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Collision Avoidance in an Agent System for Crowd Simulation

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***Abstract*—Aiming at precisely modelling people's ability to avoid collisions in crowded circumstances, as well as reducing the computation load for collision avoidance in large-scale crowd simulation, a collision avoidance method based on a set of rules and strategies for an agent system is proposed. Inspired by the pedestrian movement logic of "perception - decision - action", a group of collision avoidance rules is designed according to the analysis of obstacle perception and collision detection. When an agent encounters an obstacle, it evaluates its situation and takes action to avoid the collision by looking through the collision avoidance rule tables. Obstacle perception is analyzed by using geometric visual model, and collision detection by using the angle between the observer and obstacle. Simulation results of several scenarios show this rule-based method avoids collisions effectively, and simulation is very similar to the actual crowd behaviors.**

I. Introduction

With the social and economic development, the flow of people and large-scale cultural and sports activities have become more frequent. A large number of people often gather in stations, squares and other public places, which brings a series of security and management issues. Because of its application value in many fields such as safety science, architecture planning and crowd organization, it is of great practical significance to study large-scale crowd motion simulation [1] - [4].

We have developed a crowd simulation system based on agents, which uses the potential field model and social force model to represent the interaction and interrelation of people to obtain the direction and speed of pedestrians. We experiment with some benchmarking cases and a few more complex scenes for the system, such as Tiananmen Square, Xi'an Railway Station and the school's research building and other very crowded places. In these experiments, collision avoidance is an important problem that cannot be ignored in the field of the crowd simulation.

In a crowd simulation system, collision avoidance refers to a behavior pattern where multiple agents move toward their targets by a series of actions to ensure that they do not collide with obstructions and other agents [5] - [7]. Collision avoidance is an important issue in crowd simulation, and there are many studies on collisions and the solution. Such as the kind of collisions [8], the impact of speeds on collision avoidance [9]. In addition, there are some collision-detection and collision-avoidance methods and algorithms, including AABB bounding box (Axis Aligned) method [10], GJK-algorithm [11], optimal Event-Driven algorithm [12], Bellman's approach [13], BdDOB method containing changing frequency window [14]. These methods are effective and provide a theoretical basis for our system, which also provide a good reference.

This paper proposes a rule-based collision avoidance to control the actual movement of agents to avoid collision, which is established on the results of obstacles perception and collision detection. The rule-based method solves the problem of collision detection and collision avoidance between dynamic pedestrian and static or dynamic pedestrian.

II. Agent Collision Avoidance Method

A. Obstacle Perception

Perception of obstacles is the prerequisite for an agent to understand the environment and make decision autonomously. To emulate human's perception ability in simulation, geometric-based method usually adopted to describe the region in which collision possibly occurs. For example, a rectangle or a circle is specified around an agent. This simplification reduces the precision, but improves the computation efficiency. So it is more suitable for large-scale crowd simulation. In the simulation system, an agent needs to obtain information about the position and velocity of the surrounding obstacles before the movement.

An obstacle which is far away from an agent usually has very small influence on the agent. When an obstacle enters a certain range around an agent, the agent will respond to the obstacle. It may stops, slows down, speeds up, or adjust direction. Therefore, the scope of vision determines a judging area where collision may occur for an agent. According to observations [15], the visual field of human eyes is about 120 degrees to 180 degrees, and the reaction distance of collision avoidance is about 3 meters. In this paper, the "semi-circle" region is used to simulate agent's range of vision to simplify computation. As shown in Fig.1, the agent only considers the collision of objects less than 3 meters from the front 180-degree field of view.

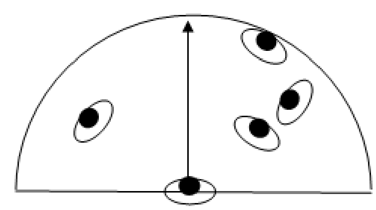

Figure 1. Obstacle perception

B. Collision Detection

Judging the collision between pedestrians requires to answer two questions [16]:

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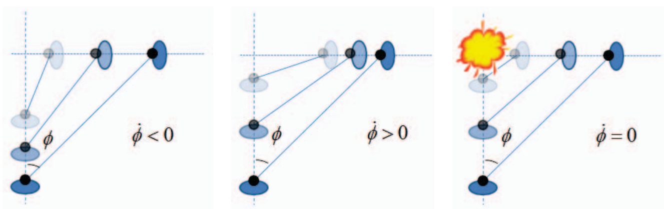
- Whether the collision will occur: set the angle between the direction of a pedestrian and an obstacle in the field of view as ϕ. If the time differential of ϕ is 0 or close to 0, there will be a collision in the near future, as shown in Fig. 2.
- When the collision will occur: agent estimates the time of the collision occurrence according to the rate of change of the size of the obstacle in the field of vision. The higher rate of the volume growth of the obstacle in the field of view is, the faster the collision occurs. Accordingly, agent can estimate the time of the collision occurrence.



