The Verification Method of MASOES applied to the Social Force Model for Pedestrian Dynamics

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Abstract: - MASOES is a multiagent architecture for designing and modeling self-organizing and emergent systems. The architecture describes the elements, relationships and mechanisms, both at the individual and the collective levels, which determine the self-organizing and emergent phenomena, without mathematically modeling the system. In this work is tested a method of verification for MASOES, in order to determine its quality to describe the self-organizing and emergent behavior of real systems. This method is based on the wisdom of crowd paradigm and fuzzy cognitive maps. The case study is based on social force model for pedestrian dynamics, in order to study its behavior and determine its self-organizing and emergent capacity through MASOES.

Key-Words: - Multiagent systems, Self-Organization, Emergent Systems, Social Force Model, Crowd Dynamics.

1 Introduction

Nowadays, the multiagent approach can be used to model systems with several agents and interactions in very dynamic and/or unpredictable environments, where solutions are not known beforehand, and/or change constantly. Thus, we define MASOES, a multiagent architecture for designing, modeling and studying self-organizing and emergent systems [1], without mathematically modeling the system. MASOES, with respect to other works [7, 11 and 14], considers both microscopic and macroscopic aspects of a system; that is, it manages the knowledge at the collective and individual level. Also, it is a generic architecture and allows each agent to change its behavior, guided by its emotional states, providing to the systems designer with a tool that can be applied in the modeling of self-organizing and emergent systems in different contexts.

In this paper, the case study is applied to the Social Force Model (SFM) [8], which is a micro-simulation model for studying pedestrian dynamics, through diverse forces for reflecting the motivations of the pedestrian and the influence of environment. Hence, this article establishes the architectural components of MASOES and the causing relationships between them for the SFM. That is, for this specific case where we know that the real system (SFM) has self-organizing and/or emergent properties, we are going to test if the verification method of MASOES can determine its self-organizing and/or emergent properties, as those are observed in real experiments [9, 10].

2 General Aspects

This section defines some aspects related to MASOES, the wisdom of crowds paradigm (WoCP), the fuzzy cognitive maps (FCM), and finally, about SFM.

2.1 MASOES

MASOES is a multiagent architecture for studying systems in order to determine their self-organizing and emergent properties. We shall describe some key

ISBN: 978-960-474-257-8

aspects in a general way (more details about components and mechanism can be found in [1]).
Our architecture is divided into two levels: *individual and collective* (see figure 1). C**ollective cognitive emergence** arises from three interaction levels: **Local Interaction Level,** which might be direct or indirect (via the environment); **Group Interaction Level,** involving social networks or structured groups; and, **General Interaction Level,** which includes the whole the community of agents. Now, with respect **to individual cognitive emergence**, the idea is to produce cognitive emergence imitating the way in which human being go from unconscious to conscious; handling the agent's behavior at 3 different levels and establishing a hierarchy of behaviors: **Unconscious Behavior** or reactive; **Emotional Behavior** oriented by the emotions; and **Conscious Behavior**. Each agent changes its behavior (behavior-switching) dynamically, guided by its emotional state in a given moment. We propose in [20], an emotional model which will be used as an indirect mechanism in the decision-making process and in choosing type of behavior in particular.

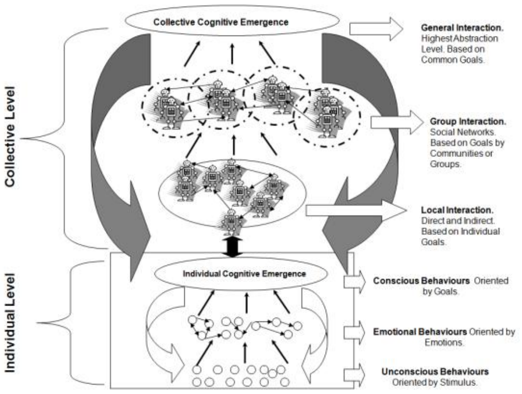

Fig. 1. Multiagent Architecture for Self-Organizing and Emergent Systems.

