Towards a MAS Model for Crowd Simulation at Pop-Rock Concerts Exploiting Ontologies and Fuzzy Logic

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ABSTRACT
This paper illustrates a formal method to support crowd profiling phase into the development of Multi Agent Systems model. After a discussion about crowd reasearch context, a methodological tool for crowd classification based on a sociological theory is proposed. The tool uses an ontology based on fuzzy logic and allows the analysis of different crowded scenarios according to crowd features (e.g. density, duration, and so on). In particular it is illustrated the use of this method in relation to concert scenarios. Finally, an interpretation of this scenario, according to agent theory, is given.

Keywords
Crowd, agents, fuzzy logic, ontology.

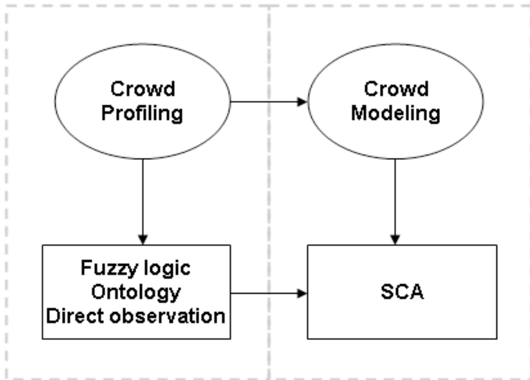

Figure 1: The two-levels approach for crowd study

1. INTRODUCTION
Crowd profiling aims at identifying the peculiar crowd features in order to model crowd behaviour. Crowding phenomena are an interesting topic traditionally studied in the context of human sciences (sociology, anthropology, and so on) [1], but also scientific disciplines have recently studied models and tools to satisfactory describe behaviors and interactions between individuals into a crowd [2].
In this paper we propose a methodological tool for crowd profiling. The aim of this tool is twofold: to provide crowd scholars and experts with a general framework to represent crowds, and to guide modeling and simulation in an agent-based model. In Computer Science, at our knowledge, no framework for crowd profiling has been proposed in literature while several modeling and computational approaches have been proposed to represent the dynamic interaction of groups of moving entities (i.e. persons, in the case of human crowds) that share a limited space. Models for pedestrian dynamics can be classified into three main classes [3] [4]: force-based models, models based on Cellular Automata (CA) and models based on Multi Agent Systems (MAS). In *force-based models* the dynamic of spatial features is studied through spatial occupancy of individuals, represented as moving particles subjected to forces: each pedestrian is attracted by its goal and repelled by obstacles (e.g. see Social Force Model [5]). Models based on *Cellular Automata* explicitly represent environment as a regular grid [6], where the size of each cell is the space occupied by a pedestrian. The state of the cell includes the representation of: presence of individuals and environmental obstacles, and direction of pedestrians. According to *MAS approach* [7] [8] pedestrians are instead explicitly represented as autonomous entities, with the ability to perceive information from the environment and to interact with each other. Recently MAS approach to pedestrian (and crowd) modeling has been largely encouraged and proposed, since a MAS can represent a potentially heterogeneous system of agents in a partially known environment [9]. According to MAS model, each agent represents an individual; other approaches are beginning to consider groups behavior instead of individual behavior into the crowd modeling as described in [10].

In Figure 1 it is shown the two-levels approach that was adopted: first step is crowd profiling, based on fuzzy logic, ontology and direct observation. Using these tools, types and features of pedestrian and abstract behavioral specification for each pedestrian type were defined. This information allows to propose a crowd modeling according to MAS-approach.
In particular, in this paper we refer to SCA model (Situated Cellular Agents) [11], a MAS-based approach in which the environment spatial structure plays a key role in agent behaviours and interactions. It must be stressed the fact that the term agent in the context of simulation has a "weaker" acceptation than the on described in [12]. In fact, the goals of the application are in apparent contrast with an unconstrained form of autonomy and proactiveness [13].
The remaining of the paper is organized as follows: first of all we present the methodological tool for crowd profiling.
Ontologies are formal tools to represent explicit knowledge or information related to a particular domain; ontology is adopted here to describe crowds domain according to one of

