Simulation of Alternative Self-Organization Models for an Adaptive Environment

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***Abstract*—The ambient intelligence scenario depicts electronic environments that are sensitive and responsive to the presence of people. The paper deals with a particular kind of system whose aim is to enhance the everyday experience of people moving inside the related physical environment according to the narrative description of a designer's desiderata. In this kind of situation computer simulation represents a useful way to envision the behaviour of the responsive environments modeled and implemented, without actually bringing them into existence in the real world, in order to evaluate their adherence to the designer's specification. This paper describes the simulation of an adaptive illumination facility, a physical environment endowed with a set of sensors that perceive the presence of humans (or other entities such as dogs, bicycles, cars) and interact with a set of actuators (lights) that coordinate their state to adapt the ambient illumination to the presence and behaviours of its users. The simulation system is used to compare two different self-organization models managing the adaptive illumination system.**

I. Introduction

The ambient intelligence scenario [16] describes future human environments as dynamic places, endowed with a large number of wirelessly interconnected electronic devices that sense the nearby conditions and react to the perceived signals. The aims of these facilities can be very different, from explicitly providing electronic services to humans present in the environment through some form of computational device (such as personal computer or PDA), to simply realizing some type of ambient adaptation to the users' presence (or deliberate acts like voice emission or gestures). Ambient intelligence comprises thus those systems that are designed to autonomously adapt the environment to the people living or simply passing by in it in order to improve their everyday experience.

Sometimes the requirements and the specification of this form of adaptation are clear, unambiguous and even already formalized (e.g. in the wintertime keep the internal temperature of each room between 19 C and 22 C); on the other hand, sometimes the idea and specification of the desired adaptation is given in a visual or narrative form by a designer or even by an artist (in case of artistic installations). In this case, while the desired overall effect of adaptation could be clear it may be very complex to fill the gap between this form of high level specification and a computational system.

In this second situation computer simulation can play a crucial role in supporting the design and realization of adaptive, self-organizing ambient intelligence systems. In fact, traditional design and modeling instruments can provide a suitable support for evaluating static properties of this kind of environment (e.g. through the construction of 3D models representing a mock-up, proof of concept of the desired appearance or also adaptation effect but in a single specific situation), but they are not designed to provide abstractions and mechanisms for the definition and simulation of reactive environments and their behaviours. Through the definition of specific models and their implementation in simulators it is possible to obtain an envisioning of the static features of the ambient intelligence system as well as its dynamic response to the behaviour of humans and other relevant entities situated in it. This allows performing a *face validation* [14] of the adaptation mechanisms and also to perform a tuning of the relevant parameters.

This paper describes the application of a modeling and simulation approach to support the design of an adaptive illumination facility that is being designed and realized by the Acconci Studio[1] in Indianapolis. In particular, the designed system should be able to locally enhance the overall illumination of a tunnel in order to highlight the position and close surrounding area of pedestrians (as well as other entities such as dogs, bicycles, cars). In this case, the simulation offers both a support to the decisions about the number and positioning of lights and, more important, it encapsulates the self-organization mechanisms guiding the adaptive behaviour of lights reacting the the presence of pedestrians and other relevant entities in the environment. By providing the current state of the environment, in terms of simulated outputs of sensors detecting the presence of pedestrians, as an input to the self-organization model it is possible to obtain its simulated response, and the current state of lights. A schema of the overall simulation system is shown in Figure 1: it must be noted that the self-organization model adopted for the simulator could be effectively used to manage the actual system, simply providing actual inputs from field sensors and employing its outputs to manage actual lights rather that a

