A Methodology for Crowd Modelling with Situated Cellular Agents

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Abstract— **This paper introduces a research activity aimed at the definition of a methodology to provide a solid conceptual framework for the development of simulation systems focused on crowd dynamics and based on the Situated Cellular Agent (SCA) model. After a brief introduction of the SCA Model, the general methodological approach is described. The main steps provide the definition of the spatial abstraction of the environment, the definition of its active elements, and the specification of types of mobile agents, the related behaviours with particular attention to their movement by means of the notion of utility. A case study is also briefly described in order to show how the methodology was applied in the modelling of crowd behaviour in a subway station.**

I. INTRODUCTION

The Situated Cellular Agents (SCA) model [1] is a formal and computational framework for the definition of complex systems characterized by the presence of a set of autonomous entities interacting in an environment whose spatial structure represents a key factor in their choices on their actions and in determining their possible interactions. The model has been successfully applied in different contexts, and in particular its focus on the modelling of the environment as well as its inhabiting agents and their interactions, make it particularly suitable for simulation of actual physical systems. In particular, crowd modelling and simulation requires to model the autonomous behaviour of individuals interacting among themselves (e.g. because they compete over a shared resource, but also because of crowding effects) and the interaction among pedestrian and the environment. In fact in this situation the concept of perception must have a very precise meaning, and it influences the modelling activities as well as the design and implementation of the simulation system.

There are several computational approaches to crowd modelling, ranging from analytical ones, which generally consider humans as particles subject to various forces modelling interactions among pedestrian (see, e.g., [2]), to Cellular Automata (CA) based models which provide a discrete abstraction of the environment, whose cells encapsulate the possible presence of pedestrian and whose transition rules represent the rules that govern pedestrian movement (see, e.g., [3], [4]). Agent based models are more suited than the previous ones to be applied to situations characterized by a certain degree of heterogeneity and dynamism of agents and environment. Moreover, several indirect interaction models provide the possibility of situated

agents to leave marks in the environment to influence the behaviour of other mobile entities. This metaphor has been often exploited to model the movement of animals but also humans (see, e.g., [5]). Also situated agents were successfully applied in this context, and in particular the Situated Cellular Agents model (SCA) [6], but to our knowledge a methodology for the analysis, modelling and design of crowd simulations through situated agent models does not exist.

Several methodologies for the analysis and design of multi-agent systems have been defined (see, e.g., GAIA [7], IN-GENIAS [8] and SODA [9]) but they are more focused to the design of general purpose software systems analyzed and structured using the notion of agent, and thus they lack focus to simulate specific issues. Some specific methodological approaches to multi–agent simulation can also be found (see, e.g., [10]) but they are still very abstract and do not provide specific support to crowd modelling. In this paper the first proposal of a methodology for the modelling of SCA based crowd simulations is introduced. In particular, the methodology provides a set of phases for the definition of an abstraction of the structure of the simulated environment, the specification of active elements of the environment able to generate signals facilitating the movement of pedestrian, and types of agents, with the related perceptive capabilities and behavioural specifications. The following Section will briefly introduce the SCA model, while the proposed methodology is defined in Section III. A specific case study focused on the modelling of pedestrian in a subway station adopting the proposed methodology is described in Section IV. This scenario was chosen in the wider domain of crowd modelling and simulation because it presents very complex behaviours that are not easily found in other typical simulation scenarios such as room evacuation. Preliminary results and future developments will end the paper.

II. SITUATED CELLULAR AGENT MODEL

The Situated Cellular Agent model is a specific class of Multilayered Multi-Agent Situated System (MMASS) [11] providing a single layered spatial structure for agents environment and some limitations to the field emission mechanism. A thorough description of the model is out of the scope of this paper, and this aim of Section is to briefly introduce it to give some basic notion of the elements that are necessary to describe the methodology.

A *Situated Cellular Agent* system is defined by the triple $\langle Space, F, A \rangle$ where *Space* models the environment where the set A of agents is situated, acts autonomously and interacts through the propagation of the set F of fields and through reaction operations.

