ETH zürich

Decision-making in the social force model for an evacuation process

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Introduction

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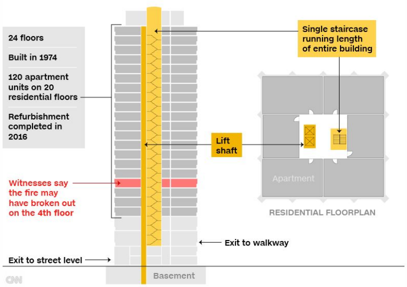
Some examples:

- Jamaraat Bridge, Saudi Arabia, 2006.
- Love Parade, Germany, 2010.
- Grenfell Tower, UK, 2017.



Motivation

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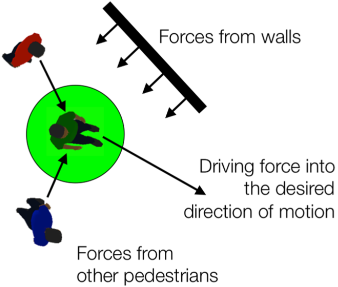
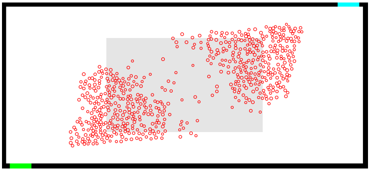
- Understand the crowd dynamics in a simple evacuation scenario.
- Minimize the danger and optimize with respect to safety.
- Many proposed models ignore the decision-making of the agents.
- We integrated the decision-making into a well-known model.

Model

Model

The agent-based *social force* model, proposed by Helbing et al. [1], with modifications from Zainuddin and Shuaib [2] and Wang et al. [3].





Model – Equations of Motion

$$m_i \frac{d\boldsymbol{v}_i}{dt}(t) = m_i \frac{\boldsymbol{v}_i^0(t) - \boldsymbol{v}_i(t)}{\tau_i} + \sum_{j(\neq i)} \boldsymbol{f}_{ij}(t) + \sum_{w} \boldsymbol{f}_{iw}(t) + \sum_{k} \boldsymbol{f}_{ik}(t)$$

- $m_i \frac{d\boldsymbol{v}_i}{dt}(t)$: total force
- $m_i \frac{\boldsymbol{v}_i^0(t) - \boldsymbol{v}_i(t)}{\tau_i}$: driving force
- $\boldsymbol{f}_{ij}(t)$: interaction force between agents
- $\boldsymbol{f}_{iw}(t)$: interaction force between agents and walls
- $\boldsymbol{f}_{ik}(t)$: interaction force between agents and exits

Model – Forces

$$\boldsymbol{f}_{ij}(t) = \boldsymbol{f}_{ij}^{psych}(t) + \boldsymbol{f}_{ij}^{push}(t) + \boldsymbol{f}_{ij}^{frict}(t)$$

$$\boldsymbol{f}_{iw}(t) = \boldsymbol{f}_{iw}^{psych}(t) + \boldsymbol{f}_{iw}^{push}(t) + \boldsymbol{f}_{iw}^{frict}(t)$$

$$\boldsymbol{f}_{ik}(t) = \boldsymbol{f}_{ik}^{psych}(t)$$

- $\boldsymbol{f}^{psych}(t)$: psychological force
- $\boldsymbol{f}^{push}(t)$: body force
- $\boldsymbol{f}^{frict}(t)$: sliding friction force

Model – Velocity

$$\boldsymbol{v}_i^0(t) = (1 - p_i)\nu_i^0 \boldsymbol{e}_i^0(t) + p_i \bar{\boldsymbol{v}}_i^0(t)$$

- ν_i^0: desired velocity
- $\boldsymbol{e}_i^0(t)$: desired direction
- p_i: panic level
- $\bar{\boldsymbol{v}}_i^0(t)$: average velocity of surrounding agents