(a) (b) (c)

Figure 2. The relationship between the occurrence of collision and the angle of view. *(a. Pedestrian barrier passes first; b. The observer passes first; c. Collision occurs)*

According to the study of synthetic vision, the variables to be examined in the collision detection are the two-tuple of the view angle ϕ between the observed and observer and the collision prediction time t_c [17], which are called collision parameters in this paper. When $t_c > 0$, if the differential of ϕ is close to 0, the collision will occur. In order to avoid collision, agent can adjust the direction of motion to the left or right. In addition, if t_c is close to 0, the collision is about to happen. The agent can increase the reaction time by reducing the speed of movement to slow down the collision.

In order to obtain the collision parameters, the model is set as shown in Fig.3.

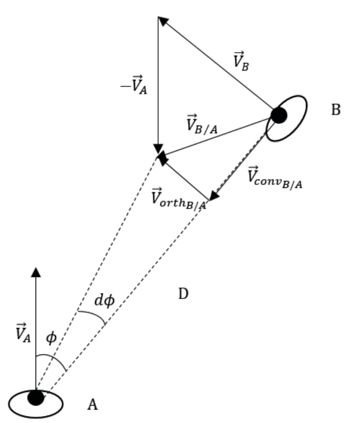


Figure 3. Collision detection model

In the figure, the observer is set to A, the coordinate position is represented by p_A, B is the observed, and the coordinate position is p_B.

- Collision Time t_c

The relative speed of B relative to A can be expressed as

$$\vec{V}_{B/A} = \vec{V}_B - \vec{V}_A \,, \tag{1}$$

where $\vec{V}_{B/A}$ is the speed of the observed B relative to A; $\vec{V}_B$ is the speed of the observed B; $\vec{V}_A$ is the speed of the observer A.

We decompose $\vec{V}_{B/A}$ in the direction of $\overrightarrow{BA}$ orthogonally, and use its component to get the collision prediction time t_c. The concrete formulas are as follows:

$$\vec{V}_{conv_{B/A}} = (\vec{V}_{B/A} \cdot \vec{k}) \cdot \vec{k} \tag{2}$$

$$\vec{V}_{orth_{B/A}} = \vec{V}_{B/A} - \vec{V}_{conv_{B/A}} \tag{3}$$

$$D = \|p_B - p_A\| - R \tag{4}$$

$$t_c = \frac{D}{\left\|\vec{V}_{conv_{p/w}}\right\|} \cdot \mathrm{sgn}(\vec{V}_{conv_{p/w}} \cdot \vec{k}) \,. \tag{5}$$

Here $\vec{V}_{conv_{B/A}}$ is the component in the direction of $\overrightarrow{BA}$ of the relative velocity of B to A; $\vec{k}$ is the unit vector in direction of B to A; D is the distance between B and A; and R is the radius of agent.

- the Viewing Angle

According to the cosine theorem, the viewing angle ϕ can be obtained through

$$\vec{q} = -\vec{k} \tag{6}$$

$$\phi = \arccos\left(\frac{\vec{q} \cdot \vec{V}_A}{\|\vec{q}\| \cdot \|\vec{V}_A\|}\right), \tag{7}$$

where $\vec{q}$ is the unit vector in the direction of A to B; ϕ is the viewing angle of A to B.

- the Viewing Angle Differential

The differential of the viewing angle can be defined as the change of ϕ in the unit time. The unit time is the time step of the crowd simulation system. $\dot{\phi}$ has a sign, which means the barrier pedestrian passes first when it is negative, and the observer passes firstly when it is positive.