Space is defined as a not oriented graph of sites. Every *site* $p \in P$ (where P is the set of sites of the layer) can contain at most one agent and is defined by the 3–tuple $\langle a_p, F_p, P_p \rangle$ where:

- $a_p \in A \cup \{\bot\}$ is the agent situated in p ($a_p = \bot$ when no agent is situated in p that is, p is empty);
- $F_p \subset F$ is the set of fields active in p ($F_p = \emptyset$ when no field is active in p);
- $P_p \subset P$ is the set of sites adjacent to p.

A SCA agent is defined by the 3–tuple $< s, p, \tau >$ where τ is the *agent type*, $s \in \Sigma_\tau$ denotes the *agent state* and can assume one of the values specified by its type (see below for Σ_τ definition), and $p \in P$ is the site of the *Space* where the agent is situated. As previously stated, agent *type* is a specification of agent state, perceptive capabilities and behaviour. In fact an agent type τ is defined by the 3–tuple $\langle \Sigma_\tau, Perception_\tau, Action_\tau \rangle$. Σ_τ defines the set of states that agents of type τ can assume. $Perception_\tau : \Sigma_\tau \to [\mathbf{N} \times W_{f_1}] \dots [\mathbf{N} \times W_{f_{|F|}}]$ is a function associating to each agent state a vector of pairs representing the *receptiveness coefficient* and *sensitivity thresholds* for that kind of field. $Action_\tau$ represents instead the behavioural specification for agents of type τ. Agent behaviour can be specified using a language that defines the following primitives:

- $emit(s, f, p)$: the $emit$ primitive allows an agent to *start the diffusion of field f* on p, that is the site it is placed on;
- $react(s, a_{p_1}, a_{p_2}, \dots, a_{p_n}, s')$: this kind of primitive allows the specification a *coordinated change of state* among adjacent agents. In order to preserve agents' autonomy, a compatible primitive must be included in the behavioural specification of all the involved agents; moreover when this coordination process takes place, every involved agents may dynamically decide to effectively agree to perform this operation;
- $transport(p, q)$: the $transport$ primitive allows to *define agent movement* from site p to site q (that must be adjacent and vacant);
- $trigger(s, s')$: this primitive specifies that an agent must *change its state* when it senses a particular condition in its local context (i.e. its own site and the adjacent ones); this operation has the same effect of a reaction, but does not require a coordination with other agents.

For every primitive included in the behavioural specification of an agent type specific preconditions must be specified; moreover specific parameters must also be given (e.g. the specific field to be emitted in an emit primitive, or the conditions to identify the destination site in a transport) to precisely define the effect of the action, which was previously briefly described in general terms.

Each SCA agent is thus provided with a set of sensors that allows its interaction with the environment and other agents. At the same time, agents can constitute the source of given fields acting within a SCA space (e.g. noise emitted by a talking agent). Formally, a field type t is defined by $\langle W_t, Diffusion_t, Compare_t, Compose_t \rangle$ where W_t denotes the set of values that fields of type t can assume; $Diffusion_t : P \times W_f \times P \to (W_t)^+$ is the diffusion function of the field computing the value of a field on a given space site taking into account in which site (P is the set of sites that constitutes the SCA space) and with which value it has been generated. It must be noted that fields diffuse along the spatial structure of the environment, and more precisely a field diffuses from a source site to the ones that can be reached through arcs as long as its intensity is not voided by the diffusion function. $Compose_t : (W_t)^+ \to W_t$ expresses how fields of the same type have to be combined (for instance, in order to obtain the unique value of field type t at a site), and $Compare_t : W_t \times W_t \to \{True, False\}$ is the function that compares values of the same field type. This function is used in order to verify whether an agent can perceive a field value by comparing it with the sensitivity threshold after it has been modulated by the receptiveness coefficient.

III. METHODOLOGY FOR SCA-BASED CROWD MODELLING

In SCA agents' actions take place in a discrete and finite space. Entities populating the environment are classified in types, which represent templates for the specification of active elements of the environment. The latter are not only mobile entities, but also specific elements of the environment which the modeller wishes to exploit to influence the former (e.g. with attraction or repulsion effects). To model an agent type in SCA means to define the allowed states, perceptive capabilities and behavioural specification. In the proposed methodology, agent's states represent attitudes, in terms of perceptions (in fact, as previously introduced, the state determines the current agent's perceptive capabilities), but also conditions which determine its choices on actions to be selected and carried out. These actions include the definition of influences of the agent on other entities of the environment (e.g. crowding effects) by means of field emissions, the specification of its motory system and movement preferences by means of the notion of movement utility, but also the transitions from one state to another (i.e. a change of attitude towards the perception and action in the environment). While some agents related to active parts of the environment may present a very simple type specifications, mobile entities with different possible movement attitudes might require several states and complex behavioural specifications.

