



Behavioral effects in room evacuation models



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HIGHLIGHTS

- We present a continuous time model for pedestrian evacuation.
- The model incorporates different behavioral profiles when the pedestrian chooses the next move.
- The model shows non trivial effects due to these profiles and close agreements with previous results.

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ABSTRACT

In this work we study a model for the evacuation of pedestrians from an enclosure considering a continuous space substrate and discrete time. We analyze the influence of behavioral features that affect the use of the empty space, that can be linked to the attitudes or characters of the pedestrians. We study how the interaction of different behavioral profiles affects the needed time to evacuate completely a room and the occurrence of clogging. We find that neither fully egotistic nor fully cooperative attitudes are optimal from the point of view of the crowd. In contrast, intermediate behaviors provide lower evacuation times. This leads us to identify some phenomena closely analogous to the *faster-is-slower* effect. The proposed model allows for distinguishing between the role of the attitudes in the search for empty space and the attitudes in the conflicts.

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1. Introduction

During the last decade there has been a multiplication of mathematical models for pedestrian dynamics and enclosure evacuation aiming at unveiling the most relevant aspects affecting such processes. Despite the fact that all these models represent similar processes (or even the same), they implement different methodologies with their corresponding strengths and limitations.

The consideration of behavioral aspects related to the interactions between individuals has produced some notable contributions in the area [1,2]. In particular, using a mechanistic approach, the so called *social-force* model [2–5] captures the fact that the motion of an agent is governed by the desire of reaching a certain destination and by the influence it suffers

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from the environment, which includes the other agents. The model links the collective motion of the individuals to self-driven many particle systems (see [6] and references therein). In order to simplify the calculations, advances have also been made with cellular automaton models [7,8].

Recently, some attention was drawn upon the fact that a full description of the behavioral aspects involved in an evacuation process needs to consider the disposition of the individuals as internal states which may influence the responses of the pedestrians and, ultimately, their motion (see, for example, [9]). The idea is that not only the environment but also the internal motivations govern their reactions [10]. Thus, some of the interactions between two or more individuals in a moving crowd can be thought of as conflicts which the pedestrians can tackle using different strategies, according to their characters or attitudes. These considerations have naturally led to the inclusion of Game Theory elements in the models for pedestrian dynamics. The first works considering Game Theory within evacuation models [11,12] analyzed the emergence of pushing behavior in evacuation situations. Subsequently, several authors analyzed various aspects of the complex subject of linking individual nature to crowd dynamics [13–22] using Game Theory. All these works considered two available strategies for each pedestrian. Namely, a cooperative one and a defecting one. The cooperative strategy is normally associated to kind and patient behavior consisting in not taking advantage of others, and, specially, not rushing to an empty space when a favorable move is available [13,17]. Conversely, the defective strategy can represent an impatient pedestrian, who rushes to conquer gaps, being disrespectful to others.

In a slightly different context, it was suggested recently [23] that, despite the success of the models based on the Social forces paradigm, simpler assumptions could lead to highly satisfactory predictions of pedestrian behavior. In [23], the authors consider that the reaction of an individual is mostly governed by the visually perceived environment, and that a pedestrian, instead of being repelled by the neighbors, actively looks for empty space or free paths through the crowd. Hence, from different points of view, the attitude of the individuals toward the empty space (i.e. the way in which pedestrians use and allow available space to be used) arises as a character-dependent key element influencing the dynamics.

Clearly, a strategy of motion reflecting the complex behavior of a pedestrian cannot be determined by a unique feature within a model. Several aspects should be included in order to define the use of space and the attitude of the pedestrian in conflicts or competitions for space. Part of the object of this work is to understand how some of the different elements which may conform a strategies profile affect the dynamics of an evacuation process when considered separately. This means, to disentangle such different components, and move toward a better understanding of the emerging results.

With this in mind we develop a spatially-continuous discrete-time model for pedestrian dynamics that enables the analysis of the influence of the individual attitudes at different stages of the evacuation dynamics. These stages include the decisions made in the presence of available space that promotes a favorable move and the strategy adopted if confronted with conflicts that may derive from these decisions. More specifically, the model considers two different stages at which the attitudes of the pedestrians can be introduced. First, a stage at which each pedestrian decides its attempt of motion according to the preferred direction, the available free space perceived, and reflecting its degree of rationality, patience, cooperativeness or aggressiveness. Second, a stage at which the conflicts among individuals that attempt to move to overlapping positions are solved at random. The actual behavioral patterns of pedestrians, which may include cooperative or egotistic attitudes and rational or impulsive decision making, are incorporated in the model through different deterministic or noisy ways of deciding the attempts of motion. The selfish or cooperative attitude is mimicked at this level through an aggressive or coordinated management of the available space to move. In particular, we focus on the analysis of the effects of the *randomness* and the *rationality* in the use of empty space to move. The difference between the two will become clear later. We also study the influence of the minimal separation threshold considered by the pedestrians for attempting a step. This parameter is related to the inclination of the individuals to avoid collision with other pedestrians and, thus, to their degree of cooperativeness or politeness.

