Northeastern University
College *of* Engineering

COVID-19 Simulation

Spring 2021 INFO6205 Project

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Introduction:

The COVID-19 pandemic is caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). This virus affects the infected person in several ways. Across the world, the government has taken several measures to control the spread of the disease.
We have compared the spread of infection by considering factors like proximity with the infected person, lockdown, wearing masks, maintaining social distancing and after taking vaccination for both the viruses SARS-CoV and SARS-CoV-2. Also, calculated R-factor and K- factor on a daily basis.

Aim:

To simulate the spread of a virus SARS-CoV and SARS-CoV-2. Take the R-factor and k factor of the disease, usage and effectiveness of masks, prevalence of testing and contact tracing, availability and efficacy of the vaccine, lockdown and social distancing all these factors into account. Understand simulations and draw conclusions from observations. Also, describe the worst-case growth of algorithm, invariant employed and entropy from the simulation.

Approach:

- For simulating, the mathematical concepts of probability, random data generation and statistics have been used for the calculations
- The input data is spread across the canvas by randomly spreading them in clusters of size 25 people
- If the infected person comes in contact with another person then spread the disease. Initially, two people are infected
- Chances of another person getting infected is calculated taking factors like mask, social distance, vaccine, contact tracing while immunity is calculated based on age and if a person is vaccinated
- Number of infected people is the count of people contracting the disease, number of active cases decreases after some days based on probability of death, increase in immunity
- R factor calculated by number of infected people upon number of infectors

Program:

Data Structures & Classes:

The data structures and classes are described as follows:

- **MainJFrame.java:**
  This is the main class of our project which will display a JFrame for the user to start the simulation for SARS-CoV and SARS-CoV-2, view graphs and apply several factors to see its effects on the data.

```
DisplaySpreadHelper.displaySpreadHelper.spreadCanavas( isplace: false,  num: 10,placeSize,varSize);
DisplaySpreadHelper.displaySpreadHelper.spreadCanavas( isplace: true, num: 50 , placeSize,varSize);
int peopleCount= ini.get( sectionName: "canvas", optionName: "peopleCount",int.class);
```

  Since people move from one place to another so they are mapped to some places , isplace value defined if a given coordinate is a place or person.

- **MainJFrameHelper.java:**
  This class creates event listeners for each JButton and assigns simulation values accordingly.

- **DisplaySpread.java:**
  This class displays the positions of people based on the coordinates created in the helper class.

- **DisplaySpreadHelper.java:**
  Populates the people based on the random generation of x and y coordinates in clusters of about 25.

```
public double populatingCanvas(PositionProvider place, List<Position> positions,
                               int placeSize, int varSize, int r, int c, boolean isPlace) {
    Random r2 = new Random();
    if (SimulationValues.flag123) r2.setSeed(500);
    //(varSize*2)
    double h = r2.nextDouble()+(placeSize-varSize);
    //*(varSize*2)
    double wid = r2.nextDouble()+(placeSize-varSize);
    for(int i=0;i<h;i++) {
        if((i+r)>= canvasSize -2) break;
        for (int j=0;j<wid;j++) {
            if((j+c)>= canvasSize -2) break;
            Position tempPosition = matrix[r+i][c+j];
            if(tempPosition.place !=null) continue;
            tempPosition.isplace1 =isPlace;
            positions.add(tempPosition);
            tempPosition.place = place;
        }
    }
    return wid*h;
}
```

Infection spread is initiated, if the people in that region have SARS, if the person doesn't have infection or is the same person then the loop is continued

- **Person.java:**
  In this class, a person is allowed to do movement if it's more than the probability of going out. A person's chances of getting infected is associated with immunity, age, exposure and distance

- **Displacement.java:**
  This class calculates the direction in which a person is moving then adds the new position in the person's list and removes the old position from list

- **Position.java:**
  It calculates the euclidean distance between the first element from the set of places to the place selected

- **PositionProvider.java:**
  It is an abstract class to generate random positions

- **AvailablePosition.java:**
  This class stores a list of random locations where a person can move

- **SarsCov.java:**
  This class contains all the data members that we have considered for the SARS-CoV simulations

- **Output.java:**
  This will print the data of number of days passed, active cases, infected people, recovered people, total deaths and R-factor on a daily basis

Algorithms :

SARS-CoV algorithm:

Step1: Get the random people and places

Step2: Add the coordinates generated in the positions list with values true or false based on people or position

Step3: Populate these coordinates and initiate the disease based on the probability of infection rate assigned for social distancing, lockdown, age , vaccination, masks.

Step4: Increment the active cases count

Step5: If the infection time exceeds the sars recovery period then decrement the count of active cases and increment total deaths count if it's greater than probability of dying

Step6: When the total number of active becomes zero, stop the spread

Step7: Get the R factor from infectors and number of infected people and k factor when number of infected people is 0.7 * people size i.e overspreading count

Invariants:

- Using masks, will reduce infection spread by 5%
- Social distancing, will reduce infection spread by 15%
- Lockdown reduces will reduce spread by 70%
- Vaccination will reduce infection spread by 50%
- Quarantine will reduce infection spread by 5%

Flowchart :

