An Efficient Simulation of Massive Crowd with Navigation and Affordance Fields

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Abstract

In this paper, we propose a simulation method for massive crowd behavior. The movement of each agent is determined by scalar energy fields, and the fields are expressed as images in order to improve the computational efficiency. The energy fields in our method are composed of navigation fields and affordance fields. The navigation fields are applied to all agents, and each agent has its own affordance field. The image-based approach can exploit the GPU functionalities to manipulate the fields, and the affordance field model makes it possible to transform the collision handling problem into a simple navigation field generation. The image-based navigation field can resolve the collision without globally considering the relations between agents. The efficient collision handling enables the proposed method to simulate massively large amount of agents in real-time

Keywords : crowd simulation, navigation field.

1. Introduction

The simulation of crowd behavior is widely used not only in the entertainment contents such as cinema, animation and games but also in the analysis of social phenomena such as evacuation behavior and traffic simulation.

There are two major approaches to crowd simulation: multi-agent system and particle system. While the particle system expresses the overall behavior of crowd, the multi-agent system focuses on simulating the realistic behavior of each agent. However, the multi-agent system requires expensive cost in computing the interactions between agents such as collision so that it is impossible to simulate massively large crowd in real-time.

In order to overcome the limitation of the multi-agent system, we propose an efficient simulation method. In the proposed method, the interaction between agents is handled with energy field which can be efficiently expressed as an image. The image-based representation of the energy field makes it possible to efficiently detect and resolve the collision between agents and the computational cost can be significantly reduced.

2. PREVIOUS WORK

As graphics hardware has been rapidly advancing, more and more video games and films are employing the massively large crowd simulation [1]. In addition to the entertainment industry, the crowd simulation is also intensively studied in various research fields such as robotics, traffic engineering, and social science [2,3,4].

Agent model has been widely adopted in previous work [5]. In this model, autonomous agents recognize their state and dynamically respond to other agents. In order to improve the computational efficiency and accuracy, they proposed many approaches such as local collision avoidance, rule-based flocking, social force model, cellular automata model, and velocity-obstacle formulation method [6,7,8,9,10].

Those methods concentrated on the realistic representation of agents by controlling the detailed behavior of the agents. Therefore, it is difficult to simulate a large amount of agents in real-time environments. Moreover, in a massively crowded situation, those methods cannot effectively handle the excessively frequent collisions and the overall crowd behaviors are often unrealistic.

In order to improve the plausibility of the previous approaches, Patil italic proposed an interactive model which utilizes vector fields directly drawn by users or extracted from video data [11]. However, this method did not provide any efficient collision handling method so that it cannot be easily employed for real-time or efficient simulation of massive crowd. The discussed model is given as follow:

3. SYSTEM OVERVIEW

In the proposed method, agent behaviors are classified into two types: primitive steering behaviors and field-driven steering behaviors. The primitive behaviors are behaviors which do not require interactions with agents or objects. These include ‘arriving’, ‘avoidance’, and ‘wandering’ behaviors, and we employed Reynolds model proposed in [6]. The field-based steering behaviors are determined by two types of fields: navigation fields and affordance fields. The affordance fields are not directly used by agents, but they produce an additional navigation field that enables agents to efficiently and effectively avoid collisions among them.

In other words, the agents are driven by basic Reynolds model and steering force are determined by the navigation fields. These behaviors are combined to plausibly simulate the agents.

In the proposed method, the collision between agents can be easily handled only by considering the navigation field computed with affordance fields of agents. Therefore, collision handling in a massive crowd simulation can also be processed in a linear time complexity.

4. AFFORDANCE FIELD AND NAVIGATION FIELD

In this section, the definition and explanation of affordance field and navigation field are given. Those fields are the essential to the proposed method which simulates massive crowd based on virtual energy field model.

4.1 Affordance Field (AF)

The affordance of an agent, in this paper, is defined as the interactive influence of the agent. The affordance field, therefore, represents the possibility of the agent's interaction a certain location.

