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Exploring crowd dynamics based on individual behaviors and local interactions

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Abstract—This paper aims to present an approach to model crowd motion in normal and panic situations in order to study the influence of the individual's decision on a crowd situation. Different aspects of the human behavior are modelled for example the individual and group strategy for evacuation, the negotiation strategy in a blocked situation and the spreading of panic into the crowd. This approach is based on the Individual Based Model (IBM) to study and simulate the complex system such as the social system of crowd motion, and presents another way to study the special spreading of panic into the environment.

The prototypes produced by our approach for crowd simulation in a virtual environment illustrate the importance of the individual's decisions within the crowd and show how disruption affects the efficiency of evacuation.

Keywords—Crowd motion simulation, human behavior, panic, Individual Based Model, Cellular Automata, individual's strategy.

I. INTRODUCTION

Pedestrian dynamics studies have caught the attention of scientists in recent years. In this domain some models study and simulate pedestrian evacuation strategies in panic and normal situations to test their effectiveness and then help decision-makers to reduce human and material losses. In addition, this better understanding of crowd behavior is needed to improve safety procedures in a variety of buildings and areas and should optimize pedestrian motion.

Crowd dynamic is a complex systems where global behavior emerge from local interactions between individuals and between individuals and their environment. In this system of interactions, decisions of one individual can modify environment and in this way affect human and non human entities.. One can schematically distinguish two ways to model pedestrian crowd: the macroscopic model and the microscopic

model which mainly reflect a differentiation in term of geographical scale.

The microscopic class model (e.g Helbing's force social model [1], CA model [2], *etc.*) focuses on individuals and their characteristics as well as their capacities to take decisions in different situations. The global behavior of crowding is then the result of individual's interactions and the resulting emergent behavior.

The macroscopic class model (e.g D. Provitolo's dynamic model for panic propagation [3], Henderson's approach “Fluid approach” [4]) studies the social system as a whole to predict a possible evolution of human motion. Detailed interactions are then looked at and the model's description is shifted toward a description of the dynamic population variation.

In this paper, we present our approach to model pedestrian motion based on the Individual Based Model (IBM). This approach is a microscopic approach according to IBM particularities, so take into account the individual's details and decisions to give a coherent evolution of the system. To simplify the representation of the spatial environment we use a discretized representation of the space based on a grid of cells, where cell state includes the representation of the presence of individuals or other environmental obstacles.

The paper is organized in the following manner. In section II, we present an overview of our model in normal and panic situations with a brief view of the IBM approach. In section III, we analyze the model based on the simulation results. Finally, we provide discussion for the evolution of the approach.

II. THE IBM APPROACH FOR PEDESTRIAN MOTION

Pedestrian dynamic models are used to control and understand crowd behavior. Different types of approaches are developed, some focus on the prediction of a possible crowd evolution, others focus on the observation of the emergent behavior produced by pedestrians' interactions. The latter are called microscopic models. Two types of these models are described in literature: continuous in space like the Helbing's

social force model, and discrete on space like the cellular automata models.

Helbing's studies are based on pedestrian observations in the real world in normal and panic situations. He demonstrated that "The transition between the "rational" normal behavior and the apparently "irrational" panic behavior is controlled by a single parameter, the "nervousness", which influences fluctuation strengths, desired speed,..." [1]. Helbing's social force model is based on force terms which influence the evolution of pedestrian motion and where the variation of one parameter may cause the appearance of panic motion.

"Cellular automata (CA) microsimulation is used to model complex behavior and is named after the principle of *automata* (entities) occupying *cells* according to localized neighborhood rules of occupancy" [5]. In fact, the CA models are based on cells changing state what is determine the emergent results, they approximate the more complex models with a minimal set of simple rules. Pedestrians' intelligence is not really modeled in CA approach, other alternative are introduced to model interactions [6] which provide collective effects and self organization.

According to Helbing's studies, the evolution of pedestrian behavior from rational to irrational is caused by the variation of certain pedestrian characteristics. These variations, brought about by a sudden disruption of the environment, influence the reasoning process of the pedestrian and causes him to panic. In fact, pedestrian motion in panic situations is the result of the variations of some distinct individual's characteristics that occur in normal pedestrian motion. Our approach is a model for pedestrian motion in general; we suppose that the disruptions that occur within the environment affect pedestrian characteristics and cause their transition to panic behavior. This approach to model panic is quite realistic because pedestrian panic motion is the result of the feeling fear that obliges pedestrians to modify their priorities and behavior to escape the potential danger.

