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Crowd queuing simulation with an improved emotional contagion model

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In crowd queuing events, the emotions of individuals are mutually infective, easily confusing the queuing order and possibly leading to crowd events. However, the impact of emotion and personality is not considered in current models of crowd behavior. Other studies focus on social interactions such as emotional transmission [1]. Thus, there is a large difference between the simulation results and the real-life behavior of crowds. To improve the realism of crowd simulation results, we use the knowledge learned from Bosse's study [2], and propose an emotional contagion method for crowd simulation. This method combines an improved susceptible-infected-recovered (SIR) model with cellular automata. Recognizing the importance of individual personalities in crowd queuing, it also adds the important personality parameters of individuals.

This research studies the emotional contagion in crowd queuing from psychological and social computing perspectives. An agent i is endowed with emotional parameters that effectively express its individual personality, such as patience ω_i, urgency u_i, friendliness f_i. By adding the emotional personality parameters in the traditional SIR model and adopting an improved emotional contagion mechanism [3], we adjust the queuing behavior of crowds and simulate the queuing events in a cellular automata model.

The urgency parameter u_i can increase the negative emotion of the crowd over time. Thus, we first calculate the u_i-induced negative emotional value e_u at time t by

$$e_u(i,t) = e_u(i,t-1) + u_i t^{\partial}. \tag{1}$$

According to this formula, e_u increases exponentially with time t, where ∂ in the exponential term denotes the time index.

A queue-jumping event stimulates and grows the negative emotions of other individuals. In this study, the negative effect of queue jumping on individual i is represented by a parameter D_{ji}, where j is the index of the queue jumper. D is computed by the following SIR-model formula:

$$D_{ji} = \left[1 - \frac{1}{(1+\exp(-L))}\right] \times E_i \times A_{ji} \times B_{ji}, \tag{2}$$

where L represents the distance between two individuals i and j. E_i and B_{ji} denote the intensities of the emotional contagions of the queuing individual i on itself and on the queue jumper, respectively, and A_{ji} denotes the intensity of the emotional effect of the queue jumper j on i.

At time t, the emotional value of i is updated by summing the negative effects of K queue jumpers within the perception range of i:

$$e_{\mathrm{neg}}(i,t) = e_u(i,t) + \sum_{j=1}^{K} D_{ji}. \tag{3}$$

We then define the negative emotional burst probability parameter p, calculated by

$$p = \begin{cases} 1 - \mathrm{e}^{-\tau u_i \Delta t}, & \Delta t \leqslant w_i, \\ 1, & \Delta t > w_i, \end{cases} \tag{4}$$

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where Δt represents the waiting time. Clearly, increasing u_i and lengthening Δt increase the probability of a negative emotional outburst.

When its negative emotions erupt, individual i will jump to a location that depends on the degree of the negative emotion. We must then consider the weakness of a negative emotional value. Eysenck [4] calculated individual emotional values using Hooke's law, which states that the elastic energy f in a spring is negatively proportional to the length change Δl of the spring. The proportionality constant is the stiffness coefficient k of the spring. Also, by the law of conservation of energy, when the amount of compression is Δl, the elastic energy is converted to kinetic energy, which restores the spring to its normal state (i.e., zero elastic energy). In this study, the individual negative emotional value $e_{\rm neg}(i,t)$ is analogous to the elastic energy of the spring, k represents the coefficient of change in the negative emotional value, and Δl represents the individual walking distance as follows:

$$e_{\rm neg}(i,t) = -k \cdot \Delta t. \tag{5}$$

The behaviors of the individual agents differ in each queue and are affected by many factors, including the factors of the agent itself (such as character, emotion, and field of vision) and external environmental factors (such as obstacles and other agents). These factors should be considered in the modeling of agent behavior. As shown in Figure 1, each agent senses the external environment, plans its behavior, and decides its path.

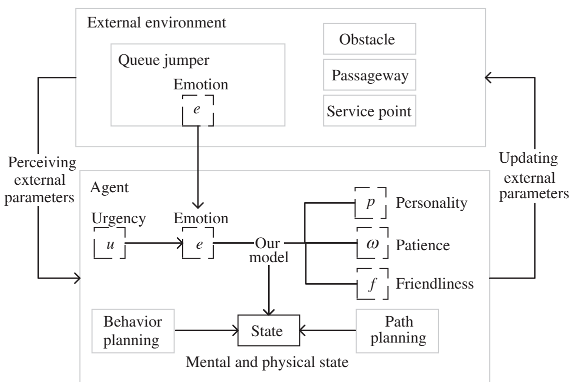

Figure 1 Behavioral modeling. In the proposed emotional contagion model, the agent interacts with the external environment parameters, and plans its next behavior and path. Finally, the agent updates its own mental and physical state, and feedbacks this information to the external environment. The external environment parameters are updated accordingly.

