Psychological Model for Animating Crowded Pedestrians

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Abstract

This paper proposes a psychological model for simulating pedestrian behaviors in a crowded space. Our decision-making scheme controls plausible avoidance behavior depending on the positional relations among surrounding persons, on the basis of a two-stage personal space and a virtual memory structure as proposed in social psychology. Our system determines pedestrian walking speed with the crowd density to imitate the measured data in urban engineering, and automatically generates plausible motions of the individual pedestrian by composing a locomotion graph with motion capture data. Our approach based on psychology and a variety of actual measurements can increase the accuracy of simulation at both the micro and macro levels.

Keywords: crowd simulation, psychological model, personal space, virtual memory, locomotion graph

1 Introduction

Crowd simulation has been widely used for creating animations of large groups of humans and creatures. Most of the systems used for the crowd simulation extend a particle system by introducing a characteristic behavior model for each agent. The behavior model is often composed of scripts or rule-based schemes for efficiently controlling groups of simple creatures. However, human crowd behavior is more complex than that of simple creatures due to the highly-advanced mechanism of perceptual information processing. Thus, the bottom-up simulation requires one to exploit human psychology and perception mechanism, which are now neglected in the conventional methods. Several methods have been proposed for controlling the crowd at will because the reflection of the designer's intention is the most important issue in animation production. However, such top-down strategy is not suited for accurately simulating the flow of crowded pedestrians.

Crowd simulation has also been used in urban engineering, which evaluates the validity or risk of a pedestrian space such as public buildings. A high-level autonomy of agents was introduced using a sociological and psychological behavior models for accurately estimating crowd behaviors. Such crowd simulation can supply a powerful tool for designing pedestrian space; its realistic animation, however, is difficult to achieve because such high-level simulations usually consider only positional changes of pedestrians.

This paper introduces a method for simulating crowd behavior using a psychological perception-reaction model. We develop a visual perception model involving the virtual memory structure corresponding to the capacity and delay of human perception, and use motion capture data to generate a detailed motion of each agent. These approaches can imitate individual behaviors of a pedestrian group. Our system also employs a rule-based scheme for deciding reactive behaviors where each rule is designed to take account of the theory of social psychology. In addition, we introduce an actual measurement of a relation between the pedestrian flow speed and crowd density to simulate a dense crowd with reasonable accuracy. These approaches can explain pedestrian behaviors as a group phenomenon. As a result, our system provides realistic simulation of crowded pedestrians at both the micro and macro levels.

In the following section, we explain related work and propose a psychological perception model in the third section. The fourth section explains how to determine a reactive behavior against the perceived environmental information. Experimental results and applications are demonstrated in the fifth section, and we discuss our conclusions in the final section.

2 Related works

Most crowd animation systems have been developed on the basis of a particle system [1]. Each agent in a crowd is simplified as a particle model, and complex crowd behavior emerges from the interactions. Individual behavior is often modeled by a rule-based scheme representing a mapping from a perception of the environmental information to a reaction against it [2]. Such a scheme is described as a set of logical rules, a probabilistic decision-making mechanism [3], and a scenario written in natural language [4]. These methods generate natural animation of a flock of birds or school of fish, but their schemes are too simple to provide natural human behavior. Several methods have introduced the psychological and sociological behavior models of pedestrians such as a personal space and prediction behavior [5]. However, these methods do not discuss how to estimate optimum parameters of the behavior model such as the size of personal space.

Several approaches have been proposed for interactively navigating the crowd. The ViCrowd system introduced multiple levels of autonomy for simulating hierarchical crowd behaviors [6]. This method controls a large crowd in multiple hierarchies such as crowd, group, and individual; it, however, requires a skilful scripting operation for a complex environment. Adaptive path planning algorithm is proposed for synthesizing the collision-free animation of flocks [7]. A leader-follower approach is well suited to avoid the collisions between not only individuals but also groups [8]. A stochastic sampling algorithm is used to search the plausible group behavior while satisfying the geometric constraints [9]. However, these top-down approaches rarely take account of human perception mechanisms such as visual range and personal space. OpenSteer, the public steering behavior toolkit, provides an intuitive way to navigate the crowd by imposing soft constraints on individual movement with a vector field [10]. Our system utilizes the vector field as a basic factor to control the directions of pedestrian flows.