2.2 Wisdom of Crowds Paradigm

According to this paradigm, the collective intelligence (global wisdom) emerges from the knowledge of individuals within a group where eventually each separate individual possesses little information. In practice, the concept of collective intelligence is the opposite of the so-called "expert opinion", which means consulting with a person that has a track record of good judgment based on their experience and specialized knowledge [2]. This is proven through different examples where can be seen how the aggregated knowledge of a large and diverse group is superior to that of one or few experts. According to Surowiecki [2], there are some wisdom of crowd principles that we use as a source of inspiration in order to define our verification criteria in [12]. These principles are: *Opinion Diversity*: Individuals must have sufficiently diverse opinions (or knowledge over an issue) as to be able to comprise the whole spectrum of possible opinions. With more diversity in a crowd more robust will be their collective intelligence. *Independence of Opinion:* Each person must feel truly free to express his opinion, without being influenced by others, that is, as autonomously as possible. Decentralization: Decentralization means that each person puts his point of view to the test, instead of simply answering to directives coming from above, i.e., each member act as a pseudo-expert of an area. *Aggregation:* There are a decentralized and distributed mechanism that summarizes, transforms and expresses individual contributions (individual knowledge) into collective contributions (group knowledge).

2.3 Fuzzy Cognitive Maps (FCM)

Cognitive maps are tools to represent complex cognitive process through a visual design in the form of a map. Political scientist Axelrod (1976) [5, 6] introduced cognitive maps as tools to represent social scientific knowledge. Cognitive maps may be graphically represented, where concepts are connected by arrows or through a connection matrix in which the interaction of each pair of concepts indicates the relationship between them. In the connection matrix the i-nth line represents the weight of the arc connections which are directed outside of the C_i concept, that is, those affected by C_i. The i-nth column lists the arcs directed towards C_i, that is, those affecting C_i. Thus:

$$w_{i,j} = M(C_i, C_j) \qquad \textbf{(1)}$$

Where M represents the causal function of the arc that has concept C_i as the preceding concept and C_j as the consequent concept, and where $w_{i,j}$ will be the weight of the relationship between these two concepts. In general, concept C_i increases C_j causally if $w_{i,j} = 1$, it decreases it causally if $w_{i,j} = -1$, and it has not a causality relationship if $w_{i,j} = 0$. With respect to the FCMs, these were developed by Kosko [4] in the mid-1980s from Axelrod's Cognitive Maps. FCMs were initially presented as fuzzy mechanisms, where concepts and relationships could be represented as fuzzy variables (expressed in linguistic terms). In a FCM the level of representation of each concept depends on the level of its antecedents in the previous iteration, and is calculated through a normalized sum of products, where the relationship between a concept and its antecedents is modeled by a simple weight, according to the following equation:

ISBN: 978-960-474-257-8

$$C_m(i+1) = S\left[\sum_{k=1}^{N} w_{m,k} \cdot C_k(i)\right] \quad \textbf{(2)}$$

Where C_m (i+1) indicates the value of the concept in the following iteration, N indicates the number of concepts, $w_{m,k}$ indicates the value of the causal relationship between the concept C_k and the concept C_m and S(y) is a function to normalize the value of the concept. Finally, the dynamic approach of the FCM (Dynamic Fuzzy Cognitive Maps, DFCM) [17] is based on the dynamics of the causal relationships, i.e. during the runtime adapt to the changes arising in the environment.

2.4 Description of the MASOES Verification Method

For the MASOES verification is used two types of concepts (more details can be found in [12]): **Architectonic Concepts:** These are the concepts linked to the collective and individual components proposed in MASOES, such as: *agents, direct and indirect interactions, learning, positive and negative feedback, aggregation mechanisms, among others*. **Concepts linked to self-organizing and emergent properties:** These are the concepts linked to the verification criteria that guarantee emergence and self-organization in a complex system: *density, diversity, independence, emotiveness, self-organization and emergence*. These concepts, once they have been instanced in an application, should ensure the existence of certain self-organizing and emergent phenomena such as: quality content, group formation, generation of rules, among others.