In agreement with the suggestions in [23], the proposed model starts from very simple assumptions and a small number of parameters. Moreover, given that it considers finite-size pedestrians in a continuous-space, it can be thought as more realistic than most cellular automaton models.

2. The model

We consider a spatially continuous model of N pedestrians, represented by rigid disks of radius $r = d/2$, occupying a square room of size L with a single door. The diameter d of the agents is determined depending on the desired *occupancy fraction* of the room, ρ , so that $d = L\sqrt{\rho/N}$. Thus, for a room completely full $\rho = 1$. On the other, in (x, y) -coordinates, the walls are located at $x = \pm L/2$, $y = 0$ and $y = L$, while the exit is in the middle of the $y = 0$ wall, running from $(-l_d/2, 0)$ to $(l_d/2, 0)$. The time is discretized in steps of duration $\delta t = 1$ (in arbitrary units) while the space is continuous so that the position of the center of the disks can be any point in the room. We analyze two versions of the same basal model, that will be referred to as *rational* and *stochastic*. In both cases, the individuals head toward the door in order to leave the room. More precisely, a walker located at position $\vec{r} = (x, y)$ heads toward the point \vec{r}_E at the exit, which is defined as $\vec{r}_E = (0, 0)$ if $|x| \geq l_d/2$ or as $\vec{r}_E = (x, 0)$ if $|x| < l_d/2$.

In the rational model, each walker selects, at each time step, a *desired position* to which he/she will attempt to move. The first choice is pointing in the direction of the exit, \hat{u}_E in Fig. 1, but a blockage or eventual superposition might forbid the move. If such is the case, the walker explores an alternative lateral motion choosing one of the two directions perpendicular to \hat{u}_E . If \vec{r}_i is the position of the walker i at time t , the preferred direction is $\hat{u}_E = (\vec{r}_E - \vec{r}_i)/|\vec{r}_E - \vec{r}_i|$ (i.e., the direction

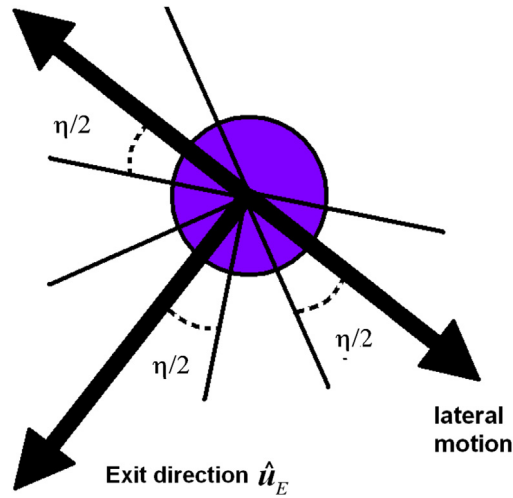


Fig. 1. Scheme showing the direction of frontal and lateral movements and the uncertainty introduced by η .

toward \vec{r}_E). In our model we include some vagueness in the choice of the pedestrian. In the first attempt, the walker selects a direction of forward motion \hat{u}_E , which is randomly chosen within an angle of amplitude η around \hat{u}_E (i.e., $\eta/2$ to each side), as shown in Fig. 1. If the forward move is not allowed for reasons that we will later discuss, the walker attempts a lateral motion (see Fig. 1). For this, he/she randomly selects one of the two directions perpendicular to \hat{u}_E , here referred to as \hat{u}_\perp , considering again some uncertainty governed by η . Once again, the movement is done only if is not forbidden, in which case the pedestrian stays still. Notice that we consider an uncertainty or randomness in the way the pedestrians point toward the exit, which is characterized by the parameter η .

We need to explain now when a movement is forbidden. We consider that any move made by the pedestrian should be longer than a certain threshold μ . Once the moving direction has been chosen, the walker analyzes what is the maximum distance he/she can move without overlapping with another walker (for this we consider all the walker's positions at time t). If such a distance is longer than the threshold μd , the walker i moves to $\vec{r}_i + \lambda \hat{u}_E$ in the case of a forward movement or $\vec{r}_i + \lambda \hat{u}_\perp$ when the walker makes a lateral move. Here, $\lambda > \mu d$ with $0 < \mu < 1$, is the maximum distance of movement without overlap or collision up to the particle diameter d , that defines a limiting speed of motion given by $d \cdot \delta t$. Note that only if the walker cannot move in the direction \hat{u}_E , he/she only checks for the possibility of a lateral move in any of the available directions, making at this point, a random choice.