The diagram shown in Figure 1 shows the main phases of the methodology, while in the following subsections the steps that bring to the definition of a complete model for crowding simulations will be introduced. It must be emphasized that the first three steps lead to the development of a computational model which can be adopted in several experiments on an analogous scenario. The last two phases are those that effectively characterize the specific experiment. Section IV will
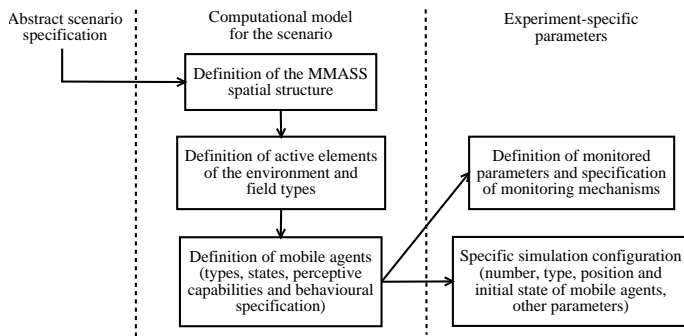
Fig. 1. A diagram showing the main phases of the methodology.

then present a concrete case study in which the proposed methodology has been applied.

A. SCA spatial structure

In order to obtain an appropriate abstraction of space suitable for the SCA model, we need a discrete abstraction of the actual space in which the simulation will take place. This abstraction is constituted of nodes connected with non-oriented arcs (i.e. a non oriented graph). Nodes represent the positions that can be occupied by single pedestrian once per time. Some of the nodes can be occupied by some agents that constitute part of the environment (doors, exits, shops etc), and that cannot be occupied by other individuals. Arcs connect nodes, representing the adjacency of one node to another. Individuals can move by single steps only from one node to other nodes that are in its immediate adjacency, so arcs and adjacency constraint agents' movement. However, as previously mentioned, the spatial structure of the environment also constraints field diffusion.

SCA space represents thus an abstraction of a walking pavement, but it has to be sufficiently detailed to be considered a good approximation of the real environment surface, and it allows a realistic representation of the movements and paths that individuals would follow. As for other crowd modelling and simulation systems we assume that a single node is associated to the space occupied by a still person [3], but the choice on the dimension of what must be considered the atomic element of the environment (a single cell) depends on the specific simulation scenario and on the related goals.

B. Active Elements of the Environment

As previously introduced, in this framework we assume that specific elements of the environment can be perceived as reference points influencing (or even determining) the movement of pedestrians. The SCA model provides a simple mean of generating at-a-distance effects that can be exploited to generate attraction or repulsion effects: the field diffusion-perception-action mechanism. However, only an agent can be the source of a field, and thus the proposed methodology requires the reification of objects or abstractions exploited to generate attraction/repulsion effects as immobile agents that are able to emit fields.

In this phase active objects in the environment have to be selected, and field types have to be assigned. Attention must be paid not only to physical objects of the environment which constraint agent movement (and that can thus be considered as reference points), but also to objects that somehow transmit conceptual information (e.g. exit signs or indications). This phase comprises two main operations:

- *selection of active elements*: the objects of the environment that are considered relevant for our simulation have to be identified. An element is considered relevant if, by a process of abstraction from reality, it can be considered as representing a target, or if it is possible to assume that it does exert an influence on the individuals that act in the environment;
- *assignment and design of field types*: the type of the fields emitted by the objects must be specified, in terms of emission intensity, diffusion and composition function, in relation to the desired extent of influence.

