Modeling the Personal Space of Virtual Agents for Behavior Simulation

Toshitaka Amaoka
Department of Information Science
Meisei University, Japan
amaoka@is.meisei-u.ac.jp

Hamid Laga
Global Edge Institute
Tokyo Institute of Technology
hamid@img.cs.titech.ac.jp

Masayuki Nakajima
Computer Science Department
Tokyo Institute of Technology
nakajima@img.cs.titech.ac.jp

***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. The distance between two persons reflects the type of their relationship. Human-like autonomous virtual agents should be equipped with such capability to simulate natural interactions. We define three types of relationships; (1) stranger relationship, (2) business relationship, and (3) friendly relationship. 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 the other agent, (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.**

***Keywords*-Proxemics, virtual environment, autonomous virtual agents.**

I. 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 [5], [6] 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 [3] 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?

The goal of this paper 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.

The remaining parts of the paper are organized as follows; Section I-A reviews the related work. Section I-B outlines the main contributions of the paper. Section II details the mathematical model we propose for modeling the PS. Section III describes the multi-agent platform we developed and discusses different agent interaction scenarios when the personal space is enabled. Results are presented in Section IV. We conclude in section V.

A. Related work

Several works aim at reproducing the human behavior on virtual agents. There is however no HCI technology that interprets the meaning of distances between people, neither the use of communication through space and distance. This concept is reflected in the notion of Personal Space (PS) which is a non-verbal communication and behavior.

1) Psychology - personal space and proxemics: The concept of Personal Space, since its introduction by Edward T.Hall [5], [6] and the discussion by Robert Sommer [12], is studied and applied in many fields; Psychologists studied the existence of PS in Second Life [3], [14]. They found that many users keep a PS around their avatar and behave in accordance with it in the virtual world. PS is also an important factor that makes a virtual agent behave naturally and human like inside the virtual world [4]. In robotics, the PS is considered as a factor for selecting a communication method between a robot and a human [13]. It can be used for example to model the intimacy of a robot to other users.

2) Virtual agents: There are many studies for simulating natural conversation and behavior of virtual agents. Rehm et al. [10] focused on the conversation and cultural difference to make natural behavior in virtual world. They treated the first meeting scenario. Mancini et al. [7] proposed an Embodied Conversational Agents (ECAs) called Greta that are virtual embodied representations of humans that communicate multimodally with the user or other agents through voice, facial expression, gaze, gesture, and body movement. They studied what happens in real life, how people differ

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in their behavior depending on the personality and situation and build up their ECAs. Furthermore, many researchers study to make natural conversation and behavior to virtual agents as macro-level like group or crowds. McDonald et al. [8] proposed human behavior models (HBMs) that are able to control a single simulated entity (or a single group of simulated entities). However, HBMs developed by different groups are unable to interact with each other. This work mainly treats crowd control.

Rehm and Endrass [9] introduced an engineering approach for the integration of social group dynamics in the behavior modeling of multi-agent systems. A toolbox that brings together several theories from the social sciences, each focusing on different aspects of group dynamics, has been developed. They combined two methods of group dynamics theory to model the virtual agents behavior. Beltran et al. [2] presented an algorithm for simulating the movement of agents based on observed human behavior using techniques developed for pedestrian movement in crowd simulations and extended a previous group conversation simulation to include an agent motion algorithm.

The PS concept is based on many complex rules. Its shape and size are affected by several factors such as gender, age, and social position.

B. Overview and contributions

In this paper we focus on the communication between virtual agents. We assume three different types of relationships: business relationship, friendly relationship and stranger relationship. Two virtual agents behave under our proposed PS model which is based on Proxemics and Personal Space theory. Our method can simulate the behavior of virtual agents according to the relationship between them.

