STUDY OF HETEROGENEOUS AGENTS' CROWD DYNAMIC

by

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A dissertation submitted for partial fulfillment of the requirements for the degree of Master of Science

March 2015

ACKNOWLEDGEMENTS

Assalammualaikum Wbt

In the name of Allah s.w.t, all praise to the most compassionate and merciful for giving me the strength and patience to complete my Master of Science project successfully.

First of all, I would like to express my utmost and sincere gratitude to my supervisor, Dr. Wan Amir Fuad Wajdi Othman, who has supported and guided me throughout this project. I really appreciated his kindness and patience. I would also like to express a deep appreciation to my beloved family for being a source of strength and providing me with support. I would like to thank the USM staff who have assisted me by providing advice, support, and brilliant ideas during this thesis, and finally my friends.

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KAJIAN DINAMIK KELOMPOK ORANG BAGI EJEN HETEROGEN

ABSTRAK

Di dalam situasi kecemasan, orang ramai sering mempamerkan tingkah laku tidak menentu yang boleh membawa kepada malapetaka yang besar jika tidak ditangani dengan baik. Fokus utama kajian ini adalah untuk mengkaji ejen heterogen di khalayak ramai dalam kepadatan yang berbeza, di dalam arena tertentu. Pemodelan dan simulasi ejen heterogen di khalayak ramai memerlukan pemahaman tingkah laku manusia. Apabila keadaan panik berlaku, setiap individu bertindak balas secara berbeza di mana ia bergantung kepada pelbagai faktor seperti sentuhan fizikal, emosi, daya tarikan, tempat dan lain-lain lagi. Kombinasi tingkah laku individu ini akhirnya mewujudkan tingkah laku orang ramai. Apabila keadaan panik berlaku, motivasi setiap ejen meninggalkan arena secepat mungkin dengan mematuhi peraturan pengikut, pengelompokan dan mengelak halangan. Model ini dilaksanakan menggunakan NetLogo versi 5.0.4, di mana alat simulasi ini memberi kecekapan yang tinggi sesuai untuk mengsimulasi fenomena yang kompleks. Analisis utama projek ini ialah mengira purata masa pemindahan dan kadar tindak balas untuk meninggalkan arena di bawah pengaruh dua pembolehubah. Apabila peratusan ejen *B* bertambah, purata masa pemindahan dan kadar tindak balas menjadi lebih baik. Manakala, apabila bilangan populasi meningkat, kadar tindak balas untuk meninggalkan arena menjadi lebih cepat, namun purata masa pemindahan menjadi perlahan.

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ABSTRACT

In an emergency, members of a crowd often exhibit unpredictable behavior which can lead to major catastrophes if not well managed. The focus of this research was to study the crowd dynamics of heterogeneous agents, at differing densities, within a particular enclosed arena. Modelling and simulating the crowd dynamics of heterogeneous agents requires an understanding of human behavior. Each individual reacts differently to a panic, based on diverse factors like physical contact, emotion, attraction, sights and many others. It is the combination of these individual behaviors that ultimately affects crowd behavior. When a panic occurs, the motivation of each agent is to leave the arena as soon as possible by obeying the flocking rule, the follower rule, and obstacle avoidance rule. The implementation of this model was done using NetLogo version 5.0.4, which provided great efficiency in simulating multiple agents and is suitable for simulating complex phenomena. The analysis of this project focuses on average evacuation time and response rate to clear the arena under the influence of two variables. As the percentage of *B* agents (able to see 15 patches, and simulating greater knowledge of the arena) increased, the average evacuation time and response rate improved. As the population increased, the response rate to clear the arena become faster, however the average evacuation time become slower.

CHAPTER 1

INTRODUCTION

1.1 Project Overview

Crowd dynamics is the investigation of human behavior while exiting an area, particularly under duress. The study of crowd dynamics is very important to architecture and civil planning because it is a major factor in the prevention of injury and loss of life due to panics induced by emergency situations within architectural structures. Crowd dynamics become increasingly important as populations and event sizes increase. This area of study can be applied to pedestrian walks in towns, riots in stadiums, rock music concerts and many other settings (Still, 2000).

To simulate crowd dynamics, it is necessary to characterize the important parameters and human behaviors. When a panic occurs in a crowd, individuals tend to not operate independently, as they adopt the behavior of the crowd entity. The transition between normal rational behavior and irrational panicked behavior is controlled by many parameters, but nervousness is one factor which will influence fluctuation strength, desired speeds and herd tendencies.

