A Framework to Simulate the Evacuation of a Crowd in Emergency Situations

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***Abstract**:*
This paper describes a model for simulating crowds in real time. We deal with the hierarchy of the crowd, groups and individuals. The groups are the most complex structure that can be controlled in different degrees of autonomy. The autonomy means that the virtual agents are independent of the user intervention. Depending on the complexity of the simulation, some simple behaviors can be sufficient to simulate crowds. Otherwise, more complicated behaviors rules can be necessary in order to improve the realism of the animation. We present two different ways for controlling crowd behaviors: - by defining behavior rules, to give intelligence to the agent. By providing an external control to guide crowd behaviors, this control is done by the user or by an autonomous agent called the guide. The main contribution of our approach is to combine these two ways of behaviors (autonomous, guide) in order to simulate the evacuation of a crowd in emergency situations. Many strategies of evacuation have been implemented and we will demonstrate that in most situations, the guided method decrease the average escape time and increase the chance of survival in emergency situation.

***Keywords**: Crowd model- behavioural animation- autonomous agent- evacuation simulation.*

1 INTRODUCTION

Crowd and group simulations are becoming increasingly important in the entertainment industry and in emergency simulation. They can be used to simulate the presence of real humans. Such technology can be used in situations where it is dangerous for real people to perform the actions. Recent research into crowd simulation has to large extent been inspired by the flocking work of Craig Reynolds (Reynolds,1987; Reynolds, 1999). A key element of this type of animation is the collision avoidance.

Many works have been done but, more recently, Musse and Thalmann presented a hierarchical model to describe crowds with different levels of control: from guided to autonomous ones (Musse, 2001). The behavior of crowds is based on rules dealing with the information contained in the groups of individuals. In their ViCrowd system, they can create a virtual crowd, when the individuals have variable levels of autonomy.

Computer models for emergency and evacuation situations have been developed and most research into panics has been of empirical nature and carried out by social psychologists and others (Helbing, 2000). An evacuation simulation is a good example of social simulation. Social interaction is extremely common and strongly influences the responses seen in real word evacuations. For example, if the evacuees hear someone scream, they tend to avoid that area.

As a first step to addressing the problem of simulating evacuation situations that include social interaction, Yohei Murakami et al (Murakami,2003) simulated the controlled experiments conducted by Ashida (Ashida,2001). He established a simple environment with human subjects to determine the effectiveness of two evacuation methods: the “follow-direction method “and the “follow-me method “. In the former, the leader shouts out evacuation instructions to the evacuees, in the latter, the leader tells a few of the nearest evacuees to follow him.

The goal of this paper is to present a model for studying the simulation of crowds with different types of control: autonomous (rules-based behaviours), guided (interactive control) and we try to combine these two types of control in order to simulate the evacuation of an crowd of people in complex environment, for example, a large and open building such as a supermarket and others. The starting point of our discussion is the ViCrowd proposed by Musse et al (Musse, 2001; Musse, 2003).

2 RELATED WORKS

2.1 behavioural animation

Many works have presented different ways for controlling the virtual humans in order to improve their ability to evolve in an autonomous way. Several authors agree with the concept of autonomous or “intelligent” agent requirements: autonomous behaviour, action, perception, memory, reasoning, learning and self controls (Ferreira, 2002). Also several methods have been developed in order to model autonomous agents: L-systems, vision systems; rule-based systems; learning methods, evolution, etc. Guided or programmed agents can also be useful depending on the application. Becheiraz (Becheiraz, 1998) presented a model of emotion to represent the behaviour of autonomous agents, Ashida (Ashide, 2001) created behaviours through statistical analysis of observation data. Recently, some behavioural systems using classifier systems (Sanza, 2001) and Petri nets are presented in order to provide autonomous behaviours to virtual agents.