The contributions of this paper are three-fold; first we propose a mathematical model of the PS. It is controlled by four parameters: the agent's age, gender, position in the 2D space, and the face orientation. The relative positions and orientations of different agents present in the virtual world at a certain time are estimated automatically. At the current stage the gender and age are set manually by the user. Finally we use the Personal Space model to: (1) control automatically the speed of an agent when it is moving to meet another agent, and (2) find automatically a natural distance to the target a moving agent should stop.

The proposed method enables the modeling of the agent's mobile territory and his relationship with others. Results of this work can be applied to modeling the behavior of autonomous virtual agents and avatars in virtual worlds, as well as analyzing people behavior in a crowd.

II. Modeling the Personal Space

Edward T.Hall in his study of human behaviors in public spaces [6] found that every person holds unconsciously a mobile territory surrounding him like bubbles. The violation of this personal space by a tierce person results in an effective reaction depending on the relation of the two persons. This suggests that the concept of PS is a non-verbal communication between two or more persons. A location in the space around a person is classified into one of the four areas according whether it is within an intimate, personal, social, or public distance to the person. The personal space is then composed of all locations which are within the intimate or personal distance, as shown in Fig. 1.

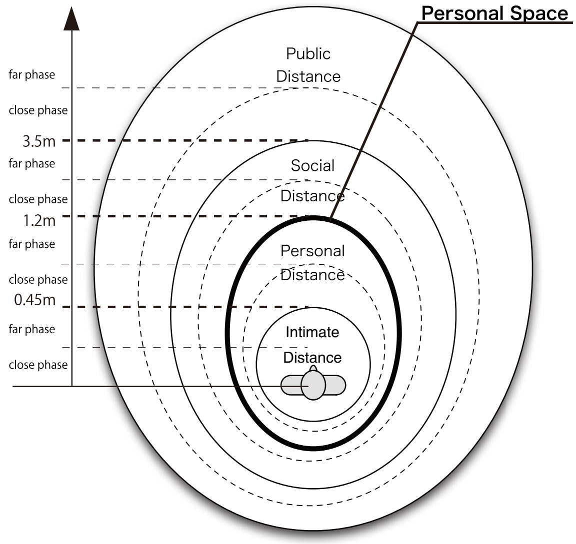


Figure 1. Definition of the Personal Space.

The shape of the PS is affected by several parameters. In this paper we consider four of them: gender, age, distance, and face orientation. The relationship between gender and PS is well studied by sociologists [6]. Many previous studies [11] suggested that the shape of the PS varies with the face orientation. For example, the PS is twice wider in the front area of a person than in the back and side areas.

A. Relationship classification

Social relationships that people maintain can be classified into three types: (1) business relationship, (2) friendly relationship and (3) stranger relationship.

The relationship of business associates includes the hierarchical relationship. For example if an employee meets with his boss, they keep social distance according to their social position. According to proxemics they communicate in social distance. This relationship will not change in the short term. When two virtual agents are under business relationship, they should keep a social distance in the range of 1.2 to 3.6m.

Friendly relationship is flat, very flexible, and varies according to several parameters such as personality and environmental conditions. According to proxemics communication is done mostly in the *not close* area of the personal distance. This distance varies from 0.45 to 1.2 depending on the degree of their intimacy.

Strangers basically do not have any relationship between them. This reflects, for example, the first meeting situation. This relationship may evolve over time as two strangers may become friends and keep meeting each other.

B. The model of the PS

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. 2. 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:

$$\Phi_p(q) = e^{-\frac{1}{2}(q-p)^t\Sigma^{-1}(q-p)}. \tag{1}$$

where Σ is a diagonal matrix:

$$\Sigma = \begin{pmatrix} \sigma_{xx}^2 & 0 \\ 0 & \sigma_{yy}^2 \end{pmatrix}. \tag{2}$$

The parameters σ_{xx} and σ_{yy} define the shape of the PS. Considering the fact that the PS is twice wider in front along the sight line than the side (left and right) areas, we define $\sigma_{yy} = 2\sigma_{xx}$.