2.4.1 Initialization Phase of Verification Method

Here is assigned a weight to each relationship among concepts according to experts. The relationships are established using an adjustment function based on fuzzy rules defined in [5, 12]. Moreover, it is assumed that the state of the concepts in a modeled system can be located in three zones: low, medium and high [5].

- A concept has a *high state* (between 2/3 and 1) when it works correctly and contributes substantially with the functioning of the modeled system.
- A concept has a *medium state* (between 1/3 and 2/3) when its functioning must be validated and its contributions to the systems' functioning is not so substantial.
- A concept has a *low state* (between 0 and 1/3) when it does not work and it does not contribute to the functioning of the system.

2.4.2. Execution Phase of Verification Method

The execution algorithm, according to the specified adjustment function, is the following:

I. To obtain the initial states for all the concepts according to the system to model and to the scenario to evaluate $C_0 = (c_0, c_1, ..., c_n)$.

II. While the system does not converge to a steady state:

a. To obtain the values of the causal relationships through $w_{i,j} = df_{i,j}(C^{t-1})$, where $df_{i,j}$ is the adjustment function for the relationship $w_{i,j}$.

b. To obtain the current states through $c_j^{\,t} = \sum_{i=0}^{n} (w_{i,j} \cdot c_i^{\,t-1})$.

III. Interpretation of the Results.

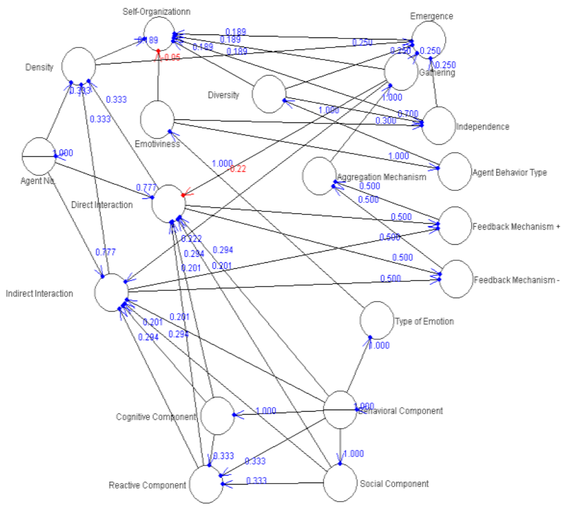

Fig. 2. The Generic FCM for our verification method.

This algorithm is done through a tool called FCM Designer, tool created in Java to visually create and to execute a FCM or DFCM (more details in [5]). Thus, the Generic FCM (see figure 2) is designed and integrated with the values assigned to each one of the relationships defined by the experts. In summary, the instantiation of the verification method for a system modeled through MASOES consists of defining the possible scenarios and then, to initialize the concepts according to the characteristics and operation of the system to study for a given scenario (step I of the algorithm). Later, according to step II, we would have a FCM of the modeled system that we must iterate with the FCM Designer, until the system becomes stabilized. Finally, we make the analysis and interpretation of the results.

2.5 Social Force Model

In the following, the main effects according to SFM [8] that determine the motion of a pedestrian α, will be introduced:

(i) Driving Force. He/She wants to reach a certain destination $\vec{r}_\alpha^{\,0}$ as comfortable as possible. Therefore, he/she normally takes the shortest possible way. His/her desired direction $\vec{e}_\alpha(t)$ of motion will be:

$$\vec{e}_\alpha(t) := \frac{\vec{r}_\alpha^{\,k} - \vec{r}_\alpha(t)}{\|\vec{r}_\alpha^{\,k} - \vec{r}_\alpha(t)\|}, \qquad \textbf{(3)}$$