Tu et al (Tu, 1994) used flocking systems to model complex group behaviours existent in aquatic ecosystems. Fishes are able to learn how to control their actuators in order to move in a natural fashion, how to be guided by their sensory perception, etc,. Brogan et al (Brogan, 1997; Brogan, 1998) and Bouvier (Bouvier, 1997) have also presented groups and crowd has been introduced using different abstractions of behaviours, like the term guided crowd defined by Musse (Musse, 1999).

2.2 Crowd animation and simulation

Some works have been discussed in the bibliography in order to simulate virtual crowds (Musse,2001). The first work in this area has been done by Reynolds (Reynolds,1987), that he described a distributed behaviour model for simulating *flocks of birds* formed by actors endowed with perception skills. In fact, the birds (or ‘boids’) maintain proper position and orientation within the flock by balancing their desire to avoid collisions with neighbors, to match the velocity of neighbors and to move towards the centre of the flock. Reynolds’s work shows very realistic animation of groups, created by applying simple local rules within the flock structure.

Mataric (Mataric,1994) described emergent behaviours of 20 mobile robots, which demonstrates group safe wandering, following, aggregation, dispersion, flocking and foraging. Some complex behaviours as flocking were generated by combining simple behaviours like aggregation and following for example. Yet, heterogeneous behaviours are investigated to provide a group hierarchy where robots can act differently.

Bouvier (Bouvier,1997) used particle systems adapted for studying crowd movements where human beings are modeled as an interacting set of particles. Yet, the motion of people is based on Newtonian forces as well as the human goals and decisions. They introduced the concept of “decision charges” and “decision fields” modeled using notions of electric charges in the sense that a particle with an electric charge will be influenced by an electric field in the same way as a person with a decision charge.

Brogan and Hodgins (Brogan,1997; Brogan,1989) have used dynamics for modeling the motion of groups with significant physics. They reproduce movements of legged robots, bicycle riders and point-mass systems based on dynamics, considering an algorithm to determine the desired position for each individual given the locations and velocities of the visible creatures and obstacles. Indeed, a perception model to determine creatures and obstacles visible to each individual in the group precedes the displacement algorithm.

Another interesting work has presented some efforts to simulate crowds of ants in an automatic way (AntZ,1998). The Crowd Simulator System is used to produce motion for up to thousands of characters, taking into consideration a combination of physical forces (flow fluids, obstacles, goals, etc) and procedural rules (flocking behaviours and finite-state machine).

SIMULEX (Thompson,2003) developed by Thompson and Marchant described two dimensional software aimed at modeling the evacuation of a large building population. The goal of SIMULEX was modeling the escape movement of each individual occupant through a building, where the walking speed of each person is assessed independently of the average density of the group in a defined area of a building.

The group of Thalmann (Musse,1999) has developed a crowd system called ViCrowd. ViCrowd presented a model to automatically generate human crowds based on groups, instead individuals. The groups are more *intelligent* structures, while individuals follow the *groups* specification. ViCrowd is based on local rules applied to the groups, similar to flocking systems but where the groups are not a rigid structure being possibly changed during simulation. Also, a definition of behavioural rules using conditional events and reactions is included to provide more autonomous crowds.

The simulation of human crowds of populating virtual words provides a more realistic sense of virtual group presence. There are several approaches for modeling autonomous crowds (Bouvier,1997; Brogan,1997; Reynolds,1999; Tu,1994). In some virtual environments, it would be useful to simulate populations in an autonomous way, thus the agents have a kind of knowledge and are able to move and interact within this environment. However, depending on the application, more ways of interaction can be required in order to provide a real time communication between participants and virtual agents. (Musse,1999) has defined three levels of autonomy: (Autonomous crowd, Guided crowd, Programmed crowd**)**

These three levels of autonomy are represented using two kinds of interface: scripted or guided interface. Scripted interface uses a script language where action, motion and behavioural rules are defined in order to specify the crowd behaviours. While action and motion describe explicit behaviours of crowd, called programmed crowd, the behavioural rules are used to define autonomous crowd. All these information can also be sent by an external process in order to guide crowds explicitly, during the simulation. They called this type of crowd as guided crowd.

