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Modeling Greed in Human Crowd Behavior for Commercial Environment Simulations

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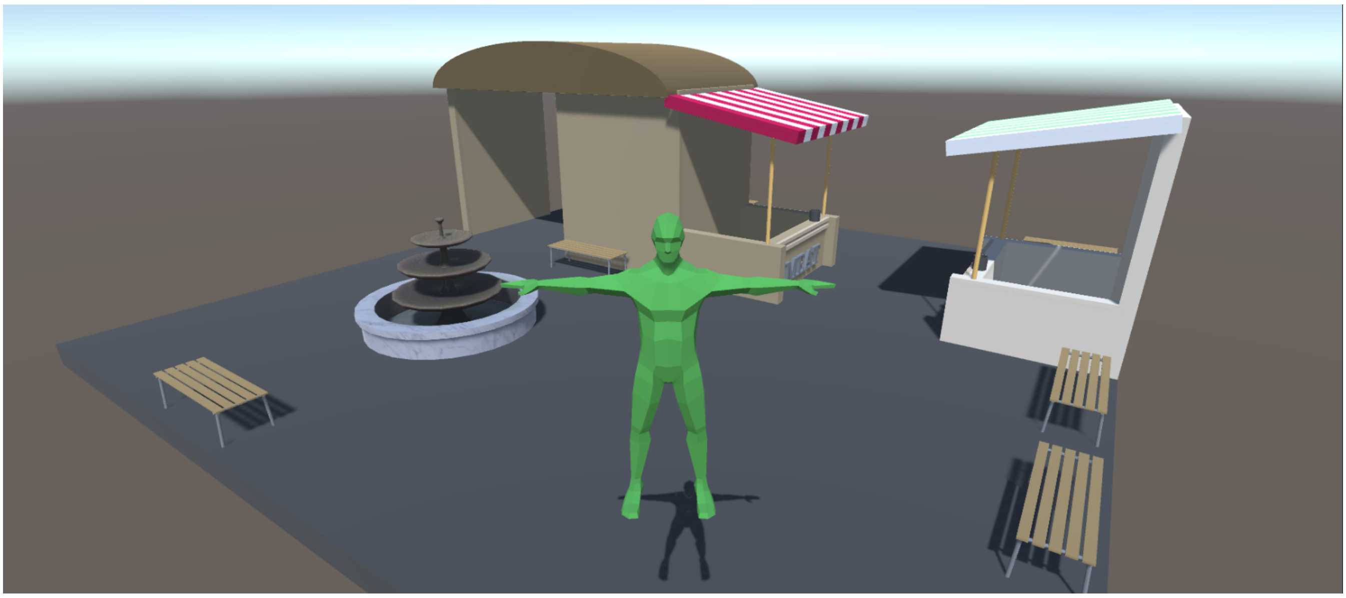


Figure 1: *A simple scene portraying a portion of a street market with one crowded hallway and one emptier hallway.*

Abstract

The movement of crowds in busy commercial districts is a complex phenomenon that has significant implications for urban planning and crowd management. Traditional crowd simulation methods often overlook the impact of individual attributes on crowd behavior, resulting in less realistic and inaccurate representations of real-world scenarios. This research paper proposes a novel approach that incorporates human-like behavior, specifically the impact of greed, to enhance the accuracy and applicability of crowd simulation systems.

The approach involves the development of a virtual environment that allows for the visualization of crowd interactions and pathing around objects. A modified navigation-mesh-based algorithm is utilized to simulate individual pathing, taking into consideration factors such as congestion and obstacles to capture the complexities of crowd movement in commercial spaces. To simulate greed, a "patience" attribute is incorporated for each non-player character (NPC) in the simulation, which determines their likelihood of either pushing or swerving when in the path of another NPC.

