Time lags in evacuation in the social force model

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AGH

SOCIONICAL

Models of pedestrian behavior

- 1958 – Hankin & Wright – passengers flow in subway.
- 1970 – Henderson – Navier-Stokes equations approach to pedestrian flows.
- 1990 – Helbing – a pedestrian specific gas-kinetic (Boltzmann-like) model.
- 1995 – Helbing – a social forces model for pedestrian motion.
- 1997 – Schadschneider – cellular automaton model of pedestrian motion.
- 2003 – Kirchner – clogging in a cellular automaton model for pedestrian dynamics.

Models of pedestrian behavior

- All model quantities (places, velocities) are measurable and comparable with empirical data.
- Pedestrian models can provide valuable tools for designing and planning pedestrians area, subway, or rail-road stations, big buildings, shopping malls, etc.
- Analogies with gases and fluids – an extreme example of mechanistic reductionism.

Model of crowd dynamics

D. Helbing, I. Farkas and T. Vicsek „Simulating dynamical features of escape panic”, Nature **407**, 487-490, 2000

$$m_i \frac{d\vec{v}_i}{dt} = m_i \frac{v_i^0 \vec{e}_i^0(t) - \vec{v}_i(t)}{\tau} + \sum_{j(\neq i)} \vec{f}_{ij} + \sum_W \vec{f}_{iW}$$

$m_i - mass\ of\ i-th\ pedestrian$, **75kg**

$v_i^0 - desired\ speed$, $\mathbf{3\frac{m}{s}}$

$\vec{e}_i^0(t) - desired\ direction$

$\vec{v}_i(t) - actual\ velocity$

$\tau - acceleration\ time$, **0.5s**

$\vec{f}_{ij}, \vec{f}_W - 'interaction\ forces'$

Model of crowd dynamics

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$$\vec{f}_{ij} = \left\{ A_i \exp\left(\frac{r_{ij} - d_{ij}}{B_i} \right) + k\, g(r_{ij} - d_{ij}) \right\} \vec{n}_{ij} + \kappa\, g(r_{ij} - d_{ij}) \Delta v^t_{ji} \vec{t}_{ij}$$

$$A_i = \mathbf{2000N},\ B_i = \mathbf{0.08m},\ k = \mathbf{1.2 * 10^5 \frac{kg}{s^2}},\ \kappa = \mathbf{2.4 * 10^5 \frac{kg}{m\,s}}$$

$\vec{r}_i =$ position of the i-th pedestrian

$d_{ij} = \|\vec{r}_i - \vec{r}_j\| -$ distance between the pedestrians

$\vec{n}_{ij} = (n^1_{ij}, n^2_{ij}) = \dfrac{\vec{r}_i - \vec{r}_j}{d_{ij}} -$ the normalized vector pointing from j to i

$r_{ij} = (r_i + r_j) -$ sum of radii $r_i = \mathbf{0.3m}$ and $r_j = \mathbf{0.3m}$

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$$\vec{t}_{ij} = (-n^2_{ij}, n^1_{ij}) - tangential\ direction$$

$$\Delta v^t_{ji} = (\vec{v}_j - \vec{v}_i) \cdot \vec{t}_{ij} - tangential\ velocity\ difference$$

$$g(r_{ij} - d_{ij}) = \begin{cases} 0, & r_{ij} < d_{ij} \\ r_{ij} - d_{ij}, & r_{ij} \geq d_{ij} \end{cases}$$

Model of crowd dynamics

D. Helbing, I. Farkas and T. Vicsek „Simulating dynamical features of escape panic”, Nature **407**, 487-490, 2000

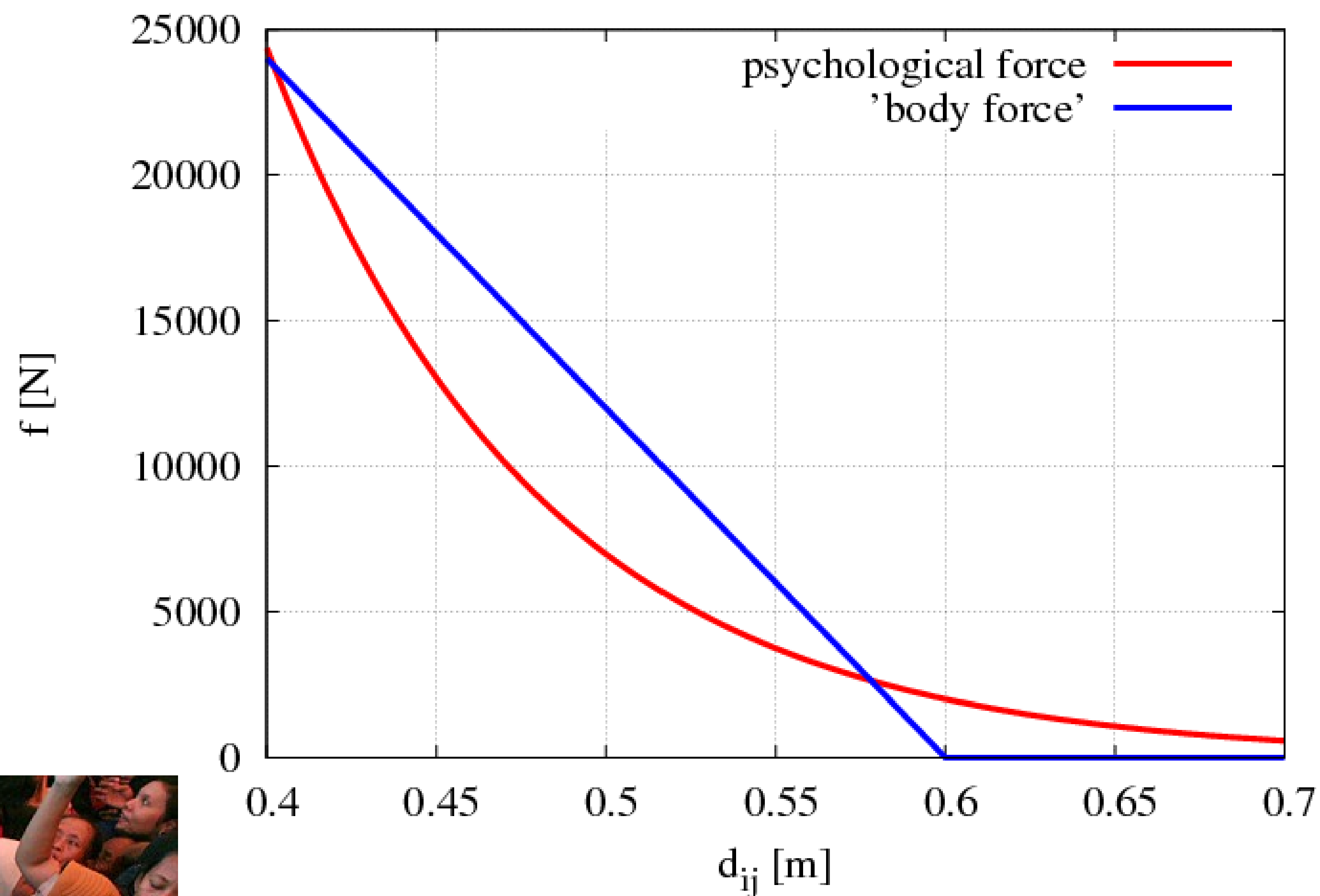
$$\vec{f}_{iW} = \left\{ A_i \exp\left(\frac{r_i - d_{iW}}{B_i}\right) + k\, g(r_i - d_{iW}) \right\} \vec{n}_{iW} + \kappa\, g(r_i - d_{iW}) (\vec{v}_i \cdot \vec{t}_{iW}) \vec{t}_{iW}$$

