A Model of Human Crowd Behavior: Group Inter-Relationship and Collision Detection Analysis*

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This paper presents a model of crowd behavior to simulate the motion of a generic population in a specific environment. The individual parameters are created by a distributed random behavioral model which is determined by few parameters. This paper explores an approach based on the relationship between the autonomous virtual humans of a crowd and the emergent behavior originated from it. We have used some concepts from sociology to represent some specific behaviors and represent the visual output. We applied our model in two applications: a graphic called sociogram that visualizes our population during the simulation, and a simple visit to a museum. In addition, we discuss some aspects about human crowd collision.

1 Introduction

There are very few studies on crowd modeling. We may mention the following related papers: *C. Reynolds* [1] developed a model for simulating a school of fish and a flock of birds using a particle systems method [2]; *D. Terzopoulos* [3] developed a model for behavioral animation of fish groups based on the repertoire of behaviors which are dependent on their perception of the environment; *S. Velastin* [4] worked on the characterization of crowd behavior in confined areas such as railway-stations and shopping malls using image processing for the measure of the crowd motion; *T. Calvert* [5] developed the blackboard architecture that allows the animator to work cooperatively with a family of knowledge based tools; *E. Bouvier* [6] presented a crowd simulation in immersive space management and a new approach of particle systems as a generic model for simulations of dynamic systems [7].

In this paper we present a new approach of crowd behavior considering the relationship between groups of individuals and the emergent behavior originated from it (i.e. the global effect generated by local rules). We treat the individuals as autonomous virtual humans that react in presence of other individuals and change their own parameters accordingly. In addition we describe a multiresolution collision method specific for the crowd modeling.

This paper is structured as follows. In section 2, we present some sociological concepts of crowd modeling which were used in our application. In section 3, we present information concerning the model : individual and group parameters, distributed group behavior and implemented sociological effects. In section 4 we present the scenarios where we have applied our model. In section 5, we describe our collision avoidance methods and we present some results and analysis of this problem in the context of crowd simulation. In section 6 we present the applied methodology. Finally, section 7 draws some conclusions about the model.

2 Some Sociological Aspects

An accepted definition of crowd is that of a large group of individuals in the same physical environment, sharing a common goal (e.g. people going to a rock show or a football match). The individuals in a crowd may act in a different way than when they are alone or in a small group [12].

Although sociologists are often interested in crowd effects arising from social conflicts or social problems [11,13], the normal behavior of a crowd can also be studied when no changes are expected.

There are, however, some other group effects relevant to our work which are worth mentioning. *Polarization* occurs within a crowd when two or more groups adopt divergent attitudes, opinions or behavior and they may argue or fight even if they do not know each other. In some situations the crowd or a group within it may seek an adversary [10]. The *sharing* effect is the result of influences by the acts of

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others at the individual level. *Adding* is the name given to the same effect when applied to the group. *Domination* happens when one or more leaders in a crowd influence the others.

Our goal is to simulate the behavior of a collection of groups of autonomous virtual humans in a crowd. Each group has its general behavior specified by the user, but the individual behaviors are created by a random process through the group behavior. This means that there is a trend shared by all individuals in the same group because they have a pre specified general behavior.

3 Our Human Crowd Model

This model presents a simple method for describing the crowd behavior through the group inter-relationships. Virtual actors only react in the presence of others, e.g., they meet another virtual human, evaluate their own emotional parameters with those of the other one and, if they are similar, they may walk together. As it is recognized that the model is limited in describing human relationships, only a set of criteria were defined based on the available literature.

The group parameters are specified by defining the goals (specific positions which each group must reach), number of autonomous virtual humans in the group and the level of dominance from each group. This is followed by the creation of virtual humans based on the groups' behavior information. The individual parameters are: a list of goals and individual interests for these goals (originated from the group goals), an emotional status (randomic number), the level of relationship with the other groups (based on the emotional status of the agents from a same group) and the level of dominance (which follows the group trend). As could be seen, some virtual human’s parameters are totally random while others parameters follow the group trend.

All the individual parameters can be changed depending on their relations with the others. Therefore, we have defined:
i) A a virtual human from the group GA and
ii) B a virtual human from the group GB.

The agents A and B have the following parameters when they are created in the initial population :
- Agent.List_of_goals = Group.List_of_goals
- Agent.List_of_interests= Group.List_of_interests
- Agent.Emotional_status= random([0;1])
- Agent.Relation_with_each_other_group *is defined by the mean emotional status value of all virtual humans from this group*
- Agent.Domination_value = Group.Domination_value

Based on these parameters, we created some situations in which the individual parameters can be changed during the simulation:

i) The virtual human A can be changed from group GA to group GB if,

i.1) *Relation* (A,GA) < *Relation* (A,GB): *if the relationship between* A *and* GA *is smaller than between* A *and* GB.

i.2) *Relation* (A,GB) > 0.90*: if* A *has a high value in relation to the group* GB.