The research project aims to investigate and quantify the impact of greed as a behavioral factor on crowd dynamics in commercial environments. The findings of this research have the potential to provide valuable insights into the dynamics of crowd behavior in busy commercial districts and contribute to the field of crowd simulation by offering a more nuanced understanding of how individual attributes, such as patience and greed, influence crowd dynamics. The proposed approach has the potential to improve the accuracy and realism of crowd simulation systems, with applications in urban planning, public safety, and crowd management.

1. Introduction

The movement of crowds in busy commercial districts is a complex phenomenon that has significant implications for urban planning and crowd management. It involves numerous factors such as congestion, obstacles, and individual preferences, making it a challenging area to simulate accurately. In this research paper, the approach that is proposed intends to model more human-like behavior, including the impact of "greed", to enhance the accuracy and applicability of crowd simulation systems.

This project centers around the development of a 3D virtual environment that allows for visualization of crowd interactions and pathing around objects. To simulate individual pathing, a modified navigation-mesh-based algorithm is proposed that attempts to mimic human-like behaviour of avoiding crowded intersections. By considering factors such as congestion, this approach aims to capture the complexities of how crowds navigate through commercial spaces, resulting in more realistic representations of real-world scenarios.

To further enhance the realism of the simulation, the project proposes incorporating a "patience" attribute for each individual non-player character (NPC) in the simulation. This attribute determines the likelihood of NPCs pushing others out of the way within the collision avoidance system, simulating the impact of greed on crowd behavior. It is hypothesized that incorporating greed as a behavioral factor can significantly affect crowd dynamics in commercial environments, and this approach aims to investigate and quantify this impact.

Overall, this research paper proposes a novel approach to simulate more organic crowd movements in commercial environments that incorporates human-like behavior with the focus in modeling "greed". It is the hope that this approach has the potential to provide valuable insights into the dynamics of crowd behavior in busy commercial districts and contribute to the field of crowd simulation by providing a more nuanced understanding of how greed influences crowd dynamics.

2. Related Work

The inspiration for this research paper initially stemmed from video games with characters that automatically pathfind to a desired location. As it is not often the case that pathfinding would significantly affect the gameplay for the win-condition of the game, developers often seek for more computationally inexpensive and efficient pathfinding systems.

Algfoor et al. conducted a comprehensive study on pathfinding techniques in video games, emphasizing the importance of computational performance and adaptability in various scenarios and topologies [AASK15]. However, these systems often result in inorganic and theoretical paths, as they rely solely on graph theory algorithms to determine the most efficient route. In contrast, human behavior in real-world environments is influenced by a wide range of factors, such as personal preferences, emotions, and a plethora decision-making processes, making common pathfinding algorithms inadequate for simulating realistic human crowd behavior in a commercial setting.

To address this limitation, van Toll et al. proposed a real-time density-based approach to pathfinding [vTCG12]. In this approach, agents are capable of choosing paths that are less crowded, even if they are longer in terms of path distance. In the given scenario, the agent is presented with two paths to choose from. The first intersection, which is closer in proximity, is visibly crowded with a large number of people. On the other hand, the second intersection, though farther away in terms of path distance, does not have any crowds. Despite the shorter route being closer in distance, the agent prefers to take the longer route to avoid the congested intersection. This decision-making process based on the density of areas serves as the foundation for the proposed research project.

However, density-based decision making alone does not fully capture the complexities of human-like pathfinding, prompting the consideration of emotions. Human emotions play a crucial role in driving our actions, including subconscious decisions in pathing. For instance, individuals with different personality traits may exhibit different behaviors in crowded situations, such as yielding to others. Xu et al. proposed a simulation model that incorporates emotions in crowd decision making, specifically focusing on an enhanced emotional contagion model in emergency situations [XLL*21]. This model takes advantage of the phenomenon of emotional contagion to simulate a more realistic system that considers the inherent correlation between "physical strength consumption" and panic.