the available theories of crowds [14]. Fuzzy logic is a mathematical theory that simplifies the management of vague terms, here used in order to model crowd features that cannot be modeled as crisp values.
Then we illustrate the application of the crowd profiling step in order to analyze a pop-rock concert scenario where several crowds types can be observed. The aim of this application is to support both security management (e.g. evacuation simulation, positioning of advertising and direction signs, structural barriers placement, and so on), and concert organization experts. We developed this part of the work in collaboration with Saturnino Celani as domain expert, one of the most famous Italian bass-players. During a concert of Jovanotti the Safari Tour 2008 crowd observations and knowledge acquisition steps have been possible. In the second part of the paper we present SCA-model approach for crowd modeling and we propose a model for concert scenario.

2. CROWD PROFILING: FROM THEORY TO COMPUTATIONAL TOOL

In order to define the model, the starting point is sociological science, in particular Canetti's theory [15] contribution. Fuzzy logic was used to model this theory and we have implemented the ontology with Protègè[1].

2.1 Ontological Representation of Canetti's theory

Elias Canetti's work describes crowd phenomena characterizations and defines a crowd classification based on:

- presence or lack of *physical boundaries* (i.e. to rule the crowd spatial growth);
- presence or lack of *psychological boundaries* (i.e. to rule the crowd membership);
- presence or lack of *movement*;
- *density*, described as the ratio between people number and the available space. Density may be high, medium or low;
- *growth* of crowd, that is the ratio between the number of people and the time spent to join the crowd. It may be high, medium or low;
- *lifespan* of crowd, from its start to its end. Lifespan may be short, medium or long;
- *destination*, that describes the time that crowd spends to reach its goal. Destination may be near or far.

Crowd classification as described in [15] and values of these features are reported in Table 1 and Table 2. Each column describes a crowd type (i.e. open, closed, stagnating, rhythmic, slow, quick) with its own peculiar value features.

While some of them were modeled as crisp values (i.e. physical and psychological boundaries, movement), for other concepts (i.e. density, growth, lifespan, destination) it has been

[1]http://protege.stanford.edu/

	Open	**Closed**	**Stagnating**
ph. boundaries	no	yes	-
ps. boundaries	no	yes	-
movement	-	-	no
density	-	-	high/medium
growth	high	medium/low	-
lifespan	-	-	-
destination	-	-	-

Table 1: Relations between types of crowd and values of observable features (I)

	Rhythmic	**Slow**	**Quick**
ph. boundaries	-	-	-
ps. boundaries	yes	-	-
movement	yes	-	-
density	low	high/medium	low
growth	low	high	medium/low
lifespan	medium/short	long	short
destination	near	far	near

Table 2: Relations between types of crowd and values of observable features (II)

necessary to evaluate the set of linguistic quantifiers (e.g. high, long, short): to model these features we have adopted fuzzy logic through the specification of opportune fuzzy set:

Definition 1. A *fuzzy set* [16] is a couple $\langle U, f \rangle$ where U is a set called "universe of definition of fuzzy set" and

$$f : U \rightarrow [0, 1]$$

is a function that returns the membership degree of a specific element to a given fuzzy set. The function f is called *membership function* and every fuzzy set is completely defined by its own membership function.

The application of fuzzy logic to concepts is obtained by specification of fuzzy sets and by creation of membership functions in order to set the membership degree of a value to the fuzzy set. According to Canetti's formalization we must model four main concepts: density, growth, lifespan and destination. We have created a fuzzy set for each sub-concept defined from the four principal concepts and overlapped with linguistic quantifiers. According to fuzzy set theory, we have described the sub-concepts of density and growth by trapezoidal functions, and the sub-concepts of lifespan and destination by bell-shaped functions (i.e. Beta Curve). Density and growth sub-concepts were defined by linear systems. In the following, we describe the parametric functions we have used to create density and growth functions (see Figure 2).

