An Emotional Path Finding Mechanism for Augmented Reality Applications

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Abstract. In this paper we present *eCoology*, an AR edutainment application for children in which emotional and social aspects are taking into consideration to improve flow or optimal experience. Particularly, we investigate the introduction of emotional agents that react and move within the AR environment according to their emotional state. We propose a model for emotional agents and a path finding mechanism with backtracking that allows exploration of different movement alternatives. In this way, virtual entities may exhibit a complex number of emotional movement behaviors within the augmented space.

1 Introduction

Studying is the major task for children, teenagers and college students across cultures, covering a significant percentage of time in their daily life [1]. Students have to deal with classmates and teachers following adult social rules of behavior and interaction, but these interactions are associated with low control of the situation and implicit motivation [2]. On the contrary, the most positive experiences are reported in activities such as sports, gaming, arts and hobbies, which merge fun with concentration and goal setting [3]. Particularly relevant in these activities has been the identification of *optimal experience* or *flow* [4] which is characterized by the perception of high environmental challenges, adequate personal skills, high levels of concentration, enjoyment and engagement, loss of self-consciousness, control of the situation, focused attention, positive feedback, clear ideas about the goals of the activity and intrinsic motivation [5]. Therefore, incorporating *flow* into learning environments [6] would encourage students to use their abilities and to find rewarding and engaging opportunities for action during work class and homework.

In this paper we report on an experience of using Augmented Reality (AR) gaming [7][8] as a key element in moving children away from apathy, lack of involvement in

R. Harper, M. Rauterberg, M. Combetto (Eds.): ICEC 2006, LNCS 4161, pp. 13 – 24, 2006.

school subjects and searching alternative dangerous sources of *flow*. AR gaming has very important features that make it ideal for optimal *flow* in learning activities. As pointed out in [9], AR games may require physical skills to the same extent as real world games; support spatial reasoning with arbitrarily complex game models and rules; contain social elements of collaboration, negotiation and relationship building; and can stimulate players emotionally across a full range of senses in a potentially vast number of mixed-reality scenarios and environments. Therefore, AR games can contribute positively to achieve all the components that constitute an optimal experience.

Particularly important, in our opinion, are the emotional and social aspects of Augmented Reality for flow building. It has been proven [10] that older and younger brains are linked by emotional systems not only in the processes of care but also in the quest for skill and understanding. Human companions support growth of intelligence and, in AR environments, artificial companions or agents may also collaborate as social entities in the processes of knowledge discovery and interpretation of the real world.

In this paper we present *eCoology*, an AR edutainment application for children in which emotional and social aspects are taking into consideration to improve *flow* or optimal experience. Particularly, we investigate the introduction of emotional agents that react and move within the AR environment according to their emotional state, and a path finding mechanism based on particle systems contributing to emotional movements of entities within the augmented space. Section 2 will introduce the main features of the *eCoology* system. Section 3 will present a model for emotional entities and a mechanism for emotional path finding. Section 4 will describe an algorithm for path resolution supporting emotional backtracking. Finally, section 5 will present our conclusions and future work.

2 The Ecoology Ecosystem

eCoology is an acronym for "An Electronic Cool Way of Learning about Ecology", and the main goal is to teach children (aged 8 to 12) about healthy everyday values such as having a balance diet, taking care of the environment, using renewable sources of energy, and behaving respectfully with others by means of an optimal flow experience based on games.

The proposed mechanism is an AR game application consisting of an ecosystem with plants, animals, energy sources and people. Children are proposed gaming activities such as, feeding animals with different types of food and, evaluating over time the health status of the animals under their responsibility. Animals that are only given unhealthy food eventually appear to be sick, and children have to find out the ultimate reasons of their illness. This problem solving task is mediated by social artificial agents and it will be presented later in this paper. The rationale behind this activity is to make children think about their own feeding behavior, and its consequences by analyzing a similar situation with virtual animals in an AR ecosystem (see Figure 1).

