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Situated Cellular Agents: a Model to Simulate Crowding Dynamics

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SUMMARY This 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), providing an explicit representation of spatial structures and different means of agent interaction. Heterogenous agents may be obtained through the definition of different agent types, specifying different behaviours and perceptive capabilities. The model is rooted on some basic principles of Cellular Automata (e.g. the definition of adjacency geometries), but also takes into account the autonomy of modelled entities, with their own internal architecture. A formal definition of the SCA model will be given, with a description of how it can be applied to forward and backward approaches to simulation. Particular attention will be paid to the crowd and pedestrian modelling, and two applications to simulation to crowding will be described.
key words: *Crowds and pedestrian modelling, MAS–based modelling*

1. Introduction

Crowd behaviour and pedestrian flows are complex phenomena emerging from the actions of single entities (see, e.g., [1]). The latter may act or react to certain events in very different ways, sometimes even opposite ones, according to their condition. For instance, people tend to be curious about the reason of crowd formation, so sometimes a high density of individuals can attract other ones. On the other hand overcrowding is generally perceived as uncomfortable and even dangerous, and thus possibly avoided. Moreover an emergency situation can alter the behaviour of individuals in a really drastic way: for example people generally try to exit rooms from the entrance they used to get in, not from the closest or less crowded one.

Several successful continuum models for pedestrian dynamics are based on an analytical approach. A relevant example are *social force* models [2], in which individuals are treated as particles subject to forces. Other analytical models take inspiration from fluid–dynamic [3] and magnetic forces [4] for the representation of pedestrian flows. A different approach to crowd modelling provides the adoption of Cellular Automata (CA) [5], with a discrete spatial representation and discrete time–steps. The cellular space includes both a representation of the environment and an indication of its state, in terms of occupancy of the sites it is divided into. Transition rules must be defined in order to specify the evolution of every cell's state; they are based on the concept of *neighborhood* of a cell, a specific set of cells whose state will be considered in the computation of its transition rule. Local cell interactions may represent the motion of an individual in the space, and the sequential application of this rule to the whole cell space may bring to *emergent* effects and *collective* behaviours, for instance lane formation [6] and evacuation configurations [7].

Even if the CA–based approach is generally better understood than analytical models by experts in different application domains, and more easily applied to model related scenarios, both these approaches share the limit of considering individuals as homogenous entities, and generally do not provide elements of flexibility and dynamism, like changes in behaviour of individuals. This may not represent an issue for large scale simulations, in which a certain degree of approximation is unavoidable and often tackled by the adoption of a stochastic approach, but in other situations it could be relevant to take this kind of information into account. For instance, the evaluation of information signs placement depends on different factors related to their effectiveness, and thus to their visibility. The latter is strongly dependant on the behaviour of individuals moving throughout the environment, their goals and destinations, but even their perceptive capabilities. These factors are relevant in the decision of what directions they take, and to include these concepts in a CA would require an extremely high number of rules, a very large cell state and probably the extension of the concept of neighborhood to simulate *at–a–distance* interactions (for instance to model the attractiveness of destination sites).

The goal of this paper is the description of a different approach to crowd modelling, based on Multi Agent Systems (MAS). Situated Cellular Agents (SCA) model is a special class of Multilayered Multi Agent Situated System (MMASS [8]), providing an explicit representation of (possibly irregular) spatial structures and different means of agent interaction: synchronous *reaction* between adjacent agents and asynchronous, at–a–distance interaction through a field emission–diffusion–perception mechanism. Heterogenous agents may be obtained through the definition of different agent types, that specify different behaviours and perceptive capa-

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bilities. The latter provide a mechanism for filtering incoming information through the definition of receptiveness and sensitivity to different field types. This model is rooted on some basic principles of CAs (e.g. the definition of adjacency geometries), but also takes into account the autonomy of modelled entities, with their own internal architecture [9]. The SCA model can be applied both to forward and backward approaches to simulation. In other words it is possible to define starting conditions and rules defining local rules related to entities' behaviour, in order to analyze system evolution and properties. On the other hand it is also possible to study and model a certain situation, defining suitable rules to mimic some system's behaviour.

