A Participatory Simulation Model for Studying Attitudes to Infection Risk

Savi Maharaj, Tamsin McCaldin, and Adam Kleczkowski

Computing Science and Mathematics, University of Stirling,
Stirling, Scotland
{savi,tli,ak}@cs.stir.ac.uk

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Abstract

This paper describes work in progress in developing an agent based participatory simulation tool to be used in experiments to investigate human attitudes to the risk of being infected by disease. Previous work used agent-based simulation in NetLogo to explore how disease spread can be controlled by human behavioural changes such as *social distancing* (reducing the number of social contacts in response to the presence of disease in the neighbourhood). This work highlighted the importance of understanding attitudes to risk: how cautiously do real people behave when confronted with the threat of disease? To allow this question to be investigated, the original simulation was converted into a *participatory simulation* activity, in which a human experimental subject is able to control the actions of an agent in the simulation. To make the activity engaging for the participant and elicit realistic responses, a game-like front-end interface was created with Flash, and virtual economic incentives were provided so as to motivate the participant to seek out social contacts while attempting to avoid becoming infected. The tool is complete and is undergoing testing, in preparation for use in actual experiments. The paper discusses the background and motivation behind the work, the design and implementation of the experimental tool, and our plans for future development of the tool and for its use in carrying out experiments.

1. INTRODUCTION

When confronted with an epidemic of infectious disease, such as SARS, avian influenza or H1N1, people often change their behaviour in an attempt to protect themselves from infection [[7], [11]]. In previous work [[8], [9]] agent-based simulation was used to investigate how such behavioural changes affect the spread of epidemics. One of the behaviours considered was *social distancing*, where individuals respond to the presence of disease within their local neighbourhood by choosing to reduce the number of social contacts they make. The results of this work highlighted the importance of a parameter we called *risk attitude* which represents how cautiously individuals behave in response to the risk of infection. Generally speaking, it was found that for many diseases, the best outcome is achieved if people behave extremely cautiously, in effect, closing their doors and stopping nearly all social contact until the threat is past. Such behaviour has the double benefit of stopping the spread of the epidemic very quickly, while causing only a small overall loss of economically beneficial social contacts. The worst outcome is seen when individuals are cautious, but not quite cautious enough. This prolongs the epidemic, resulting in social distancing being practiced for a longer period causing a large loss of social contacts without a significant reduction in the eventual impact of the epidemic. The outcome in this case is worse than if individuals do not change their behaviour and continue to make social contacts as normal.

These results raise the question of how individuals respond to the threat of disease in the real world: how does real people's behaviour compare to the parameter values used in our simulations? Do they tend to adopt the highly cautious behaviour that our simulations indicate to be optimal? Or do they instead fall into the trap of being not quite careful enough, resulting in the worst-case outcome? There is surprisingly limited quantitative data available about changes in social interactions during historical epidemics. Surveys and questionnaires [[3], [7]] provide static snapshots of behaviour but only limited information about how this behaviour changes over time. In future, it may be possible to get better data about the dynamics of social interactions through the use of wearable wireless devices to monitor interactions [[13]]. However, for obvious reasons, it is not possible to expose the wearers of these devices to epidemics induced at the experimenter's convenience. We therefore turn to the technique of *participatory simulation* as a way of creating an experimental tool to be used to investigate human attitudes to risk.

Agent-based participatory simulation is a variant of agent-based simulation in which human participants control the actions of some of the agents in the simulation. The NetLogo system [[15]], which was used to develop our original, non-participatory simulation, provides basic support for participatory simulation through its HubNet extension [[14]]. HubNet was originally developed for the purpose of using participatory simulation within classroom learning activities. A typical example is Gridlock [[16]], in

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which students control traffic lights at intersections on a road network, and must work together to control the flow of traffic through the network. It has recently been argued [[2]] that the participatory simulation technique has much underutilized potential benefit that could be brought to applications outside of strictly educational contexts. One of our aims is to explore the use of participatory simulation as an experimental tool for investigating human behaviour.

