Modeling the Spatial Behavior of Virtual Agents in Groups for Non-verbal Communication in Virtual Worlds

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Abstract

In this paper we propose a mathematical model for the concept of Personal Space (PS) and apply it to simulate the non-verbal communication between agents in virtual worlds. Persons within a group tend to maintain the distances between each other within a certain range that maximizes their degree of comfort. These distances reflect the type of their relationship, and changes in these distances reflect the evolution over time of their relationship. Human-like autonomous virtual agents should be also equipped with such capability to simulate natural interactions in virtual worlds. First we model the space around an agent as a probability distribution function which reflects at each point in the space the importance of that point to the agent. The agent updates dynamically this function according to (1) his relation with other agents in the virtual space, (2) his face orientation, and (3) the evolution of the relationship over time as a stranger agent may become a friend. We demonstrate the concept on a multi-agent platform and show that space-aware agents exhibit better natural behavior.

1 Introduction

Everyone holds, preserves, updates a space around him, and reacts when it is violated by another person. In public spaces, for example, people implicitly interact with each other using the space around them. This concept of Personal Space (PS) is well studied in psychology and sociology [Hall 1968; Hall 1990] and is considered as a non-verbal communication channel between people. The PS concept extends also to virtual worlds such as Second Life and computer games which are populated with human-like virtual agents and avatars. Recent studies [Friedman et al. 2007] show that people tend to maintain the same space around their avatars. This suggests that PS is an important factor that should be taken into account when designing autonomous virtual agents with human like behavior. For example given two agents A and B talking to each other, or one walking towards the other, at which distance to each other they should stand?

In this paper we focus on the non-verbal communication between human-like virtual agents. The goal is to develop personal space aware autonomous virtual agents. Given two or more agents interacting in a virtual space, they should maintain some distances between each other depending on the pairwise relationships. To do so, we define three types of relationships; (1) stranger relationship, (2) business relationship, and (3) friendly relationship. First we propose a mathematical model of the PS. The model quantifies the importance of each point in the space around the agent. The agent updates dynamically this model according to (1) his relation with the other agent, (2) his face orientation, and (3) the evolution of the relationship over time as a stranger agent may become a friend.

This paper makes the following contributions:

- First we propose a general mathematical model of the personal space (PS). It is controlled by two parameters: the position of the agent in the 2D space, and its face orientation. The model is general in the sense that it can model also interactions between agents and objects present in the virtual world.
- We use the Personal Space model to find automatically most comfortable distance virtual agents should keep between each other when interacting in the virtual space.

The model we propose differs from previous work in two aspects:

- First, our model takes into account the face orientation in contrast to previous works which are based only on the pairwise distances.
- Previous work define only a minimum distance that should separate two virtual agents. The model we propose in this paper assumes that an agent should stay within a range of distances from other agents. This is particularly useful from group interaction where standing far away from a group is not natural.

Results of this work can be applied to modeling the behavior of autonomous virtual agents and avatars in virtual worlds, analyzing people behavior in a crowd, as well as robot-human interaction.

2 The Personal Space model

Given a virtual agent P located at coordinates $p(x,y)$ we define a local coordinate system centered at p, with X axis along the face and Y axis along the sight direction as shown in Fig. 1. The personal space around the agent P can then be defined as a function Φ_p which has its maximum at p and decreases as we get far from p. This can be represented by a two-dimensional Gaussian function Φ_p of covariance matrix Σ, and centered at p:

$$\Phi_{p,\Sigma}(q) = e^{-\frac{1}{2}(q-p)^t\Sigma^{-1}(q-p)}. \quad (1)$$

where Σ is a diagonal matrix defined as $\Sigma = \begin{pmatrix} \sigma_x^2 & 0 \\ 0 & \sigma_y^2 \end{pmatrix}$. The parameters σ_x and σ_y define the shape of the PS. This model assumes that the shape of the front and back areas of the PS are similar. However, previous studies show that people are more strict regarding their frontal space [Shozo 1990]. Therefore the PS in the front of people is larger. We use this definition in our implementation. We build this model by blending two Gaussian functions as follows:

$$\Phi_{p,\Sigma_1,\Sigma_2}(q) = \delta(y_q)\Phi_{p,\Sigma_1}(q) + (1-\delta(y_q))\Phi_{p,\Sigma_2}(q). \quad (2)$$

where $q = (x_q, y_q)^t$ are the 2D coordinates of a point in the agent's coordinate system, $\delta(y) = 1$ if $y \geq 0$, and 0 otherwise. Φ_{p,Σ_1} models the frontal area of the person and Φ_{p,Σ_2} models the back area. They are defined as a 2D Gaussian function of covariance $\Sigma_1 = \begin{pmatrix} \sigma_x^2 & 0 \\ 0 & \sigma_{y+}^2 \end{pmatrix}$; and $\Sigma_2 = \begin{pmatrix} \sigma_x^2 & 0 \\ 0 & \sigma_{y-}^2 \end{pmatrix}$. respectively.