This model assumes that the shape of the front and back areas of the PS are similar. However, previous studies pointed out that people are more strict regarding their frontal space. Shibuya [11] defines the PS in the front of people as twice larger as the back, left and right areas. We use this definition in our implementation. We build this model by blending two Gaussian functions as follows:

$$\Phi_p(q) = \delta(y_q)\Phi_p^1(q) + (1 - \delta(y_q))\Phi_p^2(q). \tag{3}$$

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^1 models the frontal area of the person and is defined as a $2D$ Gaussian function of covariance:

$$\Sigma_1 = \begin{pmatrix} \sigma_{xx}^2 & 0 \\ 0 & 4\sigma_{xx}^2 \end{pmatrix}. \tag{4}$$

Φ_p^2 models the back area of the person and is defined as a $2D$ Gaussian function of covariance

$$\Sigma_2 = \begin{pmatrix} \sigma_{xx}^2 & 0 \\ 0 & \sigma_{xx}^2 \end{pmatrix}. \tag{5}$$

Notice that the standard deviation of Φ_p^1 along the Y axis is twice the standard deviation of Φ_p^2 along the same axis. The function δ blends the two functions and therefore it allows to take into account the face orientation. This concept is illustrated in Fig 2.

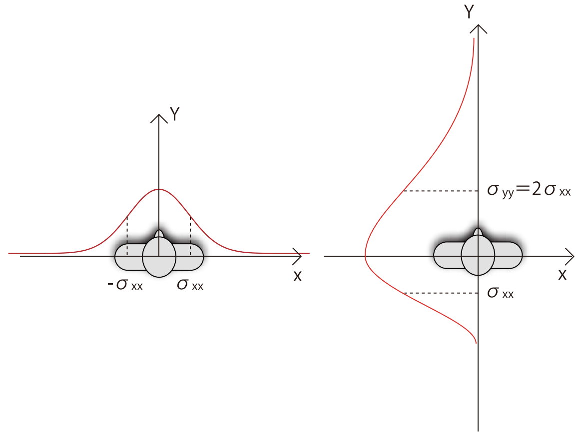


Figure 2. The Personal Space model based on the face orientation. The PS in the front area of a person is wider that the back and side areas.

In our implementation, we model the space where agents are interacting as a 2D plane parallel to the floor plane. We define a common world coordinate system and encode the floor plane as a 2D matrix. Every person P_i holds such a matrix (herein after referred as M_i). Each element of the matrix encodes the importance of the corresponding location to the person. The matrix is dynamic and is updated every time step δt. Fig. 3 shows the variation of this matrix according to location and face orientation.

In our implementation we define σ_{xx} as the threshold to which a specific zone of the space is violated. For example, to model the intimate space of a standard person we set $\sigma_{xx} = \sigma_0 = 0.45/2 = 0.225m$ as shown in Fig. 1. The figure gives also the standard values of σ_{xx} for different zones of the PS.

C. Parameterization of the PS

The personal space does not depend only on the position and face orientation but also on factors related to the person such as age, gender, social position, and character. These personal factors can be included in a function f that affects the value of the standard deviation σ_{xx}. In our implementation we consider only age and gender, hence:

$$\sigma_{xx} = f(\sigma_0, age, gender). \tag{6}$$

In the simplest case, f can be a linear function that scales σ_0 with a factor α reflecting how much a person is kin to protect his intimate space. This model is however not realistic. In our implementation we encode the age and gender dependency as a lookup table where each entry corresponds to the value of σ_{xx} given the age and gender.