Crowd simulation is also used in social psychology and urban engineering [11]. The simulation in emergency situations was proposed using a simple particle model [12], and it was later extended by introducing the individual and group characteristics [13]. The parameters of the human perception model were estimated by observing actual pedestrian flow in a train station [14]. These simulations are used to evaluate the safety and usability of pedestrian space. Although these methods successfully simulate crowd behavior using psychological and social behavior models, the resulting animation of individual agent lacks naturalness. Our system therefore generates plausible animation using motion capture data, while utilizing these psychological behavior models.

3 Psychological perception model

3.1 Psychological virtual memory

Each pedestrian reacts to observed environments, and the behavior is modeled as individual and independent intellectual entity, which is called *pedestrian agent* or simply *agent*. The human perception mechanism does not process all perceived information immediately; it selects only the important part of the information with limited memory capacity and processing delay. The virtual memory structure is therefore introduced in between the perception mechanism and the reaction decision process, so the reactive behavior is controlled by the memory contents. The memory stores the positions and the speed

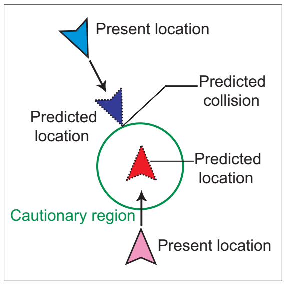


Figure 1: Prediction of future collision

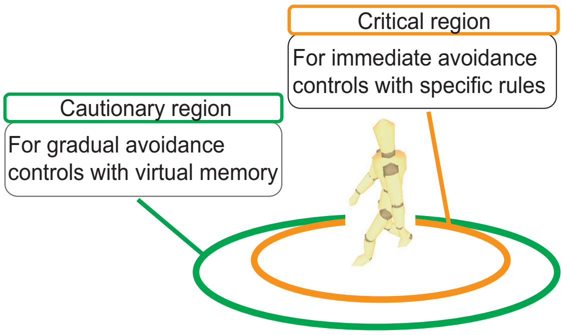


Figure 2: Two-stage personal space

of other N_m agents, and they are updated at each time interval T_m which represents the duration of the memory content. The time interval T_m is optimized through simulation, and the memory capacity N_m is fixed to $N_m = 7$ by relying on the results of a psychological experiment [15].

3.2 *Visual sensor*

A visual sensor obtains the environmental information on a semicircular front region of the agent. It detects the positions and speeds of other agents within the visual range, and fails to sense when interrupted by obstacles. Moreover, future collisions within a time span (or a prediction horizon) T_f are predicted by computing intersection points of linearly extrapolated trajectories of the agents (figure 1). Such prediction mechanism can reduce redundant movements to avoid collision [14].

From a psychological viewpoint, the neighboring agents impose mental stress on each other, which can be estimated on the basis of a personal space model [5, 16]. This model experimentally showed that mental stress increases exponentially as others get close, and it becomes critical at a certain distance [14]. We therefore developed a two-stage personal space model as shown in figure 2. Each agent tries to avoid the others detected in the outer annulus, called the *cautionary region*, by gradually steering to the sides without deceleration. The inner circle represents the *critical region* where the agent takes immediate action to avoid a collision. We optimize the radii of the critical region r_1 and cautionary region r_2, and also optimize the prediction horizon T_f through the simulation.

The agents cannot manage all predicted collision information because of their memory capacity limitation $N_m = 7$. All detected collisions are therefore prioritized by the distance between the agents, that is, the neighbors close within the critical region are memorized with high priority, and the exterior ones are memorized in the order of estimated arrival in the cautionary region within the time span T_f.