$$d_{iW} - distance \text{ to } wall\ W$$

$$\vec{n}_{iW} - direction\ perpendicular \text{ to } wall\ W$$

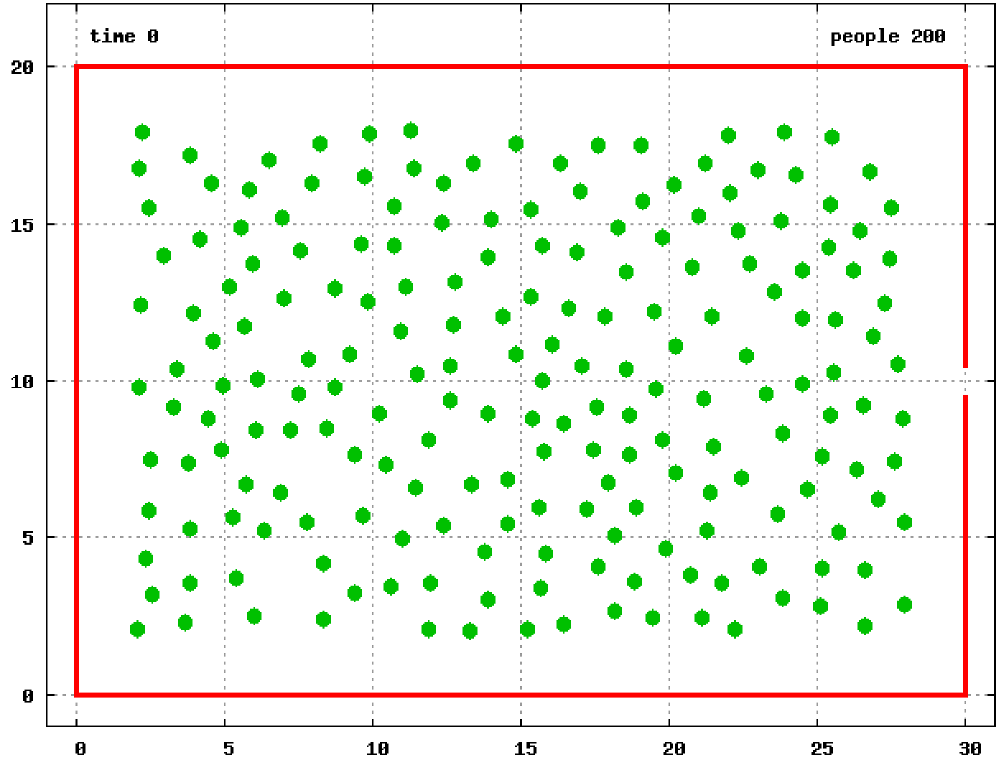
$$\vec{t}_{iW} - direction\ tangential \text{ to } wall\ W$$