When danger threatens, the target of each agent is to leave the arena as fast as possible. When too many agents arrive together at an exit, a jam forms, typically in the form of a structurally sound arch, and the press of the crowd behind can then lead to injuries and even fatalities. The probability of an incident in front of an exit is higher due to crushing, and exit times subsequently increase. By understanding, then controlling human behavior via appropriate building structures, the number of injuries due to crowd panics may be reduced.

The focus of this thesis is to understand the crowd dynamics of heterogeneous agents through the simulation of a multi-agent based model and a social force model using NetLogo version 5.0.4.

1.2 Problem Statement

As crowd panic can lead to injuries and fatalities during evacuations, it is essential for planners and designers to be able to predict crowd movement and behavior in such situations. The purpose of this project is to examine human behavior as it relates to crowd dynamics in normal and panicked situations. In panicked situations, people tend to act in illogical and dangerous ways. A deeper understanding of crowd behavior will help to formulate effective crowd control strategies that reduce the likelihood of injury and death. This project postulated a positive correlation between the percentage of agents with knowledge of the environment and reduced evacuation times.

Hypothesis: A high percentage of agents with knowledge of the arena increases the probability of quicker evacuation times and higher response rates in emergency situations.

1.3 Project Objectives

The aim of this research is to study differences in crowd behavior by varying the proportion of agents with knowledge of the evacuation arena.

1.4 Project Scope

This project was implemented using NetLogo version 5.0.4. The crowd dynamics of a mixture of two different types of agents was modeled and simulated in a two dimensional arena.

1.5 Chapter Overview

This thesis consists of five chapters. The first chapter briefly describes the project overview, problem statement, project objectives, and the scope of the project.

Chapter 2 is a literature review of research on agent behavior, crowd behavior and route choice behavior.

Chapter 3 describes the methodology of this project and simulation setup. It also discusses the flow chart for the behavior of agents and the simulation procedure.

Chapter 4 presents the simulation data and explores the effect of the applied variables.

Chapter 5 presents the conclusion of the thesis, the limitations of the research, and suggests future work that could improve the crowd behavior simulation.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Rapid development and population growth make crowd dynamics critical to the safe operation of many different types of public arenas. Proper planning and management of a building is critical, not only for day to day operation, but especially in emergency situations. Various factors affect the way people behave in normal, calm settings, versus chaotic and panic ridden situations. We focus on these differences in Section 2.2, while Section 2.3 explains crowd behavior, and Section 2.4 describes the route preference patterns during both normal and panicked conditions.

2.2 Agent Behavior

An experiment exercising both the Reynold's Boids model and the Helbing's Social force model, and using a multi-agent approach to support the decision making process by introducing intelligent agents into the model, was done by Sun & Wu (2011). The authors presented the crowd model as a two tier hierarchy. At the lower level, the social force model concentrated on agent position and movement, while at the higher level, the multi agent approach described how agents react to each other and make decisions. Agent based models are based on behavioral rules, current agent status, personal parameters and perceptions of the environment. Figure 2.1 shows the overall structure of the crowd model presented by the authors, and includes a behavioral library, agent information, action engine and simulation world. The research demonstrates the effect of individuals on crowd behavior and the ability to configure individual parameters. One way to extend this work is to consider more behavioral rules, individual parameters and to build a more complex environment to simulate agents in more realistic scenarios. By combining both the social force model and the multi-agent model, an accurate simulation and realistic crowd model can be achieved.

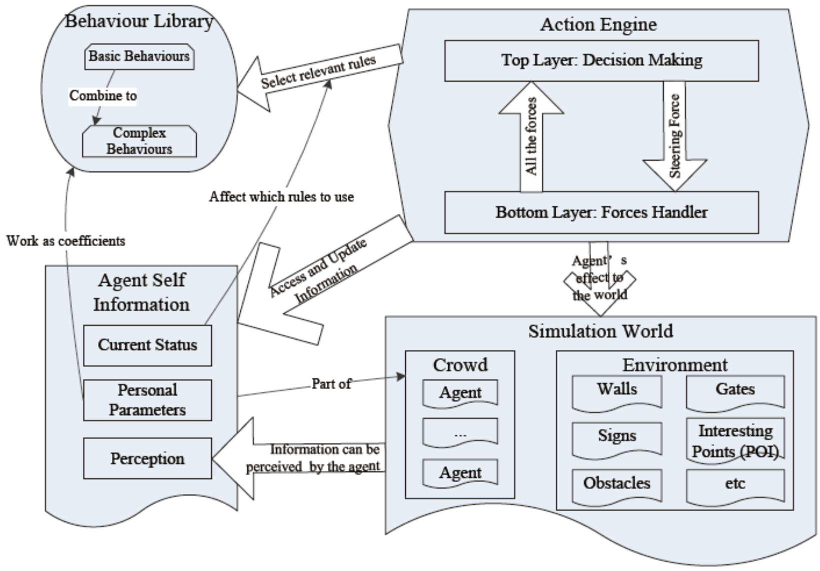

Figure 2.1: Crowd model (Sun & Wu, 2011)