In this case, some parameters of virtual human A change according to:

- A.List_of_goals = GB.List_of_goals

If A.Domination_value > *all_agents.*Domination_value from GB, *if the domination value of* A *is greater than all autonomous virtual humans from group* GB, then A *will be the new leader of group* GB *and the other virtual humans from this group will have a new tendency to follow it. This represents the changes of group parameters consequent to individual changes.*

- A.List_of_interests = random(each_goal)GB, *meaning that the list of interests for each goal of* A *is generated by a random process.*

Else

- A.List_of_interests = (List_of_interests) from_most_leader_ag from GB, *that means* A *is influenced by the leader of group* GB *and*
- A.Domination_value *is decreased.*

ii) The emotional status can be changed in the encounter of two autonomous virtual humans in a random process. Only when both have a high value for the domination parameter, one virtual human is chosen in a randomic way to reduce its emotional status. In this case a polarization between two leaders will follow. In any other case, both virtual humans must assume the highest emotional status between them.

iii) The relation of A with group GB is defined by the mean state emotional value of all GB virtual humans which have greater emotion status value than A. This value must be normalized (between 0. and 1.).

$$R(\underline{A},\underline{GB}) = \text{Normalized\_value} \sum_{\substack{N\_AGENTS \\ FROM\_GB}}^{i=0} (\text{state\_emotional})ag_i > (\text{state\_emotional})agA$$

The sociological effects modeled in the presented rules are:

- *grouping* of individuals depending on their inter-relationships and the *domination* effect;
- *polarization* and the *sharing* effects as the influence of the emotional status and domination parameters; and finally,
- *adding* in the relationship between autonomous virtual humans and groups.

The group behavior is formed by two behaviors: *seek goal*, that is the ability of each group to follow the direction of motion specified in its goals, e.g. in the case of a visit to a museum, the agents walk in the sense of its goals (the work-of-arts); and the *flocking* (ability to walk together), has been considered as a consequence of the group movement based on the specific goals (list_of_goals) during a specific time (list_of_interests). For example, if the user chooses to have flocking in the crowd, the agents from the same group change of goal just when all the agents from this group have arrived at a same point. Thus, if one group *g* must go to goal number 2 (from the list of goals), all the agents from the group *g* must arrive before at goal number 1 (also from the list of goals).

The individual behavior is composed of three simpler behaviors. A walk, a collision avoidance (section 5) and a relationship behavior which occurs when the agents meet each other.

4 The Implemented Scenarios

We have applied our model in two situations. The first is a sociogram which means a sociological graphic representing one population, its relationships, and the different levels of domination. Figure 1 shows an example of a sociogram.

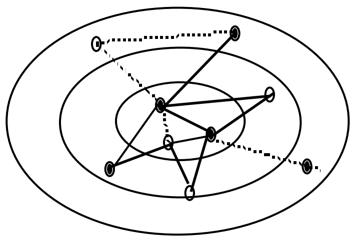


Fig. 1. A sociogram

The filled circles represent the women and the empty circles the men. The dashed line represents a relationship of hostility and the full lines represent a friendly relation. In addition, this graphic represents a certain hierarchy in the group, as the individuals in the center of the sociogram have more relationships as compared to the others in the external circles [10].

In our case, we have four groups with different behaviors and parameters (does not include the gender parameter). The autonomous virtual humans walk on the limit of the circles, like in the sociogram and these circles are delimited by points which represent the goals for each group, as we can see in the next figure.