The following Section provides formal definition of the SCA, while an informal comparison between SCA and CA will be given in Section 3. A sample application of SCA (Conway's Life) will be given to show how this model can be used with a forward approach in scenario typically described with a CA, using a concept that is fundamental in crowd modelling (i.e. population density). Section 4 also shows how the model can be applied in a backward approach, in order to represent basic crowd behaviours. More complex applications of SCA to the simulation of crowds in a 3–D environment will also be briefly described. Conclusions and future developments will end the paper.

2. SCA model

A system of Situated Cellular Agents can be specified by a three–tuple

$$< Space, F, A >$$

where A and F are finite sets including respectively agents and fields, and *Space* is a single layered environment where those agents are situated, act autonomously and interact.

It is possible to define different agent types, introducing the chance to define different abilities and perceptive capabilities. Defining T the set of types, it is appropriate to partition the set of agents in disjoint subsets corresponding to different types. The set of agents can thus be defined as

$$A = \bigcup_{\tau \in T} A_\tau$$

where $A_{\tau_i} \cap A_{\tau_j} = \emptyset$ for $\tau_i \neq \tau_j$. An agent type τ is defined by $< \Sigma_\tau, Perception_\tau, Action_\tau >$, where Σ_τ defines the set of states that agents of type τ can assume, while $Perception_\tau : \Sigma_\tau \to [\mathbb{N} \times W_{f_1}] \ldots [\mathbb{N} \times W_{f_{|F|}}]$ is a function associating to each agent state the vector of pairs

$$\left(c_\tau^1(s), t_\tau^1(s)\right), \left(c_\tau^2(s), t_\tau^2(s)\right), \ldots, \left(c_\tau^{|F|}(s), t_\tau^{|F|}(s)\right)$$

where for each i ($i = 1 \ldots |F|$), $c_\tau^i(s)$ and $t_\tau^i(s)$ express respectively a receptiveness coefficient to be applied to the field value f_i and the agent sensibility threshold to that field type in the given agent state s. In this way, agents situated at the same distance from the agent that emits a field can have different field perceptive capabilities of it. $Actions_\tau$ denotes the set of actions that agents of type τ can perform, and will be described in Section 2.3.

2.1 Space

The *Space* consists of a set P of sites arranged in a network (i.e. an undirected graph of sites). Each *site* $p \in P$ can contain at most one agent and is defined by $< a_p, F_p, P_p >$ where $a_p \in A \cup \{\perp\}$ is the agent situated in p ($a_p = \perp$ when p is empty); $F_p \subseteq F$ is the set of fields active in p ($F_p = \emptyset$ when no field is active in p); and $P_p \subset P$ is the set of sites adjacent to p. An agent placed in a site p inherits the spatial relationships defined for this site, and can be thus considered adjacent to agents placed in sites that are adjacent to p.

2.2 Fields

A field $f_\tau \in F$ that can be emitted by agents of type τ is denoted by

$$< W_\tau, Diffusion_\tau, Compare_\tau, Compose_\tau >$$

where $W_\tau = S \times \mathbb{N}$, where $S \subseteq \Sigma_\tau$, denotes the set of values that the field can assume; given $w_\tau \in W_\tau$, $w_\tau =< s_\tau, i_\tau >$, where $s \in S$ represents information brought by the field and $i_\tau \in \mathbb{N}$ represents its intensity. This value is modified through the propagation of a field throughout the space according to $Diffusion_\tau : P \times W_\tau \times P \to (W_\tau)^+$. This is the diffusion function of the field computing the value of a field on a given site taking into account in which site and with which value it has been emitted. Since the structure of a *Space* is generally not regular and paths of different length can connect each pair of sites, $Diffusion_\tau$ returns a number of values depending on the number of paths connecting the source site with each other site. Hence, each site can receive different values of the same field along different paths. $Compare_\tau : W_\tau \times W_\tau \to \{True, False\}$ is the function that compares field values. $Compose_\tau : (W_\tau)^+ \to W_\tau$ expresses how field values have to be combined.

2.3 Situated Cellular Agents

An agent $a \in A$ is defined by $< s, p, \tau >$, where: $s \in \Sigma_\tau$ denotes the *agent state* and can assume one of the values specified by its type; $p \in P$ is the site of the *Space* where the agent is situated; τ is the *agent type*.