Simulation of crowd dynamics

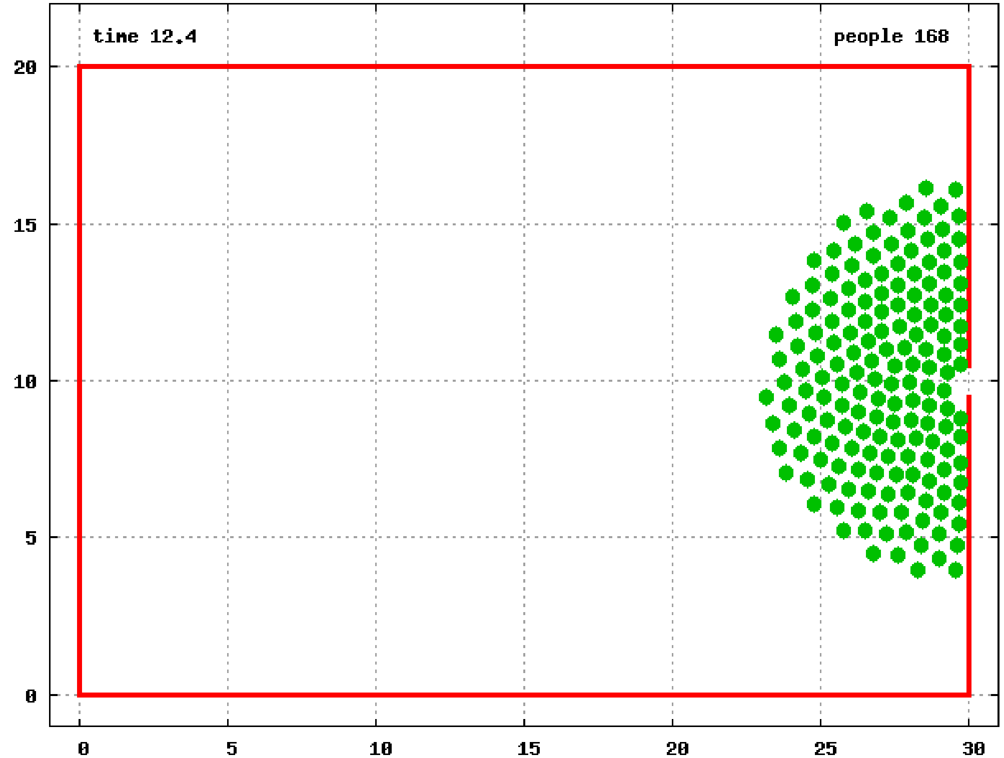


Simulation of crowd dynamics - snapshots

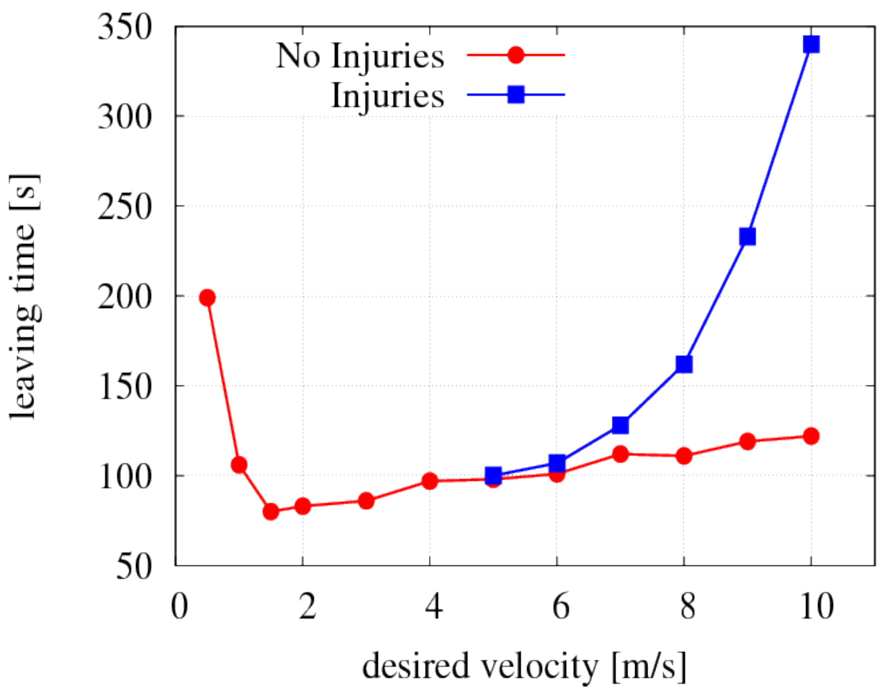
- initial state

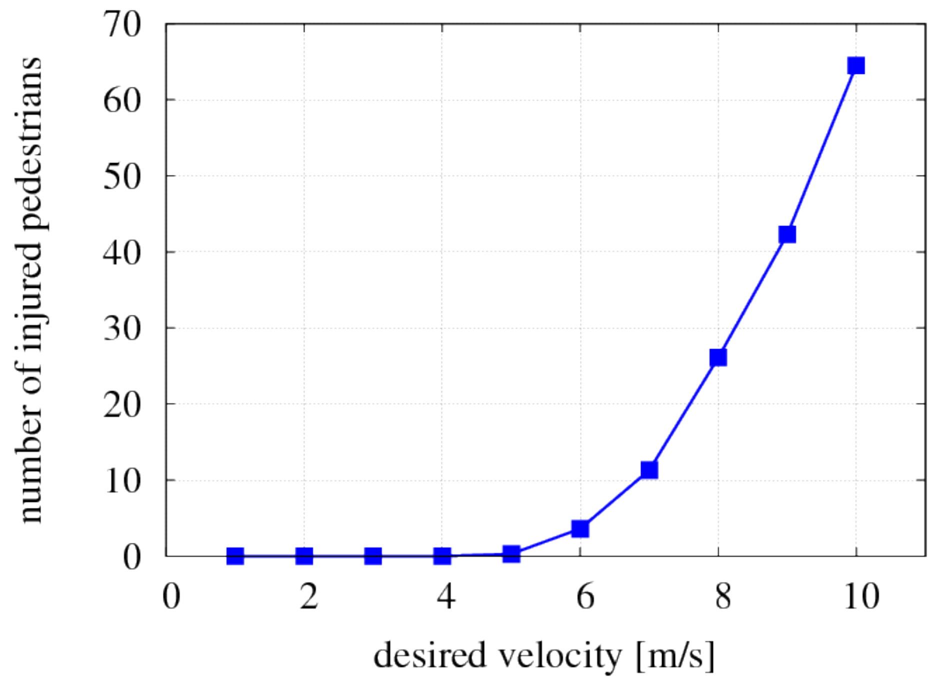


- arch-like blocking of the exit



Simulation of crowd dynamics – 'faster-is-slower' effect





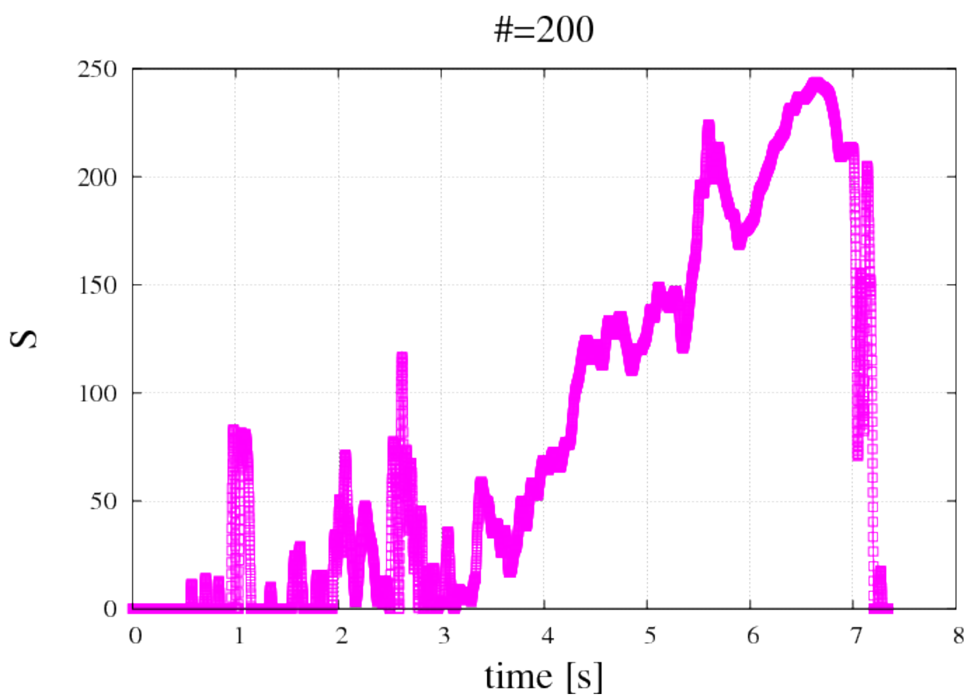
- Desired velocities $v_0 > 1.5$ m / s reduce the efficiency of leaving due to pushing, which causes additional friction effect.
- Above $v_0 = 5$ m/s pedestrians are injured if the pressure exceeds $1600 Nm^{-1}$ and become non-moving obstacles for others.