- Collision Detection Method

When the differential of the viewing angle between the pedestrians is close to 0 and the collision prediction time is positive, the collision will occur. Usually, the longer the distance between the pedestrians is, the later the potential collision occurs. Contrarily, the shorter the distance between the pedestrians is, the earlier the potential collision occurs. So the possible collision with near pedestrians should be considered to avoid in priority. Therefore, this paper sets the judgment threshold of the viewing angle differential as

$$\gamma = \frac{a}{t_c^b} \,, \tag{8}$$

where a and b are adjustable parameters.

Thus, the discriminant formula of the collision detection between pedestrians is

$$I_{c_{AB}} = \begin{cases} True, & if \ |\dot{\phi}| \leq \gamma \wedge t_c > 0 \\ False, & else \end{cases} \,, \tag{9}$$

where $I_{c_{AB}}$ is a boolean value of whether the observer A will collide with B.

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According to the direction of relative motion, collisions between pedestrians can be divided into three types: frontal collision, side collision, rear collision, as shown in Fig.4. In reality, the most common collisions are side collisions. Frontal collision and rear collision can be seen as a special case of side collision. Obviously, the frontal collision and the rear collision meet the following basic conditions:

$$I_{c_{AB}} = True \wedge \phi \leq \theta \ , \tag{10}$$

where θ is the threshold of judging whether A and B are collinear or not.

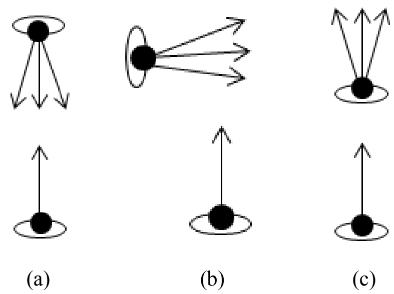

Figure 4. Three types of collision*(a.Frontal collision; b. side collision; c. rear collision)*

A frontal collision occurs when the movement directions are right opposite, while a rear collision occurs when they are in the same direction. This is the only difference between a frontal collision and a rear collision. Obviously, when it is a frontal collision, the following conditions will be satisfied:

$$\begin{cases} \psi = < \vec{M}_A, \vec{M}_B > \\ 180 - \theta < \psi < 180 + \theta \end{cases} , \tag{11}$$

where ψ is the angle of the moving direction between the observer A and the observed B; M_A is the moving direction of the observer A; M_B is the moving direction of the observed B.

As shown in Fig. 5, considering pedestrian's body, if the angle of movement directions falls within a θ-neighborhood of 180 degrees, i.e. ($180°-\theta$, $180°+\theta$), the collision can be regarded as a frontal collision. θ can be approximately estimated by

$$\theta = \arcsin(\frac{2R}{D}) \ , \tag{12}$$

where R is the radius of the body of agent, D is the distance between the observer and the observed. Here we use a cylinder to approximately represent the body of agent for convenience of computation.

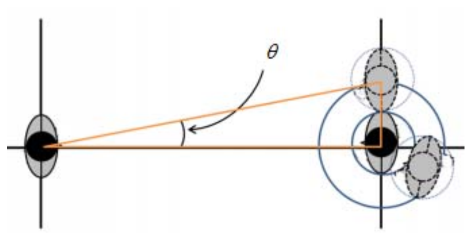

Figure 5. The threshold θ of the frontal collision

Similarly, the criteria of the rear collision is

$$\begin{cases} \psi = < \vec{M}_A, \vec{M}_B > \\ \psi < \theta \ or \ \psi > 360 - \theta \end{cases} . \tag{13}$$

C. Rule Tables of Collision avoidance

According to the actual observation, pedestrians always react first to the emergent collisions. If a collision possibly occurs, the pedestrian usually takes one or several of the following strategies to avoid it:

Deceleration: When the pedestrian perceive a collision is imminent, he habitually tries to decelerate to avoid the collision. The new speed is given by [17]

$$v_{new} = v_a \cdot (1 - e^{-0.5 t_{c\,\min}^2}) \ , \tag{14}$$

where v_a is current speed of pedestrian, and $t_{c\,\min}$ is the prediction time of the collision.

Standstill: the pedestrian reduces his speed to 0 to avoid obstacles and pedestrians. This is a special case of the strategy "deceleration".

Acceleration: facing a possible collision, one of two pedestrians can also accelerate to quickly pass the place where the collision may occur in some circumstance if possible, so that the collision can be avoid.