Fig. 1. *eCoology* augmented space

Living entities in *eCoology* behave emotionally to show happiness when healthy states are achieved, or to express different forms of aggressive behavior and unhappiness when animals detect situations related to past unhealthy states (emotional recall). This emotional behavior is not only expressed in terms of short duration reactions but even affect the movement of entities within the AR ecosystem. As a result, entities with emotional feelings about other entities, be they artificial or real, modify their movement trajectories accordingly to be near of good friends and go away from enemies or entities that could harm and entity's health.

Social learning is integrated within *eCoology* by making children aware of person-to-person and artificial agent-to-person relationships. Children have mechanisms to keep track of good and bad behaviors of other members in the ecosystem to help them to build partnership relationships with good friends, or try to fix a bad relationship if it is detected. Besides, trust building is supported by using negotiation spaces in which users interact to exchange items such as tools and needed food. The ultimate goal is, besides reinforcing responsibility values on children, to contribute to their personal growth by establishing personal relationships within the augmented reality space.

In terms of architectural design, *eCoology* is a multi-player AR game in which all users of the ecosystem perceive the same snapshot of the system in real time. *eCoology* leverages the power of P2P technology to easily maintain up-to-date all users. To develop the P2P network of *eCoology* we have used the PeerChannel [11] infrastructure present in the Windows Communication Foundation [12], which allowed us to create easily a multi-party communication network and to broadcast the simulation data to all client rendering engines.

3 Emotional Model

Emotional computing is a research area that is recently receiving a lot of attention [13] [14]. Although several definitions for "emotional behavior" can be found, all existing approaches refer to "human-like" agents when speaking about software systems that mimic human behavior biased by emotions.

Having entities in *eCoology* with emotional behavior is a key feature for children to perceive the augmented ecosystem as an attractive interactive environment for learning. Particularly interesting when dealing with immersive augmented reality experiences is the representation of emotional behavior that has an impact on entities movement. This interest arises from the need of user engagement: an augmented reality environment with virtual animals moving around according to some emotions improves users' immersion and engagement with the system.

In our first prototype we have defined a small set of emotional state ranges that influence movement of entities, namely, "fear-courage", "aggressiveness-calmness", "happiness-sadness", and "faithfulness-disloyalty". Each emotional range can be seen as a continuous variable with two extreme values. For instance, an entity may reach a very low level of fear-courage and "feel" fear when encountering another entity that behaves aggressively against it; or may "feel" aggressive (see Figure 2) if it is alone (no nearby entities of its kind) and surrounded by other types of entities. It may also reach the happiness-sadness emotional state and feel happy (see Figure 2) if it is side by side with its owner or with other entities of its kind. In terms of user interaction, the user can learn that some kind of food is not suitable for an entity if, after offering it, the entity does not obey further user commands. In the same way, if the entity likes the food, it could feel faithfulness and would follow the movements of the user. This emotional behavior affects the destination used in the path-finding of the entity.

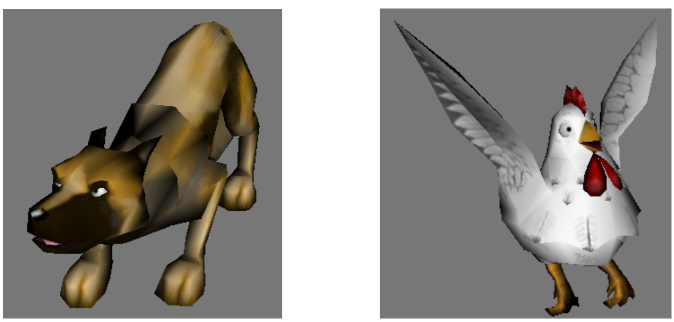

Fig. 2. Depiction of a dog that "feels" aggressive and a happy chicken

To achieve this type of complex emotional behavior, we have designed an emotional model consisting of three subsystems (Figure 3):

- **Perception:** This is a basic component of any behavioral model for entities (be they emotional or not) that have to interact with their surrounding environment. It is responsible for extracting data from the environment (stimuli). This information may be obtained from an entity's field of vision, obstacles and objects, presence of other nearby entities (their emotional state), and also from what an entity can hear, such as the call from its owner.

