Affectivity and Proxemic Distances: an experimental agent-based modeling approach

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Abstract

Many manifestations of interactive human behavior (social and with the environment) are conditioned by emotions, influencing reasoning and other rational decision making activities. The study of the interplay of emotional and non-emotional behaviors (spatial motion) is here faced through the modeling of *affective agents* where *affective states* are explicitly measured and represented thanks to the collection of data in a dedicated experiment with humans. During this experiment, we observed that subjects of different ages (focusing on elderly) react differently to particular spatial stimuli (proxemics distance calculation), manifesting a strict relation between distancing and emotional states. The agent-based modeling and simulation of this behavior here presented is a contribution to the comprehension of complex interplays between spatial distances and affective states, amplified by the recent experience of pandemic, where aware distancing become a mandatory and affecting factor of the life, especially for fragile and aged people. The presented modeling approach relies on data collected with an online experiment performed to understand what kind of personal, psychological and situational factors influenced people's behavior while distancing from others, in particular during the COVID-19 pandemic. The focus of the experiment was in the comparison of different age reactions, involving 80 participants aged between 16 and 92 years.

Keywords

affective agent, proxemics, social distancing, COVID-19

1. Introduction

Simulating a human subject and his behaviour is an always up-to-date research topic, especially in the artificial intelligence field: adopting an agent modeling approach often comes as the most natural way to represent a human, since the definition of an agent [1] as a hardware or software system situated in an environment, autonomous, reactive, proactive and social directly maps to the main features of a human too.

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The role of emotions and affect in producing more realistic agent behaviors is becoming increasingly crucial, given the important part they play in the interactions a person has with others and with the environment in which he/she lives. Emotional reactions in a given environment affect the subject's behavior differently depending on the subject's age. For instance, elderly people appear less reactive in driving ability [2] and tend to behave more cautiously while walking and facing an obstacle, passing it only when they feel save [3]. Thus in the definition of an affective agent, the influence of age in the emotional perception of the environment should also be modeled.

In this paper we propose an "affective agent model", namely, an Affective Multiagent System, and we report its initial evaluation exploiting an Agent-Based Simulation that relies on data collected with an online experiment. The key idea is to define an agent that describes the behavior of subjects belonging to different age groups, while interacting with strangers, during the COVID-19 pandemic. The subjects behavior, and in particular the distance perceived as safe, are conditioned by the fear of getting sick and by the government's impositions on the distances to be respected, among other factors. This behaviour is strictly related to the concept of *Proxemics*, and of the dimensions of the human distances introduced and deeply studied by Edward Twitched Hall [4, 5, 6]. The paper is organized as follows. In Section 2 the context background and a quick review of the state of the art about affective agents and proxemics are reported. The online experiment and its results are synthesized and commented in Section 3. The core of our model proposal is detailed in Section 4, and the simulation where the model is tested on the data acquired by the online experiment is reported in Section 5. Finally, conclusions and future works are drawn in Section 6.

2. Background

In this Section, the context background and a quick review of the state of the art are reported. In particular, in the following subsections the definition of Multiagent Systems (MAS) and preliminary works that tried to model emotions in agents are briefly sketched. Furthermore the Hall's theory on proxemics and the factors that influence human distances are introduced to better understand the online experiment. This experiment provides the data for the Agent-Based Simulation reported in this paper to evaluate the Affective Multiagent System proposal.

2.1. Multiagent Systems and Agent-Based Simulations

Multiagent Systems (MAS) are well-known models for modeling and studying and complex systems. Formally, a MAS is a collection of a certain number n of individuals or entities, called *agents*, each of them identified by an index $i \in \{1, \dots, n\}$ and taking a state from a set S, called the *set of states*. The state of each agent includes the information about the position of the agent itself inside the common d-dimensional space $X \subseteq \mathbb{R}^d$ where all the agents are situated. A *configuration* of a MAS is a snapshot of all states of the agents, *i.e.*, a vector $c = (c_1, \dots, c_n) \in S^n$, where for every $i \in \{1, \dots, n\}$, the element $c_i \in S$ is the state of the agent i. For each $i \in \{1, \dots, n\}$, the i-th agent updates its own state according to a map $f_i : S^n \to S$ on the basis of the states of (possibly all) the other agents. All the agents update their own state synchronously at each discrete time step. In this way, the overall update of the states of all the agents at any time step is described by the *transition function* $F : S^n \to S^n$ defined as:

