Simulating Crowd Behaviors with a Communication Model

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Abstract
Using computer to generate magnificent crowd animations has become a trend in film productions. Many of these animations were produced by modeling the intelligence of the agent in a crowd and its interactions with other nearby agents and the environment. However, the perceived facts or elicited emotions usually do not propagate in the crowd as they should be in the real life. In this work we attempt to use the theories in social psychology to design a communication model for crowd simulation based on heterogeneous agents and virtual forces. We have implemented such a system and will use several examples to demonstrate how different settings in the communication model affect the results of collective behaviors for virtual crowds.

Keywords: crowd simulation, communication model, collective behavior, agent-based simulation

1. Introduction
Crowd animations have been used to create astonishing visual effects in many film productions in recent years. Similar techniques can also be used for Non-Player Control in games, building and urban planning for evacuation, etc. However, most previous efforts focus on generating plausible crowd animations for applications targeting more on visual effects without considering how communication among the agents could affect the behaviors of a crowd. In fact, perception of the local environments is one type of visual communication that usually is modeled in agent-based simulation. However, how to model communication among the agents in a more general way is a critical issue for realistic simulation of collective behaviors for a virtual crowd. A good communication model can be used to generate a large variety of crowd behaviors including the course of crowd formation. A simulation system developed with this kind of model can also be used to study the prevention or control of certain social behaviors such as riots [3].

In this paper, we propose to use the theories in sociology and psychology to build the model of communications for creating a variety of crowd behaviors. We propose to build a crowd animation system that can simulate the social behaviors of heterogeneous agents under different communication settings. We will report our study on how temporal and spatial factors and individual differences affect the resulting collective behaviors. However, the modeling of internal mental states is not our current focus.

We will review the research pertaining to our work in the next section and survey related theories in social science as the foundation of our approach in Section 3. In Sections 4 and 5, we will propose the architecture of our simulation system and the design of our communication model. Then, we will report our experimental results with several examples in Section 6 and conclude our work with future research direction in the last section.
2. Related Work

Crowd simulation has been studies in the field of computer animation for many years [15][9][19]. Reynolds [15] proposed a flocking model with local rules that can generate realistic flocking behaviors for groups of virtual creatures called boids. Three types of virtual forces: separation, cohesion, and alignment, were used to create emergent crowd behaviors. Reynolds later extended this model to account for more local rules such as seek, flee, pursuit, wander, obstacle avoidance for the creation of steering behavior [14]. Tu and Terzopoulos [19] adopted similar techniques and a cognitive model to simulate schools of fishes with rich behaviors. Shao and Terzopoulos [16] extended the cognitive model in a hierarchical environmental modeling framework for the simulation of pedestrians in a train station.

Many recent researches also focused on how to simulate crowd behaviors in evacuation. For example, Helbing had proposed to use social forces to compute pedestrian dynamics [2]. In a panic situation, it was observed that people tend to form a fan shape in front of an exit [3]. Pelechno et al. [13] also used the social force model to simulate the escaping behavior. They used the attributes of leadership and training to define three roles played in an evacuation: trained personnel, leader, and follower. They also equipped an agent with a mental graph that can be used to exchange information with other agents. In [12], they used psychological and geometrical rules to create behaviors such as pushing, lining-up, and falling. When the panic mode is turned on for some agents, it was observed that the mode can propagate to the surrounding people through perceived increasing crowd density, which one type of visual communication.

3. Related Theory Survey in Social Sciences

The process of how people gather and interact with each other has been studied in psychology and sociology [1][18]. Gustave regarded a crowd as a group of people prone to accept suggestions from others via communication [6]. Ideology propagates through contagion. An individual may substitute his/her self-consciousness with group consciousness at certain situations. The formation of “casual crowd” usually is due to anonymity, contagion, and suggestibility. Although these propositions were made from observations, emotion contagion has been verified to some degree by modern psychologists and neuroscientists [1][7][11].