Model – Decision-making

$$\boldsymbol{e}_i^0(t) = -\nabla d_{k_i^*}(\boldsymbol{r}_i)$$

$$k_i^*(t) = indmax\left\{(1+g_i)U_{ik_i^*}(t)\,, \max_k\left(U_{ik}(t)\right)\right\}$$

$$U_{ik}(t) = \exp\left(-l_i d_{ik}^{unc}(t)E_i\right)\left(1-\alpha_i\left(\frac{r_k(t)}{\max_k\left(r_k(t)\right)}\right)^{\beta_i}\right)\delta(\varphi_{ik}(t))$$

Decision-making process:

1. Each agent has a field of view $[180^\circ, 360^\circ]$, depending on the excitement factor $E_i \in [0, 1]$.
2. He calculates the value $U_{ik}(t)$ of the visible exits, according to the distance and congestion of each exit.
3. He chooses the exit k_i^* with the highest value and changes his direction $\boldsymbol{e}_i^0(t)$ accordingly.

Research Questions

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2. How does the *desired velocity* affect the evacuation time?

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2. How does the *desired velocity* affect the evacuation time?
3. How does the *panic level* affect the behaviour of the agents during the evacuation?
4. How does the *panic level* affect the evacuation time?
5. How does the *excitement factor* affect the behaviour of the agents during the evacuation?

Simulations – Desired Velocity

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For a desired velocity of $\nu_i^0 = 2.22 ms^{-1}$:

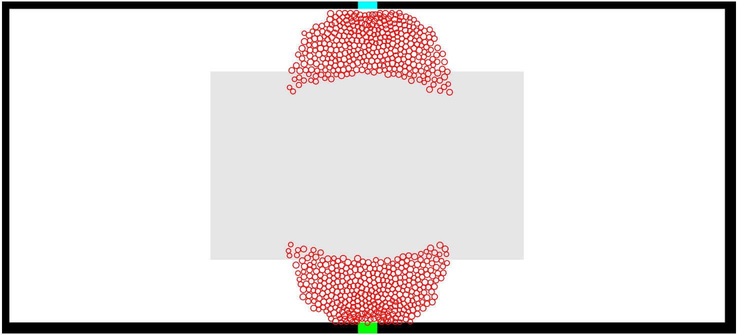


Figure: $t = 5s$

Simulations – Desired Velocity

For a desired velocity of $\nu_i^0 = 2.22ms^{-1}$:

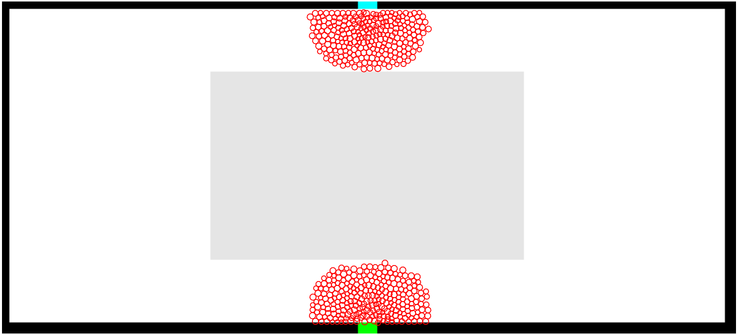


Figure: $t = 10s$

Simulations – Desired Velocity

For a desired velocity of $\nu_i^0 = 2.22ms^{-1}$:

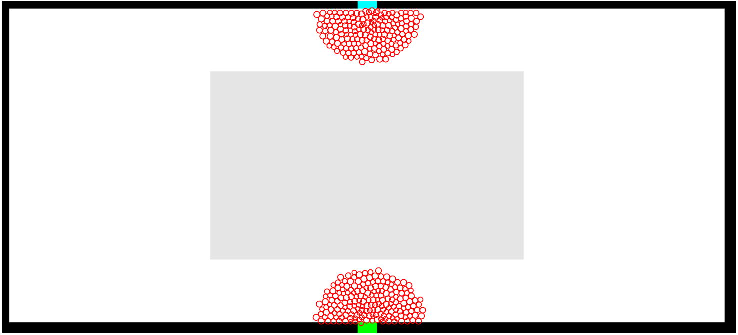


Figure: $t = 15s$

Simulations – Desired Velocity

For a desired velocity of $\nu_i^0 = 2.22ms^{-1}$:

