AGENT BASED MODELLING OF VIRUS SPREAD AMONGST GROUPS WITHIN A TOWN

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This project uses Agent Based Modelling (ABM) to replicate the virus spread amongst the general population within a town. The rules of the model are predefined and allow visualisation and observations of how the agents interact with one another within this environment. These rules are based on daily human behaviours and the parameters are designed to follow published Covid-19 statistics. This allows certain parameters to be changed within the model such as infectious rate/ social distancing/masks use/vaccinations within a population and allows for observations on what effect this has on the system as a whole. This document explains what ABMs are, the purpose and rules within this model, the intended results, and the reason for tracking these. This document also outlines the results of the project and any findings. All code for this project can be found in the Gitlab repository alongside a README file for how to run the code. There are separate files for running the model as is and for running the file using command line specified parameters. (https://gitlab.computing.dcu.ie/dockreg2/ca4024_abm_virus_spread)

Agent Based Models

ABMs are widely used systems for generating simulations of a collection of agents. ABMs are useful systems as they can help to replicate the behaviour of a complex system through a bottom up approach. This approach requires the boundaries and conditions of the system to be pre-defined and allows for interesting patterns to emerge when these agents interact with one another based on these predefined set of rules. These agents may represent animals, humans, cars, molecules, or other objects and are assigned attributes that may also occur within a certain probability that can help us to randomly assign features across a population. ABMs allow for repeated experiments across a range of features and although they may be computationally expensive to run, they can allow for very useful probabilistic predictions under certain circumstances and environments. The other benefit of ABMs is the ability to observe the behaviour of vast quantities of agents all at once. In this project each agent will represent a person within the environment. These human representations will have a set of characteristics and rules around how they are allowed to interact with the environment and how they are allowed to interact with one another.

Virus Spread Model

This model is designed to simulate the interaction of a selection of infected human agents within a town across a variety of groups. The selected agents will have an initial probability of being infected with the Covid-19 virus.

The purpose of this model is to understand how the variation of attributes, behaviours and environmental constraints impacts the number of infected individuals amongst selected groups within the general population. The experiments are run with a variety of different parameters and observations are made on the results. Some of these rules are based on assumptions such as social distancing thresholds and their effectiveness in reducing Covid-19 transmission.

The rules of the ABM govern the allowable behaviours of the agents and also of how they are allowed to interact within their environment. This environment replicates that of a small town. There is a probability assigned to each of the agents at the start of the simulations as to whether they are already infected with the virus. Agents will be placed at random across the whole town map to start. There will be three classes of agents. These are workers, students, and unemployed. These classes will dictate certain rules and parameters for the agents. The workers will congregate at the Central Business District (CBD) towards the north east of the town centre, the students will congregate at the University to the south west of the town centre, and the unemployed members will move at random across the map. Student agents will have limited social distancing and therefore a higher threshold for being closer to another member of the population. Workers will have an element of social distancing although they will still congregate at the CBD. Unemployed members of the population will not congregate at all and so will have a much smaller ‘social circle’. The number of infected individuals across all three classes will be one of the metrics used to understand the effect of social distancing. There is also a time element assigned to this simulation. The time is recorded and is a factor in agents movements. The simulation mimics a single day within the town, which begins with all agents randomly placed on the map. This starting point represents their respective homes and then the agents move towards their respective places of work/study for a fixed period of time before they disperse. The simulation is run to replicate an eight hour time period including travelling to work/university and also returning home.

The reasons for these behaviours is to as closely mimic that of real life for the general population within a town environment. The rules are created to allow us to model slight changes in agents attributes and slight changes within the environment to understand what effect that has on the overall outcome of virus spread across all three classes.

The intended results for this model are to show that the time spent near an infected individual is a large attributing factor to the spread of Covid-19. The difference in social distancing rules across all three classes is inspected to understand how much of a factor this is for virus spread. The model also explores the relationship between mask wearing/vaccination uptake and Covid-19 infections. The infections over time are plotted as a graph below the simulations. Infected individuals are also displayed by class in a graph allowing for comparison across scenarios.

Environment

The environment represents a town where the general population go about their day to day business. The environment has two places of interest. They are the CBD and the University and are placed at a relatively central location as can be seen in Figure 1. These are the areas where the workers and students will congregate.