$$\forall c \in S^n, \quad F(c) = (f_1(c), \ldots, f_n(c)) \ ,$$

and hence the sequence $\{F^t(c)\}_{t \in \mathbb{N}}$, is nothing but the *dynamical evolution*, or *orbit*, of a given MAS starting from its initial configuration $c \in S^n$, where for every $t \in \mathbb{N}$ the element $F^t(c)$ of that sequence is the configuration of the MAS at time $t \in \mathbb{N}$. We stress that the set $\{f_1, \ldots, f_n\}$ completely determines the transition function F of a MAS. Therefore, a MAS can be concisely defined as the triple $\langle n, S, \{f_1, \ldots, f_n\} \rangle$.

An *Agent-Based Simulation (ABS)* is a MAS as described before together with all the information needed for performing a *simulation*, *i.e.*, the description/reproduction of a specific dynamical evolution of the given MAS, or, better, a finite segment of that, including, for instance, the data for setting up the initial configuration of the MAS, the total number of time steps corresponding to the duration of the phenomenon the MAS models (the duration of the considered online experiment in our case), and so on.

2.2. Modeling emotions in Agents

In the case of agent-based simulations, the design of a new generation of systems supporting agent modeling taking into account emotions and affects represents a new research frontier, research that also prides itself of multidisciplinarity by involving human disciplines [7]. Numerous researchers have already started working towards integrating new factors into agent modeling, in order to obtain more realistic and plausible simulations, with different approaches to the matter leading to different objectives and results.

One first example can be given by investigating the works of Colombi et al. [8] and of Feliciani et al. [9]. In the presented papers, pedestrian agents with different behaviours were designed and modeled after observing people's behaviour in a real-live experimentation. Rather than concentrating on emotions, though, the researchers modeled the agents in their simulations to reflect the subjects' behaviour by focusing on movement and speed, basing their designs on the information contained in the videos recorded during the experimentation.

Adam et al. [10] introduced in their design the notion of fear as the only emotion involved in the agent modeling. Emotion dynamics and propagation were then modeled after popular psychological theories in literature.

Tsai et al. [11] focused their work on an evacuation modeling that contemplated spread of knowledge, emotional contagion and social comparison between groups of different agents. Their design too was influenced by previously done research on matter of evacuation scenarios and psychological theories.

Looking at works more concerned on human personality used as blueprint for agent simulation and modeling, Zoumpoulaki et al. [12] and Belhaj et al. [13] both focused their work on implementing emotion and personality inside their agents following famously recognized psychological models. In particular, the ones they contemplated were the OCEAN (or BIG5) model [14] and the Ortony Clore Collins (OOC) model [15].

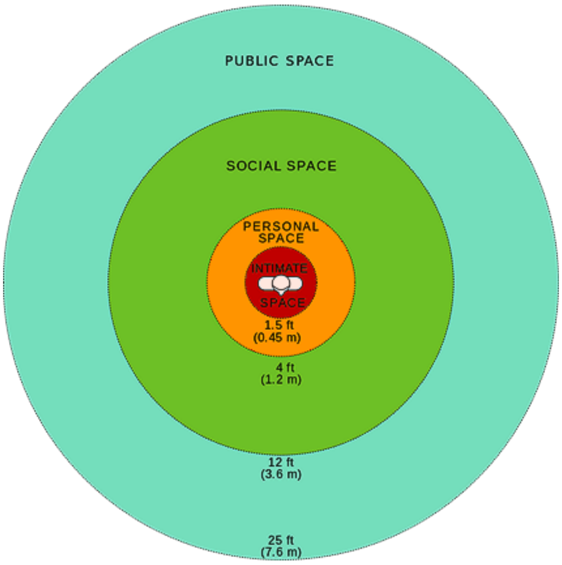

Figure 1: The four different spaces identified by Hall.

