 33 people are infected, vaccinated on day 16
??-*-*-*-?**+**-*-?-*----+?**---*-*--***----*-*-?-*-+----?-*---*-?-*--*-*------*-*+*+-*-***--**---?*?  |  5, 34 people are infected, vaccinated on day 17
??-*-*-*-?**-**-*-?-*-----?**---*-*--***----*-*-*-*-+----?-*---*-?-*--*-*------*-*+*+-*-***--**---?*?  |  3, 35 people are infected, vaccinated on day 18
??-*-*-*-?**-**-*-?-*-----?**---*-*--***----*-*-*-*------?-*---*-?-*--*-*------*-*-*--*-***--**---?*?  |  0, 35 people are infected, vaccinated on day 19
```

Conclusion

First allow me to talk about herd immunity and its function within this code, it works to keep people who are not vaccinated or infected left susceptible at the end of the program. Through this we are able to achive immunity without taking any precautions or infection on the indivdual scale, instead its applied within the population scale. As seen below two people at the bottom left corner are left susceptible when the disease is eradicated. The larger the population and lower transmission and higher vaccination will help increase this effect.

```
???*????????????????????+?????  |  1, 1 people are infected, vaccinated on day 0
???*??*????????*?????*??+?????  |  1, 4 people are infected, vaccinated on day 1
???*??*????????*????**+?+?????  |  2, 5 people are infected, vaccinated on day 2
??+*+?*+?+????**????**+?+?????  |  6, 6 people are infected, vaccinated on day 3
??+*+?*+++???***????**+?-?????  |  6, 7 people are infected, vaccinated on day 4
??+*+?*+++???***????**+?-?????  |  6, 7 people are infected, vaccinated on day 5
??+*+?*+++???***+???**-?-??+?+  |  8, 7 people are infected, vaccinated on day 6
??-*-?*-+-???***+???**-?-??+?+  |  4, 7 people are infected, vaccinated on day 7
??-*-?*---+??***+??+**-?-+?+?+  |  6, 7 people are infected, vaccinated on day 8
??-*-?*---+??***+?++**-?-+?+?+  |  7, 7 people are infected, vaccinated on day 9
??-*-?*---+??***-?++**-?-+?-?-  |  4, 7 people are infected, vaccinated on day 10
??-*-?*---+??***-?++**-?-+?-?-  |  4, 7 people are infected, vaccinated on day 11
??-*-?*----??***-?+-**-?--?-?-  |  1, 7 people are infected, vaccinated on day 12
??-*-?*----+?***-?--**-?--?-?-  |  1, 7 people are infected, vaccinated on day 13
??-*-?*----+?***-?--**-?--?-?-  |  1, 7 people are infected, vaccinated on day 14
??-*-?*----+?***-?--**-?--+-+-  |  3, 7 people are infected, vaccinated on day 15
??-*-?*----+?***-?--**-?--+-+-  |  3, 7 people are infected, vaccinated on day 16
??-*-?*-----?***-?--**-?--+-+-  |  2, 7 people are infected, vaccinated on day 17
??-*-+*-----?***-?--**-?--+-+-  |  3, 7 people are infected, vaccinated on day 18
??-*-+*-----****-*--**-?------  |  1, 9 people are infected, vaccinated on day 19
??-*-+*-----****-*--**-?------  |  1, 9 people are infected, vaccinated on day 20
??-*-+*-----****-*--**-?------  |  1, 9 people are infected, vaccinated on day 21
??-*--*-----****-*--**-?------  |  0, 9 people are infected, vaccinated on day 22
```

The disease simulation is a great tool that can be used in real life scenarios and assist humanity in the future, it can allow for predictions based on factors that we know now such as masks and social distancing. We assume from the finding that an increase in population can be an ally to the threshold that is lower, thus making the specific disease very important along with vaccinations. The implications of this work can mean data for unknown problems the world may face such as covid-19 and others.