Changing direction: In most cases, pedestrians often select to turn left or turn right with a suitable angular velocity not to collide with others. Obviously, for an immediate collision, the angular velocity of the rotation $\dot{\varphi}$ should be larger. The formula for the angular velocity $\dot{\varphi}$ may be given as follows, where $\dot{\varphi}$ is in the opposite direction to $\dot{\phi}$, the differential of viewing angle ϕ.

$$\begin{cases} \dot{\varphi} = \gamma' - |\dot{\phi}| \\ \gamma' = \frac{a}{t_{c\,\min}^b} \end{cases} \tag{15}$$

The response of a pedestrian to a collision is quite different, which depends on the emergent level of the potential collision. We use the left time (t_c) before the collision can be avoid as a measure to describe the emergency. Based on above computation and analysis, we propose a response mechanism for collision avoidance in the form of a group of rules, as shown in Table I, Table II, and Table III.

TABLE I. AVOIDANCE DECISIONS OF COLLISION ($t_{c\,min} \leq 0.5s$)

The observed B	Types of collision	Strategies
standstill	frontal collision	Observer A decelerates and adjusts the direction. If useless, A reduces speed to 0.
standstill	rear collision	Same as above
standstill	side collision	Same as above
movement	frontal collision	A and B both decelerate and change directions simultaneously. If useless, A and B reduce speed to 0.
movement	rear collision	A moves at B's speed.
movement	side collision	Randomly either A or B reduces his speed to 0.

TABLE II. AVOIDANCE DECISIONS OF COLLISION($0.5s \leq t_{c\,min} \leq 3s$)

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The observed B	Types of collision	Strategies
standstill	frontal collision	Observer A changes direction.
standstill	rear collision	Observer A changes direction.
standstill	side collision	Observer A decelerates and changes direction.
movement	frontal collision	Both A and B decelerate and change direction simultaneously.
movement	rear collision	A decelerates OR A changes direction and accelerates.
movement	side collision	Both A and B decelerate and change direction simultaneously.

TABLE III. AVOIDANCE DECISIONS OF COLLISION($t_{c\,min} > 3s$)

The observed B	Types of collision	Strategies
standstill	frontal collision	Observer A changes direction.
standstill	rear collision	Same as above.
standstill	side collision	Same as above.
movement	frontal collision	Both A and B change their own direction simultaneously.
movement	rear collision	No reaction.
movement	side collision	No reaction.

According to statistics, the minimum avoidance distance between pedestrians is about 70cm, and the average speed is about 1.4m/s. Thus, when the collision time is less than 0.5s, pedestrians may make more intense response. When the collision time is more than 3s, pedestrians may temporarily not make any response.

III. EXPERIMENTS AND RESULTS

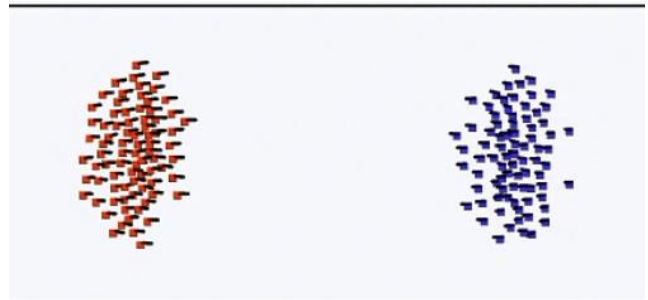
In order to examine the above presented collision avoidance rules, we used our agent-based simulation system to analyze the crowd behaviors in 3 scenarios designed by a team of Zhejiang University [18]. In simulation we illustrated the process that the flow of pedestrians meets, mixes, evades each other and finally separates. All collision avoidance is realized by adopting the strategies and rules listed in Table I, II and III.

A. Two-way Flow

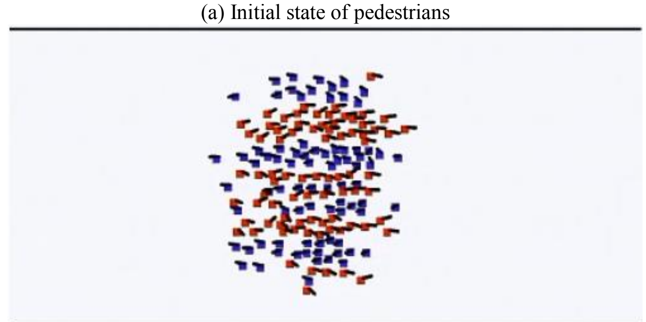
In this case, two groups of pedestrians are walking in the opposite way on a narrow road with no obstructions. In this example, collisions are mainly frontal and rear. The flow of pedestrians are shown in Fig. 6.