Where $\vec{r}_\alpha(t)$ denotes the *actual position* of pedestrian α at time t. And, he/she will at every time t steer for the *nearest* point $\vec{r}_\alpha^{\,k}(t)$. If a pedestrian's motion is not disturbed, he/she will walk into the desired direction $\vec{e}_\alpha(t)$ with a certain *desired speed* υ_α^0. A deviation of the *actual velocity* $\vec{\upsilon}_\alpha(t)$ from the *desired velocity* $\vec{\upsilon}_\alpha^{\,0}(t) := \upsilon_\alpha^0 \vec{e}_\alpha(t)$ due to necessary deceleration processes, or avoidance processes, leads to a tendency to approach $\vec{\upsilon}_\alpha^{\,0}(t)$ again within a certain *relaxation time* τ_α. This can be described by an *acceleration term* of the form:

$$\vec{F}_\alpha^{\,0}(\vec{\upsilon}_\alpha, \upsilon_\alpha^0 \vec{e}_\alpha) := \frac{1}{\tau_\alpha}(\upsilon_\alpha^0 \vec{e}_\alpha - \vec{\upsilon}_\alpha) \qquad \textbf{(4)}$$

(ii) Repulsive Effects. *The motion of a pedestrian* α *is influenced by other pedestrians*. In particular, he/she keeps a certain distance from other pedestrians that depends on the pedestrian density and the desired speed υ_α^0. This results in *repulsive effects* of other pedestrians β that can be represented by vectorial quantities:

$$\vec{F}_{\alpha\beta}^{\,0}(\vec{r}_{\alpha\beta}) := -\nabla_{\vec{r}_{\alpha\beta}} V_{\alpha\beta}\left[b(\vec{r}_{\alpha\beta})\right] \qquad \textbf{(5)}$$

We will assume that the *repulsive potential* $V_{\alpha\beta}(b)$ is a monotonic decreasing function of b with equipotential lines, having the form of an ellipse that is directed into the direction of motion. Where $\vec{r}_{\alpha\beta}$ is the order of the step width of pedestrian β.

A pedestrian also keeps a certain distance from borders of buildings, walls, streets and obstacles, among others. Therefore, a border *B* evokes a *repulsive effect* that can be described by:

$$\vec{F}_{\alpha B}(\vec{r}_{\alpha B}) := -\nabla_{\vec{r}_{\alpha B}} U_{\alpha B}(\|\vec{r}_{\alpha B}\|) \qquad \textbf{(6)}$$

With a repulsive and monotonic decreasing potential $U_{\alpha B}(\|\vec{r}_{\alpha B}\|)$. Where $\vec{r}_B^{\,\alpha}$ denotes the location of that piece of border *B* that is nearest to pedestrian α.

(iii) Attractive Effects. Pedestrians are sometimes attracted by other persons (e.g. friends, street artists, etc.) or objects (e.g. window displays, etc.). These *attractive effects* $\vec{F}_{\alpha i}$ at places $\vec{r}_i$ can be modeled by attractive, monotonic increasing potentials $W_{\alpha i}(\|\vec{r}_{\alpha i}\|, t)$ in a similar way like the repulsive effects:

$$\vec{F}_{\alpha i}(\|\vec{r}_{\alpha i}\|, t) := -\nabla_{\vec{r}_{\alpha i}} W_{\alpha i}(\|\vec{r}_{\alpha i}\|, t) \qquad \textbf{(7)}$$

The main difference is that the *attractiveness* $\|\vec{F}_{\alpha i}\|$ is normally decreasing with time t since the interest is declining. We can now set up the equation for a pedestrian's total motivation $\vec{F}_\alpha(t)$. The total SFM is [8]:

$$\vec{F}_\alpha(t) := \vec{F}_\alpha^{\,0}(\vec{\upsilon}_\alpha, \upsilon_\alpha^0 \vec{e}_\alpha) + \sum_\beta \vec{F}_{\alpha\beta}(\vec{e}_\alpha, \vec{r}_\alpha - \vec{r}_\beta) + \sum_B \vec{F}_{\alpha B}(\vec{e}_\alpha, \vec{r}_\alpha - \vec{r}_B^{\,\alpha}) + \sum_i \vec{F}_{\alpha i}(\vec{e}_\alpha, \vec{r}_\alpha - \vec{r}_i, t) \qquad \textbf{(8)}$$