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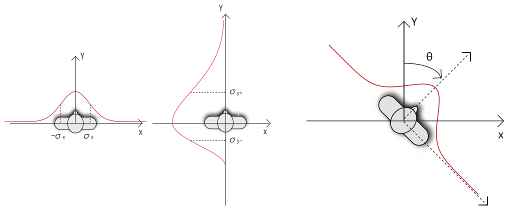


(a) (b)

Figure 1: The Personal Space model based on the face orientation. (a) The PS in the front area is wider that the back and side areas. (b) The PS model taking into account the face orientation.

The function δ blends the two functions and therefore it allows to take into account the face orientation. This concept is illustrated in Fig 1. Recall that, the personal space is a pairwise relationship which may not be symmetric. That is, given an agent A_i located at position p_i, we define its personal space with respect to agent A_j located at p_j as a function Φ_{ij} of parameters $p_j, \Sigma_1^{(i,j)}, \Sigma_2^{(i,j)}$.

To take into account the fact that an agent should evolve between a near and far distances to maintain his high degree of sociability, we define $\Phi_{i,j} = \Phi^-_{i,j} - \Phi^+_{i,j}$, where $\Phi^-_{i,j}$ of parameters $p_j, \Sigma_1^{(i,j)-}, \Sigma_2^{(i,j)-}$ corresponds to the near range, and $\Phi^+_{i,j}$ of parameters $p_j, \Sigma_1^{(i,j)+}, \Sigma_2^{(i,j)+}$ corresponds to the model of the far range.

Finally, to take into account arbitrary orientations we consider the angle θ between the Y axis and the direction of sight of the agent (its face orientation) as shown in Figure 1(b), and define define a rotation matrix R_θ which encodes this rotation. The new model is then defined by rotating the Gaussians of Equation 2 and the new covariance matrix, denoted by Σ_θ, is given by $\Sigma_\theta = R_\theta \Sigma R_\theta^t$ where R_θ^t is the transpose matrix of R_θ, and Σ is either equal to Σ_1 or Σ_2.

3 System

We model the virtual space in which the agents are evolving as a matrix U, which is a discretization of the floor plane. Each agent A_i will hold a matrix U_i which encodes at each location (x,y) the degree of comfort of this agent if he stands in that location.

Given two agents A_i and A_j, located at time t at points p_i^t and p_j^t respectively. In the next time step, A_i tends to move to an optimal position and orientation where he is comfortable with respect to A_j. The importance of each location (x,y) and orientation *theta* to A_i with respect to A_j is given by Equation 2. The face orientation of the agent embedded in the parameter Σ_i. The degree of comfortability of the agent A_i is then defined as:

$$U_{ij}(x,y,\theta) = 1 - \Phi_{ij}(x,y,\theta). \tag{3}$$

At each time step, the agent moves and rotates in order to maximize locally U_{ij}. Therefore the optimal solution is given by:

$$(x^*, y^*, \theta^*) = \arg\max_{x,y,\theta} U_{i,j} \tag{4}$$

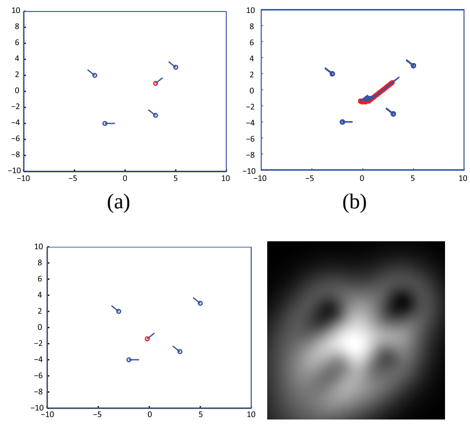
To solve this optimization problem we first discretize into a regular grid the space in which the agents are evolving. An agent located in a position (x,y) can move to any of the eight possible locations $(x \pm 1, y \pm 1)$, or stay in the same position (x,y). The agent also can rotate to any angle in the range $[0, 2\pi]$, but we constrain the agent movements to allow only smooth variations in his face orientation. We divide this range into N_{rot} equi-spaced discrete values. In our implementation we considered eight values with $\pi/4$ spacing. The size of the search space become $9 \times N_{rot}$ with $N_{rot} = 3$. Given this setup, we evaluate at each time step the $9 \times N_{rot}$ possible configurations. We choose the one with higher comfort value as the next position and orientation the agent should move to.

To handle multi-agents, we assume that the scene contains a fixed number N of agents, and every agent is aware of the number of agents in the scene, their location, and their orientation. The most comfortable configuration of an agent A_i is given by:

$$(x^*, y^*, \theta^*) = \arg\max_{x,y,\theta} U_i(x,y,\theta) = \arg\max_{x,y,\theta} \frac{1}{N} \sum_{j=1, j\neq i}^{N} U_{ij}(x,y,\theta). \tag{5}$$

The optimization proposed in this paper is performed independently at each time step, i.e., does not take into account the history information such as the path that an agent has taken. Incorporating such information and adding a smoothness constraint will guarantee smooth transitions which are suitable since sudden changes in an agent path is not natural.

4 Results



(c) (d)

Figure 2: The agent indicated in red searches for the location that maximizes his comfort. The face orientation is indicated with a blue line. (a) The initial configuration, (b) the estimated agent's path, (c)the final agent's position and orientation that maximizes his comfort, and (d) The comfort matrix maintained by the agent.

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