For convenience of comparison, we also simulated the same scenario using the social force model, in which collision avoidance is not considered. The initial state of pedestrians is the same as in Fig. 6 (a). The pedestrian flow when two groups of people meet are shown in Fig. 7.

According to the realistic observation, in the crowded places such as subways, corridors, marketplaces and big squares where the crowd density is very high, people will form two or more pedestrian flows spontaneously, which is known as self-organization phenomenon. We can see from Fig. 6, the method presented in this paper gives a reasonable way to avoid collision, and the self-organization phenomenon is also observed. However, as shown in Fig. 7, the traditional social force model doesn't obviously show this characteristic.



(a) Initial state of pedestrians



(b) The pedestrian flow when they meet

Figure 6. Simulation results of two-way flow

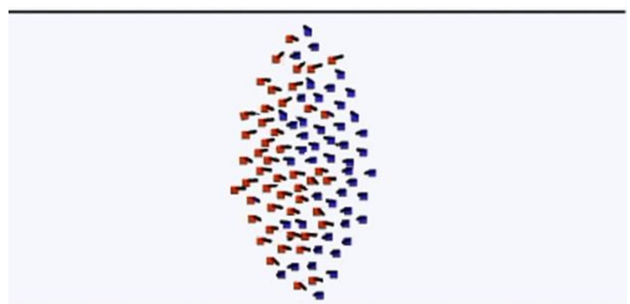


Figure 7. Pedestrian flow generated by social force model

B. Low-density Cross-flow

In this case, two groups of pedestrians are crossing the road at an intersection. Here collisions are mainly side and rear. Three snapshots in different stages of simulation are shown in Fig. 8.

Due to the view limitation at a crossroad, pedestrians cannot obtain the information of the other group until they meet. Once they meet, extensive collisions may occur immediately, while in the previous case, collisions increase gradually. The purpose of this case is to examine the performance of the rule-based method to process extensive collision avoidance computation.

Simulation shows that agents keep their own direction and maintain its original movement at the crossroads. As shown in Fig. 8, agents spontaneously form a few flows at each direction to avoid collision as much as possible. This is consistent with observations at realistic crossroads.

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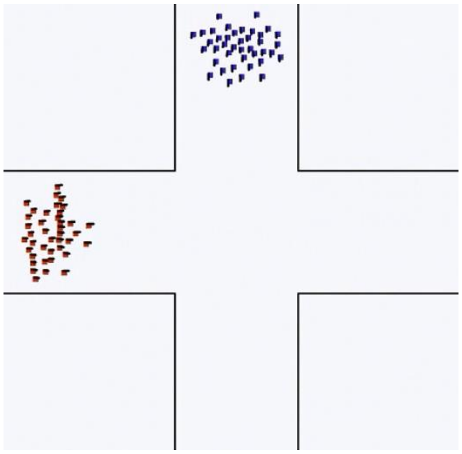
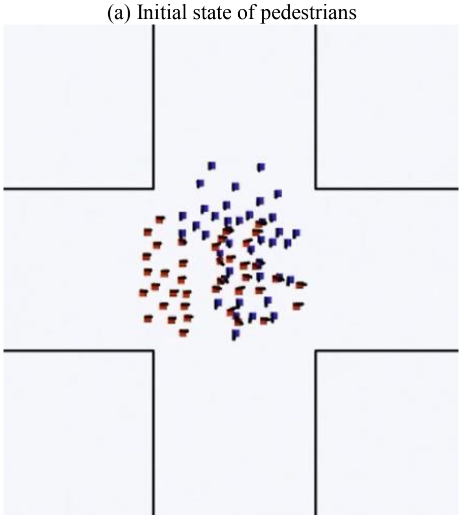