3.3 *Parameter optimization*

Since the parameters of the personal space model deeply affect both individual and crowd behaviors, simulated annealing is used to optimize the four free parameters: the memory duration T_m, the prediction horizon T_f, and the radii of the personal space r_1 and r_2. The reward function of the optimization is then designed to maximize the flow speed of pedestrians and to minimize collisions, by computing two metrics: the validity of a moving direction and the number of collisions. The first metric is computed by the dot product of the actual moving direction $\mathbf{v}(t)$ and the vector $\mathbf{d}(t)$ from the agent's location to the target. The second metric exerts a negative effect by counting the number of collisions $n_c(t)$ with the other agents while walking. The reward is therefore computed as follows:

$$reward = \sum_{t=0}^{T_r} \{\omega_p(\mathbf{v}(t) \bullet \mathbf{d}(t)) - \omega_c n_c(t)\}$$

where ω_p and ω_c represent weighting coefficients which are empirically set to 5 and 2000, respectively. Notice that the optimization is iterated until all parameters converge. Table 1 shows the optimized values by using the simulation in which two ten-person-groups pass

Table 1: Optimized parameters of psychological perception model

$T_m[ms]$	$T_f[ms]$	$r_I[cm]$	$r_A[cm]$
1270	5000	75	320

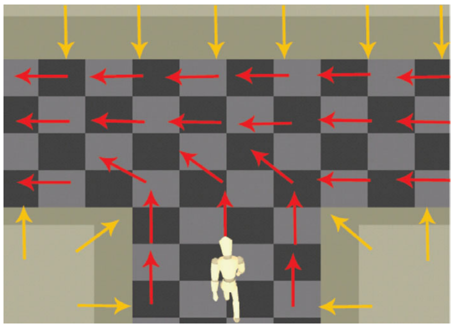


Figure 3: Example of vector fields

through each other at various angles (0, 45, 90, 135, 180 deg).

4 Reactive behavior

4.1 Navigation with vector field

A vector field represents the mapping from a present agent position to a desired moving direction [10]. The pedestrians determine their moving direction by referring to the vector fields at the present location. This strategy is well suited to design a complex flow pathway including branch and loop. Moreover, it is possible to assign a different vector field for each group, and to avoid colliding with the obstacle by setting the outward vectors. Our system uses an attractive and repulsive force model [17] for designing such vector fields as shown in figure 3, where the attractive force lies along the pathway, and the repulsive force surrounds the wall.

4.2 Avoidance behavior

Collision avoidance behavior is controlled by the environmental information stored in virtual memory. The agent keeps walking along a vector field while no collision information is stored in the memory. After the future collision is detected, the optimum avoidance behavior is selected between urgent and smooth avoidances, according to the following rules:

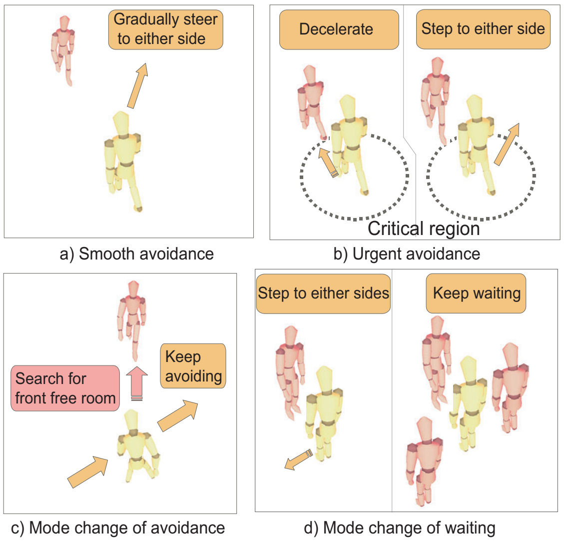


Figure 4: Rules for collision avoidance

Urgent avoidance The agent rapidly decelerate or sharply veer by side stepping when another agent is detected in the critical region of personal space. We set higher priority on deceleration over rapid steering in order to keep following the preceding pedestrian. If the collision cannot be avoided using both avoidance behaviors, the agents keep stopping and waiting until they find room to step forward.