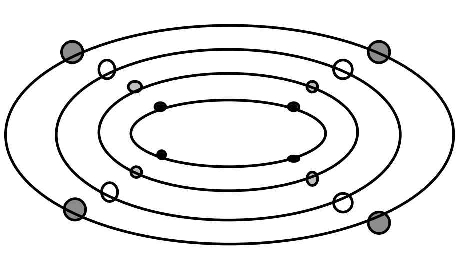


Fig. 2. The sociogram in our case

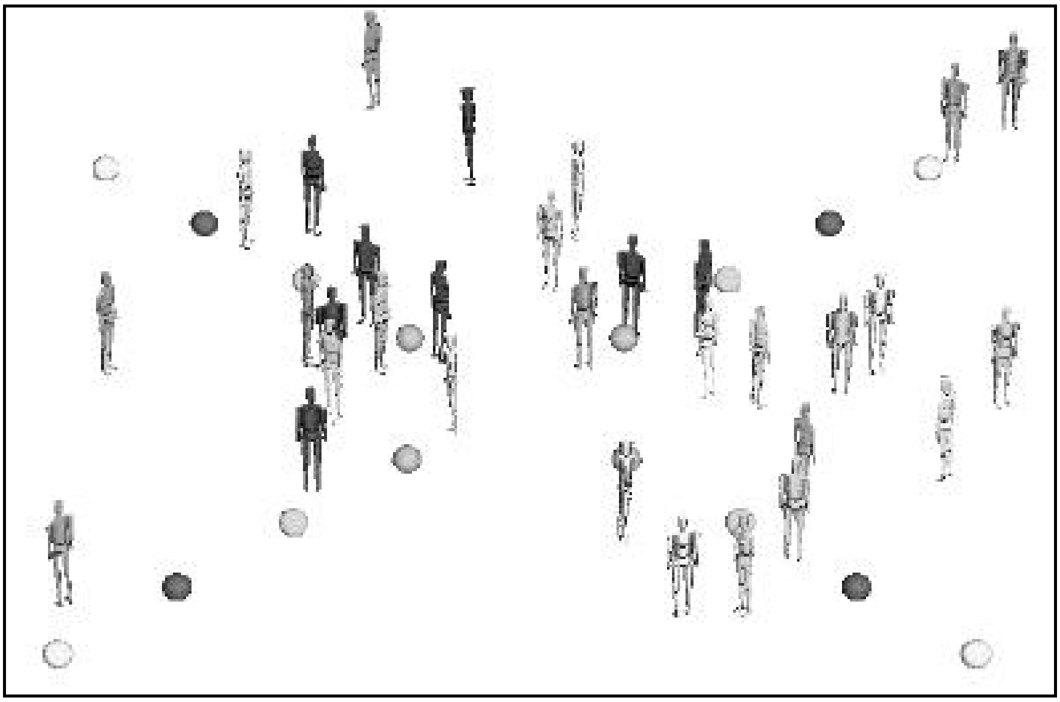


Fig. 3. Initial population in sociogram

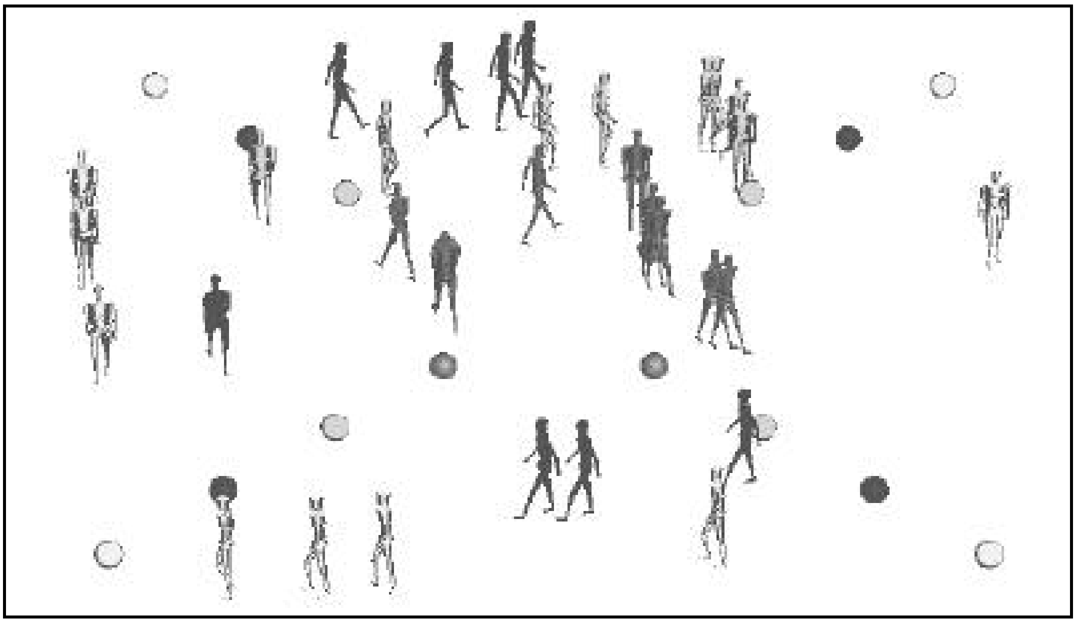


Fig. 4. Formed groups in sociogram

The virtual humans walk in the direction of their goals. Each group has one different color allowing to show when the virtual humans change groups. Figure 3, we can see the start of the simulation where all autonomous virtual humans are in the initial (randomized assigned) positions. In Figure 4, the virtual humans walk within the limits of their group in the sociogram.