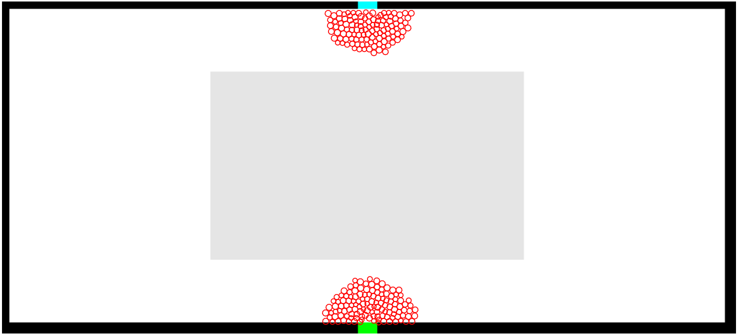


Figure: $t = 20s$

Simulations – Desired Velocity

For a desired velocity of $\nu_i^0 = 2.22ms^{-1}$:

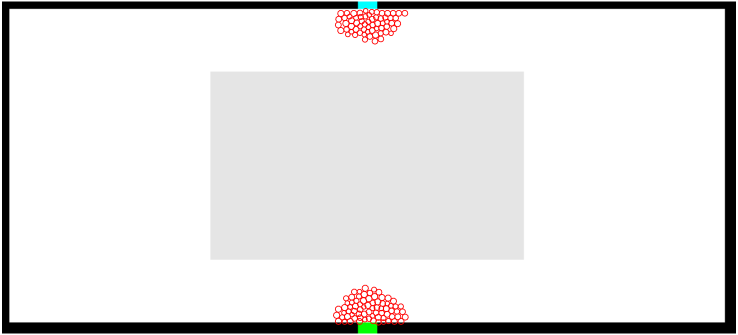


Figure: $t = 25s$

Simulations – Desired Velocity

For a desired velocity of $\nu_i^0 = 2.22ms^{-1}$:

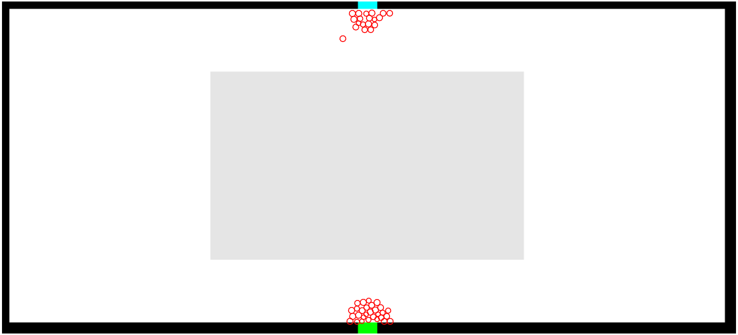
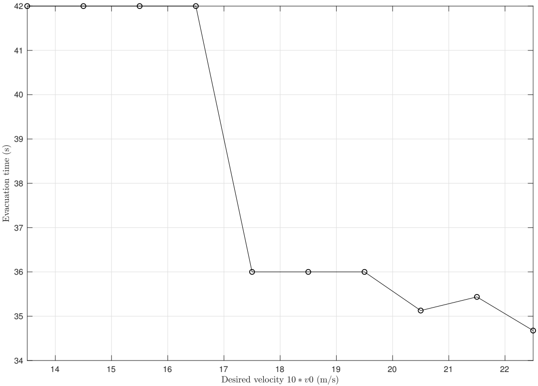


Figure: $t = 30s$

Simulations – Desired Velocity

For a desired velocity of $\nu_i^0 = [1.35, 2.25] ms^{-1}$:



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- How does the desired velocity affect the behaviour of the agents during the evacuation?

  A higher desired velocity caused the agents to try and move with a higher velocity.

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- How does the desired velocity affect the behaviour of the agents during the evacuation?

  A higher desired velocity caused the agents to try and move with a higher velocity.