Once all of the individuals have defined their moves, we record the new chosen position for each one. Still, the move is not guaranteed as we have to check for the availability of this position and the possibility of conflicts. A conflict may arise when the desired positions of two or more walkers overlap. As only one individual is allowed in each of the new projected positions we need to solve the conflict. In the present work this task is done by randomly selecting one of the walkers involved in the conflict, which will be finally allowed to move. The rest of the individuals participating from the conflict will stay still, remaining at their former positions. It is at this stage that we could introduce a different prescription for solving the conflict including Game Theory ingredients as in [17]. Once all of the conflicts have been solved, the favored pedestrians, together with the non conflicting ones move to their new positions. The update dynamics is synchronous.

It is worth remarking that the rational model includes two main parameters defining the stepping dynamics. Namely, the angle η characterizing the randomness in the pointing toward the exit by the walkers, and μ ($0 < \mu < 1$), which defines the threshold distance (μd) for attempting a step.

As for the stochastic model, the main difference is that, from the first attempt, the walker randomly chooses between a forward and a lateral move. There is not a second attempt, so in the case that this first chosen movement is not allowed, the walker remains still. Thus, each walker attempts a forward motion with probability $(1 - \alpha)$ and a lateral one with probability α .

Two things should be stressed. First, in the stochastic model each walker chooses at random between the directions \hat{u}_E and \hat{u}_\perp and the impossibility of motion does not allow a second attempt. Second, in addition to the parameters η and μ , the stochastic model adds a third parameter α ($0 \leq \alpha \leq 1$), which defines the probability of taking a lateral movement as a first choice, something that is not rationally optimal.

In both models we consider randomly distributed initial positions for the N pedestrians within the room, avoiding overlaps.

The parameters μ and η , and also α for the stochastic case, define the way in which the pedestrians decide their attempts of motion. Thus, they can be interpreted as associated to the character of the pedestrians. For instance, a relatively large value of μ could be related to a more respectful (cooperative) attitude than a low value of μ , since a walker with larger μ is more careful in avoiding physical interaction with the pedestrians in the direction he/she moves. Similarly, larger values of η

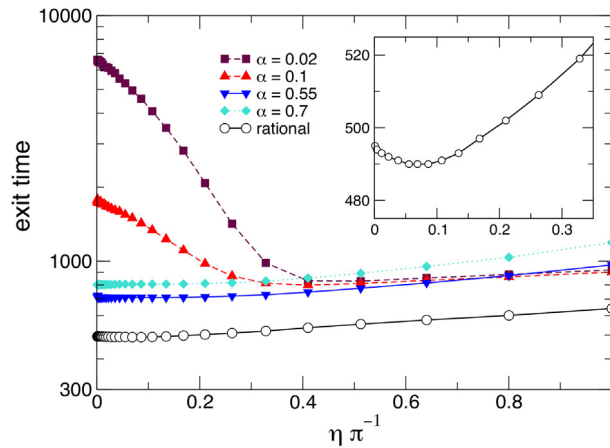


Fig. 2. Log–lin plot of the mean evacuation time for the rational and stochastic models as a function of η/π . Here each curve corresponds to a different choice of α with $\mu = 0.1$, while the solid black curve with white circles corresponds to the rational version of the model, zoomed in the lin–lin plot of the inset. The results were obtained by averaging over 1000 realizations considering a room of size $L = 100$ with a door of size $l_d = 6d$, containing $N = 1000$ agents with an occupancy fraction $\rho = 0.4$.

or α indicate a lower propensity for moving straight to the exit, so that this may be also attributed to a more cooperative attitude. The predisposition of the individuals can be naturally introduced in the model to define the strategy of motion, that affect both the decision making process when searching for empty space to move (ruled by the parameters μ , η and α), and the attitude or strategy during a conflict resolution. As indicated in the introduction, in this work we focus on the effects observed only during the first case. Our definition of cooperative and defective attitudes alludes to the observed behavior during the choice of the next move and not to deeper internal motivations that the individuals may have. In this sense, walking straight to the exit ignoring the presence of the others is the most intuitive and obvious interpretation of an egotistic attitude.

3. Results

3.1. Exit times and dependence on the parameters

We begin by analyzing the dependence of the mean evacuation time (or exit time) on η within the two models. For this we consider a fixed value $\mu = 0.1$ and different values of α in the case of the stochastic model. The effects of varying that threshold μ will be studied later. The results are shown in Fig. 2.

First we observe that, for any value of α , the stochastic model results in longer exit times than the rational one. As we show later, this result is independent of the values of the rest of the parameters with the exception of very small values of μ . We can affirm that, in most cases, the rational behavior is strategically more effective than the stochastic one (both for each individual and for the crowd).

