# The Crowd Simulation for Interactive Virtual Environments

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## Abstract

The paper will cover the issues of Collective Behavior in complex and critical event in Virtual Environment and its Application by Visualizing Space and Information. This is related to the on-going research results concerning development of the crowd simulation for interactive virtual environments. The simulation aims to reproduce realistic scenarios involving large number of the virtual human agents. We define interactive VE as an architecture of multi-agent system allowing behaviors of the agents to interact among them, with the virtual environment as well as with the real human participants. The first behavior is known as Collective behavior. One of collective behavior to be described in this paper is maximum dispersion for the group of three agents. There are some complexities in identifying the procedure for maximum dispersion behavior among three agents. For experimenting with the determined procedures, the path planning of crowd dispersion in the building environment at the time of emergency situation is applied. With this complex and critical environment an experiment is carried out and the result of simulating maximum dispersion behavior of agents is discussed.

**CR Categories**:

**Keywords**: collective behavior, the A* algorithm, multi-agent coordination.

## 1 Introduction

Crowd simulation may be defined as an animation of a group of animated character. Animated characters or we may call agents moving together in virtual environment. The movement in certain cases requires agents to coordinate among them self. They may follow after one another, walking in line or dispersing using different directions. All these actions contribute a collective behavior that need to be explored.

Path planning is used to generate motion and this motion also constitutes a set of actions. As virtual worlds are normally populated by more than one agent, incorporation of multi-agent actions is one of the most important areas in animation techniques. This is another test case of the relationship between high-level descriptions (actions) and low-level motion. In this case, we will investigate how high-level semantics can govern low-level motion from a population of agents instead of one single agent.

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Short Paper

Path planning produces correct solutions but the associated semantics is not easily accessible. This can be related to the underlying heuristic search techniques, which essentially compile information into heuristics, which are not high-level representations.

Conversely, adopting a semantic approach to path planning opens the way to a better and more appropriate control of autonomous agents. The introduction of semantics in heuristic path planning has been proposed by Bandi and Cavazza [Bandi and Cavazza 1999]. This paper will describe the extension of this approach to the case of multi-agent co-ordination, a problem with many applications in computer animation.

## 2 Research Problem

There are three aspects to the problem of crowd simulation specifically co-ordinating group of agent. The first one is to search for the minimal path from source to destination, the second is to co-ordinate a group of actors for the purpose of embedding semantic information i.e. maximum dispersion and finally to convert action to motion for animation.

However, the paper concentrates on the co-ordination of agents to move together as a group or crowd. Co-ordination will result in the generation of alternative paths if such paths exist. The procedure for co-ordinating path planning for three agents in virtual environments has been implemented.

The on-going research result presented in this paper will introduce the synchronous path planning method in order to tackle the first two problems. The result of path generation is the list of direction and then converts into a transformation of animation i.e. to solve the third problem. With a single path planning calculation, multiple paths will be generated to provide different paths for multiple agents from the same location to the same destination. In other words, this can provide alternative paths for agents to proceed to a certain destination. The property of admissibility is used to enhance the capabilities of the A* algorithm to serve this purpose. Coordination is embedded in path planning using application-dependent data for the semantic interpretation, i.e. maximum dispersion. It is subsequently included as a collective behavior for multi-agents movement in a virtual environment.

## 3 Related Work in Collective Behavior

In this section, some details of the architectural crowd will be described. Collective behaviors have been studied and modeled with very different purposes. Besides single work concerned with generic crowd simulation [Musse 2000.], most approaches were application specific, focusing on different aspects of the crowd behavior.

## 3.1 Behavioral Levels in Groups

Behavior in groups of a system may be described at three levels: the individual agent, relationships among individual agents and collective structure of a group. Each level has its own complexity and emergent phenomena.

Relating with animation in VE, the behavior may be referred to as a sequence of motions. Where as, the behavior in the real world would counterpart to action in virtual world. Typical work on action is concerned with how to control the motion or to create the animation. Thus a computer animation technique is often referred to motion control systems [Watt and Watt 1992]. An animation establishing the interaction between objects and their surrounding may be classified as behavioral animation. In this case, a desired goal is specified, and the system attempts to generate a suitable series of position and orientation on a moving object in spatial coordinates.