2.3. Proxemics

Proxemics is one among several subcategories in the study of nonverbal communication, and the term was coined by cultural anthropologist Edward Twitched Hall in 1963. He described proxemics as an ensemble of interrelated observations and theories regarding human use of space. In particular, Hall focused on how people differently used the space because of their cultural differences. The anthropologist reported his findings in many publications [4], [5], [6]. The majority of studies done on proxemic behaviors relates to Hall's research and, in particular, to the definition he gave on four distinct zones on human interpersonal distances: intimate, personal, social and public (fig. 1).

Human behaviors regarding proxemic distances can be influenced by a series of factors: personal attitude, relationship, and cultural characteristics among others. Gender proved to be one of those factors. Women, in fact, show a lower tendency to physical contact, especially when interacting with people of the opposite gender, and stranger [16, 17, 18, 19]. More differences were found regarding age [20, 21, 18]. The concept of proxemic matures with increasing age: children under 12 interact with other at very close distances, sometimes entering the intimate space, then the interaction distance increases, hitting its apex during adulthood, while nearing elderly age, this distance starts to decrease once again, and this tendency seems to be justified by the lower social independence of the elderly [22]. Also, the perceived safety can influence the comfortable distance from the others [23, 23, 24].

2.4. Integrating Affectivity into Agent Modeling: the Case of Proxemic Distances of the COVID-19 era

The perception of safety while choosing a proper distance from another subject is strongly conditioned by the emotional state of the person, and influenced by the surrounding situation [25], [23], [26]. Nowadays this distance can also be linked to the fear of infection induced by the COVID-19 pandemic. Our risk perception is heavily influenced by information coming from the media and by our personal experiences [26, 27]. As a direct consequence, different intensities of fear, anxiety and stress inevitably condition interpersonal interactions and distances.

We decided to perform on online experiment to collect distances adopted while interacting with others during the COVID-19 era in different scenarios. These data are strongly conditioned by the affective state of the participant, not only as a consequence of government impositions, but also due to the fear of contagion. These distances depend on affective reactions among other factors and can be related to the four Hall's distances, and provide valuable data for an Agent-Based Simulation to support our proposal of Affective Multiagents System.

3. Online Experiment

The virtual experiment has the aim of collecting the distances perceived as comfortable by the participants in different environments. The experiment was made public between 27/12/2020 and 18/01/2021, We involved 80 subjects that had not previously contracted COVID-19, (44 women), between 16 and 92 years old, (25 of them elderly i.e. aged 65 and older).

The first phase of the experiment involved the administration of a questionnaire, introduced by a policy statement to better present the experiment and its finality. The participants were informed of the anonymous nature of the questionnaire.

The questionnaire was divided into three main parts, in order to gather different types of information:

- generic information: age, sex, sociability level, population density of their municipality and living conditions (with or without others).
- part administered only to elderly. The questions were focused on the aids the subject had (glasses, hearing aid, walking cane).
- information about the fear of being infected by the COVID-19 virus, and about the perception of safety during different day-life activities.

In the second part of the experiment, we developed virtual *figure-stop activities* inspired by previous studies [25, 28, 22]. The experiment can be described as follows:

- Subjects were presented an avatar (fig. 2), chosen in respect of their indicated gender and age group, positioned in an outdoor (park) or indoor (restaurant) environment.
- While their avatar was on the left side, there was another figure of opposite gender and age group, positioned on the left side of the environment (fig.3 right).
- Participants were then instructed to move their avatar towards the other figure through a slider, stopping when they felt that the distances between them and the figure could get uncomfortable if shortened further.

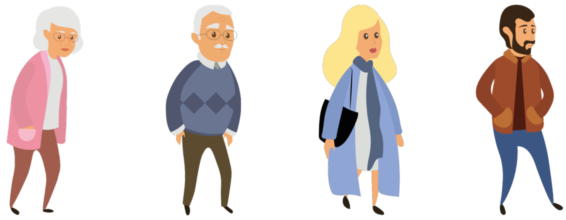

Figure 2: The four avatar used in the experiment, differentiated by age group and gender.