Fig. 2 also shows us that the evacuation time has a non monotonic behavior, adopting a minimal value for an intermediate value of η . This indicates that the presence of a limited amount of *noise* improves the overall performance of the pedestrians, but the effect is reversed once η exceeds a critical value, i.e., with an increase in the uncertainty when choosing the moving direction. This can be understood by considering that for very small η , the desired directions of movement of several pedestrians can point to similar targets, increasing the possibility of blockage, while large uncertainties can lead to unnecessary winding of their trajectories increasing the exit time. We have verified the robustness of this result against changes in μ , as shown later, in the sizes of the door and the room and in the number of pedestrians.

Additionally, we observe that for the stochastic model there is an optimal non-negligible value of α that minimizes the exit time. To observe this more clearly we present in Fig. 3 the information about exit times for different values of η as a function of α . Qualitatively, the dependence of the exit time on α has the same behavior for any value of η . There is always an optimal value that minimizes the exit time and that is almost constant for a given size of the door. For example, for $l_d = 6d$, the optimal value is $\alpha \approx 0.47$ with only small variations (less than 7.5%) as a function of η , as shown in the inset of Fig. 3.

For that optimal situation, the resulting exit time is of the order of the one found for the rational model, and even the dependence on η is qualitatively the same, as shown in Fig. 2 for stochastic and rational agents. However, this is not the case for lower and higher values of α . On the one hand, when α is very low, the whole group of pedestrians might end up in a clogged configuration or, with some intermittences, stay blocked until a noisy event helps to clear the blockage. We have observed these two effects in several simulations.

As mentioned before, the increase in the exit time is mainly due to a noisy wandering behavior (more evident for the stochastic version of our model) or to the occurrences of blockages due to the lack of space for the pedestrians to move. The first can be tuned by the amount of noise considered in the dynamics (characterized by the parameters η and α). This, in

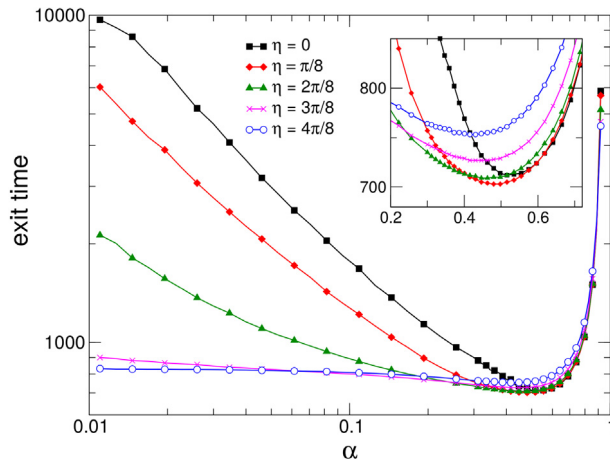


Fig. 3. Log-log plot of the mean evacuation time for the stochastic model as a function of α with $\mu = 0.1$. We consider different values of η . The results were obtained by averaging over 1000 realizations, considering a room of size $L = 100$ with a door of size $l_d = 6d$, containing $N = 1000$ agents with an occupancy fraction $\rho = 0.4$. The inset shows a zoomed in lin-lin plot of the curves.

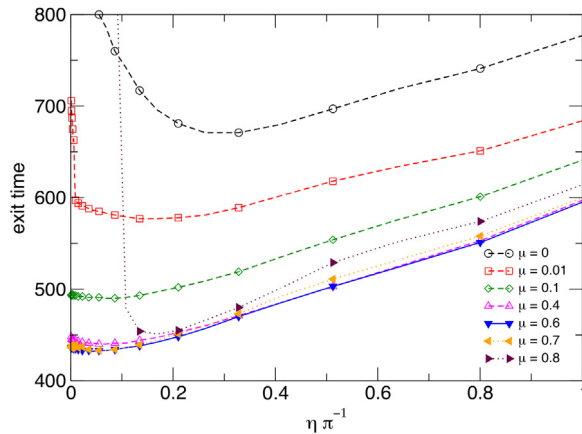


Fig. 4. Mean evacuation time for the rational model as a function of η/π for different values of μ . The results were obtained by averaging over 1000 realizations, considering a room of size $L = 100$ with a door of size $l_d = 6d$, containing $N = 1000$ agents with an occupancy fraction $\rho = 0.4$.

turn, also affects the distribution of the available space and consequently the number of blockages. Still, there is something else we can do to prevent clogging. Namely, to increase the parameter μ , which characterizes the minimal empty space that a given individual has to observe for attempting a move in certain direction.

In Fig. 4 we show the exit-time vs. η curves for several values of μ within the rational model. We observe that the effect of preserving a certain distance from the other pedestrians favors the evacuation speed unless this distance is too large and so, the restriction has a completely different effect: the effective free space to move is reduced to the point that no one can move, as the condition for a minimal empty space to attempt motion by the pedestrians becomes harder to fulfill (in a way, the motion threshold effectively extends the size of the pedestrians leading in some instances to clogging). As a consequence, the dependence of the exit time on μ shows that there is an optimal value ($\mu \approx 0.6$ for a door of size $l_d = 6d$). When $\mu > 0.75$ there is a considerable proportion of realizations that show transient or permanent blockages. Surprisingly, this phenomenon is not replicated when considering the stochastic model, for which increasing the value of μ always results always in a longer exit time, as shown in Fig. 5. This fact might be indicating that the randomness in the lateral motion (measured by α) is already efficient in creating empty spaces and adding the effect of μ results also in an effective reduction of the available space as μ increases. Although Fig. 5 only shows the exit time for $\alpha = 0.55$, we have studied what happens for several other values of α observing the same behavior in all of the cases.