The *social force model* is now defined by:

$$\frac{d\vec{w}_\alpha}{dt} := \vec{F}_\alpha(t) + \text{fluctuations}. \qquad \textbf{(9)}$$

Where $\vec{w}_\alpha(t)$ is the preferred velocity. Here we have added a *fluctuation term* that takes into account random variations of the behavior. This fluctuation is Gaussian distributed and perpendicular to the vector pointing in the desired direction. In order to complete the model of pedestrian dynamics, a relation between the actual velocity $\vec{\upsilon}_\alpha(t)$ and the preferred velocity $\vec{w}_\alpha(t)$ must be introduced for the next movement.

3 Case Study: Social Force Model

In this case we will characterize the individual and collective levels of the components and processes involved in the SFM [8] via MASOES. Later, this will allow us to evaluate if the SFM behaves as a self-organizing and emergent system according to the model generated by MASOES, using the verification method described in [12].

A. SFM according to MASOES.

In this section, SFM is described using MASOES, following the methodology proposed in [13]. The first three stages: analysis, design and integration are described in this section.

I) Analysis Stage:

I.1. Agents and their Tasks in SFM

Modeling SFM through MASOES means to consider the pedestrians as agents with a high degree of homogeneity, i.e., with a large quantity of pedestrians with a similar behavior. Pedestrians interact in a common space, the street (environment), and each pedestrian obeys the same set of rules or forces defined in [8] and described in section 2.5, in order to reach his/her objective (destination).

I.2. Interaction Levels

There are 3 levels of interaction:

- Local. Pedestrians interact with each other in a direct and indirect manner when each pedestrian must select the direction and speed in relation to other pedestrians, obstacles, etc. in order to produce his/her local motion. Moreover, each pedestrian acts in agreement with the local information and his/her objective, avoiding borders and other pedestrians.
- Group. In this level, the pedestrians should interact following the attractive and repulsive effects which are responsible for the formation of pedestrian groups (joining behavior).
- General. It represents the highest interaction level, where the interactions are among the existing flows of pedestrians (crowd motion).

<u>II) Design Stage:</u>

II.1. SFM's Components and Processes at the Individual Level

In this section, the SFM's components and processes at the individual level are described. According to the SFM, the pedestrians must be defined without emotions because they are not considered in the SFM. Additionally, it is convenient that the agents develop two types of behavior proposed by MASOES (reactive and imitative) in accordance with SFM equations. Thus, each pedestrian agent will have the 3 individual components: reactive, social and behavior component in MASOES, without the cognitive component (see table 1).

II.2. SFM's Components and Processes at Collective Level

The involved components and processes can be seen in tables 2 and 3, respectively.

<u>III) Integration Stage:</u>

III.1. Phases for Knowledge General Management in the SFM

In the table 4, the three phases of our architecture for the knowledge management are instanced for the SFM.

In spite of the fact that there is neither a collective objective nor a collective knowledge base, and nor an emotional or cognitive behavior, according to the instantiation of the analysis, design and integration stages in the SFM, it can be affirmed, in accordance with MASOES, that the modeled system has the key components and processes, at the individual and

Table 1
Individual Components of MASOES in SFM

INDIVIDUAL COMPONENT IN MASOES	REPRESENTATION IN THE SFM
Behavior	The pedestrians in the SFM activate their behavior depending on the situation they face at a given time. The equations of the SFM describe different forces which will allow the behavioral component to dynamically carry out changes of the agent´s behavior.
Reactive	Pedestrians demonstrate reactive behavior in case of avoiding collision with other pedestrians or obstacles, and for maintaining a segregation behavior in case of walking in group or being attracted by something or some person.
Cognitive	It is not represented by the SFM for pedestrian dynamics.
Social	Each pedestrian requires space for the next step, which is taken into account by other pedestrians. Hence, the behavior of each pedestrian depends on the position and velocity of the other pedestrians and the environment, in order to adjust his/her velocity.