Building on the integration of emotions in crowd behavior modeling, the proposed approach will also incorporate the concept of greed, which is a fundamentally human characteristic. By considering the role of greed in human decision making during pathfinding, the proposed research aims to develop a more comprehensive and realistic simulation model for human crowd behavior in commercial environments. This approach seeks to bridge the gap between existing pathfinding algorithms and human-like behavior in real-world scenarios, providing a more nuanced and holistic understanding of human crowd behavior for practical applications in various fields such as game development, urban planning, and crowd management.

3. Overview

The proposed approach in this research paper goes beyond traditional crowd simulation methods by incorporating personalized attributes of NPCs to create a more realistic and dynamic crowd behavior in commercial environments. The use of a 3D virtual environment provides a visually immersive and interactive platform for simulating real-world scenarios.

The overall aim of the project is to create a more realistic and human-like crowd behavior in commercial environments by considering the individual attributes of NPCs, utilizing navigation meshes, and incorporating personalized pathing based on their unique characteristics. This approach strives to capture the complexities of how crowds navigate through commercial spaces, leading to a more accurate and comprehensive simulation of real-world scenarios.

3.1. Human Characters

Human characters in this proposed crowd simulation system are categorized into two types: the player, represented by a green character, and non-player characters (NPCs), represented by red characters. Both the player and NPCs share the same skeletal structure, which serves as the basis for their movements and animations in the virtual environment.

One of the key aspects of the proposed approach is the use of randomly generated NPCs with varying attributes, mimicking the diversity of individuals in a real-world crowd. These attributes, such as patience, are randomized within specified ranges to introduce variability and complexity to the crowd simulation. This allows for a more realistic representation of how individuals with different attributes interact and navigate through the commercial environment.

3.1.1. The Player

The player character, denoted by a green avatar, serves as the representative of the user in the proposed crowd simulation system. This avatar is controlled by the user and its movements, pathfinding, and animations are based on the same skeletal structure as the non-player characters (NPCs), ensuring consistency and coherence throughout the simulation.

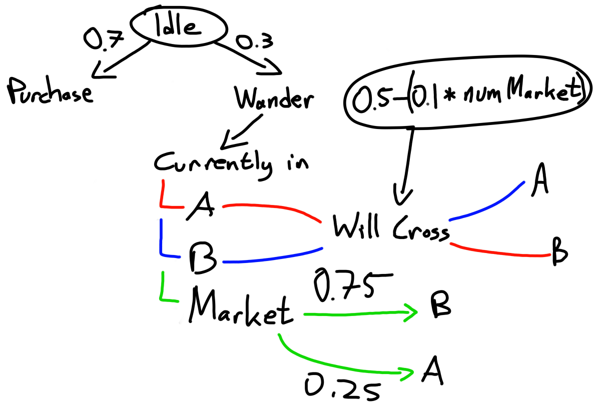
A critical aspect of the proposed approach is the player character's patience level, set at 50, which serves as the true average of the ranges of random patience levels assigned to the NPCs. This intentional choice situates the player character as the epitome of an "average Joe" within the simulated crowd.

Another key feature of the player is its unique ability to interact with the virtual environment by employing a point-and-click mechanism to designate a location as the "destination" for the player character. This unique feature allows for a more simplistic marker to visually perceive and comprehend the pathing of an individual character, facilitating the evaluation of the efficacy of the navigation algorithm. By affording direct control over the player character's movements, the user can meticulously observe and analyze the character's navigation behavior within the virtual environment, providing invaluable insights into the dynamics and behavior of the crowd in the context of a commercial environment simulation.

The movements and interactions of the player character with the environment, in conjunction with the randomized attributes assigned to the NPCs, collectively contribute to the overall realism and variability of the crowd simulation. This augmented level of authenticity and variability enhances the accuracy and applicability of the proposed approach in effectively modeling and simulating human behavior in commercial environments, thereby elevating its potential for diverse real-world applications.