- LowFunction(n, m) with $m > n$:

$$y = \begin{cases} 1 & \text{if} \quad 0 < x < n \\ \dfrac{m - x}{m - n} & \text{if} \quad n \leq x \leq m \\ 0 & \text{if} \quad x > m \end{cases}$$

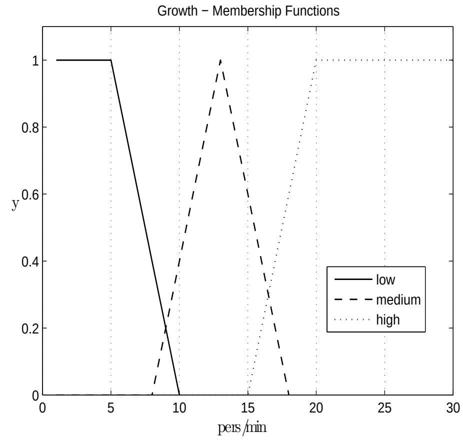

Figure 2: Functions for growth sub-concepts

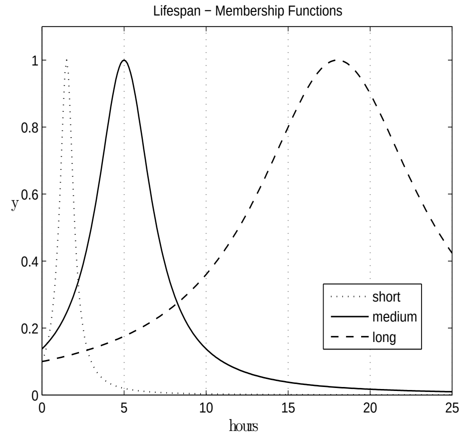

Figure 3: Functions for lifespan sub-concepts

where n represents x-coordinate value where the function assumes true value (equal to 1) and m represents x-coordinate value where the function assumes false value (equal to 0). In Figure 2 $n = 5$ and $m = 10$.

- MediumFunction(s, t) with $t > s$ and $k = \left\lfloor \frac{s+t}{2} \right\rfloor$:
  - if $(s + t) \bmod 2 = 0$

$$y = \begin{cases} 0 & \text{if} \quad x < s \\ \frac{x-s}{k-s} & \text{if} \quad s \le x \le k \\ \frac{t-x}{t-k} & \text{if} \quad k < x \le m \\ 0 & \text{if} \quad x > t \end{cases}$$

  - if $(s + t) \bmod 2 = 1$

$$y = \begin{cases} 0 & \text{if} \quad x < s \\ \frac{x-s}{k-s} & \text{if} \quad s \le x < k \\ 1 & \text{if} \quad k \le x \le k+1 \\ \frac{t-x}{t-(k+1)} & \text{if} \quad k+1 < x \le m \\ 0 & \text{if} \quad x > t \end{cases}$$

where s and t represent x-coordinate values where the function assumes false value (equal to 0) and k, defined as mean value between s and t, represents x-coordinate value where the function assumes true value (equal to 1). In Figure 2 $s = 8$, $t = 18$, $k = 13$.

- HighFunction (w, z) with $z > w$:

$$y = \begin{cases} 0 & \text{if} \quad x < w \\ \frac{x-w}{z-w} & \text{if} \quad w \le x \le z \\ 1 & \text{if} \quad x > z \end{cases}$$

where w represents x-coordinate value where the function assumes false value (equal to 0) and z represents x-coordinate value where the function assumes true value (equal to 1). In Figure 2 $w = 15$ and $z = 20$.

Lifespan and destination sub-concepts are represented by a bell-shaped function named Beta Curve. The general function for Beta Curve is:

$$B(x, \gamma, \beta) = \frac{1}{1 + \left(\frac{x-\gamma}{\beta}\right)^2}$$

where γ defines the point that takes value 1 in the y-axis and β settles the size of bell-shaped curve and is used to fix amplitude of fuzzy set compared with γ. Functions for lifespan sub-concepts are shown in Figure 3.
In order to establish parameters of the membership functions, it is necessary to consider a set of experimental data related to crowd scenario. In particular, it was used a set of experimental data related to concerts and songs durations by singers who belong to different musical kinds.
The aim of membership functions is to assign a membership degree (on y-axis) for each input observation (on x-axis). An observation is defined on the basis of crowd measurements in relation to values of density, growth, lifespan and destination. Membership degrees are used to define rules into the ontology.

