

# A CROWD MODEL WITH MULTIPLE INDIVIDUAL PARAMETERS TO REPRESENT INDIVIDUAL BEHAVIOUR IN CROWD SIMULATION

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**ABSTRACT:** This paper presents a crowd model which aims to simulate the individual behaviour and increase the heterogeneity in crowd simulation thus to achieve a more realistic simulation result. This model builds upon the physics foundation by referencing both Reynolds' Boids model and Helbing's Social Force model. The mechanism of behaviour processing is based on the Reynolds' steering behaviours model. The basic individual behaviours such as seek, wander and avoid obstacles are identified and serve as the basis to achieve the more complex behaviours, such as follow the leader (grouping), queue at doorway (clogging) and so on. Fine network model is used to obtain the precise positions of each individual and the multi-agent system approach is adopted to support the decision making process. A set of key personal parameters (both physical and psychological) are identified for the individuals, which act as independent intelligent agents and conduct their own decision and behaviour. The group/collective behaviour can also be observed through the individuals which react to the surrounding crowd (those personal parameters also determine how they would response). All the individual parameters are configurable in order to provide the ability to fine-tune the model to fit various needs and scenarios. A series of test simulations with various individual parameters have been conducted during the research and the results are presented in the paper.

**Keywords:** *Crowd Simulation, Crowd Modelling, Individual Behaviour, Multi-Agent System, Social Force Model*

## 1. INTRODUCTION

As emergency incidents in crowded environment (e.g. shopping malls, football stadiums) could cause crowd panic and result in fatal casualties during the evacuation, it will be beneficial for designer and planner to be able to predict the crowd movement and behaviours in such situation. In the past 20 years, many models [1] have been developed to present and display some typical crowd phenomena (e.g. clogging, pushing, unadventurous exiting and faster-is-slower). Those models have taken different approaches: some focused on the rules which decide how a person moves to an empty position (e.g. cellular automata models [12]); some considered that each person is affected by a force which is generated from nearby crowd or physical objects (e.g. social force models [2,3]); and others were more concerned about how the human make decisions (e.g. agent-based models [4-6]). Several studies

[5,6,7] had combined those approaches to achieve a more accurate and realistic crowd model.

In the previous studies, the crowd was usually treated homogeneous in order to ease the complexity of the model. Recent approaches [7,8] had shown that individual behaviours can affect crowd behaviours to some extent, and heterogeneous crowd do have a different performance. However, it is still a challenge to integrate multiple human behaviours into a crowd model. This paper presents a crowd model, which integrates multiple human behaviours through personal parameters with aim of providing the flexibility to configure individual behaviours / parameters and observe the results in real time.

This paper is organised as follows: section 2 is the related works and literature surveys; section 3 presents the crowd model and implementation; in section 4, several simulation experiments are presented to indicate the impacts of

individuals with different personal parameters; the conclusions and future works come at section 5.

## 2. RELATED WORKS

Force-based models consider that the individuals in the crowd are affected by some forms of forces. The motions of the individuals are determined by the total effects of all those forces. The forces can be calculated by a set of formulas. This idea was first seen at 1986 when Reynolds [9] published his “Boids” program which can simulate the motion of bird flock. In the flock, each bird updates its position by applying a steering force in each time frame. In 1995, Helbing and Molnar [1] first proposed the social force model to describe the movement of pedestrian. The pedestrian’s movement was determined by the forces which are generated from his/her own desire and the repulsions/attractions from other pedestrians and objects according to the model. Helbing et al. [2] further developed this model to simulate the panic situation by mixing the social psychology in 2000. Panic evacuation from a room [13] can be simulated by applying social force model.

The human intelligence is usually ignored in force-based models as the process of thinking and decision making is difficult to be represented only by mathematical equations. An agent-based model (aka. multi-agent system) [3,4] contains autonomous agents who make their own decisions and can be used to simulate human systems. The agent-based models are usually combined with cellular automata (CA) model [5,6] to represent the movement of the agents. As agents can be easily attributed, individual behaviours have been considered in many agent-based models [7,8].