Table 2
MASOES Collective Components in SFM

COMPONENT IN MASOES	REPRESENTATION IN SFM
Set of Rules	This set of rules is made up of all the equations of the SFM.
Action Field	It is thanks to the set of direct and indirect interactions that the pedestrians delimit their action field within the pedestrian environment (the street). In fact, this action field is made up of the pedestrians's trajectories.
Collective Knowledge Base	There is not a collective knowledge base in the SFM.
Collective Objective	There is not a collective objective in the SFM.

Table 3
MASOES Collective Components in SFM

COLLECTIVE PROCESSES	REPRESENTATION IN SFM
Formation of Social Networks	We shall consider a *social network* as an open, horizontal system, grouping a number of people identified with similar needs and problems and which, additionally, work together with intense social interaction in order to maximize resources and contribute to the solution of problems [4]. Social interaction for problems resolution in the SFM does not take place since each pedestrian has only his/her objectives without a collective or common objective.
Feedback Mechanisms	With respect to flows generation, there are mechanisms for the generation of pedestrians's trajectories. The involved feedback mechanisms in the SFM are: • Acceleration Process guided by actual velocity, desired speed. • Deceleration or Avoidance Processes such as: repulsive and attraction effects.

Table 4
SFM through the Knowledge Management Phases

PHASE	REPRESENTATION IN THE SFM
Socialization	Pedestrians make explicit their knowledge to the others through creation, modification and elimination of his/her trajectory.
Aggregation	The aggregation process is carried out through the potential fields formed by the different forces from all the pedestrians who interact in the environment (street). Thus, the aggregation of the movements of the pedestrians forms different trajectories that are translated in flows at macro level.
Appropriation	Pedestrians could interact or to communicate with other pedestrians directly or indirectly, but SFM considers the pedestrians like unthinking elements. For this, pedestrians have not an explicit learning mechanism in this model. However, there is a reinforcement learning like in the case of the colonies of ants, since the pedestrians can follow or not other pedestrians (attraction or repulsion effects).

Table 5
Definition of the concepts linked to the self-organizing and emergent properties in SFM

Concept	Description
Density	It measures the degree of complexity within the society of agents. It is measured through the number of agents as well as the direct and indirect interactions. In the SFM is necessary a high density of pedestrians so that the self-organization effects can happen [9].
Diversity	It measures the homogeneity or heterogeneity of the society of agents. For the SFM there are a number of agents of same type defined within the system, i.e. There is a high homogeneity.
Gathering	It measures the degree of aggregation in the system, measured by the quality of the aggregation mechanism, the feedback mechanisms used in the system, and the degree of delimitation of the action field that favor coordination of activities at a collective level.
Independenc e	It measures the degree of autonomy and appropriation of the agents. Agents should be capable of issuing their own opinions independently, that is, without the influence and manipulation of others. It is measured by the quality of the learning mechanism used by the agent, and by the decisions they make without imitating others, based on their cognitive and reactive behavior and on the use of individual emotions, more than the social ones.
Emotiveness	It measures the degree of emotiveness in the agent. With respect to SFM, the handling of emotions in its mathematical model is not considered.
Self-organization	It measures the degree of adaptability in a system. Hence, the spatiotemporal patterns (self-organized phenomena) which could emerge are the result of a self-organization process among pedestrians rather than of external forces or deliberative actions [3, 9].
Emergence	It measures the degree of system's evolution through the possibility of the appearance of emerging properties. In pedestrian crowds are spatiotemporal patterns that could emerge such as: the development of lanes (groups) consisting of pedestrians walking in the same direction. Oscillatory changing of walking direction at narrow passages (e.g. Doors) and, spontaneous formations of roundabout traffic at intersections, i.e., the behavioral patterns are clustering, lanes and queues.

