Situated Cellular Agents for Crowd Simulation and Visualization

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Abstract: The paper presents a Multi Agent Systems (MAS) approach to crowd modelling, based on the Situated Cellular Agents (SCA) model. This is a special class of Multilayered Multi Agent Situated System (MMASS), rooted on Cellular Automata, providing an explicit spatial representation and the definition of adjacency geometries. The model also defines a concept of autonomous agent, provided with an internal architecture and individual state and behaviour, capable of different means of space–mediated interaction (synchronous, between adjacent agents, and asynchronous among distant entities). Heterogenous entities may be modelled through the specification of different agent types, defining different behaviours and perceptive capabilities. After a brief description of the model, its application to simple crowd behaviours will be given (e.g. lane and group formation), and an application providing the integration of a bidimensional simulator based on this model and a 3D modelling application (3D Studio) will also be described. The adoption of this kind of system allows to specify, simulate and evaluate a design solution, but also to easily produce a realistic visualization of the simulation, in order to facilitate the communication with involved actors. In fact, while expert decision–makers often require only abstract and analytical results deriving from the simulation, other people involved in the decision–making process related to the design may be helped by other forms of graphical representation.

Keywords: multi–agent systems, simulation, crowd behaviour.

1 INTRODUCTION

The design of different kinds of environmental structures, at different detail levels, from the corridors or emergency exits of a building to the road system on urban or regional scale, requires some kind of simulation system, in order to evaluate strategies and designs before they are actually implemented. There are different approaches to simulation, based on different theoretical models, ranging from analytical ones [Helbing [1991]] to those based on Cellular Automata [Wolfram [1986]]. Rather than tackling simulation problems in a global manner, defining centralized solution methods that manage various aspects of the modelled system, they can be suitably reformulated in terms of local interacting agents, that try to achieve their own goals, by means of coordination or competition schemes. The solution, global system behaviour, is obtained as an emergent effect of agents' individual local behavior [Ferber and Drogoul [1992]]. In this framework, approaches based on Multi Agent System (MAS) principles [Ferber [1991]] that propose to focus on interaction aspects of agent groups and crowds have been defined. These works have shown that intelligent group behavior and solution to complex problems can be obtained as the result of interactions between agents characterized by a simple internal model [Drogoul [1995]]. A MAS could thus represent a mean of modelling those self–organizing systems that carry out the planning operation to obtain the solution of the design problem. MASs could even be useful in another kind of iterative design process, centered on simulation [Caneparo and Robiglio [2003]]. The latter could provide a first phase in which the designer makes some preliminary choices about the environment, the entities that inhabit it and their behaviour, then a cycle of simulations is performed and the design can thus be evaluated. If necessary it can be suitably modified, manually by the designer or in a semi–automatic way. Then a simulation, evaluation and adaptation cycle could be iterated until the design produces results that are considered acceptable.
The acceptance of the design is generally based on some kind of quantitative analysis of the simulation results performed by experts, but especially in

this area there are often stakeholders and people involved in the decision process that are not able to understand this kind of information. Where graphs and tables may not be effective, a realistic visualization of simulation dynamics can integrate them and allow non–experts to better understand the effects of the design on system dynamics.

The aim of this paper is to describe the Situated Cellular Automata (SCA) model, a particular class of Multilayered Multi Agent Situated Systems (MMASS)[Bandini et al. [2002a]], that has been designed for applications requiring an explicit representation of the spatial structure of the environment. This structure can be regular or irregular and agents' behaviour is strongly influenced by their position, as it is determined as a consequence of synchronous interaction with other adjacent entities (i.e. *reaction*) or according to the perception of signals asynchronously emitted by at–a–distance agents (i.e. *field diffusion*). Such a remote interaction represents a mean of modelling the concept of locality, while reaction can represent a direct cooperation between neighbours. The following Section briefly describes the SCA model, focusing on agent interaction, while Section 3 describes how to exploit it in order to represent crowd behaviours. Later two sample applications will be shown, respectively in indoor and outdoor situations. Conclusions and future developments will end the paper.