A. The IBM approach

In our approach we use Individual based models (IBM) which are a part of a multi agent system which includes a computational system composed of entities in interaction to produce a solution. The particularity of IBM is the autonomy of the entities which interact with each other and with their environment to produce a global behavior. Individual based models are used in many social sciences and physical sciences, in fact in all complex systems to investigate the properties that emerge from entities in interaction.[7]

This microscopic approach offers tools to take into account the heterogeneity of the entities, the characteristics of each individual are tracked through time, in contrast with the macroscopic approach where "the characteristics of the population are averaged together and the model attempts to simulate changes in these averaged characteristics for the whole population" [8], (Graig Reynolds).

The IBM approach provides agent notion to model system's entities (e.g an individual, a wall, a moving obstacle within the environment etc.). Agent can be a mobile or a static entity and

can have reactive or cognitive behavior, it depends on the characteristics of the entity it models.

1) Reactive agents

Reactive agents are autonomous agents with a partial representation of the environment. They choose actions by using their current state and the external stimuli as a reference in the base rule to get the appropriate reaction. The architecture of these agents is based on the perception to produce behaviors called "stimuli-response" behavior. The simplicity of the architecture and the behavior of these agents allow them to model and study complex systems where behaviors emerge from interactions of a large number of entities.

The purely reactive agent's drawback is its lack of adaptability. This type of agent cannot generate a plan to reach one's goal because of its incapacity of taking into account past actions in later decisions.

2) Cognitive agents

Cognitive agents also called Belief Desire Intention (BDI) agents[9], have a global representation of the environment. The architecture of those agents contains three classes; beliefs, desires and intentions:

- Beliefs: describe the internal representation of the agent's state and properties, the agent's beliefs and habits and the agent's environment and the neighbors' characteristics.
- Desires: define the goals of agent. First of all the agent has to select a goal according to the environmental interactions.
- Intentions: define the goal selected to reach first

The specificity of these agents is their architecture which allow reasoning. Their ability to generate a plan according to the particularity of their environment, even in unforeseen situations catch up with specially human ability.

The main problem with a purely cognitive agent is the reasoning process, because, for some simple well known situations, reasoning may not be required at all. So controlling the agent's reasoning process can save time in simulations.

B. The IBM model for pedestrian motion in normal and panic situations

The agent in our approach is a hybrid agent which use "reactive" and "cognitive" approaches to get the best properties. In fact, a graduation exists between purely reactive agents and purely cognitive agents which represents the extremity of a line and not a categoric opposition [10].

Our hybrid agent adapts its reasoning process to specific situations and reacts in a deterministic way to different situations. It is able to act as a reactive agent and gets a quick response for external stimuli those which do not need a plan, and acts as a cognitive agent to generate or use plans in some complicated situations.

The architecture of the agent comprises three classes or containers: Beliefs, Desires, Intentions. We introduce three essential functions: Perception, Deliberation and Action upon which the agent behavior is based:

- Perception: the agent's perception updates the agent's knowledge base "Belief" according to the interactions with the environmental entities. These interactions require a

“communication” between the entities which are normally assured by sensory capacities (i.e vision capacity, hearing capacity, oral capacity).

- Deliberation: deliberation is a cognitive capacity of the agent, it assures the reasoning process to find the desire to firstly achieve. To deliberate, the agent takes into account his beliefs, his action base (i.e the base is an agent base rules which contain a set of actions that the agent can carry out, in response to stimulations) and his perceptions.
- Action: after deliberation the agent's goal is to realize the desire chosen, a set of actions (i.e plan) is then established, the agent is able to update its plan according to its perceptions.

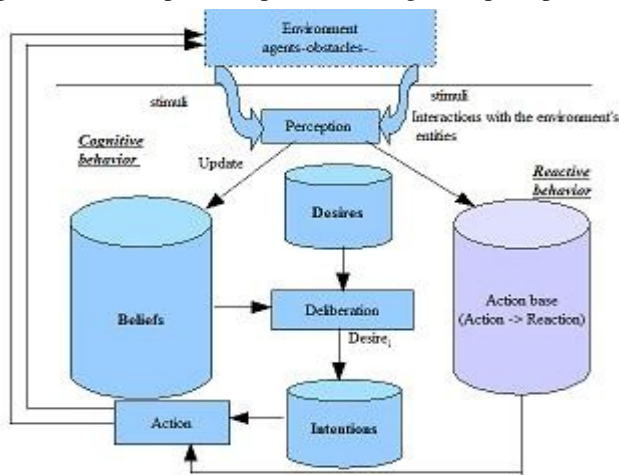


Fig .1: Hybrid agent's architecture

Space is defined as a grid of cells where every cell can contain one agent (e.g an individual, a wall, an obstacle, etc.) per time step. Pedestrians move into this discrete space from one cell to another according to their velocity characteristics. They have to refer to their perceptions to recognize other pedestrians and objects in their vision field, and have to communicate with their environment to exchange information and so coordinate their actions.