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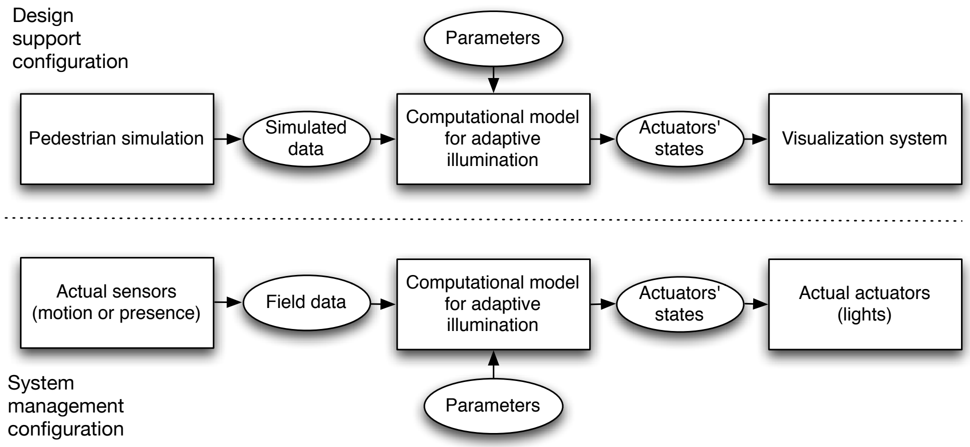

Fig. 1. A schema describing the components of the simulation system.

virtual visualization of the actual environment.

Besides the specific aims of the ambient intelligent system, there is an increasing interest and number of research efforts on approaches, models and mechanisms supporting forms of self-organization and management of the components (both hardware and software) of such systems. The latter are growingly viewed in terms of autonomous entities, managing internal resources and interacting with surrounding ones so as to obtain the desired overall system behaviour as a result of local actions and interactions among system components. Examples of this kind of approach can be found in both in relatively traditional pervasive computing applications (see, e.g., [10]), but also in a new wave of systems developed in the vein of amorphous computing [2] such as the one on paintable computers described in [9]. In this rather extreme application a whole display architecture is composed of autonomous and interacting graphic systems, each devoted to a single pixel, that must thus interact and coordinate their behaviours even to display a simple character. There is however a significant number of heterogeneous approaches to the definition of models supporting forms of self-organization in artificial systems and their application involves several important modeling and engineering choices.

It must be stressed that in the Indianapoli tunnel renovation scenario the designer had a precise idea of the desired overall adaptive illumination effect, combining a functional overall illumination of the tunnel – allowing pedestrians and drivers to effectively have a sufficient visibility of the environment but also emphasizing their presence and passage through the tunnel – but the choice of the computational model to achieve this effect was definitely not obvious. For instance, the rationale of the desired adaptive illumination pattern (that will be more throughly described in Section II) is to manage lights as if they were animated and able to follow the movement of pedestrians. This was tecnically impossible in the specific scenario and the effect had to be achieved by turning on and off in a coordinated way a set of lights characterized by a fixed position in the environment. However, the metaphor adopted by the designer could lead to consider specific computational models whose first class concepts are moving entities, like Boids [15], whose presence in the portion of the environment associated to a light indicates the need to turn a specific light on. On the other hand, a different approach, based on Cellular Automata [17], would lead to consider the physical structure of the environment, that is, a discrete and finite grid whose nodes could be either sensors or actuators, and the effective nature of the kind of action that must be managed, that is a change of state of the actuators.

The aims of the paper are thus twofold: on one hand it describes a concrete experience in which computer simulation was adopted to fill the gap between an abstract specification of the desired behaviour of an adaptive self-organizing environment; on the other hand the paper discusses the adequacy and feasibility of the adoption of two alternative computational models to generate the desired adaptation effect and to be effectively deployed in the real infrastructure.

The following section will introduce more in details the specific scenario in which this research effort is set, describing the requirements for the adaptive illumination system and the environment adaptation model. Section III introduces the pedestrian modeling approach, while the self-organization models that were experimented to guide the adaptive illumination facility are described in Section IV. A description of the developed environment supporting designers will follow, then conclusions and future works will end the paper.

