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Simulating Epidemic Response and Communication using AI-Powered NPCs in Virtual Reality

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Abstract

This study introduces a simulation framework designed to examine epidemic communication and behavioral interventions utilizing AI-driven non-player characters (NPCs) within a 3D environment created in Unity. The framework rectifies the limitations of conventional epidemiological models by integrating various agents that exhibit adaptive and context sensitive decision-making capabilities. Agents employ large language models (LLMs) and behavior trees to facilitate realistic conversations and responses in epidemic scenarios, contrasting with static rule-based systems. This results in interactions that closely resemble real-world human communication. The simulation enables real-time communication between agents and users in natural language. There are different ways that public health interventions, like social distance measures and communication attempts, can be used and evaluated. The technology enables agents to know what's going on around them and how far away other people are, so they can act in the right way. The rendering engine in Unity makes the game more realistic, which makes it more interesting and useful. This study shows that agents were able to take part in COVID-19-related conversations using GPT and Convai and give appropriate answers to user questions. The framework makes it easy to do experiments on a large scale and can be used in many different public health settings. Future improvements will include simulating emotional states, making agents more diverse, and adding visual health indicators. This study introduces a scalable, ethical, and interactive instrument intended for researchers to examine human behavior, decision making, and intervention outcomes in simulated epidemic scenarios.

1. Introduction

A key component of an effective public health response during an epidemic is the ability to assess and influence human behavior. Ethical concerns, logistical challenges, and high costs make it difficult to conduct controlled studies of human behavior and communication, limiting the scope of scientific investigations into epidemics. Computational epidemiology offers a robust, dependable, and systematic approach by facilitating the simulation of human behavior and disease transmission within virtual environments. Conventional epidemiological models, such as SIR and SEIR, ignore the complexities of human decision-making and social relationships, instead relying on equation-based assumptions that consider people as homogeneous units. Agent-based modeling (ABM) is a technique for representing various groups of people, each with their own set of characteristics, activities, and interactions. Traditional Agent-Based Models (ABMs) lack precision due to their dependence on inflexible, rule-based behaviors that fail to offer the flexibility necessary to address novel or evolving situations. Recent breakthroughs in artificial intelligence, especially large language models (LLMs) and reinforcement learning, present compelling methods for endowing agents with adaptive, context-aware reasoning abilities. These AI-driven entities can replicate more authentic human behaviors, such as learning from prior experiences and adjusting to evolving pandemic circumstances. Realism demands more than just intelligence. It requires agents who are physically present and capable of navigating interactive environments with spatial awareness. By incorporating AI agents into virtual 3D environments, such as those provided by Unity, these agents can navigate, interact, and react in a simulated world that mimics real-world dynamics. To accurately depict the diversity of communities in reality, each agent must possess distinct social positions, communication networks, and behavioral profiles. This study introduces a novel simulation platform that utilizes AI-driven non-player characters (NPCs) and Unity's real-time 3D environment to investigate how humans converse about epidemics and alter their behavior. Researchers can evaluate various public health initiatives in a live, interactive context, such as social distance limitations and awareness campaigns. The system provides real-time visualizations, facilitates agent-user interactions, and includes a researcher control panel for modifying intervention parameters and monitoring activities. This all-encompassing approach to the project addresses various issues, including ethical constraints, overly simplistic models, and the necessity for authentic, real-time simulation environments. The end result is an interactive and scalable platform for studying how people behave during an outbreak.

2. Related Work

New AI-to-AI interactions in virtual environments can simulate social behavior, public health communication, and crisis management thanks to generative AI, virtual reality, and embodied conversational agents. This section discusses relevant contributions in virtual agent design, pandemic simulation, healthcare AI, and embodied VR systems.