It must be noted that a field represents a signal and per se it does not imply an effect on agents' behaviours, in fact the possible reaction to the perception of a signal is provided by the agent type specification; moreover the actual behaviour of an agent is influenced by its current state. In this way, it is possible to model an environment as a source of different indications that are exploited in different ways by different agents to determine their paths. For instance, the window of a shop could be modelled as the source of a field diffusing outside the shop; such a field could cause a movement towards the shop for agents which consider interesting the represented goods, but could also be completely ignored by other agents. Moreover, different fields can be spread over the environment, and thus agents may perceive them and combine their effects according to a private criteria for action selection. In this way agents are not provided with a sort of script specifying their movement paths, a predefined map, or in general a strict behavioural specification, but they are provided a simple mean for evaluating the available actions against their current attitude in a more autonomous way.

C. Mobile Agents

Once the spatial abstraction has been defined, and the active elements of the environment and the related fields have been specified, the third phase of the methodology is to define the behaviour of the pedestrian. The model allows to define heterogenous agents thanks to the notion of agent type, which comprises the definition of related state, perceptive capabilities and behavioural specification. However, the modelled behaviour can be quite complex, as an individual may be endowed with several distinct attitudes towards movement and action selection that are activated in different contexts.

The behaviour of an agent type can thus be segmented in relevant states. The more complex is the behaviour that we want to capture, the higher will be the number of states that an agent can assume. This definition can be summarized in the two phases below:

- *definition of agent type's states*: in this phase of the modelling it must be established the number of states

that each agent can assume. Each state represents diverse priorities, and a different attitude of the agent. For each state must be determined the field emissions of the agent type (i.e. the influence of agents of this type towards other entities in the system), and the sensitivity to fields emitted by other agents. In addition to these elements, that are required for every SCA agent type, this methodology also provides the definition of the utility value for every field type, as a measure of the relevance of the perception of this field on agent's choices on its own movement;

- *definition of conditions for states transition*: the change of the state of an agent is related to the perception of a specific condition in its current context that determines a transition from a movement attitude towards a different one. These conditions must thus be carefully defined and modelled by means of a *react* or a *trigger* operation.

As previously introduced, in this framework possible attitudes of that type of agent are reified as states in order to specify the actions that can be selected only for agents. In these states its perceptive capabilities can be differentiated, but also its preferences on possible available moves. This can be modelled by means of a *utility function* which computes a sort of "desirability" value for every site in which the agent might move, in relation to its current state. Utility functions represent a flexible mean of combining different aspects influencing the selection of actions [12] and in this specific case these aspects are represented by different fields. In fact, fields are related to entities, either mobile (i.e. other pedestrian) or immobile (e.g. doors), that influence mobile agents' motion in a different way according to their context. It is thus necessary to specify, for each agent state, what is the impact of the perception of each field type on the desirability of the related place. The overall utility of a place is the aggregation of all these influences, that can have a positive, negative or null impact on the total value. The basic agent strategy for the choice on single movement action is thus to select the adjacent free place with highest utility value. According to the specific scenario, the possibility to remain still could be considered acceptable, penalized or even not allowed.

Before the conclusion of this paragraph we must specify that the utility values and the action modelling are not properly phases, but are activities that permeate the whole process of the construction of a simulation, and are subject to constant revision (a process that in some cases is referred to as simulation calibration).

D. Specific Simulation Configuration

The configuration for an experiment in a specific simulation scenario, not only in the case of crowd simulation, is a crucial phase that has to be performed carefully. In particular the effort of conceptualization carried out in the previous passages is wasted unless a realistic configuration for the experiment is defined. In fact, the data that are obtained through the execution of simulations are obviously strongly dependant on the starting conditions, as well as on the modelling of the simulated reality.

To configure a crowd simulation means to set the following parameters:

- *agents number and starting positions*: the number of the mobile agents that will populate the simulation must be decided in relation to the crowd scenery that is being represented; their positions must also be specified;
- *agents' initial states*: the initial state of every agent has to be specified. The decision to assign to an agent an initial state or another is taken in relation to the goals of the specific simulation: in fact, this parameter determines the initial movement attitude of the agent in the environment;
- *field emission intensity*: field emission intensity is a parameter that allows to modulate stronger or weaker influence effects; the choice on this parameter (together with the diffusion functions to be adopted for various field types) also determines the extent of the effects. The possibility to tune these parameters is a key factor in the definition of specific effects, both at individual level (e.g. amplifying or attenuating the field emission intensity of a specific agent) as well as on the collective scale (for instance modifying the intensity of fields related to elements of the environment).