The starting point is our original NetLogo model of epidemic spread and social distancing. This has been transformed into a participatory simulation model, which allows a human participant to control the behaviour of a single individual agent. To engage the interest of the participant, the model is presented as a game, in which the participant plays the role of a susceptible (not yet infected) individual in the midst of an epidemic. On each simulated "day" of the epidemic, the player is shown information about the current level of infection in the local neighbourhood and must choose how to respond: whether to go about everyday activities as normal, or to reduce the level of social contacts. The player's decision is mirrored by the remaining (computer-simulated) individuals in the population and the epidemic advances by one day. The aim of the game is to collect points, which are designed to model the economic benefit of social contact and the economic loss of becoming infected. The player must try to make as many contacts as possible so as to maximise the number of points collected. Each contact, however, exposes the player to the risk of becoming ill through contact with an infected individual, incurring a substantial loss of points. The system records the choice made by the player on each day. This can then be analysed to get quantitative data about the player's attitude to risk.

Section 2 of this paper gives an overview of the underlying agent-based simulation model of disease spread and social distancing on which this work is based. Section 3 explains in detail how the original model was transformed into a participatory simulation activity suitable for use in experiments. Section 4 explains our plans to use the resulting tool to carry out experiments, and discusses other areas for future investigation.

2. ORIGINAL SIMULATION MODEL

The underlying model used in this work is an SIR model [[1]] of disease spread on a spatial network. The network is a two-dimensional square lattice containing 50x50 cells. Each cell is occupied by one individual, which may be *susceptible*, *infected*, or *removed*. Susceptible individuals have never been infected, and may become infected by contact with an infected individual. Infected individuals may eventually recover, after which they are immune from further infection. Each individual has its own personal *contact radius* which may be reduced or increased during the course of an epidemic as the individual practices social distancing. Two individuals may contact each other if each is within the other's contact radius (modelled as Euclidean distance).

At the start of a simulation run, there are a small number of infected individuals and all others are susceptible. Figure 1 illustrates the transitions that individuals then undergo. At each time step, contact occurs between all pairs of individuals who are within each other's contact radius. Contact between a susceptible and an infected individual may result in the susceptible becoming infected, with probability p. The parameter p represents the infectiousness of the disease: the higher the value of p, the more infectious the disease. Infected individuals may recover, with probability q.

Initially, all individuals have the same, maximum contact radius, c_{max}. Each susceptible individual is considered to be aware of the local infection pressure, i, defined as the ratio of infected to non-infected neighbours within a fixed radius around that individual. At each time step, susceptible individuals practice social distancing by increasing or reducing their contact radius, c, in response to the current value of i. The degree to which c is reduced for a given infection pressure depends upon a parameter α, representing the attitude to risk of individuals in the populations. All individuals are considered to share the same attitude to risk. Lower values of α represent more cautious, or risk-averse attitudes, and result in a greater reduction to c for a given i. Formally, the new contact radius, c', is determined by the formula:

$$c' = c_{max}\ (1 - i^{\alpha}) \qquad \text{(Equation1)}$$

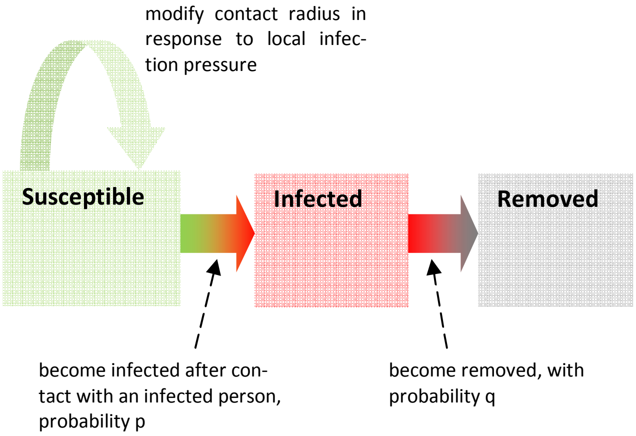

Figure 1: Transitions of an individual in the model

Figure 2 shows a snapshot of a NetLogo simulation run of the model. In this run, social distancing is successfully suppressing the spread of the epidemic. Susceptible individuals who have infected neighbours nearby have become aware of their presence and reduced their contact radii. The result is that the infected individuals are surrounded by "walls" consisting of cautious susceptible individuals practicing social distancing. These susceptible individuals avoid contact with their infected neighbours until these neighbours have recovered, preventing the disease from spreading significantly beyond the initial patches of infection.

