A swarm algorithm for wayfinding in dynamic virtual worlds

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ABSTRACT
Wayfinding is a cognitive element of navigation that allows people to plan and form strategies prior to executing them. Wayfinding in large scale virtual environments is a complex task and even more so in dynamic virtual worlds. In these dynamic worlds everything, including the objects, the paths, and the landmarks, may be created, deleted, and moved at will. We propose a wayfinding tool using swarm creatures to aid users in such dynamic environments. The tool produces dynamic trails leading to desired destinations and generates teleport/warp gates. These are created as a consequence of swarm creatures exploring dynamic worlds. In this paper, we describe the swarm algorithms developed to create such a tool to generate wayfinding aids in dynamic virtual worlds.

Categories and Subject Descriptors
H.5.1 [**Information interfaces and presentation**]: Multimedia Information Systems – *Artificial, augmented, and virtual realities.* I.2.11 [**Artificial intelligence**]: Distributed Artificial Intelligence – *Multiagent systems*

General Terms
Algorithms, Design

Keywords
Virtual worlds, wayfinding, navigation, swarm intelligence, navigation/wayfinding aids.

1. INTRODUCTION
Even with the advancement in visual and aural technologies, there still exists the problem of people getting lost in 3D virtual worlds [2,3,4,5,7]. In order for people to use these worlds without getting lost, they must be able to maintain "knowledge of their location and orientation" [4]. Hence the purpose of navigation aids research is to "prevent disorientation problems as much as possible" [2] while still allowing users to explore and discover the worlds they are in.

Figure 1 A 3D dynamic virtual world

For large scale virtual environments, the navigation problem becomes much more critical as users cannot "learn the structure of the environment from a single view point" [2]. Consequently, they are forced to explore the environment extensively. This task of exploration can be a complex task due to the absence of many sensorial stimuli that exist in the physical world [2].

This problem in navigation becomes even more critical in the midst of a dynamically changing world, illustrated in Figure 1. In dynamic virtual worlds, the elements of the world (e.g. buildings, structures, objects, landmarks, etc.) can be created, deleted, and moved at will. Hence while the user moves towards a target building, the building may be moved before the user arrives or the path the user travels on may be blocked or disappear altogether. Users in such environments cannot maintain spatial knowledge of the world as such knowledge gained may no longer be accurate. The current wayfinding aids do not cater for this type of worlds [3].

In this paper, we describe a swarm based tool which generates wayfinding aids in the form of a trail, and, in time, teleport gates in dynamic virtual worlds. We propose swarm algorithms since the inherent behavior of swarm creatures makes it ideal in gathering wayfinding information in dynamic worlds. We then present two simulations of the swarm wayfinding tool in a dynamic 2D environment.

2. SWARM ALGORITHM

Foraging ants exhibit a complex behavior by finding the shortest path to food sources as they forage for food [1,6]. First, they explore the environment in search of food. Once the ants locate a food source, they bring the food back to the nest whilst marking the trail with pheromones. Even with the introduction of foreign objects to the trail, the ants are able to maneuver around the object and adjust the path accordingly. Resnick [8] shows that such complex behavior in the foraging ants can be recreated in artificial ants by having them follow a simple set of rules. We use the artificial ant foraging model for our wayfinding creatures. The wayfinding creatures also explore the environment in search of a required target. Once the target is located, they return home whilst marking the trail with attractants.

Resnick's artificial ants [8] are designed as single agents capable of working independently without a controlling body. These agents have sensors that sense adjacent locations, illustrated in Figure 2, for signs of food, pheromones, obstacles, and other agents. They also have effectors that allow them to deposit a pheromone in their current location.

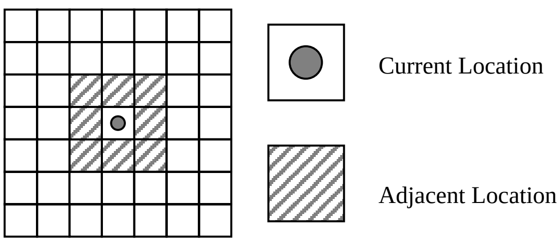

Figure 2 Sensing adjacent locations

2.1 Swarm behavior

Swarm behavior is an emergent property which is not explicitly programmed. Hence as an individual, a swarm creature only knows about itself and its local surroundings. Essentially, a swarm creature behaves by following a simple set of rules. A single creature cannot explore the world fast enough to look for the required target. The wayfinding aids emerge as a consequence of having a large number of relatively simple creatures. As a swarm, the creatures can locate the target faster than when acting alone. The traces of attractants dropped by the creatures as they move emerge as a trail which the user can then follow. Since the creatures continuously explore the world, the wayfinding aids readily adapt in a changing environment without a controlling body.

