Crow Path Planning: Emotion Contagion Model Enhanced with a Fuzzy Logic-Based Approach

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Abstract

Numerous models have been developed to simulate pedestrian crowd path planning, each introducing unique assumptions that influence their outcomes depending on the specific scenario examined. Our objective is to integrate two distinct approaches to construct a more comprehensive and realistic model. First, we will implement the model from Wu et al. [2024], which incorporates emotional contagion into agents' decision-making processes. We then aim to enhance this model by reformulating its decision rules using fuzzy logic, based on the methodology presented in Xue et al. [2017]. This approach enables our model to account for both the social environment and the fuzzy boundaries of real-world spaces. By providing a more accurate representation of these factors, we expect our model to yield more relevant behavioral predictions, drawing on insights from the two original models.

1. Introduction

Crowd path planning has been an essential aspect of multi-agent simulation, particularly in dynamic environments such as evacuation scenarios or crowded spaces. Traditional methods often rely on rigid, objective-based path planning strategies, where agents choose paths based solely on distance or density, without accounting for the emotional states or personalities of individuals. These approaches include both macroscopic models, which focus on the overall movement of large groups, and microscopic models, which simulate interactions and behaviours of individual agents. Methods such as shortest distance and density-aware path planning have limitations in simulating real-world crowd behaviour, as they fail to capture the nuances of agent interactions and psychological factors.

2. Method

2.1. Global Project

Our project merges the Emotion Contagion Model presented by Wu et al. [2024] and the Fuzzy Logic Model from Xue et al. [2017] to create a more nuanced multi-agent system. Building on the Emotion Contagion Model, agents' behaviours — specifically their *preferred distance* and *preferred velocity* — are initially determined by their OCEAN personality traits. Emotional contagion allows agents to influence one another dynamically, simulating group-wide emotional shifts. However, the original model's reliance on strict thresholds to map traits to behaviours limits flexibility, as variations near these thresholds are oversimplified.

To address this limitation, we integrate the Fuzzy Logic Model, which replaces rigid thresholds with fuzzy rules. This approach smooths transitions between OCEAN scores and behavioural variables, enabling agents to exhibit more realistic, continuous variations in their responses. By combining these methods, our model enhances the simulation of complex social interactions, offering improved realism in scenarios like crowd navigation and emergency evacuation.

2.2. Implementation

2.2.1 Crowd Modelling

The initial phase of the project involved selecting an appropriate framework to model fundamental aspects of crowd dynamics. In this section, we detail the modelling choices and representation methods adopted.

Our model represents the environment as a grid, where each cell corresponds to a potential location for an agent. It is important to note that two agents can not occupy the same cell at the same time. We set the size of each cell as 35×35 cm. This choice was motivated by findings in the literature (Staff [2021], Fouloscopie [2021], among others), which highlight that a density exceeding 8 persons per square meter represents a critical threshold. Beyond this limit, crowd movement becomes not only increasingly deadly but also almost impossible. By assigning one agent per cell, our grid ensures a density near this threshold, making it a relevant and realistic representation of actual crowd dynamics.

Agent Movement: To determine how an agent moves, the agent first identifies its neighbours, which are the cells it can access. This means the neighbouring cells must be within the agent's range, free of obstacles, and within the grid boundaries. For each accessible neighbour, the agent assigns a score to the cell based on several parameters, with lower scores being more favourable. The scoring is performed using the following formula, derived from the first paper:

$$score\_cell = \left(\frac{\text{dist}_{exit}(e_{k-1})}{vel_0 \cdot e^{-(\text{den}(e_{k-1})\cdot(P_v+1)/(P_d+1))^2}} \right)$$

This score function takes into account various parameters, including P_v and P_d, which are derived from the agent's Ocean personality traits, the density around the cell, its distance to the exit, and a parameter vel_0, which represents the agent's optimal velocity. After scoring all accessible cells, the agent moves to the one with the lowest score.

Velocity and Step Size: To model agent velocity, we represent it as the maximum step size an agent can take, defined by the vel_0 parameter. The agent considers a neighbourhood of 9 possible directions (including staying in the current cell), with the step size corresponding to the maximum number of cells the agent can move in any direction.

Handling Agent Movement Conflicts: One of the main challenges in multi-agent simulations is managing the movement of multiple agents, as they may end up in conflict by attempting to occupy the same cell. To address this, we adopt a sequential approach to agent movement: each agent is displaced one at a time in a random order. As each agent moves, its trajectory and final position are marked as obstacles for subsequent agents, preventing any conflicts in their movement.

At the end of an episode, after all agents have made their respective steps, we remove all trajectory markings, clearing the obstacles and preparing the system for the next simulation round.

2.2.2 Towards a more complex model

Emotion contagion and external sources: Wu et al. [2024]'s emotion contagion algorithm, implemented in the *update_emotions* function, simulates emotional contagion between agents in a crowd. Each agent updates its emotions by taking into account interactions with its neighbours and external influences, such as a fire.