– **Emotional Profile:** An important point to increase user engagement is to endow each entity with a different type of behavior, i.e., not just a differentiation among types of entities but also among individuals of the same type. This approach is a totally established trend in entertainment industry (games, movies, commercials [15]). This subsystem establishes the character of an entity in terms of what an entity will feel for a certain type of stimulus. Besides, it also contains an *emotional memory* to remember past interactions with other entities so that an entity may express emotional feelings with respect to them. Based on an entity's character and its emotional memory this subsystem generates a vector of emotional state ranges (as defined earlier) that are processed by the behavioral performer subsystem.

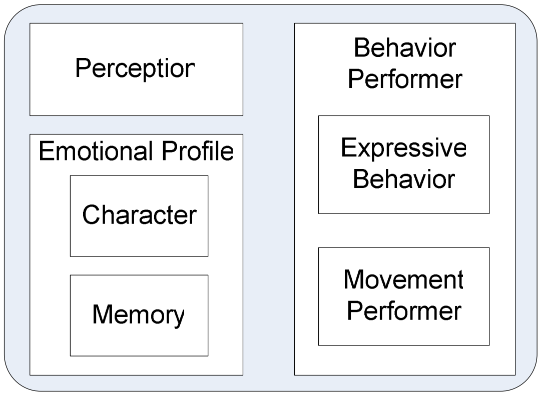

Fig. 3. Model of an emotional entity of *eCoology*

– **Behavioral performer:** This subsystem is responsible for expressing reactions and behaviors that relate to emotions generated by the emotional profile subsystem. These reactions include body expressions such as those depicted in Fig. 2 and movement behaviors. This subsystem takes a stimulus from the perception subsystem and the set of emotions associated to it from the emotional profile. Then, it makes the entity react either with a body expression and/or a movement in the augmented space towards a specific destination according to the emotion the stimulus produces. For example, if the stimulus is a person calling an animal and the animal feels a certain level of happiness and loyalty towards him, then it will select the person's current position as its next movement target. The details of how this process is done will be described next.

Emotional Selection of a Destination

Entities in *eCoology* perceive stimuli in many forms such as: detection of nearby entities, food being thrown at the ecosystem, and voice commands. These stimuli belong to two categories: stimuli related to presence of objects or entities in the ecosystem such as "saw a cake next to you", "saw user A is at position (20,30)", or "saw dog C at position (2,3)"; and stimuli related to actions performed on an entity by another entity such as "user A is screaming at you", "user B is giving you a carrot", or

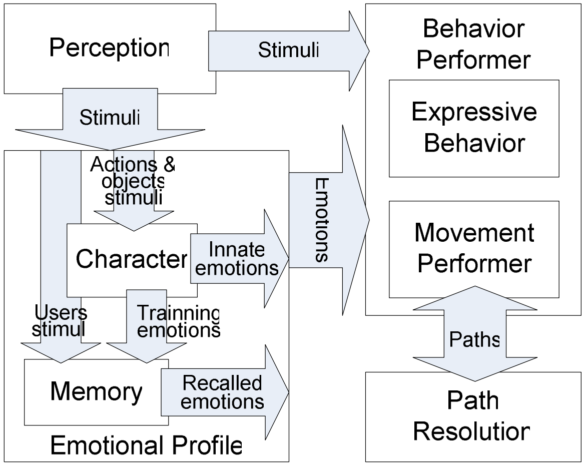

Fig. 4. Emotional selection of reactions and destinations

"dog C is barking at you". These stimuli are collected by the perception subsystem and passed to the Emotional profile and Behavioral Performer subsystems.

Actions and objects may produce "*innate emotions*" per se with different intensities. For instance, "barking at me causes I feel a certain level of aggressiveness", "Giving me love makes me feel happy and loyal", or "cakes make me feel happy". These emotions are part of the innate emotional profile of an entity and are generated by our character module within the emotional profile (Figure 4).