Table I shows an example of such table as defined in [1]. The distances are given in centimeters, and are for Anglo ethnic group. The table also shows that the personal space

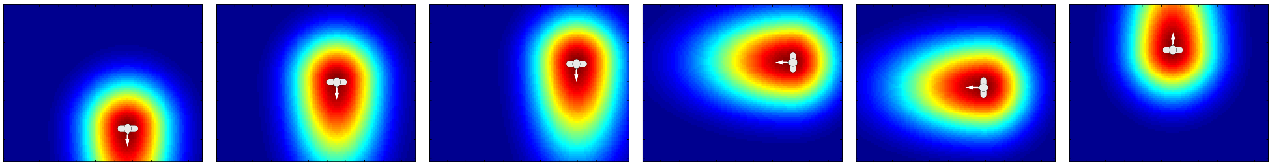


Figure 3. Illustration of the representation of the PS function as a 2D matrix where each cell encodes the importance of the corresponding location to the agent. The arrow indicates the face orientation.

Table I

VARIATION OF THE FRONTAL AREA OF THE PERSONAL SPACE WITH RESPECT TO AGE AND GENDER. THE VALUES VARY WITH ETHNICITY. WE CONSIDERED ONLY ANGLO ETHNIC GROUP IN INDOOR AND OUTDOOR LOCATIONS [1]. THE DISTANCES ARE IN cm AND ARE EQUIVALENT TO $2\sigma_{xx}$.

Sex combination	Indoor			Outdoor		
	Adult	Teen	Child	Adult	Teen	Child
M-M	83	83	63	83	75	62
M-F	71	63	58	79	68	58
F-F	75	62	59	75	73	67

Table II

VARIATION OF THE PERSONAL SPACE IN DIFFERENT SITUATIONS ACCORDING TO GENDER.

Relationship	Situation	$\sigma_0(cm)$
Friendly	Male approaching male	40
	Male approaching female	30
	Female approaching female	35
	Female approaching male	72
Stranger	Male approaching Male	110
	Male approaching female	100

varies depending on the situation such as being in indoor or outdoor environment.

Table II illustrates the variation of σ_0 according to the gender and in different situations. For example, in both business, stranger, and friendly relationship, the PS of a male agent approaching a female agent is slightly smaller than the case of the same gender.

In summary the Personal Space model is parameterized by two types of factors:

- The inter-personal factors, which include distances and face orientations, are embedded inside the parameter σ_{xx}. These two parameters are estimated automatically as the agent is moving and interacting with other agents in the virtual space (Section III).
- The personal parameters such as age, gender, and social position embedded in the function f. These parameters are input manually by the user and are encoded as a lookup table.

In the following we describe the multi-agent platform and scenarios we used for controlling the behavior of virtual agents with respect to their Personal Spaces.

III. SYSTEM

We model the virtual space in which the agents are evolving as a matrix U, which is a discretization of the floor plane. This approximation is reasonable since the movement of human-like agents is often horizontal. 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. To illustrate how the matrix U_i is built we consider first the a two-agent case, then show how the formulation extends to an arbitrary number N of agents.

A. The two-agents case

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 is trying to move to an optimal position and orientation where he is comfortable with respect to A_j. The importance of each location (x, y) to A_i with respect to A_j is given by Equation 3 and reformulated as follows:

$$\Phi_{ij}(x, y, \theta) = f_{p_j,\Sigma_i}(x, y) \tag{7}$$

where θ is the face orientation of the agent embedded in the parameter Σ_i. Φ_{ij} is normalized to the range $[0, 1]$ so it can be seen as a probability density function. The degree of comfortability of the agent A_i is then defined as:

$$U_{ij}(x, y, \theta) = 1 - \Phi_{ij}(x, y). \tag{8}$$

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

$$(x^*, y^*, \theta^*) = \arg\max_{x,y,\theta} U_{i,j} \tag{9}$$

A continuous solution can be obtained, but we adopt a discrete solution for the simplicity of implementation:

- First we 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) as illustrated in Figure 4.
- The agent also can rotate to any angle in the range $[0, 2\pi]$. We divide this range into N_{rot} equi-spaced discrete values as shown in Figure 4. In our implementation we considered eight values with $\pi/4$ spacing.
- This gives $9 \times N_{rot}$ possible configurations. However, we constrained the agent movements to allow only

smooth variations in his face orientation. Hence, at each time step, can remain unchanged or rotate with $+\pi/4$ or $-\pi/4$. 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. Notice that this optimization is local and is based only on the current knowledge of the scene configuration (i.e., the future positions of the other agents are not predicted in advance).