It is possible to combine the force-based model with agent-based model to integrate some level of human intelligence. Reynolds [7] proposed to create autonomous agents by implementing steering behaviours. Braun et al. [8] had used agents to simulate group behaviour with social force model. Pelechano et al. [9] suggested the agent model can be used at a high level for communication and wayfinding and social force model can be applied at a low level to present the crowd local motions. This approach gains the

benefits of both models but the two models are still working in isolation.

In this paper, we propose to create a crowd model, which combines the force-based model and agent-based model together through integrating the forces into the behaviour decision process and converting the behaviours into forces to affect the motions of agents.

## 3. THE CROWD MODEL AND IMPLEMENTATION

The proposed crowd model is built based on Helbing’s Social Force model [2,3] and Reynolds’ steering behaviours model [11]. In our model, the effects between entities (include individuals and other physical objects) are represented in forms of forces. They will determine the behaviours of individuals by taking into account the personal parameters. The resulted behaviour will also be converted into forces, which are represented in the model. The model also adopts the multi-agent system approach [4,10] to simulate the decision making process of an individual, which is represented as an intelligent agent in the model (the term “agent” will be used from now on).

The crowd model can be viewed at two levels. In the lower level, the model can be seen as how an agent changes its position. Agent’s movement is affected by the forces generated from itself, nearby crowd and other objects [2,3,9,11]. It will update its position when a steering force (an effect which changes agent’s position) is applied. A fine network (2D coordinates) is utilized in this model to represent the continuous position of each agent.

In the higher level, the model describes how an agent reacts to others and how it decides and conducts its own behaviours. The multi-agent system approach [4,10] is adopted to simulate the decision making process. The agent’s behaviours are determined based on:

- Behavioural rules
- Agent’s current status
- Personal parameters
- Perception of the simulation world

As a result, the decided behaviour will be translated into a final steering force.