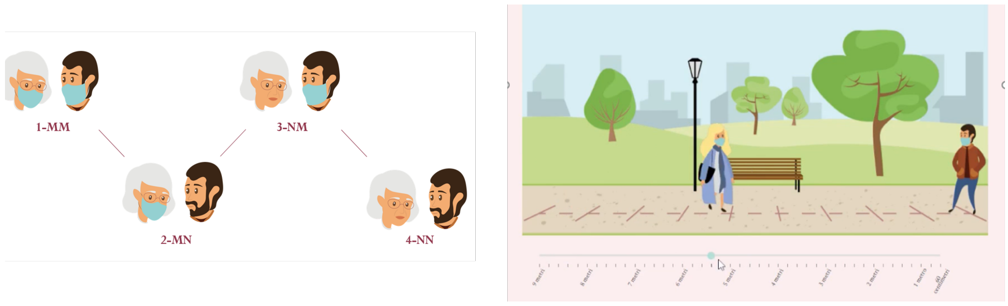

Figure 3: Left: The four mask configurations, right: the figure-stop activity in the outdoor environment.

A total of eight tasks were presented to the participants, using both of the environments previously mentioned and four different mask configurations (fig. 3 left) for the figurines in each of the environments: (1) the subject's avatar and the other avatar both had a mask on, (2) only the subject's avatar had a mask on, (3) only the other avatar had a mask on and (4) no avatar had a mask on.

The collected data were analyzed by applying a Generalized Linear Model (GLM).

We designed 6 between subject factors (gender, sociability level at home and outside, hearing problems, movement impairments and fear index), 1 between subject covariate (age) and 2 within subject factors (environment and mask).

We here report only the results obtained from the performed analysis, that are more related to our goal of defining an affective agent model. The factors that influence more distances are:

- gender: in particular females tend to leave their character farther away from the other figure;
- age: we noticed that, the older the person, the farthest was the distance adopted from the other agent in order to feel comfortable;
- mask conditions: people generally deemed safe being closer to the other figure when both of them had a mask on, while the complete absence of masks compelled them to stop way farther in order to remain comfortable;
- fear of contagion (evaluated from the questionnaire over 9 levels): people with lower fear levels adopt shorter distances, while people who fear contagion much more tend to stay farther from the others;
- sociability levels (evaluated from the questionnaire): people who do not usually interact

with people at home tended to adopt farther distances, and this tendency changed the more people were included in the participant household.

Thus, from data analysis of this experiment it is possible to correlate the distance perceived as safe with several factors, and to relate the distances, chosen varying the environmental conditions, to the 4 distances of the Hall space.

4. Agent Modeling

Starting from data collected with the online experiment, we intend to model an Affective Multiagent System able to capture the affective state of subjects while interacting with strangers and the corresponding distances adopted with respect to the four Hall distances. The information included inside the agent modeling coming from the experiment were gender, age group, mask information and Hall's proxemic spaces derived from the recorded distances.

4.1. Affective Multiagent Systems

We now define the MAS that integrates affectivity into agent modeling.

Definition 1. An *Affective Multiagent System (AMAS)* is a MAS $\langle n, S, \{f_1, \dots, f_n\}\rangle$ with set of states $S = X \times G \times M \times R \times A \times H \times D$, where

- $X \subseteq \mathbb{R}^d$ is the d-dimensional space of all the possible positions the agents can be in;
- G, M, and R are the sets of the binary values g, m, and r, respectively, that state, when associated with any agent i, if i is male ($g = 1$) or female ($g = 0$), if i wears a mask ($m = 1$) or not ($m = 0$), and if i can move around the environment ($r = 1$) or i stays in a fixed position ($r = 0$), respectively;
- $A = \{y, ya, a, e\}$ is the set of the age groups an agent can belong to (y = young, ya = young-adult, a = adult, e = elderly);
- $H = \{in, pr, sc, pb\}$ is the set of zones coming from Hall's interpersonal distances of humans an agent can embrace (in = intimate, pr = private, sc = social, pb = public); The individuation of one of these Hall spaces using different factors (as it will be later explained) influences the D value explained next, since every Hall space has precise upper and lower bounds;
- $D \subseteq \mathbb{R}^+$ is the set of values for the **minimum** distance an agent can have from any other agent.