## 3.2. Modeling of Behavior in Groups

### 3.2.1 Autonomous Modeling

The model gives agents some ability to improvise, and frees the animator from the need to specify each detail of every path. An autonomous agent determines its own actions, at least to a certain extent. Agents may be guided by external process (users interact with agents), may be controlled by the use of notation to define possible behaviors (robotic field term is teach and pendant), and may independently behave as individuals who posses the ability to think and react to events around them. The last capability relates to the field of artificial intelligence.

### 3.2.2 Collective Behavior Formulation

In building a mathematical formulation for the crowd behavior, we have to assume that there are some certain regularities (e.g. follow stochastic laws, for examples, A*, Dijkstra's and The least effort algorithm). Helbing [Helbing1992] describes crowds into three formulations: *i.e.* a stochastic, a gaskinetic or by a fluid dynamic formulation.

Some examples of applications concerning crowd behavior both the formation of freely forming groups and the behavior in queues include crowd motion simulations to support architectural design both for everyday use [Bouvier and Guilloteau, 1996], for emergency evacuation conditions [Still, 2000; Thompson and Marchant, 1995] and simulations of physical aspects of crowd dynamics [Helbing et.al. 2000]. Ulicny [Ulicny at.al 2001] has developed the crowd simulation for interactive virtual environments such as virtual reality training system for urban emergency situations and defined architecture of multi-agent system allowing both scripted and autonomous behaviors of the agents as well as interactions among them, with the virtual environment and with the real human participants has been.

Most of the solutions to crowd movement will cause agents to move to another place whilst staying close to each other and avoiding collisions. Information sharing between objects is used to make sure that the objects will move together and that objects will not collide with each other. On the contrary, in this on-going research co-ordination among multi-agent is so specifically as to disperse for alternative paths leading toward the same destination.

## 4 Motion Control for Non-Player Characters

Non-Player Characters (NPCs) are the autonomous characters that are free from the user's control. NPCs will interpret an action carried out by the main animated character or player avatar. The interpretation process is important for this view in behavioral animation. This will lead to further autonomous actions in the virtual environment as well as intelligent responses to the action being carried out. Thus motion or path planning becomes much more complicated when an animation for large crowds must be made. Recent development in motion planning and in global techniques for improving the approach has been discussed [Overmars, 2002] but it concentrated on the probabilistic roadmap (PRM). Whereas the improvement for path planning techniques used for large crowds is very few.

Algorithms that simply co-ordinate agents around a group leader [Brock et al, 1992] without actually sharing a common goal are faced with a certain number of limitations. For instance, flocking algorithms [Reynolds 2000] are vulnerable to local phenomena in the virtual world: if one actor splits from the group it might not be able to reconvene on the basis of the flocking algorithm only, especially if the terrain contains obstacles. More specifically, it is difficult with flocking algorithms to devise strategies for multiple path planning that enable co-ordinate agents to follow different routes to the same destination [AbdLatiff and Cavazza 2000]. In addition to this, flocking method is not easily applicable to specific constraints, such as the maximum dispersion problem. In other words, they go on different routes and reconvene back to a same destination. This problem would generally lead the flock to "loose" some of its elements, as most flocking procedures ensure flock cohesion rather than agent dispersion.

The separate paths that are created for each agent using linear interpolation as implemented in crowd behavior [Thalmann et al. 2000; Farenc et al 2000; Musse et al 1998, 1997] do not involve a path planning process. The movement is based on guided crowd behavior from one interest point (IP) to another IP and collision detection with obstacles is included in separate module for each agent. It is impossible for the crowd behavior to plan the path and to find the shortest path to destination.

Schooling behavior [Tu 1996, 1994] particle systems [Bouvier et al. 1997), voxel spaces [Zhang and Wyvill, 1997] as well as flocking algorithm are ill-suited to the simulation of human movements in planar environment. Their main purpose is to simulate the movement of agents in open space. Although Bouvier et al [Bouvier et al. 1997] have successfully used particle system in simulating human crowd movement, it is difficult to include proper path planning in this kind of simulations. Moreover, special purpose actions such as obstacle avoidance are controlled by a separate behavior routine, for instance avoiding-static-obstacles and avoiding-fish in schooling behavior.

