Simulation of Complex Systems

Simulation of Escape Panic Behavior

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20th December 2013

This paper reports the project connected to Simulation of Complex Systems Course FIM750, which was done during the 29th October and 20th December 2013. It contains detailed elaboration of all achievements and difficulties that occurred during the project work.

1 Introduction

Fear and panic are very natural features in the human character and behavior. Surges of adrenalin released in terrifying situations are sometimes useful allowing humans to increase their heart rate and therefore react or run faster. In crowded places or rooms however, this panic can affect large groups of people leading to stampedes. Such mass panics often become disasters where people get injured or killed by other people in the crowd. The aim of this project was to simulate features of human escape panic in a crowded room with a single exit. Further we tested different architectures of the room investigating whether they lead to an improvement in the pedestrian outflow or not.

2 Model

For this project we took the model used by Dirk Helbing et al. [1] as starting point for an agent based model where the pedestrians try to escape of a crowded room through a single exit. For convenience the so-called agents represent the pedestrians as circles in a two dimensional space in our model. The basic playground of the simulation consisting of the escaping agents and two walls is shown schematically in Figure 1a. The agents are defined due to their coordinates $\vec{r}_i$, velocities $\vec{v}_i$ and radii r_i which results in five parameters per agent for the two dimensional model. Further the two walls can be tilted by the so-called wall angle which is also shown in Figure 1b.

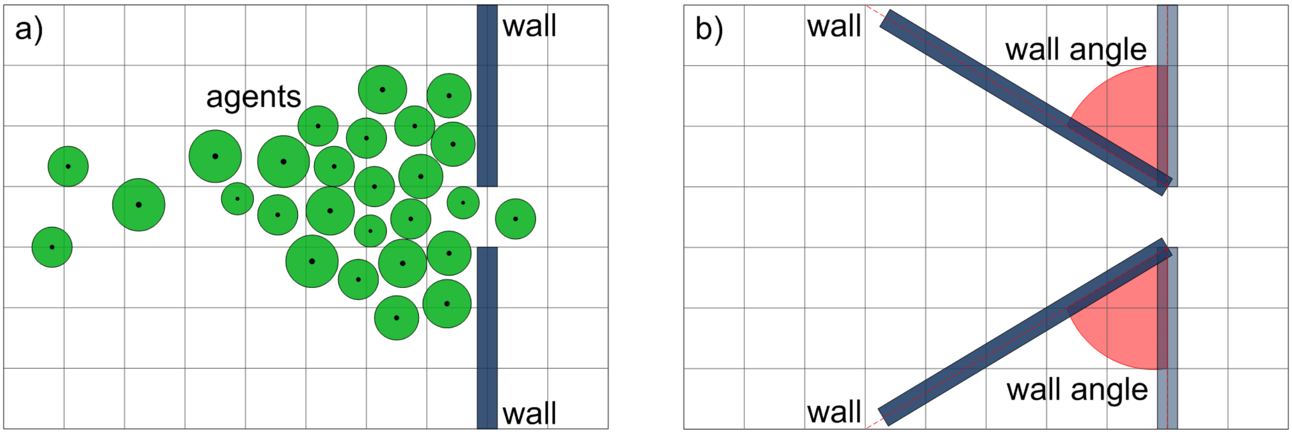

Figure 1: a) Basic playground with agents (green) and the two walls (blue) with exit. b) Tilted walls with definition of the wallangle.

According to Dirk Helbing et al. [1] we also introduced a variation of the agent's radii in order to break symmetry in our simulation. Instead of using radii between 25 and 35 cm and a constant mass, we decided to use randomly generated radii ranging from 25 to 30 cm according to empirical statistics about average shoulder breadths [2], as well as we decided to include a constant surface density of 350 $\frac{kg}{m^2}$ for all agents, leading to masses between 60 and 100 kg per agent. Furthermore, each agent i with mass m_i experiences a force $\vec{F}_i$, such that the following equation of motion has to be solved:

$$m_i \vec{a} = \vec{F}_i \tag{1}$$

The forces $\vec{F}_i$ were calculated due to the model used by Dirk Helbing et al. [1]. In the following we briefly want to summarize the appropriated force model. The force acting on an agent i is

$$\vec{F}_i = \frac{m_i \cdot v_{des}}{\tau} \left(\vec{e}_i - \vec{v}_i\right) + \sum_{j \neq i} \vec{f}_{ij} + \sum_{w} \vec{f}_{iw}. \tag{2}$$