In the previous approaches, the fields are usually implicitly expressed with field functions which require expensive computation. In order to alleviate the computational cost, two-dimensional array data structures are employed to store the precomputed field values at sampled locations. However, the two-dimensional array also requires computational cost for interpolation as shown in Fig. 1. In the proposed method, we regard the affordance field as an image so that the interpolation in the sampled field data or the transformation of the field can be performed with hard-wired computation in GPU. The actual affordance field is visualize in Fig. 2.

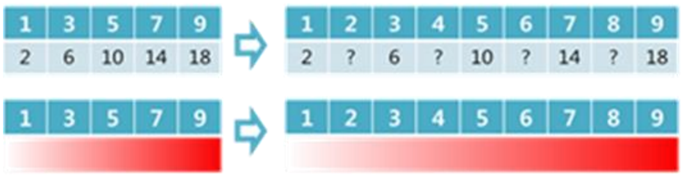


Fig. 1: Array Representation (upper) and Image Representation(lower) of Field

4.2 Navigation Field (NF)

The navigation field actually drives the agents. The agents in a navigation field are influenced with the steering force determined by the navigation field. The most common approach to the navigation field is to make it describe the energy level at each location and let the agents move along the gradient of the energy field. However, this approach cannot effectively or efficiently express the collision avoidance behavior. Therefore, in the previous methods, the collisions between agents have not been handled with this navigation field model, and been a major bottle-neck in massive crowd simulation.

In order to efficiently handle the collision, we exploited the affordance field explained in the previous subsection. The navigation field in our method successfully include the collision avoidance behavior by taking into account the intersection of the affordance fields of agents.

The collision avoidance with navigation field is efficient because it does not compare all the possible collision pairs of the agents. Moreover, the navigation field is also represented as an image so that GPU-based fast computation can be exploited.

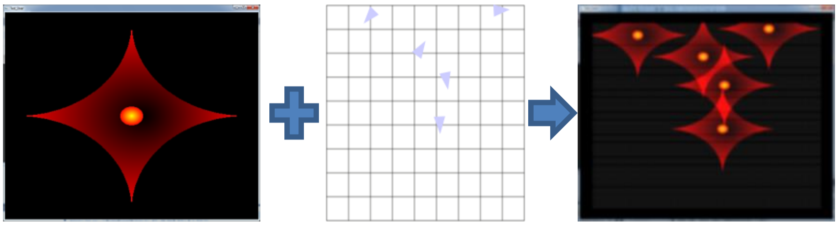


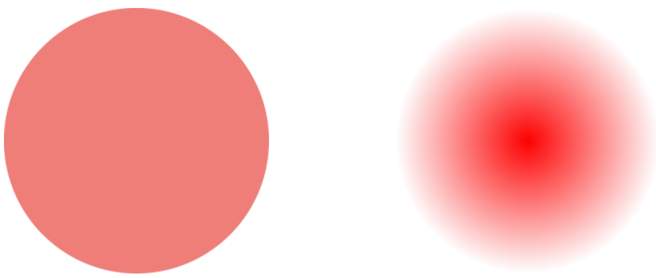
Fig. 2: Affordance Field Applied to Each Agent

5. COLLISION HANDLING

In this section, we describe our navigation field based collision handling approach. The brute-force handling of collisions in massive crowd simulation is the most important computational bottle-neck. The real-time or efficient simulation can be obtained only when the collisions are efficiently handled.

In this paper, we transform the steering forces that make agents avoid collisions between each other into energy values in the navigation field by considering the affordance of each agent. This approach makes it possible to reduce the computational complexity of collision handling from form $O(n^2)$ to $O(n)$.

The collision handling in this paper is composed of two phases: detection and avoidance. Therefore, we devised two affordance fields for detection and avoidance respectively as shown in Fig.3.