- How does the desired velocity affect the evacuation time?

  A higher desired velocity leads to accelerated evacuation, with diminishing returns.

Simulations – Panic Level

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For a panic level of $p_i = 0.4$:

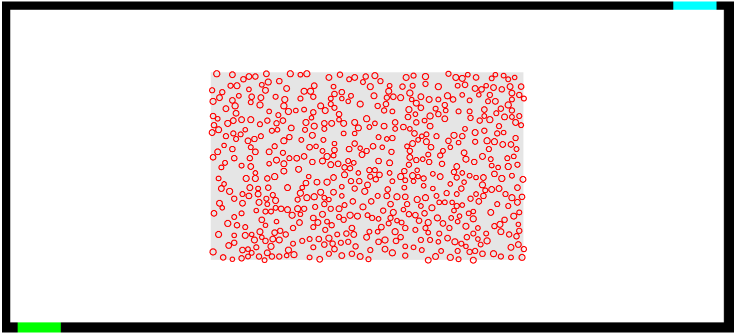


Figure: $t = 0s$

Simulations – Panic Level

For a panic level of $p_i = 0.4$:

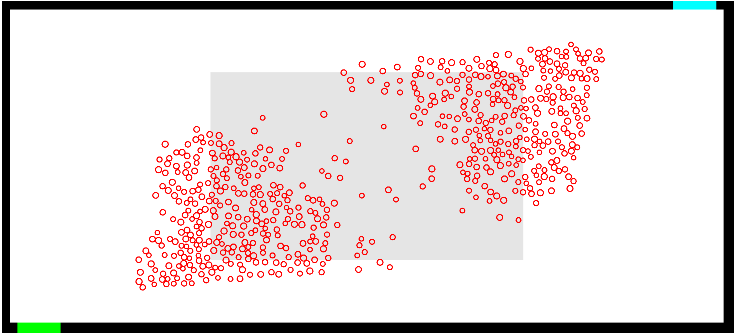


Figure: $t = 4s$

Simulations – Panic Level

For a panic level of $p_i = 0.4$:

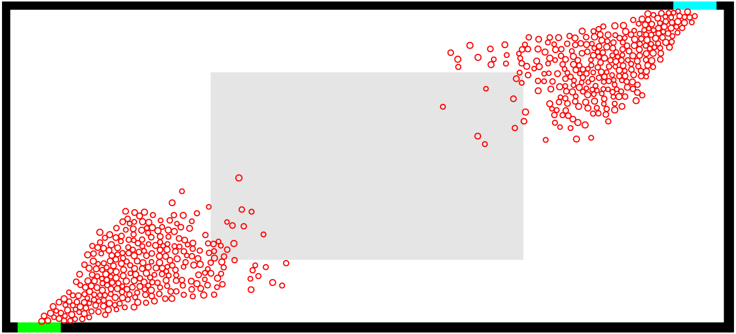


Figure: $t = 8s$

Simulations – Panic Level

For a panic level of $p_i = 0.4$:

Figure: $t = 12s$

Simulations – Panic Level

For a panic level of $p_i = 0.4$:

Figure: $t = 16s$

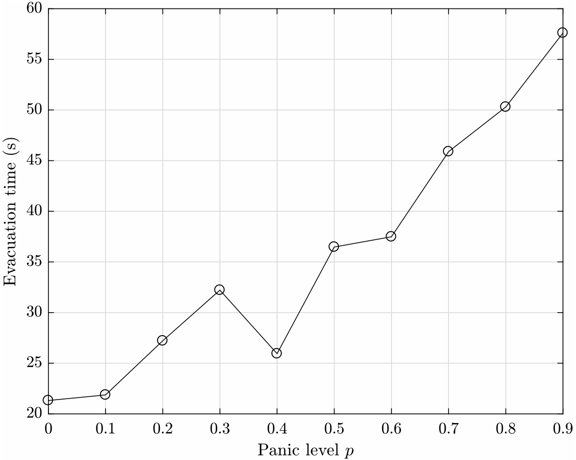
Simulations – Panic Level

For a panic level of $p_i = 0.4$:

Figure: $t = 20s$

Simulations – Panic Level

For a panic level of $p_i = [0, 0.9]$:



Research Questions – Panic Level

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- How does the panic level affect the behaviour of the agents during the evacuation?