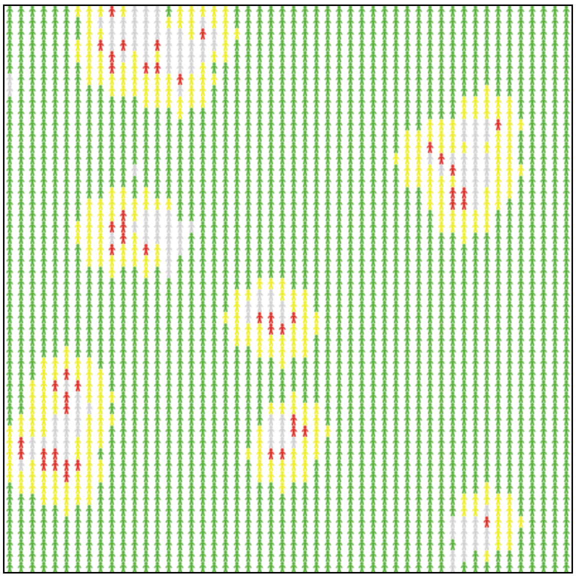

Figure 2: Screenshot of a simulation run. Red = infected; grey = removed; green = susceptible; yellow = cautious

3. PARTICIPATORY SIMULATION MODEL

In the original simulation model, the attitude to risk, α was supplied to the simulation as an input parameter. The purpose of creating a participatory simulation version of this model is to find out what attitude a *real* person would adopt, when confronted with the same disease scenario. The value of α must therefore be determined by the choices made by a human participant. This is achieved by allowing the participant to control the behaviour of a single susceptible individual. At each step of the simulation the participant is shown the information available to the controlled individual, namely, the current infection pressure in the individual's local neighbourhood. The participant must then choose the contact radius, c', for the controlled individual to adopt during the current simulation step. The participant's effective risk attitude, α is then calculated using a formula derived from Equation 1:

$$\alpha = \log_{i} (1 - c' / c_{max}) \qquad \text{(Equation 2)}$$

Equation 2 does not give a defined value for α in the case where the participant adopts the maximum contact radius ($c' = c_{max}$) or the case where there is no infection present in the local neighbourhood ($i = 0$). In the first case, we take the view that the participant is not exercising any caution, and set α to a suitably high value. (Recall that high values of α represent low levels of risk-aversion.) In the latter case, if the participant has chosen to reduce the contact radius ($c' < c_{max}$), despite the absence of any infection in the local neighbourhood, then we take the view that the participant is being immoderately cautious and set α to a suitable low value.

Once the value of α has been determined, all of the remaining (computer-controlled) susceptible individuals in the population modify their contact radii in accordance with equation 1, and the simulation progresses another step. Effectively, the computer-controlled individuals are made to mirror the attitude to risk displayed by the participant. It could be argued that there is no need for this mirroring of the participant's behaviour: if our only concern is to observe the participant's responses to his/her own situation, then this can be done without forcing the other individuals to replicate those responses. The benefit of mirroring is that it magnifies the influence that the participant has on the course of the epidemic (if a single individual acts cautiously while others continue as normal, this has negligible effect on the epidemic, whereas if others adopt the same cautious attitude then this could stop an epidemic that would otherwise go unchecked). Our view is that this magnifying effect makes the simulation more engaging for the participant, as his/her choices can have a real effect on the final outcome.

Limitations of HubNet

Our first attempt to turn the original model into a participatory simulation activity involved using HubNet, a NetLogo extension that provides basic support for participatory simulation. HubNet uses a client-server model, in which a NetLogo simulation acts as a "server" and multiple HubNet "client" applications can connect to and interact with the server. Unfortunately, HubNet provides only limited options for customizing the view provided on the client interface. It was not possible to use HubNet to create an engaging graphical interface which gives the participant information about the infection pressure in the local neighbourhood, while hiding information about the actual spatial location of infected individuals. The spatial information could only be hidden by removing the graphical view completely, showing only the numerical value of the infection pressure. This seemed unlikely to engage the interest of participants.