Using the parameters specified in section 3, we have modeled a sociogram including time information which allow us to see changes in crowd behavior during the simulation. In this example, the flocking behavior is represented by walking in a specific region of each group (each circle).

The second example is a crowd which visits a museum. In this simple example, the crowd is formed by different groups. In the beginning of the simulation all virtual humans of the same group visit the museum within the time of their group including, for example, the time to see a specific work of art. However, during the simulation, we can observe agents which change groups and assume the time of those from their new group to visit and walk. In this case, we consider that the virtual humans change groups as a result of both individual and group relationships.

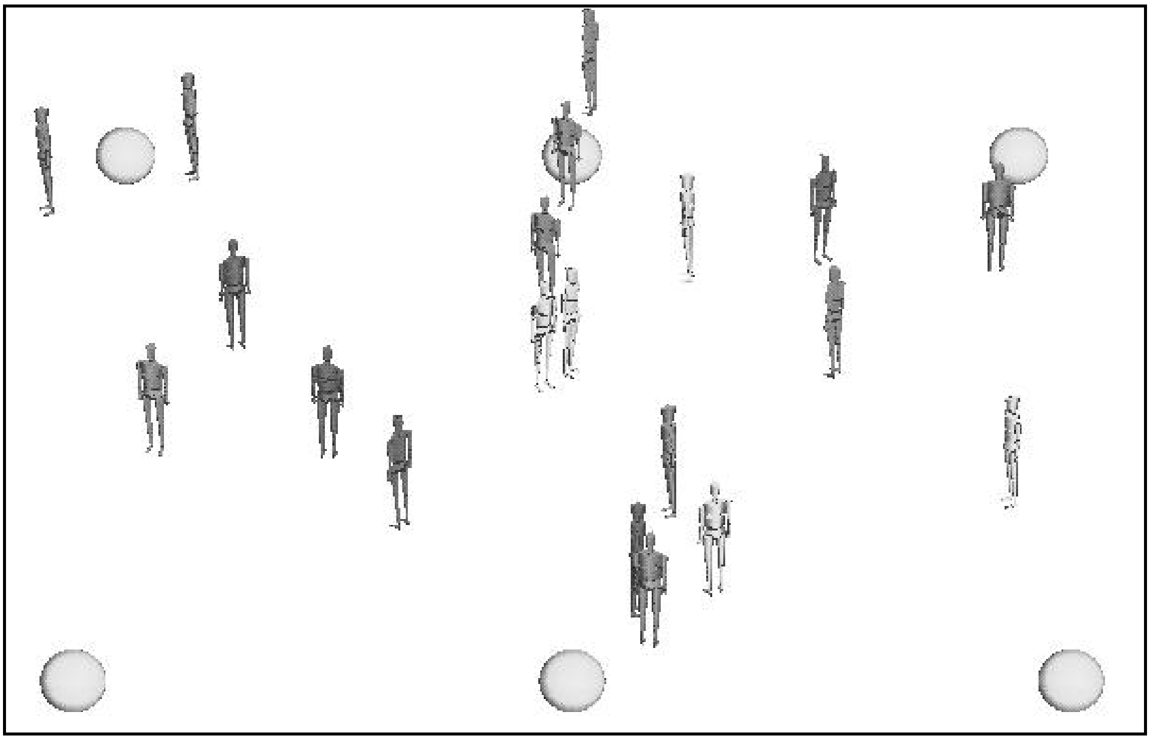


Fig. 5. Initial population visiting a Museum.