B. Extension to multiple agents

We extend the two-agent model to handle multi-agent case in a straightforward manner. 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 comfort function of an agent A_i is then defined as:

$$U_i(x, y, \theta) = \frac{1}{N} \sum_{j=1, j \neq i}^{N} U_{ij}(x, y, \theta). \tag{10}$$

and the optimal solution is then given by:

$$(x^*, y^*, \theta^*) = \arg\max_{x,y,\theta} U_i(x, y, \theta) \tag{11}$$

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. We plan to investigate the path smoothness issue in the future.

IV. RESULTS

To illustrate the personal space concept we propose in this paper we developed a basic multi-agent platform and conducted experiments using two virtual agents. At the internal representation, each agent is represented by its *geometry* and *personality* nodes. The personal space parameters are attached to the personality node.

Using the model of Equation 3 for interaction requires the each agent to sense the position and face orientation of other agents in the virtual world. We model the agents as smart objects allowing the agents to access each others information.

In the following we describe two interaction scenarios.

A. Single agent

To visualize the Personal Space of an agent we consider the three levels as shown on Fig. 1. We define a PS function for each zone using Equation 3. The user can set manually the factor α for each zone. Others like position and face orientation are estimated automatically.

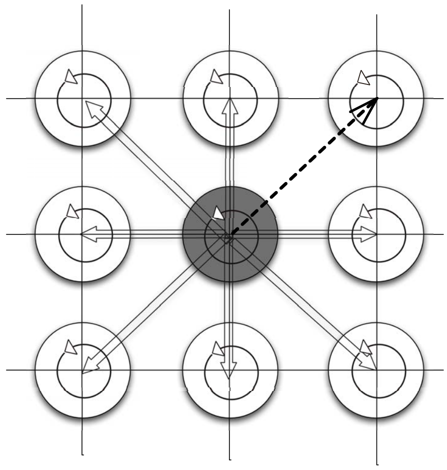


Figure 4. Illustration of the search space for the optimal position and orientation. An agent located in the central position can move in the next step to 9 possible locations or remain in the same location. At each location the agent can rotate into N_{rot} different rotations to maximize his comfort function.

The PS function as defined in Equation 3 can be also interpreted as the degree of the agent's response to the violation of a zone in his PS. Depending on its relation with the other agents, it activates one of the three functions.

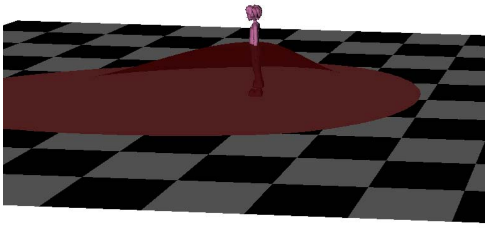
Figure 5(a) shows the shape of the personal space around an agent. Each point in the space is weighted by its important to the agent. This figure shows that our mathematical model behaves naturally: the frontal space is more important and therefore the PS is wider in the frontal area.

B. Two agents

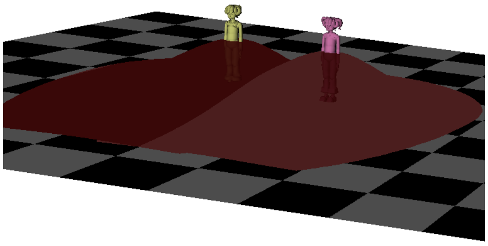
Figure 5(b) the case of two agents standing side by side and not looking to each other. As the agents personal spaces are smaller in the left and right area, they are allowed to get closer to each other. As the agent on the right starts rotating to face the other agent (Figure 5(c) and 5(d)) the shape of the PS function evolves, by following the face orientation, and assigning larger weights to the frontal locations.