Controlling NetLogo with Adobe AIR

NetLogo runs on the Java Virtual Machine and can be invoked and controlled by other programs running on the JVM. This means that a customized user front-end could be programmed directly in a suitable language such as Java or Scala, and could communicate directly with the back-end NetLogo simulation. However, for creating engaging interactive user interfaces and developing computer games, a more attractive option is Adobe Flash and its associated programming language ActionScript. Unfortunately, as ActionScript does not run on the JVM, there is no straightforward way to enable communication between ActionScript and NetLogo. The solution adopted was to use a system of shared files to allow the NetLogo back-end simulation to communicate with a front end created with Adobe AIR (a

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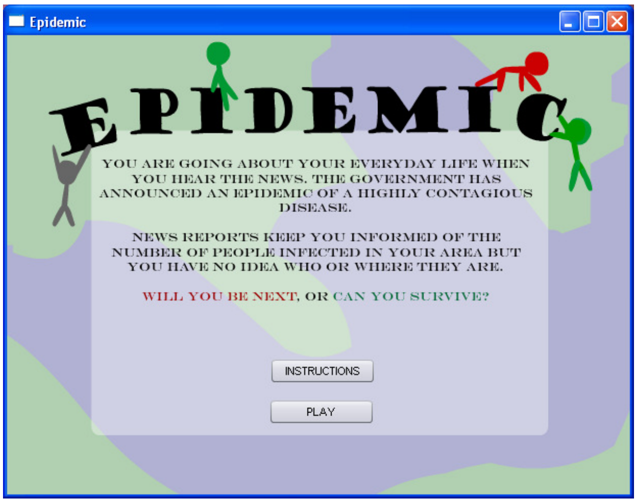
desktop equivalent of Flash which is permitted access to the local disk). The shared files perform two functions: they allow the two components of the system to communicate with each other, and they are also used to ensure correct synchronisation of actions between across the two components. Although writing files to disk is a slow operation, this does not impair the performance of the system because the overriding factor affecting performance is the much slower speed of response of the human participant interacting with the simulation.

The Participatory Simulation User Interface

The participatory simulation model is presented as a game, which is played by the experimental subject via a Flash front-end. The front-end communicates via a system of shared files with the back-end NetLogo simulation model. In framing the experiment as a game, the aim is to engage the interest of the participant, encouraging him/her to buy into the scenario that is presented and make choices that are reflective of the participant's real life attitude to the risks of infectious diseases. The hope is that a participant who is, for instance, very cautious in real life, perhaps tending to avoid public places during the flu season, will display similar behaviours during the playing of the game.

Figure 5 shows the initial welcome screen shown to the participant, which explains the epidemic scenario. Figure 6 shows the instructions given to the player.

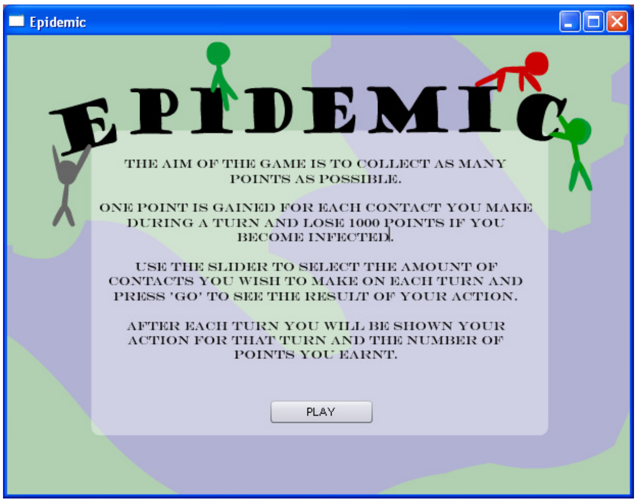


YOU ARE GOING ABOUT YOUR EVERYDAY LIFE WHEN YOU HEAR THE NEWS. THE GOVERNMENT HAS ANNOUNCED AN EPIDEMIC OF A HIGHLY CONTAGIOUS DISEASE.

NEWS REPORTS KEEP YOU INFORMED OF THE NUMBER OF PEOPLE INFECTED IN YOUR AREA BUT YOU HAVE NO IDEA WHO OR WHERE THEY ARE.

