Towards Patterns of Comfort: A Multilayered Model Based on Situated Multi-agent Systems

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Abstract. The paper presents the agent-based model we developed to study crowd dynamics in multi-cultural aggregation contexts. Social and cultural aspects (in particular derived from proxemics theory) are explicitly modeled in order to study the social network resulting from local spatial interactions and cultural differences. To this aim, an agent-based model based on SCA*PED (Situated Cellular Agents for PEdestrian Dynamics) is presented, where pedestrian dynamics result from the local interaction and behavior of an heterogeneous system of autonomous entities situated into a structured environment. The proposed model represents pedestrians' behaving according to local information and knowledge on two separated yet interconnected layers representing different aspects of the overall system dynamics (i.e. Spatial and Proxemic layer). The model explicitly represents on Proxemic layer how cultural differences can influence the perception of neighbors. The model is presented as a formal approach to study comfort properties in spaces where multicultural crowds share a limited structured environment.

1 Introduction

In this paper we describe partial results of a multidisciplinary research we are conducting in order to develop a modeling and computational model for heterogeneous crowd systems in which cultural differences of crowd members are explicitly considered. Social and cultural aspects are explicitly represented in the agent-based model in order to take into account heterogeneity in the system of pedestrians who behave locally (i.e. according to local information) and interact at a physical level (i.e. due to limited shared space).

Traditional modeling approaches (mainly in computer science, fire engineering, building and urban design and planning) focus on pedestrian dynamics with the aim of supporting decision-makers and managers of crowded spaces and events [1] [2] [3]. However, some multidisciplinary proposals have recently been suggested to tackle the complexity of crowd dynamics by taking into account emotional, cultural and social interaction concepts [4] [5] [6] as well.

In this paper we propose an extension of an agent-based approach previously presented to study pedestrian dynamics (i.e. SCA*PED, Situated Cellular

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Agents for PEdestrian Dynamics [7]) towards a multi-layered model. According to agent-based modeling and simulation, crowds are studied as complex systems whose dynamics result from local behavior among individuals and their interactions with their surrounding environment [3] [8] .

After an outline of the main concepts of Hall's theory [9] [10] on perceived distance and proxemic behavior, we will describe the model based on SCA*PED modeling approach in which proxemic behavior and perceived distance concepts are included. SCA*PED models pedestrian dynamics as resulting from the local interaction and behavior of an heterogeneous system of autonomous entities. The proposed multi-layered model represents pedestrians behaving according to local information and knowledge on two separated yet interconnected layers representing different aspects of the overall system dynamics (i.e. *Spatial* and *Proxemic* layer). The Proxemic layer explicitly models heterogeneities in system members from the view point of the perception of neighboring individuals due to cultural differences. Whenever a local spatial interaction occurs at Spatial layer, the involved entities react differently according to their cultural specifications. In this paper we represent cultural differences according to Hall's theory. Such differences imply different perceptions which on their side allow the study of dynamic comfort properties given a multicultural crowd sharing a structured environment.

2 Perceived Distance and Proxemic Behavior

Proxemic behavior includes different aspects which could it be useful and interesting to integrate in crowd and pedestrian dynamics simulation. In particular, the most significant of these aspects being the existence of two kinds of distance: *physical* distance and *perceived* distance. While the first depends on physical position associated to each person, the latter depends on proxemic behavior based on culture and social rules. The term *proxemics* was first introduced by Hall with respect to the study of set of measurable distances between people as they interact [9]. In his studies, Hall carried out analysis of different situations in order to recognize behavioral patterns. These patterns are based on people's culture as they appear at different levels of awareness.

In [10] Hall proposed a system for the notation of proxemic behavior in order to collect data and information on people sharing a common space. Hall defined proxemic behavior and four types of perceived distances: *intimate distance* for embracing, touching or whispering; *personal distance* for interactions among good friends or family members; *social distance* for interactions among acquaintances; *public distance* used for public speaking. Perceived distances depend on some elements which characterized relationships and interactions between people: posture and sex identifiers, sociofugal-sociopetal[1] (SFP) axis, kinesthetic factor, touching code, visual code, thermal code, olfactory code and voice loudness.

[1] These terms were first introduced in 1957 by H. Osmond in [11].

3 The Two-Layered MAS

In order to integrate some aspects of proxemic behavior into an agent-based model of a crowd, we defined a constellation of interacting *Multi Agent Systems* (MAS) situated on a two-layered structure (i.e. *Spatial* and *Proxemic* layers in Figure 1). Following the SCA*PED approach definition, in each structure, the agents are defined as reactive agents that, as effect of the perception of environmental signals and local interactions with neighboring agents, can change their internal state or their position on the environment. According to SCA framework, each layer is defined by a triple

$$\langle Space, F, A \rangle$$

where *Space* models the environment in which the set A of agents is situated, acts autonomously and interacts through the propagation/perception of the set F of fields. The *Space* is modeled as an undirected graph of sites (i.e. $p \in P$). Each $p \in P$ is defined by $\langle a_p, F_p, P_p \rangle$, where $a_p \in A \cup \{\perp\}$ is the agent situated in p, $F_p \subset F$ is the set of fields active in p and $P_p \subset P$ is the set of sites adjacent to p. Fields can be propagated and perceived in the same or different layers. In order to allow this interaction, the model introduces the possibility to export (import) fields from (into) each layer.