collective levels, in order to generate self-organizing

Table 6
Definition of architectonic concepts of Level II in SFM

Concept	Description
Agent N°	It refers to the number of pedestrians in the system.
Agent Behavior Type	It refers to the different types of behavior the agents might have. In SFM, there are homogeneous agents in the system with a reactive and imitative behavior.
Direct Interaction	It refers to the number of interactions between the pedestrians in the system, for example, collisions and oral communication.
Indirect Interaction	It refers to the number of interactions between the pedestrians in the system through the environment, for example, the generated trajectories in the street through their steps.
Feedback Mechanism +	It refers to how correctly the mechanism works. In case of SFM is represented through the acceleration force, which is a reinforcing mechanism that affects the aggregation process, contributes to imitative or social behavior and acts locally [15, 16].
Feedback Mechanism. -	It refers to how correctly the mechanism works. In case of SFM is represented through the deceleration process, which is a mechanism to stabilize processes and self-regulate them, avoiding undesirable fluctuations. It leads to adaptive, emerging behavior, favors robustness before new situations and acts globally [15, 16].
Aggregation Mechanism	It represents the quality of the mechanism in charge of obtaining information relative to each individual and combining it in such a way that it may be useful to the collective. In the SFM, like a stigmergic system, is a decentralized and distributed aggregation mechanism that allows indirect coordination and communication through action fields or potential fields.

and emergent behaviors at the macro level like a stigmergic system, with a reactive and imitative behavior guided by responses, in an environment with an action field as aggregation mechanism. Besides, the modeled system has a high density of pedestrians and behaviors based on the local interactions.

B. SFM through MASOES'S Verification Method.

In this section are instantiated the architectonic concepts and the concepts linked to self-organizing and emergent properties for the SFM according to the stages described in previous section, see tables 5, 6 and 7.

4 Experiments

Scenario 1: SFM through MASOES. For the instantiation of SFM through MASOES, the initial values of the architectonic concepts were determined according to the used values for the key parameters in

Table 7
Definition of architectonic concepts of the level III in SFM

CONCEPT	DESCRIPTION
Reactive Component	It represents the quality of this component for producing reactive behavior in the pedestrian. Reactions are rules associated to walking, obstacle and pedestrian collision avoidance and attractive effects.
Cognitive Component	It represents the quality of this component for producing cognitive behavior through the cognitive mechanisms (learning, reasoning) of the pedestrian, and also of intentional or deliberate decision-making, among others. In the SFM, this component is not represented.
Behavioral Component	It represents the quality of this component for favoring the adaptation of each pedestrian with its environment, since it creates an internal model of the world (handling explicit knowledge) that regulates its behavior. In the SFM, the pedestrian has his/her decision-making process based on its individual goals since an emotional state is not considered.
Social Component	It represents the quality of this component for promoting consciousness in pedestrians about the position and speed of others pedestrians.
Type of Emotion	It refers to the type of emotion an agent might have at any given time. In the SFM, emotions are not considered in pedestrians.

the simulations done recently with this model [9, 18]. The values of the concepts linked to the self-organizing and emergent properties are initialized in zero in order to determine which values will be reached when the system is stabilized. In addition, the type of emotion and cognitive component concepts are initialized in zero also, since there is neither emotional nor cognitive management in the SFM's pedestrians. Finally, a high density of pedestrians is assumed according to [9], as well as the number of indirect interactions, since the pedestrians communicate more indirectly than directly [19] following the steps of other pedestrians. Therefore, the number of agents and indirect interactions concepts are initialized at 1, and direct interactions concept at 0.25. The other concepts of the verification method that represent the quality of the involved mechanisms assume that work correctly, for this reason, these concepts are initialized at 1 (see figure 3).