The behavior of Situated Cellular Agents is influenced by agents situated on adjacent positions and, according to their type and state agents are able to synchronously change their states. Synchronous interaction (i.e. reaction) is a two–steps process. Reaction among a set of agents takes place through the execution of a protocol introduced in order to synchronize the set of autonomous agents. When an agent wants to react with the set of its adjacent agents since their types satisfy some required condition, it starts an *agreement* process whose output is the subset of its adjacent agents that have agreed to react. An agent agreement occurs when the agent is not involved in other actions or reactions and when its state is such that this specific reaction could take place. The agreement process is followed by the synchronous reaction of the set of agents that have agreed to it. Reaction of an agent a situated in site $p \in P$, where $p =< a_p, F_p, P_p >$, can be specified as:

$action : reaction(s, a_{p_1}, a_{p_2}, \dots, a_{p_n}, s')$
$condit : state(s), position(p), agreed(a_{p_1}, a_{p_2}, \dots, a_{p_n})$
$effect : state(s')$

where $state(s)$ and $agreed(a_{p_1}, a_{p_2}, \dots, a_{p_n})$ are verified when the state of agent a is s and agents situated in adjacent sites $\{p_1, p_2, \dots, p_n\} \subseteq P_p$ have previously agreed to undertake a synchronous reaction. The effect of a reaction is the synchronous change in state of the involved agents; in particular, agent a changes its state into s'.

Other possible actions are related to the asynchronous interaction model, based on field emission and to the perception–deliberation–action mechanism. Agent emission can be define as follows:

$action : emit(s, f, p)$
$condit : state(s), position(p)$
$effect : added(f, p)$

where $state(s)$ and $position(p)$ are verified when the agent state is s and its position is p. The effect of the emit action is a change in the active fields present in sites involved in the diffusion, according to $Diffusion_f$.

The effect of an agent perception of a certain field f_i can be defined as

$action : trigger(s, f_i, s')$
$condit : state(s), position(p), perceive(f_i)$
$effect : state(s')$

where $perceive(f_i)$ is verified when $f_i \in F_p$ and $Compare_\tau(c^i_\tau \cdot f_i, t^i_\tau) = true$ (in other words, field intensity modulated by an receptiveness coefficient exceeds the sensitivity threshold for that field). The effect of the trigger action is a change in agent's state according to the third parameter. The last possible action for an agent causes a change in its position and can be specified as follows:

$action : transport(p, f_i, q)$
$condit : position(p), empty(q), near(p, q), perceive(f_i)$
$effect : position(q), empty(p)$

where $empty(q)$ and $near(p, q)$ are verified when $q \in P_p$ and $q =< \perp, F_q, P_q >$ (q is adjacent to p and it does not contain agents). The effect of a transport action is thus to change the position of the related agent. A term $suitable(q)$ could be added to the conditions in order to specify additional conditions, such as the presence of a specific field type in possible destination sites.

3. CA and MAS: an informal comparison

Cellular Automata can be seen as a kind of Multi Agent System, where spatial structure of agent environment is explicit and structured in a grid, agents are immobile, homogeneous and dense (all the cells of the CA are identical and include agent representation) and their behavior is synchronous. This is not the general case in MAS–based models, since heterogeneous and asynchronous agents might live in the same, possibly not structured, environment. Thus, as clearly stated in [10], "CA can be considered either as 'degenerate' MAS in which agents have become fixed or, more positively, as good environmental models". A MAS consists of a number of agents that are defined in terms of their behaviors and characteristic parameters and are located in an environment that makes their interactions possible. The behavior of a MAS is defined as the global effects of local interactions among autonomous agents populating the environment.

Accordingly, Multi Agent Based Simulation (MABS) is based on the idea that it is possible to represent the global behavior of a dynamic system as the result of interactions occurring among an assembly of agents with their own operational autonomy. MAS have been used to simulate artificial worlds [11] as well as natural or social phenomena. In MABS, agents might represent animals in ecosystems, vehicles in traffic, people in crowds, or autonomous characters in animation and games [12]–[15]. Unlike CA–based simulation, which is based on a dense and uniform dissection of the space where the execution control is centralized and the simulation inner loop proceeds cell by cell [16], in MABS applications the system simulation is based on autonomous and distributed agents (i.e. it proceeds agent by agent each one with its own thread of control).