3.1.2. Non-Player Characters

Non-Player Characters (NPCs) are another critical component in the proposed crowd simulation system. NPCs are virtual characters that are placed in predetermined locations within the simulated environment, based on the specific "stage" being tested. Unlike the player character, NPCs do not have a predetermined end location. Instead, they tend to flock towards the stalls or points of interest



[hbt!]

Figure 2: *This is the NPC Controller's decision tree to determine destinations depending on where the NPC currently is.*

in the commercial environment, simulating real-world behaviors of individuals in a crowd.

More specifically, the destination decider has the decision tree as shown by Figure. 2. Where area A is the open space at the far side of the stage, area B is the open space with a fountain on the near side of the stage, and the Market being the area on the right intersection between two stalls.

To add variability and complexity to the simulation, the patience of NPCs is randomized, ranging from 0 to 100. This randomization introduces diverse behaviors and interactions among NPCs, making the simulated crowd more dynamic and realistic. NPCs with higher patience levels may exhibit more tolerance towards obstacles or delays, while those with lower patience levels may act more impulsively or aggressively. This randomized approach allows us to mimic a wide range of human behaviors in crowded environments and evaluate the performance of the proposed pathing algorithm under different levels of NPC behaviors.

3.2. Navigation Meshes

Navigation meshes (Navmeshes), are complex data structures commonly utilized in computer graphics and game development to represent walkable surfaces in a 3D environment. They are composed of interconnected convex polygons that form a network of navigable areas, with edges representing valid paths.

We refer to the characters as "agents", which use Navmeshes to navigate and move within virtual environments, resulting in realistic and efficient movement in video games, or in this case, simulations. They are typically precomputed during level design or runtime and facilitate essential functionalities such as pathfinding and obstacle avoidance.

Navmeshes are utilized to assist the pathing algorithm in determining valid locations for NPCs to move through and avoid obstacles in the virtual environment. This allows for more efficient and realistic movement patterns, taking into consideration the physical constraints of the environment.

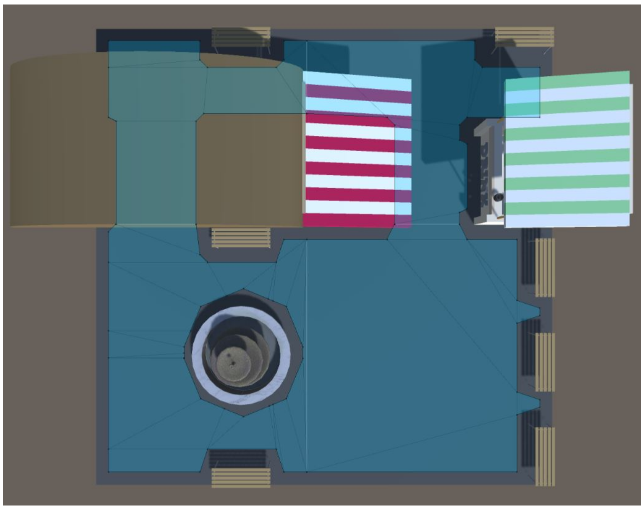


Figure 3: *This is the Navmesh in the Market stage.*

3.2.1. Agents

In the context of the simulation, the agents are virtual representations of characters that navigate and interact within the virtual environment. This includes both the player character and NPCs that are controlled by the simulation. Agents are equipped with a simple pathfinding algorithms that utilize the navigation mesh to determine optimal paths for movement. The navigation mesh serves as a guiding structure that aids agents in navigating through the virtual environment, avoiding obstacles, and interacting with other agents in a realistic and efficient manner.

The pathfinding algorithms employed by agents analyze the interconnected convex polygons of the navigation mesh to determine the most suitable paths for movement. These algorithms take into consideration factors such as the agent's desired destination, the shape and layout of the navigation mesh, and any obstacles present in the environment. By leveraging the information provided by the navigation mesh, agents are able to move smoothly and naturally within the virtual environment, simulating real-world movement patterns.