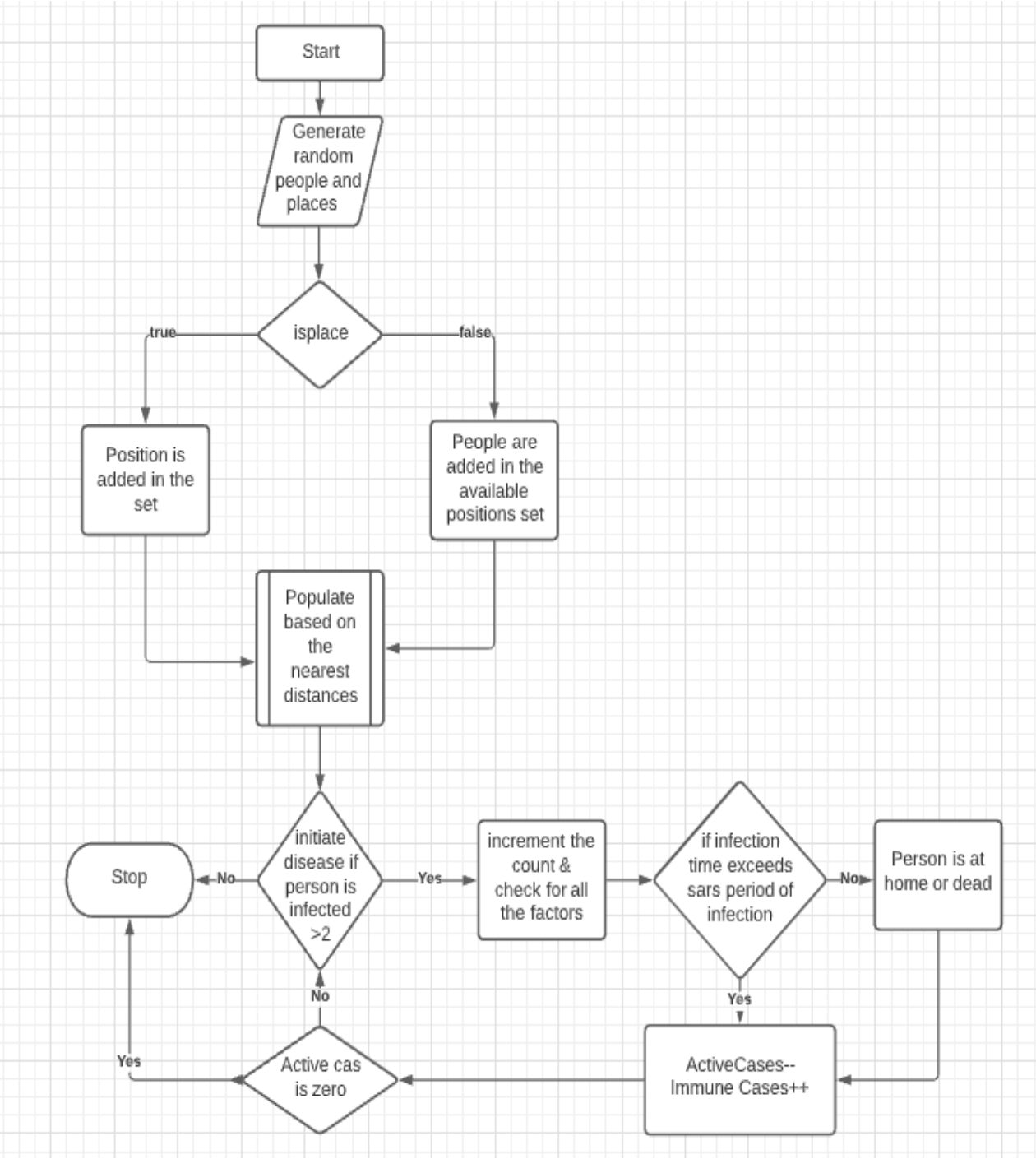


Fig. SARS-CoV Flowchart

UI Flow:

Home Page :

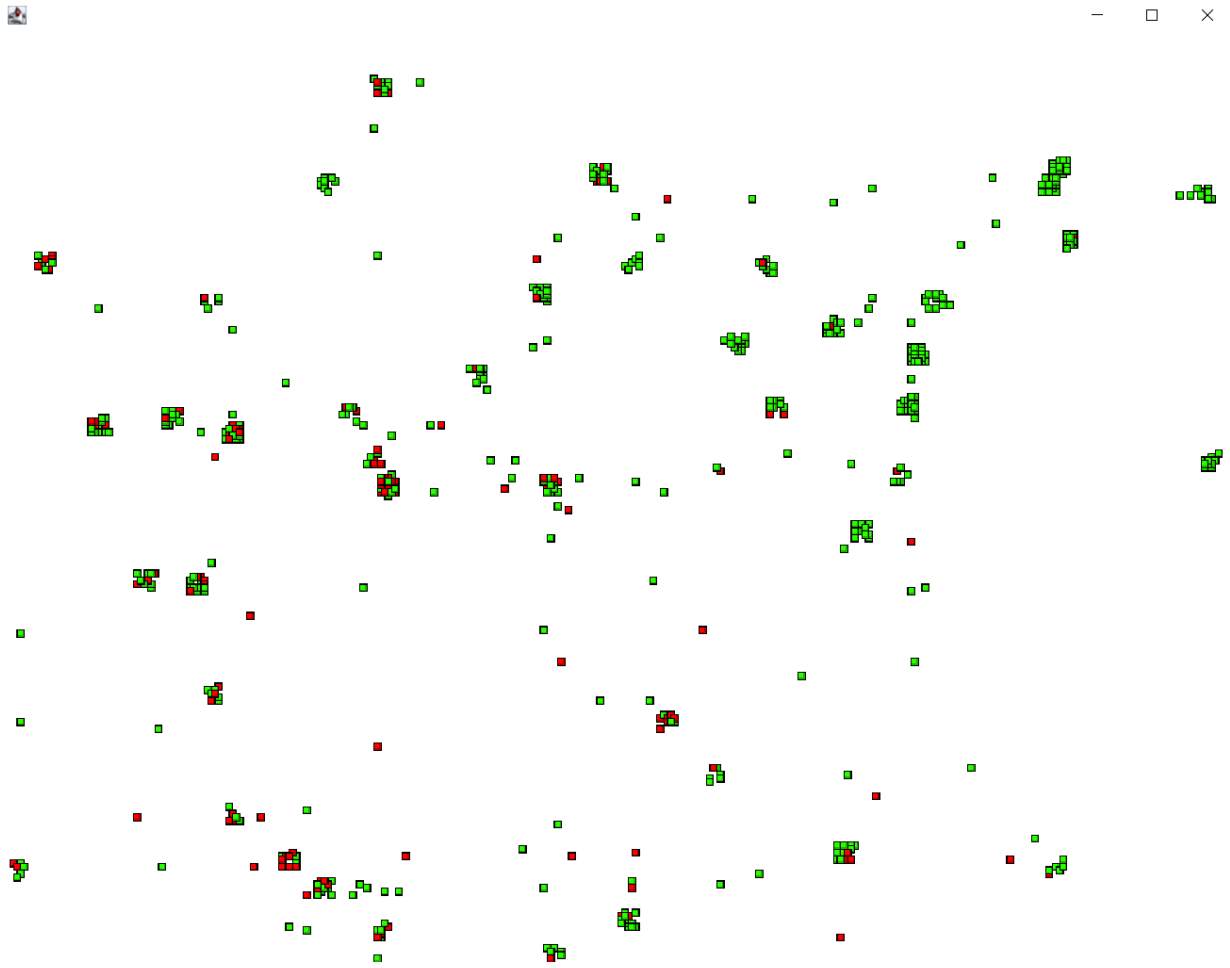
- **Consists of a drop down menu to select the type of infection (SARS-COV and SARS-COV2)**
- **Buttons**
  - Run : Initiates the simulation on a new JFrame
  - Start : Initiates the spreading of the virus among different people of various communities and the report of total number of infected people, deaths, number of active cases, infectors and daily R value is printed in the console
  - Stop : Pressing the “stop” button would stop the simulation

- **Buttons for influencing the spread of the virus**
  - Initiate Lockdown : This will impose a lockdown situation which inturn would reduce the number of active cases and the spread of disease
  - Start Quarantine : This will ensure the infected person is under home quarantine for a period of 14-21 days and doesn’t spread the infection further
  - Apply Mask : This functionality ensures reduction in the spread of infection by using masks
  - Initiate Social Distancing : This button will enable the distance between two people to increase the and reduce the number of active cases
  - Initiate Vaccination : This will enable the use of vaccines to control the spread of

infection

- **Buttons for visualization**
  - View Graphs for SARS-COV : To visualize the number of active cases, deaths, infected cases, recovered cases and infectors for SARS-COV infection against the number of days
  - View Graphs for SARS-COV2 : To visualize the number of active cases, deaths, infected cases, recovered cases and infectors for SARS-COV2 infection against the number of days