Figure 1. Town Map

Agents

The agents for this project have a defined set of attributes which governs how they will interact with their environment. Each agent will have the following attributes:

- Covid status
- Job
- Home location
- Current location

These attributes determine to an extent what each agent is allowed to do at any time. Covid status is the probability that the person is Covid-19 positive and is initially set to p(covid)=0.1. Job is the class of the agent and will be an equal split between worker, student, and unemployed with the population being 900 individuals within the town resulting in 300 of each class. The time component of the model will influence whether the agents move towards their place of work, stay nearby their work, or return to their homes. Another variable, r_catch, is the likelihood that an agent will catch covid from a nearby infected individual and can be changed within the model. r_catch is set to 0.1 for all simulations.

Historical data of 17,600 daily cases (Dong et al., 2020) across the Irish population (~4,995,000) at the peak of December 2021 infections would result in a probability of having covid being ~0.004. For the purpose of this model and the visualisations the covid_status is set to 0.1 for all five scenarios which can be changed from the command line when running each example. This selection is influenced by computational and time constraints.

Masks are proven to reduce the spread of covid 19. The N95 masks have a 95% effectiveness in preventing the spread of the covid 19 particles (Qian et al., 1998) and so these will be used as a variable in this model. With the addition of masks the model reduces the rate of catching covid by 50% (allowing for poor mask wearing, meal times etc.).

Vaccinations are another variable in this model which reduce the risk of contracting and spreading Covid-19. The study of vaccine efficacy in reduction of Covid-19 Delta transmissions has shown that vaccines reduce the risk by 50% (Eyre et al, 2022). The uptake of vaccinations in Ireland was 90%+ and so this vaccination parameter will be used in this model. Similar to the masks variable the use of vaccinations reduces the rate of catching covid by 50% for the whole population.

Experiments

Five separate scenarios are run with population, covid_status, r_catch all fixed and variations in distance threshold, mask use, and vaccinations. The classes within the model have varying behaviours and attributes which also allows us to inspect variations such as social distancing measures. This distance threshold is the distance within which a normal individual can be infected by an infected individual. Distance is set as normal for the unemployed. This value is doubled for workers and tripled for students to mimic the variety in social distancing which is deemed to be lower in students than in workers and unemployed. Table 1 shows the parameters for the five scenarios. Mask wearing and vaccinations are applied to all agents within the system.

scenario	population	p_covid	r_catch	distance	masks	vaccinations
1	900	0.1	0.1	0.0004	0	0
2	900	0.1	0.1	0.0004	1	0
3	900	0.1	0.1	0.0004	0	1
4	900	0.1	0.1	0.0004	1	1
5	900	0.1	0.1	0.004	0	0

Table 1. Scenarios

The scenarios are run and live updates are returned showing movement of the agents, real time trends of infections and figures on exact numbers of infections across all three classes as shown in Figure 2. Workers are represented as triangles, students are represented as circles, and unemployed individuals are represented as crosses. All normal individuals are green with infected individuals in red.