2.2 Ontology Implementation

After the creation of the membership functions, we have focused on ontology creation for crowd classification. We have used Protègè, the standard de facto editor for ontologies. First of all, we have fixed the main elements of ontology.
Ontology is composed by five classes named Crowd, Density, Growth, Lifespan and Destination. Density, Growth, Lifespan and Destination have subclasses that match with the sub-concepts modeled with fuzzy sets; Crowd has subclasses that overlap with the different types of crowd classification (Open, Closed, and so on).

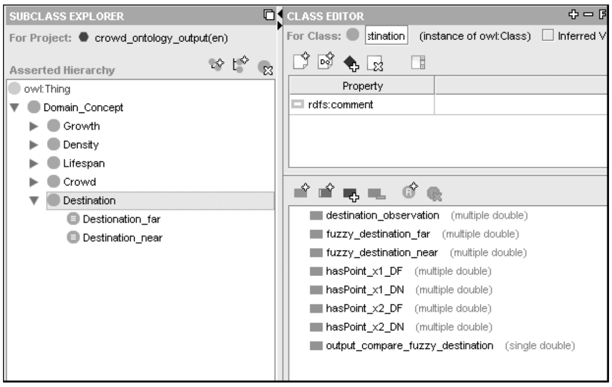

Figure 4: Ontology Interface

Each sub-class is defined by a rule based on features values. In particular, the sub-classes of Crowd are defined by rules that implement the different crowd types according to Table 1 and Table 2.
Crowd class is connected to the other main classes by unambiguous properties: each Crowd type instance is related to its own density, growth, lifespan and destination instance.
Moreover, for each main class we have defined a datatype list which is the basis for the classification. For each class, datatypes define:

- *observation value* for the described feature;
- *parameters values* of the class membership functions;
- *membership degrees* of observation computed using membership functions;
- *fuzzy set* connected with observation in input.

In order to compute membership degrees we have implemented an external program, in Java[2] language, that takes inputs and parameters values and manages the choice of the fuzzy set to assign to observation that is stored into a datatype. The program uses the OWL API[3] library that allows setting and getting information into the ontology.
Based on membership degrees and sub-classes rules, a reasoner allows classifying instances and links each crowd element with the corresponding crowd type. We have used Pellet[4], an Open Source OWL DL Reasoner to classify instances.
Ontology interface is shown in Figure 4: on the left, the five main classes with their sub-classes are shown, and on the right the Destination datatype list with its properties is presented. User can use the ontology following three steps:

- to pick data about density, growth, lifespan and destination on crowd that must be classified and to verify the presence of movement, physical and psychological boundaries;

[2]http://java.sun.com/
[3]http://owlapi.sourceforge.net/
[4]http://clarkparsia.com/pellet/

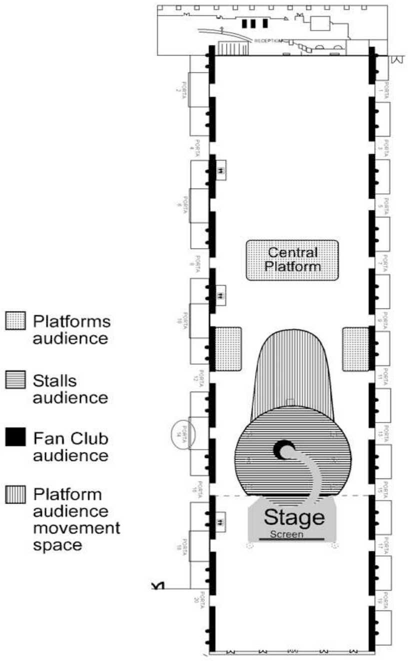

Figure 5: Map of public disposition (1:1500)

- to put observations about crowd into ontology and to start the reasoner;
- to obtain the classification of studied crowd in output.

In the next section we test the ontology based on data collected during a real event.

2.3 Concert case Study

In this section we present concert case: we classify crowd at music event in collaboration with Saturnino Celani, our domain expert. We have collected necessary information during a concert of Jovanotti Safari Tour 2008 that took place on December 13^{th} 2008, at the PalaBrixia arena in Brescia (Italy).
At first we apply ontology and we obtain a general crowd classification. Then, we propose a more specific crowd analysis in order to underline some features characterizing sub-crowds within the main crowd.
The first general analysis is related to:

- *structure* (presence of physical boundaries);
- number of *tickets sold* (presence of psychological boundaries);
- *concert duration*;
- *affluence* of *audience* into the structure.