Is it possible to leave the crowd?

- The evidence from bent steel railings in several fatal crowd accidents have shown horizontal forces over 4500 N (equivalent to a weight of approximately 460 kg.)
- When the density of crowd becomes too large, pedestrians may die by e.g. compressive asphyxia.
- Before it happens **they might want to leave the crowd, but on what condition it is possible?**

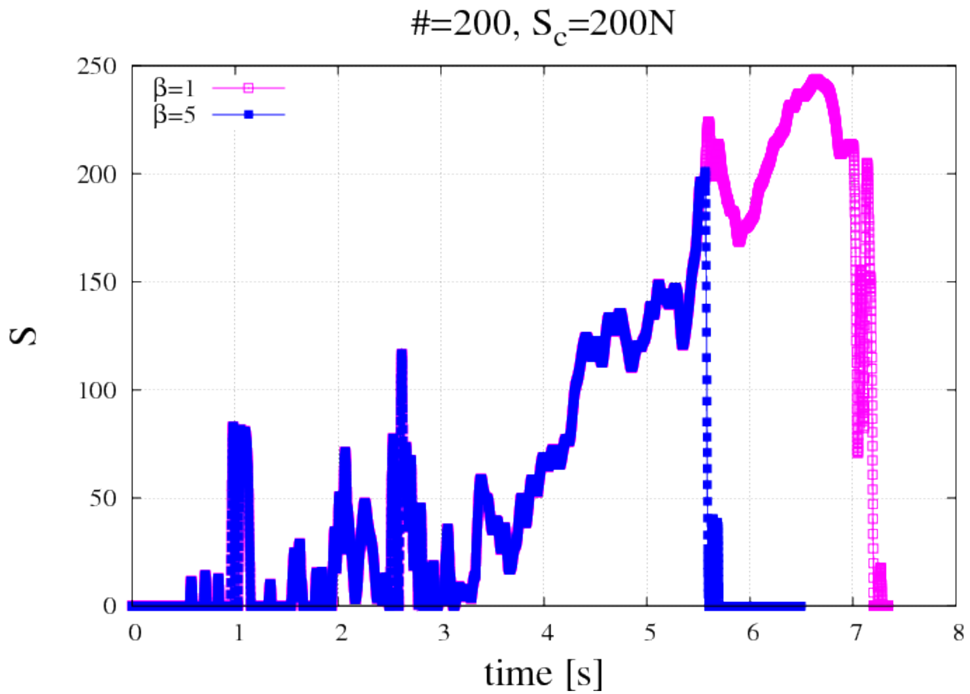
Is it possible to leave the crowd?

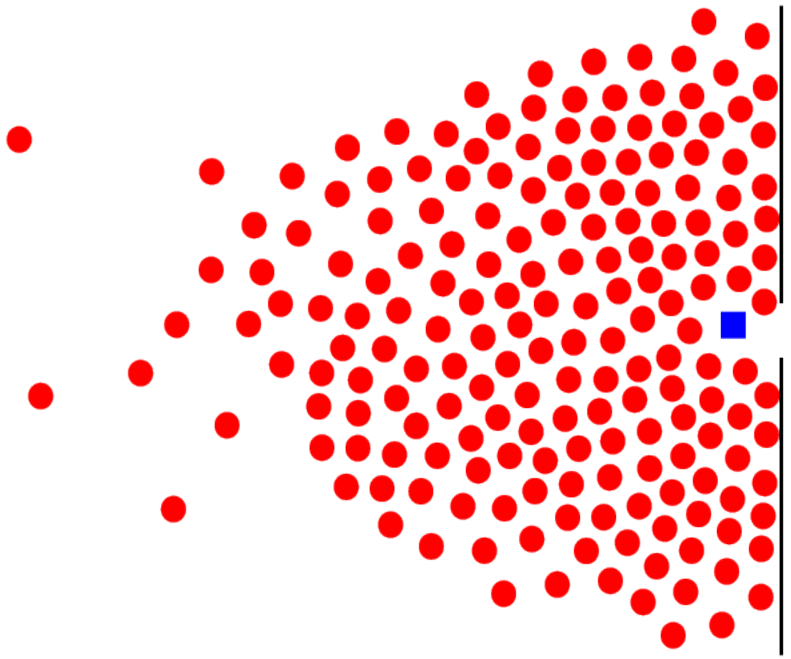
- *S* – sum of modules of the physical (not the psychological) compressive forces acting on pedestrians.
- *S* – a rough measure of pressure inconvenience in a crowd.



Is it possible to leave the crowd?