WILL YOU BE NEXT, OR CAN YOU SURVIVE?

Figure 5: Welcome screen



THE AIM OF THE GAME IS TO COLLECT AS MANY POINTS AS POSSIBLE.

ONE POINT IS GAINED FOR EACH CONTACT YOU MAKE DURING A TURN AND LOSE 1000 POINTS IF YOU BECOME INFECTED.

USE THE SLIDER TO SELECT THE AMOUNT OF CONTACTS YOU WISH TO MAKE ON EACH TURN AND PRESS 'GO' TO SEE THE RESULT OF YOUR ACTION.

AFTER EACH TURN YOU WILL BE SHOWN YOUR ACTION FOR THAT TURN AND THE NUMBER OF POINTS YOU EARNT.

Figure 6: Instruction screen

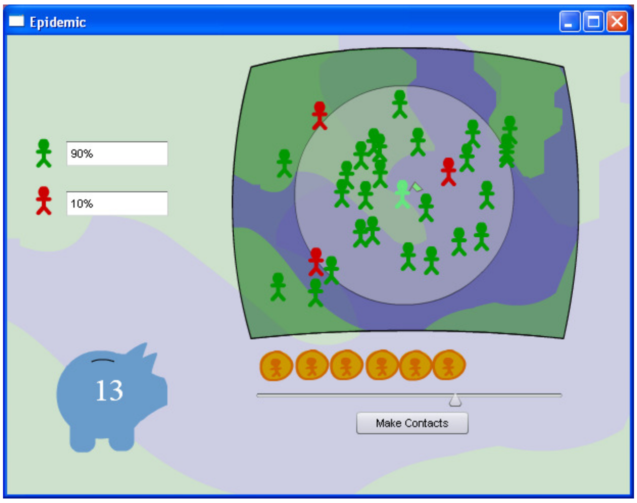


Figure 7: The player is shown the current infection pressure and must choose how many contacts to make on the current "day". The light circle indicates the contact radius and expands or contracts as the slider is moved.

Figure 7 shows a typical view during the playing of the game. The player controls the choices of a single susceptible individual, indicated by the green figure bearing a flag in the middle of the screen. The current infection pressure in the player's neighbourhood is indicated by the numbers at the top left (showing the proportions of uninfected and infected neighbours) and also by the relative numbers of green (uninfected) and red (infected) figures shown on the main screen. These figures move around continuously and quickly, so that that the player is given an impression of how many neighbours are infected, but cannot tie these down to specific locations. The light circle on the main screen indicates this player's current contact radius; he/she will make contact

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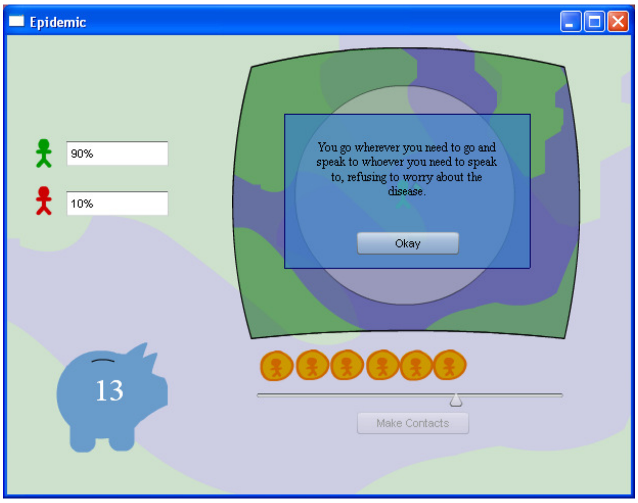
with all neighbours within this radius. The slider allows the player to choose the contact radius for the next simulation step. The row of coins above the slider increase or decrease as the slider is adjusted, reminding the player that making more contacts results in greater economic reward. The piggy-bank displays the number of points that the player has collected so far.

Once the player has made a choice and clicked the button, the interface writes the value of the player's choice to a shared file so that it can be read by NetLogo. The interface displays the screen shown in Figure 8, giving the player some entertaining feedback about his/her choice. While the player reads the message, the NetLogo back-end simulates another step in the epidemic, using the player's choice of contact radius to set the value of α to be adopted by the computer-simulated susceptible individuals. NetLogo then writes to a shared file to inform Flash of the updated infection pressure for the next "day" of the epidemic.