First, the agent computes the effect of its close neighbours. For each neighbour, it measures the distance and adjusts its emotional preferences (P_d for distance and P_v for speed) according to the gap between their emotions. The closer a neighbour is, the stronger its influence. Secondly, external sources, such as fire, also influence the agent. If a source is nearby, it modifies the agent's preferences, simulating a panic or stress reaction.

Preferences are then adjusted by "selective perception". For instance, if the agent is close to his destination, he gives more importance to the distance to be covered. If his speed is low, he is more influenced by the need to go faster. A damping factor is applied to prevent emotions from changing too quickly, thus maintaining part of the agent's initial personality. Finally, preferences are normalized for consistency.

Clustering: Emotion contagion plays an important role in the crowd simulation under complex environments. Prior research and observations in sociology and behavioural psychology have suggested that real-world crowds are made of groups. A group is composed of two or more agents that share similar goals and exhibit collective movements or behaviours. Actually, an agent will largely refer to the ones sharing the similar motion in the same group. Therefore, we need to be able to recognize such groups to model the interactions among agents.

To do so, Wu et al. [2024] introduces a practical algorithm for this purpose. Initially, the algorithm identifies the agent with the highest density as the centre of the first cluster. Subsequently, it examines each remaining agent in order of increasing density. For each agent, it evaluates whether the agent belongs to an existing cluster by calculating the distance between the agent and the highest-density agent in its vicinity. If no association with a pre-existing cluster is established, the agent forms a new cluster.

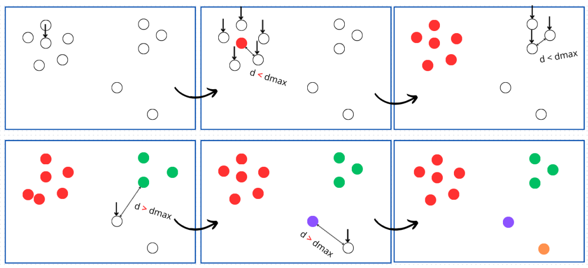

Figure 1: *Example of clustering.*

3. Results

We have implemented a multi-agent simulation using Mesa, representing pedestrians navigating a crowded environment with obstacles. The simulation includes two exits, each 4 cells wide (these parameters are adjustable). A total of 400 agents are initialized in the environment, each with a unique personality defined by the Big Five traits, which influence their movement behaviour. Each pedestrian agent is colour-coded according to their dominant personality trait: Openness (O) as blue, Conscientiousness (C) as purple, Extraversion (E) as orange, Agreeableness (A) as yellow, and Neuroticism (N) as green.

The agents' paths are influenced by their distance to the exit and their preference for velocity, as described by Wu et al. [2024]. The simulation also accounts for emotional contagion between agents, where the emotional state of one agent can influence the behaviour of others in the crowd. The agents update their emotional preferences dynamically, based on interactions with nearby agents, simulating group-wide emotional shifts.

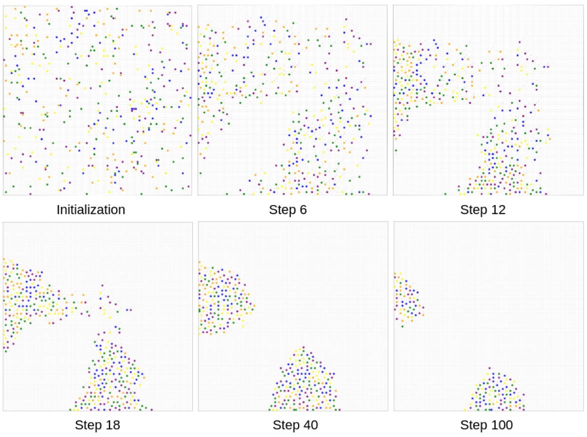

Figure 2: *Example of simulation.*

4. Discussion

While the agents' personalities are already complex and their emotional states dynamically updated, further refinement could involve incorporating external stressors (e.g., fire sources) that could alter agents' decision-making processes and emotional contagion dynamics.

Moving forward, we plan to implement fuzzy logic as outlined in Xue et al. [2017], which would allow for more continuous preferences, replacing the current discrete definitions for P_d and P_v. Additionally, we will continue to refine the density computation to better simulate how crowd density affects agent movement and interaction.

Future simulations will explore different meaningful scenarios, including the effect of external sources on agent behaviour, and variations in the number and layout of exits. These tests will help us better understand how different personality traits and emotions interact in more complex scenarios, such as whether agents with high Neuroticism (N) are more likely to choose exits under stress.

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Luc Brun: Implementation of crowd modelling agents and collision system; Writting of crowd modelling
Manon Tregon: Writting of Global Project, Results, and Discussion; Formatting of the report; Polishing of the English language
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Alexis Mourier: Implementation of the model and clustering parts; Writting of the abstract, and Clustering
All authors have contributed in the decision-making process regarding the implementation of the model.