Simulation Panel :



This panel will map the spread of the virus with Green dots representing the people in different communities, while the red dots representing the number of infected people

- Command-line result:

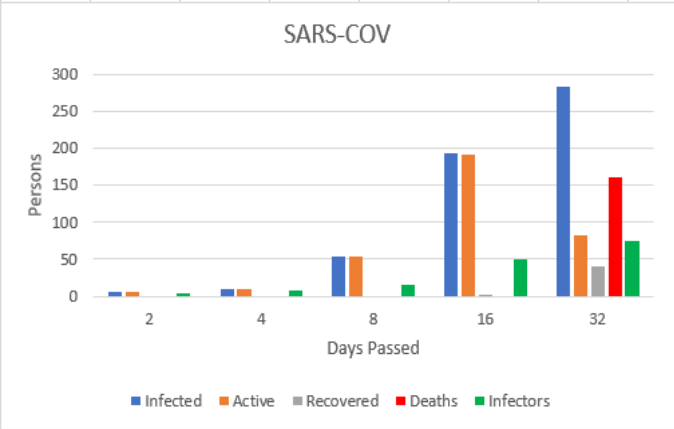
```
Days passed: 42
Infected: 456
Active Cases: 206
Immune people: 233
Total deaths : 17
Infectors: 57
Daily R-Factor: 3.6140350877192984
----------------------------
Days passed: 43
Infected: 456
Active Cases: 181
Immune people: 256
Total deaths : 19
Infectors: 121
Daily R-Factor: 1.4958677685950412
----------------------------
Days passed: 44
Infected: 456
Active Cases: 160
Immune people: 277
Total deaths : 19
Infectors: 66
Daily R-Factor: 2.4242424242424243
----------------------------
```

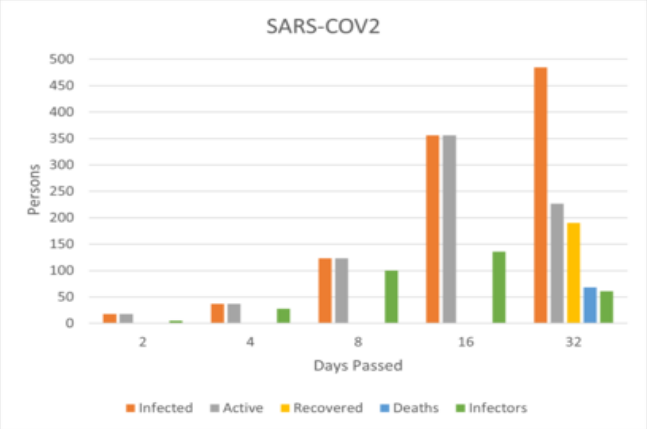
- The report prints the total number of infected people, total active cases, total number of immune people, total deaths, total infectors and the daily r factor of the infection according to the number of days passed

Observations and Graphical Analysis:

SARS-COV & SARS-COV2

BEFORE IMPLEMENTING LOCKDOWN, QUARANTINE, MASK USAGE, SOCIAL DISTANCING & VACCINATIONS



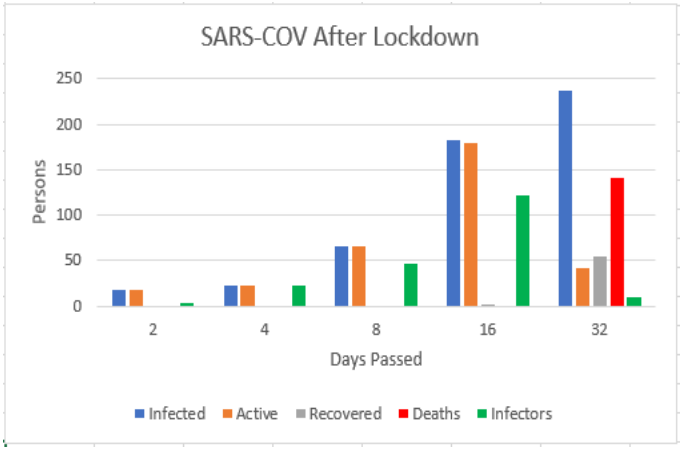


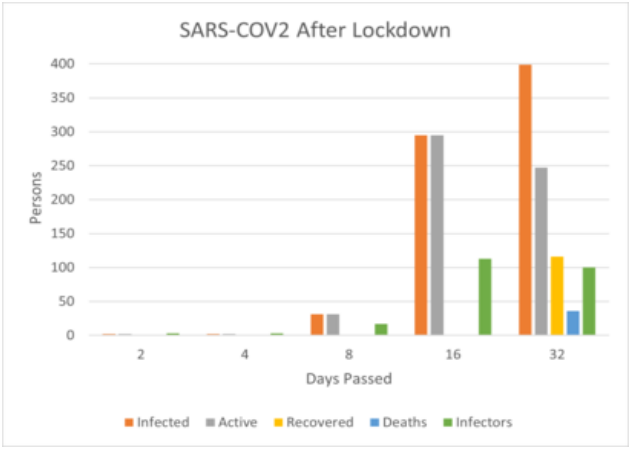
Analysis :

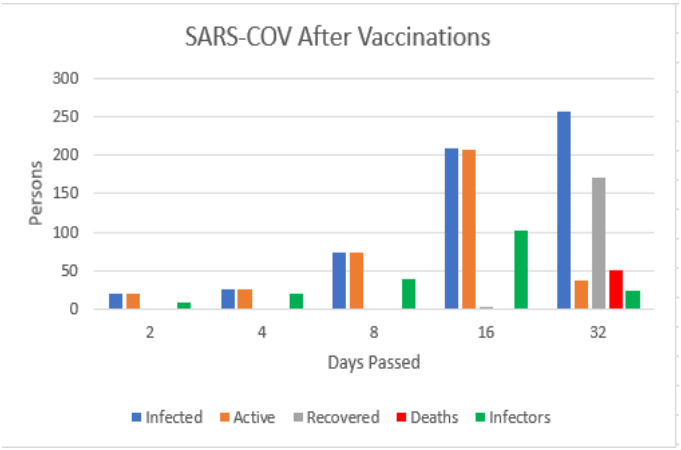
- Gradual increase in the number of infected cases, active cases and infectors
- As the recovery period is between 14-21 days, number of recovered patients is increasing
- As the number of infected patients rise, eventually number of deaths also increase
- Since, no precautionary measures are implemented there is a spike in the number of infected cases, active cases, deaths and even the infectors