2 SCA MODEL

The SCA model defines MAS whose entities are situated in an environment whose structure (i.e. *space*) is defined as an undirected graph of sites. This Section is not meant to represent a thorough and formal description of the SCA model, but it will be focused on interaction mechanisms that it defines. In fact it will be shown that it is possible to focus on interactions and specify very simple reactive agents, obtaining realistic behaviours.

Agents may interact in two different ways: if they are adjacent in the environment structure they can perform an agreement process in order to synchronously change their state with a *reaction* operation; instead field emission–diffusion–perception mechanism allows at–a–distance, space–mediated, asynchronous communication mean. According to its own state and behaviour specification an agent may emit a field, defining its parameters (type and intensity value). Field values propagate throughout the space according to the diffusion function, specified by the field type. The $Perception_\tau$ function, characterizing each agent type τ, defines the perceptive capabilities of an agent. It defines whether

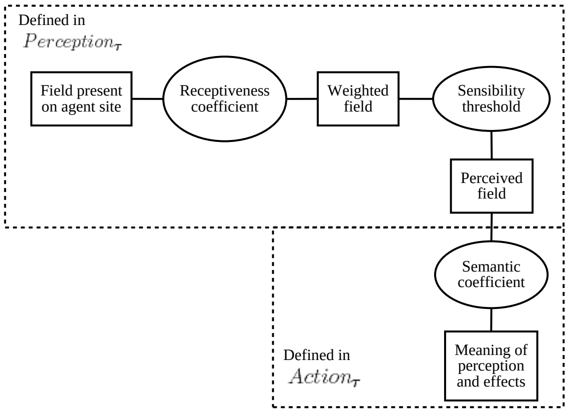

Figure 1: A schematic description of the perception mechanism.

or not a certain field is perceived by an agent or is neglected, as its value at the site is such that it is considered too faint. Field perception constitutes a fundamental aspect of the perception–deliberation–action mechanism that specifies SCA *agent behavior*. This mechanism describes agents as characterized by a set of possible actions, and a mechanism for the selection of the action to be undertaken based on the internal state and the position of the agents themselves. The set of possible actions (i.e. $Actions_\tau$) specifies whether and how agents of type τ change their state and/or position, how they interact with other agents, and how neighboring agents can influence them. In general, actions have two possible purposes: they can be undertaken by an agent in order to modify its state or position (*intra–agent actions*), or to interact with other agents in both synchronous or asynchronous ways (*inter–agent actions*). In the following more details of agents interaction and behaviour will be given.

2.1 Modelling signals through fields

Each agent is provided with a set of sensors that allow its interaction with the environment and other agents. At the same time, agents can constitute the source of given fields acting within the space (e.g. noise emitted by a talking agent). Each field is characterized by the set of values that the field can assume during its propagation throughout the space, a diffusion function, and field composition and field comparison functions that define field manipulation. The diffusion function of a certain field type computes the value of a field on a given space site taking into account in which site and with which value it has been generated (since the spatial structure is generally not regular and paths of different length can connect each pair of sites, it may return a number of values depending on the number of paths connecting the source site with each other site). The composition function expresses how fields of the same type have to be combined (for instance, in order to obtain the unique value of that field type at a site), and the comparison function that matches field values. For instance, in order to verify whether an agent can perceive a field type, its value at a site, modulated according to a receptiveness coefficient, and agent sensitivity threshold are compared by this function. A general agent interaction mechanism based on the field emission–diffusion–perception mechanism can be defined through the specification, for each interaction, of:

• a *field source* that can correspond to an agent (that may have a very limited behavior, modelling thus an object). For instance, fields can be emitted by agents to indicate their availability to fulfil given tasks (e.g. a guide agent in a museum, a policeman in a city, a public phone);

• a *function* to define field diffusion throughout the environment structure and that specifies how field values have to be modulated (e.g. when an agent moves far from a group of agents its view must be reduced and it is no more visible when he goes out from a room);

• a *field sensor* and *perception function* associated to each agent that allows the representation of different and dynamic agent perceptive abilities. Agent perception can be dependent on agent state, goals, and context (e.g. agent sensitivity to the presence of a fire exit must be higher in an emergency situation). Fields themselves are neutral even if they can have related information in addition to their intensity; they are only signals, with an indication on how they diffuse in the environment, how they can be compared and composed. Different agent types may be able to perceive them or not and, in the first case, they may have completely different reaction. Therefore, the effect of attracting or repelling objects or agents is obtained with the suitable definition of field types and behaviours related to certain agent types.