Wei Shao and Terzopoulos (Wei,2005) have addressed the difficult open problem of emulating the rich complexity of real pedestrians in urban environments. Their artificial life approach integrates motor, perceptual, behavioral, and cognitive components within a model of pedestrians as individuals. Their comprehensive model features innovations in these components, as well as in their combination, yielding results of unprecedented fidelity and complexity for fully autonomous multi-human simulation in a large urban environment. They represent the environment using hierarchical data structures, which efficiently support the perceptual queries of the autonomous pedestrians that drive their behavioral responses and sustain their ability to plan their actions on local and global scales.

3 PANIC RESEARCH

The movement of large numbers of people is important in many situations, such as the evacuation of a building in an emergency. In large crowds there is a risk of injury, and even loss of life, owing to the enormous forces that can be exerted on a single individual by the surrounding throng.

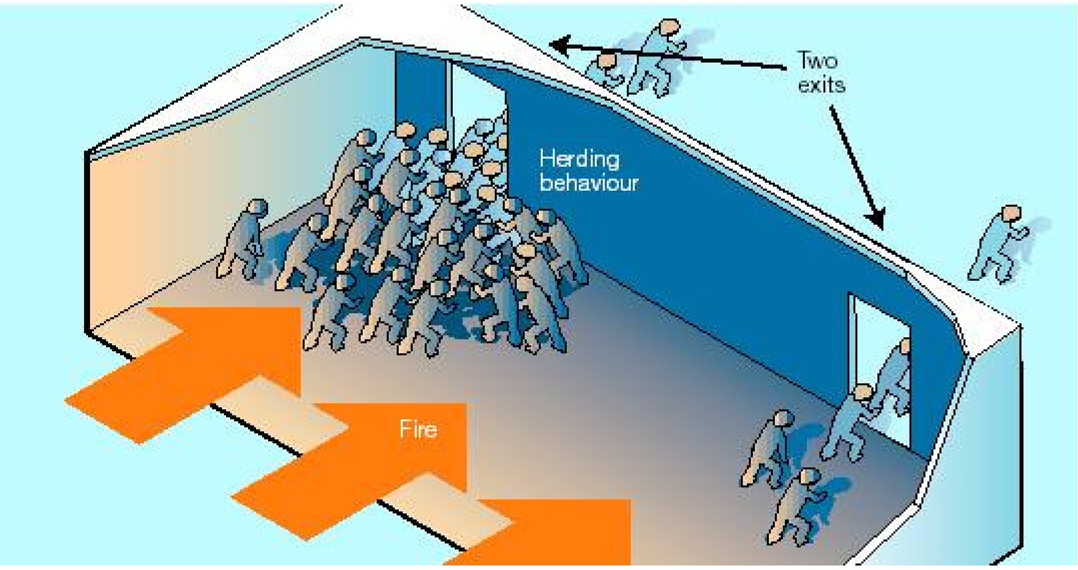


Figure 1 (Helbing,2000)

The figure 1 shows how crowd behaviour affects escape from a smoke-filled room. Previous simulations of pedestrian behaviour in crowds have used a model based on fluid flow through pipes, but these ignored the actions of individuals. According to the individual centred model of Helbing *et al.*, the evacuation of pedestrians from a smoke-filled room with two exits can lead to herding behaviour and clogging at one of the exits. By contrast, a traditional fluid-flow model would predict the efficient use of both exits. A more individual-centred approach is required to reproduce the behaviour of real crowds.
Helbing (Helbing,2000) proposed a model based on physics and socio-psychological forces in order to describe the human crowd behavior in panic situations This model generates realistic phenomena, as arcs formation in the exit and the increasing evacuation time with increasing desired velocity. Helbing (Helbing,2001) in his investigation on pedestrian motion for several years, has divided the movement on two types, normal and panic situations