The first term results of an agent's wish to reach a given desired velocity v_{des} along the normalized direction towards the exit $\vec{e}_i$ within a certain characteristic time τ. We easily see that a high desired velocity results in a high force towards the exit which means in other words, that high values of the desired velocity are directly correlated to the panic behavior of the agents. For this reason the parameter of choice which allows us to study situations under different panic behavior is the desired velocity v_{des} in equation (2). During the simulation we observed that the two last agents could easily get 'stuck' in front of the door if they had approximately the same size, as their force with which they push towards the exit is about the same. We therefore multiply this acceleration force with a random number between 0 and 2 at each time step to avoid this scenario. The second part of equation (2) is the sum of all interaction forces $\vec{f}_{ij}$ between two agents i and j. The third term sums the interaction forces $\vec{f}_{iw}$ between agent i and the walls w.

$$\vec{f}_{ij} = \left[A\, e^{(r_{ij} - d_{ij})/B} + k\, g\left(r_{ij} - d_{ij}\right)\right] \cdot \vec{n}_{ij} + \kappa\, g\left(r_{ij} - d_{ij}\right) \Delta v^t_{ji} \cdot \vec{t}_{ij} \tag{3}$$

$$\vec{f}_{iw} = \left[A\, e^{(r_i - d_{iw})/B} + k\, g\left(r_i - d_{iw}\right)\right] \cdot \vec{n}_{iw} + \kappa\, g\left(r_i - d_{iw}\right) \left(\vec{v}_i \vec{t}_{iw}\right) \cdot \vec{t}_{iw} \tag{4}$$

The agent-agent interaction force consists of a long range repulsive force $A \exp\left[\left(r_{ij} - d_{ij}\right)/B\right] \cdot \vec{n}_{ij}$ which keeps the agents away from each other. Additionally a repulsive body force $k\, g\left(r_{ij} - d_{ij}\right) \cdot \vec{n}_{ij}$ and a tangential sliding friction force $\kappa\, g\left(r_{ij} - d_{ij}\right) \Delta v^t_{ji} \cdot \vec{t}_{ij}$ are also included but only considered if the two agents i and j do touch each other. Therefore the function $g\left(x\right)$ is equal to zero for center of mass distances larger than the sum of the agent's radii ($d_{ij} > r_{ij}$) and otherwise equal to its argument x. Here $r_{ij} = r_i + r_j$ is the sum of the radii, $d_{ij} = \|\vec{r}_i - \vec{r}_j\|$ is the center of mass distance of the two agents i and j and $\vec{n}_{ij} = \left(n_{ij}^1, n_{ij}^2\right) = (\vec{r}_i - \vec{r}_j)/d_{ij}$ is the normalized vector pointing form agent j to agent i. In addition is $\vec{t}_{ij} = \left(-n_{ij}^2, n_{ij}^1\right)$ the normalized vector in tangential direction and $\Delta v_{ji}^t = (\vec{v}_j - \vec{v}_i) \cdot \vec{t}_{ij}$ the tangential velocity difference of the two agents. The interaction forces of the agents with the walls $\vec{f}_{iw}$ are then given in the same way as the agent-agent interaction forces with d_{iw} as the distance of agent i from the wall w, the normalized direction perpendicular to the wall $\vec{n}_{iw}$ and the tangential direction vector $\vec{t}_{iw}$. The remaining parameters were hold constant and set to the values $\tau = 0.5$ s, $A = 2000$ N, $B = 0.08$ m, $k = 1.2 \cdot 10^5 \ \frac{\mathrm{kg}}{\mathrm{s}^2}$ and $\kappa = 2.4 \cdot 10^5 \ \frac{\mathrm{kg}}{\mathrm{m \cdot s}}$ according to Helbing et al. [1].