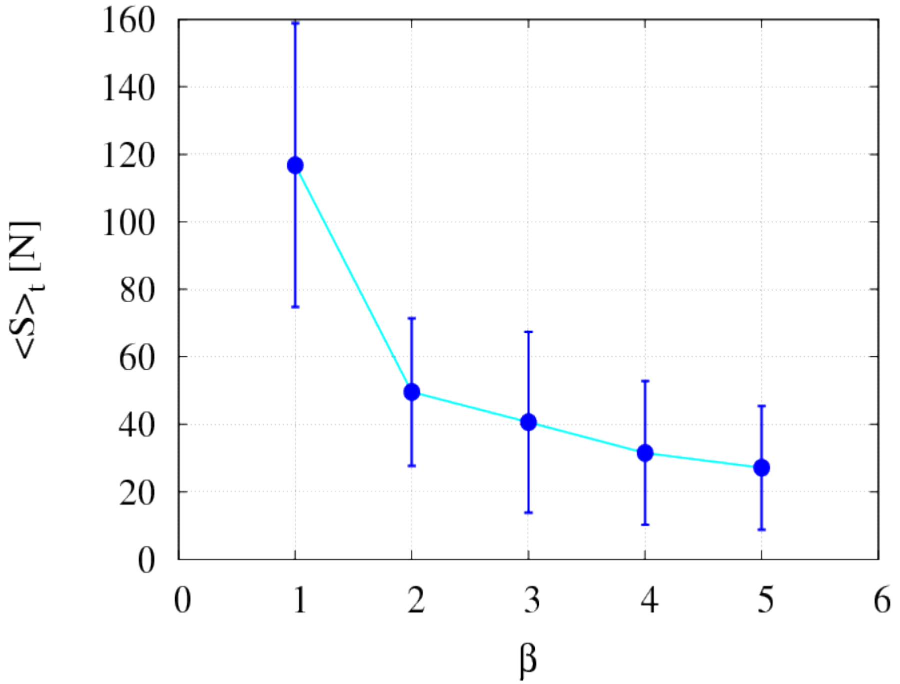
- Once S exceeds some predefined threshold Sc at one of the pedestrians i, the social force exerted by this pedestrian on the others is modified: $A'i = \beta * Ai$.





- The psychological interaction of pedestrian i forced the others to withdraw, S acting on him decreases.

Is it possible to leave the crowd?



- The average sum of forces decreases with β.
- The rate of this change decreases with β, as well.

Thrown out against one's will?

- Pedestrians cross the exit one by one. If density is large enough, it's impossible to move with respect to our neighbors.
- **Can one withdraw from the crowd or she/he will be thrown out through the exit against her/his will?**

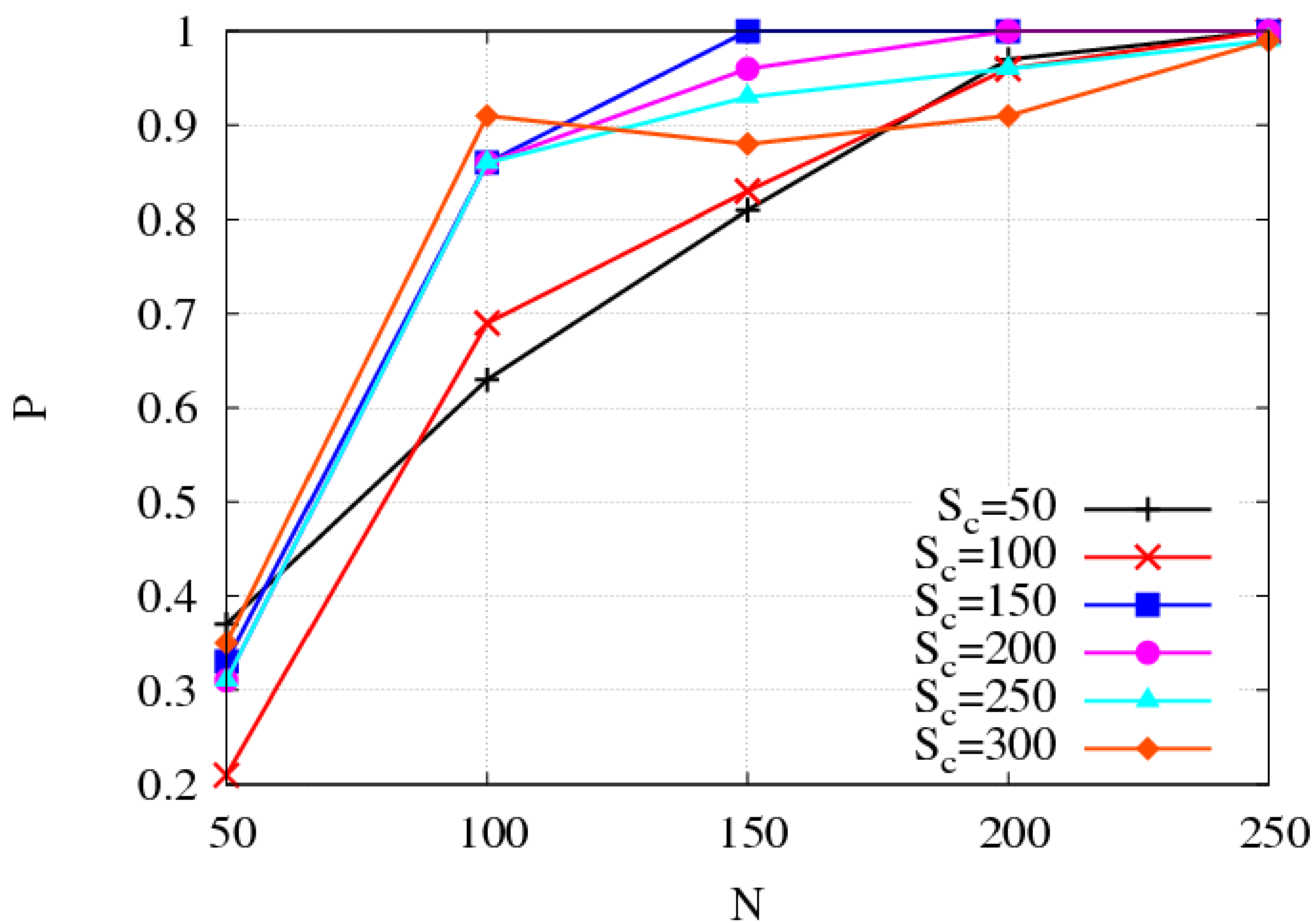
Thrown out against one's will?

- Pedestrians, numbered by $i=1, \ldots, N$, are going to leave a room through a small exit.
- The sum *Si* of compressive mechanical forces acting on each individual *i* is registered during the motion.
- Once for individual *X* the sum *Sx* exceeds the threshold value *Sc*, the direction of the desired motion of this individual is reverted.
- *K* nearest neighbors of *i-th* pedestrian decide to accompany her/him.
- The desired direction of *K* individuals, who are closest to *X*, when the threshold *Sc* is exceeded is now equal desired direction of *X*. The repulsive psychological force between *X* and her/his neighbors is attractive now.

Thrown out against one's will?

- The group of $K+1$ individuals tries to evade the exit, as if they tried to help a victim of the interpersonal forces in the crowd.
- The outcome of the simulation is the probability P, that the crowd throws X out through the exit, despite her/his struggling to withdraw from the crowd.
- If X crosses the exit despite this change of her/his intention, we call the crowd *'jammed'*.