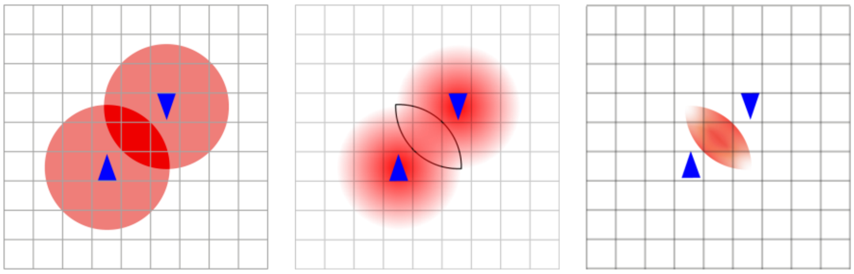


<a>Affordance for Detection <b>Affordance for Avoidance

Fig. 3: Affordance Fields for Collision Avoidance

The affordance field shown in Fig.3.(a) is used for collision detection, and has the identical scalar value within the affordance area. This field of each agent is accumulated on a navigation as shown in Fig.4.(a), and we can efficiently detect the intersection area of the accumulated field by extracting the region with values larger than the original affordance field.

The collision avoidance is driven with the affordance field shown in Fig.3.(b). We apply the fields to the navigation field as shown in Fig.4.(b) and remove the values outside the intersection detected in Fig.4.(a). Then we obtain the collision avoidance energy which can be incorporated into other navigation fields as shown in Fig.4.(c).



<a> <b> <c>

Fig. 4:Computation of Navigation Field with the AFs of Colliding Agents

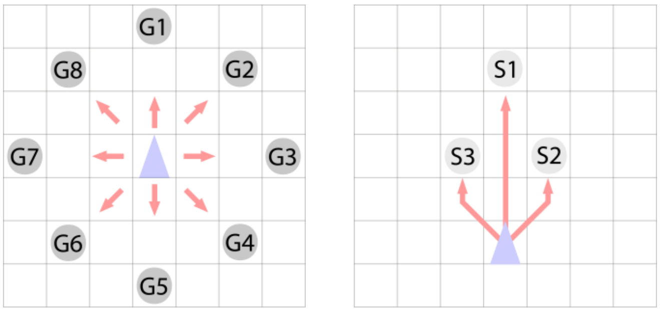
These operations are performed in GPU with image manipulation functions. Therefore, the collision avoidance energy field can be computed in linear time with respect to the number of agents, and the collision avoidance behavior of each agent can be directly computed (i.e., in time) only by considering the obtained navigation field for collision avoidance.

6. Field Sensors for Agents

The agents in our method move in accordance with the navigation field. Therefore, the agents must be able to acquire the current state of the navigation field. In the previous methods based on field model, each agent usually detected the current state of the field where the agent is located. However, this approach makes the agent a passive object which falls down along the energy gradient. This passive behavior does not plausibly represent the autonomous agent.

In order to enable an agent to intelligently interact with other agents and environments, we attached multiple sensors to an agent. There are two types of sensors: basic energy sensor and vision sensor as shown in Fig.5.(a) and (b) respectively.

The basic energy sensors detect the energy at their locations in the field and determine the steering force based on the energy gradient. We attached 8 basic sensors to an agent as shown in Fig.5.(a). The vision sensors are located in front of the agent in the moving direction. These sensors predict the energy state which the agent will encounter in the future. The distance between a vision sensor and the agent varies in accordance with the velocity of the agent in order to produce more plausible behaviors.



<a> Basic Sensors <b>Vision Sensor

Fig. 5 : Sensor for an Agent

7. EXPERIMENTS

We verified the proposed method with 20,000 agents in interactive crowd simulation environments. The agents were spawned at random locations and forced to rotate along the geometric center of the simulation area as shown in Fig. 6.

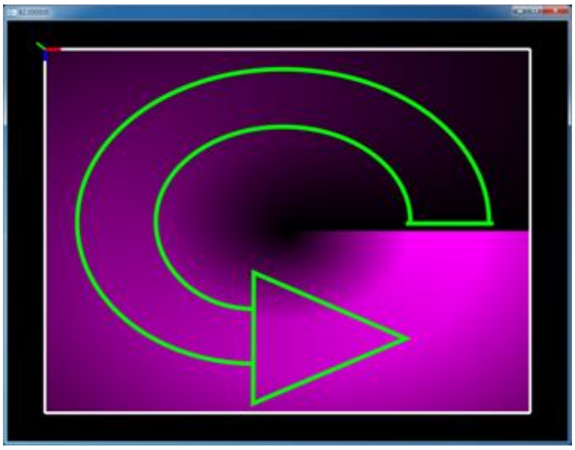


Fig. 6:Navigation Field for Global Mission of Agents

The proposed method could simulate the crowd with 10~12 frames per second which is significantly improved efficiency compared to previous methods. Moreover, the collision avoidance behavior of each agent was sufficiently plausible. Fig.7. shows the simulation results and the visualized crowd animation based on the simulation

The computational complexity of the simulation is dependent on the number of agents and the resolution of the navigation field image.