2.1. Virtual Labs and Multi-Agent Simulations

Nechesov et al. [1]presented evidence of AI-powered venture capitalists. The multi-layer simulation system, encompassing cognitive, behavioral, and governance levels, promotes AI-driven community experimentation. AI agents could document epidemic discussions to facilitate the realization of this theory. This increases public discourse and misinformation. Sharma et al. [2] explored how virtual labs and multi-agent environments enhance agents' activities, goal setting, and cognition. This method complements the simulation's experimental and instructive role in health communication. Healthcare virtual agents must be trustworthy and social. Sarmento and Loureiro [3] demonstrated that societal and personal norms significantly affect behavior in the context of AI agents used in sensitive sectors such as tourism and sustainability. This indicates that health agents should incorporate well-calibrated norms and habits to achieve optimal behavioral outcomes.

2.2. Large Language Models (LLMs) for Dialogue and Decision-Making

According to Brown et al. [4], models like GPT-3 can be taught fast and perform well on numerous natural language processing tasks without much modification. These skills help Unity AI bots communicate. Mishra et al. [5] suggested that medical cognitive virtual characters that can communicate in different ways could make healthcare more accessible and personalized. Being in inviting settings improves mental, physical, and social wellbeing. Dermody et al. [6] found that older adults utilizing VR applications had diminished discomfort, improved cognitive function, and a decreased frequency of falls.

Multiple studies demonstrate that AI can aid students in problem-solving and model implementation. Hu et al. [7] proposed that nursing students engage in a video game including LLM-powered patients to enhance decision-making skills. In reality, LLMs facilitate discourse and interact in a human-like manner. Izzouzi et al. [8] proposed that LLMs can enhance group dynamics, brainstorming, and communication efficacy in virtual collaboration. These models facilitate communication and creativity during pandemics. Guo et al. [9] found that LLM-powered bots can replicate real-world decision-making, dialogue, and situational awareness. They efficiently enabled communication between physicians and influencers in epidemic contexts by analyzing agents-environment interactions and defining agents.

2.3. Domain-Specific Avatars and VR Training

Vallefuoco et al. [10] developed a biomedical virtual reality training system using conversational instructional bots. Their research demonstrates that domain-specific avatars can enhance learning and engagement in healthcare. Dutta and Kannan Poyil [11] illustrated the transformative influence of AI on learning and growth via collaborative human-AI decision-making. Inkarbekov et al. [12] conducted a thorough assessment of AI visualization within the key platforms of VR Unity and Unreal Engine. They highlight VR's capacity to elucidate AI functionalities, while also noting limitations such as elevated cognitive demands and restricted scalability. Lim et al. [13] examined the impact of embodied AI agents in virtual reality on health-related attitudes via likeness matching, whereby the agent mimics the user's look or behavior. Their findings show that perceived similarity increases trust and persuasive impact in health conversations.

2.4. AI-XR and Biomedical Applications

Bin Akhtar and Rawol [14] proposed that AI-XR could transform diagnostics, training, and therapy within the field of biomedical engineering. They recommended achieving a balance among innovative concepts, privacy considerations, and the need for explainability. The solution established this equilibrium by rendering AI persona interactions within a moral virtual environment transparent.

2.5. Agent-Based Simulation (ABS) in Epidemic Contexts

Agent-based simulation (ABS) has been an established method for modeling emergent behaviors in complex systems. According to Chan and Son [15], ABS is capable of simulating autonomous and interactive entities, which makes it suitable for applications in emergency evacuation, crowd behavior, and healthcare. This solution utilizes these concepts to enable realistic epidemic response interactions for role-based AI agents, including physicians and influencers.

2.6. Embodied Virtual Agents (EVAs) in Healthcare Communication

EVAs, or embodied virtual agents, are often used in health care to reach more people and get them interested in public health issues. Kruse et al. [16] conducted a comprehensive study on virtual healthcare agents, revealing the preferences and aversions of professionals in the field. It was established that medical acceptance and confidence must be proven by empathy, understanding of individuals' concerns, and adaptation. This is analogous to pretending to have a conversation with a doctor influencer during an epidemic response, where trust and clarity are essential. Yang et al. [17] investigated how conversational AI bots' knowledge depth influences user perceptions of factuality, trust, and engagement.