II. The Scenario

The Acconci Studio, partner of the described research effort, has recently been involved in a project for the renovation of a tunnel in the Viginia Avenue Garage in Indianapolis. The tunnel is currently mostly devoted to cars, with relatively limited space on the sidewalks and its illumination is strictly functional. The planned renovation for the tunnel includes a set of interventions, and in particular two main effects of

Fig. 2. A visual elaboration of the desired adaptive illumination facility (the image appears courtesy of the Acconci Studio).

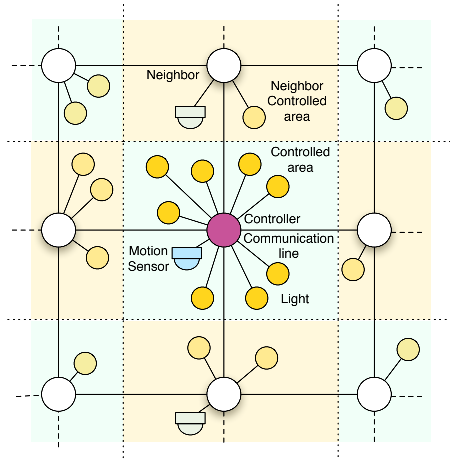

Fig. 3. A schema of the CA model for the adaptive illumination facility.

illumination, also depicted in a graphical elaboration of the desired visual effect shown in Figure 2: an overall effect of *uniformly coloring* the environment through a background, ambient light that can change through time, but slowly with respect to the movements and immediate perceptions of people passing in the tunnel; a *local effect of illumination* reacting to the presence of pedestrians, bicycles, cars and other physical entities.

The rationale of this local and dynamic adaptive illumination effect is better explained by the following narrative description of the desired effect:

> The passage through the building should be a volume of color, a solid of color. It's a world of its own, a world in itself, separate from the streets outside at either end. Walking, cycling, through the building should be like walking through a solid, it should be like being fixed in color.
>
> The color might change during the day, according to the time of day: pink in the morning, for example, becomes purple at noon becomes blue, or blue-green, at night. This world-in-itself keeps its own time, shows its own time in its own way.
>
> The color is there to make a heaviness, a thickness, only so that the thickness can be broken. The thickness is pierced through with something, there's a sparkle, it's you that sparkles, walking or cycling though the passage, this tunnel of color. Well no, not really, it's not you: but it's you that sets off the sparkle – a sparkle here, sparkle there, then another sparkle in-between – one sparkle affects the other, pulls the other, like a magnet – a point of sparkle is stretched out into a line of sparkles is stretched out into a network of sparkles.
>
> These sparkles are above you, below you, they spread out in front of you, they light your way through the tunnel. The sparkles multiply: it's you who sets them off, only you, but – when another person comes toward you in the opposite direction, when another person passes you, when a car passes by – some of these sparkles, some of these fire-flies, have found a new attractor, they go off in a different direction.

The first type of effect can be achieved in a relatively simple and centralized way, requiring in fact a uniform type of illumination that has a slow dynamic. The second point requires a different view on the illumination facility. In particular, it must be able to perceive the presence of pedestrians and other physical entities passing in it, in other words it must be endowed with sensors (detecting either the presence or the movement of relatively big objects). Moreover, it must be able to exhibit local changes as a reaction to the outputs of the aforemetioned sensors, providing thus for a non uniform component to the overall illumination. The overall environment must be thus split into parts, cells that represent proper subsystems: Figure 3 shows a schema of the approach we adopted to subdivide the physical environment into autonomous units, provided with motion/presence sensors (able to detect the arrival/presence of relevant entities) and lights (to adapt the ambient illumination, highlighting the presence of pedestrians).

However, the effect of the presence of a pedestrian in a portion of space should extend beyond the borders of the occupied cell. In fact, the illumination effect should "light the way" of a pedestrian through the tunnel. Cells must thus be able to interact, in order to influence neighboring ones whenever a pedestrian is detected, to trigger a (maybe less intense) illumination.