When an agent moves to meet an other agent, it should stop at a certain location in a similar way to human. Our PS model allows the implementation of such behavior as shown in Figure 6; An agent A (on the left) moves to meet another agent B (on the right). Agent A automatically slows down as it gets closer to his target B. It automatically stops at a certain distance from the target, which is defined as when the importance of the location of Agent B to the Agent A exceeds a certain threshold.

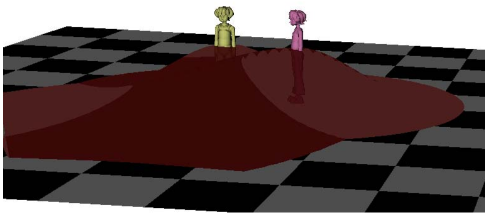
Notice that in existing systems such behavior cannot be implemented. Furthermore, our platform is flexible; each agent is equipped with a personality module and can be tuned independently of other agents.



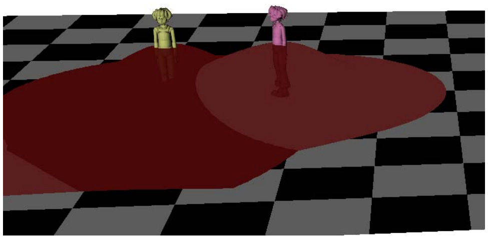
(a) The PS of a single agent



(b) Two agents not facing each other.



(c)



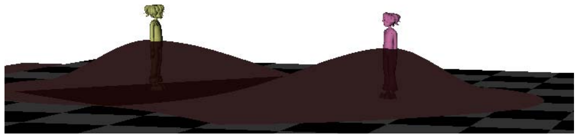
(d) Agent on the rights starts looking to the other agent: the PS is a mobile territory which rotates and moves with the agent.

Figure 5. Visualization of the personal space around an agent. The PS rotates with the rotation of the face of the agent. The value of the PS function returns the importance or weight of each point in the space to the agent.

C. Interaction between multiple agents

Finally we simulate how an agent moves in the virtual space in order to maximize his comfort, in the presence of multiple agents and with different types of relationships. Figure 7 illustrates the initial configuration, the agent's path towards his optimal position, and the final configuration.

(a)



(b)

(c)

(d)

Figure 6. An agent (on the left) moves to meet another agent (on the right). The moving agent automatically slows down as it gets closer to his target. It automatically stops at a certain distance from the target.

In this experiment we assume that all the agents are static except one. Figure 7(d) shows the comfort matrix maintained by the moving agent where white color encodes high comfort and black the low comfort.

V. Conclusion

In this paper we have proposed a mathematical model of the personal space. We particularly implemented a method for automatically incorporating two parameters of the PS: the position and face orientation of the agent. We demonstrated the effectiveness of the model on a platform of multiple virtual agents.

At the current stage, the search for the location and orientation that maximizes the agent's comfort is done locally. However, to guarantee a natural behavior, the agent path should be smooth. We will consider this issue in the future work. A possible solution would be to analyze the agent's path history and impose a smoothness constraint on the energy function that models the agent's comfort (Equation 10).

ACKNOWLEDGEMENT

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REFERENCES

[1] J. C. Baxter. Interpersonal spacing in natural settings. *Sociometry*, 33(4):444–456, 1970.

[2] F. S. Beltran, L. Salas, and V. Quera. Spatial behavior in groups: an agent-based approach. *Journal of Artificial Societies and Social Simulation*, 9(3), 2006.

[3] D. Friedman, A. Steed, and M. Slater. Spatial social behavior in second life. *Intelligent virtual agents 2007*, pages 285–295, 2007.

[4] M. Gillies and M. Slater. Non-verbal communication for correlational characters. *Proceedings of the 8th Annual International Workshop on Presence, London*, September 2005.

[5] E. T. Hall. Proxemics. *Current Anthropology*, 9(2-3):83–108, 1968.