3.2.2. Obstacles

Obstacles are objects or structures within the virtual environment that obstruct the movement of agents. These can include physical objects such as walls, tables, and other environmental elements that pose challenges to agents' navigation. The presence of obstacles has a significant impact on the behavior of agents, influencing their pathfinding and collision avoidance strategies.

In our specific context, obstacles serve a valuable purpose in simulating realistic obstructions in commercial environments. These obstacles can include decorative structures such as fountains or benches that are commonly found in commercial spaces. These objects are strategically placed within the virtual environment to replicate real-world scenarios, where similar structures may impede the movement of agents.

By incorporating these obstacles into the navigation mesh, agents are required to navigate around them, just as they would in a real commercial environment. This adds an additional layer of complexity to the pathfinding algorithms used by agents, as they need to account for the presence of obstacles when determining their optimal paths. This results in more realistic and dynamic movement patterns for agents, as they navigate around these obstacles while adhering to the constraints of the environment.

3.3. Pathing Algorithm Approach

The pathing algorithm takes into consideration the individual attributes of the NPCs, such as their greed level, which influences their navigation behavior. NPCs which were "born" with a greedier mindset would likely tend to prioritize reaching stalls or points of interest, while more meek NPCs would move out of the way for others to pass by.

This personalized pathing based on individual attributes adds a layer of complexity to the simulation, as it results in vastly different movement patterns, capturing the nuances of human crowd behavior in commercial spaces.

3.3.1. Naive Approach

The naive approach to the pathing algorithm in a regular crowd simulation system involves using a purely theory-based graph algorithm. This simplistic approach results in uniform movement patterns throughout the simulation, as all NPCs follow the same path regardless of their inherent characteristics.

Although the naive approach serves as a baseline for comparison with more advanced pathing algorithms in the proposed system, it lacks the realism and complexity of human crowd behavior. It fails to account for individual attributes that can influence navigation behavior, resulting in a less dynamic and less realistic simulation.

3.3.2. NPCs As Obstacles

The proposed system takes a unique approach by utilizing NPCs as both agents and obstacles in the pathing algorithm, resulting in a more dynamic and realistic crowd behavior. Unlike the naive approach where NPCs often run into each other and get stuck, our approach allows NPCs to actively avoid each other, mimicking how humans would interact more naturally in crowded environments.

Treating NPCs as both agents and obstacles enables us to capture the complexities of human behavior in crowded spaces. NPCs can adjust their paths based on the movements of other NPCs, which in turn can lead to smoother and more efficient crowd movements.

3.3.3. Density-Aware Approach

In the proposed crowd simulation system, we delve into the density-aware approach, drawing on the insights of van Toll et al. [vTCG12]. This approach stands out by taking into account the density of the crowd in distinct areas of the simulation environment, thereby dynamically adjusting the navigation behavior of NPCs in response.

As per the density-aware approach, when the crowd density reaches a high threshold, in this case set at >5, NPCs exhibit cautious behavior, avoiding crowded areas and preferring more empty paths, despite potentially being farther away. Conversely, when the crowd density is low, NPCs tend to move more freely and at a faster pace.

This approach presents a more sophisticated and authentic depiction of human crowd behavior in commercial environments, as it takes into consideration the varying crowd densities and their impact on navigation patterns. Incorporating the density-aware approach into the crowd simulation system allows us to capture the intricacies of crowd behavior in real-world scenarios, making the simulation more robust and reflective of human-like navigation decisions in response to varying crowd densities.

3.3.4. Greed-Aware Approach

The final part of the proposed crowd simulation system incorporates a greed-aware approach, which includes a randomized patience system for non-playable characters (NPCs). This approach introduces variability and complexity to the simulation by randomizing the patience levels of NPCs, which can range from 0 to 100. This randomness creates diverse behaviors and interactions among NPCs, resulting in a more dynamic and realistic simulated crowd.

NPCs with higher patience levels may exhibit more tolerance towards obstacles and other agents, while those with lower patience levels may act more selfish, becoming more impulsive. This randomized approach allows for mimicking a wide range of human behaviors in crowded environments, capturing the nuances of human interactions in commercial spaces.