Multi-agent Real-Time-A* with selection [Yokoo and Kitamura 1996] is not meant to provides the solution for multi-agents movement. Multiple agents are used only to concurrently search the same goal or destination and at the final stage competing each other to find one best solution. All other multi-agent search such as Ishida [Ishida 1998] normally serves the same purpose. In this case, multiple agents are used for distributed problem solving: only the best solution found is relevant and the agents are not featured as such in the simulation.

## 5 System Algorithm and Its Initial Results.

Using traditional algorithms, calculating the path for a group of actors originating from the same place towards the same destination results in all actors following the same path. Figure 1 shows the path taken by three actors that calculate their own path using the normal A* algorithm. There are moving from the left middle room to the right room with a few obstacles for them to avoid on the way. The collective behavior is “following” i.e. leading one after another. This is impractical at the time of emergency. The agents are rushing to find an alternative path to save them self or to vacant the building.

Bandi and Cavazza [1999] have shown how to integrate semantic information in to the A*ε path planning using a secondary heuristic. Abd Latiff and Cavazza (2000) have come out with SNA* algorithm to incorporate application-related knowledge or application-dependent data into path planning.

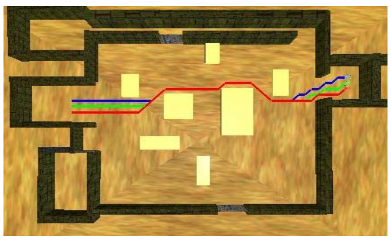

Figure 1. Three agents follow one after another using normal A*

Basically in A* algorithm, there is a set of nodes called OPEN and another set called CLOSED. Each time through the main loop, the best element (an element with the lowest cost) from OPEN is picked out, and evaluated at its neighbors. Then, it is put in any unvisited neighbors into the OPEN set. The cost of a node is the sum of the current cost of walking from the start to that node and the heuristic estimate of the cost from that node to the goal.

Most of the improvements in the A* algorithm principally involve its *heuristic evaluation function*. This includes the manipulation of its heuristic function, **h (n)** as well as the computation time of **f (n)**. The enhancement of A* can be done by including *application related knowledge* in the selection of **f (n)**. This enhancement is applied in the co-ordination of path planning for multiple agents or the movement of a crowd. In the research a secondary heuristic is employed to incorporate the behavior of multi-agent, which is termed *collective behavior*.

For the secondary heuristic, the expanded node is no longer the best node in the OPEN list, but a node from FOCAL list will be used instead. The best or several selected nodes in FOCAL are induced with the application-dependent knowledge or collective behavior.

There are some complexities in identifying the procedure for maximum dispersion behavior in crowd simulation. In early experiment crowd simulation was limited to three leader agents and four different procedures. Each leader has two follower agents as seen in Figure 2. Leaders and followers must coordinate among them.

The dispersion method for coordination must be no collision and no deadlock. For instance, agent_A can have the maximum distance to agent_B but this is not assured with agent_C. If agent_A has the maximum distance to agent_B and agent_C, it is quite complicated to make agent_B to have the maximum distance with agent_C at the same time. For this purpose four different procedures have been set up as given below and the result produced from it are analyzed.

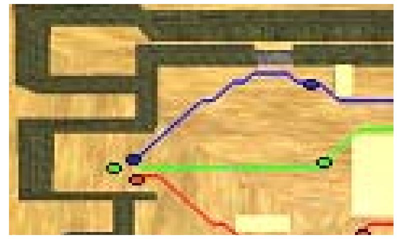

Figure 2. Three leader agents with two followers each

Procedure [1]
$a_n$=max_dist($a_c$, $b_c$ ); $b_n$=max_dist($a_c$ , $b_c$ ); $c_n$=max_dist($a_n$ , $c_c$ );

Procedure [2]
$a_n$=max_dist($a_c$, $b_c$ ); $b_n$=max_dist($a_c$ , $b_c$ ); $c_n$=max_dist($b_n$ , $c_c$ );