Recent results in complexity science [17] suggest that the topology of agent interaction is critical to the nature of the emergent behavior of the MAS. With the exception of some preliminary proposals [18], none of the MAS models presented in the literature explicitly takes into account the spatial structure (i.e. topology) of the environment where agents are located. This happens despite of the fact that a large class of problems is characterized by unavoidable spatial features requiring the related modelling approach to incorporate an explicit or implicit model of the space. In fact, several domains deal with space itself (e.g., geographical location) or a model of it (e.g., information flow in an organizational structure) or both of them (e.g., to conquer some favorable selling location in a region or to play a new role implying a move in the physical and organizational structure of a company). In traditional MAS approach, agents can be associated with a location in their environment, but no explicit structure of the environment is given. For instance, mobile information agents that are located on MAS models of networked computers do not refer to the network structure as an explicitly defined geometrical space.

On the contrary, CAs offer a very interesting framework to model and simulate natural and artificial phenomena involving space, due to their basic definition and structure [19]. CA have been profitably used in various cases of simulation where space has a crucial role. In this respect, we can distinguish between CA models that intrinsically allow parametric spatial conditions to be represented (e.g. fluid–dynamics in porous media, cellular geography and so on), and CA models that allow a spatial representation to be created (e.g., in competitive behavior, population dynamics, financial data clustering). CA modelling is designed to simulate the dynamics of spatial interaction and, as a consequence, CA have been employed in the exploration of various urban phenomena (e.g. traffic simulation, regional urbanization, land use dynamics) explicitly dealing with the spatial relation and interaction among locations [20]. Moreover, in some cases, CA offered the possibility to conceptualize and visualize abstract and intrinsically not spatial problems [21].

Interesting results have been shown by the combination of MAS and CA [22]. The approach basically consists in the positioning of a MAS on a cellular space and has been mainly applied to analyze urban system dynamics and pedestrian activity [23]. Two sets of example scenarios where agents have been combined with cellular spaces to model environmental and urban systems can be found in [20] and [24]. In these examples, the cellular space simulates the dynamics of the urban infrastructure (e.g. land–use transition, real estate development and redevelopment, urban growth) while a MAS simulates the dynamic of the interacting entities that populate this infrastructure (e.g. residential location, pedestrian movement, traffic simulation).

4. SCA: forward and backward approaches

4.1 Life: modelling loneliness and overcrowding

Conway's Game of Life is a typical example of a cellular automaton, and it is a very interesting one as it represents one of the simplest examples of emergent behaviour. In fact elaborate patterns and behaviours emerge from its simple rules, based on the concept of neighborhood in a regular grid. Cells can be either *dead* or *alive*, and transition rules are essentially based on two concepts:

- *loneliness*: a cell that has not enough alive neighbors will die or remain dead;
- *overcrowding*: a cell that has too many alive neighbors will die or remain dead.

Balance between loneliness and overcrowding determines the conditions that allow a cell to remain alive or switch its state from dead to alive.

Modelling this kind of situation with a SCA requires the definition of a suitable mechanism to represent transition rules in terms of reaction between agents or through the perception–deliberation–action mechanism. The concept of crowding modelled in Life is strictly bound to neighborhood, while a more general idea of locality could be modelled through the use of a *vitality* field. Every live agent is a source of this kind of field that is diffused in the space, degrading during its propagation in the space from the source site according to the distance from the destination. Every agent could be characterized by its state (dead or alive), by an indication of its *strength* (i.e. the starting intensity of the vitality field it emits), and by two values representing respectively the loneliness and overcrowding thresholds. Agent behaviour could be specified as follows:

- if it is alive it emits a vitality field whose starting intensity is equal to its strength;
- if the intensity of the vitality field in its place is below the loneliness or above the overcrowding thresholds its next state will be dead;
- otherwise (i.e. local vitality intensity is between the thresholds) its next state will be alive.

Agents with different sensivity (i.e. different thresholds) and different strength can be defined, obtaining an heterogenous system. Including these parameters into agent state allows even to modify them dynamically.

Some tests have been performed with different conditions (homogeneity, heterogeneous sensitivity or strength, heterogeneity with reference to both of those parameters). Figure 1 shows the number of alive agents per turn in a complete heterogeneous situation. A through analysis of these experiments is still on–going, but preliminary and qualitative considerations seem to point out that agents with a low sensivity to loneliness tend to survive longer, and stronger agents have a role in spreading life but are more subject to overcrowding conditions. An interesting result of these experiments is the detection of patterns and oscillators, similar to those that can be identified in CAs.