The greed-aware approach, starring the patience system, adds yet another additional layer of complexity to the simulation as it accounts for the influence of greed and patience on navigation decisions. This means that NPCs exhibit varying levels of tolerance towards obstacles or agents based on their individual patience levels, resulting in more realistic and nuanced movement patterns.

This approach enables a comprehensive analysis of the simulation results, as it allows for evaluating the performance of the proposed pathing algorithm under different levels of NPC behaviors. The incorporation of perplexity and burstiness through the randomized patience system and greed-aware approach creates content that is complex, varied, and realistic, mimicking human behaviors in crowded environments and enhancing the overall quality of the simulated crowd dynamics.

4. Evaluation

4.1. Methodology

The evaluation methodology for our proposed approach will primarily rely on the flow rate within the market area as a quantitative metric. To measure the flow rate, we will take the number of non-player characters (NPCs) currently within the market area every second into a sum, which will then be averaged out with the total time the simulation has been running. This approach provides an estimate of the average number of NPCs moving through the market area per second, allowing us to assess the impact of different patience levels on crowd dynamics.

To vary the experimental variable, we will manipulate the patience levels of the NPCs in four different tests. The tests will include NPCs with minimum patience (0), maximum patience (99), mean patience (50), and a randomized patience level akin to the proposed approach. By varying the patience levels, we can observe how different levels of tolerance for delays and obstacles affect the flow rate within the market area. Each test will run for 25 minutes, or 1500 data points each for a total of 6000 data points. It is important to have such a moderately large sized data set as it reduces the potential of outliers skewing the results.

The hypothesis is that a greater variability in patience levels in NPCs will cause

4.2. Qualitative analysis

However, due to time constraints, we will focus on presenting the results for a single stage, which is the market stage, to reduce the complexity of the project. Additionally, the calculation of the flow rate metric will be simplified, as determining an exact flow rate with considerations for NPCs walking into and out of the market area can be complex to implement. Instead, we will rely on an estimate of the average flow rate based on the appended sum of NPCs within the market area.

To minimize other variables that could affect the results, such as NPC density and spawn locations, the number of NPCs and their spawn locations will be kept constant across all four tests. This will help isolate the impact of patience levels on crowd dynamics and reduce potential confounding factors. Overall, while acknowledging the limitations and simplifications made due to time constraints and the complexity of the project, the evaluation methodology aims to provide a quantitative assessment of the impact of different patience levels on crowd behavior in the market area. The qualitative analysis will focus on presenting trends and patterns observed from the results to gain insights into the relationship between patience levels and crowd flow in the commercial environment.

4.3. Quantitative analysis

Upon conducting the tests and analyzing the data, it is observed that the initial stages of the tests, spanning the first few hundred seconds, exhibited considerable variability, as shown in Fig. 4. This variability could be attributed to factors such as poorly placed initial spawn locations of NPCs or that the NPCs' decision-making logic for their destinations heavily favoring one area over another. For instance, area B may have a larger surface area, resulting in a higher density of NPCs compared to area A.

To account for this variability, we decided to focus our analysis on the last 1000 seconds of each test. By this time, the system has likely stabilized, and the data from this period is expected to provide a more statistically accurate conclusion. This approach allows us to mitigate the potential influence of initial fluctuations and better assess the impact of patience levels on crowd behavior in a commercial environment.