In pandemic AI-to-AI conversations, domain-specific knowledge improved trust and satisfaction, suggesting role-specific conditioning. Zikas et al. [18] developed CVRSB, a virtual reality application designed to educate healthcare professionals on COVID-19 testing and personal protective equipment (PPE). Machine learning-enhanced virtual reality interactions illustrate the potential of immersive platforms to assist crisis victims in learning and adapting their behaviors more rapidly. This study illustrates that immersive generative systems can effectively model communication in public health, extending their application beyond virtual training. AI agents replicate social separation within SoDAIVR, a virtual reality environment based on digital twin technology developed by Marti Mason et al. [19]. Students may investigate epidemics and the transmission of diseases through virtual environments and proximity models.

3. Methodology

The proposed approach combines AI-powered agent-based modeling with an immersive 3D virtual environment to mimic epidemic communication and assess behavioral treatments. The methodology follows a structured workflow that includes planning, environment setup, agent configuration and interaction, and simulation execution and analysis (***Figure 1.***).

3.1. Planning phase

The Planning Phase establishes the conceptual foundation for the simulation by defining its objectives, which encompass replicating authentic pandemic talks, assessing intervention strategies, and documenting role-specific behaviors. The NPCs exhibit two distinct interaction logics: the Healthcare Professional (GPT-based) addresses epidemic-related inquiries through a custom GPT script integrated with the OpenAI API, while the Public Health Officer (Convai-powered) disseminates policy updates, guidelines, and public health messages utilizing the Convai SDK's real-time, voice-enabled dialogue system. AI capabilities are integrated by selecting and configuring large language model (LLM) APIs that facilitate role-specific communication skills while ensuring scalability for multi-agent interactions.

3.2. Environment Setup

This step builds up and configures the virtual space for agent communication. The process begins with the creation of a 3D environment in Unity that facilitates spatial navigation, proximity-based interaction, and dynamic agent location. The virtual simulation setup aims to improve simulation flow through the integration of navigation meshes, environmental colliders, lighting, and interactive zones.

The integration of the GPT and Convai APIs establishes dialogue functionality, connecting Unity to AI services via their own SDKs and scripts to enable effective dialogue management. Epidemic discussion scenarios are then created, integrating conversation prompts for public health communication, disease awareness, and intervention strategies. Behavioral triggers and event listeners are utilized to dynamically commence interactions amongst NPCs or between users and NPCs.

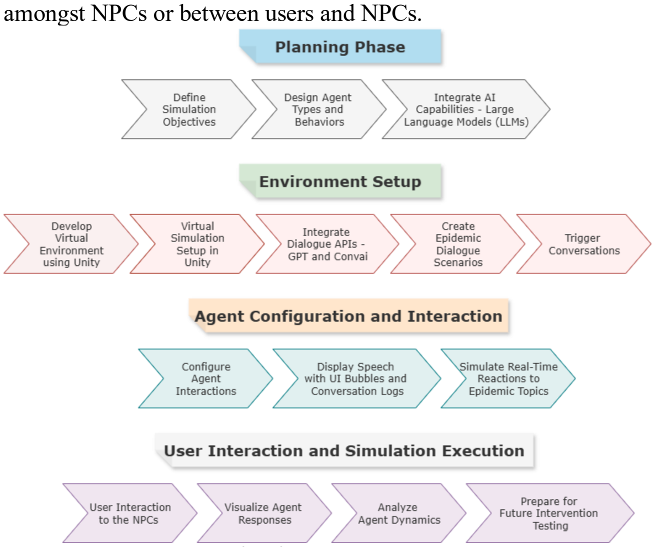

Figure 1. *Methodology workflow for simulating epidemic communication and behavioral interventions using AI-powered multi-agent NPCs in Unity*

3.3. Agent Configuration and Interaction

By outlining rules for inter-agent conversations, techniques for taking turns, and parameters for response relevance, agents can be set up with role-specific logic and communication pipelines. To integrate AI dialogues, we use the Convai SDK for real-time, multi-turn public health communication with voice capability and a GPT-based custom script for adaptive, healthcare-oriented dialogue production. Dialogue control logic is implemented utilizing behavior trees and scripted prompt sequences to manage time, context, and speaker coordination, so preventing overlapping talks. Finally, speech is visualized in real time above the agents using TextMeshPro speech bubbles, which are synchronized with audio output for Convai-powered answers where applicable.