3 Implementation and Graphic User Interface

For the implementation of the above mentioned model we used the programming language MATLAB. Since the body forces and sliding friction forces can reach very large values for short distances between two agents or between agents and walls it was necessary to use a suitable differential equation solver for equation (1). Matlab's solver 'ode23' turned out to be exact and fast enough for our purposes. Further we tried to improve the computing speed of our algorithm by calculating only the interaction forces of the next nearest neighbors and walls. Therefore we superimposed a grid with $1\,\mathrm{m} \times 1\,\mathrm{m}$ cells and only calculated interacting force between agents when they were to be found in the same cell or one of the neighbored eight cells. This resulted in an approximate $\mathcal{O}(N)$-algorithm per time step where N is the total number of agents. Since we had to use some 'for'-loops which are expensive in Matlab it turned out that for our purposes ($N < 300$) this algorithm was slower than calculating all interaction forces which is $\mathcal{O}(N^2)$. Additionally Matlab is very good in dealing with large matrices so we decided to calculate all interaction forces between all agents in the room in a $N \times N$ matrix.

Further we decided to implement a graphic user interface (GUI) which simplifies the handling of the program. It consists of a main window containing the basic playground with the two walls, an exit and a number of agents trying to escape. The play/pause button allows us to run and stop the simulation at any point we wish. Further a reset button and a record button are added which allow resetting the playground or capturing a video of the simulation. The settings option shows a variety of parameter settings and allows us to load any desired agent and wall configuration from a saved file. The edit option supports a drag and drop modification of the agents and walls. New elements are quickly added, changed or removed with a single mouse click and can be saved if needed. A 'statistics' option provides some statistic features for multiple runs that record the data and plot them graphically at the end of a run. All together this GUI was very useful for our purposes and allowed us to change parameters, agents- and wall-configurations very flexible and within seconds.

4 Results

At first we tried to reproduce some data form Helbing et al., before we experimented with different geometries of the room. We therefore used the same values for all parameters as Helbing et al. [1] did and measured the total time needed for all agents to get out of the room in dependence on the desired velocity of the agents. The result of this measurement is shown in Figure 2a.

For fairly low velocities the agents naturally need a long time to leave the room. As the desired velocity and therefore the panic of the people increases, the leaving time first drops until we reach a minimum leaving time for a desired velocity of about 2 m/s. Higher velocities now