Smooth avoidance The agents gradually steer to the sides when they have enough time to avoid collision. The moving direction is determined according to the positional relation among the agents.

After a certain time span from the beginning of avoidance, the agent searches for room in their front and discontinues the avoidance behavior to return to normal walking (figure 4 (c)). When two waiting agents are confronted with each other, they try to step to either side (figure 4 (d)). If there is no room to avoid, the waiting behavior is again maintained for a certain time period.

4.3 Density-based walking speed control

The walking speed of pedestrians heavily depends on the crowd density; for example, the

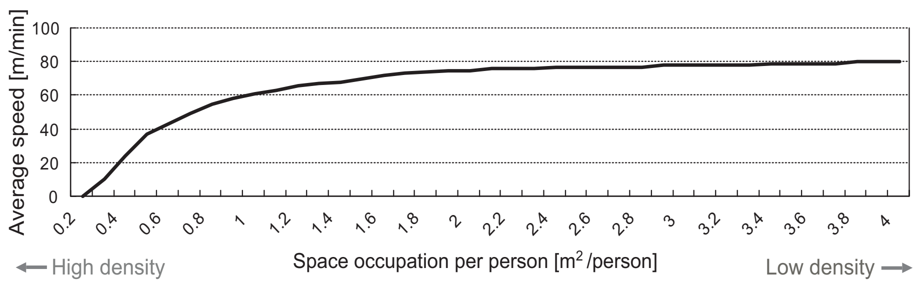


Figure 5: Relation between crowd density and average walking speed [18]

pedestrian tries to maintain a slower pace in a more crowded space owing to severe mental stress. The relational model between the space occupied per person and average walking speed is represented by the saturation function shown in figure 5 [18]. With this relation, we limit the pedestrian walking speed by sensing the local density of the personal space within the given visual range.

4.4 Detailed motion generation

The detailed motion of each agent is synthesized using the motion capture data. Our system uses four types of locomotive motions: gait, side stepping, starting, and halting. Each motion clip is represented as a node and has a locomotive state transition path to construct a *locomotion graph* [19]. The transition over the graph is selected according to the reactive behavior, and motion in the transition process is synthesized using ease in/out interpolation. Table 2 shows a list of all motion data used in our system, and figure 6 gives the constructed locomotion graph.

Gait motions are generated by blending several motions at various walking speeds for continuously controlling the speed. The six types of gait motions shown in table 3 are blended with linear interpolation where the blending weights are computed so that the synthesized motion has the desired walking speed. However, the resulting motion often involves some artifacts such as foot skating because a curved locomotion is generated by simply manipulating a trajectory of straight walking. We are implementing a smarter interpolation mechanism based on statistical analysis [20] for more accurately generating gait motions with less artifacts.

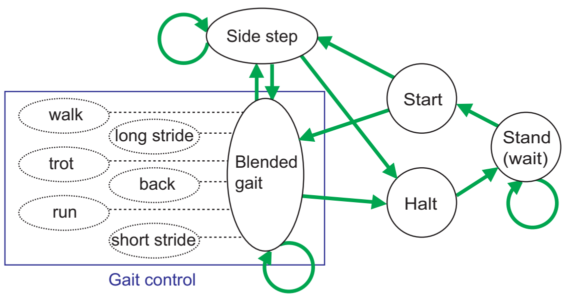


Figure 6: Locomotion graph

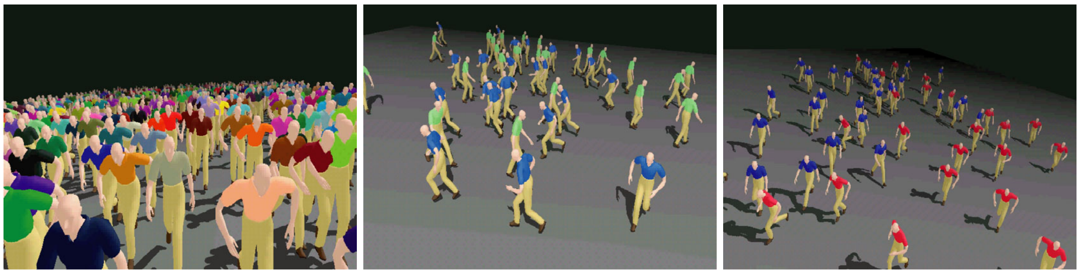
Table 2: Motion data used for simulations