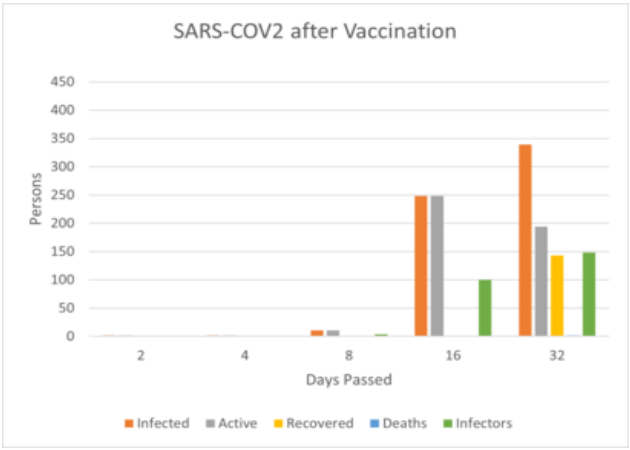
Covid-19 Simulation

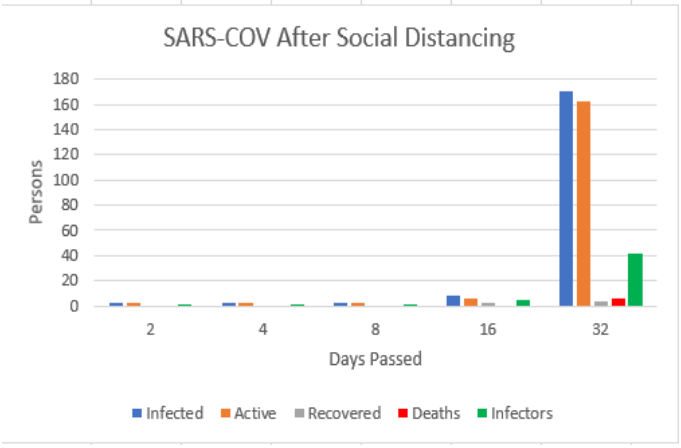
AFTER IMPLEMENTING LOCKDOWN, QUARANTINE, MASK USAGE, SOCIAL DISTANCING & VACCINATIONS (Implemented from 20th day)

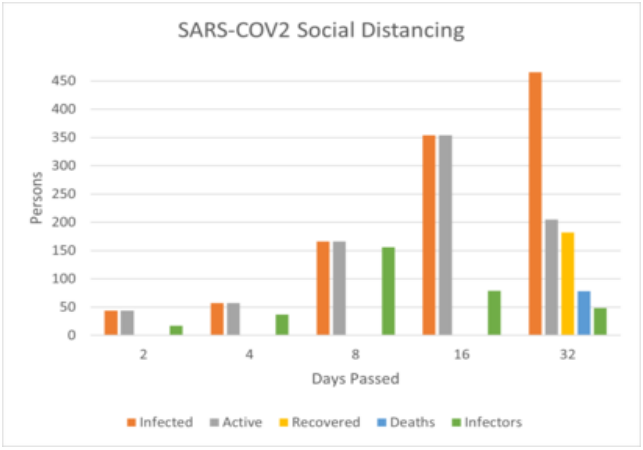




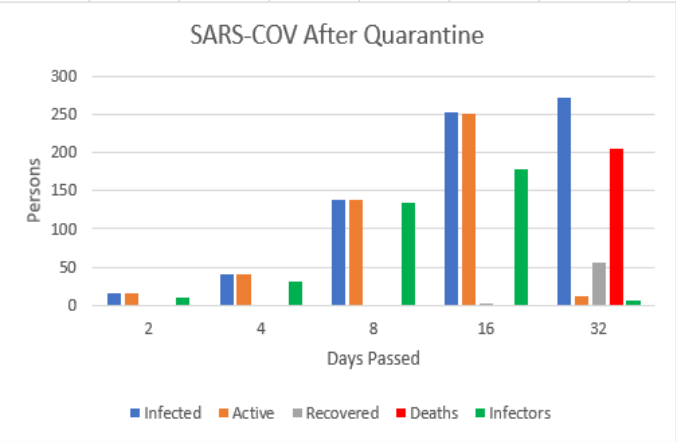


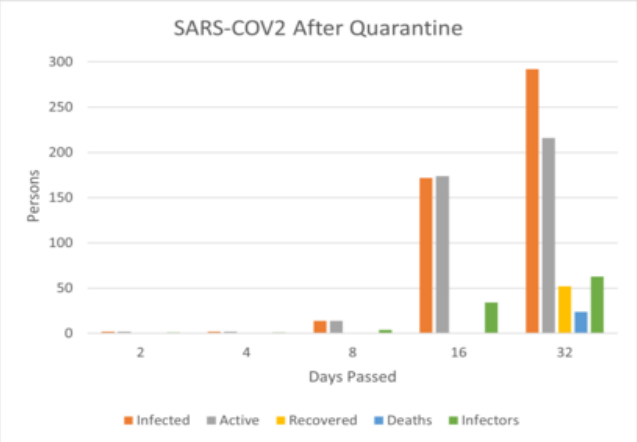


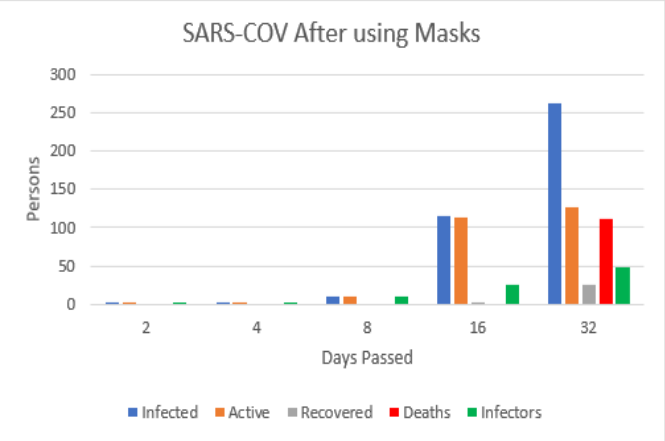


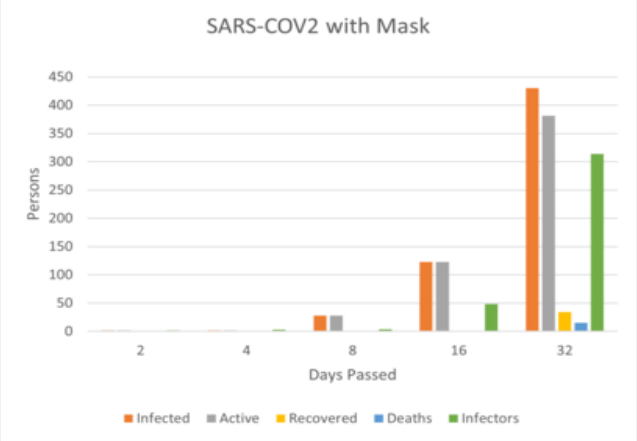


Covid-19 Simulation









Analysis :

- Gradual increase in the number of infected cases, active cases and infectors
- As the recovery period is between 14-21 days, number of recovered patients is increasing
- As the number of infected patients rise, eventually number of deaths also increase