Before implementing any behavior, the agent must gain some important information from the external environment, such as the location and emotional value of other agents, the locations of obstacles, and service point information. After obtaining these parameters, the agent calculates and updates its own information by the proposed emotion model, and determines its next action as queuing or queue-jumping. After completing the decision-making, the agent starts the path planning. Most importantly, the chosen path must avoid other agents and obstacles detected in the scene information.

Queue scenes differ mainly by their number of service points, queuing form, and the placement of fences. There are two types of service points: one-to-one services, and many-to-many services. Meanwhile, queues can be formed in single or multiple columns, and the fences affect the movements of individuals (without the fences, the agents move freely). Here, the proposed model is validated on five representative queuing scenes: an ATM, a subway platform, a bus platform, an indoor service window, and an outdoor service window. Although these five scenes do not embody all possible queuing scenes, they include the features of other queuing scenes. The features of these five typical queuing scenes are itemized below.

- The ATM scene is among the commonest one-to-one service queuing scenes. Although individuals can jump the queue, ATM scenes are generally orderly and uncrowded.
- The subway scene is a special queuing scene that offers individuals many choices of subway doors. In the absence of special circumstances, individuals always seek the waiting area with the fewest number of gathered individuals.
- The bus scene is another common queuing scene. Unlike the ATM scene, queues for single cars are easily disordered in cities with large population densities.
- The final two scenes are similar: an indoor service window with fences and an outdoor service window without fences. The fence is the most common infrastructure in queuing scenes: as individuals cannot queue-jump by crossing the fence, it effectively prevents crowd confusion.

To improve the analysis, the various states of the agent were visualized in the three-dimensional development platform Unity 3D. The model was experimentally validated in the above four scenes. In the ATM and subway platform scenes, we compared the results of our model with those of the traditional emotional model. In the indoor and outdoor service window scenes, we compared our model results with observations of real scenes. We also performed a heat-map analysis of the experimental data.

After summarizing the existing crowd simulation models, this research analyzed the importance of the emotional infection model, and studied the emotional infection of crowd queuing events from a psychological and social computing viewpoint. Finally, it established and verified an emotional contagion model based on patience, urgency, friendliness, and other human factors in crowded situations. The main contributions of the research are as follows:

- To embody the effects of individual emotions on crowd queuing, this research borrowed concepts from the SIR model, and proposed emotional parameters that effectively represent individual personalities, such as patience, urgency, and friendliness.
- The weakening process of individual negative emotions in queuing events was calculated by a Hooke's law analogy. Based on this calculation, an emotional contagion model was established.
- Taking a variety of human queuing events (ATM, subway stations, bus stations, and indoor and outdoor service windows) as the simulation objects, a three-dimensional interactive simulation program of crowd queuing emotions was created in Unity 3D. In this simulation, the process of emotional contagion can be observed from different angles. By comparing and analyzing a large amount of experimental data, we found that regardless of the individuals' characters (positive or negative), negative emotions among the queuing individuals can confuse the queuing order if the individuals are waiting for a long time or have a high degree of urgency. In addition, the evolution of people's emotional infection relates not only to the queuing scene, the initial state, and the personality parameters, but also to the number of administrators and fences, the timing of the occurrence, and the location distribution of the administrators and fences. When the crowd contains a large number of agents with negative emotions, a large area of the crowd becomes infected. If the administrator is suitably located in advance, it can effectively control the crowd's emotional infection and maintain the queue.

Based on the study results, we propose increasing the role of administrators [5]. To collect the crowd movement parameters, we will also combine computer vision techniques with an efficient method for computing crowd aggregation in public areas [6]. Finally, we hope to control negative emotions by studying the number and distribution of administrators.

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Supporting information Videos and other supplemental documents. The supporting information is available online at info.scichina.com and link.springer.com. The supporting materials are published as submitted, without typesetting or editing. The responsibility for scientific accuracy and content remains entirely with the authors.

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