3.1 Normal situations

- Pedestrians feel a strong aversion to taking detours or moving opposite to the desired walking direction, even if the direct way is crowded. However, there is also some evidence that pedestrians normally choose the fastest route to their next destination, but not the shortest one. In general, pedestrians take into account detours as well as the comfort of walking, thereby minimizing the effort to reach their destination.
- Pedestrians prefer to walk with an individual desired speed, which corresponds to the most comfortable (i.e. least energy-consuming) walking speed as long as it is not necessary to go faster in order to reach the destination in time.
- Pedestrians keep a certain distance to other pedestrians and borders (of streets, walls, and obstacles). This distance is smaller the more a pedestrian is in a hurry, and it decreases with growing pedestrian density.

3.2 Panic situations

Panic is one of the few natural catastrophes caused by humans; by natural we mean that it is not deliberate. Collective hysteria may be set off by other disasters like fires, earthquakes. At times it is prompted in less drastic scenarios such as concerts, religious gatherings, or sporting events, though with equally shocking consequences. Documentation exists since a long time and as recent as this year, proving and reminding us that we are still victims of this dilemma. Some characteristics of panic, according to Helbing et al.(Hebing,2001) are the following:

- People try to move considerably faster than normal.
- Individuals start pushing, and interactions among people become physical.

- Moving, in particular passing thru a bottleneck, becomes uncoordinated.
- At exits, arching and clogging are observed. Jams build up.
- Escape is further slowed by fallen or injured people acting as obstacles.
- People show a tendency towards mass behavior.

4 OUR CROWD MODEL

We defined our crowd as a set of groups composed each one of individuals. In normal situation, our model distributes the crowd behaviors to the groups and then to the individuals. In panic situation, and depending on the evacuation method chosen, the concept of group is lost. The priority is done to the basic behavior of the individuals. Each Individual has a repertoire of basic behaviors. Examples of basic behaviors: collision avoidance, obstacle avoidance, goal seeking, etc…as in (Reynolds,1999)

4.1 Crowd information

We deal with three categories of information in order to characterize the crowd

- **Crowd obstacles**: The first type of obstacles to be avoided by the crowd is defined as simple objects (cylinders or cubes). The user can choose the number, the position of the obstacle and can modify their size. The second types are the walls.
- **Crowd exits**: The second information needed for the crowd is the number, the size and the positions of the exits. We defined in our system two types of exits
    - **Blocked exits**: the exit is visible to crowd but is closed.
    - **Open exits**: the exit is visible and open.
- **The individuals (agents**): The crowd is a set of groups and each group is formed by a number of individuals. In normal situation the agents of the same group walk together. The user of the system can modify the environment by initializing:
    - The number of groups
    - The number of individuals in each group
    - The position of each individual
    - The initial speed of each group

4.2 Crowd movement

The individuals of the crowd moved in free-way or free-walk-way. The space is limited by the walls. In real life, less than a half of pedestrians walk alone, most people walk by two. To simulate a realistic environment, it is necessary to implement a group behaviour. Reynolds in his fames article invented the well-known boids. Boids abide by a flocking rule that is simulated using the three separation, cohesion and the alignment basic steering behaviours. The result of the combination of these three laws was very good to model flocks, herds or schools but not ordinary humans.

High level behaviors are specified in order to characterize the crowds. These behaviors can be programmed or directly informed using guided control by the user. In our model we have used the above list of group behaviors:

- **Flocking:** The agents from the same group walk together at the same speed towards the same goals in normal situation.
- **Following:** The individuals of the same group follow the leader of their group
- **Goal changing:** in panic situation, the individuals change their initial goal to the appropriate (goal) exit.
- **Attraction:** groups of individuals are attracted around an attraction point in normal situation and are attracted around an exit in panic situation