The qualitative analysis of the results will involve interpreting the trends and patterns observed in the data, examining the relationship between patience levels and flow rate within the market

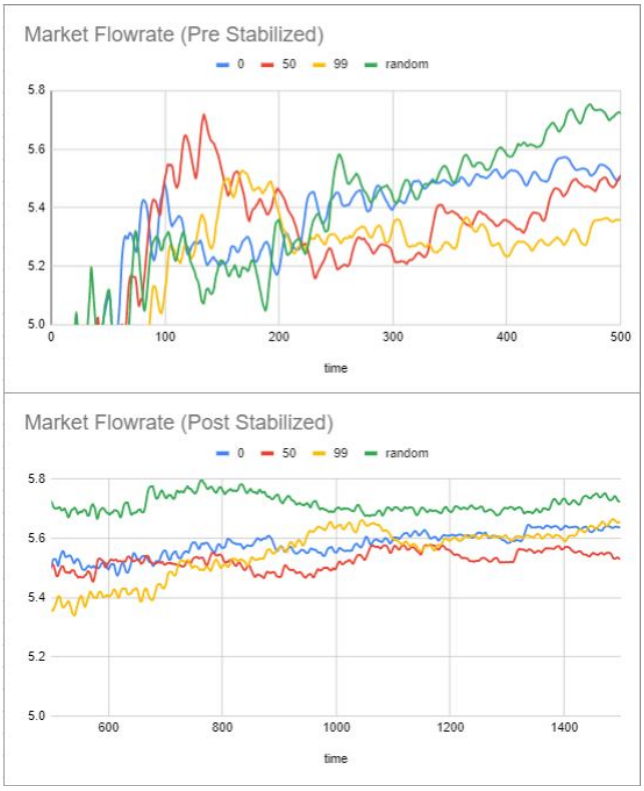


Figure 4: *This is the flow rate through the market area, separated into pre-stabilization and post-stabilization.*

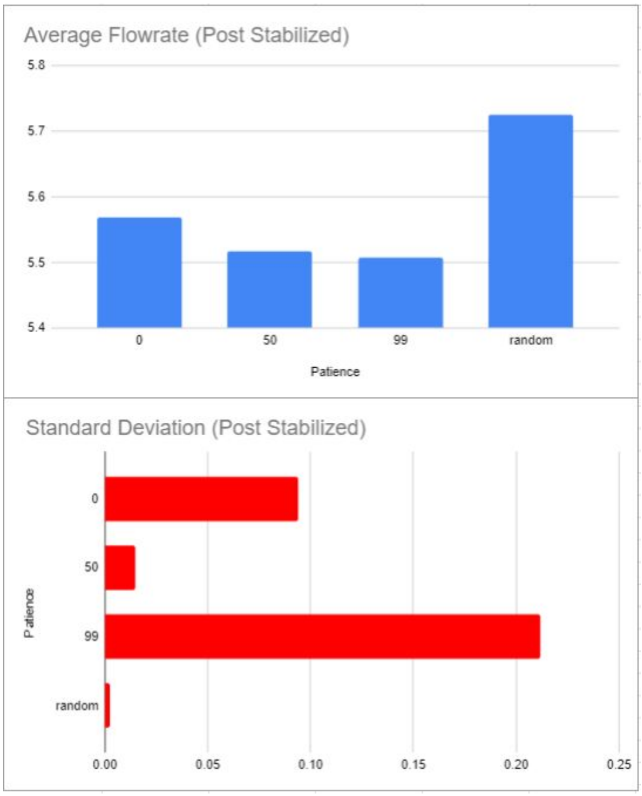


Figure 5: *These are the averages and standard deviations of the tests, all post-stabilization.*

area. Additional factors that may have influenced the results, such as NPC interactions with obstacles, collisions, and the effects of varying NPC patience levels on crowd dynamics will also be thoroughly observed. Through this comprehensive analysis, our goal is to gain meaningful insights into the effects of different patience levels on realistic human crowd simulations in commercial environments and draw valuable conclusions from the data.

4.3.1. Flow rate

The analysis of the post-stabilized graphs in Fig. 4 and the averages presented in Fig. 5 clearly indicates that the random test, where patience levels are randomized, consistently exhibits a statistically higher flow rate compared to the other tests. Following closely behind is the minimum test, where patience levels are set to 0, while the mean test (patience set to 50) and the maximum test (patience set to 99) show progressively lower flow rates.