3.4. Simulation execution and analysis

The simulation runs predetermined scenarios, logging and evaluating all interactions. Each exchange is first logged in the Unity console log, together with metadata such as speaker identification, dialogue content, and timestamps. Epidemic scenarios, particularly those involving COVID-19, are used to evaluate real-time role-based discourse generation. Agent activities are displayed to monitor NPC reactions, dialog flow, and speech bubble changes, ensuring clarity and engagement. Agent dynamics are explored by measuring response accuracy, latency, trust indicators, and role-specific efficacy.

The system is evaluated by ensuring that both agents provide correct and context-relevant responses, that user inquiries are handled successfully in real time, and that speech displays are properly synchronized, in addition to extensive conversation logging. Finally, the platform is set up for future intervention testing by allowing adaptive trials that include new policy initiatives, public notifications, or simulated outbreak conditions.

4. Results

The proposed structure was successfully deployed in Unity, facilitating dynamic and contextually relevant communication among AI-powered agents and between agents and human users. The results show that the system can handle two-way communication in two ways: NPC-to-NPC conversation and NPC-to-user conversation.

4.1. Interaction Between Agent and User

The simulation environment enabled the GPT-driven Healthcare Professional and the Convai-driven Public Health Officer to participate in authentic, multi-turn dialogues concerning epidemic-related subjects. As shown in ***Figure 2.***, the two agents converse autonomously without user intervention, discussing topics such as public trust in scientific information, the importance of credible sources, and the role of facts in ad dressing misinformation. Dialogue exchanges were displayed using floating TextMeshPro speech bubbles above the speaking agents, ensuring clarity for observers.

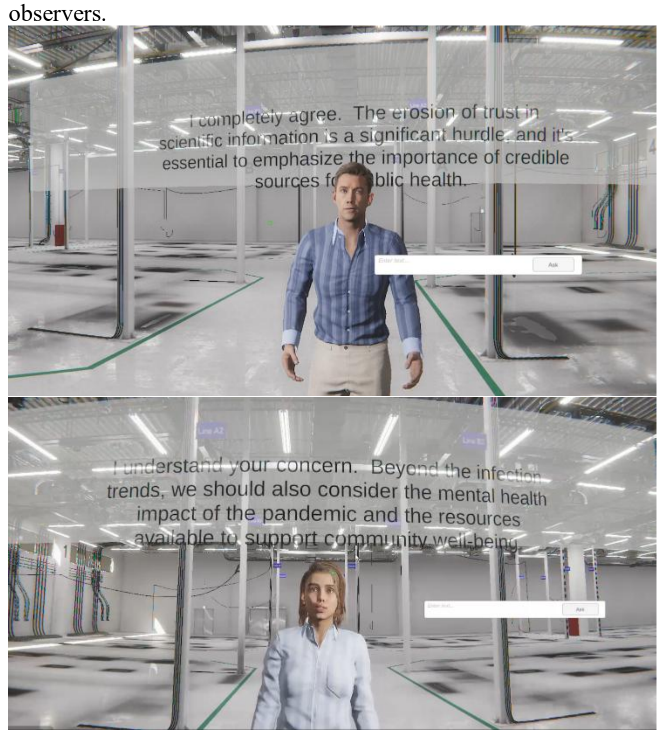

Figure 2. *Agent-to-user interactions where the user inputs a query and receives a role-specific, context-aware response from the appropriate AI-powered agent*

The conversation flow was regulated using dialogue control logic, which ensured context continuity and eliminated overlapping speech. This functionality successfully replicated a natural, role-specific dialog between two virtual characters, resulting in a realistic reproduction of professional discussions in pandemic communication contexts.

4.2. Interaction Between Agents

The framework also enabled real-time user interaction with either agent. ***Figure 3.*** shows that the user can type a question into the text input field. The Input Manager script then processes the question and sends it to the right agent. The agent the player is attempting to contact responds in real time with a context-aware and role-specific response shown above the character's head.