- **Avoid static obstacles:** We have used a very simple method of obstacles avoiding using mathematical equations to determine the future position from the current one; in this case, we are able to detect a possible obstacle event. Before arriving to the obstacle, we change the direction of the agent depending of the distance between the line between the current position and the goal position and the outside limit of the obstacle (including volume) and we try to avoid the collision by going around the obstacle.
- **Collision avoiding:** collision avoiding is one of the most important and most commonly performed behaviors in all human being and animals. Once the agent perception system detects a potential collision it immediately acts to avoid it by altering the direction and the speed. Collision between agents cannot always be avoided. We have treated two main situations of collision avoiding:

We have developed six key reactive behaviour routines, each suitable for a different set of situations in a dynamic environment. The agent processes a set of motor skills ,such as standing still, moving forward, turning in several directions, speeding up and slowing down, The problem is how best activate the six reactive behaviour routines. Since the situation encountered by an agent is always some combination of the six key situations that are covered by the six routines, we have chosen to activate them in a sequential manner. We have given a permutation ordering for these routines.

When a group of individuals forms a queue at an exit, the ones who are closer to the exit get higher priority in the queue. In consequences the individuals form a clogging at that exit.

5 EVACUATION SIMULATION

An evacuation simulation is a good example of social simulation. Social interaction is extremely common and strongly influences the responses seen in real word evacuations. For example, if the evacuees hear someone scream or se a danger, they tend to avoid that area. The absence of evacuation leaders is observed in traditional simulators, so we all know of several key situations in with some level of leadership anticipated to be provided by the police, security guards etc…, This issue interesting since it is a subset of the social interaction, because of its importance to have a realistic simulation, we have included in our system the notion of the guide.

In order to have a global view of the evacuation simulation we have decided to use three strategies of evacuation for each kind of behavior (individual or group), so we have six in total: The nearest exit, the less encumbered exit and the guided.

5.1 The less encumbered exit

The evacuees percept the visible exits and choose the exit which not crowded at this moment. This exit will be the goal of this evacuee. He has no idea of the status of the exit where is blocked or no. So he may choose the wrong exit for many times and in this case he wasted time. The first one who finds the wrong exit, inform the others and at this moment they choose another exit and modify theirs paths.

5.2 The nearest exit

They used the same strategy of the less encumbered; only they choose the nearest exit.

5.3 The guided

The choice of the exit is done by the guide, it could be an autonomous agent that has a global view of the environment, and this guide can direct all the individuals of the scene or all the groups. He knows the status of the exits and can combine the last two strategies discussed before. The guide knows the perfect knowledge of the word.

The architecture of the system is described in figure 2.

- The first step of our system is the modelisation of the environment, and then the user can activate the normal situation of the crowd. The individuals or the groups of the crowd walk

in random manner using the behaviors of the crowd movement until a panic event arrived from the user.
- The second step occurs when a panic event arrived. In this case the user will choose one of the six evacuation strategies and calculate the evacuation time.