Factors influencing the spread of SARS-COV

SARS-COV	After Lockdown	After Quarantine	After Social Distancing	After Using Mask	After Vaccinations
Infected	Moderately rising	Moderately rising	Slowly rising	Moderately rising	Moderately rising
Active	Decreased after lockdown	Decreased after quarantine	Increased due to rise in infected cases	Slowly increasing	Decreased after vaccinations
Recovered	Increased after lockdown	Increased after quarantine	Slowly increasing	Increased after using masks	Increased after vaccinations
Deaths	Increased slowly with the rise in infected cases	Increased slowly with the rise in infected cases	Increased slowly with the rise in infected cases	Increased slowly with the rise in infected cases	Increased slowly with the rise in infected cases
Infectors	Decreased	Decreased	Slowly Increased	Slowly Increased	Decreased

Factors influencing the spread of SARS-COV2

SARS-COV 2	After Lockdown	After Quarantine	After Social Distancing	After Using Mask	After Vaccinations
Infected	Moderately rising	Moderately rising	Slowly rising	Moderately rising	Moderately rising
Active	Decreased after lockdown	Decreased after quarantine	Increased due to rise in infected cases	Slowly increasing	Decreased after vaccinations
Recovered	Increased after lockdown	Slowly increased after quarantine	Increased after social distancing	Slowly increased after using masks	Increased after vaccinations
Deaths	Increased slowly with the rise in infected cases	Increased slowly with the rise in infected cases	Increased slowly with the rise in infected cases	Increased slowly with the rise in infected cases	Very slowly increasing after vaccinations
Infectors	Decreased	Slowly increased but decreased later	Decreased	Increased inspite of using masks	Slowly increased but decreased later

Result & Mathematical Analysis:

- **Euclidean distance to find the distance between two people**
  public int getEuclideanDistance(int x1,int x2,int y1,int y2)
  {
  return (int)Math.sqrt(Math.pow(x1-x2,2)+Math.pow(y1-y2, 2));
  }

- **Direction of people**
  signum|x-y|

- **Immunity of a person based on the age factor**
  if (this.age > 60) {
  t -= 0.005 * this.age;
  }
  if (this.age < 12) {
  t -= 0.03 * (12 - this.age);
  }

- **Calculating the chance of a person to get infected**
  - Chance of a person of getting infected **> 1.4**
  - Chance of not getting infected by wearing a mask is **0.05**
  - Chance of not getting infected by following social distancing is **0.15**
  - Chance of not getting infected by implementing lockdown is **0.7**
  - Chance of not getting infected by taking a vaccine is **0.5**
  - Chance of not getting infected by following quarantine rules is **0.05**
  - The distance between the people is increased by implementing social distancing which results in decrease of infection

```
double chance=0.0;
chance += sars.virusInfect;
chance -= powerImmun;
if(t);
chance+=0.1;
if(SimulationValues.mask)
    chance-=0.05;
if(SimulationValues.lockdown)
    chance-=0.7;
if(SimulationValues.socialDistance && dist>(SimulationValues.sprange /2))
    chance-=0.15;
if(SimulationValues.vaccine)
    chance-=0.5;
if(SimulationValues.contactTrace)
    chance-=0.4;

if(chance>1.4) {
    infectPerson();
```

- **Calculating the values of R and k**

```
int min = 1;
int max = DisplaySpreadHelper.numberOfActiveCases + 1;
int randomNum = r.nextInt( bound: (max - min) + 1) + min;
double d = randomNum * 1.0;

avgRfactor.add(DisplaySpreadHelper.numberOfActiveCases/d);
```

Definition:
R is the number of people that one infected person will pass on a virus to, on average
k is the dispersion value

Calculation:
According the simulation we found the daily value of R as:
R = (Number of Active Cases / Number of infectors)

```
Days passed: 16
Infected: 197
Active Cases: 195
Immune people: 2
Total deaths : 0
Infectors: 47
Daily R-Factor: 4.148936170212766
------------------------------
Days passed: 17
Infected: 206
Active Cases: 184
Immune people: 10
Total deaths : 12
Infectors: 58
Daily R-Factor: 3.1724137931034484
------------------------------
```

For the final value, we take the average of daily values of R until the number of active cases become 0

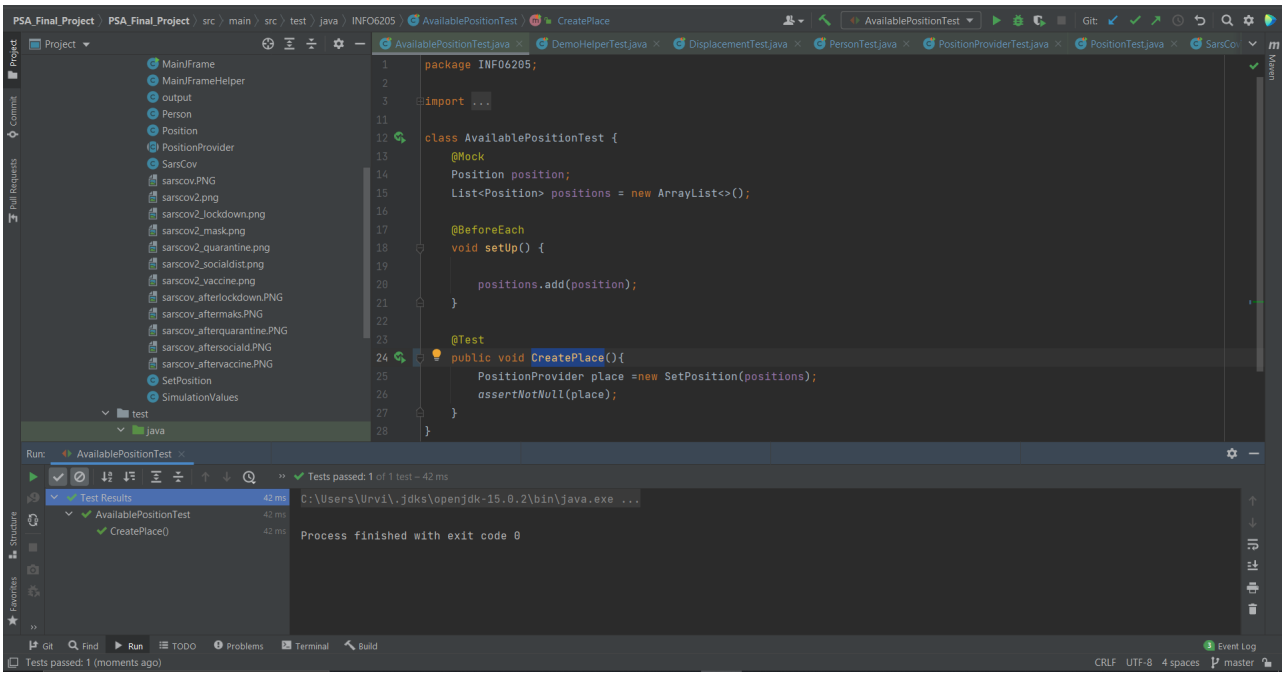
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
Days Passed	R value		Days Passed	R value		Days Passed	R value		Days Passed	R value		Days Passed	R value		Days Passed	R value		Days Passed	R value
1	0.666666667		11	2.7		21	39.8		31	1.2		41	3.22		51	1		61	0.5
2	1.333333333		12	1.645		22	1.17		32	1.12		42	2.6		52	1		62	1
3	2		13	1.148		23	3.18		33	1.54		43	1.19		53	4		63	0
4	1.285714286		14	1.032		24	3.729		34	4.125		44	0.95		54	3			
5	11		15	1.29		25	4.86		35	2.26		45	1.88		55	2			
6	1.8		16	3.918		26	2.33		36	1.59		46	1.714		56	1			
7	5.22		17	1.21		27	1.58		37	2.56		47	2		57	2			
8	3.31		18	1.11		28	24.6		38	1.32		48	3.66		58	2			
9	1.238		19	9.26		29	1.64		39	2.66		49	1.8		59	2			
10	10		20	4.38		30	1.65		40	1.07		50	8		60	2			