2.2 Perception and action

Agents are entities that are situated in an environment and that, according to an internal representation of their state, perceive their local environment (*perception*) and select within a set of possible actions (*deliberation*) in order to move, modify their state, and interact with other agents (*action*). Perception, deliberation and action characterize SCAs that can differ according to their type. Field perception for each agent and field type can be informally defined through the specification of the set of *fields* that agents are able to perceive (i.e. maximal agent capabilities, e.g. deaf agents can not perceive sound fields); a *sensitivity threshold* that indicates, according to agent state, the minimum field value that the agent is able to perceive (e.g. when they are involved in a conversation, agents are less sensitive to surrounding feeble noises); a *sensitivity coefficient* that modulates field values according to agent state (e.g. when an agent is in a hurry, it is more sensitive to exit and elevator signs). The perception mechanism is summarized in Figure 1: its first part is related to the physical possibility of the agent to perceive a signal in a certain situation, while the second one refers to the semantic value that the agent gives to the perception in the current circumstances. Agent behaviour can be specified using the L*MASS [Bandini et al. [2002b]] language that defines the following primitives:

• $reaction(s, a_{p_1}, a_{p_2}, \ldots, a_{p_n}, s')$: this primitive defined for agent a situated in the site p allows it to synchronously interact with agents $a_{p_1}, a_{p_2}, \ldots, a_{p_n}$, situated in $p_1, p_2, \ldots, p_n$ adjacent to p, that have agreed to take part in the interaction; the effect of this interaction is the change of its state from s to s';

• $emit(s, f, p)$: the $emit$ primitive allows an agent to start the diffusion of field f on p, that is the site it is placed on;

• $trigger(s, f_i, s')$: this primitive specifies that an agent must change its state from s to s' when it perceives a field f_i;

• $transport(p, f_i, q)$: the $transport$ primitive allows to define agent movement from site p to site q (that must be adjacent) upon reception of field f_i.

For all these primitive, some conditions (i.e. sort of guards on the execution of the related operation) on agent state and perceived fields can also be specified. In some cases these two parameters can be insufficient, as they are just related to a single site, therefore these conditions can include the intensity of fields present in adjacent sites. For instance, in order to specify a $transport$ operation, this is necessary to model the behaviour of an agent wishing to move to the adjacent site with the highest intensity of a certain field. In order to specify that a certain agent of type τ_a can attract agents of type τ_b one must respectively define a field type $F_{a \leftarrow b}$, specifying required parameters, insert a specific $emit$ action in $Action_{\tau_a}$ and a $transport$ operation in $Action_{\tau_b}$ indicating that the related agent of type τ_b should move towards the adjacent site with the highest value for field type $F_{a \leftarrow b}$. More precisely the $trasport$ action would be specified as follows:

$$\begin{aligned}
&action : transport(p, f_{a \leftarrow b}, q)\\
&condit : position(p), empty(q), near(p, q),\\
&\qquad\quad perceive(f_{a \leftarrow b}), best(q)\\
&effect : position(q), empty(p)
\end{aligned}$$

where p and q are sites, $position(p)$ specifies that the related agents is placed in p, $empty(q)$ indicates that site q is not occupied by other agents, $near(p, q)$ specifies that the arguments are adjacent sites (i.e. connected by an edge in the spatial structure) and $perceive(f_{a \leftarrow b})$ indicates that the agent is able to perceive a field $f_{a \leftarrow b} \in F_{a \leftarrow b}$. The additional condition $best(q)$ is verified when for all sites r adjacent to p and currently empty, the intensity of field type $F_{a \leftarrow b}$ is lower or equal than is site q. Repulsion requires the same operations, with a difference in the $transport$ action, whose destination is the site with the lowest value for the repelling field type. More complex conditions for the transport operation can cause interesting effects, such as an agent that keeps at a certain distance from the source of a specific field type, following thus its movement but avoiding contact. The definition of different field sources and types (or, equivalently, the inclusion of an indication of the related source in the information related to fields) allows to define different way–points, intermediate steps in a movement script. An agent may be perceptive to the first field type and move towards its source. When the perceived field intensity reaches a certain level, in other words when the distance has reduce under a certain degree, the agent may change its goal, becoming perceptive to the field emitted by the next way–point. In order to obtain more complex behaviours, related for instance to agents interests, goals, and more autonomous behaviours requires a more composite field definition, that should encapsulate more information than their simple intensity, and different agent actions. A formal description of the introduced modelling elements can be found in [Bandini et al. [2004 – to appeara]].