Perceptions are controlled by the sensory capacities of each agent, namely the vision capacity and the hearing capacity. In our approach vision is defined by two parameters the *vision angle* and the *vision radius* controlling the visual perception of the agent. The agent's hearing capacity is defined by the parameter *perturbation*, the agent is continually listening to its environment, thus the hearing capacity is always active and is ready to detect any perturbation in sounds such as an alarm..

Communication is a basic agents' interaction process, it provides the interchange of decisions, thoughts, or information by speech, signs, etc. Three major parts in human face to face communication are distinguished in literature; body language, voice tonality and words [11]. In order to simplify the modelisation of the agents' communication, we firstly consider that the agent can communicate only with its Moore neighborhoods (8 neighbors) [12], and then we propose a simple protocol of communication based on the sending and the receiving of messages. When communication is needed between two agents, each agent asks its neighbor for

information. The reception of these information allows the update of the agent's knowledge base, so that it can decide the appropriate actions to perform.

The agent's perceptions are the base of the interaction process. The exchange of information between agents, and the reception of the vision or the sonorous information, influence the decisions taken and therefore the evolution of the system modeled.

The agents' motion is based on realistic pedestrian motion rules. When we look at Helbing's observations [1], we can note that pedestrian motion is controlled by certain rules which influence its orientation choice. Helbing's observations demonstrated that:

- Pedestrians keep a certain distance from other pedestrians and borders (walls, obstacles, etc.).
- Pedestrians prefer to walk at their own speed which depends on their characteristics and desires.
- Pedestrians choose the fastest route to their next destination rather than the shortest one.

To model such behavior we introduce a few known properties in our agent base rules like repulsion and attraction properties, and collision avoidance strategies. Agents in our approach are attracted by agents who are walking on the same side as them and avoid agents walking in the opposite direction [13]. These repulsive and attractive behaviors are controlled by the agents' interactions and allow the description of a lot of quite realistic observed phenomena such as *lane formation* which refers to a self-organization of pedestrians into separate flows according to their walking direction, and *oscillations at bottlenecks* which refer to oscillations of the passing direction at bottlenecks [14].

However, despite the collision avoidance strategies' the agent sometimes may be in a conflictual situation when its desired next position is occupied by another agent, and without a reliable strategy, agents can remain still for a long time which may cause bottlenecks. To solve this situation we propose a conflict resolution strategy inspired by the “Game theory”, which is a reliable theory to study and model social science problems and situations where the individuals' decisions affect each other [15].

In a blocked situation where two pedestrians aim to reach the same position, a negotiation must be done between the individuals to decide who does what. In the “Game theory” this situation is represented in an hybrid game which contains cooperative and non cooperative player behavior, negotiation and competition strategies are then defined to guide individuals' decision and to control the evolution of the system. The conflict resolution strategy that we propose in our approach is based on this hybrid strategy where the agent is free to decide whether to cooperate or not.

In a blocked situation the agent's action depends on its strategy (i.e a cooperative strategy or a competitive strategy). In fact, in that situation deliberation function provides the action to perform according to agent's conflict resolution strategy and agent's current state. After deliberation each agent informs the other about its decision and moves to target cell. To accelerate simulations, agents move to the target cell providing that they

do not create another blocked situation, otherwise agents have to negotiate again. In fact, blocked situations will be resolved in all cases, the only variable which changes is time. The cooperative behavior may reduce conflict time between agents, and so save time for pedestrians to achieve their destinations.

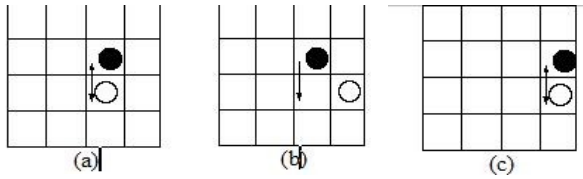


Fig. 2: Solving conflict situations. These figures present a solving conflict situations of the initial situation (a). The figure (b) illustrate a cooperative behavior of the agent in white. The figure (c) present a conflict situation due a conflict behavior of the two agents , agents still blocked again.