In each layer, pedestrians and/or relevant elements of the environment (i.e. active elements) are represented by different types of agents. An agent type $\tau = \langle \Sigma_\tau, Perception_\tau, Action_\tau \rangle$ is defined by:

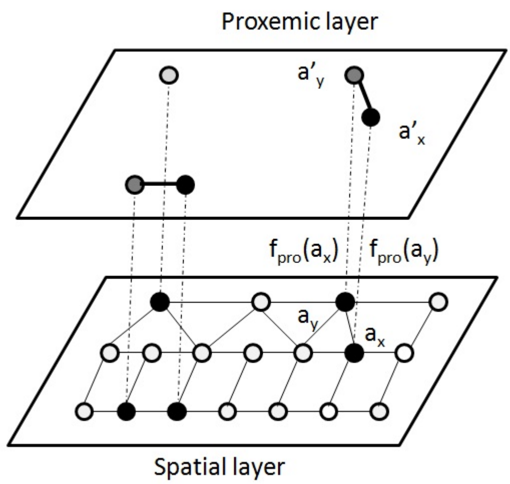

Fig. 1. Two-layered MAS model is shown. Spatial layer describes the environment in which pedestrian simulation is performed while Proxemic layer refers to the dynamic perception of neighboring pedestrians according to proxemic differences. When an agent $a_y \in A_{spa}$ enters the neighborhood of an agent $a_x \in A_{spa}$, both agents emits a field f_{pro} that is perceived by a'_y and a'_x in A_{pro}.

- Σ_τ: the set of states that agents of type τ can assume;
- $Perception_\tau$: a function to describe how an agent is influenced by fields defining a *receptiveness coefficient* and a *sensibility threshold* for each field $f \in F$;
- $Action_\tau$: a function to allow the agent movement between spatial positions, the change of agent state and the emission of fields.

Each agent is defined as a triple $\langle s, p, \tau \rangle$ where τ is the agent type, $s \in \sum_\tau$ is the agent state and $p \in P$ is the site in which the agent is situated.

In the remaining of the paper *Spatial* and *Proxemic* layers will be described. The first describing the environment in which pedestrian simulation is performed while the second referring to the dynamic perception of neighboring pedestrians according to proxemic distances.

3.1 The Spatial Layer

In the *Spatial* layer, each spatial agent $a_{spa} \in A_{spa}$ emits and exports to Proxemic layer a field to signal changes on physical distance with respect to other agents. This means that when an agent $a_y \in A_{spa}$ enters the neighborhood of an agent $a_x \in A_{spa}$, both agents emits a field f_{pro} with an intensity id proportional to the spatial distance between a_x and a_y. In particular, a_x starts to emit a field $f_{pro}(a_y)$ with information related to a_y and intensity id_{xy}, and a_y starts to emit a field $f_{pro}(a_x)$ with information related to a_x and intensity id_{yx}. Obviously, $id_{xy} = id_{yx}$ due to the symmetry property of distance and the definition of id.

When physical condition changes and one of the agents exits the neighborhood, the emitting of the fields ends.

Fields are exported into Proxemic layer and influences the relationships and interactions between proxemic agents. How this field is perceived and influences the agent interactions in the Proxemic layer, will be described in the next section.

3.2 The Proxemic Layer

As previously anticipated, *Proxemic* layer describes the agents behavior taking into account some aspects of Hall's theory. Proxemic layer hosts a heterogeneous system of agents where several types of agents $\tau_1, .., \tau_n$ represent different attitudes of a multicultural crowd. Each type τ_i is characterized by a perception function $perc_i$ and a value of social attitude sa_i. This value takes into account all the Hall's categories introduced before and indicates the attitude to sociality for that type of agent.

In this layer, space is described as a set of sites where each site is occupied by a proxemic agent $a_{pro} \in A_{pro}$ and connected to the corresponding site at Spatial layer. Proxemic agents are influenced by fields imported from Spatial layer by means of their perception function. The latter interprets the field f_{pro} perceived, modulating (amplifying or reducing) the value of its intensity id on the basis of sa value associated to agent type.

When in the Spatial layer $a_x \in A_{spa}$ emits a field with information on a_y, in the Proxemic layer $a'_x \in \tau_i$ perceives the field $f_{pro}(a_y)$ as:

$$perc_i(f_{pro}(a_y)) = sa_i \times id_{xy} = ip_{xy} \quad (1)$$

In the same way $a'_y \in \tau_j$ perceives the field $f_{pro}(a_x)$ as:

$$perc_j(f_{pro}(a_x)) = sa_j \times id_{yx} = ip_{yx} \quad (2)$$

Values ip_{xy} and ip_{yx} quantify the different way to perceive the physical distance between a_x and a_y from the point of view of a_x and a_y respectively.