2.2 Stigmergy

Stigmergy is a type of indirect communication through the environment. It alters the state of the environment in a way that affects the behaviors of others for whom the environment is a stimulus [6]. Bonabeau et al. [1] explain stigmergy as an indirect interaction between two individuals when one of them modifies the environment and the other responds to the new environment at a later time. For foraging ants, they use chemical droppings called pheromones. As ants gather food, they drop pheromones on the path leading to the food source. As pheromones accumulate, the scent becomes stronger attracting nearby ants to the trail. These chemicals evaporate and diffuse over time. Hence the ants are able to use the concentration of pheromones to determine the location of food and to estimate the time elapsed since food was located.

Algorithm 1 Wayfinding creature behavior algorithm

```
function wayfinding_creature_behavior
    repeat
        Explore_World();
    until Target located;
        Return_Home();
```

In a wayfinding swarm, we employ two different types of pheromones: repellents and attractants. They provide a means of communicating to other wayfinding creatures the areas already explored and the location of the target.

2.2.1 Repellents

The wayfinding creatures drop repellents to mark visited spaces while exploring. Hence when they sense repellents in adjacent locations, they are encouraged to move to unexplored spaces. Because the repellents evaporate, the creatures are encouraged to explore the spaces previously visited in due time.

2.2.2 Attractants

The attractants are dropped by creatures returning home once they find the target. These attractants disappear over time allowing fresh trails to be constructed when either the target and/or home changes. The trail marked by attractants is not used by wayfinding creatures alone. Users can also follow the trail since it is a form of bread-crumb aid for wayfinding [3].

2.3 Local rules/individual behavior

Each wayfinding creature follows rules as described in Algorithms 1-3. These rules define how each individual makes a decision about a local move and the actions to take. The rules also define what and how each creature senses and effects. The overall algorithm for the creature (Algorithm 1) has the creature exploring the world (Algorithm 2) until a target is found, and then it returns home (Algorithm 3).

Algorithm 2 describes how the wayfinding creature explores the world while looking for the target. Until the target is located, every time the creature moves, it checks to see if the required target is located in the adjacent locations. If the target is found, the creature simply moves to the target and creates a teleport gate. Otherwise the creature senses the adjacent locations for traces of

Algorithm 2 Explore World Algorithm

```
function Explore_World()
    if Target found in adjacent locations
        Move to Target;
        Create teleport gate;
    else
        if attractant found in adjacent locations
            Move to location with highest
               concentration of attractant;
        else
            Drop repellent in current location;
            Move to empty adjacent location;
```

pheromones. If attractants are found, it moves to the location with the highest concentration of attractants. If not, it drops a repellent in its current location prior to moving onto an adjacent location that is not occupied by objects, other creatures, and, if repellents exist, repellents of concentration above a certain threshold.

Algorithm 3 Return Home Algorithm

function Return_Home()
    Drop attractant in current location;
    Repeat
      if Home found in adjacent locations
          Move to Home;
      else
          Move to empty adjacent location closer to Home;
  until Home;

The wayfinding creatures follow Algorithm 3 when returning home after locating the target. Prior to relocation, the creature drops an attractant in the current location. It then senses whether home is found in the adjacent locations. If located, the creature moves to it then turns back again to explore the world. Otherwise, the creature moves to an adjacent location closer to home than the current location. This adjacent location must not be occupied by obstacles. If the location is occupied by an obstacle, the creature moves around the obstacle by choosing some other adjacent location taking it closer to home either horizontally or vertically compared to the current location.

It can be seen from these rules that each individual has the knowledge of its current location and the location of home, and is capable of sensing adjacent locations. Because the swarm creatures do not depend on the experiences they have gained or any other knowledge they may have accumulated, they are ideal in producing wayfinding aids in dynamic worlds. The wayfinding aids adapt to the changes made in the world without having the world remember the changes made in it.

3. SIMULATIONS IN A DYNAMIC 2D ENVIRONMENT

The swarm rules have been implemented and simulated in a 2D world to test the validity of the algorithms. The size of the world used in the simulations does not properly reflect the size of a large scale virtual environment for which the creatures are being developed. However, the initial results indicate that the creatures are able to create a trail establishing a path between Target and Home. There are two simulations. First simulation tests swarm algorithms and illustrates that the creatures are able to find Target and return Home even when the locations of both change abruptly. In the second simulation, obstacles are introduced to observe the creatures' reaction.