We must mention that the optimal value for μ in the case of rational agents (see Fig. 5), or for α in the case of stochastic ones (see Fig. 3), depends on the size of the door l_d as shown in Fig. 6. In particular, the insets in the figure show the dependence of the position of the minimal, μ_0 and α_0 , as a function of l_d for the rational and stochastic cases, respectively. As apparent from the figure, these results suggest that, in order to optimize the flow of pedestrians out of the room in an evacuation situation, one needs only to control the mean distance among the pedestrians in relation to the size of the door

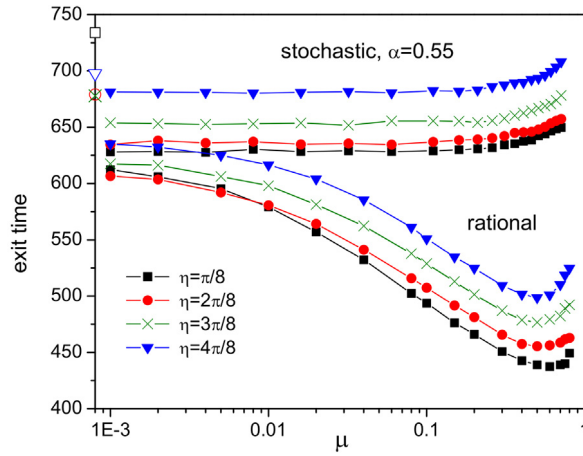


Fig. 5. Lin-log plot of the mean evacuation time as a function of μ . Here each curve corresponds to a different choice of η . We show the rational and the stochastic cases; for the last one, the case when α is optimum. The horizontal axis is in units of d^{-1} . The results were obtained by averaging over 1000 realizations, considering a room of size $L = 100$ with a door of size $l_d = 6d$, containing $N = 1000$ agents with an occupancy fraction $\rho = 0.4$.

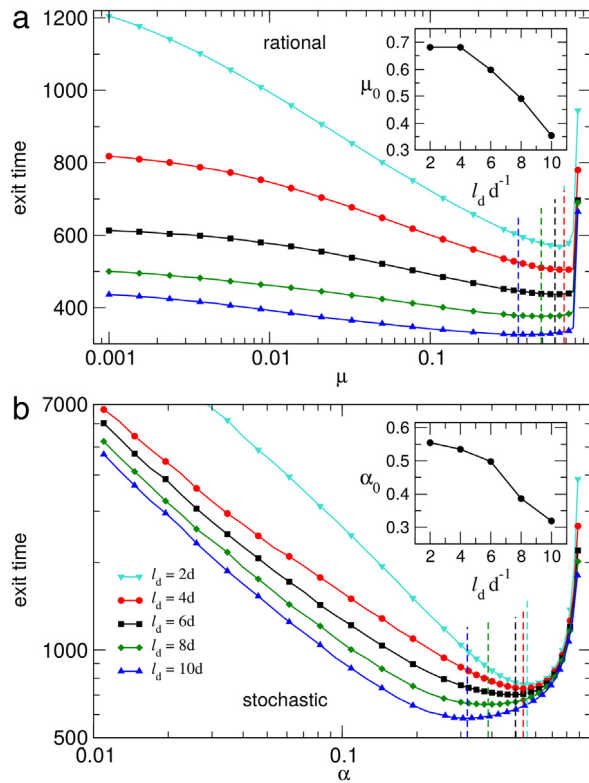


Fig. 6. Mean evacuation time (a) for the rational case and as a function of μ and (b) for the stochastic case as a function of α . The results were obtained by averaging over 1000 realizations, considering a room of size $L = 100$ and different door sizes, as shown in (b). The room contained $N = 1000$ agents with an occupancy fraction $\rho = 0.4$. The vertical dashed lines depict the corresponding position of the minimum μ_0 and α_0 for each curve, for the rational (a) and stochastic (b) models, respectively. This data was later used to generate the corresponding insets as a function of the door size.

itself (and the mean diameter of the agents): the narrower the door, the more distance is required among agents to keep an optimal flow through the door.

Now let us go back to the interpretations of large and small values of the parameters μ , η and α as signatures of cooperative or egotistic behavior, respectively. From this point of view, the fact that we find non vanishing values of these parameters minimizing the exit time indicates that neither the most egotistic nor the most cooperative behavior of individuals is optimal from the perspective of the crowd. In the following section we analyze the connection of this results with a well known effect observed in evacuation processes.