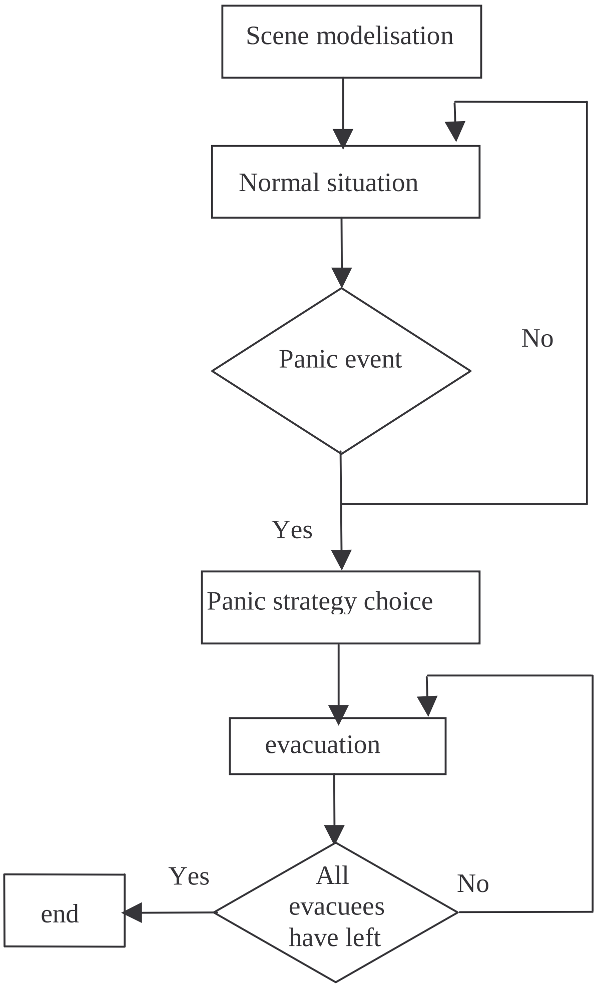


Figure 2: system architecture

6 RESULTS ANALYSIS

Our System is a prototype to simulate the evacuation of a crowd in an open environment like supermarket. It is a three dimensional software as described in figure 4. Our simulation runs on a 2.66 GHZ Intel Pentium PC and implemented in C++ Builder 6 with OPENGL library.

Before starting the evacuation of the crowd, the system saves the environment in order to be compared for each strategy.

We have to fix the different parameters:

- The number, size, position of the obstacle
- The number, size, position and status of the exits
- The number of groups and the number of individuals in each group of the crowd

Change the strategy of evacuation and then comparing the evacuation time of the crowd. All the parameters listed below affect the evacuation time but we emphasis on some of them, like the number of individuals, the number and the status of the exits. The significance of this evacuation simulation is described as below. To have an idea of the evacuation time (seconds), we have given two simulations and we can compare between the methods

Simulation 1:

5 groups of 6 individuals each one
2 obstacles
3 exits were one is blocked

individuals	groups	
28	16	The nearest exit
19	32	The less encumbered exit
14	23	The guided

Simulation 2:

4 groups of 9 individuals each one
1 obstacle
2 exits were one is blocked

individuals	groups	
25	43	The nearest exit
28	26	The less encumbered exit
20	32	The guided

For one exit in the environment, there is no difference in evacuation time between the strategies. This model generates realistic phenomena, as arcs formation in the exit. It is similar to Helbing (Helbing, 2001).