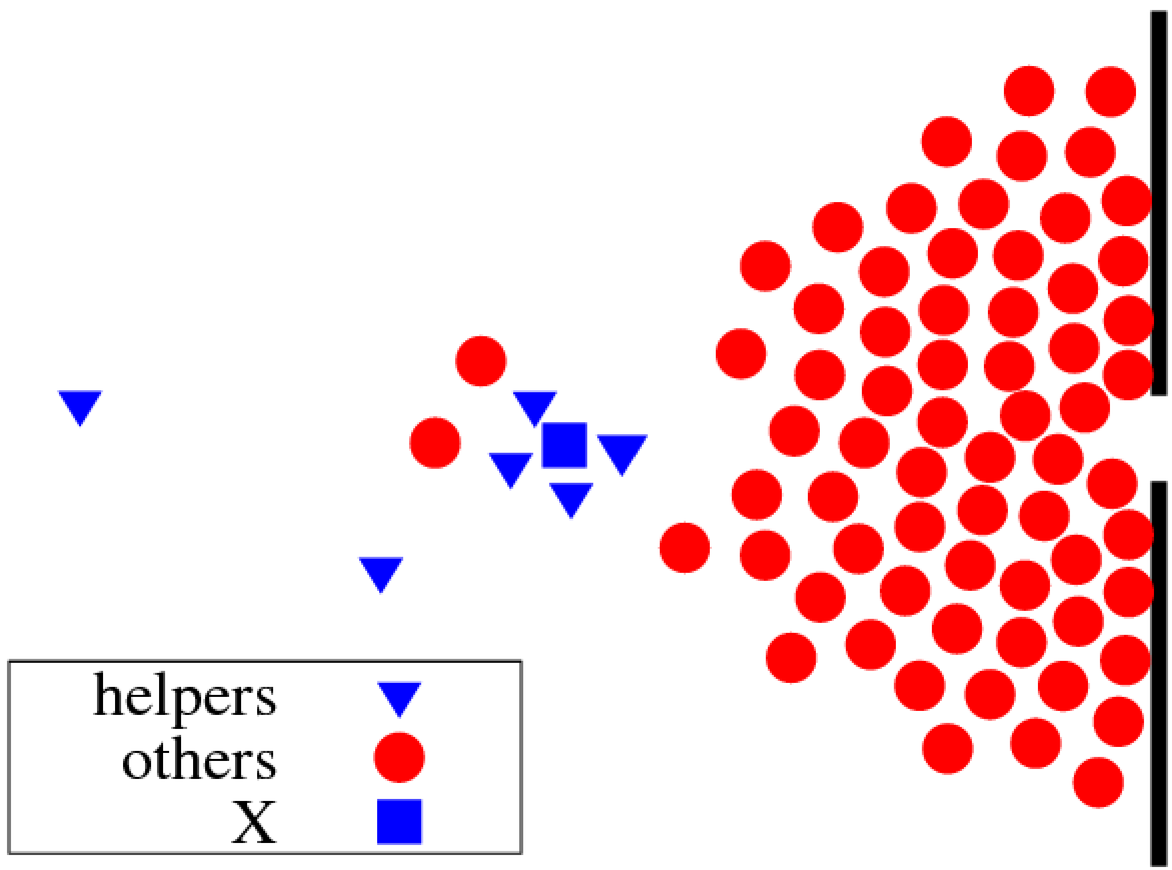
Thrown out against one's will?



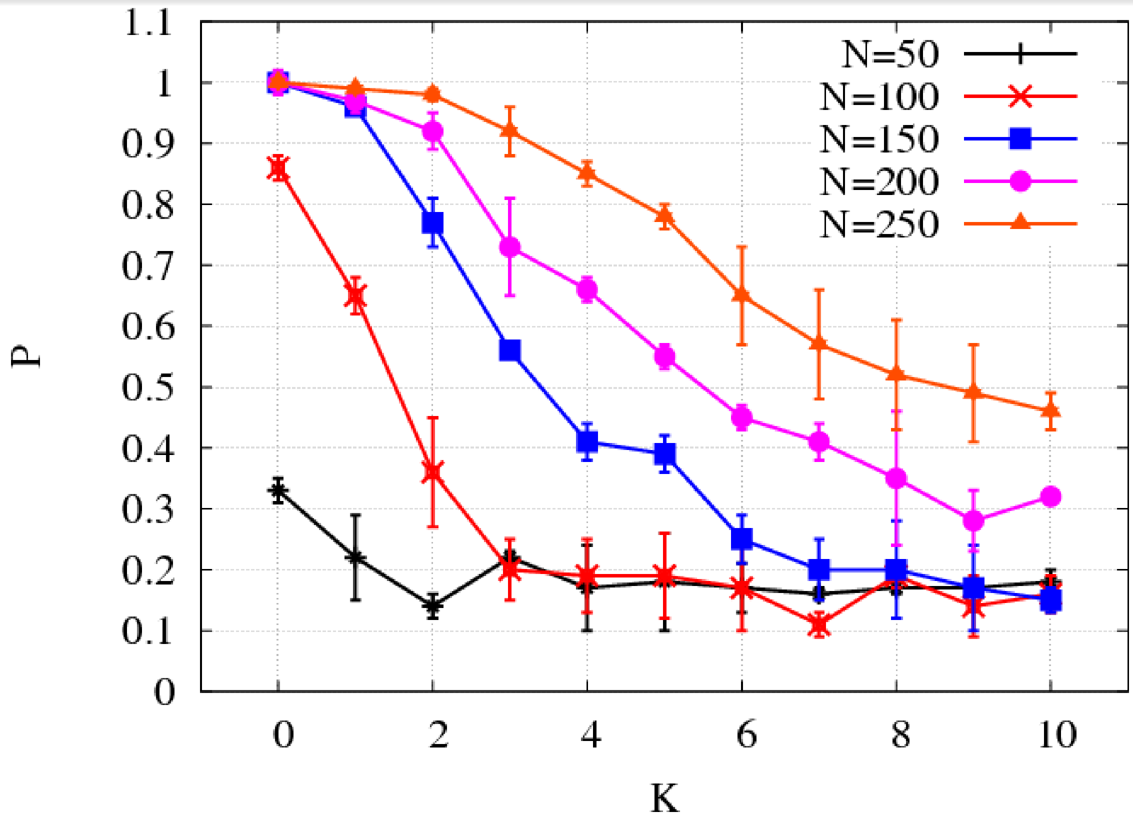
- $K = 0$ (no helpers). Average over *70* samples.
- The probability P weakly depends on Sc. The crowd size N is decisive.