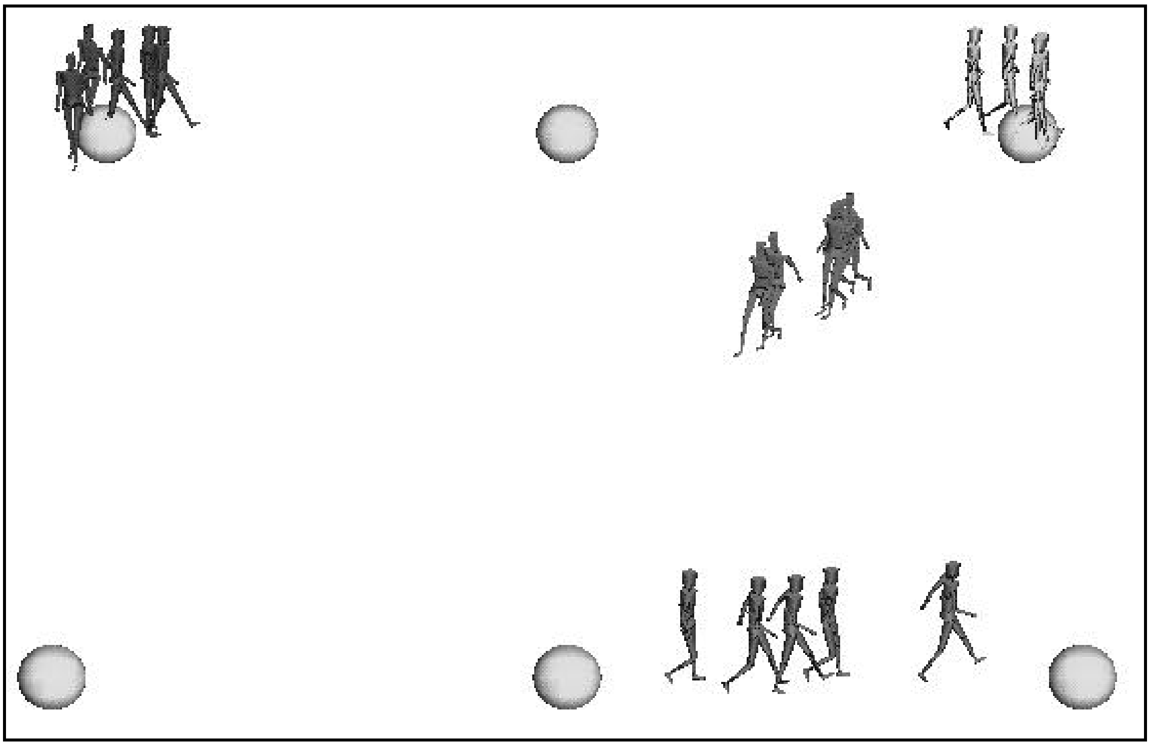


Fig. 6. Formed groups in the Museum.

Figures 5 and 6 show one example of this simulation. Figure 5 show is the beginning of the simulation, the virtual humans are in their randomized initial position. After one hundred interactions, the agents are gathered in groups and walk in the museum. The autonomous virtual humans of the same group look during a similar time to a specific work of art. Figure 7 (see Appendix) shows one image of this simulation integrated in a DIVE environment in COVEN Project [15].