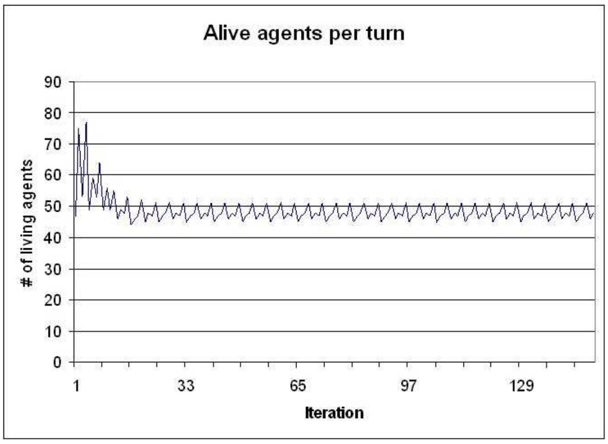

Fig. 1 number of alive agents per turn in a complete heterogeneous situation.

4.2 Exploiting SCA in the crowding context

While Section 2 has shown concepts and elements defined in the SCA model, in the following we are going to give some indications and examples of how they could be exploited in the representation of pedestrians and related behaviours. Pedestrians and individuals can be modelled as agents, and the spatial structure on which they are situated can be represented as a graph of sites. One of the main elements that characterizes this model is the possibility to define goals and behaviours of the modelled entities.

A possible way to specify the tendency of an agent to move towards specific areas is the definition of attractive fields and specific actions to define a suitable reaction to their perception. A simple attractive field f assumes values in $\mathbb{R}^+$, its *Compose* and *Compare* functions are respectively the sum and the less than relation, and $\forall p \in P$

$$Diffusion_f(p_0, f_{p_0}, p) =$$

$$= \begin{cases} f_{p_0} - dist(p_0, p) & dist(p_0, p) < f_{p_0} \\ 0 & otherwise \end{cases} .$$

where p_0 and f_{p_0} are respectively the site in which the field has been emitted and the value at its emission.

A possible perception function for agents sensitive to this kind of field maps any state s into $\langle c, t \rangle$,where c may be part of agent state (and thus a possibly dynamic value) indicating its receptiveness to this field type, while t is a threshold for filtering low intensity fields. Given an agent situated in the site p, the set of empty adjacent sites where an attractive field f is active is defined by

$$P_p^f = \{p' \in P_p | a_{p'} = \perp \wedge f \in F_{p'}\}$$

In this framework, the behaviour specification for agents that should seek the site where the field value is (locally) maximum should include a *transport* action in which the *additional condition* term is defined as:

$$condition(q) = q \in P_p^f \wedge \forall r \in P_p^f, f_r < f_q$$

where f_x indicates the value of field f at a site x.

This kind of mechanism is not suited to model situations in which an agent should try to keep at a certain distance from the source of certain field, for instance to generate a flow of pedestrians that follow each other without getting too close. To this aim, agents could be defined as sources of specific attractive fields, and sensitive only to the signals emitted by the preceding one. In this case the additional condition of the transport action could include:

$$condition(q) = q \in P_p^f \wedge f_l < f_q < f_h$$

where f_l and f_h are constant thresholds indicating the minimum and maximum desirable field intensity for that kind of agent.

A negative consequence of this modelling solution is related to the high number of field types that have to be defined (at least one for each agent). Another possible modelling choice provides the inclusion of the identifier of the emitting entity (field source) into the attractive field value. More precisely a more flexible attractive field could be defined as follows:

$$F_h = < W_h, Diffusion_h, Compare_h, Compose_h >$$

with $W_h = \mathbb{N} \times \mathbb{R}^+$. For every $w_h \in W_h$, $w_h =< f_{Id}, f_{In} >$ where the first component of field value indicates the identifier of the field source, while the latter represents its intensity.

In this case, the agent state should include the identifier of the preceding entity. It could thus be defined as a pair $< s, Sens >$, where the first component contains other agent internal information, while the second one is the set of entity identifier whose emitted fields will be perceived and considered. In this framework, a field value $< f_{f_Id}, f_{In} >$ is perceived by an agent $<< s, Sens >, p, \tau >$ only when the field intensity value is greater than the agent sensitivity threshold and the field identifier (i.e. f_{Id}) is contained in the *Sens* set of the agent.