(a) Initial state of pedestrians


(b) The pedestrian flow when they meet

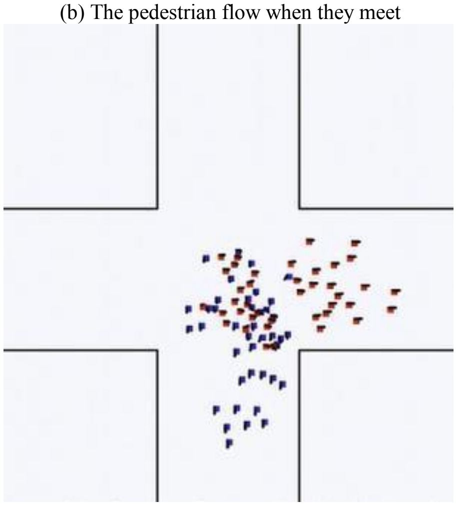
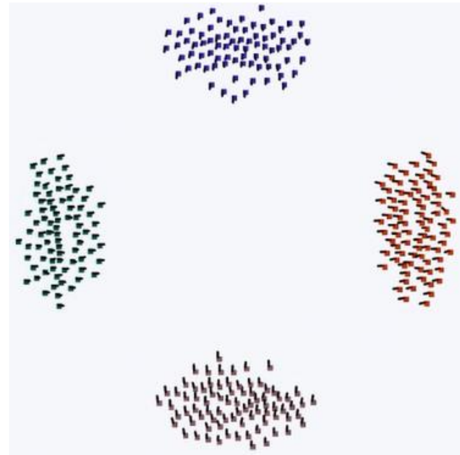
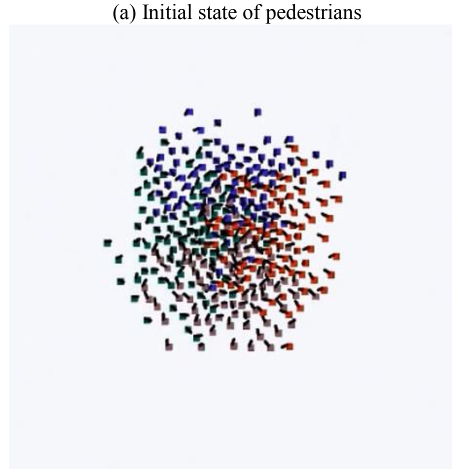

(c) The pedestrian flow when they separate

Figure 8. Simulation results of low-density cross-flow


(a) Initial state of pedestrians


(b) The pedestrian flow when they meet

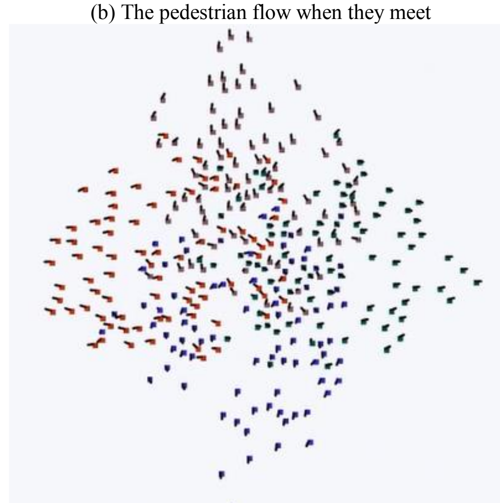

(c) The pedestrian flow when they separate

Figure 9. High-density cross-flow simulation results

C. High-density Cross-flow

In this case, four groups of pedestrians are crossing the road at an intersection, in which collisions include frontal, side and rear ones. Three scenes in simulation are shown in Fig. 9.

This case includes much more potential collisions, and their amount increases suddenly and quickly. For each pedestrian, the possibility that he collides with others is much higher than above examples.

Although there is high-density computation for large amount of collision avoidance, the pedestrian flow displayed in the simulation interface is still smooth. And similarly to the last example, from Fig. 9, we can see that agents also

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naturally form a few flows at four directions to avoid collision as exhibited in reality.

IV. Conclusion

In subways, corridors, squares and other crowded places, collision may happen very frequently. But under normal circumstances, there is little collision among the crowd in real world. This is because people trend to avoid colliding with others or obstacles consciously or unconsciously. Crowd simulation should model this kind of ability for people to avoid collisions. This paper studies and implements collision avoidance mechanism in an agent-based crowd behaviors simulation system. For simplifying computation, the mechanism is realized through a set of rules and strategies.

We used 3 benchmarking examples to verify these rules. The simulation results show that the method has a good ability to cope with dense collisions inherently in large scale crowd simulation. Although we haven't use concrete data to measure the performance, the individual trace, their flows and the crowd's behavioral characteristics are very close to our intuition and observation on the actual crowd. This can also be observed in simulation of more complex scenes.

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