In 1978, Granovettee proposed a threshold model [3] to explain why similar crowds may behave differently. He regarded that there existed a threshold in every agent’s mind affecting the decision of taking a group action. This threshold depended on personality and how other agents behave. The perception of other agents’ behaviors via various ways of communications may have a domino effect on the crowd behavior when the tipping point is reached (above the threshold value). For example, consider a crowd of tens of agents. Suppose that the threshold values for the number of agents taking a protest action before an agent decides to take the same action is 0, 1, 2, 3, etc. Then a riot may be unavoidable because the domino effect starts after the agent of threshold zero starts to take the group action. In the above threshold model, it is usually assumed that the crowd does not move far and their spatial relations remain about the same all the time. However, this may not be true in the real life since people has mobility and motion will change the spatial relation and the perceived subset of the crowd. Agent-Based Modeling (ABM) with the virtual force model mentioned in the previous section can be used to describe and evolve the temporal and spatial relations among the agents and serve as a good tool for visualization and customization as described in the following section.

4. System Architecture Design

Our crowd simulation system consists of five levels of modules in a simulation loop (see Figure 1. System architecture).
Figure 1: physical, perception, primitive behavior, action selection, and communication.

In the physical module, every agent is treated a rigid body under physical constraints such as maximal linear and angular accelerations. These hard constraints are used to prevent the agents from exceeding physical limits. In the perception module, a fan-shape area centered at the agent is used to model the perception region (see Figure 2). Only the agents in this region are visible. We have used a grid-based partitioning algorithm to maintain the agents in nearby proximity in linear time.

In the primitive behavior module, we have implemented seven primitive behaviors: seek, flee, arrival, flocking, obstacle avoidance, wandering, and leading/following. These primitives are mutual exclusive except for flocking and obstacle avoidance which may be used together with other behaviors. In the action selection module, an action is selected based on the scenario and the type of consciousness taken. By using the flocking behavior, we are able to reproduce the emergent flocking behavior as reported in Reynolds’ work [15]. In addition, as shown in Figure 3, we have succeeded in reproducing the interesting phenomenon of Circular Mill that has been observed in the nature for animals like ants. However, in this case except for local perception no other communication means or group consciousness is assumed. For a scenario such as walking through a sequence of goals with casual points of interest, the action being selected should actually depend on whether the individual or group consciousness is activated. This will in turn depend on the underlying communication model as described in the next section.

5. Communication Model Design

The communication model we attempt to build is shown in Figure 4. We assume that there are three states for an agent in the process of emotion contagion: clean, latent, and infected. When exposed to a contagion environment where there exist infected agents in the view, a clean agent changes its state to latent. An agent that has been in the latent state for a period of time change its state to infected.

A threshold $\alpha_i$ is used to determine the latent time of an agent $a_i$ according to a parameter $\alpha$ of the infection source, and the individual rationality $\gamma_i$ of $a_i$. That is, $\alpha_i = \alpha \gamma_i$, where $\gamma_i$ is a real number in $[0, 1]$. A counter $c_i$ is updated according to the number of affected agents in the view, and a state change is issued when $c_i \geq \alpha_i$. $c_i$ is decremented when there is no infected agent in the view, and an infected agent may switch back to the latent state if $c_i$ is below $\alpha_i$.

An infected agent may not take an action under group consciousness. According to the threshold model described in the previous section, an agent takes the action under the group
consciousness only if the number of agents \( N_a \) taking the group action in the current perception region exceeds the threshold \( \sigma_i \) of the agent \( a_i \) under consideration. The taken action will last for some period of time \( \beta \) until the motivation of taking the action disappears (e.g. losing interest). In this case, the agent becomes immune to this specific stimulus. Another important parameter affecting the simulation result is the distribution of threshold \( \pi \) in a crowd. For the domino effect to appear, there must be some agents with low enough threshold to take a lead on forming the group consciousness. The study of these factors will be reported in the next section.

6. Experimental Results

We have implemented the proposed agent-based system for crowd simulation in Java. In Figure 5, we show an example of crowd performing seeking (a goal on the right), flocking, and obstacle avoidance. The produced simulation result can be exported to a script for further modification and rendering in animation packages such as Maya. An example of crowd animation generated with this mechanism is shown in Figure 6.