Procedure [3]
$a_n$= max_dist($a_0$, $b_0$ ); $b_n$= $b_0$; $c_n$=max_dist($b_0$ , $c_c$ );

Procedure [4]
$a_n$= max(max_dist($a_c$ , $b_c$ ), max_dist($a_c$ , $c_c$ ));
$b_n$= max(max_dist($b_c$ , $a_c$ ), max_dist($b_c$ , $c_c$ ));
$c_n$= max(max_dist($c_c$ , $a_c$ ) max_dist($c_c$ , $b_c$ );

Procedure [3] gives the best result for the maximum dispersion behavior for three agents. It is shown in Figure 3. In this procedure agent_B will always take the shortest distance and can be assumed as a group leader, i.e. $b_n = b_0$. Agent_A will take the left alternative path, i.e. $a_n$= *max_dist*($a_0$, $b_0$ ) whereas agent_C takes the right of its leader, i.e. $c_n$=*max_dist*($b_0$ , $c_c$).

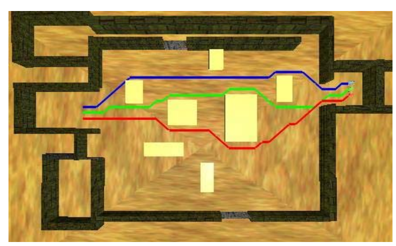

Figure 3: Total dispersion using behavior in procedure [3]

Both classical A* and SNA* algorithm path planning technique were used to control the animation. The path planning provides the shortest path between source and destination, and will automatically avoid obstacles. Even though, they could be extremely expensive if we have large crowds those techniques may result a model that similar to ‘real life’ crowd in some respects. As we know that the techniques will lead to paths that have sharp corners.

We introduce directive method as a technique to convert action to motion animation. Collective behavior is an action generated from path planning algorithm. The result is a list of direction number to represent two orientations i.e. the new translation and a new rotation. The procedure below is used to map the list of directions into the actual move orientation in a 2D planar environment:

```
Begin
    For every loop/frame displayed
      if artificial actor starts to walk
        newTranslation = setLinearVelocity(direction_no);
        newRotation = setAngleOfRotation(direction_no);
        getNewTransformation(newTranslation,
                                   newRotation);
        direction_no++;
      end-if
    end
end
```

The animation loop continues for every 20 milliseconds to generate the new frame. The new transformation occurs only when the agent starts to walk. The setLinearVelocity( ) function is used to set the velocity at that particular time. This function will look up the direction/velocity conversion table (Table 1) and translate the direction number to velocity vector for the new translation. The setAngleOfRotation( ) function consequently sets the rotation for the whole body of the agent towards the direction of movement. Another look up table has been developed to synchronize the facing and the movement direction of the synthetic actor.

Table 1: The relation between rotation and velocity as well as direction number

| Direction number | Velocity value | | Rotation value in ° | |
|---|---|---|---|---|
| 0 | North | ( 0.0 , 0.0 , -0.5 ) | π | ↑ |
| 1 | North west | ( -0.5 , 0.0 , -0.5 ) | π x -3/4 | |
| 2 | West | ( -0.5 , 0.0 , 0.0 ) | π x -1/2 | ← |
| 3 | South west | ( -0.5 , 0.0 , 0.5 ) | π x -1/3 | |
| 4 | South | ( 0.0 , 0.0 , 0.5 ) | 0 | ↓ |
| 5 | South east | ( 0.5 , 0.0 , 0.5 ) | π x 1/3 | |
| 6 | East | ( 0.5 , 0.0 , 0.0 ) | π x 1/2 | → |
| 7 | North east | ( 0.5 , 0.0 , -0.5 ) | π x 3/4 | |
| 8 | Stop | ( 0.0 , 0.0 , 0.0 ) | 0 | ↓ |

## 6 Conclusion

This paper has discussed the importance of multi-agent interaction, but the concentration has been on the co-ordination of agents to move together as a group or crowd. Co-ordination will result in the generation of alternative paths if such paths exist. The procedure for co-ordinating path planning for multiple agents in virtual environments has been introduced. This procedure is derived from traditional path planning techniques developed for isolated agents, based on the A* algorithm. This solution is a generic approach to include semantic information in multiple agent movement.

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