3 MODELLING WITH SCA

As previously specified in Section 2, the SCA model provides a discrete representation of the environment. The latter provides an abstraction of the actual spatial structure in which the simulation takes place. In order to exploit the SCA model, the first step is thus to describe the simulation scenario in terms of a discrete and possibly irregular network of nodes. Figure 2 shows the 3D representation of

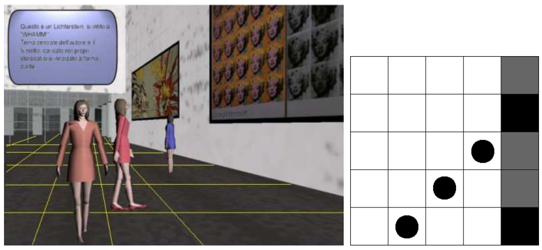

Figure 2: 3D representation of museum room and the related 2D representation with a grid structure.

a museum room and the related abstraction with a grid structure. Black squares are occupied by walls, grey ones represents artworks, while agents are represented with black circles. The decision on the granularity of the tessellation depends on the goal of the simulation and the features of the scenario: for instance, if the simulation goal is to evaluate the design of a corridor in an evacuation situation, the tessellation should reflect the actual dimensions of a human body and its space occupancy.

The second step is to describe the behaviour of various entities placed in the environment, in order to obtain a realistic system dynamic. With reference to the same figure, we could model artworks and doors as sources of fields that can have an attractive effect over agents roaming in the environment, according to their own internal state and goals. Agents may be perceptive to fields emitted by artworks placed at a distance lower than a specified threshold, and be attracted for a specific time interval, but only if they still have not already observed it. They may also be perceptive to doors and passageways, with a different priority: for instance they may decide to move from one room to another, following the field emitted by the door, after they have observed every artwork present in the room. The placement of field sources must be decided taking into account the diffusion function related to field types: in order to obtain a realistic behaviour of agents they should not be able to perceive the presence of an artwork if they do not see it. This consideration indicates that the diffusion of some signals can exploit the actual 3D model of the environment for the diffusion of specific field types, while for other ones (e.g. audible signals) the bidimensional abstraction can be enough to obtain believable system behaviour. The definition of fields and diffusion functions, with reference to the representation of the environment, is just one side of behaviour modelling. The other one is related to the specification of the actions undertaken by agents, for instance, as a reaction to the perception of a certain signal. Different entities may

Figure 3: A screenshot of a 3D application showing a procession formation.

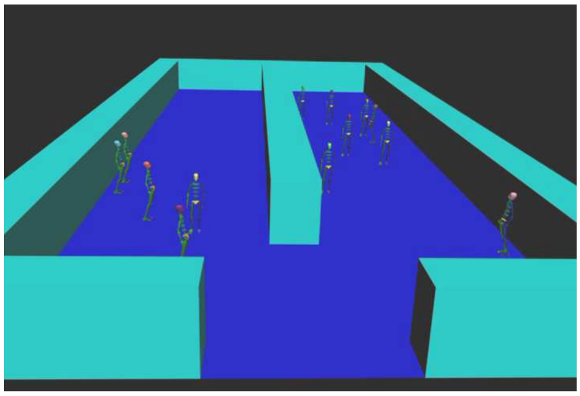

Figure 4: A screenshot of the animation produced by the 3D modelling tool in an indoor scenario.