In panic situations people are overwhelmed by a feeling of fear and anxiety. The sudden disruption which accrued affect their behaviors and makes them loose their reasoning capacities and behave “irrationally”[16]. In our model, agent's perceptions detect disruptions which affect its characteristics and cause variations in its behaviors. Panicking agent boost then its velocity in order to escape as fast as possible the danger. Agent's interactions increase then, an imitation behavior appears which affects the evacuation process and may produces the emergence of collective behavior like “boids”[13].

Hybrid agent increases its walking speed when it starts to panic. Because of the lack of information about the panic propagation process, we concentrate on interactions as a unique means for panic propagation. When a non panicking agent interacts with panicking neighbors, panic ensues if the number of those panicking reaches a fixed limit. The new panicking agent then increases its speed which corresponds to the maximum speed that it can reach, and may follows agents with same speed. Boids will be formed then and the emergent behavior will appear as a response to the environmental variations.

III.SIMULATION RESULTS

We describe in this section the results of simulations of two situations, namely normal situations and panic situations. The simulations provide critical informations to study the variation of pedestrians' behavior according to environment stimuli and the pedestrians' conflict resolution strategy.

A.The influence of the conflict resolution strategy on evacuations

We investigate in this part the behavior of pedestrians leaving the environment when strategies to resolve potential conflict situations vary. The simulations are performed in a 41*41 NetLogo[17] lattice, with 112 heterogeneous agents located in a random cell (i.e 56 agents in the up part of the environment and 56 agents in the down part, the distribution is uniform). In fact, in the simulations agents do not have the same Beliefs (i.e speed, conflict resolution strategy, faith neigh

boors, and alarm detection), because these beliefs depend on individual's culture, age, sex, experience, etc. We take into account these human characteristics in the model to make it as much realistic as possible.

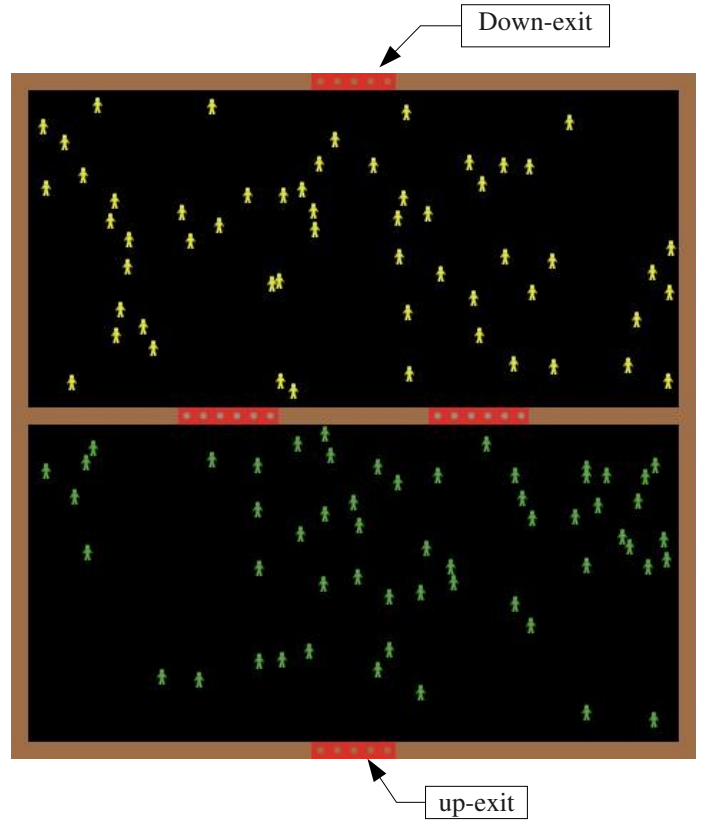


Fig. 3: The figure shows the screen shots of the simulation with a population of 112 heterogeneous agents. Agents in yellow represent pedestrian on the up part of the environment who try to reach the up-exit. Agents in green represent pedestrians on the down part of the environment who try to reach the down-exit.

The exits *up-exit*, *down-exit*, and *middle-exit* are represented by a still agents that occupy red patches. To exit environment agents on the up-part (i.e yellow agents) have to reach first the *middle-exit* and then the *up-exit* to exit the environment. At the same time agents on the down-part (i.e green peoples) have to reach first the *middle-exit* but the *down-exit* to exit the environment. When the agents reach their exit the *down-exit* or the *up-exit*, they exit the simulations.

The middle exits in the simulations act like doors walkable in both direction, they are performed in order to reduce space for agents and to provoke bottlenecks with agents moving on opposite direction. This is environment is artificial but it allows the study of conflict phenomena and the observation of the emergent one.