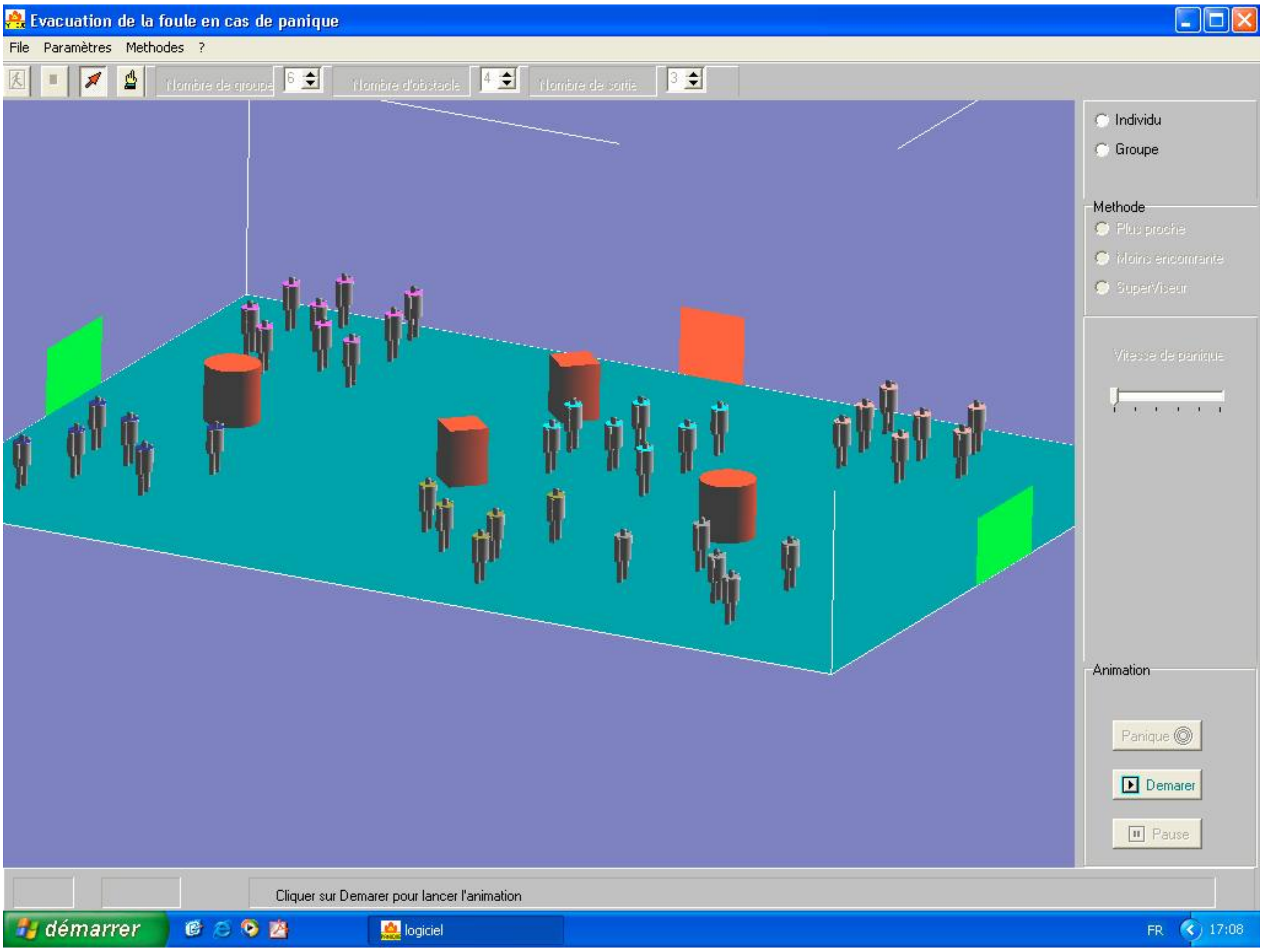
In the event of panic, the concept of group increases the time of evacuation. The individuals of the same group should go to the same exit. This problem is resolved by using the individual methods.

The evacuation time of the less encumbered exit is variable because at the beginning an exit is less encumbered and after a certain time this exit becomes too encumbered. This method becomes advantageous if we prevent the concept of anticipation in the movement of individuals.

In every method of our system the density of the crowd affects too much the time of evacuation.

The blocked exit causes problems in the treatment of collision avoidance. A group or a whole of individuals is spirit of going towards a blocked exit on the other hand, a second group or another whole of individuals is spirit to return from this exit.

For many exits, the majority of simulations, the guided method give better results than the others. The guide has a total sight of the environment (free exits, blocked exits, less encumbered exit or closest one). It is a combination of the two other methods.



Nombre de groupe 6
Nombre d'obstacle 4
Nombre de sortie 3

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Figure 3: The two green exits are visible and open, the red exit is visible and blocked. We have 5 groups and 4 obstacles.

7 CONCLUSIONS AND FUTURE WORKS

We have described in this paper a model to simulate the movement of crowds in real time. Two situations were implemented, normal and panic or emergency situations. A novel idea of this paper is to present the possibility of simulating various levels of realism including individuals and group behaviors. For each level, we have implemented several strategies of evacuations (the less encumbered exit, the nearest exit, and the guided). For many simulations and environments, the guided method decrease the average escape time and increase the chance of survival in emergency situation. Comparing the group-based method with the individual approach, we believe that in panic situation the sense of group behaviors increase the evacuation time.

We are currently investigating the sociological behaviors of the individuals in these situations, and we are trying to improve the behaviors of collision avoiding especially when two groups are walking in opposite ways. We are trying to find the perfect combination of the six reactive routines discussed in the implementation.

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