Wijermans *et al.* (2007) stated that crowd behavior arose from individual behavior. From experiment, there are three factors that are represented at the individual level; arousal (physiology), leadership (social) and needs (functional). As discussed by the authors, when aggressive behavior is salient and arousal is high, the probability of showing aggressive behavior will also be high, and rioting more likely. The research only presented conceptual structure and three hypotheses were discussed by the authors:

Hypothesis 1: High levels of arousal increase the probability of a crowd rioting by 'impairing' the behavior selection process.

Hypothesis 2: If a leader is engaged in aggressive behavior, the likelihood of a riot will increase.

Hypothesis 3: If some individuals show aggressive behavior, the high dominance of the need to belonging to a group, will increase the probability of a riot.

According to the Warren & Bonneaud (2014), crowd behavior can be understood by first understanding that the behavior of individual agents affects the entire environment. When people find themselves in an emergency, their first priority is to flee the facility as quickly as possible. Wagner & Agrawal (2013) offer three rules of movement when modelling the evacuation of concert venues in the presence of fire; selection of an exit, movement from the seating area to the pathway, and movement along the pathway to the selected exit. These three components are further influenced by a fourth component, which is fire avoidance. A person will move to the next location by choosing the minimum angular difference while calculating the absolute angular difference between each valid direction and the direction directly to the desired exit. Figure 2.2 shows the direction selection choices of a person for whom θ_2 has minimum value compared to θ_1 and θ_3, so that the person will choose path θ_2.

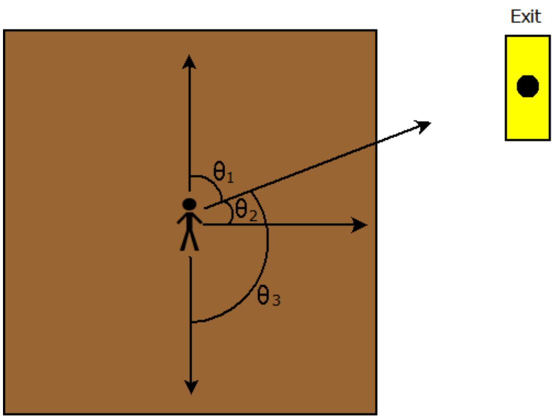

Figure 2.2: Person Movement (Wagner & Agrawal, 2013)

Stroehle (2008) reported that pedestrians will always find the shortest and easier way to reach their next destination, and if possible they will avoid detour even if the shortest way is crowded. This reflects the “least effort principle”, which means that people prefer to reach their desired destination with the least amount of energy expended. Individuals usually keep enough distance between themselves and others so that everyone can maintain their personal comfort zone. Under normal conditions, each individual has a comfortable walking speed that depends roughly on sex and age (Henderson, 1971; Klüpfel, Schreckenberg, & Meyer-König, 2005). However, when panicked, people will try to leave the facility as fast as possible; individual velocities increase, and less care is taken to maintain their comfort zone. Without knowledge of the facility, panicked pedestrians run for the exit that they used as an entrance, even when other exits are safer or easier to reach. Furthermore, people tend to lose the ability to orientate themselves in their surroundings and display herding or flocking behavior, in which new behaviors like pushing and other physical aggressions become apparent. The situation is exacerbated when people fall down and create new obstacles that further slow the evacuation flow. In front of constrictions, solid arches of bodies form, which due to this structure, and the added pressure, are then difficult to clear.

Paradoxically, obstacles, such as pillars, placed before exits, tend to ameliorate this effect, as they slow the ingress of pedestrians and allow the exit to remain relatively clear. Convex guides around door edges also prevent doors from clogging. (Helbing *et al.*, 2005; Helbing *et al.*, 2002; Piccoli & Tosin, 2009). With less clogging, flow rates through doors are higher.

As mentioned by Camillen *et al.* (2009), in an enclosed environment and in the presence of unusual demand flows, there are many uncertainties that need to be taken into account when simulating individual decision making. For example, geometry, randomness, social preference, and the collective behavior of other individuals. Agent-based micro-level simulation of human behavior in spatial environments is superior to previous models which were based on assumptions and complex theory. Camillen *et al.* (2009) used the NetLogo platform to simulate agents capable of reactive (perceiving and responding to changes in the environment), proactive (able to take initiative to achieve their goals), and social behavior (agent can interact with other agents to satisfy their goals) to demonstrate pedestrian motion in enclosed environments. The NetLogo platform has become a valuable tool for exploring crowd behavior and testing service and public safety levels.