Analysis starts with audience density. PalaBrixia Map is shown in Figure 5: density is calculated into the circular area that describes space taken by stalls audience. We can describe this area in the following way:

$$\text{Area} = \pi * r^2 = 3,14 * (22,5)^2 = 3,14 * 506,25 \approx 1.590 \text{ mq}$$

Moreover, the number of tickets sold for the event is 5.000, 3.000 for stalls and 2.000 for platforms. From these values we compute density as ratio between people who have taken place on stalls and the Area volume:

$$\text{Density} = \frac{people}{Area} = \frac{3.000}{1.590} \approx 2 \text{ pers/mq}$$

To evaluate crowd growth we first identify the affluence value as the ratio between the number of people and the time spent in order to enter into the structure (in minutes).

$$\text{Affluence} = \frac{people}{time} = \frac{5.000}{90} \approx 55 \text{ pers/min}$$

We can then express crowd growth as the ratio between the affluence value and the number of entry gates into the structure.

$$\text{Growth} = \frac{Affluence}{entries} = \frac{55}{4} \approx 14 \text{ pers/min}$$

In order to derive crowd lifespan we have considered the concert duration: the event started at 9:15pm until 11:45pm. During this time, the singer proposed 27 songs and two external events (only the sum of songs duration contributes to concert duration). Event duration corresponds to crowd lifespan and it is thus

$$\text{Lifespan} = 1:58:50 \approx 2 \text{ hours}$$

Now, we can compute song average duration. Song average duration overlaps with temporal distance of crowd destination (the end of the song corresponds to crowd goal, in fact it is the moment of maximum crowd cohesion).

$$\text{Destination} = \frac{1:58:50}{27} = 0:04:24 \text{ minutes}$$

Values obtained are average values and they are necessary whereas ontology allows a single number input. We have inserted values into the ontology settling the datatype lists in the following way:

- *physical boundaries* = `TRUE`;
- *psychological boundaries* = `TRUE`;
- *density* observation = `2,00`;
- *growth* observation = `14,00`;
- *lifespan* observation = `2,00`;
- *destination* observation = `4,24`;

We have not considered movement as influential in crowd classification because there was not a uniform behaviour related to this feature. Using Pellet reasoner we have obtained crowd classification as closed and quick. Data collected during the concert by Jovanotti are consistent with experimental data used for the implementation of membership functions.

A more specific crowd analysis is useful in order to underline some features characterizing sub-crowds within the main crowd. There are three sub-crowds:

- *Fan-Club sub-crowd* (in the sequel denoted by FC);
- *Platforms Audience sub-crowd* (PA);
- *Stalls Audience sub-crowd* (SA).

In particular, FC introduces different features compared to main crowd: it can be identified on the basis of Canetti's theory as a "crystal crowd". Crystal crowd is a little group of individuals that contributes to make a crowd and it has peculiar features: fixed number of individual, density is medium or high and formation is very quick. On the basis of these features, FC is classified by ontology as slow crowd.

Moreover, using information derived by direct observation it was noted that FC is the highest involved crowd. With regard to PA and SA, the only difference among them is the presence/absence of movement as key feature. In particular, SA is dominated by movement, whereas PA is static. SA sub-crowd movement is related to its involvement degree. Anyway, these two sub-groups are classified by ontology as closed and quick crowd, in the same way as main crowd.

Classification provides general information for crowd management while involvement degree allows defining different behaviours that characterized different sub-crowds inside the main crowd: next section describes three different agent types derived according to the three sub-crowds identified by the crowd profiling step.

3. CROWD MODELING: A PROPOSAL BASED ON SCA

SCA approach allows to model different agents types related to different behaviours identified. In the next two sections we illustrate the SCA-approach and a proposal of SCA-model for the concert case study.