Each $a_{pro} \in A_{pro}$ is also characterized by a state $s \in \Sigma$ which dynamically evolves on the basis of the perceptions of different fields f_{pro} imported from the Spatial layer. The transition of state represents the local change of comfort value for each agent[2].

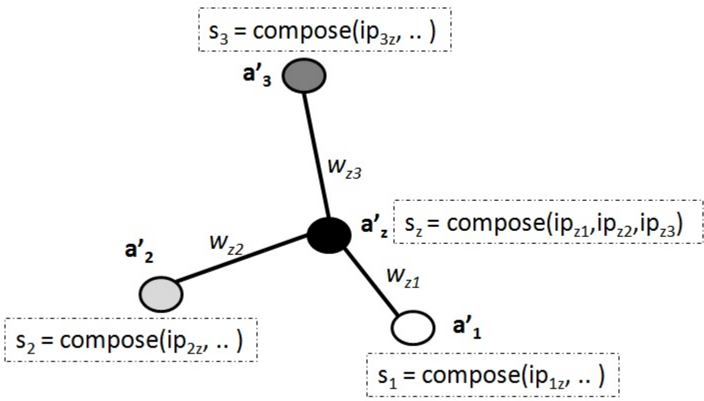

Fig. 2. A system of four agents where the state of agent $a'_z \in A_{pro}$ results from the composition of its perceived neighbors (i.e. $a'_1, a'_2, a'_3 \in A_{pro}$)

In particular, the state evolves according to the composition of the different ip calculated on the basis of interactions which take place in the Spatial layer. Figure 2 shows an heterogeneous system composed of four neighboring agents where the comfort state of each agent results from the composition of all perceived neighbors, that is for each $a'_z \in A_{pro}$:

$$s_z = compose(ip_{z1}, ip_{z2}, .., ip_{zn})$$

where $a'_1, .., a'_n \in A_{pro}$ are the corresponding proxemic agents of $a_1, ..a_n \in A_{spa}$ which belong to the neighborhood of $a_z \in A_{spa}$.

[2] State change may imply also a change in the perception. This aspect may be introduced into the model by specifying it into the perception function (i.e. $perc_i(f_{pro}, s) = perc_i(f_{pro})$. Future works will investigate on this issue.

After the perception and modulation of fields perceived, it is possible to consider the relationship between i and j in (1) and (2).

If $i = j$ the two agents belong to the same type (i.e. $\tau_i = \tau_j$) and the values ip_{xy} and ip_{yx} resultant from the perception are equal (i.e. $sa_i = sa_j$ and $id_{xy} = id_{yx}$ for definition). Otherwise, if $i \neq j$ the two agents belong to different types (i.e. $\tau_i \neq \tau_j$) and the values ip_{xy} and ip_{yx} resultant from the perception are different (the agents perceive their common physical distance in different way).

Proxemic relationships among agents are represented as an undirected graph of sites where edges are dynamically modified as effect of spatial interactions (occurring at Spatial layer) and social attitude sa. When a field is perceived from agent a'_x with information on a_y, an edge between a'_x and a'_y is created. When field emission ends (due to the exit of the neighborhood by one agent), the edge previously created is eliminated. The edge (x, y) is characterized by a weight w_{xy}:

$$w_{xy} = |ip_{xy} - ip_{yx}|$$

and represents the proxemic relationships between agents x and y. Obviously, only if $ip_{xy} \neq ip_{yx}$ the w_{xy} is non null.

3.3 Network Evolution on the Proxemic Layer

The evolution of the graph on the Proxemic layer is a dynamical process which depends from spatial changes, so it is possible to study how graph evolves. Let us consider the graph $G = (V, E)$ on Proxemic layer, where V is the set of nodes and E is the set of edges that connect pairs of nodes. In general, the graph G will be composed of areas with connected nodes and areas with non connected nodes. In particular, considering situations in which the density of spatial agents is medium, we can study the properties of the system identifying the heterogeneous and homogeneous areas, their changes and movements. In particular, two interesting cases are:

1. $G = (V, \emptyset)$: the graph is a null graph in which there are no edges. This situation occurs when all proxemic agents belong to the same type τ or when spatial agents are far from each other and there are not fields imported from Spatial layer;
2. $G = (V, E)$ and G is a connected graph (i.e. at least one path connects each couple of agents): this situation occurs when the system is characterized by high heterogeneity at Proxemic layer and high density at Spatial layer.

4 Future Works

This work is part of an ongoing research project with the aim of supporting crowd management of multicultural aggregation contexts, by taking into account cultural attitudes and comfort properties. Studying the dynamics of the Proxemic layer can fruitfully suggest feedback actions on the physical spatial structure that drives pedestrian movement. Preliminary investigations are ongoing about the study of network properties in order to identify available formal tools for this aim (e.g. 'small worlds' networks, the identification of clustering coefficient and the degree distribution [12]).

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