	# of motions	Total # of frames
Gait	9	100
Side step	2	191
Start	6	172
Halt	8	230

5 Results and applications

5.1 Simulation of crossing groups

Figure 7 provides snapshots of the resulting animations. Figure 7 (a) illustrates the flow of a dense crowd where every person runs in one direction while occupying approximately 1.0 m^2 in area, and figures 7 (b) and (c) are simulations of two groups passing through at right angles and opposite angles, respectively, by navigating them with different vector fields. These animations demonstrate plausible behaviors without causing unnecessary collision, avoidance, and deceleration. The computational time for figure 7(a) takes 20 msec per frame on a 1.8GHz Athlon XP CPU.



(a) Dense crowd (1.0 $[m^2/person]$) (b) Two groups passing in opposite directions (c) Two groups passing at right angles

Figure 7: Simulations of pedestrian groups

Table 3: Gait motions for controlling walking speed

Gait style	speed [m/min]
Run	165
Trot	90
Long stride	85
Normal walking	75
Short stride	60
Backward walking	-60

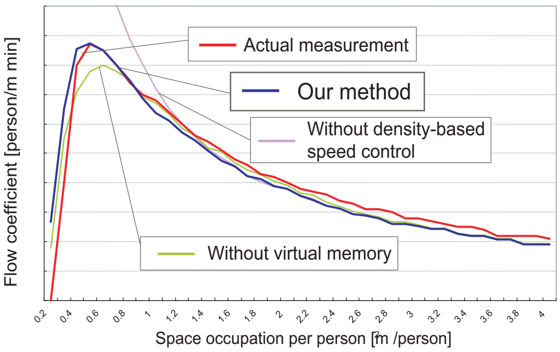


Figure 9: Comparison of flow coefficient with actual measurement

5.2 Comparison with actual measurement

The simulation accuracy of our system is evaluated through comparison with the actual measurement in urban engineering [18]. A pedestrian flow coefficient represents the number of pedestrians passing through one meter wide space per minute, and we use this value as a metric for evaluating the plausibility of crowded walking at the macro level. The simulation was done in a straight lane as shown in figure 8, and the crowd is composed of three pedestrian groups of the same number that have different gait styles (velocity): jog (110 m/min), slow walk (50 m/min), and normal walk (80 m/min). The flow coefficient and the average crowd density $[m^2/person]$ are computed by randomly changing the number of pedestrians moving in the lane.

The simulated flow coefficients and actual measurements are compared in figure 9. As this comparison demonstrates, our simulation well approximates the actual measurement, especially at the peak range, by which we can accurately simulate the pedestrian flow in a very crowded space. Figure 9 also shows the effectiveness of both the virtual memory and the density-based speed control. Excessive avoidance behaviors are caused from the lack of the virtual memory due to faulty selection of the avoidance direction, which results in the abnormal decrease of the flow coefficient at the peak range. Without the density-based speed control, the flow coefficient monotonically increases according to the density because pedestrians do not slow down their walking speed regardless of the increase of collisions in the crowded space.