However, innate emotions caused by actions are particularly interesting because they are used as training sets for the memory component. This component uses emotions related to actions together with the entity that performed them to create "emotional memories". Emotional memories make an entity "remember" emotions that were caused as a result of actions performed by other entities in the past. Therefore, whenever an entity A perceives the presence of another entity B as a stimulus, the emotional profile of A uses its emotional memory to generate evoked emotions about B. To perform this process, the emotional memory component uses a machine learning mechanism based on clustering algorithms. Clustering deals with the construction of subsets (clusters) based on similarity mechanisms from input data sets. In our case, input data sets are innate emotions produced by the character module and a single cluster is obtained for each external entity that interacted in the past with a given entity. This way, whenever an entity A perceives another entity B, the centroid of the cluster representing B in the emotional memory of A is obtained and the emotional values contained in this centroid are generated as an emotional response. These emotional responses are called "recalled emotions".

Once an emotional response (innate or recalled) has been generated and passed to the behavioral performer, the latter can start its task. The first step is to select among the perceived stimulus the one the entity will react to. To do this, the behavioral performer analyzes the emotions associated to each stimulus to evaluate the one with the most intense set of emotions. Once this selection is done, the expressive behavior component uses the emotion with highest level of intensity to make the entity react visually (3D animation) according to the emotion. Besides, if the selected stimulus determines a movement towards or away from a given target in the augmented space then the movement performer component (Figure 4) communicates with a path resolution subsystem. This subsystem calculates all feasible routes (see next section) and returns them on demand to the movement performer which selects the best possible route based on the remaining stimuli and associated emotions. For instance, a certain route may be rejected if it passes close to the location of a stimulus that has produced a negative set of emotions. This way, entities exhibit emotional movements in the augmented space.

4 Ecoology Path Finding

Emotional behavior, as was described earlier, can be expressed in many forms including motion in a surrounding space. We describe in this section a path-finding service in charge of providing alternative paths to reach targets which the higher level behavioral system evaluates and, eventually, accepts or discards.

In the context of autonomous moving agents, the path-finding problem can be addressed as the problem of providing, given the current and final position, and a set of spatial constraints (usually a map), one or more possible ways of reaching our goal without violating any of the constraints.

There are several approaches which are commonly used to solve the path-finding problem but most path-finding algorithms work with graphs in the mathematical sense, a set of vertices with edges connecting them. In the most general case, a graph-based path finding algorithm will try to find a set of nodes to visit in order to be able to connect two requested nodes. Many of these algorithms try to find out the path of *minimum* cost, given a cost function to evaluate the alternative paths and a set of spatial constraints. However, despite graphs are widely used, and there exist very efficient algorithms to deal with them, they also have important implications that must be considered.

Probably the most important issue is the fact that graph-based algorithms work in a *discrete* version of the space, i.e. the map. This may not be a problem in some kind of tiled maps, where graphs fit effortlessly, but it is when the map is described as a continuous space as it occurs in *eCoology*.

Graph nodes are considered the positions of the space that can be reached and therefore, it quickly becomes obvious that an infinite amount of nodes would be necessary to cover the whole area of the map. Moreover, those moving entities could be flying entities as well, which would mean having three-dimensional maps with an exponential number of nodes. Since this is usually not feasible, the immediate consequence of having a finite amount of possible destinations is that moving entities are only able to reach *certain* places on the map, which is not acceptable in an interactive augmented reality application.

Think about a frequent situation in *eCoology* where an animal is wandering around the map. Then it is called by its owner, located in a random position on that map which the animal *can not reach* according to the underlying graph. The perceived experience would be that the animal disobeys his orders, or acts silly, coming closer and then stopping at some point before actually reaching him.

Extreme solutions like a massive graph covering the whole map do not seem the way to work around the problem due to computational costs, besides that reducing their density with variable-grain discretisation would result in an accuracy decrease. On the other hand, the user cannot be expected to move to a *reachable* position for the animal, in order to be able to call it. Trying to force users to behave this way would evidence the inner working of the application and, therefore, heavily penalize the immersive user's experience. Thus, an approach based only on graphs seems not to fit well enough the *eCoology* path-finding requirements, and will be enhanced in our context with a different technique: particle systems.

Particle Systems

A particle system can be seen as a small physics simulator where individual elements, the particles, are treated according to a set of real-physics laws [16]. Particles are defined with a set of physic properties (e.g. position, speed, acceleration, mass, etc.) and they are usually treated as punctual entities, they have no extents in space. Given a set of particles, usually generated by an *emitter*, a simulator is in charge of updating each particle life cycle, which is usually limited. Since the moment a particle is spawn, its properties are updated on discrete time spans according to the current active physic laws –i.e. the *rules* of the simulation.