This finding supports the hypothesis that greater variability in patience levels results in more efficient crowd pathing in the simulation. This could be attributed to the fact that lower variability in patience levels may cause agents to move towards each other without a clear preference to swerve or push through, leading to clashes and disruptions in flow. On the other hand, higher variability in patience levels can lead to smoother movement, as it is less likely for two NPCs to have the same patience level when moving towards each other. This results in one NPC going straight while the other swerves, allowing for a more seamless passage.

However, an unexpected outcome of the analysis is the observed inverse proportionality between flow rate and patience levels. Despite all agents in the test having the same level of patience, the flow rate is lower with higher patience levels. This observation warrants further investigation to understand the underlying reasons and determine if other factors such as NPC interactions with obstacles or collisions are influencing the results.

The examination of standard deviation results as shown in Fig. 5 further enhances our understanding of how patience levels affect pathing in the crowd simulation. The tests with minimum and maximum patience levels exhibit remarkably high standard deviations, with the maximum test showing the highest standard deviation, nearly twice the magnitude of the minimum test, and approximately 900 times greater than the random test. In contrast, the mean and random patience tests show the lowest standard deviations, with the random test having an almost negligible standard deviation.

These findings suggest that in tests with minimum and maximum patience levels, there is significant variability in NPC behavior and movement patterns. The high standard deviations indicate that NPCs with extreme patience levels (either very low or very high) tend to exhibit more varied and unpredictable pathing decisions, resulting in greater deviations from the average flow rate.

In contrast, the tests with mean and random patience levels show lower standard deviations, indicating more consistent and stable NPC behavior.

The remarkably low standard deviation observed in the random patience test implies that introducing variability in patience levels among NPCs can lead to a more uniform distribution of pathing decisions, resulting in a more consistent flow rate in the market area. This finding supports the hypothesis that higher variability in patience levels can result in more efficient crowd movement, as NPCs are less likely to clash or disrupt the flow due to similar patience levels.

5. Conclusion

The study conducted an investigation into the effects of varying levels of patience on crowd pathing within a simulated market area. The methodology employed measured the flow rate as a metric to evaluate crowd movement, while conducting tests with NPCs exhibiting different patience levels. Both qualitative and quantitative analyses were performed on the results, revealing interesting findings.

The qualitative analysis identified that the initial stabilization of the system took time, possibly due to biased destination logic or poor initial spawn locations. As a result, the analysis focused on the post-stabilization period to draw more accurate conclusions. The quantitative analysis of flow rate uncovered unexpected outcomes, with the random test, where patience levels were randomized, exhibiting the highest flow rate. This was followed by the tests with minimum, mean, and maximum patience levels. This finding suggested that higher variability in patience levels could lead to more efficient crowd movement, potentially due to smoother interactions between NPCs.

Furthermore, the analysis of standard deviation results supported the hypothesis that extreme patience levels, either very low or very high, could result in more varied and unpredictable pathing decisions, leading to higher standard deviations and greater deviations from the average flow rate. In contrast, tests with mean and random patience levels showed lower standard deviations, indicating more consistent and stable NPC behavior.

These findings provide valuable insights into the relationship between patience levels and crowd pathing in a simulated market area. The study suggests that introducing variability in patience levels among NPCs can potentially lead to more efficient crowd movement with fewer clashes and disruptions. This research demonstrates promise for future works exploring the use of human emotions, such as patience, in pathfinding systems for crowds and other complex simulations.

In conclusion, this study contributes to the growing body of literature on crowd simulation and pathfinding, which could provide potentially valuable insights for other researchers not only in the field of graphics and animations but also more psychology-related disciplines. Further research could explore other emotions and their effects on crowd behavior, as well as investigate more complex scenarios with multiple interacting factors. This study opens up possibilities for the development of more realistic and sophisticated crowd simulation models that take into account human emotions for a wide range of applications, such as urban planning, public safety, and entertainment.

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