E. Monitored Parameters and Mechanisms

This phase represents a formal statement of what is the goal of the simulation, a precise specification of what has to be observed and how. When simulating crowd dynamics in an evacuation scenario, the average number of turns required for agents to exit from a room is a crucial parameter to be monitored, while it can be of no interest when the goal of simulation is to observe the behaviour of pedestrian in a shopping centre. Other possible observable parameters could be average crowd density, average (or maximum) number of people waiting in a queue, occurrence of specific events, and many others dependant on the specific simulation context.

The variety of possibly monitored parameters, and thus also the number and heterogeneity of distinct monitoring mechanisms, does not allow to define specific guidelines for this phase.

IV. A CASE STUDY: THE UNDERGROUND STATION

An underground station is an environment where various crowd behaviours take place. In such an environment passengers' behaviours are difficult to predict, because the crowd dynamics emerges from single interactions between passengers, and between single passengers and parts of the environment, such as signals (e.g. current stop indicator), doors, seats and handles. The behaviour of passengers changes noticeably in relation to the different priorities that characterize each phase of their trips. That means for instance that passengers close to each other may display very different behaviours because of their distinct aims in that moment. In a crowd dynamic behaviours of the singles can also constitute a hindrance for the purpose of someone else. Passengers on board may have to get off and thus try to reach for the door, while other are instead looking for a seat or standing beside a handle. Moreover when trains stop and doors open very complex crowd dynamics happen, as people that have to get on the train have to allow the exit of passengers that are getting off. Passengers
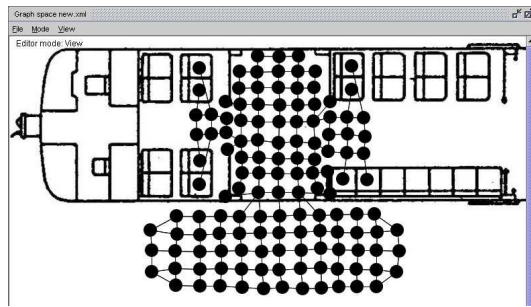
Fig. 2.   Discretization of a portion of the environment

Fig. 3.   Immobile active elements of the environment.

have to match their own priority with the obstacles of the environment, with the intentions of other passengers, and with implicit behavioural rules that govern the social interaction in those kind of transit stations, in a complex mixture of competition over a shared resource and collaboration to avoid stall situations. Given the complexity of the overall scenario, we decided to focus on a specific portion of this environment in which some of the most complex patterns of interaction take place: the part of platform in presence of a standing wagon from which some passengers are attempting to get off while other waiting travellers are trying to get on.

However the value of the realized simulation is not the main goal of this work, as our main aim is to show how the proposed methodology was applied in this case study. The goal of a complete simulation system in this context would be the possibility to support expert users in the detection of critical problems of the structure of the station, as bottlenecks, wrong disposition of the exits and so on, by offering the modelling instruments able to capture interaction between passengers and the environment, simultaneously on board and on the waiting platform. Such a tool would be of great aid for the prediction of security measure in situations of overcrowding or in presence of an unexpected hazard.

To build up our simulation we made some behavioural assumptions, now we will make some brief examples of the kind of behaviours we wanted to capture. Passengers that do not have to get off at a train stop tend to remain still, if they do not constitute obstacle to the passengers that are descending. Passengers will move only to give way to descending passenger, to reach some seat that has became available, or to reach a better position like places at the side of the doors or close to the handles. On the other hand in very crowded situations it often happens that people that do not have to get off can constitute an obstacle to the descent of other passengers, and they "are forced to" get off and wait for the moment to get on the wagon again. Passenger that have to get off have a tendency to go around still agents to find their route towards the exit, if it is possible. Passengers on the platform enter the station from the ingress points (station entrances) and tend to distribute along the threshold line while waiting for a train. Once the train is almost stopped they identify the entrance that is closer to them and move towards it. If they perceive some passenger bound to get off, they first let them get off and then get on the wagon.
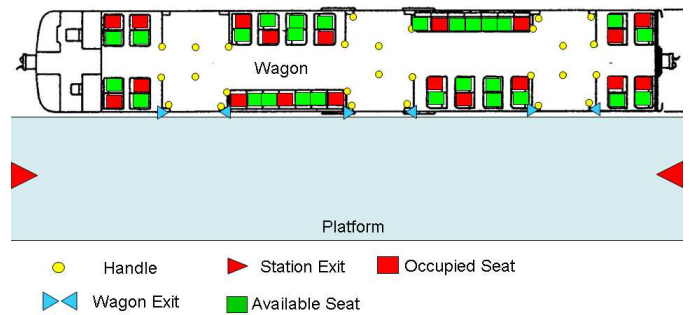
A. Environment Abstraction: a Metro Station