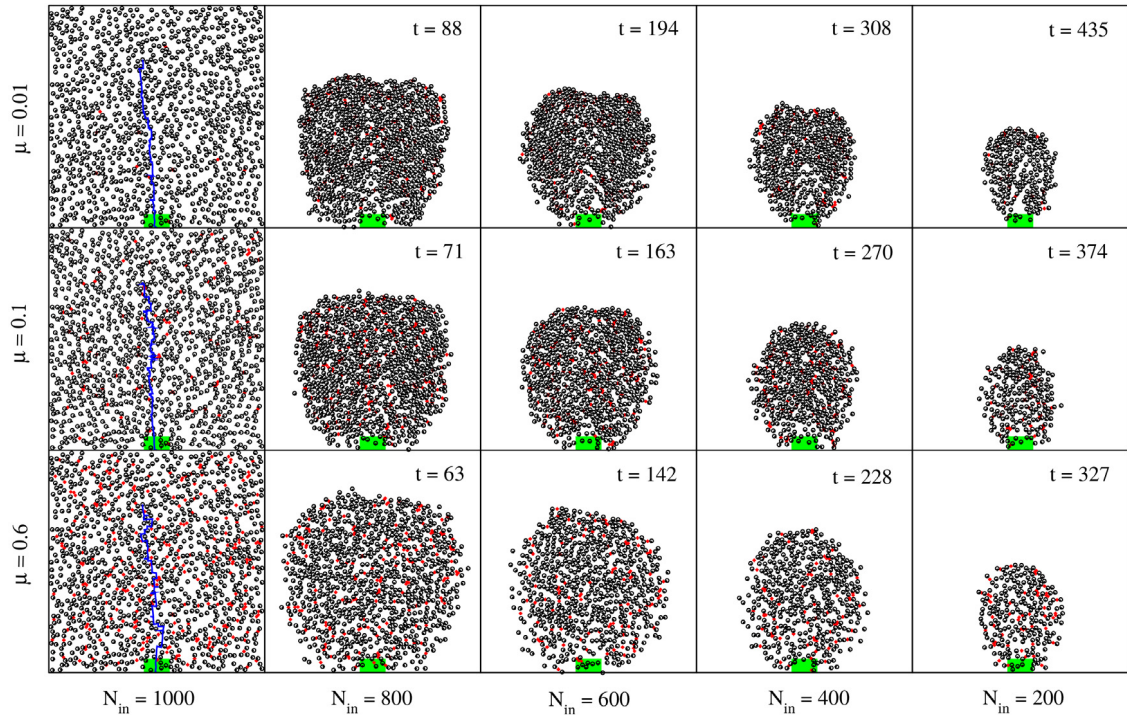


Fig. 7. Snapshots for different instances of the evacuation process with *rational* agents (black circles) for different values of μ and $\eta = \pi/8$. The red diamonds represent the conflicts between two or more agents that are solved randomly with just one of them advancing to the desired position. The green square represents the position and width of the door at the bottom wall of the room with $L = 100$ and $l_d = 6d$. The initial condition on the left column is the same in all cases, with $\rho = 0.4$ and $N = 1000$, while the blue curve corresponds to the trajectory of one of the agents as it leaves the room. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

3.2. Analogies with the faster-is-slower effect

The so called *faster-is-slower* effect, originally predicted in [2], is associated to the fact that the optimal evacuation time through a narrow door is minimized at a given critical value of the pace at which the pedestrians try to move [5,24]. Hence, for desired velocities above the critical one, we have that the larger the velocity, the slower the evacuation process. This effect has been recently confirmed experimentally for many different systems [25], suggesting that this phenomenon is a universal behavior for active matter passing through a narrowing.

As we now indicate, some of the simulations results presented before have clear analogies with the *faster-is-slower* effect. In the present model the desired speed of displacement is not a parameter of the model, as in [2] where the pedestrian can choose whether to move faster or slower. Here, the speed is constant but as the model is continuous in space, the individuals might be limited in their movements by the availability of free space, making the step shorter than the maximum allowed one. The dynamics of the system leads to the emergence of an effective mean-velocity that in the optimal scenario can be shown to be larger than zero, but lower than the maximum desired one $d/\delta t$. The haste of the pedestrians to leave the room is captured in different ways by the model parameters. For instance, a small value of μ indicates an impatient or hurried behavior, since the pedestrians try to take advantage of every empty space available, without caring about the distance to other individuals. Meanwhile, low values of η and α (only in the stochastic model) indicate a propensity to walk straight to the exit, and a low disposition to perform lateral motions or temporal turn-offs which may benefit the whole group. Therefore, the increase in the exit time with decreasing μ obtained for the rational model, at low values of μ , resembles the *faster-is-slower* effect. The same can be said about the increase of the exit time obtained for decreasing α observed within the random model at small α , or the increasing exit time with decreasing η for both models at small η . It is worth saying that in the three cases there is a region where the exit time decreases monotonically, until reaching the corresponding critical values at which the *faster is slower* effect starts to be observed. This monotonic behavior has been observed when the pedestrians only show a moderated haste [26].