In order to define a way for particles to interact with their environment, another kind of element is introduced in the simulation: deflectors. Deflectors are objects which the particles can collide with. They are characterized by their shape –a plane, sphere…- and properties like friction, which determine particles' reaction when colliding with them. The horizontal bar in Figure 5 is a plane deflector.

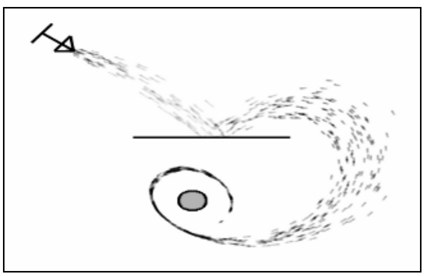

Fig. 5. A particle system

Using the elements defined so far, a simple navigating system can be implemented. Moving entities are modeled as particles, providing them with physical properties like their mass and, optionally, constants that constraint their maximum velocity and acceleration. The desired destination for a given entity is defined as an attractor, which will make its particle tend towards to it and eventually reach the destination. Finally the environment is modeled using deflectors which prevent the particles from going through the walls. See Figure 6.

One substantial benefit of this approach with respect to graphs is that particle simulation works in continuous space rather than discrete. This means an entity would

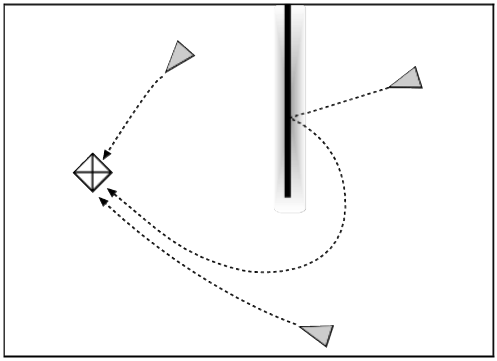

Fig. 6. Particle-based navigation

be able to move as smoothly as desired across the map. Moreover, since it is not restricted by a discrete space, it is possible for it to reach –almost- everywhere.

The continuous evaluation of the environment conditions –i.e. existing forces- makes paths able to <u>*react*</u> to changing conditions, which a static generated path can not take into account. Reaction to changing emotional as well as physical space conditions is a fundamental requirement in *eCoology*.

Path Finding in *eCoology*

When evaluating the requirements for the path-finding component in *eCoology* it was decided to take the best from both graph and particles, in order to create a powerful yet flexible system. This way, our hybrid approximation is based on a particle system but also reinforced with graph-based algorithms concepts.

In general terms, the characteristics of a scenario in *eCoology* are indoor spaces where the activities take place. Thus, scenarios are built up from sets of planar and spherical **deflectors** that define the walls or solid elements, and **attractors** which define points of interest a given entity may want to walk towards. Each particle also implements a repelling force for the rest of particles, preventing entities to “collapse” when forming groups.

However, these elements in isolation result in entities colliding and bouncing against the walls, making them appear as non natural elements in the augmented space. To solve this problem several refinements are introduced. Firstly, entities are given properties commonly used in *vehicle physics* [17] such as mass, acceleration, and velocity, which results in a smooth and more pleasant movement. Secondly, besides having normal colliding functions, deflectors play two more important roles in *eCoology*. On the one hand, they are considered as **repelling elements,** forcing particles not only to avoid colliding with them, but also to try to dodge them as long as the remaining forces allow it. Note this *smoothes* the performed trajectories and, even more important, it makes entities not looking blind when trying to “touch” the walls before dodging them.

On the other hand, deflectors are also **occluding elements**, i.e., entities cannot see through them. This is to simulate a natural behavior, the sight sense. In our path-finding system, a particle is not –directly- attracted, or repelled, by an object if it cannot be seen. So this apparent hinder in the normal functioning of the particle system actually has its justification for the sake of movement realism.

