A Multi-Agent Simulator for Infection Spread in a Healthcare Environment

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Abstract. A Multi-Agent simulator made in Unity 3D is proposed to track the spread of Hospital Acquired Infections transmitted by contact in hospital wards. The tool generates a real-time contamination risk map for both people and spaces, depending on the profile, behavior and activities of virtual agents, the characteristics of pathogens and the role of inanimate objects and places.

Keywords: Multi-Agent Simulation, Hospital Acquired Infection, Decision Support System.

1 Introduction

Hospital infections are a critical challenge for the safety requirements of healthcare environments, since they are the principal hazard for hospital users worldwide. If admitted to a hospital, there is an 8% chance of contracting a Hospital Acquired Infection (HAI) and on average, the length of hospital stay increases by 17 days. Furthermore, this occurrence contributes to the development of antimicrobial resistance, which is one of the biggest threats to global health. In US hospitals alone, the Center for Disease Control estimates that HAIs account for an approximate 1.7 million infections and 99,000 associated deaths each year. This contributes to health care costs of $30 billion a year, since almost 10% of inpatient costs are HAI-related [1, 2, 3].
A demonstration of a Multi-Agent simulator to track the spread of infection transmitted by contact in hospital wards is presented. The tool generates a real-time contamination risk map for both people and spaces. The simulation visualizes the dynamic propagation of pathogens depending on the profile, behavior and activities of virtual agents, the characteristics of pathogens and the role of inanimate objects and places.

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2 Main Purpose

HAI prevention and control programs rely on a normative approach, practitioners' expertise and past experiences. Nevertheless, HAIs lie hidden from cognitive agents up until their appearance with symptoms. Current strategies are insufficient, as they are mostly counter measures to deal with the problem once it is evident. To establish an effective infection prevention and control system, it is essential to foresee the effects of intervention policies, workflow organization and spatial design. This is critical in order to propose strategies to reduce pathogen propagation beyond an increased adherence to Hands Hygiene and toward a more comprehensive understanding of the role of the environment in contamination (direct: surfaces, equipment and furniture; indirect: effect on human spatial behavior), which to date is impossible to evaluate promptly and is therefore largely underestimated [4].
The simulator adopts an Event-Based approach, which is a modelling method of human building use based on Event Narrative System architecture, whereby spaces, actors and activities are grouped into computational entities. These direct agents' behavior in space [5]. Events allow for the description of behavior from the point of view of the procedures that need to be performed to achieve a task (fig. 1). This allows for a realistic representation of complex coordinated human activities.

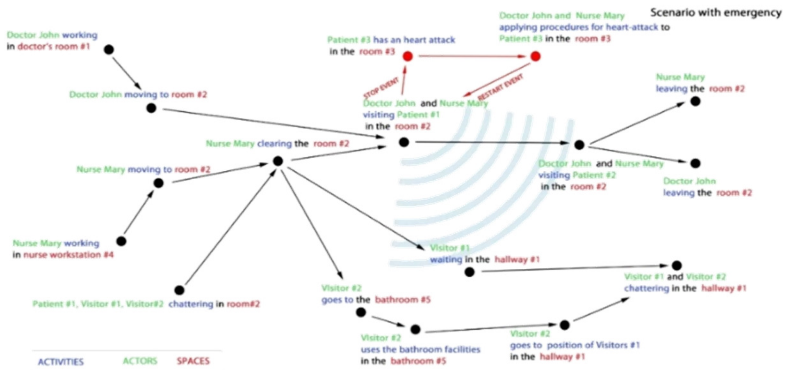

Fig. 1. – Example of Event Narrative System architecture in the case of an unplanned event [6].

During the simulation, actors interact with each other and with the environment. This is the mechanism through which HAI transmission occurs. The contamination relational law between agents (either actors or spaces) drives the transmission flow. It varies with the type of activity, the type of pathogen and the cleansing of involved agents, which represents the level of efficacy in hand hygiene or ward cleaning. An expert system is translated into a system function to account for the agents' predisposition in complying with prevention and control procedures (e.g. hand hygiene), depending on human factors (local conditions, perceived barriers, risk awareness). The case study was built with information gathered from real-life observations and on real work activities carried out within hospital wards and was developed considering scientific literature on HAIs [7]. Sessions with hospital managers widened our knowledge on measures and policies to manage HAI spread. The system elements and the transmission law were implemented in C# in a virtual simulation built with a Unity 3D engine.

3 Demonstration

Germs spread from person to person through a common series of spatial events. These follow one another in the chain of infection, which is the transmission path of an infectious pathogen. Therefore, the proposed Multi-Agent Simulator simulates building use by actors in coherent and dynamic situations of HAI risk. This represents exogenous cross-infection transmitted by contact route in a spatially explicit, heterogeneously mixed environment. The initial contamination level for each actor can be set, as well as his susceptible and asymptomatic conditions. Likewise, each space can act as a pathogen source or vector. To demonstrate the potential applications of the simulator, the working proof of a trial HCW carrier scenario is presented. This shows a building use situation where HCWs start from a staff location before moving to the central medicine room to prepare medicines and then move through the patients' rooms to distribute medicines. The simulation displays actors' movements and activities within the hospital ward and visualizes the correlated contamination propagation through a real-time contamination risk map with a range of colors for the increasing level of contamination. This output allows us to understand the dissemination of pathogens over time and space.

Fig. 2. Contamination risk map: initial and final screenshots from the simulation.

4 Conclusions

The proposed simulator integrates the system agents in a virtual simulation of building use, correlated with the contamination propagation through a contact transmission route, with real-time results and a data-log. The produced output is a dynamic contamination risk map which visualizes how pathogen diffusion varies depending on a number of factors: initial set up causes and conditions, the heterogeneity of agents' features and spatial layouts, users' spatial behavior and activities, the effect of different prevention and control measures and architectural design and spatial distribution. By depicting the environmental spread of contamination, simulations are more geared toward the reality of the phenomenon. The what-if scenario analysis provides an understanding of different qualitative factors. It reveals clusters of infected patients and patterns of occurrence. It assesses the effectiveness of practices and procedures, e.g. agent hygiene behavior, contact precautions and isolation. It gives insights on how the spatial design of buildings, facilities location and equipment distribution can affect or reduce the risk of HAIs. Thus, the simulator sets up a Decision Support System for the management of safety and health risk in healthcare facilities. It can be employed as a forecasting tool for the evaluation of policy proposals and to address the architectural design of future hospitals and the restructuring of existing ones. Finally, the simulator could be useful in facilitating managers to issue instructions and recommendations to healthcare staff members, as well as using realistic scenarios to act as a knowledge support tool for HCW training.

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