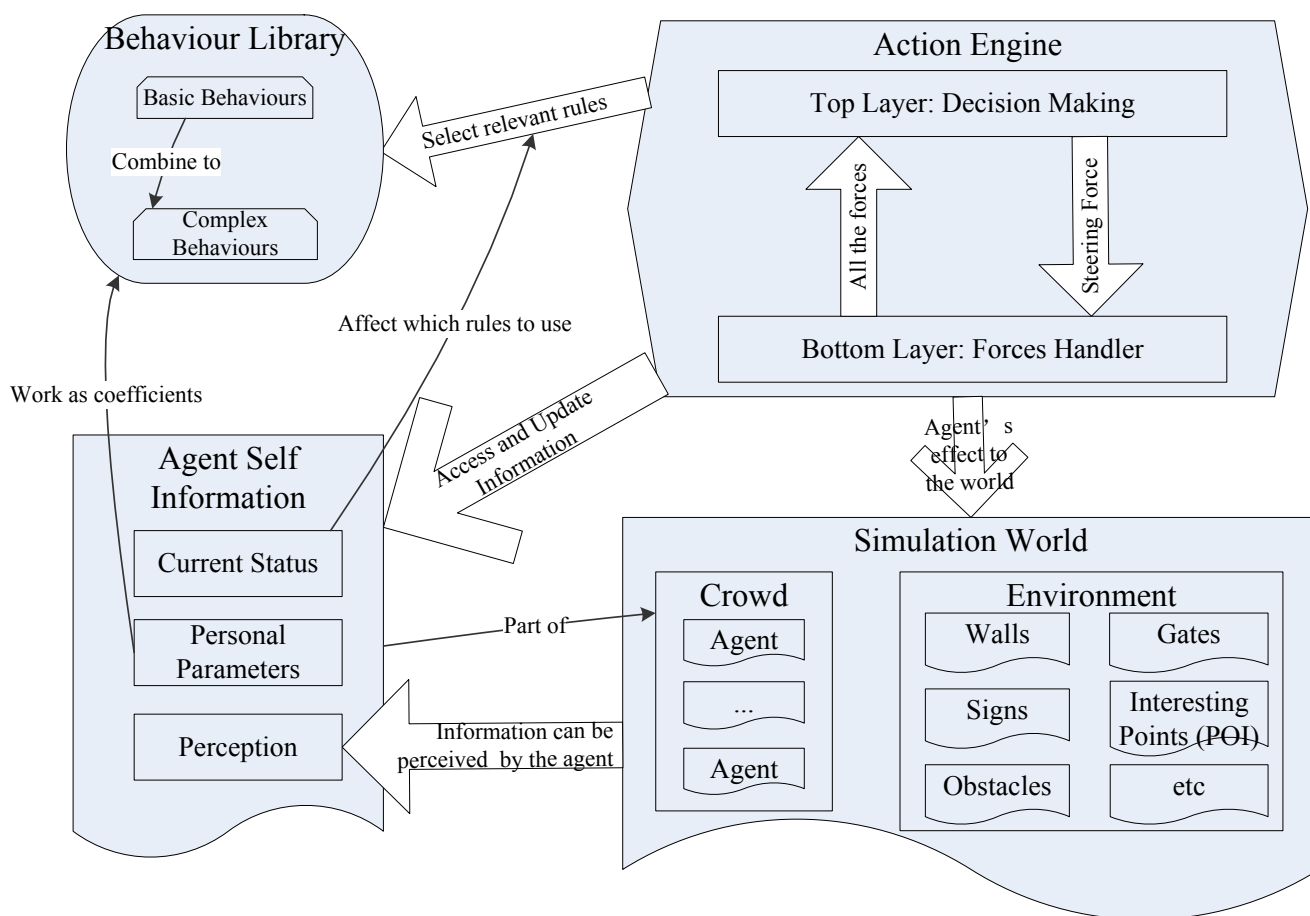


Fig. 1 Crowd Model.

Fig. 1 outlines the overall structure of the crowd model, and how internal factors are interacted with each other. In brief, the crowd model includes four parts: behaviour library, agent information, action engine and simulation world.

### Behaviour library

The behaviour library consists of a set of pre-defined rules (behaviours), which determine how an agent will act under certain situations. The agent's status, personal parameters and its perception will decide which rule to apply and to what extent. By adopting the steering behaviours [11], some basic rules (e.g. seek to, stop, avoid and keep distance from) have been established in our model. More complex behaviour (e.g. following, grouping and clogging) can be achieved by the combination of the basic rules.

The implementation of the behaviour library is to translate the behaviours into relevant behavioural forces and rules. The forces are in the forms of 2D vectors (force is represented as an effect of changing agent's position in a

time frame). The agent updates its position through applying the final steering force onto the current position:

$$\text{Next Position} = \text{Current Position} + \text{Final Steering Force}$$

Formula 1. Calculate new position

Based on the basic behaviours, more complex behaviours can be achieved and the personal parameters can also be taken into account, e.g. the repulsions from the crowd can be calculated through the following equation:

$$RF_c = \sum_{i=1}^n (i \neq s) \frac{K_c \times (P_i - P_s). \text{Normalize} \times S_d \times RM_i \times RM_s}{D_{is}}$$

Formula 2. Forces for nearby crowd ( $D_{is} < \text{threshold}$ )

$n$  represents the total number of agents within agent's sense range.  $K_c$  is a constant which can be used to adjust the scale of the unit force.  $P_i$  and  $P_s$  represent the position of agent  $i$  and agent itself.  $S_d$  is the desired speed of the agent which usually equals to the default speed but could be changed on varies situations (e.g. the agent may want to slow down in a congestion and may speed up when find something interesting). The  $RM_i$  is the modifier which

indicates to what extent the agent  $i$  can affect the agent's feeling of the force while  $RM_s$  indicates how much the agent itself can feel. Their default values are 1 and should be adjusted to fit the agent role (e.g. a smelly person should have a big RM value so that everyone feels a large repulsion from him/her).  $D_{is}$  is the distance between the two. Our experiment suggested that the threshold should be no smaller than 1 (Note. The unit of distance in this formula must fit the display coordinates, i.e. the real measurement has to be scaled before using in the formula. In our implementation, 1 pixel in the screen represents 0.05m in the real world, which means if the distance between the two agents is 0.5m, 10 should be used as the  $D_{is}$  value). When  $D_{is}$  goes shorter than the threshold, the threshold is used to calculate the repulsion.