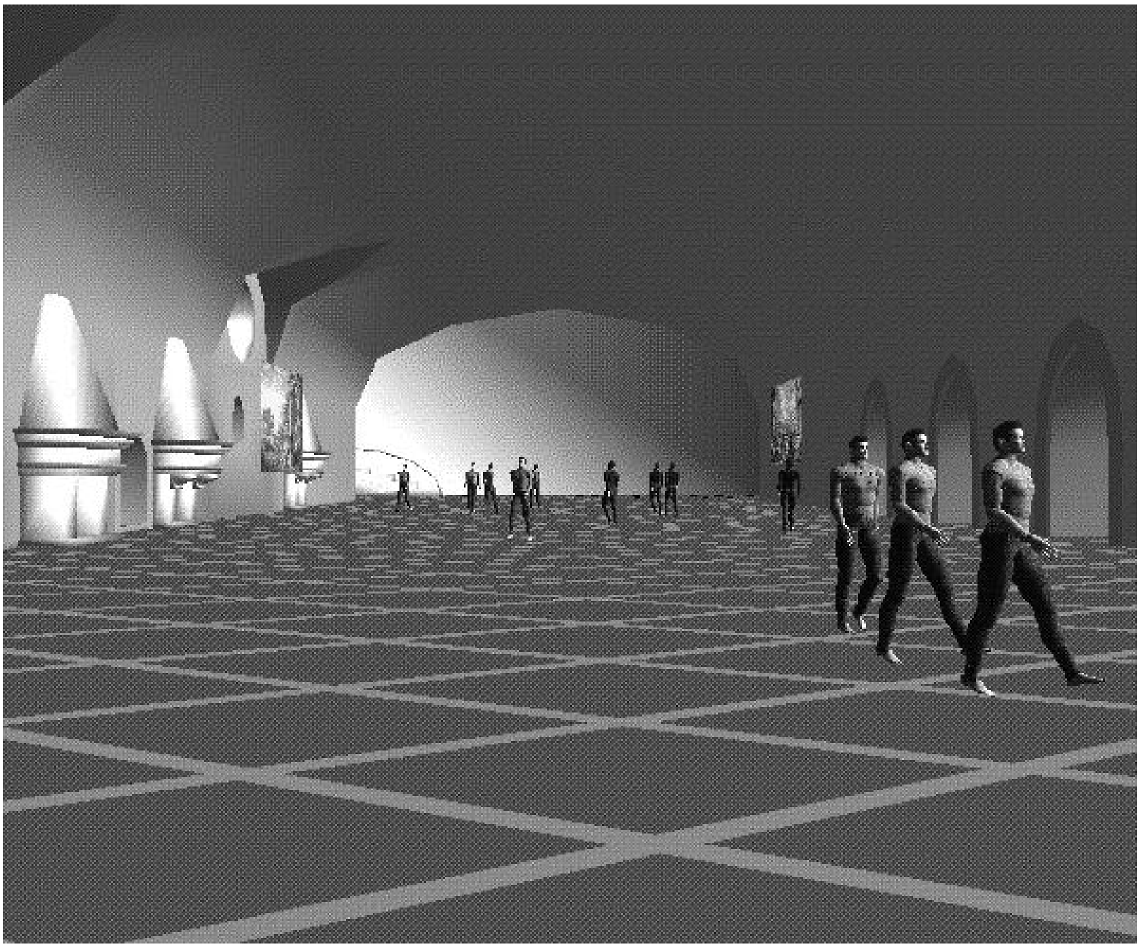


Fig. 7. Simulation integrated in DIVE

5 Collision Analysis

The mainly question that we want to answer in this section is the possibility of using the crowd model as an advantage. That is, if we have a crowd model with many autonomous virtual humans, we may decide whether the collision is necessary or not and depending on the cases. Here, we can use some concepts of multiresolution in order to decide which method of collision must be applied. But for this, we need some information to compare different kinds of collision avoidance. Therefore, we implemented 2 types of collision avoidance which we present in this section with a comparison of the results.

5.1 Collision Avoidance Type 1

This is a very simple method for avoiding collision. Using simple mathematical equations (intersection of two lines and distance from two points) to determine the future positions from the current ones, thus, we are able to detect a possible collision event. Before the collision occurs, we decide (through some rules of priority) to stop one virtual human and let the other one pass. Unless if the vectors of the virtual humans' movements are collinear, all other situations work just with this condition.

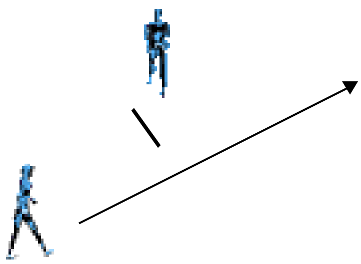


Fig. 8. Virtual human stops for the other

In the collinear cases, it is necessary one simple vector analysis to know which agent we must stop or if the agent can have its directions changed (section 5.2).

The following execution flow shows the priority rules:

For each pair of agents
  If vectors are not collinear
    If linear velocities are different
      Stop the slower agent
    else
      Choose one agent in a random way
  else
    If the vectors are convergent
      Choose one agent in a random way
      Change its movement direction
    else
      Increase the linear velocity of the agent
  which walks in the front of the other

In the following images we can see some examples of the collinear cases.

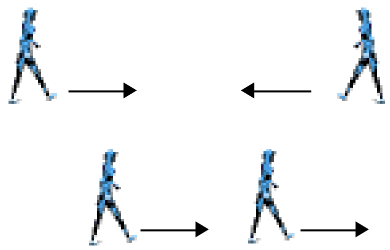


Fig. 9. The special collision cases

In the situations of Figure 9, as we can see in the priority rules, it is necessary to decide which virtual human must wait or change the direction. In this latter case, we used the method which will be presented in the next section.

5.2 Collision Avoidance Type 2

This other collision method is also very simple, but it is based on the directions changes. Instead of waiting for the other one, the autonomous virtual human can predict the collision event (knowing the position of next virtual humans) through a simple geometric computing (intersection of two lines). Thus, it can avoid the collision by changing its directions through its angular velocity changes. After a specific period of time, the virtual human returns to its last angular velocity (which was stored in the data structures), and also comes back to its previous direction, it represents the goal seeking group behavior.

We assumed:
(ang_vel)A = func(position_all_next_agents), *it means that the new angular velocity from the agent A is a function of the position vectors of the agents in a near distance.*

The next images show a sequence of the collision detection method type 2. We can see the agent avoiding collision by changing his angular velocity.