react in a completely different way to the perception of the same field, and even the same agent can select different actions according to its own state. For instance, in order to specify that an agent should follow a specific path, the related way–points could be associated to field sources. The agent could be sensitive to the field emitted by the closest way–point and moving towards it, becoming sensitive to the next one once its distance becomes lower than a certain threshold. Moreover the way–points could be exploited by different agent types related to different paths. In other words the order of the points to visit could be defined in the behaviour specification related to a specific agent type, and sources could be just relevant points indicating their presence through the emission of a presence field. In the same way effects of attraction and repulsion can be defined in order to fine tune the behaviour of various entities roaming in the environment according to its infrastructure. Agents movement anyway can also be based on the behaviour of other active entities. In other words agents may be at the same time affected by fields but also sources of signals affecting other entities. For instance, a specific agent may be the source of a presence field that is considered attractive by a specific agent type. In this way crowds can concentrate around a leader and follow him/her in a procession (see Figure 3). In a similar way lanes and queues can be obtained specifying that every agent is only sensitive to the signals emitted by the preceding one, and having leaders that guide the crowd, following specified paths.

4 Sample experiments

One of the applications developed to implement SCA based simulations exploits a simulator based on a bidimensional spatial structure representation and an existing commercial 3D modelling instrument (3D Studio MAX). The simulator has been developed as an experimentation and exploitation of a long term project for a platform for MMASS based simulations [Bandini et al. [2004 – to appearb]]. This software is based on the Java platform and its goal is to implement basic elements and mechanisms of the MMASS model in order to allow a user to rapidly use these components to build a simulation.

This simulator produces results that can undergo a quantitative analysis whose results can be easily understood by experts of the area of application. In different situations it can be useful, for sake of communication with non–experts, to obtain a more effective visualization of simulation dynamics. To do so, the bidimensional simulator produces a log–file provided with a fixed–record structure, in which every record is related to a node of the spatial structure or the position of an agent with reference to this structure. Initially, the simulator prints the structure of the environment, then the starting position of each agent. For every iteration the new position of every agent is also printed. This file is parsed by a 3D Studio Max script which generates a plane and walls related to the spatial structure, nodes related to sites, and bipeds related to agents. Splines are then generated starting from the discrete positions assumed by various agents, and represent bipeds' movement. This process introduces modifications to trajectories defined by the bidimensional simulator whose sense is to give a more realistic movement to agents' avatars. This application was tested in an abstract indoor situation, related to an evacuation scenario (see Figure 4).

The interaction mechanism between the simulator and the 3D modelling tool is currently being mod-

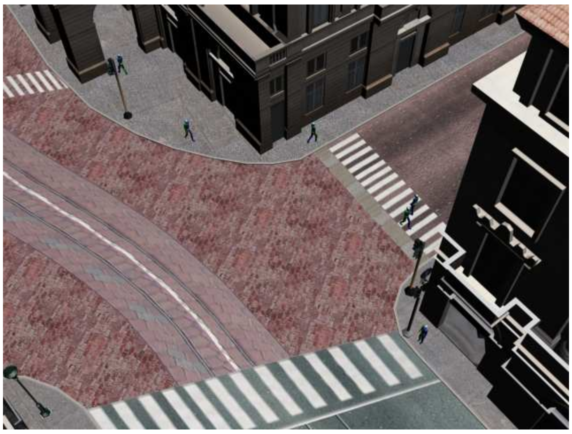

Figure 5: A screenshot of the animation produced by the 3D modelling tool in an outdoor scenario.

ified in order to allow an easy integration with existing models of the environment. To do so it will be possible to draw the bidimensional abstraction of the environment directly on images obtained by the model. The development of this tool for the specification of the environment is currently on–going and will allow an easy adoption even in a realistic outdoor scenario. A screenshot of an animation produced in this kind of scenario is shown in Figure 5[1].

5 CONCLUSIONS

This paper has presented the application of the SCA model to crowd modelling, simulation and visualization. The model provides the possibility to explicitly define a spatial structure of the environment in which the simulation takes place. Relevant objects are modelled as sources of fields, signals that diffuse in the environment and can be perceived by agents. The reaction to the perception of these fields is defined by agent type, which also specifies perceptive capabilities with reference to their state.
Currently the SCA model is being applied to simulation supporting localization, design of environments, but it is also being considered as an instrument for urban and environmental planning.
The applications that were described in this paper provide the integration of a simulator and a 3D modelling tool, but the design of an integrated simulator and 3D engine for the development of real–time applications exploiting elements of the model is currently under–way.

[1] The 3D model of Scala Square appears courtesy of Geosim systems.

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