To understand the dynamical properties that lead to the *faster-is-slower*-like effect at small values of the parameters, we analyze in more detail the evolution of the populations and individual position for various simulations. In Figs. 7 and 8 we present snapshots of different instances of the evacuation process for the rational and stochastic models, respectively, considering the same initial condition. The bottom row presents the optimal situation in each case for the value of η and l_d (and μ for the stochastic case) considered. Notice how the generation of available space between the agents, through

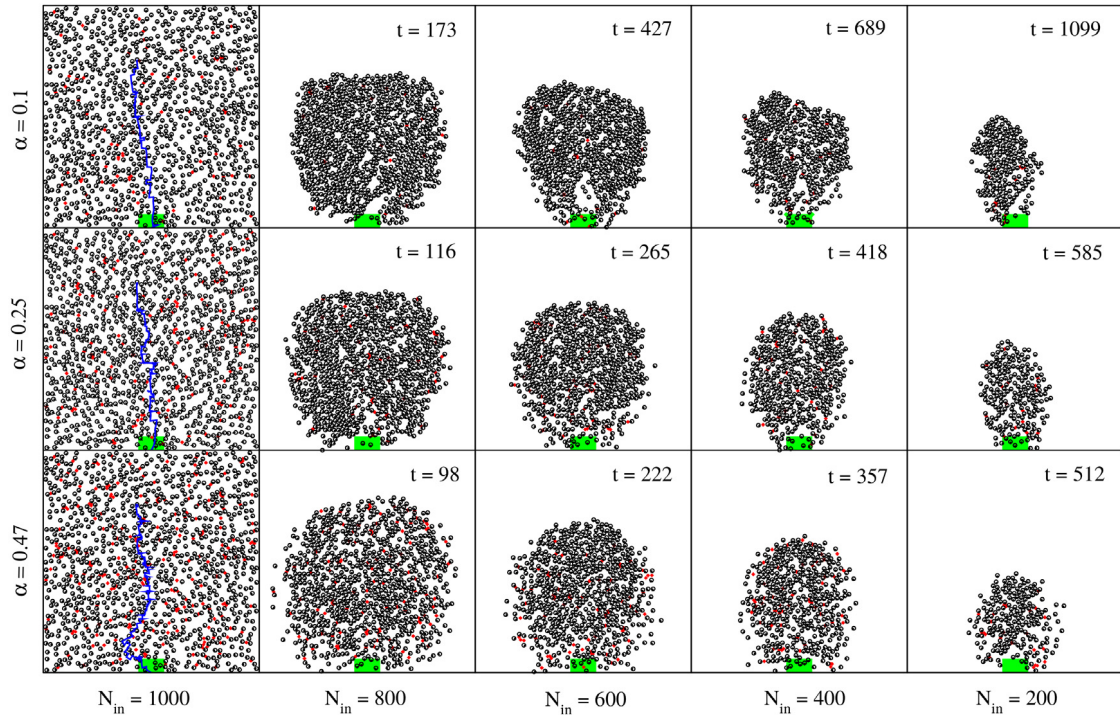


Fig. 8. Snapshots for different instances of the evacuation process with *stochastic* agents (black circles) for different values of α , $\mu = 0.1$, and $\eta = \pi/8$. The red diamonds represent the conflicts between two or more agents that are solved randomly with just one of them advancing to the desired position. The green square represents the position and width of the door at the bottom wall of the room with $L = 100$ and $l_d = 6d$. The initial condition on the left column is the same in all cases, with $\rho = 0.4$ and $N = 1000$, while the blue curve corresponds to the trajectory of one of the agents as it leaves the room. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

the threshold for the rational case (associated with the parameter μ) or by performing random lateral movements for the stochastic one (associated with the parameter α), speeds up the evacuation process.

Moreover, these results put in evidence an interesting fact regarding the effects of μ on the rational agents. As mentioned before, if a rational agent cannot advance toward the door a distance of at least μd , it will opt for a lateral movement. In contrast, a stochastic agent will randomly choose a lateral movement depending only on the value of α . In both cases the agent will stay still if it cannot advance a distance of at least μd in the chosen direction. Notice that, for the stochastic agents, this threshold has been taken into account with $\mu = 0.1$ in the figure. Nonetheless, the rational agents require a larger value of μ to optimize their exit time, as their decision making process regarding the implementation of frontal or lateral movements is tied to this parameter, contrary to what happens with the stochastic agents. Therefore, this points to the fact that it is the implementation of a sizable amount of lateral movements in both cases, with the consequent generation of space among agents, the most important feature to optimize the exit time of the whole group.