According to the obtained results for this scenario (see figure 4), it was reached a medium level of self-organization (41%) and emergence (43%), verifying with these results that the SFM is a model able to generate self-organization and emergence. The concepts emotiveness, agent behavior type, diversity and independence finished in values close to zero, since the pedestrians do not have emotions, nor cognitive behavior, nor diversity (high homogeneity) nor independence (autonomy). The quality of the social component (1.0) is higher than the quality of

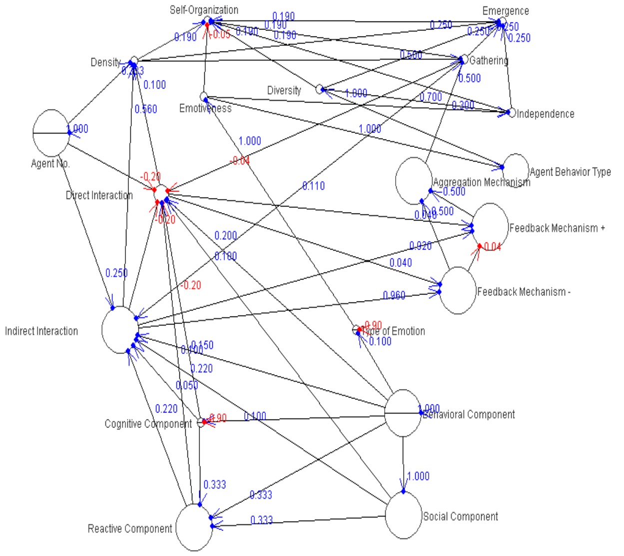

Fig. 3. Scenario 1: Initial FCM for the SFM.

the reactive component (0.69), this could be because each pedestrian has an imitative behavior more than reactive towards the end, indicating that each pedestrian has adapted his/her behavior to the environment and the other pedestrians when the system is stabilized. According to [19], this imitative behavior predominates when the system self-organizes.

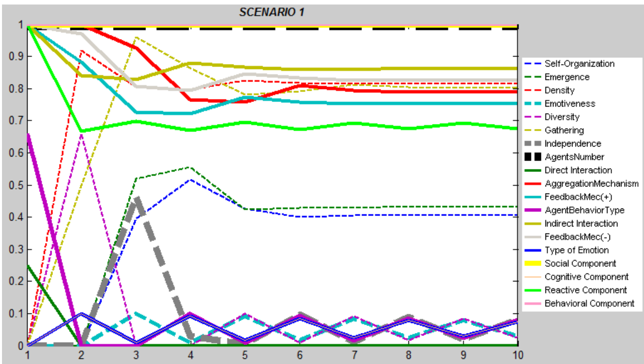

Fig. 4. Obtained Results for Scenario 1.

On the other hand, density reaches (0.82) towards at the end since indirect interactions decrease of 1 to 0.86 but they continue higher than the direct interactions (Zero). The decrease in the number of direct interactions are explained through segregation effect of lane formation [9], it normally leads at the end to a more effective pedestrian flow since time-consuming avoidance maneuvers occur less frequently i.e., it is reduced the number of encounters with oppositely moving pedestrians. The slight decrease in the number of indirect interactions is due to a predominantly imitative behavior rather than reactive at the end. The concept agent behavior type in zero explains the high homogeneity of the pedestrians according to the SFM. Besides, all the other concepts reach a high state indicating that they

ISBN: 978-960-474-257-8

work properly and contribute significantly to the level of self-organization and emergence obtained.

5 Conclusion

The interest of this study was to test the verification method in a system formally modeled, and found that performs well i.e. it is able to detect the self-organizing and emergent properties of the system. Thereby, MASOES is showed as an interesting tool for modeling systems with or without known self-organizing and emergent properties and for studying the self-organizing and emergent behavior of the modeled system.

The case study based on the SFM is useful to validate the verification method for MASOES, since it allows showing its capability to predict/study self-organizing and emergent behaviors in real systems. In previous works were modeled through MASOES other applications, such as Wikipedia and Free Software Development [12, 13] (both collaborative and participative architectures), this work is in an attempt to capture the characteristics and properties of another type of system, with a known self-organizing and emergent behavior like SFM, which has a well-known mathematical model to describe how the pedestrians organize themselves into counterflowing streams in a corridor.

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