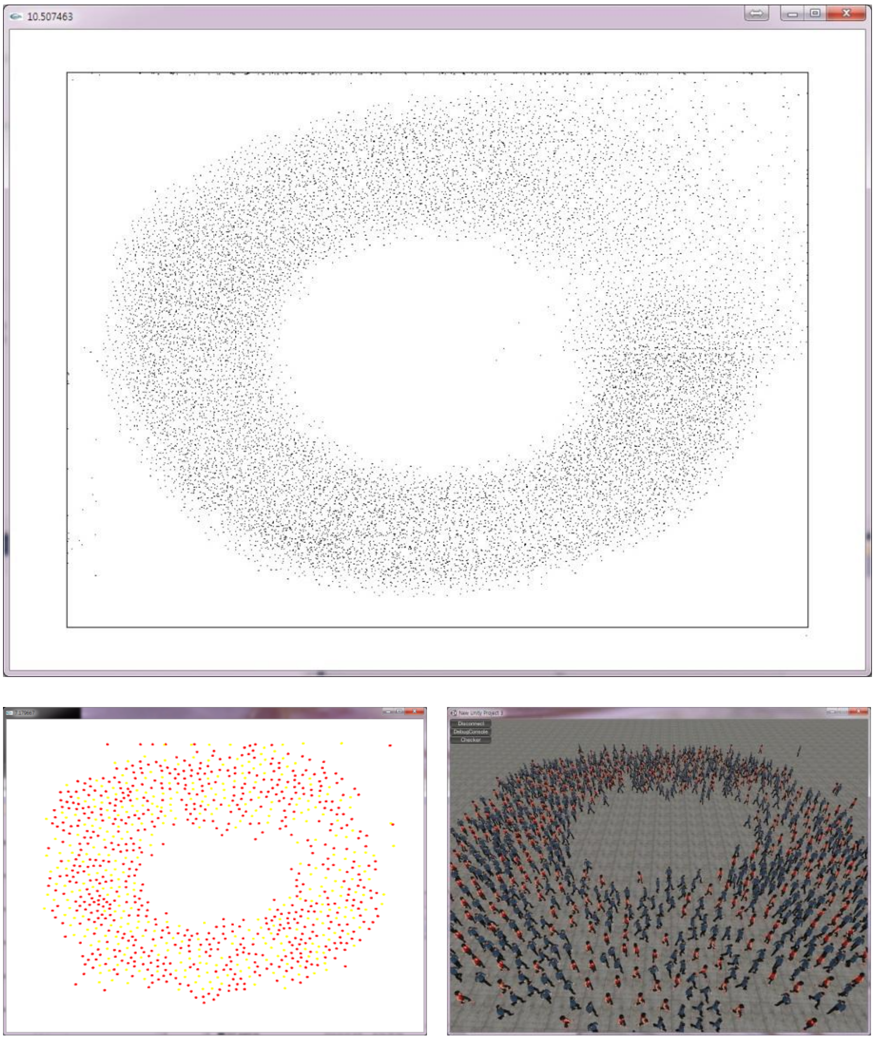


Fig. 7 : Crowd Simulation Results and Visualization System

8. CONCLUSION

In this paper, we proposed an efficient method for massive crowd simulation. The method employed affordance field and navigation field to reduce the computation cost for collision handing, and the fields are expressed as image data which can be rapidly manipulated with hard-wired computation of GPU.

The experimental results show the proposed method can plausibly and efficiently simulate the massive crowd by removing the pairwise detection and handling of agent collisions. The proposed method, therefore, can be successfully utilized in real-time or interactive systems for massive crowd simulation.

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