Normal Worker | **Infected Worker**

Normal Student | **Infected Student**

Normal Unemployed | **Infected Unemployed**

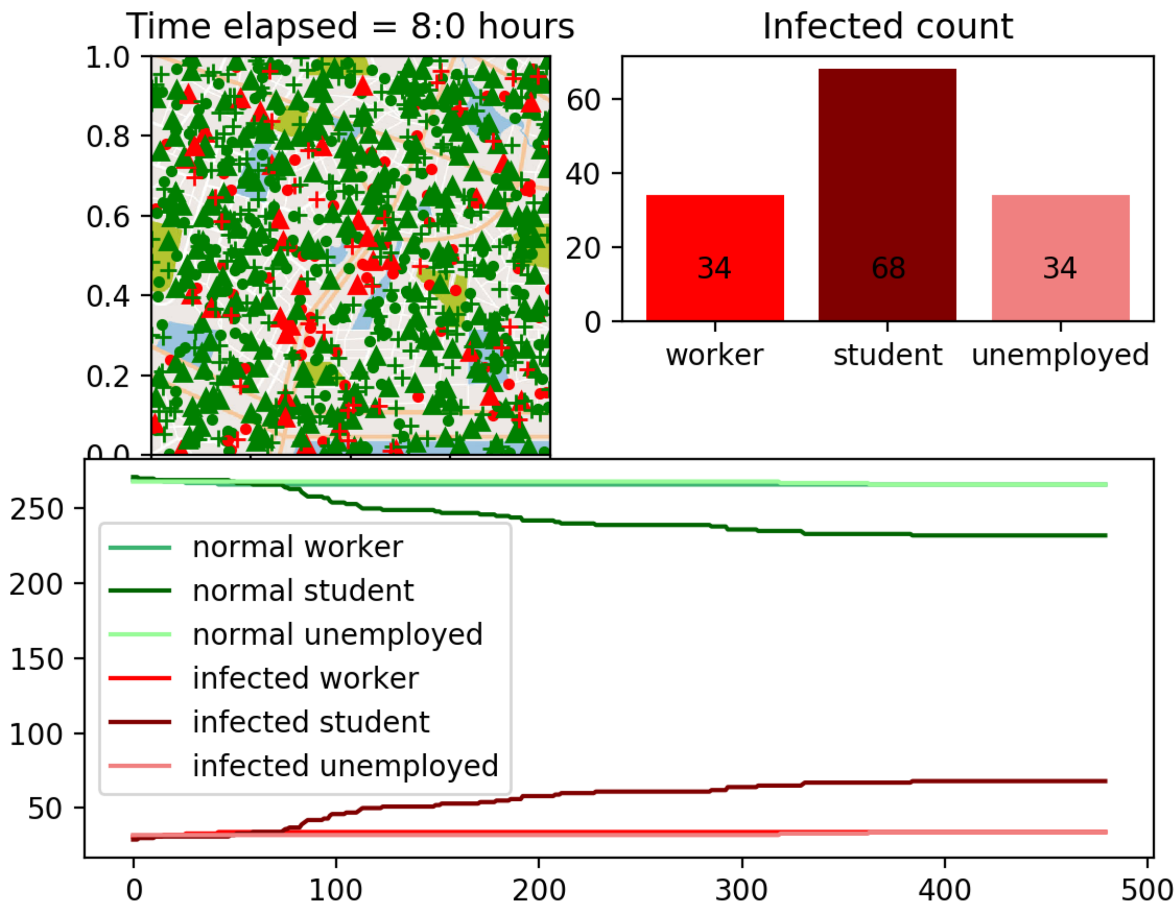

Figure 2. Model Display for Scenario 3

Results

The results of the five scenarios are shown in Table 2.

Scenario	Worker	Student	Unemployed	Total
1	45	72	28	145
2	34	78	34	146
3	34	68	34	136
4	20	63	29	111
5	30	63	39	132

Table 2. Results of Infected individuals after simulation.

The effectiveness of mask wearing and vaccinations are shown in the above simulations. Scenario 4 has the lowest infection rate across individuals due to a combination of mask use and vaccinations. Students record the highest infections across all classes for all simulations. This is as expected due to their pre-programmed lower threshold to distance(i.e. less social distancing). Interestingly the unemployed have a similar number of infected individuals as the workers. This may be due to a limitation in the model which does not increase the chance of contracting covid when surrounded by more than one infectious individual, which is something that would need to be improved for this model to be more representative of a real world scenario. Scenario 5 had a larger distance threshold for all agents and so would have been expected to result in a larger number of infected individuals however it can be seen that this parameter increased infected unemployed but did not greatly affect the students or workers. This further highlights an inefficiency in the model to replicate the effect of being surrounded by multiple infected individuals. Graphed results for all five scenarios and code can be found on gitlab (linked in the introduction).

Conclusion

The use of masks and vaccinations reduce the number of Covid-19 infected individuals within this model as do social distancing and a reduction in the number of daily contacts.

This model is an attempt to replicate the virus spread across a population comprising three separate classes through a day. Some naive assumptions were made to create this model and so for future work, creating a more realistic movement of agents, and increasing the capabilities of the model for replicating risk when surrounded by infectious individuals would need to be undertaken. In future it would be worthwhile to set the number of infected individuals as equal across all classes to closer inspect the relationship between behaviours and infected individuals. The random element of having covid initially often determined whether workers or unemployed were more infected after the simulation. Another possibility would be to run the system as is with Monte Carlo simulation, however this would be extremely time consuming. Another limitation of this model is that it allows agents to be infected and then immediately pass on covid to another agent which isn’t representative of real life virus spread. There were computational limitations to running these simulations. The p_covid was set at a higher level than ever experienced in Ireland due to the small population size of 900 individuals. This population size was the threshold above which the ABM model struggled to complete all computations and displays within a reasonable time frame. For future work, a larger population could be used with a lower probability of Covid-19 across all individuals but would need a more efficient system.

This model provides a framework to build upon for the replication of the movement of agents across an environment and the resulting virus spread across this population. All parameters can be modified and run using the code in the Gitlab repository which is linked in the introduction.

References

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