Figure 4 illustrates the variation of the pedestrians' flows in normal situations. We see that in cooperative strategy pedestrians evacuate quickly than in conflict strategy, this is because in a conflict strategy the face-to-face conflict can make last blocked situations. The figure 5 illustrates evacuation flows in panic situations with varying conflict resolution strategy, the

result is similar than the one in normal situations. With the same initial conditions, in cooperative strategy pedestrians leave the environment in less than 45 time step whereas evacuation time pass the 60 time steps with a conflict resolution strategy.

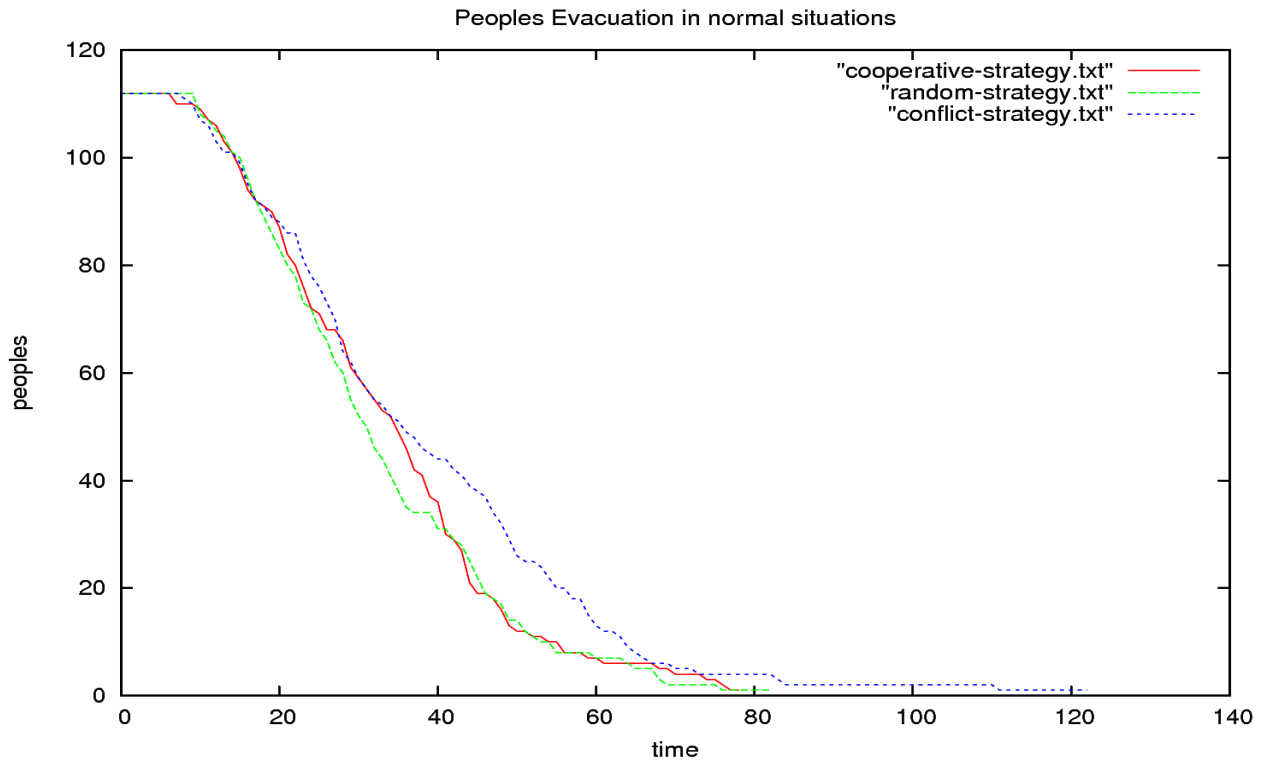


Fig. 4: Variation of the evacuation flows in normal situations

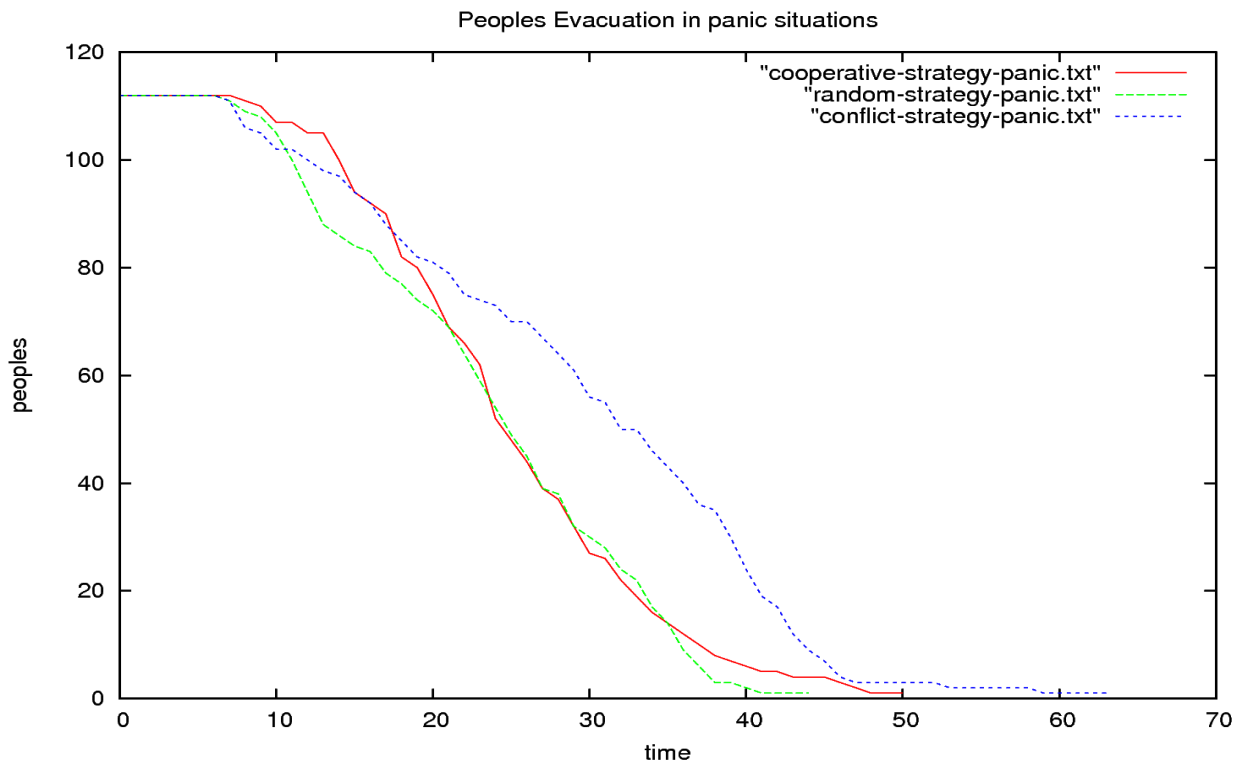


Fig. 5: Variation of the evacuation flows in panic situations

From these two figures we note that conflict resolution strategies influence the pedestrians evacuations flows. The cooperation is the best behavior that individuals have to take when they are in face-to-face situations to avoid bottleneck situations. This result is confirmed in figure 6 which illustrates the variation of bottlenecks in normal situation with the two conflict resolution strategy, namely cooperative and conflict resolution strategy.