III. Pedestrian Simulation Model

The adopted pedestrian model is based on the Situated Cellular Agent model, a specific class of Multilayered Multi-Agent Situated System (MMASS) [6] providing a single layered spatial structure for agents environment. A thorough description of the model is out of the scope of this paper, but we briefly introduce it to give some basic notion of the elements that are necessary to describe the SCA crowd modeling approach.

A. Situated Cellular Agents

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* consists of a set P of sites arranged in a network (i.e. an undirected graph of sites). The structure of the space can be represented as a neighborhood function, $N : P \to 2^P$ so that $N(p) \subseteq P$ is the set of sites adjacent to $p \in P$; the previously introduced *Space* element is thus the pair $\langle P, N \rangle$. Focusing instead on the single basic environmental elements, a site $p \in P$ can contain at most one agent and is defined by the 3–tuple $\langle a_p, F_p, P_p \rangle$ where:

- $a_p \in A \cup \{\perp\}$ is the agent situated in p ($a_p = \perp$ 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 (i.e. $N(p)$).

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. $Perception_\tau : \Sigma_\tau \to [\mathbf{N} \times W_{f_1}] \ldots [\mathbf{N} \times W_{f_{|F|}}]$ 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;
- $react(s, a_{p_1}, a_{p_2}, \ldots, a_{p_n}, s')$: this kind of primitive allows the specification of 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.

B. SCA Based Pedestrian Model

The above introduced SCA model has beed applied to represent a very simple tunnel with two ends and some columns in it; pedestrians enter the tunnel from one end and they move towards the other end, avoiding obstacles either immobile (i.e. columns), and mobile (i.e. other pedestrians moving in the opposite direction).

The SCA $Space$ is the same cellular space defined for the D-MAN described in Section IV. To support agent navigation in this space, in each end of the tunnel we positioned an additional site in which a "beacon" agent (a static agent emitting a simple presence field) is situated. In the environment, thus, only two types of field are present.

To exploit this environmental specification in order to obtain the above overall system behaviour, we defined two types of agent, respectively interpreting the one type of field as attractive and ignoring the other one. This can be achieve through a simple $transport$ primitive, specifying that the agent should move towards the free adjacent site in which the intensity of the field considered attractive is maximum. The behavioural specification of these agents is completed by an obstacle avoidance rule (another $transport$ that moves the agent towards a random different lane whenever the best possible destination is occupied by an obstacle). Finally, agents reaching their destination, that is, one of the tunnel ends, are removed from the environment and they are positioned at the other end, so they start over their crossing of the tunnel.

IV. Adaptive Illumination Model

A. CA Based Approach

We employed a Cellular Automata model to realize the local effect of illumination as a self-organized reaction to the presence of pedestrians. CA cells, related to a portion of the physical environment, comprise sensors and actuators, as schematized in Figure 3. The former can trigger the behaviours of the latter, both through the interaction of elements enclosed in the same cell and by means of the local interaction among adjacent cells. The transition rule models mechanisms of reaction and diffusion, and it was derived by previous applications to reproduce natural phenomena such as percolation processes of pesticides in the soil, in percolation beds for the coffee industry and for the experimentation of elasticity properties of batches for tires [5]. In this specific application the rule manages the interactions of cells arranged through a multilayered architecture based on the Multilayered Automata Network model [8], schematized in Figure 3.

Multilayered Automata Network have been defined as a generalization of Automata Networks [11]. The main feature of the Multilayered Automata Network is the explicit introduction of a hierarchical structure based on nested graphs, that are graphs whose vertexes can be in turn be a nested graph of lower level. A Multilayered Automata Network is directly obtained from the nested graph structure by introducing states and a transition function.

The irregular nature of the cellular space is not the only difference between the adopted approach and the traditional CA models. In fact, CAs are in general closed and synchronous systems, in which cells update their state in parallel triggered by a global clock. Dissipative Cellular Automata (DCA) [18] differ from the basic CAs mainly for two characteristics: while CA are synchronous and closed systems, DCA are open and asynchronous. DCA cells are characterized by a thread of control of their own, autonomously managing the elaboration of the local cell state transition rule. DCA can thus be considered as an open agent system [13], in which the cells update their state independently of each other and they are directly influenced by the environment.