Average R value = R value / Total days = 218 / 63 = 3.4

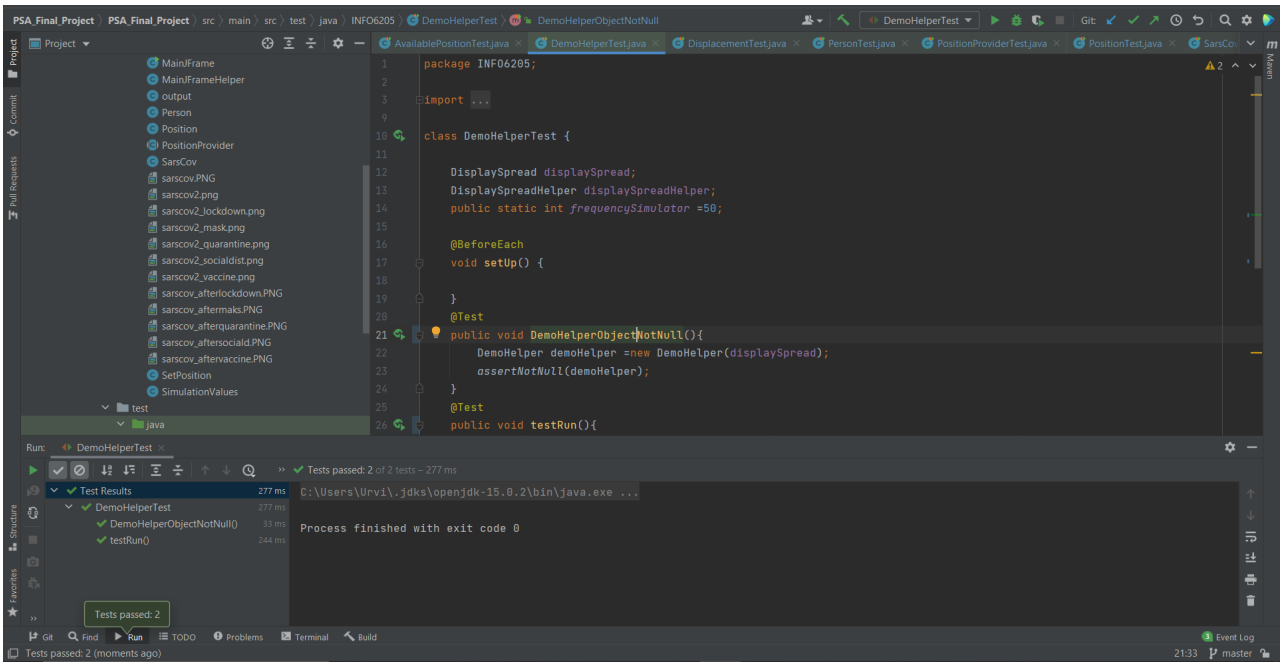
Test Case Screenshots :

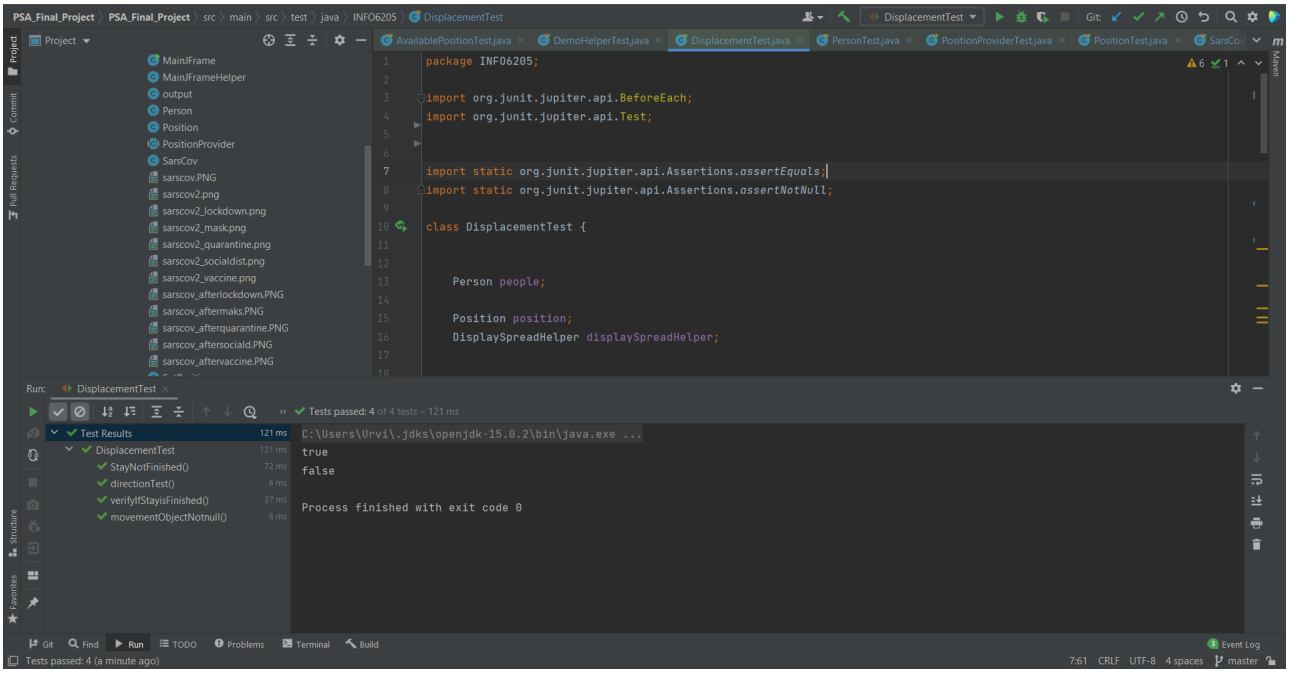
100% classes, 72% lines covered in package 'INFO6205'

Element	Class, %	Method, %	Line, %
AvailablePosition	100% (1/1)	100% (1/1)	100% (2/2)
DemoHelper	100% (1/1)	60% (3/5)	45% (10/22)
Displacement	100% (1/1)	100% (5/5)	96% (31/32)
Position	100% (1/1)	100% (3/3)	100% (8/8)
PositionProvider	100% (1/1)	50% (1/2)	71% (5/7)
SarsCov	100% (1/1)	100% (1/1)	100% (10/10)
SetPosition	100% (1/1)	100% (1/1)	100% (3/3)
SimulationValues	100% (1/1)	50% (1/2)	51% (20/39)