In Figure 7, we show an example of the fleeing behavior triggered when a mammoth is encountered. The mammoth is treated as a special agent with the ability to infect other agents. The information of the encounter is propagated in the crowd very quickly. All infected agents (in green) take the group consciousness of escaping from the source of danger and performing the fleeing behavior. In Figure 8, we show another example where a special agent is placed in the scene (as shown in second snapshot in Figure 8) to disseminate the information about the point of interest (the Olympic 2008 icon) at the lower right corner. An infected agent (yellow) propagates this information to other surrounding agents but the group action of approaching the point of interest is not taken until some early birds with a lower
threshold have taken a lead (and become green).

A main feature distinguishing our work from the previous simulation systems proposed in the literature is that the emergent collective behavior in a crowd occurs via a communication model with a foundation in the theories of social sciences. By varying the parameters in the communication model, we are able to produce a variety of crowd behaviors with different end results. We have also conducted experiments to study how the values of these communication parameters affect the simulation results. One example scene with four cases is shown in Figure 9. In all cases, fifty evenly distributed agents move toward one of the four goals located at the four corners of the virtual world. A special agent acting as the contagion source distributed information about the attraction at the center of the scene. We would like to see how this information is propagated in the crowd and how the agents change their behaviors according to the actions taken by nearby agents.

Four cases (Case 1 to Case 4) with different communication parameters considered in this paper are summarized in Table I. In Case 1, \((\alpha, \beta) = (1000, 2000)\) (unit: simulation step) and the threshold \(\sigma\) for the agents is uniformly distributed over \([0, 10]\). The simulation result is shown in Figure 9(a). Compared to other cases, the crowd in this case is prone to infection but also becomes immune more quickly. In Case 2 (shown in Figure 9(b)), \((\alpha, \beta) = (3000, 7500)\). A longer latent period \((\alpha)\) in this example results in a slower propagation speed and thus slower gathering. But the gathering phenomenon also lasts longer because of a larger \(\beta\). In Case 3 (shown in Figure 9(c)), the parameters are the same as in the second example except for that \(\beta\) is changed to a smaller value: 2000. Consequently, the gathering phenomenon does not last as long as in Case 2. The settings for the last example (Case 4, as shown in Figure 9(d)) are the same as Case 2 except for that the interval for threshold distribution becomes \([0, 5]\). As a result, the agents not only adopt the
group action much earlier and the gathering phenomenon is also much apparent.

If we take a look at the number of infected agents during the simulation for these four cases, we can see more clearly how the collective behaviors have evolved over time. In Figure 10 (a), we show the number of infected agents taking the group action (depicted in green in Figure 9). The gathering phenomenon resulting from taking the group action can be observed more easily in Case 2 and Case 4 than in Case 1 and Case 3. The speed of ascending for Case 4 is the most significant because of the lower threshold values. In Figure 10(b), we show the number of agents (depicted in yellow in Figure 9) who have been infected but have not decided to take the group action because the threshold is not reached. Case 1 has the steepest ascending and descending curves because of lower \( \alpha \) and \( \beta \). For Case 3, the number seems to remain at a constant level because the numbers of agents becoming infected and un-infected (latent or immune) are balanced. The crowd in Case 4 is the most impetuous because infected agents take the group action promptly because of the lower threshold and the domino effect.

7. Conclusions and Future Work

In this work, we have designed a communication model for the simulation of collective behaviors for virtual crowds. This simulation system is based on the classical motor-sensor and virtual force model to generate various kinds of behaviors such as flocking, goal seeking, collision avoidance, etc. A novel communication model is also proposed. We have done experiments to simulate how information can be propagated through contagion and how the threshold model affects the formation of a collective behavior. We believe that this kind of modeling can not only be used to produce a good variety of crowd behaviors, but it can also be used to study collective social behaviors such as preventing a riot from happening. We are working on this kind of example in order to shed some lights on how to use computer to facilitate the study of sociology.

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References