The model we defined and adopted, Dissipative Multilayered Automata Network (D-MAN), takes thus the advantages of both the Multilayered Automata Network and the Dissipative Cellular Automata. An informal definition this model describes D-MAN as Multilayered Automata Network in which the cells update their state in an asynchronous way and they are open to influences by the external environment.

The multilayered cellular structure of the D-MAN is composed of three layers:

- the first layer is related to the basic *discretization* of the physical environment into cells, corresponding to a local controller. Each of these cells effectively comprises the two additional layers;
- the *perception* and *actuation* layers, respectively comprising the sensors and actuators (lights).

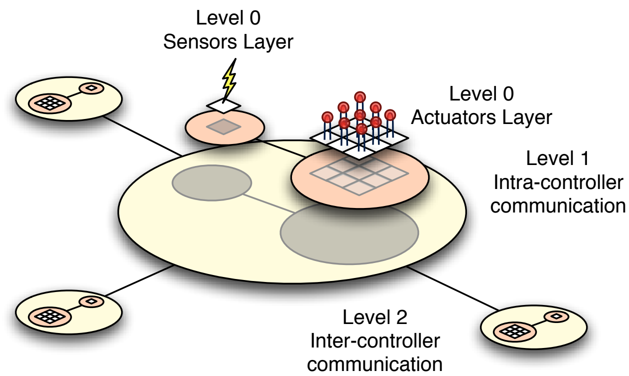

Fig. 4. The proposed automata network for the D-MAN.

This structure is schematized in Figure 4. The rationale of keeping separated these cells is to be able to specify and configure specific functions describing (i) how to compute the overall internal activation state of a cell given the status of the internal sensor(s) and the current state of activation of neighbours and (ii) how to translate this state of activation into a state of actuation for that specific layer (in other words, how to translate into a lighting effect the state of the cell).

Specific transition rules must thus be defined to manage different interactions and influences that take place in this structure, and mainly (i) the direct influence of a sensor that detected a pedestrian to the actuators in the same cell, and (ii) the influence of a high level cell to the neighboring ones (given the internal structure of each cell, due to the presence of a specific level of actuators inside it, this interaction effectively affects *a part* of a neighboring cell). Moreover, the effect of external stimuli must gradually vanish, and lights must fade in absence of pedestrians: while an active state of the sensor and high activation states of neighbours cause an increase of the cell activation state, it decreases in absence of these triggering conditions. More details about the formal definition of the model can be found in [4].

The adaptive illumination model is thus characterized by several features that make it difficult to predict how it will react to particular stimuli (i.e. patterns of pedestrian movement in the related environment), from the number and positioning of sensors and actuators, to the parameters of the transition rule. The transition rule per se is characterized by several parameters whose configuration can actually deeply alter the achieved illumination effect, to the point that we developed an ad hoc UI to show its behaviour when triggered trough mouse clicks [3]. To couple this model with a pedestrian simulation model sharing the discrete representation of the spatial aspect of the environment allows to simulate the behaviour of the adaptive illumination facility as a response to specific patterns of usage of the environment by pedestrians was thus considered an effective way to envision the performance of the adaptive illumination facility in plausible situations.

