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DOI:
10.1145/3489849.3489946

Incorporating Human Behavior in VR Compartmental Simulation Models

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ABSTRACT

A novel strand of Coronavirus has affected a large number of individuals worldwide, putting a considerable stress to national health services and causing many deaths. Many control measures have been put in place across different countries with the aim to save lives at the cost of personal freedom. Computer simulations have played a role in providing policy makers with critical information about the virus. However, despite their importance in applied epidemiology, general simulation models, are difficult to validate because of how hard it is to predict and model human behavior. To this end, we propose a different approach by developing a virtual reality (VR) multi-agent virus propagation system where a group of agents interact with the user in a university setting. We created a VR digital twin replica of a building in the University of Derby campus, to enhance the user's immersion in our study. Our work integrates human behavior seamlessly in a simulation model and we believe that this approach is crucial to have a deeper understanding on how to control the spread of a virus such as COVID-19.

ACM Reference Format:

Ryan Skull, Will Kitchen, David Phoenix, Connor Mackenzie, Nathan Allison, Roisin Hunt, and Leonardo Stella. 2021. Incorporating Human Behavior in VR Compartmental Simulation Models. In *27th ACM Symposium on Virtual Reality Software and Technology (VRST '21), November 14–17, 2021, Virtual Event, Tokyo.* ACM, New York, NY, USA, 3 pages. https://doi.org/10.1145/3385956.3422093

VRST '21, December 14–17, 2021, Virtual Event, Tokyo

ACM ISBN 978-x-xxxx-xxxx-x/YY/MM.
https://doi.org/10.1145/3385956.3422093

1 INTRODUCTION

An unprecedented epidemic caused by a novel strand of Coronavirus called SARS-CoV-2 has rapidly spread across the globe since its first outbreak in Wuhan, Hubei Province, China [1]. Despite the extremely fast response in the approval process for a range of vaccines and a fast roll-out, this virus is still cause of extreme concerns due to its ability to mutate quickly, causing new more transmissible variants such as the recent delta variant [2, 3]. Computer simulation models have been at the forefront of the battle against the spread of the virus for their aid in providing guidance on the most appropriate control measures [4]. For example, Covasim is an agent-based simulation where agents progress through the different epidemiological states, producing the state data as output [5]. A portion of the general public is skeptical of the effectiveness provided by the restrictions, and others struggle to grasp their importance. One of the most common control measures involves maintaining a minimum physical distance of 1-2m, which often people fail to maintain. To help people visualize the physical distance, Marti-Mason *et al.* developed a digital twin virtual reality application called SoDAlVR, that let the user move around in a building populated with AI agents: based on the relative distance between the user and the agents, the user receives visual feedback relating to the social distancing rules [6].

Virtual Reality has a heavy background in its potential usage for education. In an effort to understand the psychological motivations that underpin the policy acceptance by the vast majority of the population, a study finds that empathy promotes physical distancing and wearing of face masks during the epidemic [7]. Within the context of the COVID-19 epidemic, the same research group studied the impact of pedagogical agents in VR [8] and created a serious game application where the user can play the role of an infected individual or a vulnerable person traversing a square to emphasize the importance of vaccination [9].

In this paper, we created a virus propagation system in VR, where agents follow a schedule and propagate the virus based on distance and other non-pharmaceutical interventions (NPIs) such as mask adoption. Finally, we created a VR digital twin of one of the main buildings at our university, to act as a faithful replica.