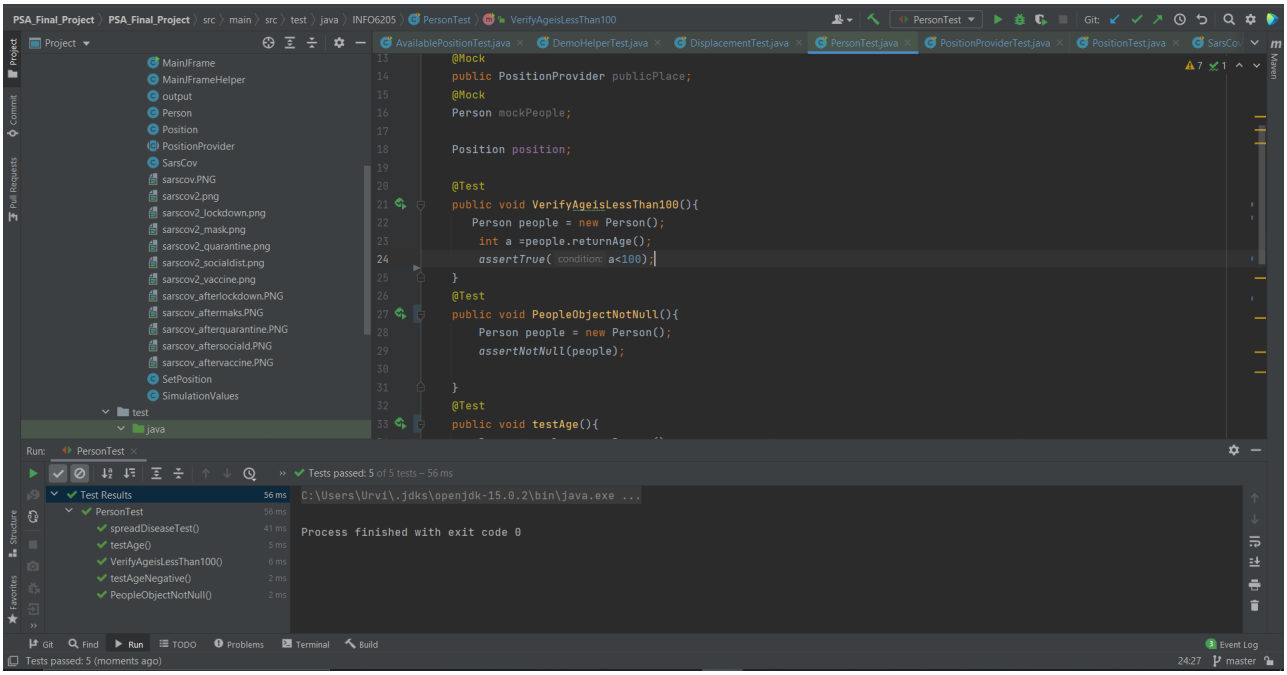


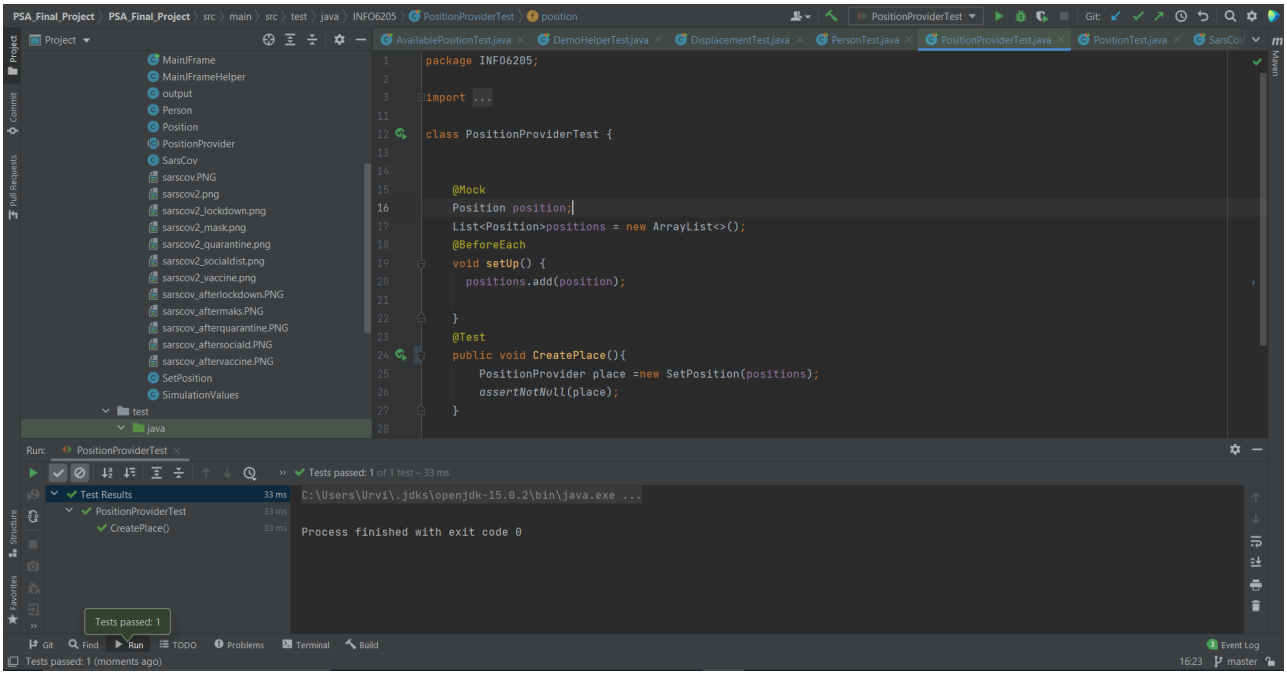
Covid-19 Simulation



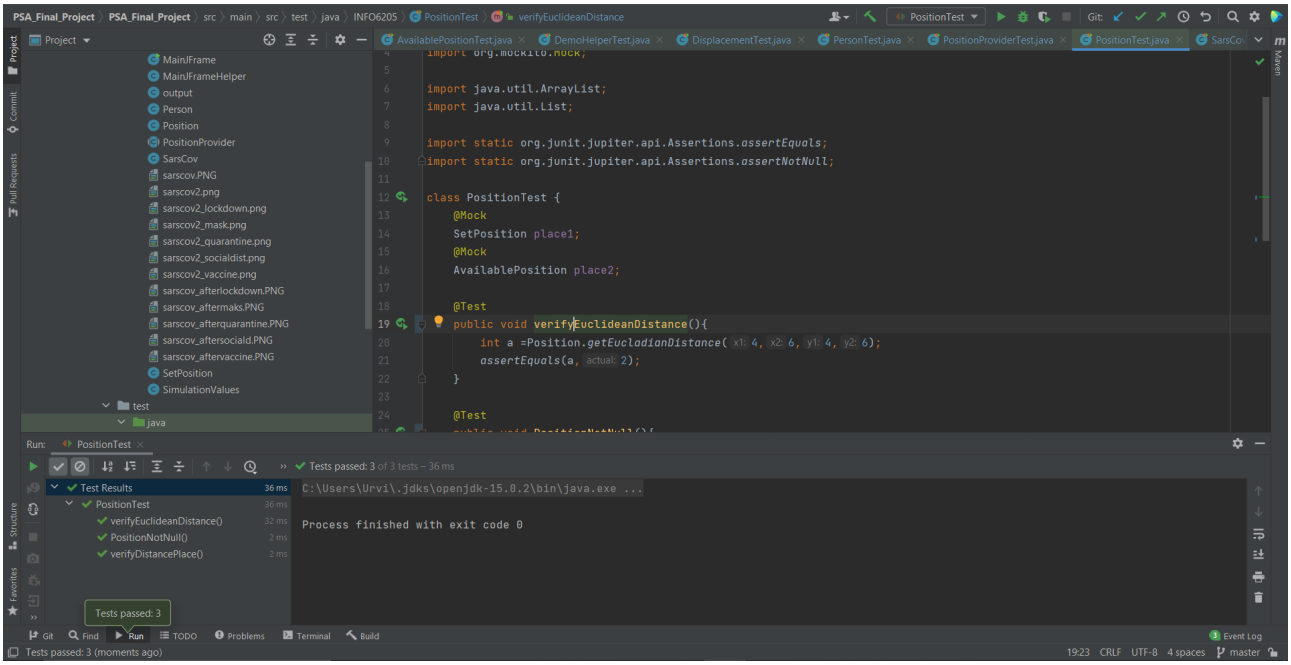


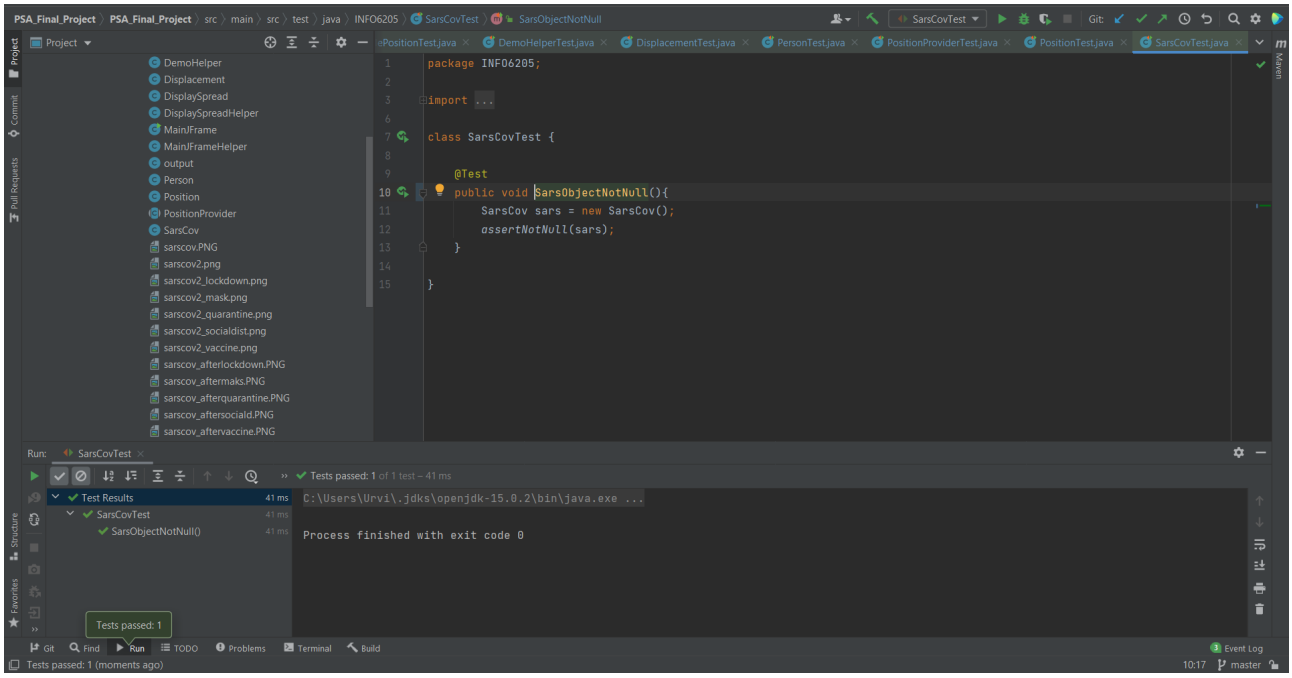
Covid-19 Simulation





Covid-19 Simulation





Conclusion:

Values of R and k

- Theoretical R value for SARS-COV is 2.5 while practical value according to the simulation is found to be 2.8
- Theoretical R value for SARS-COV2 is 3.0 while practical value according to the simulation is found to be 3.4
- k value for SARS-COV is 0.16 and SARS-COV2 is 0.1

Spread of virus depending on R and k

- Depending upon the values of R, infection spread for SARS-COV2 is more than SARS-COV since R value for SARS-COV2 is greater than R value of SARS-COV. Therefore, higher the R value, higher is the infection spread
- Similarly, depending upon the values of k, infection spread for SARS-COV2 is more than SARS-COV since k value for SARS-COV2 is less than k value of SARS-COV. Therefore, lower the k value, higher is the infection spread

Implementing Lockdown, quarantine, social distancing, mask usage and vaccination facilities reduces the spread of the infections

- Chance of not getting infected by wearing a mask is **5%**
- Chance of not getting infected by following social distancing is **15%**
- Chance of not getting infected by implementing lockdown is **70%**
- Chance of not getting infected by taking a vaccine is **50%**
- Chance of not getting infected by following quarantine rules is **5%**

Importance of k value :

Early research shows that COVID-19 is not spreading in a “reliable” manner. Rather, it is often spreading in an “over-dispersed” manner, sometimes in what have been called “super-spreader” events, making an average figure like the R perhaps less representative of the reality of the pandemic.

Order of Growth :

According to doubling hypothesis, the order of growth is:

SARS-COV : quadratic

SARS-COV2 : quadratic

This growth reciprocates with the simulated R factor

References:

1. R value ad k value for SARS-COV and SARS-COV2
   https://www.ctvnews.ca/health/coronavirus/the-covid-19-k-factor-and-what-it-means-for-contact-tracing-1.5130508

2. Estimating the overdispersion in COVID-19 transmission using outbreak sizes outside China
   https://wellcomeopenresearch.org/articles/5-67

3. How is the R Infection Rate Calculated
   https://www.labmate-online.com/news/laboratory-products/3/breaking-news/how-is-the-r-infection-rate-calculated/52825

4. The K factor: Nevermind R, here's the number we need to understand
   https://www.sciencefocus.com/news/the-k-factor-nevermind-r-heres-the-number-we-need-to-understand/