Generative Agents in Crowd Simulation: A Cognitive Approach with Large Language Models

Nizar Ntarouis
nizardarwish001@gmail.com

Roland Geraerts
Utrecht University
r.j.geraerts@uu.nl

***Abstract*—Crowd simulation is a powerful tool used in fields such as urban planning, emergency response, and entertainment to model and predict human movement and behavior in various scenarios. As society becomes increasingly complex and interconnected, the need for simulations that accurately capture human behavior at both the individual and group level grows. Understanding these interactions can help institutions and experts develop more effective mitigation strategies in dynamic social environments.**

This research explores the potential of the power of Large Language Models (LLMs) in crowd simulations, leveraging their capabilities to model individual behavior and enable the emergence of realistic crowd dynamics through agent-level interactions.

We propose a novel architecture that integrates key cognitive components—such as perception, planning, memory, reflection, and action—on an algorithmic level. This approach allows generative agents to process environmental and social contexts in a human-like manner. Our findings show that these agents exhibit diverse and contextually appropriate behaviors, closely resembling human decision-making, particularlys in crisis situations.

***Index Terms*—Crowd Behavior, Large Language Models, Cognitive Models, Crisis Scenarios**

I. Introduction

In the rapidly advancing field of crowd simulation, emulating the complexity of human interaction is essential, as its fidelity has profound implications for crisis management, urban planning and public safety. Central to this quest is the process of pattern extraction through the concept of Patterns of Life (PoL) [1], which refers to the repetitive and structured aspects of existence, whether societal, individual, or organizational level. These patterns may involve cycles, rhythms, or structures that are recurrent and contribute to the overall order and functioning of a particular system.

Large Language Models (LLMs) offer a transformative capability in this regard, enabling the nuanced simulation of individual behaviors and interactions [2] [3]. Our goal is to study patterns related to observation and analysis of behaviors in crisis and evacuation scenarios. This includes examining the thought processes of individual actors, as well as the interactions and collisions that occur both internally (within the actors' minds and their mental models of the world) and externally with nearby actors.

Traditional Methodologies and PoL research often fall short, oversimplifying human cognition and complexities by generalizing and focusing on clusters of group movement and navigation [4]. These methods typically overlook subtleties of individual cognition -the thoughts, decisions, and interactions that result in the passive formation of crowds. Addressing this gap necessitates a shift from group-centric modeling to ones centered on individual cognition. Furthermore, understanding crowd dynamics involves recognizing emergent properties that arise from individual interactions but are not inherent in isolated individuals.

Fig. 1. Festival in Full Swing: Generative agents mingle, form clusters, and navigate through a vibrant festival, showcasing the emergent complexity of crowd dynamics.

In our exploration of the vast network of human behavior, we pose the question: Can Large Language Models be used to simulate realistic crisis scenarios? This inquiry unfolds into two avenues of exploration, which underpin aspects and challenges of the complex network of interplay that defines crowd behavior:

- Can LLM-based agents exhibit human-like reasoning and communication, leading to emergent behavioral patterns that closely resemble those observed in real-world human interactions?
- What are the performance and scalability limitations of LLM-based simulations, particularly in complex scenarios involving large populations?

II. Methodology

Achieving the creation of artificial agents capable of natural language interactions and emergent social behaviors [5] [6] represents a significant challenge in artificial intelligence, particularly at the micro level of human behavior. This study leverages recent advancements in generative AI and cognitive models, centering around a Large Language Model (LLM) as the primary architecture controller [7]. The architecture integrates cognitive modules that enable agents to navigate environments and facilitate communication between the LLM and geometric simulations. We aim to determine whether generative agents within this setup could effectively coordinate, form relationships, carry out activities, and respond dynamically in a virtual context.

We propose a novel architecture for crowd simulation that integrates cognitive components—such as perception, planning, memory, reflection, and action—on an algorithmic level to enable generative agents to process environmental and social contexts in a human-like manner [8]. Inspired by dual-process theories of cognition [9], we deploy two systems embedded inside the agentic framework: the Intuitive and Deliberative systems.

A. Two Thinking Systems

System 1 operate automatically, driven by heuristics from previous experiences and emotions. In the context of generative agents, it is activated for events requiring immediate responses, using predefined symbolic decisions to each agent's personality.

System 2 involves deliberate and logical processing, requiring more cognitive resources. Representing the LLM architecture, System 2 is responsible for analyzing significant events and constructing rational responses. This system enables agents to process information, consult memories, and develop plans effectively.

Generative agents operate within dynamic environments, influenced by current settings and past experiences. This study proposes an innovative agent architecture that integrates a large language model with mechanisms for gathering, processing, and utilizing information.

B. Architecture Design

The architecture comprises a profiling module, memory module, reflection module, planning module, and action module, all working in harmony to enable for real-time dynamic simulations, critical for multi-agent environments.

This comprehensive framework allows generative agents to exhibit sophisticated behaviors that closely resemble human cognition, enhancing the realism and applicability of simulations. As a result, agents naturally form group patterns that reflect real-world human behavior.

III. Results

Evaluating the realism and effectiveness of generative agents is inherently complex, requiring a nuanced approach that examines behavior across multiple crisis scenarios. We conducted experiments in various simulated evacuation scenarios, comparing the emergent behaviors of LLM-based agents to those observed in human studies. Furthermore, a subjective evaluation was conducted to assess the agents' realism, emotional intelligence, behavioral diversity, and resemblance to human traits. Our evaluation framework concentrates on four critical indicators:

- **Pattern Comparison:** Agents' behaviors were aligned with documented real-world patterns, evaluated on both micro and macro scales. Participants confirmed the realism of the simulated behaviors, although some robotic and uncanny actions were noted.
- **Crowd Scalability:** The architecture's scalability was tested by examining the relationship between scalability and real-time responsiveness. Our trials demonstrated that the system maintained performance with up to 150-200 agents before encountering computational bottlenecks, primarily due to the processing constraints of the LLM models used.
- **Agent Interviews:** We leveraged the generative agents' ability to engage in natural language by conducting interviews. Through these interactions, we analyzed their capacity to recall, reflect, plan and reason about past experiences and memories. Results indicated that agents could plan future actions, understand concepts of time and place, perceive their surroundings, and respond appropriately to events within their simulated lifetime.
- **Patterns of Life Scoring:** Utilizing Silverman's scoring matrix for Patterns of Life (PoL) simulations [10], our model achieved a score of 8/9, indicating a high level of behavioral fidelity.

Our findings demonstrate that the agents exhibit diverse and contextually appropriate behaviors, closely resembling human decision-making in crisis situations. Future research could explore the use of fine-tuned LLMs to capture a broader spectrum of human emotions and decision-making nuances. Further enhancing agents' emotional intelligence and their ability to respond to complex social cues.

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