Furthermore, a very interesting approach has been proposed by Helbing & Molnar (1995). This method is based on a "social force concept" which measures the internal motivation of individuals to perform certain actions or movements, as influenced by the dynamic variables (velocity, acceleration, distance) of others. Pedestrians aim to reach their destination as easily as possible, and thus the motion of individual pedestrians is influenced by other pedestrians and the environment.

Pedestrian motion can be described by the social force model in terms of both individual behavior and route choice behavior. Hence, the social force model is the best method for applications describing group dynamics and social phenomena.

According to Dziergwa, Frontiewicz, & Kaczmarek (2012), the agent-based model can be used to simulate panic and crowd movement by applying the social force technique. They extended the concept of cellular automata by adding elements like knowledge of emergency exits and susceptibility to panic. The advantage of the agent based approach is the possibility of adding additional physical and psychological elements to the model, so that agent behavior can better simulate real life. These simulations have proven that the location and number of exits, knowledge of the facility, and number of people in the facility have influence on the evacuation process. With reference to Pelechano & Badler (2006), there are two psychological aspects of evacuation; (i) knowledge of emergency exits, (ii) and resistance to stress. When panicked, people who are unfamiliar with a building will evacuate using the same path they entered the building, and this will result in jamming in front of doorways. However, this problem can be reduced if information is shared between agents, whereby those with knowledge of emergency exits can guide others. Identifying these parameters helps planners to improve the process of designing buildings and to ameliorate design faults in existing structures.

According to Pan *et al.* (2007), human behaviors are a complex phenomenon and difficult to capture in mathematical equations. They therefore proposed to use a multi-agent based computational framework to simulate human behavior and to explore social and collective behaviors. The multi-agent approach is a suitable method to model complex emergent phenomena where agents are able to interact with the virtual environment and other agents to simulate more closely a real environment. The system not only simulates simple behavior (e.g. finding exits), but is also able to simulate complex behaviors (e.g. queuing and herding behavior). Figure 2.3 shows the hierarchy of agent behavior used by the authors. There were three layers of modelled agent behavior. (i) Locomotion layer, involving agent motions such as stepping, walking forward, running forward, stopping, side-shifting, turning and moving backward. The locomotion type is dependent on the situation (e.g. if the agent detects an exit in front, and no obstacle exists, the agent may choose to walk forward). (ii) Steering layer, whereby the agent will seek to avoid obstacles. Other types of steering behavior implemented in the experiment were random walk, seek negotiation and target following. (iii) Social behavior, which is used to model social phenomena including competition, queuing and herding behaviors. Understanding these behavior parameters and implementing them in a computational framework can lead to valuable findings in the field of crowd safety.

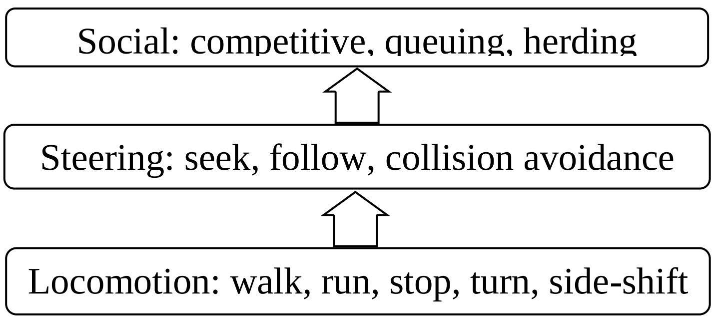

Figure 2.3: A hierarchy of agent behavior (Pan *et al*., 2007)

2.3 Crowd Behavior

Modeling and simulating human behavior in crowds during emergencies is a crucial aspect of building design. Table 2.1 shows some disasters that have occurred due to crowd panic, many of which were due to poor building design. Disasters may still occur due to human behavior, and this is very hard to predict. Even with education on how to react in emergency situations, disasters can still happen because of the many unpredictable factors involved. In an evacuation, it is human nature to follow instinct and to leave as quickly as possible and this gives rise to the phenomena of “faster-is-slower”, where the quick uncoordinated movements of individuals cause slower exits. The simulation done by Winter (2012) on understanding individual behavior in crowds extended the existing methods of cellular automata, social force models, fluid dynamic models, and agent based simulation. The author also introduced game theory, used to study competitive and cooperative behavior.