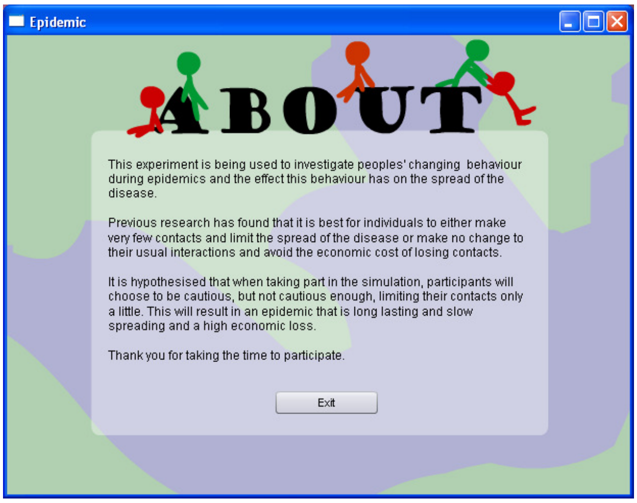


You go wherever you need to go and speak to whoever you need to speak to, refusing to worry about the disease.

Figure 8: A randomly chosen, amusing feedback message is shown after the player submits his/her decision.

The game comes to an end either when the epidemic runs its course (no infected individuals are left) or when the player becomes infected. The player is then shown the outcome (Figure 9), including the final number of points earned. Points are collected for every contact made by the player during the course of the game with a large penalty applied if the player becomes infected. After viewing the result, the player is invited to view a debriefing screen (Figure 10) which explains the purpose of the experiment.

Figure 9: Two possible outcomes for the player.



This experiment is being used to investigate peoples' changing behaviour during epidemics and the effect this behaviour has on the spread of the disease.

Previous research has found that it is best for individuals to either make very few contacts and limit the spread of the disease or make no change to their usual interactions and avoid the economic cost of losing contacts.

It is hypothesised that when taking part in the simulation, participants will choose to be cautious, but not cautious enough, limiting their contacts only a little. This will result in an epidemic that is long lasting and slow spreading and a high economic loss.

Thank you for taking the time to participate.

Figure 10: Debriefing screen

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4. CONCLUSIONS AND FUTURE WORK

The development of the participatory simulation tool is now essentially complete. Two rounds of user testing were carried out by recruiting visitors to the university on “open days” to act as experimental subjects. Test subjects responded very well to the tool, and made suggestions for improving the user interface, in particular, by providing clearer instructions for participants. Once these improvements are complete, the tool will be used to carry out experiments. In the first instance, experimental subjects will be recruited from amongst the university population. Suitable incentives, such as small cash rewards or small prizes, will be provided to motivate participants to aim at maximizing their point score when playing the “game”. Data about the subjects’ decisions and behaviour in regard to risk will be collected and analysed so that this behaviour can be compared with the optimal behaviour found in the earlier simulation work.

Future work will involve creating a web-based version of the tool. Deploying the experiment on the internet will make it easier to recruit subjects outside of the university campus. We anticipate that this will give us access to a pool of subjects from a broader socio-economic background than university staff and students, and one that is more representative of the general population. However, there are some technical problems to be solved before a web version of the tool can be developed, as the current version relies on the ability to write to the local file system, which is not generally possible with web applications.

Although much effort has gone into making the experimental tool interesting and engaging for participants, it is still very far removed from a real world experience of an epidemic. In future work we intend to look at creating more realistic experimental tools by using virtual world systems such as Second Life or Open Simulator.

Another avenue for future work will involve allowing variation in the behaviour of individuals. In the current model, all individuals behave exactly the same, in that they share the same risk attitude. In reality, different people may make different choices and it would be interesting to explore the consequences of this. Another fascinating phenomenon is herd behaviour: do people tend to copy the actions of their neighbours? This could be investigated by extending the experimental tool to permit multiple participants, and giving each participant information about the choices made by their neighbours within some defined radius.

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