To build an environment suitable for SCA platform, first of all we need to define a discrete structure representing the actual space in which the simulation is set. In our case study we started from an available diagram of an underground wagon. A discrete abstraction of this map was defined, devoting to each node the space generally occupied by one standing person, as shown in figure 2. Arcs connecting nodes are not necessarily uniform across the space: in fact we decided to allow some specific movement opportunities to agents in critical positions of the environment. However a thorough analysis of the effects of this kind of heterogeneity in the spatial structure on field diffusion is needed, and will be the object of future works.

B. Active Elements of the Environment: Train and Station

In our simulation fields are generated by elements of the environment but also by agents that represent passengers. We identified the following objects as active elements of the environment: *Exits*, *Doors*, *Seats* and *Handles* (see figure 3 for their disposition). Now we give a brief description of the kind of fields that those static agents emit. Station exits emit fixed fields, constant in intensity and in emission, that will be exploited by agents headed towards the exit of the station. Exits could also constitute ingress points for agents that arrive on the platform. Agent-doors emit another field which can guide passengers that have to get off towards the platform, and passengers that are on the platform and are bound to get in the wagon. Seats may have two states: occupied and free. In the second state they emit a field that indicates their presence. An analogous field is emitted by handles, which however are sources of fields characterized by a minor intensity.

C. Mobile Entities: Passengers

We have identified the following states for agent of type passengers: *waiting* (w), *passenger* (p), *get-off* (g), *seated* (s), *exiting* (e). In relation to its state, an agent will be sensitive to some fields, and not to others, and attribute different relevance to the perceived signals. In this way, the changing of state will determine a change of priorities. A state diagram for passenger agents is shown in figure 4. State w is associated to an agent that is waiting to enter in the wagon. In this state agents perceive the fields generated by the doors as attractive, but they also perceive as repulsive the fields generated by
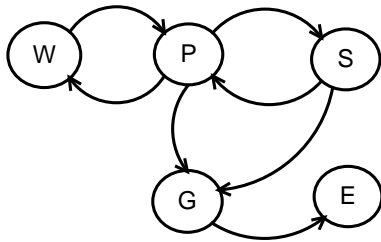
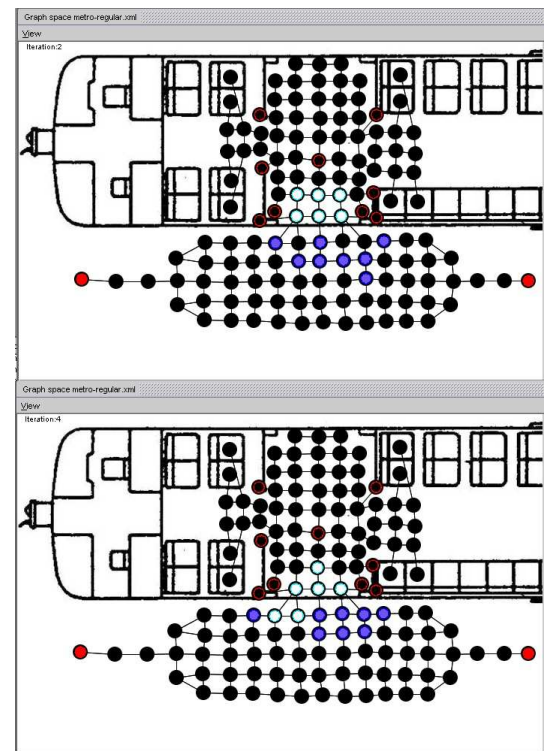Fig. 4.   A diagram showing various states of agent type passenger.