#### Agent information

The agent information comprises agent's status, personal parameters, and its perception. The agent status includes: position, state (rest, wandering, seek to goal, follow target or avoid collision), orientation (current and next), speed (current and desired), current target point and goal. The personal parameters set consists of: size, default speed, sense range, leadership, willingness to follow, probability of being affected by POIs (point of interests), desired distance from others, distance to feel repulsion, distance to reach maximum repulsion, repulsion modifier (to self and to others) and desired distance to wall. The agent's perception includes both information of the nearby crowd and environment and the forces which the agent feels from them. This is a subset of the simulation world.

#### Agent action engine

The agent action engine interacts with the behaviour library, agent information module and the simulation world. It follows the agent action process (Fig. 2) to calculate a steering force which is used to update the agent position. The agent's status will also be updated during the process. The agent action engine will notify the outcome of process to the simulation world. For the purpose of computer animation, 60 FPS (frames per second) is adopted. At each time frame, the agent will repeat the action process to decide its behaviour and update relevant information.

#### Simulation world

The simulation world contains all the entities (agents, wall, gates, POIs, obstacles, signs and etc). All the entities are dynamic and their information can be changed depends on the outcome from the agent action engine (e.g. interactions between agents and environment). The simulation world is currently presented in a 2D format the agents are displayed as circles with directions.

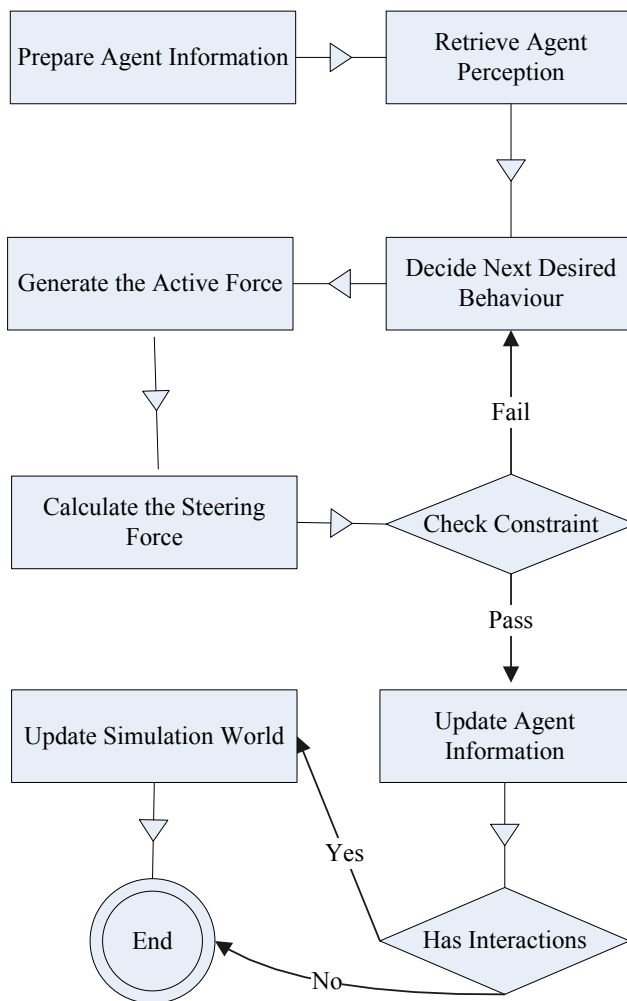


Fig. 2 Agent action process

## 4. EXPERIMENTS AND RESULTS

A scenario of a group of 24 agents exiting a corridor (Fig. 3) has been selected. The length of corridor is 30m and the width is 5m. The agents have a default speed of 1.5 m/s. In order to show the impacts of individual behaviours on the crowd, following personal parameters have been considered (used in formula 2):

- Walking Speed (m/s)
- Desired Distance (m) from Others (Dist Des)
- Level of desire for adjusting (RMs)
- Probability of being affected by POIs



Fig. 3 Initial status of the simulation

Simulations with different parameters have been carried out and the following crowd behaviours have been observed (Results are the total time (in second) of agents passing through the corridor. All simulations have been repeated ten times and the results in the paper represent the average result for the each simulation):

(1) Crowd can achieve the fastest speed if they have reached a stable status (formation). The overall movement of the crowd will be slowed down if the members tried to adjust their relative positions. Various desired distance values have been tested through the simulations (The initial distances between agents is 0.3 m). Table 1 presents the results of homogenous crowd: the crowd took more time to pass the corridor if they tend to change to a larger desired distance from each other. Table 2 reveals when the crowd are heterogeneous, the result time are more close to the higher limit of desired distance range. In other words, the crowd overall speed is mainly determined by the people who want to change to large desired distance.