3.1 SCA-model approach

The basic idea of the modeling SCA-approach is that the pedestrian movement can be generated by attraction and repulsion forces [17]. These forces are generated by fields that can be emitted by specific environment points, and that can be perceived or ignored by different types of moving entities. Also pedestrians themselves are able to emit fields and they can generate attraction/repulsion forces. An exhaustive discussion of this modeling approach is out of the scope of this paper and it can be found in [3]. We describe the main steps to follow in order to define a SCA model are:

Definition of the spatial infrastructure of the environment: a SCA-space can represent a discrete abstraction of a physical environment, where a site corresponds to a portion of space that can be occupied by a pedestrian;

Definition of points of interest/reference in the environment: specific spots of the environment can represent elements of interest, reference points or constraints influencing pedestrian movements. These elements must be associated with immobile agents able to emit fields that represent the presence of the point of interest/reference to pedestrians;

Definition of the pedestrian attitude towards space: the behavioural specification of an agent is realized through an utility function associating agent's states to a set of weights determining how to combine the presence of fields in a site to compute its attractiveness. This function is employed by a single transport action, representing the main element of agents' behavioural specification. The agent needs to know when to change state: this information must be explicitly defined as part of an agent behavioural specification, through a state diagram. States represent different attitudes towards the movement in the environment.

3.2 SCA-model proposal

According to the steps described in the previous section, a SCA-model for concert scenario can be defined as follows:
Definition of the spatial infrastructure of the environment. This step consists in the abstraction of space that describes the structure that hosts the concert. The environment is modeled as a non oriented graph of sites where each node represents a pedestrian position. Nodes proximity depends on crowd density in different areas of the structure (using previous analysis, density is equal to 2 pers/mq on stalls and it decreases going away from the stage). Each site p can contain at most one agent and it is defined by the agent situated in p, the set of fields active in p and the set of sites adjacent to p.
Definition of points of interest/reference in the environment. This step consists in the identification of active elements of the environment which are able to shape and influence crowd behaviour. We have defined two active agents types: Artist Agent τ_a and Audience Agent τ_{au}. A agent τ_a emits a field with intensity i depending on song features (e.g. a greatest hits generates a high intensity fields). Diffusion function is constant: it is uniform related to the space. A agent τ_{au} emits a field with intensity l in a particular state (afterwards defined); the intensity of the field interests only adjacent nodes.
Definition of the pedestrian attitude towards space. This step consists in the definition of agents behaviour. We have defined three agent types using information obtained from crowd profiling:

- Fan-Club Agent τ_{fc};
- Platform Agent τ_{pa};
- Stalls Agent τ_{sa}.

Each type is characterized by a threshold t whose value is defined according to audience behavioral attitude in relation to the position related to the stage. We have discretized t into three values, one for each agent type, that increase going away from the stage.
The composition function for perceived fields is additive: the perceived final intensity h is obtained adding each l perceived to i value. The comparison function uses fields values in order to verify if there is an adjacent site with a field greater than its own. Agents use this function in order to choose destination site during their change of position.
An agent τ_{fc} and τ_{sa} have the same states and actions because they have the same behaviour within the crowd. The only difference between them is the t value: τ_{fc} has the minimum t value and τ_{sa} has the medium t value. States diagram of τ_{sa} and τ_{fc} is shown in Figure 6. They are characterized by three states:

- *Static* state (initial state): the agent waits for field h;
- *Listening* state: the agent has perceived a field $0 < h \leq t$. The agent pays attention to events that take place on the stage. If agent perceives $h = 0$ (the song/concert is finished), it returns to *Static* state;
- *Involvement* state: the agent has perceived a field $h > t$. It is involved with dances and sngs and it emits a field with intensity l used in order to compute the total intensity h. If an agent perceives $h = 0$ (the song/concert is finished), it returns to *Static* state.