Thus, the additional condition on site q of the *transport* action

$action : transport(p, < f_{Id}, f_{In} >, q)$
$condit : position(p), empty(q), near(p, q), perceive(< f_{Id}, f_{In} >), condition(q)$
$effect : position(q), empty(p)$

can be defined as before (i.e. $condition(q) = q \in$

$P_p^f \wedge f_l < f_q < f_h$), while the *perceive()* condition is verified only when $t < c \cdot f_{In}$ and $f_{Id} \in Sens$.

Since agent state is dynamic, the possibility to include field source identifier in it offers the chance to force agents to follow a specific path. To this aim, the search for local maximum of certain field values (and, thus, field sources) could be suitably combined; static field sources can be placed as way–points, and agents can be provided with two kinds of actions: one to follow the field gradient and another one to switch to the next way–point. These actions (for an agent $<< s, Sens >, p, \tau >$) could be defined as follows:

$$\begin{aligned}
&action : transport(p, < f_{Id}, f_{In} >, q)\\
&condit : position(p), near(p, q), condition(q),\\
&\qquad perceive(< f_{Id}, f_{In} >)\\
&effect : position(q), empty(p)
\end{aligned}$$

$$\begin{aligned}
&action : trigger(< s, Sens >, < f_{Id}, f_{In} >,\\
&\qquad < s, Sens \setminus \{f_{Id}\} >)\\
&condit : state(< s, Sens >), position(p),\\
&\qquad perceive(< f_{Id}, f_{In} >), f_{In} > f_{next}\\
&effect : state(< s, Sens \setminus \{f_{Id}\} >)
\end{aligned}$$

where $perceive(< f_{Id}, f_{In} >)$ is verified when $f_{Id} \in Sens$ and $t < c \cdot f_{In}$, $condition(q) = q \in P_p^f \wedge f_r < f_q,\ \forall r \in P_p^f$, and $f_{next} \in \mathbb{R}$ is a constant that indicates the distance from the way–point below which the agent can consider to have reached it and, thus, can change its state in order to change the target way–point (i.e. $< s, Sens \setminus \{f_{Id}\} >$).

5. SCA applications to crowding

According to the SCA model above described, a system for the 3D representation of virtual actors populating virtual worlds has been developed. The system allows a real–time user interaction with the virtual worlds and with its inhabitants. 3D virtual worlds with an arbitrary number of virtual agents and user avatars can be defined. Heterogeneous MASs (e.g. composed by human–like, animals, unanimated objects) can populate the virtual world through the specification of different SCA agent types. For instance, objects relevant to the application can be represented by an agent type that is not able to move and perceive other agents but can emit a presence field and can change its state; human–like agents that populate a virtual city can be represented as 3D human–like agents able to move in the city, to avoid collisions but with no specific goal. Moreover, specialized agents can be defined as city inhabitants that have the ability to react to other agent requests (e.g. need of help or information from museum guides and policemen, pricing information and products for shop sellers).

In order to obtain high system configurability, a parser for different 3D graphical model of agents, avatars and other virtual objects has been developed. This parser is independent from visualization libraries and the rest of the system, and exports a set of data structures conceptually similar to the binary 3DStudio format. This parser, whose detailed description is out of the scope of this paper, is more than just an syntactical interpreter of heterogeneous file formats, but it also enhances the graphical models with semantical information (e.g. to force agents to walk along sidewalks and avoid green areas). Moreover, a complete 3D engine based on Microsoft DirectX libraries[†] has been developed. Its main features are real–time lightning, texture mapping, materials and transparency management, agents and user avatar animation, collision detection and effect of the perception of fields.3D virtual worlds populated by virtual MASs that can be created with this system can provide system users with useful tools for different types of applications (e.g. collaborative environments, simulation scenarios). In the following two examples of virtual worlds will be shown: the *virtual museum* that has been created in order to test system functionalities and the *virtual city* in which crowd dynamics is simulated.

Fig. 2 Guide Calling.

5.1 Test in a Virtual Museum

The first virtual world (Figure 2) that has been created for test purposes represents the Frankfurt Museum fur Kunsthandwerk[††].