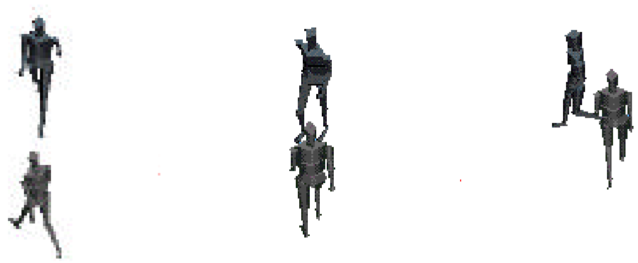
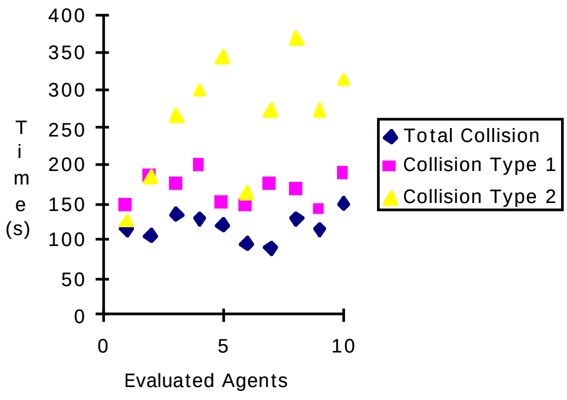


Fig. 10. Avoid collision sequence

Sometimes, however, the virtual human does not have enough time to modify its direction because the collision position is too close to the current position. In this case, we are using the last method (section 5.1) as a solution, that is, we decide which virtual human must wait (priority rules presented in section 5.1).

We do not intend to present in this work a new collision algorithm but just to present some useful considerations for the crowd case. Thus, we evaluated these two collision methods and a total collision (i.e, no collision avoidance). The following graphic presents the time data for ten autonomous virtual humans which start at an initial aleatory position and must arrive to a specific final position.



Graphic 1: Comparison of the collision methods for 10 agents

The y axis is the time spent by each virtual human to arrive to their goal. The x axis shows each evaluated agent. As their initial positions are totally random, we can explain the time spent by agent 1 (its initial position was close from its goal position, by coincidence). As the initial population and the behaviors are the same in all three cases, we can compare their time data. The next table presents some results.

Situation	*Mean Time (sec)*
Total Collision	117.6
Collision Avoidance Type 1	166.9
Collision Avoidance Type 2	261.8

Table 1

As it can be seen in Table 1, in terms of computational time, collision type 2 is 55% more expensive than total collision and 36% more expensive than the collision type 1.

Based on this analysis we specified our multiresolution model. We defined the position limits of the autonomous virtual humans and the collision method implemented. The next figure shows one possible model: consider the distance from the observer to the virtual humans as a high value and the three agents represent the positions limits of the different specific collision methods.

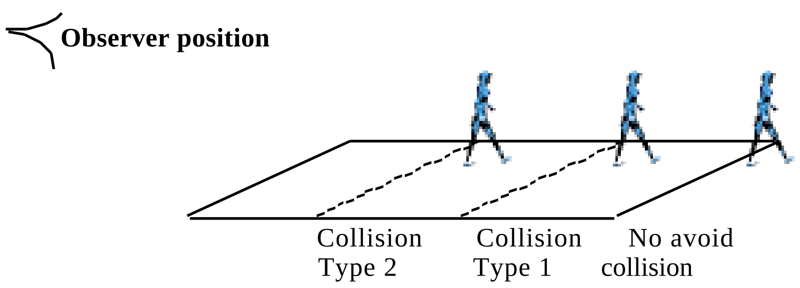
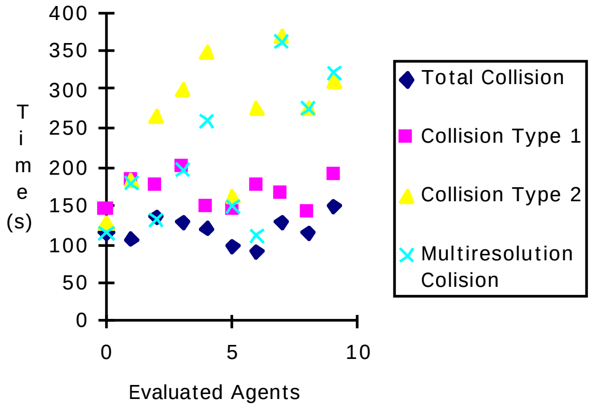


Fig. 11. The model of multiresolution collision

In this case, the virtual humans that do not avoid collision must be a long distance from the viewer. We need this kind of multiresolution because we believe that when we have thousands of autonomous virtual humans, a detailed collision response may not be seen and thus become unnecessary. We must emphasize here that the dynamic movement of these three groups will be different because in case of changing trajectory or just waiting for another agent, the time and the path followed by each agent can change. In spite of this, the agents will seek their goal. We have measured the time for multiresolution collision as showed in Graphic 2 and Table 2.