Fig. 5.   Two screenshots of the metro simulation. On the first one light gray agents are inside the train and going to get off, while dark agents are standing outside and are going to get on. On the second, the latter have made some rooms for the former to get off.

passengers that are getting off, in other words those in state g. In state w the agent "ignores" (is not sensitive to) the fields generated by other active elements of the environment, such as exits' attractive fields, chairs attractive field and so on. Once inside the wagon, the agent in state w changes its state in p (passenger), through a trigger function activated by the perception of the maximum intensity of field generated by agent-door type. Agent in state passenger is attracted by fields generated by seats and handles, and repulsed by fields related to passengers that are getting off. It does not have any sensitivity for the attraction field of the doors. In state g the agent will instead emit a field warning other agents of its presence, while it is attracted by fields generated by the doors. Once passed through the wagon door, or in immediate proximity (detected by means of specific thresholds on related field intensity), the agent in state g changes its state to e (exiting) and its priority will become to find the exits of the station. The agent in state e is thus attracted by fields related to exits.

Table I summarizes the sensitivity of the passenger to various fields and it also sketches a first attribution of the utility of the presence of these field types on empty nodes considered as destination of a transport action. In particular, cells provide the indication of the fact that the related field is perceived as attractive or repulsive and the priority level (i.e. relevance) associated to that field type.

All passengers except those in state g emit a presence field that generally has a repulsive effect, but a lesser one with respect to the "exit pressure" generated by agents in get-off state.

V. PRELIMINARY RESULTS

A simulator implementing the previously introduced model was realized exploiting the MMASS framework [13] (please note that SCA is a particular class of MMASS model): only a subset of the overall introduced model was implemented, and more precisely active objects of the environment and passenger agents in state w, g, e, p. Figure 5 shows a screen-shot of this simulation system, in which waiting agents move to generate room for passenger agents which are going to get off the train. The system is synchronous, meaning that every agent performs one single action per turn; the turn duration is about one second of simulated time.

The goal of this small experimentation was to qualitatively evaluate the modelling of the scenario and the developed simulator. The execution and analysis of several simulations showed that the overall system dynamics and the behaviour

of the agents in the environment is consistent with a realistic scenario, and fits with our expectations. In particular, we executed over 100 simulations in the same starting configuration, which provides 6 passengers located on a metro train in state g (i.e. willing to get off), and 8 agents that are outside the train in state w (i.e. waiting to get on). This simulation campaign is motivated by the fact that an agent having two or more possible destination sites characterized by the same utility value makes a non deterministic choice. In all simulations the agents achieved their goals (i.e. get on the train or get out of the station) in a number of turns between 40 and 80, with an average of about 55 turns.

Nonetheless we noticed some undesired transient effects and more precisely:

- *oscillations* and "forth and back" movements;
- static forms providing "groups" facing themselves for a few turns, until the groups dispersed because of the movement of a peripheral element.

These phenomena, which represent minor glitches under the described initial conditions, could lead to problems in case of high pedestrian density in the simulated environment. This points out the need of additional mechanisms correcting the movement utility. In particular, some possible improvements to the basic movement utility mechanisms are:

- introduce a notion of agent *facing*: the SCA model does not provide an explicit facing for agents because is not always relevant or even applicable (consider for instance the modelling of immune system cells [14]);

State	Exits	Doors	Seats	Handles	Presence	Exit press.
W (getting on)	not perc.	attr. (2)	not perc.	not perc.	rep. (3)	rep. (1)
P (on board)	not perc.	not perc.	attr. (1)	attr. (2)	rep. (3)	rep. (2)
G (getting off)	not perc.	attr. (1)	not perc.	not perc.	rep. (2)	not perc.
S (seated)	not perc.	attr. (1)*	not perc.	not perc.	not perc.	not perc.
E (exiting)	attr. (1)	not perc.	not perc.	not perc.	rep. (2)	not perc.

* = The door signal also conveys the current stop indication.