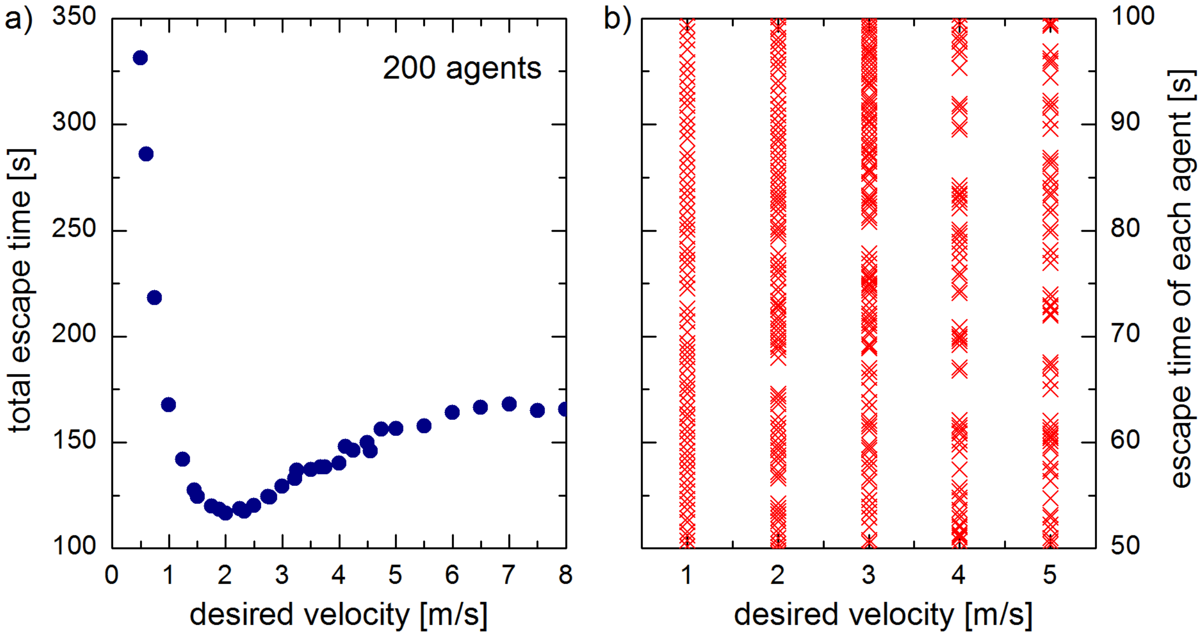

Figure 2: a) Total time needed for all agents to exit the room for increasing desired velocities and therefore increasing panic behavior of the agents. b) Pedestrian outflow which is quite continuous for small desired velocities but becomes irregular for higher velocities.

result in a higher leaving time, as agents start to block each other in front of the door. While the leaving of the agents for lower velocities seems to be very orderly and continuously we observed a large discontinuity for higher desired velocities, which can also be observed in Figure 2b. This does not only seem to be in accordance with actual experience of panicking crowds but is also a good reproduction of the results by Dirk Helbing et al. [1] and serves therefore as a sanity check of our simulation. For all further measurements we used the modified agent mass and radii as discussed in chapter 2.

We were also interested in the pressure acting on the agents during the panic. In our model we define the pressure on one agent as the sum of the magnitude of the body forces, whenever they touch either a wall or an agent. In Figure 3 you can see the pressure for two desired velocities. We notice that the pressure is unrealistically high for fairly low desired velocities. According to Dirk Helbing et al. people should die at pressures above 1600 N/m. The chosen parameters defined in chapter 2 should therefore be revised in future simulations.

In a next step we were wondering whether a change of the walls in front of the door could raise the leaving rate. Therefore we tested what happened if we would slowly increase the angle of the walls (see Figure 1). Here a wall angle of 0° corresponds to the original wall configuration, 45° would be a door in the corner of a room and a wall angle of 90° corresponds to a corridor leading to the exit. Our theory was that a small wall angle would guide the agents towards the door, reduce pushes from the sides of the door and therefore decrease the exit time. In Figure 4a we see that the leaving time decreases linearly for a desired velocity of 1 m/s, which corresponds to a very calm crowd. For a panic situation however (desired velocity of 4 m/s), we even observe a raise in the leaving time for small angles. Only wall angles larger than 45° lead to faster escape times. During the simulations we observed that the agents built bridge-like formations from one wall to the other and therefore blocked themselves and others to get towards the exit (see Figure 4b). From these results we can conclude that our model can not recommend a small increase of wall angles in front of exit doors.

Dirk Helbing et al. suggest in their paper that a column placed slightly asymmetrically in