Graphic 2: Comparison with the multiresolution collision

Situation	*Mean Time (sec)*
Total Collision	117.6
Collision Avoidance Type 1	166.9
Collision Avoidance Type 2	261.8
Multiresolution Collision	209.7

Table 2

For the same population of graphic 1, the time spent avoiding collision is 20% smaller than the collision type 2 in the multiresolution method. We concluded that this is a good method but it will be used when we have many autonomous virtual humans, thus we can not see the collision problems originated from the totally-not-avoiding collision method even if the agents were far away.

6 Applied Methodology

Our system was developed in C Language and we have used the libraries SCENElib and BODYlib [8] dedicated to the creation of 3D objects scenes and human actors. We have also used the AGENTlib and BEHAVIORlib [9], the first one is responsible for the coordination of perception and action, and the second enables the definition of a behavior as a hierarchical decomposition in simpler behaviors performed either sequentially or concurrently. We do not use a synthetic vision approach [14] because this feature spends a lot of computational time, thus, we have used here a simple model of perception that just needs the position and orientation vectors of the autonomous virtual humans. In the next graphic (figure 12) , we show the system architecture.

Figure 12 presented the execution flow of our system. As we could see in the last sections, the user specifies the group behavior, which is distributed to all the virtual humans creating the individual parameters. Through these parameters, each agent acts according to three possible behaviors: walk, collision avoidance and relationship with the other, for each time that one virtual human meets an other. This relationship can change the individual parameters and the group behavior, e.g., when one virtual human changes a group and becomes the leader within this new group, the other autonomous virtual humans will try to follow him. In addition, the groups seek the goals and maintain the flocking movement.

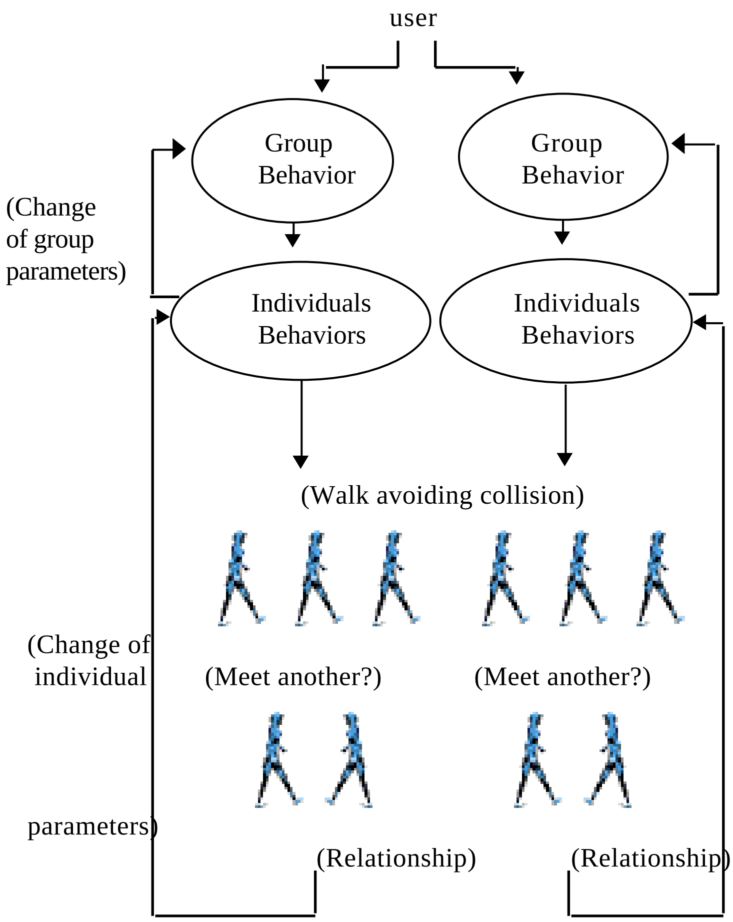


Fig. 12. The system architecture

7 Conclusions

We have described a model for the creation of a behavior based on inter-groups relationships. We think that our results show that we can create a crowd through the group's behavior and drive it through few parameters. Our parameters are still very simple given that we intend to simulate a generic crowd. However, we believe that our model will allow the creation of a totally generic crowd model in the future using mainly the inter-relationships between the autonomous virtual humans and the goals schema (interest points).

As a direct application, we can imagine the museum example for a real simulation where the goal is finding the best locations for the most visited works of art. Or in the sociogram example, we can have a statistical measure of the population behavior.

In the future we intend to model a panic situation in which all virtual humans will have their goals changed to an unpredictable direction. In this case, it is necessary to have a good model of adaptation of the autonomous virtual humans in a unknown environment.

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