5.3 Application of layout design

Our system can be applied to evaluate the layout of a crowded public space such as an urban train station. Designers can visually and numerically evaluate the arrangement of equipments with our simulation by interactively changing their locations. Figure 10 demonstrates a simple optimization of a pedestrian space by randomly

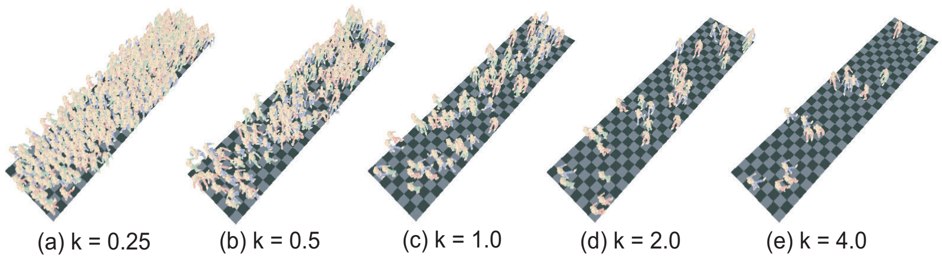
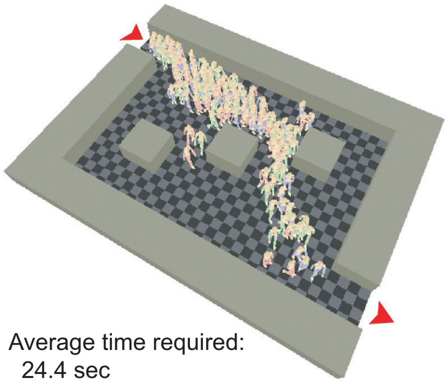
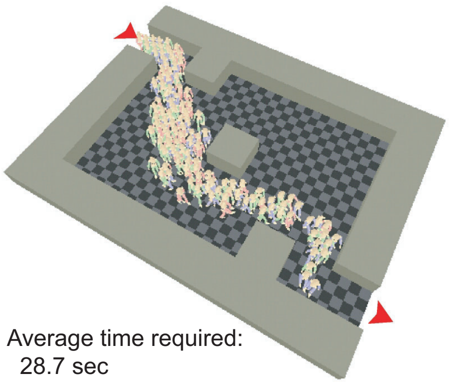


Figure 8: Virtual environments for measuring flow coefficient (k: space per person [$m^2/person$])



(a) Moderate layout



(b) Obstructive layout

Figure 10: Prediction of required travel time

moving each of three square obstacles around in the central area. Each arrangement is evaluated with the total time required for 128 pedestrians to pass through the virtual room. Figures 10 (a) and (b) show one of the moderate and the most obstructive layouts computed by using our simulation. These results intuitively show that agents must make a detour when an obstacle is arranged to obstruct the shortest path.

6 Conclusions

We have proposed a crowd simulation method using a psychological behavior model. The contributions of our method may be summarized as follows:

- The two-stage personal space model can produce more plausible interactions among agents.
- The virtual memory selects the minimum targets to be avoided, which can reduce the redundant movements in a crowded space.
- Density-based speed control can imitate the speed of actual measurement and thus enhances the accuracy in estimating pedestrian flows.
- Realistic animation using motion capture data allows the user to analyze crowd behavior at the micro level.

Our personal space model neglects the individualities and adaptable nature of actual humans. For example, the range of personal space should be varied according to gender, age, job, and moving speed [14], and it should vanish in emergency situations. The other limitation is the lack of the naturalness of motions at the micro level due to the narrow variety of motion samples that urgently avoid collisions. Our system currently requires users to manually set vector fields for driving pedestrians and automatic generation of the vector fields should be developed to enhance plausibility of individual behaviors, using smart path planning techniques or some decision-making rules.

Our future work includes a development of a more human-like perception model and the mechanism of generating vector field from environmental information. A wider variety of motion samples of collision avoidance and locomotion should be provided and managed for more accurately simulating various complex conditions. Integration of pedestrian behaviors with different kinds of behaviors, such as resting and communicating ones, is also indispensable to develop practical applications.

Acknowledgements

This work was supported by the 21st century COE program (Intelligent human sensing) and grants-in-aid for scientific research from Ministry of Education, Culture, Sports, Science and Technology. We would like to thank Toyohisa Kaneko for supervising, and the staff of Links DigiWorks Inc. for the support of motion capturing

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