The virtual environment represents museum rooms and its garden populated by a MAS of human–like agents that differ both in their appearance (e.g. clothes) and in their behavior (e.g. object observation speed, reaction time to collisions). Human–like agents represent museum guides, visitors and user avatars. Guide agents are able to conduct user avatars in a

[†] www.microsoft.com/directx/

[††] The museum graphic model is a modified version of a graphic model downloaded from lava.ds.arch.tue.nl

Fig. 3 Obstacle Avoidance.

Fig. 4 Crowd Formation.

guided tour throughout the museum, to manage multiple tours and to give information to user when requested. More in detail, the guide stops and waits for the user avatar when it is too far to hear her, she modifies the default tour if asked by the user, and after the end of a guided tour she can be called back in order to give more details about a specific object.

When an user enters the application, his avatar is first of all guided for a complete museum tour (inside the building and in the garden): the default tour can be modified by the system user that can indicate to the guide the objects he is not interested to, and those for which he needs more details.

Within the museum virtual environment, some tests have been performed in order to verify basic agent behaviors and to validate the application of the SCA model to 3D virtual worlds. Performed tests have shown that the non transparency of objects to some fields (e.g. building walls) is effective and provides agents and MASs with realistic behaviors (e.g. the guide agent is not able to hear user calls coming from the museum when, for instance, she is in the garden).

Moreover, agent ability to avoid obstacles has been tested within the same scenario. For instance, it has been verified that in the situation in which a solid obstacle (e.g. a wall) is located between some agents and their goal locations, agents either direct to another goal object or go around the obstacle in order to reach the goal object. Figure 3 shows this situation. It has been obtained through the definition of a presence field emitted by building walls that is perceived only by agents moving towards the wall and that, as effect of its perception, change direction.

5.2 Crowd Simulation in a Virtual City

In order to apply the developed 3D system to agent–based simulation domain, a second virtual scenario representing a virtual city populated by MAS of human–like agents has been created. The aim of this simulation system is to verify phenomena as crowd formation and basic crowd behaviors.

At the simulation start up a large number of agents (i.e. about two hundred) are randomly distributed in the city space. Each city building emits a presence field that indicates its type (e.g. simple building, shop). As in the museum virtual environment, agents differ in their appearance and in their behavior (e.g. internal goals, reaction time to collisions, perceptive capabilities). In particular each agent is characterized by a set of preferred building types that it tends to reach. Moreover some of the agents have been defined with the additional goal to react to the user avatar presence field when they can perceive it. When the user avatar is activated and a given building is defined as its goal, the user avatar starts emitting a presence field and moving to reach the building. A small number of agents that perceive the avatar presence field aggregate to form a group that follows it in its movement. Iterating the avatar activation process in different city zones, multiple agent groups can be obtained. Moreover after some simulation time, the groups aggregate into a single wider crowd (see Figure 4). Crowd movements can be directed changing the building goal of the user avatar that, from now on, represents the crowd leader (Figure 5).

During the simulation, the 3D system automatically manages agents that move within the virtual city, following building presence fields according to their goal (i.e. preferred building type). Moreover, agent collisions with other agents and with buildings is automatically avoided by the 3D system. Simulations have been performed in order to study relationships between agent parameters and crowd form, density (i.e. number of agents per unit area) and behavior. Moreover, relationships between city topology and crowd behavior during its movement in the city have been analyzed. The results of this analysis have shown that agent be-

Fig. 5 Crowd Behavior while the leader is moving.

haviors influence group form and density (e.g. MASs composed by a single type of agents aggregate into uniform crowds, while heterogeneous MASs produce irregular ones). Moreover, when the crowd has to pass through a street of limited dimensions, some agents are left behind and can leave the crowd until more space is newly available (e.g. when the street dimensions grow or the crowd stretches out).

6. Conclusions and future developments

The paper has presented the Situated Cellular Agents (SCA) approach. After a brief overview of its main analogies and differences respect to the Cellular Automata approach, its application to forward and backward approaches to simulation has been shown (i.e. Conway's Game of Life and pedestrian behaviors). Moreover, a 3D system designed and developed in order to represent virtual agents in virtual worlds has been introduced and an overview of its exploitation to simulate basic pedestrian dynamics (e.g. crowd formation, crowd movements) has been reported.

As previously introduced, future works will concern a quantitative analysis of Life experimentation, while the backward approach to simulation will be applied in other interesting domains (e.g. localization problem, immune system modelling).

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