Figure 3. Agent-to-agent interaction between the GPT-powered Healthcare Professional and the Convai-powered Public Health Officer

This feature allows users to participate in simulated conversations, ask follow-up questions, and receive immediate responses. The interaction design ensures that NPC-to-NPC and NPC-to-user discussions run smoothly, maintaining a uniform discussion environment.

4.3. Observations and System Performance

- Both agents adhered to role-specific communication styles, with the Healthcare Professional emphasizing medically precise, evidence-based information and the Public Health Officer providing policy-oriented details.
- The conversations maintained contextual relevance, with AI models tailoring responses according to the dialogue history.
- Synchronization of speech bubbles guaranteed that the text appeared instantaneously alongside the spoken dialogue for Convai-enabled agents.
- User inquiries were handled with minimal delay, facilitating near real-time engagement.
- The Unity console log effectively recorded all dialogue exchanges, including timestamps, speaker identification, and message content, facilitating post-simulation analysis of communication patterns.

5. CONCLUSION

This study proposes an AI-driven multi-agent simulation system that accurately simulates epidemic communication and behavioral interactions in a Unity-based 3D virtual environment. The system combines two separate roles: a GPT-driven Healthcare Professional who provides medically precise, context-sensitive responses, and a Convai-powered Public Health Officer who communicates policy changes and public health guidelines via real-time voice-enabled interactions. Collectively, these agents effectively participate in autonomous agent-to-agent dialogues and interactive agent-to-user communications, delivering seamless, contextually relevant, and role-specific interactions. The simulation demonstrates a significant degree of realism by coordinating visual voice displays, managing dynamic dialogue flow, and responding promptly and precisely. The integrated conversation recording function documents speaker identity, dialogue content, and timestamps for each encounter, facilitating comprehensive post-simulation analysis of trust dynamics, message clarity, and behavioral response patterns. These features make the framework an adaptable tool for public health teaching, scenario-based policy testing, and computational epidemiology research, where doing large-scale human trials is often problematic. By addressing major drawbacks of previous epidemic models such as oversimplified human behavior, rigid communication rules, and a lack of interaction diversity, this framework lays the groundwork for next-generation immersive epidemic simulations. Future work will concentrate on expanding agent diversity, simulating emotional states, incorporating nonverbal cues, and facilitating real-time intervention assessments to examine the impact of policies, alerts, and misinformation countermeasures. This platform provides a scalable, adaptive, and morally robust environment for advancing the science of epidemic communication and decision-making.

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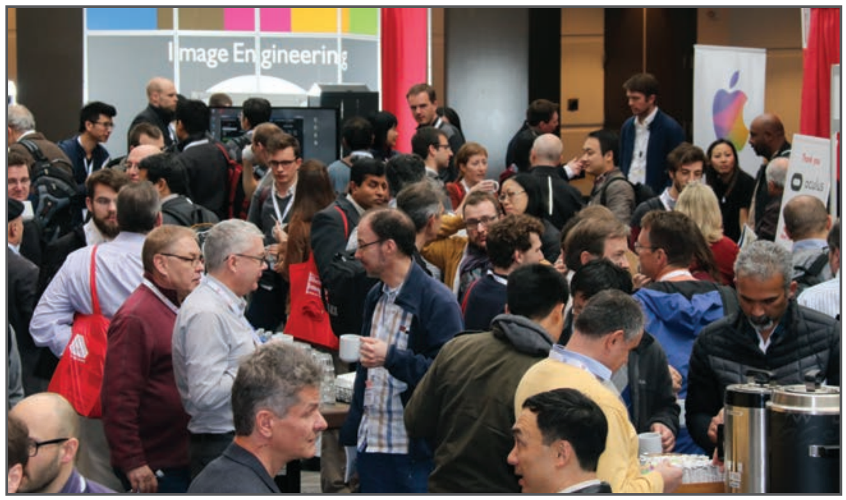

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