In the sequel, for any state $s \in S$ and for each $j = 1, \dots, 7$, the j-th component of s will be denoted by s^j. In other words, we will write $s = (s^1, s^2, s^3, s^4, s^5, s^6, s^7)$, where, clearly, $s^1 \in X$, $s^2 \in G$, $s^3 \in M$, $s^4 \in R$, $s^5 \in A$, $s^6 \in H$, and $s^7 \in D$.

4.2. The AMAS modelling our online experiment

The AMAS modelling our online experiment is $\langle n, S, \{f_1, \dots, f_n\}\rangle$ where the number of agents is $n = 2$ and the maps $f_1, f_2 : S^2 \to S$ are defined as follows.

As to f_1, for any configuration $c = (c_1, c_2) \in S^2$, the state $f_1(c) \in S$ is such that

$$f_1(c)^1 = \begin{cases} c_1^1 + \operatorname{sgn}(c_1^1 - c_2^1) \cdot \delta & \text{if } |c_1^1 - c_2^1| < c_1^7 \\ c_1^1 - \operatorname{sgn}(c_1^1 - c_2^1) \cdot \delta & \text{if } |c_1^1 - c_2^1| > c_1^7 \\ c_1^1 & \text{if } |c_2^1 - c_1^1| = c_1^7 \end{cases}$$

where sgn is the standard signum function and δ is a positive real number which indicates the step length of the moving agent 1 ($\delta = 0.1$ in our model), while $f_1(c)^j = c_1^j$ for every $j \neq 1$.

The map f_2 is simply defined as

$$\forall c = (c_1, c_2) \in S^2, \quad f_2(c) = c_2$$

In this way, during the evolution of such an AMAS starting from any initial configuration $(c_1, c_2) \in S^2$, the following facts hold according to what happens in our online experiment:

- agent 1 can move, while agent 2 always stays in a fixed position (the initial one c_2^1);
- except the position of agent 1, all the other components of the state of both the agents keep unchanged;
- if $c_1^1 < c_2^1$, agent 1 always keeps itself on the left of the agent 2 and at each time step it moves to the right, resp., left, of a space quantity δ if its distance from agent 2 is at that time large enough, resp. too small, with respect to the limit dictated by c_1^7, while it no longer moves if it is as far as dictated by c_1^7 from agent 2.

5. Simulation

We decided to implement the present AAS on the Netlogo[1] platform (a free, open source simulation environment already widely used for agent based simulation) to simulate the data collected by our virtual experiment.

Figure 4 shows the Netlogo interface for the simulation after the environment and the agents have been properly instantiated through the setup function.

In the simulation, we took into consideration the variables that were identified during the modeling phase. We took the gender of the main agent, its age group and the mask configuration both its and of the second agent and, together with the environment type, we defined them as the variables the user can attune as wished before starting the simulation (the green buttons in fig. 4). The Hall space and the distance that the agent will reach before halting its movement and terminating the simulation execution are then showed below the simulation rectangle (the yellow windows in fig. 4), since these two variables are not actively chosen by the user.

The first thing that needs to be done to prepare the simulation is the proper set up of the initial configurations of the agents, the ones that we referred to as c_1 and c_2 in the previous section. In order to do this, every component of the two configurations needs to be instantiated accordingly to the role of the agent, the one that c_1^4 and c_2^4 specify. In our case, being the simulation a virtual transposition of the online experiment, two agents are involved in the simulation, where the