In each of the plots in the first columns of Figs. 7 and 8, we also show the trajectory for one of the agents (blue solid curves). It can be seen that the trajectories for the stochastic model are more winding than those from the rational one. This leads to the larger exit times observed in the stochastic model.

The *faster-is-slower*-like effects remind us of *social dilemmas*. This means situations in which there is a conflict between individual and collective interests. In a social dilemma, each individual receives a higher payoff for a socially defecting choice than for a socially cooperative choice, no matter what the other individuals do, but all individuals are all better off if all cooperate than if all defect. The payoff to be selfish is higher than the payoff to be non-selfish, but group members are worse off if everyone is selfish than if everyone is not [27,28]. In an evacuation scenario, the individuals would in principle always profit from moving in a faster way to the exit, but if everybody does the same, the result is an increase in the evacuation time, a collective disadvantage.

4. Final remarks and conclusions

Recently it was suggested that formalisms with simpler assumptions than the Social Force model could lead to satisfactory predictions of pedestrian behavior [23]. In that paper, the authors assume that the reactions of the pedestrians are mostly governed by the visually perceived environment and the active search for empty spaces. The present work points in the same direction. In the models here proposed, the movement of the pedestrians is driven by the wish of reaching the exit and the search for empty space to move, and limited by the competition for space with other pedestrians.

Due to their relevance, the behavioral aspects involving the character and internal motivations of the pedestrians has called the attention of scientist interested in modeling evacuation processes. The simplest but powerful approximation is to consider that there are two types of characters, prompted sometimes as defectors and collaborators or patient and impatient. Those two archetypes represent the usual conflict presented in any social dilemma: the compromise between the collective and the individual interest and the choice to favor one or the other. A given behavioral profile or strategy of motion, however, results from a combination of several factors that are reflected in and affect the pedestrian dynamics in different ways. The present work tries to disentangle these effects to promote a better understanding of the results.

First, our model helps us to distinguish between the behavioral features affecting the decision making processes associated to the selection of the next move, and those associated to the behavior at conflicts in the competition for space. To emphasize the relevance of the distinction between these two levels of behavior, we can imagine two extreme but possible attitudes of a pedestrian. First, we can think of an individual who is impatient or unkind in his/her search for space, but who avoids physical contact and, thus, acts as a cooperative person in conflicts. This behavior could correspond to that of a disrespectful but coward individual. On the other hand, we can think on an individual who is gentle in his/her search for possibilities of motion, and tries to avoid conflicts but who becomes a strong competitor in any conflict in which he/she is forced to enter.

Our studies focus on the analysis of the influence of different behavioral features arising on the first stage, i.e., on the use of empty space. At this level, the recognition of available spaces and the decision processes for stepping is affected by the internal moods and character of the individuals. The consequences of these internal states on the stepping behavior are modeled through a set of independent parameters defining the dynamics. Namely, μ , which characterizes the tendency to keep a distance from others, η , which measures the fluctuations in the definition of the preferred direction, and α , which defines the probability of a lateral movement (only for the *stochastic* i.e., *non-rational* model). We have argued that low values of these parameters can be associated to impatient or defective behaviors, while relatively large values correspond to more cooperative attitudes. Our results show that, in most cases, the exit time is minimized at intermediate values of the parameters, indicating that neither the most cooperative nor the most defective attitudes are optimal from the point of view of the crowd. We have then argue that the existence of regions of the parameters, for which the exit time grows with the hurry or impatience of the pedestrians, indicates global behaviors analogous to the *faster-is-slower* effect. We have shown that a thorough explanation of the slowing down of an evacuation process is due to an amalgam of several effects but ultimately connected to the reduction of the available empty space.

As part of our studies we have shown that a distance-preserving attitude favors the evacuation by inhibiting clogging. Perhaps one of the most interesting implication of these results is the possibility that, by communicating simple basic instructions to the pedestrians, the evacuation process can be optimized. If people could overcome panic by having clear instructions, the behavior associated to the rational walker with the addition of maintaining a certain distance from others would clearly help. Moreover, our results show that the optimal value for this distance depends on the size of the door, thus allowing one to design evacuation strategies particular to the geometry of the enclosure where the pedestrians move.

Additionally, this model enables the inclusion of Game Theory formalism to solve the conflicts which emerge in the competition for space. The resolution of a conflict could in principle include Game Theory elements to reflect the character of the pedestrians and their fitnesses to win the competitions. Due to these properties, we believe that the model can be relevant for the analysis of many aspects of pedestrian dynamics beyond those studied in this work. Moreover, by considering appropriate adaptations and more complex geometries, it may constitute a useful tool for the design of actual spaces and buildings.

As a final remark, we want to emphasize the claim given in the introduction concerning the utility that the model here developed may have for studying general features of pedestrians dynamics, as well as for particular applications.

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