However, at the end, it is always desired for an entity to be able to reach its attractor whenever the map allows it. To achieve this goal we cover the map with a simple graph, making sure the important areas have a node in them. We call these nodes *buoys*, and they are not actually used to solve the path but helping the particle system to do so. Each buoy links those other buoys that are *visible* from its position, those that are not hidden by any occluding element. Then, when a particle looks for its attractor, it may make use of the underlying net of buoys to find it, in case it is not directly visible. A simplified version of the algorithm is given next:

```
Given a destination D for an entity
While D not reached do
    If have an assigned attractor which is visible then
        Update physics simulation
  else
        Check D's visibility against occluders
        If  D is directly visible then
            Assign an attractor located at D
        Else
            Obtain a suitable buoy which leads us to D
        End if
  End if
end while
```

List 1. Pseudo code of path solving process

A practical example of this process is shown in Figure 7. The upper figure shows two particles sharing the same attractor. The one on the left has direct visibility, so it can perform the simulation and accelerate towards its destination. However, the remaining particle has two deflectors hindering its way. It will then make use of the buoys, symbolized as “b” in the figure, to solve the way to go, and sequentially locate its attractor on each of them. Moreover, note its trajectory will be smoothed due to the vehicle physics –accelerations and decelerations-, and the repulsion of the deflectors, preventing from sudden changes in direction.

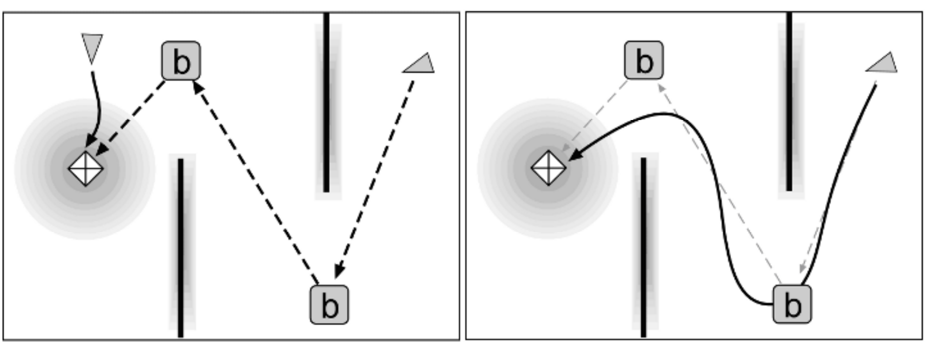

Fig. 7. Path solving

Obtaining a suitable buoy, as it is pointed out in our algorithm, is a slightly more complex process, which involves both "low" level information –the map- and the higher level behavioral processes. Think about a destination for an entity that can be reached from several alternative ways. Our algorithm would not obtain a single buoy, but rather a **set** of possible alternatives. Each one of those alternative paths is then presented to the controlling emotional behavioral layer, requesting a validation or rejection for it, as it was described in the previous section. If a proposal is rejected, then a backtracking process is performed, obtaining another possible alternative until an emotionally valid path is found. If the algorithm runs out of possible paths, the behavioral system is notified, so it can perform the proper actions. This backtracking method produces paths that exhibit both individual and collective group emotional behaviors [18]. For instance, in case of a group of frightened entities having a common threat, a collective defensive movement can be easily included in the system by assigning the same attractor to all the entities forming a group and dynamically positioning it in the geometrical center of the group. This makes our path finding mechanism a flexible tool for implementing multiple emotional movement schemes within the augmented space.

5 Conclusions

We have presented in this paper *eCoology*, an AR edutainment application with emotional components to enhance the learning process. Particularly interesting are our model of emotional entities that calculate their paths in the augmented space according to emotional states encouraging children to analyze and solve existing problems in the ecosystem. The proposed model is generic enough to implement a whole range of emotional movements in the augmented space in a non procedural way. Our future work includes the study of more complex emotional interaction mechanisms based on voice analysis that help users to interact with entities in the ecosystem in a natural way. The final goal is to evaluate how social and emotional concepts may help to reach *flow* not only in learning environments but also in any other AR application.

Acknowledgments

Our thanks to the Microsoft Research Labs in Cambridge for supporting us, under grant "Create, Play and Learn" [19].

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