[6] E. T. Hall. *The Hidden Dimension: Man's use of Space in Public and Private*. Anchor Books, Re-issue, 1990.

[7] M. Mancini, B. Hartmann, and C. Pelachaud. Non-verbal behaviors expressivity and their representation. 2004.

[8] D. McDonald, R. Lazarus, A. Leung, T. Hussain, G. Bharathy, R. J. Eidelson, N. Pelechano, E. Sandhaus, and B. G. Silverman. Interoperable human behavior models for simulations. 2006.

[9] M. Rehm and B. Endrass. Rapid prototyping of social group dynamics in multiagent systems. *AI Society*, 24(1), 2009.

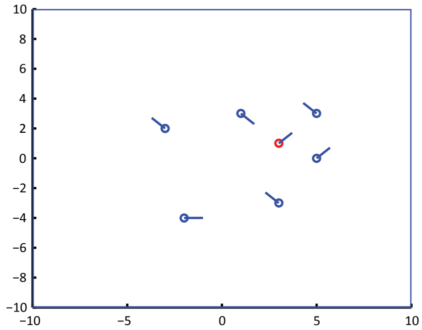
[10] M. Rehm, Y. Nakano, E. Andres, and T. Nishida. Culture-specific first meeting encounters between virtual agents. pages 223–236, 2008.

[11] S. Shozo. *Comfortable distance between people: Personal Space*. Japan Broadcast Publishing Co., Ltd, 1990.

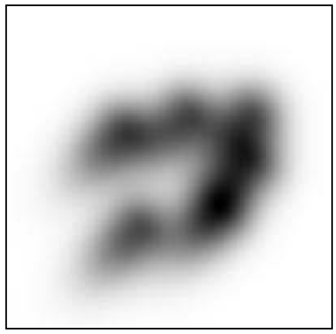
[12] R. Sommer. *Personal Space: The Behavioral Basis of Design*. Prentice Hall Trade, 1969.

[13] T. Tasaki, S. Matsumoto, H. Ohba, S. Yamamoto, M. Toda, K. Komatani, T. Ogata, and H. G. Okuno. Dynamic communication of humanoid robot with multiple people based on interaction distance. *Transactions of the Japanese Society of Artificial Intelligence*, 20:209–219, 2005.

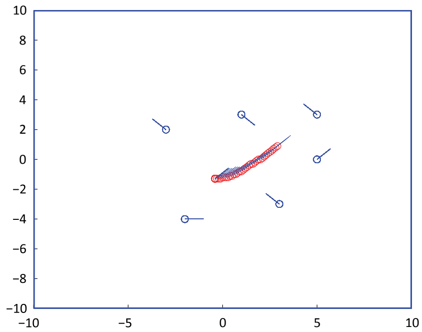
[14] N. Yee, J. N. Bailenson, M. Urbanek, F. Chang, and D. Merget. The unbearable likeness of being digital: The persistence of nonverbal social norms in online virtual environments. *Journal of CyberPsychology and Behavior*, 10:115–121, 2007.



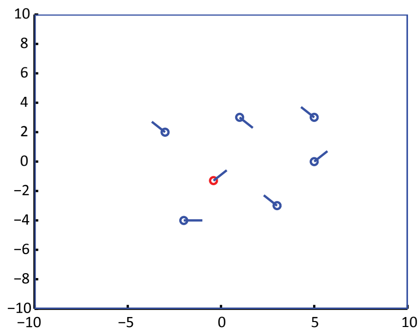
(a) The initial configuration.



(b) The comfort matrix, in the frontal direction, maintained by the agent. Each agent maintains $N_{rot} = 3$ comfort matrices, each corresponding to one possible face rotation.



(c) The estimated agent's path.



(d) The final agent's position and orientation that maximizes his comfort.

Figure 7. Multiple agents. The agent indicated in red searches for the location that maximizes his comfort. The face orientation is indicated with a blue line.