Does collective action help?

- A successful help. A spatial configuration of individuals near the exit.

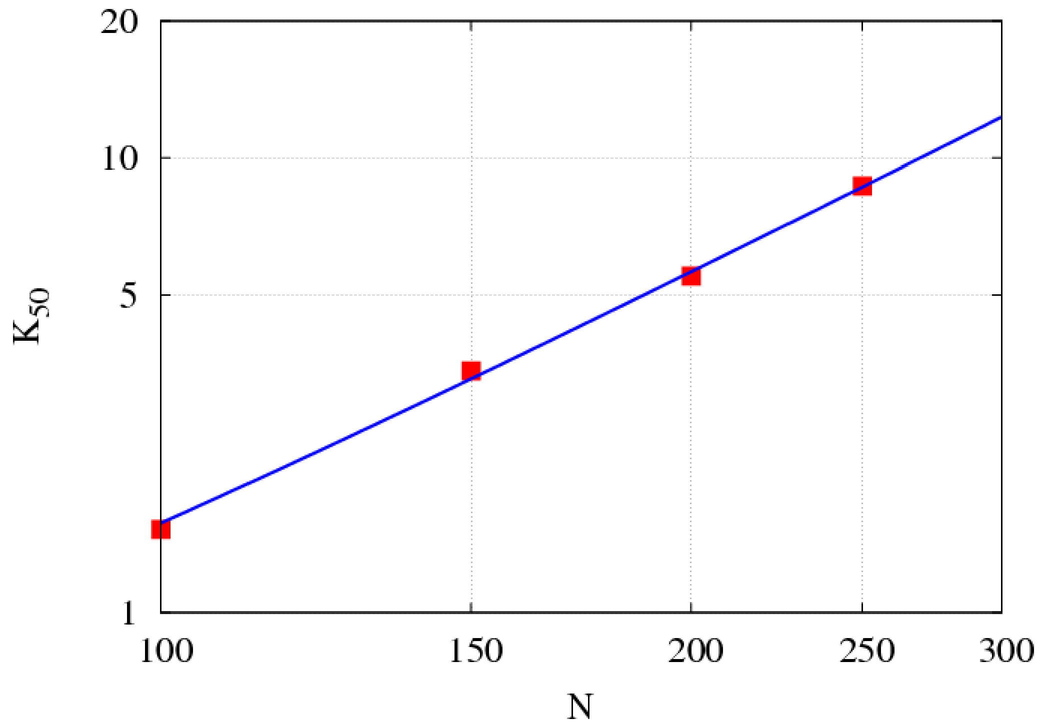


Does collective action help?



- Crowd size *N* is relevant, but can be to some extent neutralized by the number of helpers.
- For example, *P* close to *0.5* can be achieved in a crowd of $N = 100$ pedestrians with *K* about *2* helpers, in a crowd of $N = 200$ pedestrians with *K* about *5* helpers and so on.

Does collective action help?

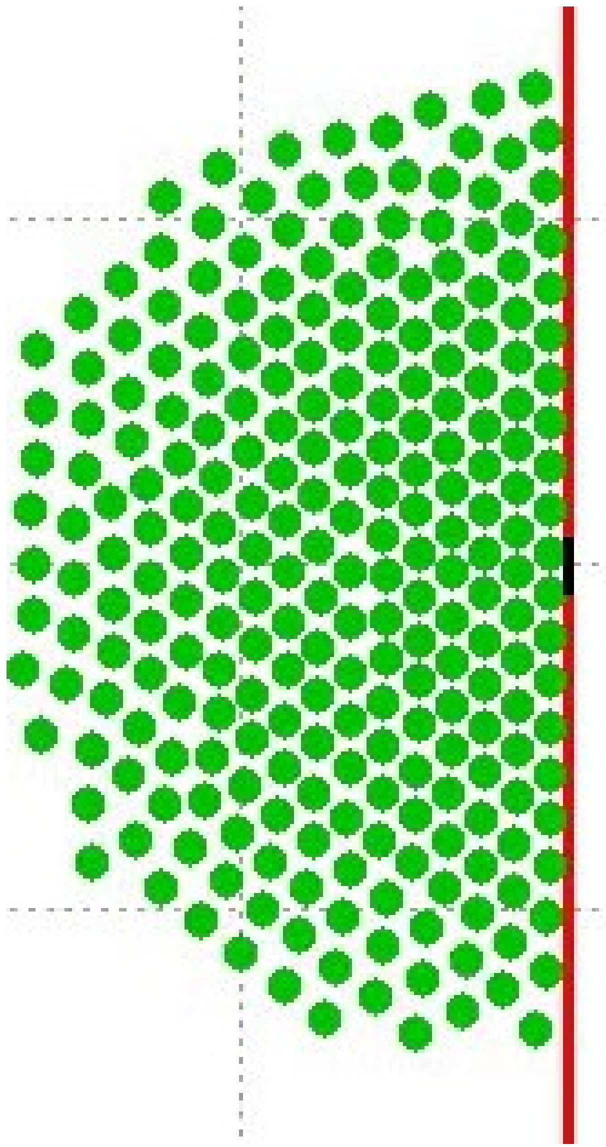


•How many helpers must be found to have a chance of *50 %* to withdraw from the crowd?