[1]Netlogo Homepagehttps://ccl.northwestern.edu/netlogo/

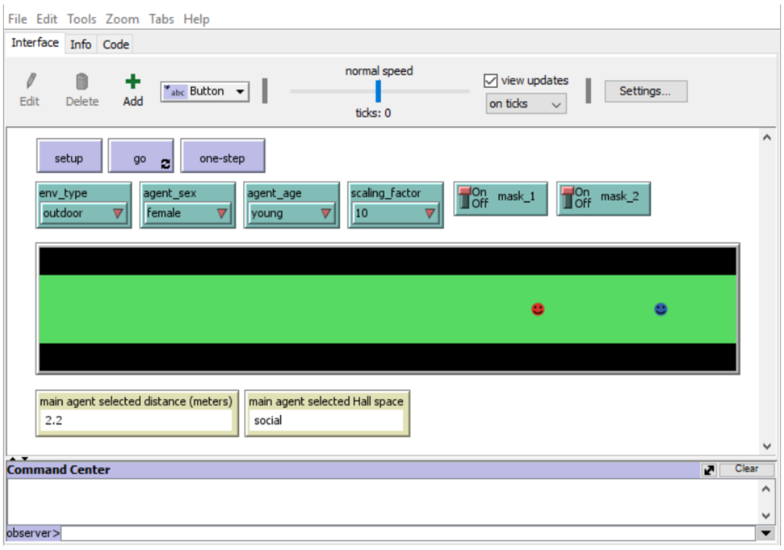

Figure 4: A screenshot of the Netlogo simulation after the setup. The light blue buttons are used to handle the simulation, the green buttons allow the user the desired parameters for the main agent (on the left) and only the mask for the secondary agent (on the right), while the yellow windows show the Hall' space and the distance of the main agent.

first and main agent (agent 1) is the one that moves and the second one (agent 2) remains still throughout the trial.

To be more precise, each value of the two agent configurations is selected in the following way:

- The initial position of the agent (c_1^1 and c_2^1) is randomly selected for agent 1 following a uniform probability distribution, while being set in coordinates $(200, 0)$ for agent 2;
- The gender of the agent (c_1^2 and c_2^2) is selected by the user just for agent 1, since for agent 2 it is automatically set as the opposite gender;
- The information indicating if the agent has its mask on or not (c_1^3 and c_2^3) is selected for both agents;
- The age group the agent belongs to (c_1^5 and c_2^5) is selected by the user just for agent 1, since for agent 2 this is not a relevant information and is thus left undefined;
- The Hall space embraced by the agent (c_1^6 and c_2^6) is selected for agent 1 by the system, which follows a discreet, non uniform probability distribution taking into account $c_1^2, c_1^3, c_2^3, c_1^5$. Each of the different combinations of these four factors leads up to a different probability distribution, previously extracted from the experimental results taking into consideration the same information. This value too remains undefined for agent 2;
- The maximum distance the agent gets to while approaching other agents (c_1^7 and c_2^7) is randomly selected for agent 1, following a uniform probability distribution, within the bounds identified before with the choice of c_1^6. Once again, since this could only provide a superfluous information for agent 2, this parameter remains undefined;

After everything has been properly set up, then, the simulation is ready to be started, and the main agent (on the left) acts just as the character the participants moved in the online experiment, with the only difference that now it can be placed near or far the other agent in order to observe its behaviour when its distance isn't respected from the start.

Following the behaviour described in sec. 4.2, the agent can found itself being far or near the other agent. In the first case, the simulation starts with the agent beginning to move towards the other one, and it ends when it gets too close following the distance randomly selected before. In the second case, the simulation starts with the agent going backwards since it needs to distance itself from the other agent in order to respect its distance, and it ends when the agent distanced itself enough.

6. Conclusion

In this paper we made a first step in formalizing an Affective Multiagent System integrating the notion of affective state, here related to safety perception, into a formal agent model that we were then able to concretely implement in our simulation. The interesting and encouraging results obtained are a good first start to proceed in this direction and investigate more this particular research area, and some next steps are already being contemplated in order to further this work, in particular in the direction of the Affective Multiagents modelling expansion. The example presented here is still in a primitive state, especially considering how not all of the variables introduced into the virtual experiment were contemplated when designing the agent tuple and the relative function.

Also, another fundamental step regards the validation of the model once its design is complete: trying in a real simulation the agents' behaviour and comparing it to the results obtained by the virtual experiment is a needed verification in order to understand if our model correctly depicts the information we acquired.

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