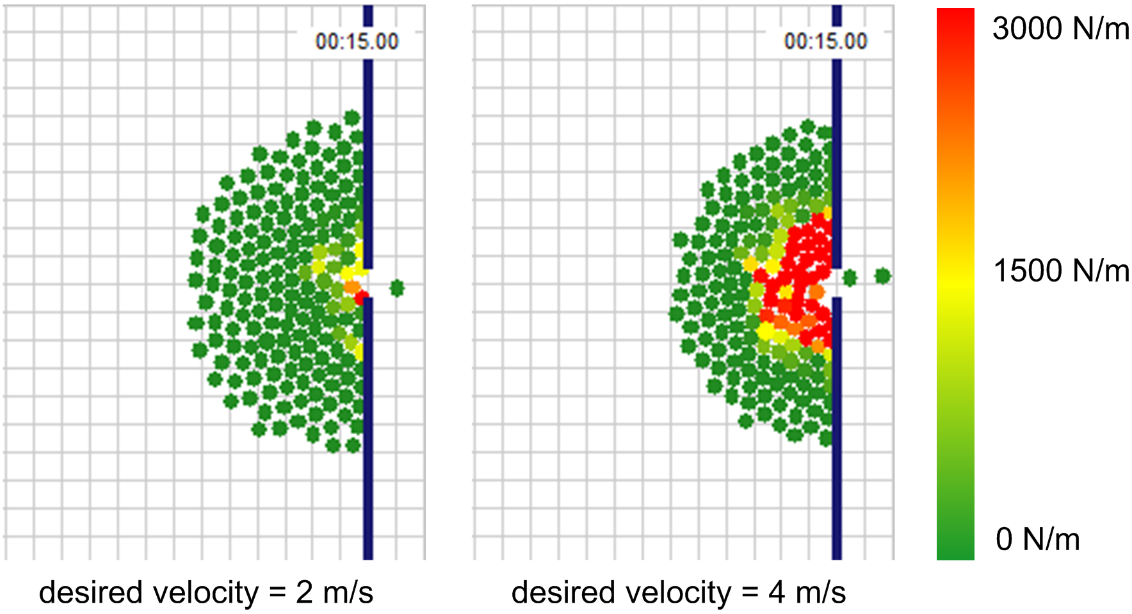

Figure 3: Pressure distribution for two different desired velocities. The total pressure increases with the desired velocity and accordingly for increasing panic.

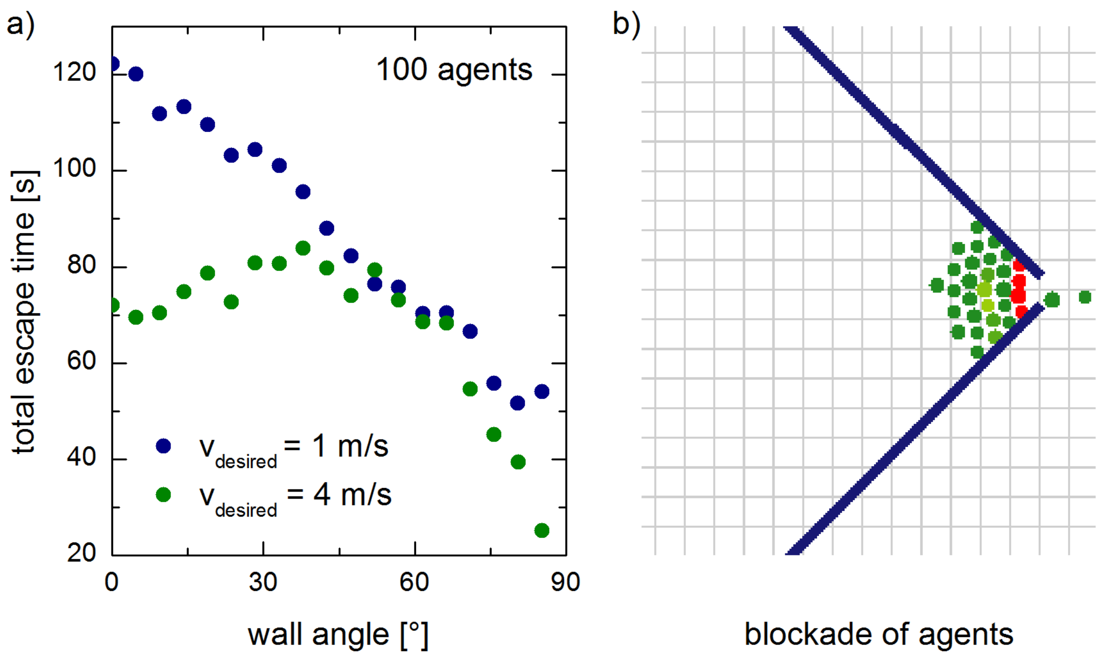

Figure 4: a) Total escape time for different wall angles. Under panic behavior there is no decrease in the total escape time for wall angles smaller than 45 °. b) Bridge-like blockade of agents in front of the exit.