Figure 3 explains symbols used in the simulation.

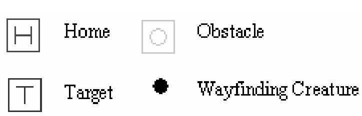

Figure 3 Symbol representation

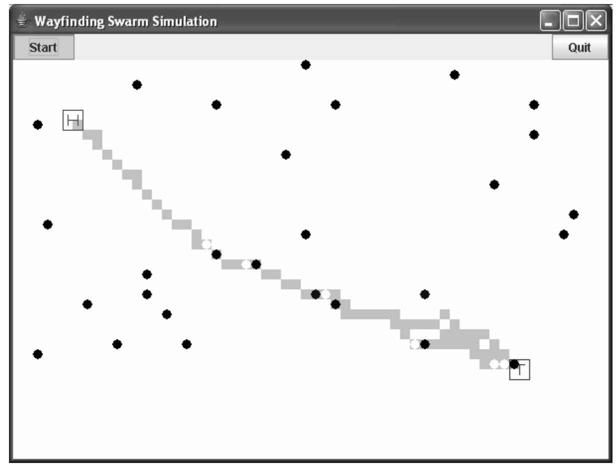

Figure 4 Formation of a pheromone trail

3.1 Moving Home and Target

Initially the wayfinding creatures start their exploration of the world from Home. The Target is located in the world. The creatures have the knowledge of the location of Home but not of the location of Target.

First, the creatures explore the immediate surrounding areas of Home. However as time progresses, they move further away while dropping repellents. When Target is found, they return home dropping attractants as in Figure 4. These attractants emerge as a trail to which the creatures in adjacent locations are attracted. Other creatures which are not in adjacent locations to the trail are unaffected by it.

When Target and Home change their locations, initially the creatures continue to follow the old path due to the high concentration of the attractants that have accumulated on it. At the end of the old path, the wayfinding creatures randomly wander around due to the relocation of Target. This is shown in Figure 5 where a large number of creatures are gathered around the old Target location (bottom right hand corner). Unable to locate Target in the vicinity of the old Target location, they eventually move away. The creatures re-explore the world trying to locate Target. When it is found, a new trail is created. The old path evaporates in time as new attractants are not deposited on it.