2 VIRUS PROPAGATION SYSTEM

In this section, we present the compartmental model underpinning our VR application, see [11, 12]. We use a microscopic SIR model to determine the probability of being in any of the three states for each agent, namely susceptible, infected and removed. The underlying network topology changes over time based on the position of the agents. The following system of ordinary differential equations (ODEs) describes the time evolution of the infection probability:

$$\begin{cases} \dot{p}_j^S &= -p_j^S \sum_{k=1}^N \beta_{jk} p_k^I, \\ \dot{p}_j^I &= -\delta p_j^I + p_j^S \sum_{k=1}^N \beta_{jk} p_k^I, \\ \dot{p}_j^R &= +\delta p_k^I, \end{cases} \tag{1}$$

where $\dot{p}_j^S$ is the change in probability of being susceptible, $\dot{p}_j^I$ infected, and $\dot{p}_j^R$ removed. For the conservation of mass, we have that $\dot{p}_j^S + \dot{p}_j^I + \dot{p}_j^R = 1, \forall j = 1, \ldots, N$. In the above, the Greek letters represent the parameters of the model: agents recover at rate δ, and become infected at rate $\beta_j k = \gamma_{jk} \alpha_{jk} \nu$, where parameter ν acts as a base infection rate, γ_{jk} acts as a multiplier to the base infection representing the distance and α_{jk} takes value based on the mask adoption, ranging from 0.5 when both agents wear a mask to 1.5 when none does.

3 TIMETABLE SYSTEM

The application uses a timetable system to form groups of agents who arrive at the university for a given time, perform tasks and then leave the building. Unity's scriptable objects are a suitable data container for both the schedule that individuals use, as well as an overarching configuration for the current scenario. Schedules consist of multiple tasks, a task consists of a location for the task to occur, the time that the task begins, and the duration that the task will take. The configuration then stores groups of agents who share the same schedule, how many agents share the same schedule, and their probability of infection and mask adoption. Lastly the configuration also stores the infection and recovery rates. Data can be exported at the end of the simulation allowing for comparison between simulations, such as the impact of the user on the simulated world, or the difference between control measures. Figure 1 shows the different components of the timetabling system in a diagram.

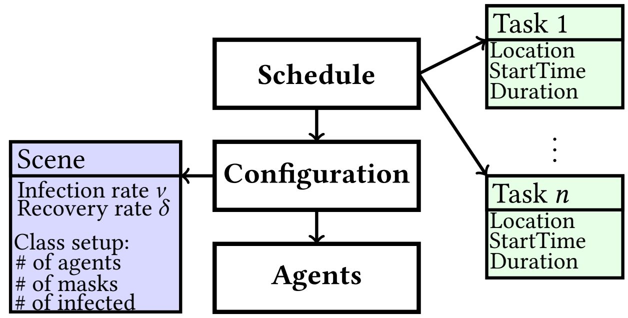

Figure 1: Diagram representation of the timetabling system.

4 DIGITAL TWIN

We created a faithful replica of one of the main buildings at the University of Derby through a number of specialised softwares, including Blender, Substance painter, Maya and Photoshop. Texturing of doors and tape was performed by editing substance painters pre-made materials to be suitable and realistic, whereas bigger building props were textured using free open source textures [13] and applied in engine. Figure 2 shows the final result.

Figure 2: Sample of the environment, the cafeteria.

For the characters we used Mixamo character models as a base [14]. This allowed us to leverage their rigs and animations and to provide more variations. We then modified the clothing and hair to create a wide array of student models, for a better user immersion. Figure 3 shows some of the characters and the outline, representing their infection probability: the darker the outline the higher the probability of being infected.

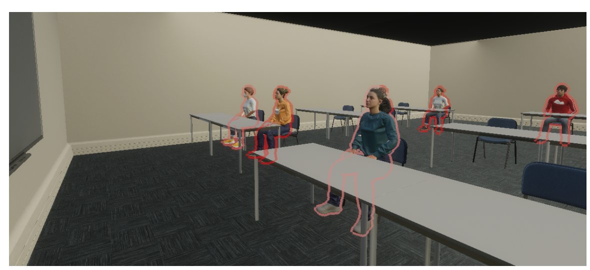

Figure 3: Character models and their outline.

5 CONCLUSION

In this paper, we have developed a VR application to visualize the transmission of COVID-19 between AI agents and a user in a university setting. Future research includes the integration of multiple users through online networking and a study of the interactions between users and agents.

ACKNOWLEDGMENTS

This research was supported by the Early Career Researchers Development Fund, University of Derby.

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