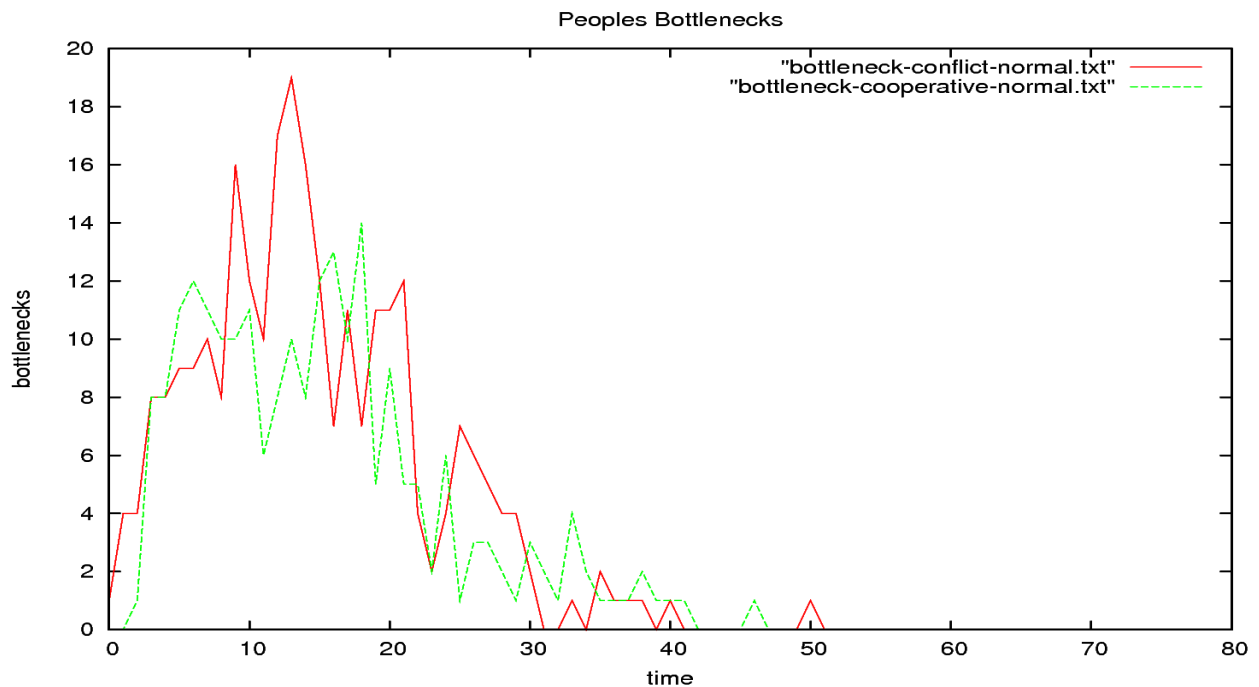


Fig. 6: Bottlenecks variation according to the conflict resolution strategy

B. The influence of panic behavior on evacuations

We investigate in this part the effect of panic on evacuations process. The figure 7 presents the evolution of evacuation on normal and panic situations with pedestrians' cooperative strategy. In fact, for 150 time steps about 121 pedestrians are evacuated in normal situations whereas only 71 pedestrians are evacuated in panic situations. We note that evacuation time in panic situations is greater than the one in normal situation, thus trying to move fast can slow down evacuation and then may cause human disasters by reducing chances to survival in catastrophic situations.

Trying to move fast increase pedestrians bottlenecks (see figure 8) which has a bad effect on the pedestrians' evacuation flows. This phenomena has been observed in Helbing's social force model [1] "*Faster-is-slower-effect*" due to impatience where he demonstrated that trying to move fast can cause a smaller average speed of leaving.

Getting nervous and panic make pedestrians behave "irrationally" and make them take decisions that worsen the catastrophic situations. Alternative solution can be developed for panic solution to avoid such behavior and to improve the evacuations flow.