Table 1 Results of agents with same Dist Des values

Result(s)	20.0	21.7	22.6	23.2	23.7
Dist Des(m)	<0.3	0.5	1	1.5	2

Table 2 Results of agents with random Dist Des value

Result(s)	22.4	22.9	23.2	23.4
Dist Des Range(m)	0.5-1	0.5-1.5	0.5-2	1-2
Average (m)	0.75	1	1.25	1.5

(2) Crowd get even slower when the people are in a hurry to adjust their distances. In test simulations, the values of  $RM_s$  present the agents' desire level to adjust their distance. It can be seen from the results (Table 4) that the quicker they adjust to their desired distance, the slower the crowd move. Fig. 4 shows the crowd have reached similar

formation in the test of  $RM_s = 3$  and  $RM_s = 5$ , but the latter one takes one more seconds.

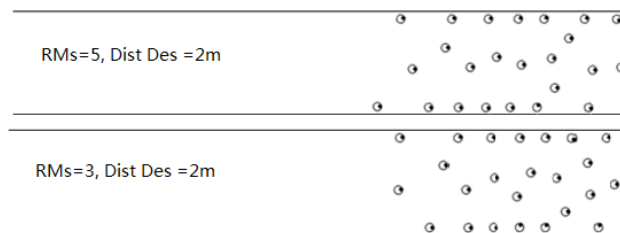


Fig. 4 Crowd formation near the end of corridor

Table 4 Agents with different desire to adjust distance

Result(s)	$RM_s=1$	$RM_s=3$	$RM_s=5$	Dist Des(m)
21.7		21.8	21.9	0.5
22.6		24.2	24.8	1
23.1		25.1	26.2	1.5
23.7		26.3	27.4	2

(3) Crowd are more sensitive to the effects of slowing down rather than speeding up. In test simulations, agents would be triggered to slow down (50% of original speed) or speed up (200% of original speed) when inside the grey area (Fig. 5). The results (Table 5) show the crowd can be slowed down when a small percentage of members want to slow down.

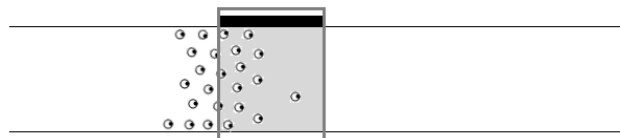


Fig. 5 Speed of agents may be affected in grey area

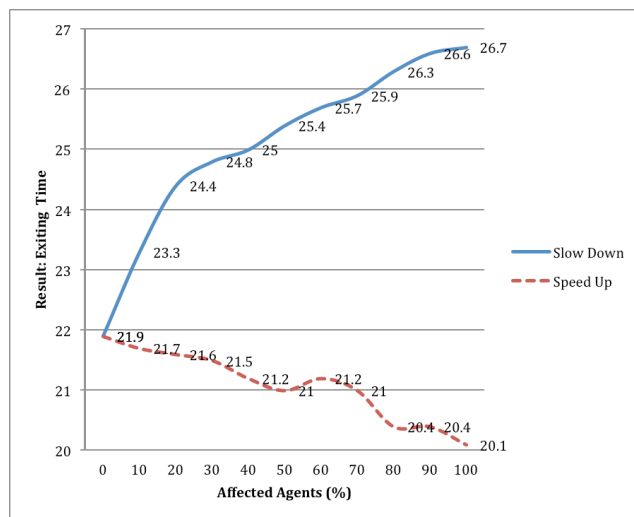


Fig. 6 Effects of changing speed

## 6. CONCLUSIONS AND FUTURE WORKS

This paper presents a crowd model, which combines the forces-based modelling and agent-based decision-making process. The experiments demonstrated effects of individuals on whole crowd and the ability to configure individual parameters. Following the architecture of the model, more behaviour rules and individual parameters will be considered in the future to achieve accurate and intelligent individual behaviours. Furthermore, more complex environments should be built to test the agents in more realistic scenarios (e.g. customers visit a shopping mall and select different shops based on their own interests, advertisements on site and actions of other customers).

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