TABLE I

THE TABLE SHOWS, FOR EVERY AGENT STATE, THE RELEVANCE OF PERCEIVED SIGNALS.

however in this specific simulation scenario this is a relevant factor for agents' choices on their movement. Instead of modifying the general model, a possible way of introducing this notion is to allow agents to keep track of their previous positions, in order to understand if a certain movement is a step back. The utility of this kind of movement should be penalized, in order to discourage this choice;

- *penalize immobility*: in order to avoid stall situations, or simplify the solution of this kind of situation, an agent should generally move, unless it has attained the goal for a movement attitude (i.e. agent state), such as to be adjacent to a handle for an agent in state p. To achieve this effect, the memory of the past position, introduced in the previous point, could also be exploited to penalize the utility of the site currently occupied by the agent whenever it was also its previous position.

These correctives were introduced in the behavioural specification of mobile agents, and a new campaign of tests was performed to evaluate the effect of these modifications in the overall system dynamics. Once again, in all simulations the agents were able to achieve their goals, but the number of turns required to between 28 and 60, with an average of about 35 turns.

However, this reduction of time required for the completion of agents' movements, is not the only improvement obtained by introducing these correctives in agent behaviours. In fact another relevant part of the project in which this work has been developed provides the generation of effective forms of visualization of simulation dynamics to simplify its analysis by non experts in the simulated phenomenon. In particular, the developed simulator can be integrated with a 3D modelling and rendering engine (more details on this integration can be found in [15]), and a sample screenshot of the animation of the simulation dynamics is shown in Figure 6. In this kind of visualization the issues that were caused by the uncorrected movement utility specification brought to confusing, unrealistic and thus ineffective rendering of system dynamics. By introducing these correctives, the occurrence of oscillating agent movement was drastically reduced, and the penalization of immobility simplified the solution of stall situations among facing groups.

While these correctives can be easily modelled and implemented, to apply this approach to problems in larger scale scenarios, such as those related to malls or multi-floor buildings, it could be necessary to introduce some additional elements for the specification of agents' behaviours. In particular, in order to endow agents with the possibility to select in a more autonomous way those signals that are relevant to direct their movement, it could be necessary to introduce some form of abstract map of the environment. However the introduced methodology is focused on supporting the modelling of situations in which there is a strong focus on specific spots of a spatial structure, such as a hall or a part of a building floor, in specific situations (e.g. evacuation).

VI. CONCLUSIONS AND FUTURE DEVELOPMENTS

This work has presented the first proposal of a methodology for the modelling of crowds through the SCA model. The main phases of this methodology were introduced, and in particular the first two provide the definition of an "active environment", able to support simple reactive agents in the navigation of its spatial structure according to their behavioural specification. A case study related to a complex modelling scenario was introduced in order to show how the proposed methodology can be applied in a concrete case study.

Future developments are aimed at refining both the methodology and the MMASS platform, in order to better support the modeller/user, in the construction of complex simulation scenarios. In particular the platform still does not provide specific user interfaces and modules aimed at supporting the definition of an active environment, and parameters for specific simulations. Moreover specific libraries for active objects and paradigmatic pedestrian behaviours could be defined after a thorough analysis of psycho/sociological studies of crowd behaviors.
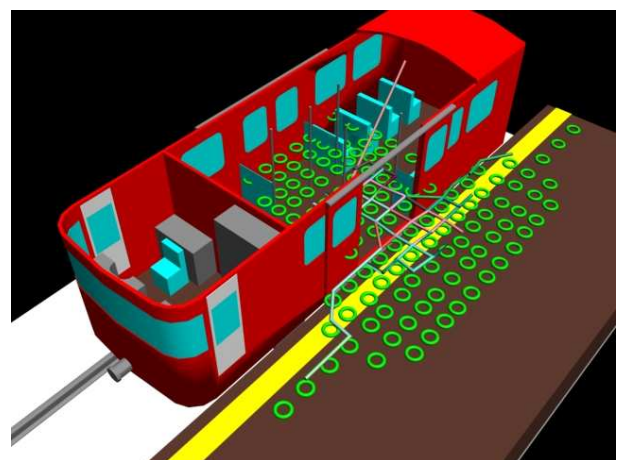

Fig. 6.   A screenshot of the 3D modelling of the simulation dynamics.

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