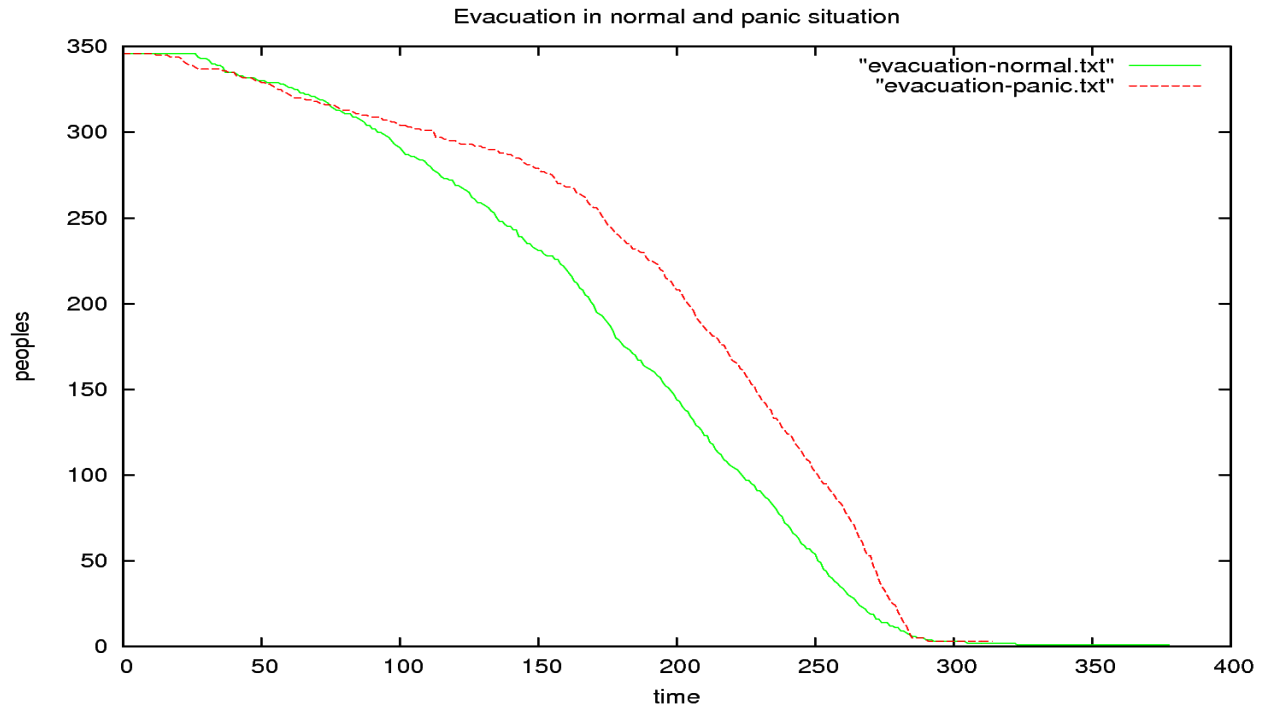


Fig. 7: Influence of the conflict resolution strategy in peoples' evacuations. 346 heterogeneous pedestrians (173 pedestrians in up part, 173 pedestrians in down part). The Beliefs' parameter "*detect-alarm?* = true" and "*speed* = 1" for all pedestrians.

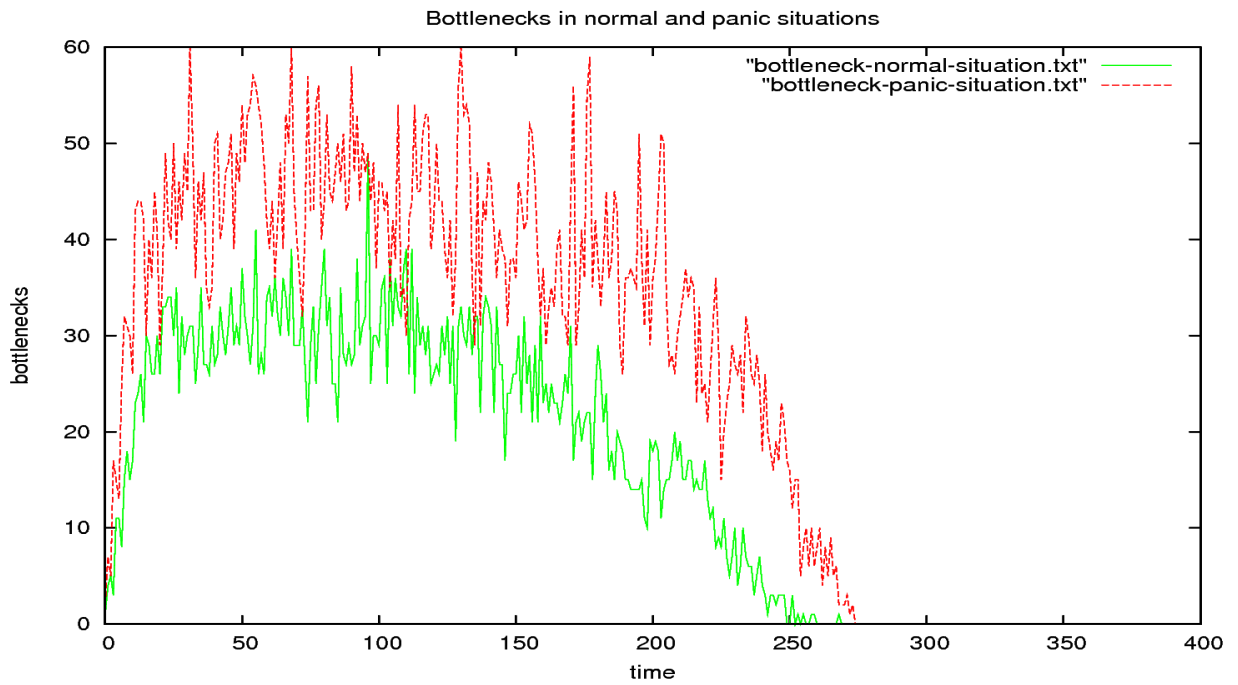


Fig. 8: Bottlenecks' variations on panic and normal situations. The beliefs' parameter are the same a Fig. 7.

IV. CONCLUSION AND PERSPECTIVES

We have presented a model of crowd motion in normal and panic situations. Pedestrians' characteristics and behaviors are tracked through time to investigate the properties that emerge from entities' interactions. Results obtained by this IBM model shows that cooperative strategy reduce blocked situation between pedestrians while conflict strategy makes them stand still for a long time. In panic situations pedestrians try to move fast to escape danger. The increase of the velocities increase on the same time bottlenecks which can produce deadlocks.

Since human life is connected with delays the best strategies have to be taken and the best behaviors have to be adopted by pedestrians in order to reduce human loses.

These are a preliminary results and we aim to improve our model by detailing and including more pedestrians' characteristics, and by introducing more detailed conflict situations. Besides, we will concentrate on emergent phenomena that have been observed like *lane formation*, or *freezing by heating*.

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