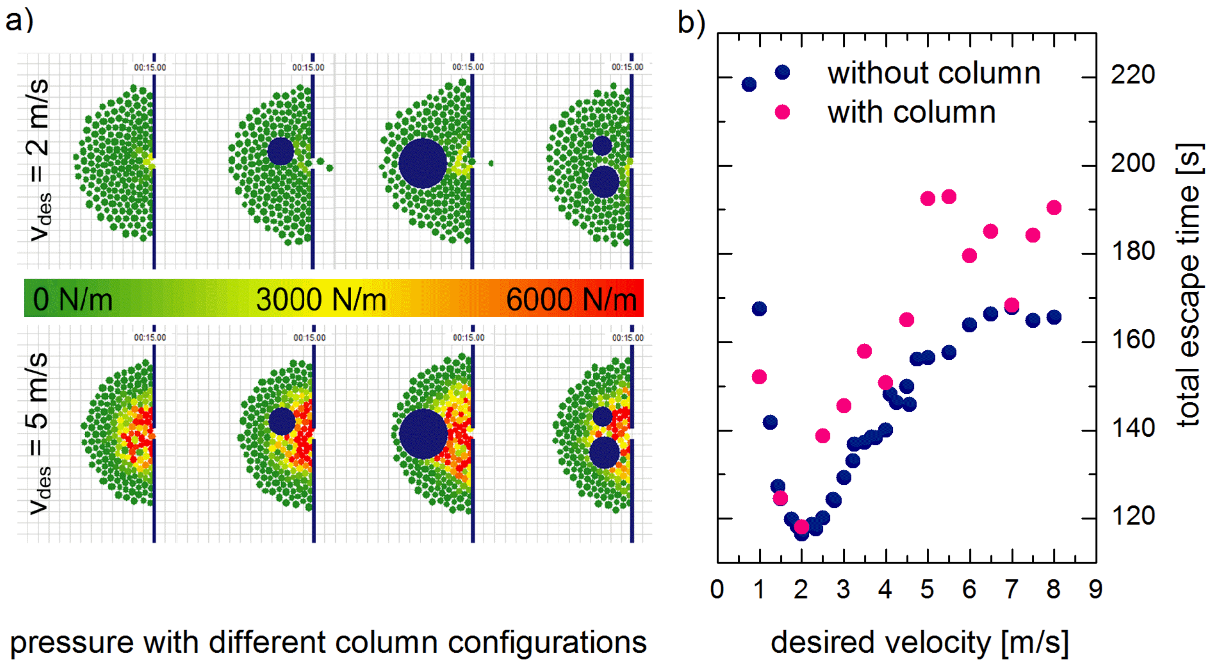

Figure 5: a) Pressure for a set of different column configurations and two different desired velocities. b) Even one of the best column configurations in front of the exit could not reduce the total escape time of the agents at any desired velocity.

front of the exit door would reduce the pressure on each agent and the leaving time. As they do not specify size and position of the column we tried out many different column configurations but came to the result that none of them actually reduces the pressure (Figure 5a). They even lead to higher leaving times as can be seen in Figure 5b.

5 Limitations of the model

Apart from the already mentioned unrealistic high pressure we encountered two more problems with this rather simple model of panicking people. One is, that agents can get stuck as shown in Figure 4b. In this case the agents remained static in front of the door, blocked forever. This would not happen in real life, where something would move in the end. A solution to that would be the introduction of higher random forces on agents to avoid static situations. The second issue is that for low desired velocities ($v_{\text{des}} < 1\,\text{m/s}$) and certain wall angles the repulsive force of the wall is so big, that one agent alone, without the push from others behind him, will not get through the door, as its acceleration force is too low. Since we do not want to simulate claustrophobic people, this is still an unsolved drawback of the model.

6 Conclusion

We presented our agent based model of panicking people, which could imitate some features of a real panicking crowd very well. The total leaving time of agents reaches a minimum for fairly low desired velocities, which encourages the often given advice to keep calm in case of an emergency. Another outcome was that a tilted wall in front of the exit does not lead to faster escape times in case of panicking people. Furthermore we could not find a decrease of the exit time when placing a column in front of the exit. The developed graphical user interface allows users with no knowledge of the code to try out much more modifications to the layout of the room in question and also gives the possibility to change many parameters. This way the model could be used by a larger group of people.

7 References

[1] Dirk Helbing, Illes Farkas, Tamas Vicsek, Simulating dynamical features of escape panic *Nature* **407**, 487-409 (2000)

[2] U.S. Department of Health and Human Services, Centers for Disease Control and Prevention National Center for Health Statistics, Anthropometric Reference Data for Children and Adults *CDC* **11**, 249 (2009)