Table 2.1: List of crowd related disasters 2010-2011 (Winter, 2012)

Year	Location	Deaths	Injuries	Reason
2010	Mali	26	55	Design
2010	India	63	44	Design
2010	Germany	21	511	Design
2010	India	10	12	Behavior
2010	Kenya	7	70	Behavior
2010	Cambodia	347	395	Design
2011	India	102	44	Design
2011	Hungary	3	20	Design
2011	Nigeria	11	29	Behavior
2011	Mali	36	70	Design

As reported in February 2003, in a Chicago stampede, over 70 people were killed or injured due to a fight in a nightclub that caused a crowd to surge down a stairwell (CNN, 2003b). Additionally, in same year, 97 people was killed in a Rhode Island nightclub due to the crowd attempting to escape through the clogged front exit due to fire (CNN, 2003a). Due to these tragedies, people in planning, architecture and design must improve building layout so that when stampedes or fires occur, innocent lives are not lost. Kirkland & Maciejewski (2003) used the social force modelling introduced by Helbing & Molnar (1995) to understand how crowd dynamics significantly impact the disaster scenario. As discussed by the authors, the social force model accounts for the interactions between individuals through social and physical force. The authors expanded the social force model by adding autonomous robots into the environment to alter the crowd dynamic efficiency, by demonstrating the desired behavior. Based on this experiment, the introduction of robots into a social force model can improve pedestrian flow.

Wijermans *et al.* (2007) related that to better understand crowd behavior, the interaction and influencing factors between individuals must first be studied. Crowd behavior is the behavior shown by a large number of people gathered together. When some people express aggressive behavior in a crowd, rioting may ensue. The probability of a riot is influenced by, (i) external influences, from the surrounding environment where the riot begins. Interactions with the environment will affect the crowd. (ii) Internal factors, for example mental states that determine individual behavior at the group level. Figure 2.4 shows an overview of the influencing factors on individual behavior. While Figure 2.5 shows an overview of multilevel influencing factors on individual behavior.

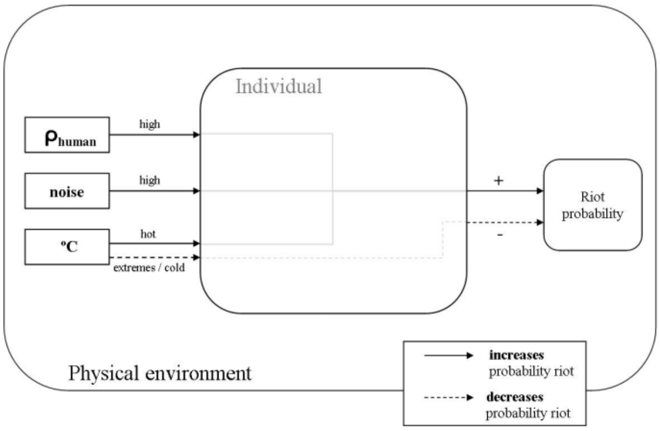

Figure 2.4: Physical environment factors related to aggressive/violent behavior in a crowd (Wijermans *et al*., 2007)

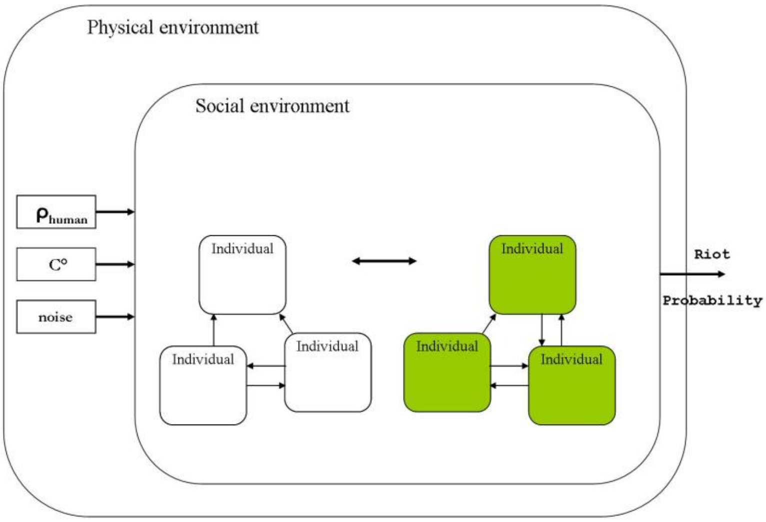

Figure 2.5: Overview of the multi-level influencing factors that are related to aggressive, violent and riot behavior (Wijermans *et al*., 2007)