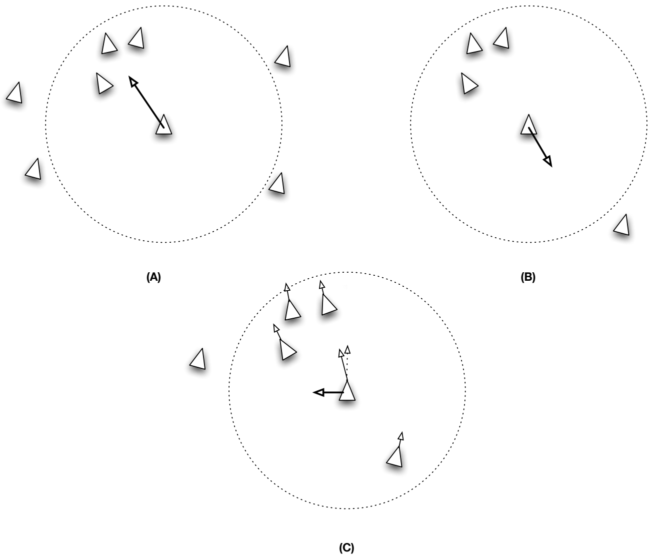

Fig. 5. A diagram schematizing the three basic steering behaviours of a boid: (A) cohesion, (B) separation and (C) alignment.

B. Boids Based Approach

The narrative description of the desired adaptive illumination effect by the designer explicitly mentioned “fire-flies”, insects forming a swarm. This description effectively leads to consider the possibility to adopt for the self-organization of the illumination facility computational models developed to generate collective behaviours of insects (but also flocks, herds and schools) such as the *boids* model. This particular model is very effective in generating coordinated animal motion, with a relatively simple computation essentially based on the mutual local perception of individuals situated in a physical environment. In our system, lights cannot actually move, but boids can represent the fact that a light is active in a predefined environment structure representing a discrete and finite set of allowed positions. The movement of boids represents thus the dynamic update of lights’ statuses in the illumination facility.

The basic model comprises three simple steering behaviors, describing how an individual boid maneuvers basing on the positions and velocities its nearby flockmates. These behaviours, also schematized in Figure 5, are:

- *cohesion*: steer to move toward the average position (the centroid) of local flockmates;
- *separation*: steer to avoid crowding (i.e. in the opposite direction of the the centroid of local flockmates);
- *alignment*: steer towards the average heading of local flockmates.

The notion of locality mentioned in these rules is essentially related to the possibility of boids to detect others of their kind situated within a certain range from their current position. These three steering behaviours produce vector representing a contribution to the overall action of the single boid, that is thus obtained as the vectorial sum of these contributions multiplied for specific scalar constants. These constants must be properly calibrated to avoid excessive dispersion and cohesion of the boids. Moreover, in this specific application, boids must also be attracted by people situated in the environment: a fourth contribution to the overall boid behaviour must thus be introduced, otherwise the boids wander in a realistic way (from the point of view of simulating a collective behaviour) but completely ignoring the presence of humans in the environment.

Before introducing an additional contribution to the behavioural specification of a boid to tackle this issue, we first considered that the basic boid model is conceived for a continuous environmental spatial representation, that is not suited to this situation. The adopted approach was to translate the cohesion and separation contributions of the model into elements of the aforementioned SCA model, mainly for two reasons: (i) this model is by definition discrete and (ii) it was already adopted to model pedestrians and the environment they are situated in. Alignment was not considered since SCA agents are not characterized by a direction or heading in space, but just by their position (i.e. a node in a graph structure).

To realize a model featuring the main characteristics of boids using SCAs we decided to provide each boid with a form of *presence* field, diffusing a sign indicating its position in nearby sites. Presence fields’ diffusion function decreases by a constant value the intensity of a field for each node the site crosses in the course of the diffusion operation until the value is void, while the composition function simply adds up the value of all presence fields in a given site. In this way, presence field in a given site represents a measure of its crowdedness and it can be used by boids to select sites that represent a good compromise between cohesion and separation. The behavioural specification of SCA boids comprises thus essentially two basic actions, a field emission and a trasnport action interpreting the value of the presence field as sort of social force [12]. In addition, we model the presence of pedestrians as another presence fields that is generated by the pedestrian agents present in the coordinated model simulating the behaviours of people moving in the tunnel. Boids agents’ transport action favors thus as a preferred destination those sites characterized by an average intensity of the boids presence field and a high intensity for pedestrian presence field. Also in this case, the model is characterized by a number of parameters having a serious impact on the overall adaptive illumination effect.