  A lower panic level caused the agents to behave in a more individualistic way.

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- How does the panic level affect the behaviour of the agents during the evacuation?

  A lower panic level caused the agents to behave in a more individualistic way.

- How does the panic level affect the evacuation time?

  There was a positive correlation between the panic level and the evacuation time.

Simulations – Excitement Factor

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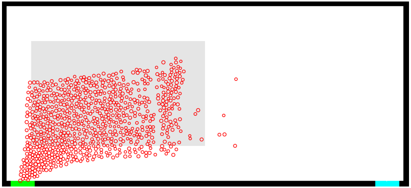
For an excitement factor of E_i = 0.2 (up) and E_i = 0.8 (down):



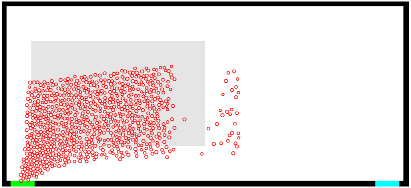


Figure: $t = 6s$

Simulations – Excitement Factor

For an excitement factor of E_i = 0.2 (up) and E_i = 0.8 (down):

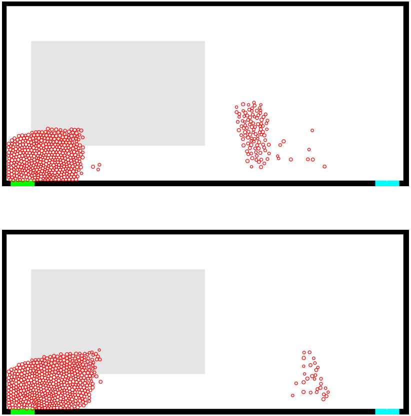


Figure: t = 16s

Simulations – Excitement Factor

For an excitement factor of E_i = 0.2 (up) and E_i = 0.8 (down):

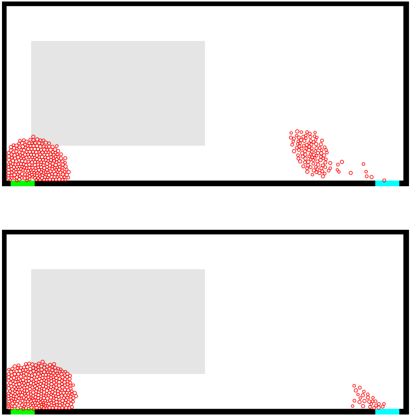


Figure: $t = 26s$

Simulations – Excitement Factor

For an excitement factor of E_i = 0.2 (up) and E_i = 0.8 (down):

Figure: $t = 32s$

Research Questions – Excitement Factor

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- How does the excitement factor affect the behaviour of the agents during the evacuation?

  A lower excitement factor caused the agents to make well-informed decisions.

Further Ideas

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- An injury mechanism if the total force on an agent is too large. The injured agent could work as an obstacle to other agents or have different behaviour and parameters.

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- A memory mechanism for the agents, so that they consider previously seen exits.
- A different pathfinding algorithm that considers the density of agents at every point.

References

[1] D. Helbing, I. Farkas, and T. Vicsek. Simulating dynamical features of escape panic. *Nature*, 407:487–490, 2000. `doi:10.1038/35035023`.

[2] Z. Zainuddin and M. Shuaib. Modification of the decision-making capability in the social force model for the evacuation process. *Transport Theory and Statistical Physics*, 39(1):47–70, 2010. `doi:10.1080/00411450.2010.529979`.

[3] L. Wang, J. Zheng, X. Zhang, J. Zhang, Q. Wang, and Q. Zhang. Pedestrians' behavior in emergency evacuation: Modeling and simulation. *Chinese Physics B*, 25(11):118901, 2016. `doi:10.1088/1674-1056/25/11/118901`.