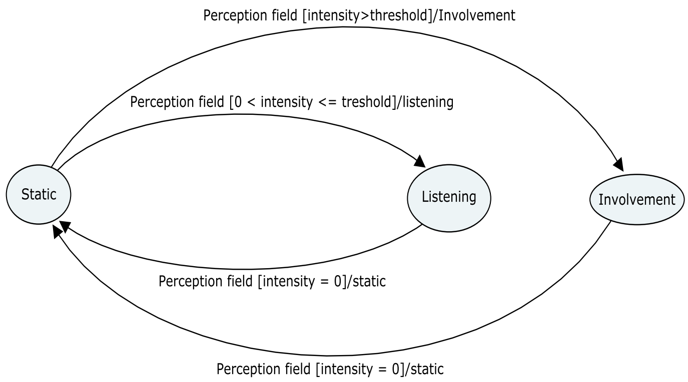

Figure 6: States diagram of τ_{sa} and τ_{fc}

An agent τ_{pa} is characterized by the highest t value. It is defined by five states (Figure 7):

- *Static* state (initial state): the agent waits for field h and memorizes the starting site s;
- *Listening* state: the agent has perceived a field $0 < h \leq t$. The agent pays attention to events that take place on the stage. If the agent perceives $h = 0$ (the song/concert is finished), it returns to *Static* state; if the agent perceives $h \geq t$ it changes its state to *Going to* state;
- *Going to* state: the agent has perceived a field $h > t$ and it wants to reach the stalls. The agent starts going closer to the stage and verifying if $h > t$ and if destination d_d is free. If the agent perceives $h = 0$ (the song is finished), it wants to return to its starting site s; if the agent perceives $h > t$ and d_d is occupied it changes its state into the *Involvement* state. If the agent perceives $h = 0$ it changes its state to *Going away* state;
- *Involvement* state: the agent has perceived a field $h > t$. The agent has reached the free position closest to the stage, all adjacent sites are occupied and it is involved with dances and songs. Agent emits a field with intensity l. If the agent perceives $h = 0$ it changes its state to *Going away* state;
- *Going away* state: the agent has perceived $h = 0$ (the song is finished) and it wants to return to its starting site s. The agent starts going closer to s ((d_u) in Figure 7) verifying if s is free. When s is free it changes its state into the *Static* state.

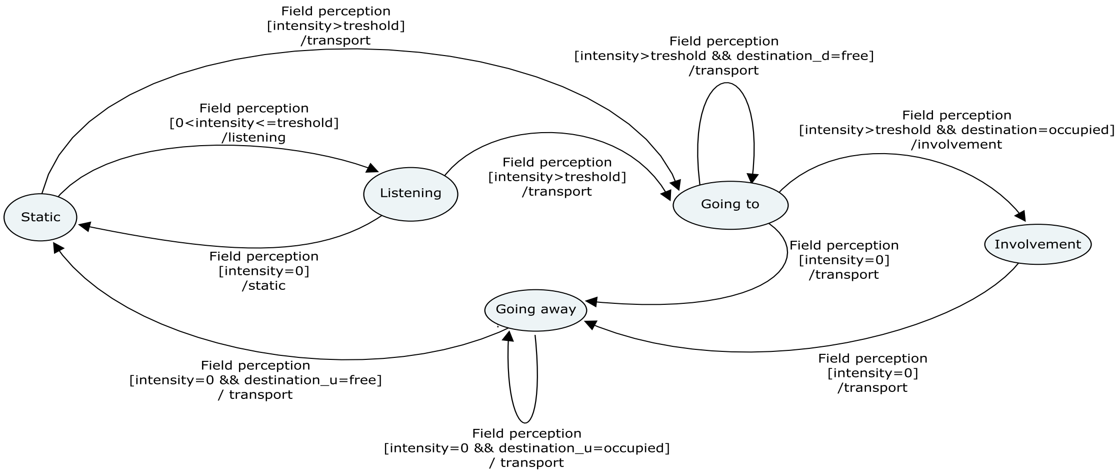

Figure 7: States diagram of τ_{pa}

4. CONCLUSIONS

In this paper a methodological tool for crowd profiling has been presented. The tool has provided a general framework to represent concert crowd features and it has guided us into proposing an agent-based model for concerts. We have introduced the methodological tool based on ontology and fuzzy logic and then we have illustrated its application to the pop-rock concert scenario. We have used application results in order to propose the concert SCA-model and to define the different agents types.

This is a work in progress: future developments concern a more specific formalization of the model previously proposed and an analysis of different possible solutions for the SCA-model development. After this evaluation phase, future works will be focused on implementation and testing steps in order to verify the model consistency.

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