C. Discussion

The above introduced models were adopted and tested in the Indianapolis tunnel scenario; both of them proved their adequacy to effectively represent a formal, computational, non ambiguous and executable specification of the designer’s narration. They undergone a successful face validation, that followed several iterations to define a good value for the models’ parameters to achieve the desired results. However, the models have specific features that can have an impact on some of the non-functional properties they exhibit.

Fig. 6. Screenshot of the simulation environment: the central window shows a three-dimensional view of the tunnel (the actual 3D model of the tunnel was adopted), while the top panel shows a bi-dimensional view highlighting the position of pedestrians and the state of lights.

It must be stressed that even if the designer used the term “fire-flies” in the narrative description of the desired effect, the idea to follow the metaphor and to employ one of the most commonly adopted model for this kind of collective behaviour does not necessarily imply a smooth and simple definition of a model achieving the desired effect. First of all the boids model is based on a continuous spatial representation and thus it must be adapted to the discrete spatial structure of the illumination facility. Then a modification to the basic model must be introduced to achieve a “goal driven” behaviour (i.e. the tendency of boids to move towards people, preserving the swarm behaviour). Finally it must be noted that this modeling approach does not take into account the effective infrastructure that will be effectively employed to realize the illumination facility.

The CA based approach is based on the idea of viewing the environment itself as an assembly of autonomous units able to interact with their neighbours. The adaptive illumination effect is achieved as a reaction of these units to an external stimulus generated by sensors and as a results of their interaction. As a result it is much simpler to conceive a direct effective implementation of this approach in a concrete system made up of a set of micro-controllers responsible for the monitoring of a certain part of the environment and for the control of the lights it includes. On the other hand, there is no simple way to distribute the boids model in a distributed control system: the simple fact that boids can perceive the presence of other individuals of their kind in a potentially distant position, according to their range of perception, leads to consider that in case of distribution of this form of computation to different autonomous units would lead to higher costs in terms of network communication, that is instead essentially constant in the CA based case.

V. Conclusions and Future Works

The paper introduced a simulation approach to supporting the design of an ambient intelligence infrastructure aimed at improving the everyday experience of pedestrians and people passing through the related environment. A specific scenario related to the definition and development of an adaptive illumination facility was introduced, and two different computational models model specifying its dynamic behaviour was defined. An agent-based pedestrian model simulating inputs and stimuli to the adaptation module was also introduced. The models described in the previous Sections are part of a prototype supporting the design and definition of the overall illumination facility through the simulation and envisioning of its dynamic behaviour according to specific values for the relevant parameters (e.g. parameters of the transition rule of the CA, but also the number of lights and sensors, and so on); a screenshot of the system is shown in Figure 6: the central window shows a three-dimensional view of the tunnel, while the top panel shows a bi-dimensional view highlighting the position of pedestrians and the state of lights. The simulation takes place in the actual 3D model of the tunnel, that was adopted to achieve in a semi-automatic way a discrete representation of the environment that was adopted both for enabling the pedestrian simulation and for the positioning of lights. Part of the simulator, based on an platform for agent–based simulation [7], generates patterns of movement of pedestrians simulating inputs for the CA and another part of the system generates a visualization of the system dynamics, interpreting the states of the CA.

The renovation project is currently under development on the architectural and engineering side, whereas the introduced models have shown their adequacy to the problem specification, both in order to provide a formal specification of the behaviour for the system components and possibly as a control mechanism. The realized prototype explored the possibility of realizing an ad hoc tool that can integrate the traditional CAD systems for supporting designers in simulating and envisioning the dynamic behaviour of complex, self-organizating installations. It has been used to understand the adequacy of the modeling approach in reproducing the desired self-organized adaptive behaviour of the environment to the presence of pedestrians. We are currently improving the prototype, on one hand, to provide a better support for the Indianapolis project and, on the other, to realize a more general framework for supporting designers of dynamic self-organizing environments.

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