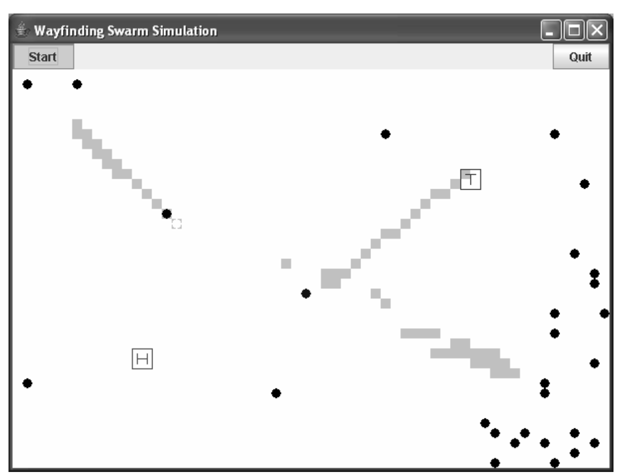

Figure 5 Finding a new path

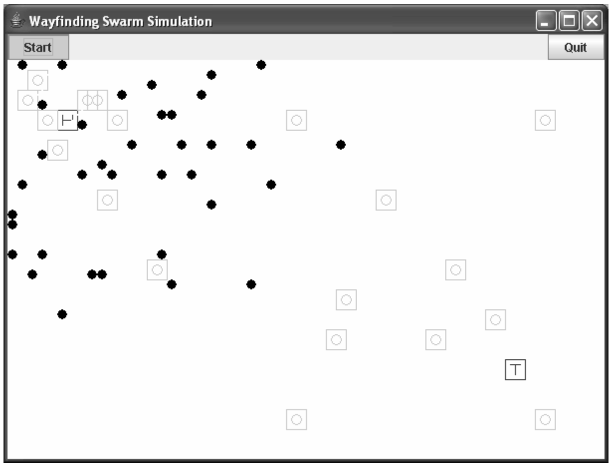

Figure 6 Simulating swarm behavior

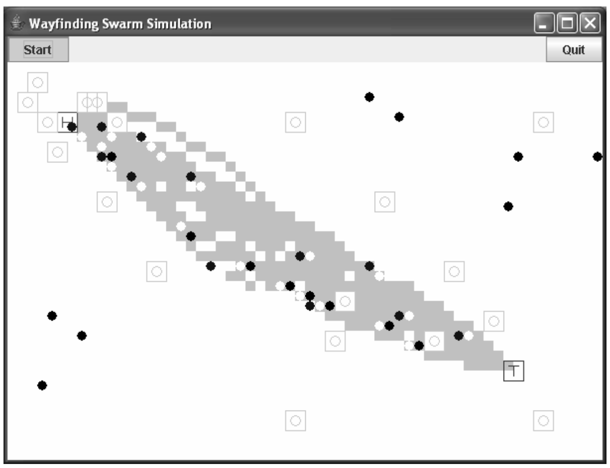

Figure 7 A path from Home to Target found

3.2 Presence of other objects

In the second simulation, objects are introduced to the world. In this simulation, objects that are not Targets are considered to be obstacles to be avoided. As with the first simulation, the wayfinding creatures explore the area around Home first while avoiding the obstacles. The creatures are able to avoid the obstacles by sensing adjacent locations and moving to an adjacent location that does not contain any obstacle (See Figure 6).

The wayfinding creatures return Home from Target by moving to an adjacent location that is closer to Home than its current location. The creatures move around obstacles by choosing an adjacent location that is either horizontally or vertically closer to Home. Hence even in the presence of obstacles, the creatures are still able to locate Target and form a trail back Home as illustrated in Figure 7.

When locations of Target and Home change, the creatures respond in the same way as the first simulation. Initially they congregate in the old Target location. But they move out eventually and find the new Target. Figure 8 shows the old path evaporating while a new trail is created linking Home to Target. As they re-explore the world and form a new path, the creatures simply move around the obstacles when sensed.

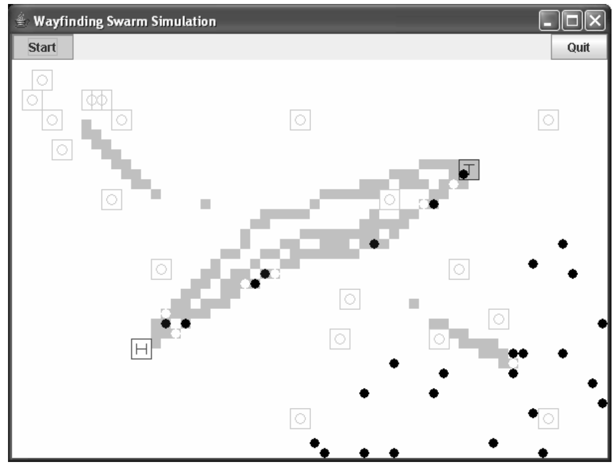

Figure 8 Emerging of a new trail

4. BENEFITS OF THE APPROACH

A wayfinding swarm tool is beneficial in a dynamically changing environment. By having simple creatures exploring the world, the swarm tool generates wayfinding aids which adjust to dynamically changing environments without a controlling body. Hence the designers of virtual worlds do not need to modify the wayfinding aids whenever adjustments are made in the worlds.

5. REFERENCES

[1] Bonabeau, E., Dorigo, M., and Theraulaz, G. *Swarm Intelligence: From Natural to Artificial Systems*. Oxford University Press, New York, 1999.

[2] Chittaro L. and Burigat S. 3D Location-pointing as a Navigation Aid for Virtual Environments, *Proceedings of AVI 2004: 7th International Conference on Advanced Visual Interfaces*, ACM Press, New York, May 2004, 267-274.

[3] Darken, R. P. and Peterson, B. Spatial Orientation, Wayfinding, and Representation, In K. Stanney (Ed.), *Handbook of Virtual Environment Technology*, Lawrence Erlbaum Associates, New Jersey, 2001.

[4] Darken, R. P. and Sibert, J. L. Wayfinding Strategies and Behaviors in Large Virtual Worlds, In *Proceedings of CHI'96*, ACM Press, New York, 2001, 142-149.

[5] Darken, R. P. and Sibert, J. L. A Toolset for Navigation in Virtual Environments. In *Proceedings of UIST '93*, 1993, 157-165.

[6] Kennedy, J. and Eberhart, R. C. *Swarm Intelligence*. Morgan Kaufmann Publishers, San Francisco, 2001.

[7] Ramloll R. and Mowat D. Wayfinding in Virtual Environments using an Interactive Spatial Cognitive Map, *IV2001 Proceedings*, IEEE Press, London, 2001.

[8] Resnick, M. *Turtles, Termites, and Traffic Jams: Explorations in Massively Parallel Microworlds*. MIT Press, Cambridge MA, 1995.