$$K_{50} \propto N^{\beta}, \beta = 1.88 \pm 0.05$$

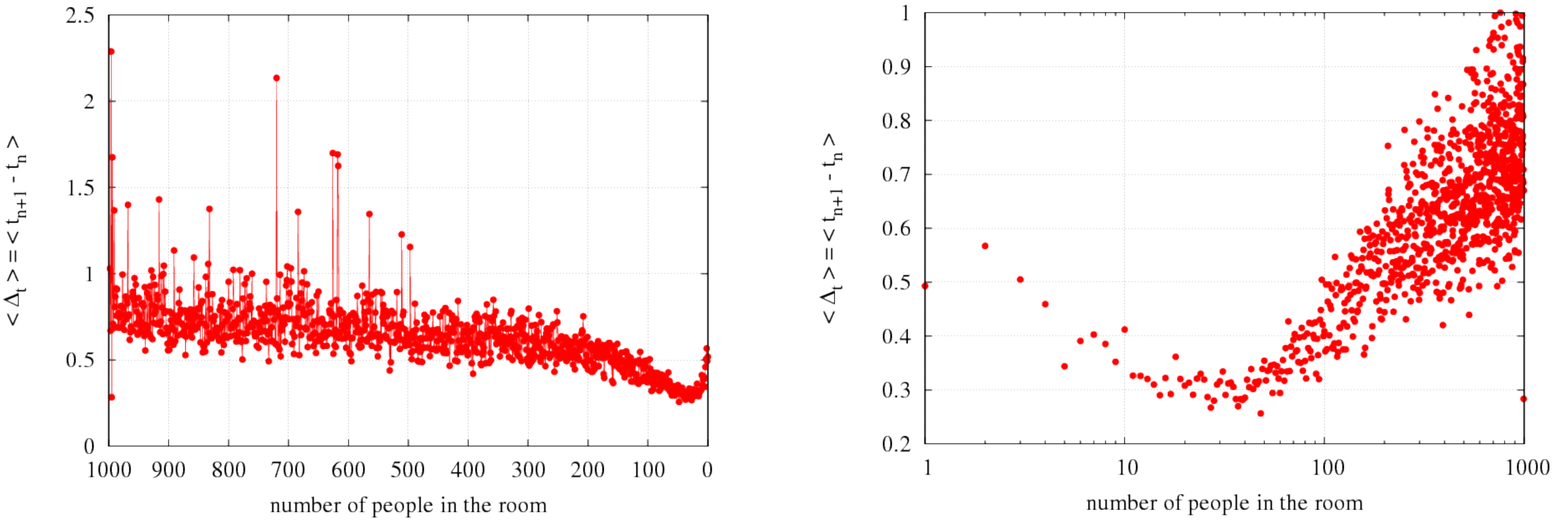
•However, as K_{50} cannot be greater than N, this behavior must end with some crossover for larger N.

A closed door scenario.



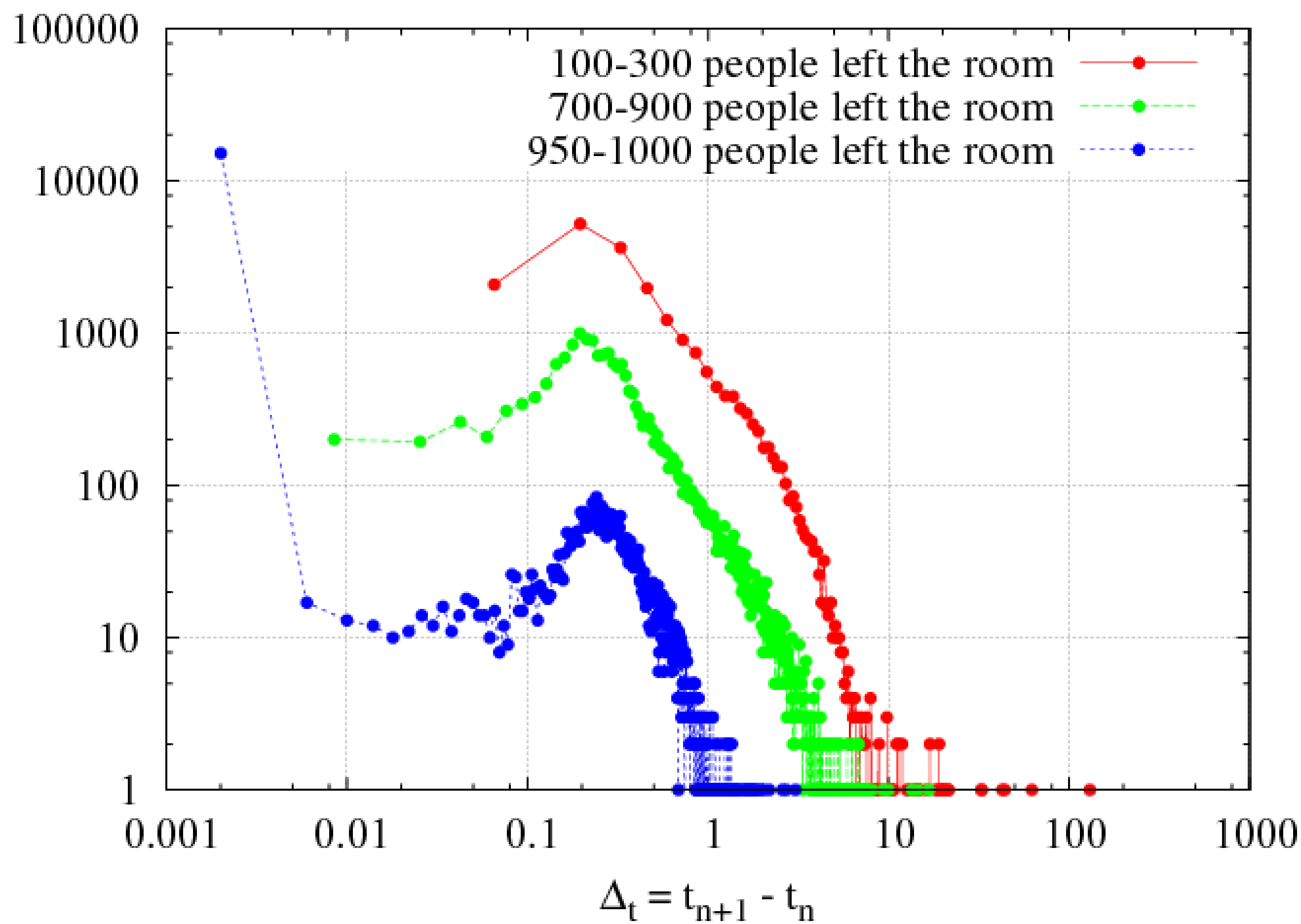
- N=1000 persons in a room with a small exit.
- At the initial state the door is closed and the people are crowded.
- When the crowd is formed we open the door, and we register the time at which each individual leaves the room.
- Time lags $\Delta_t = t_{n+1} - t_n$

A closed door scenario:2 phases in the evacuation process



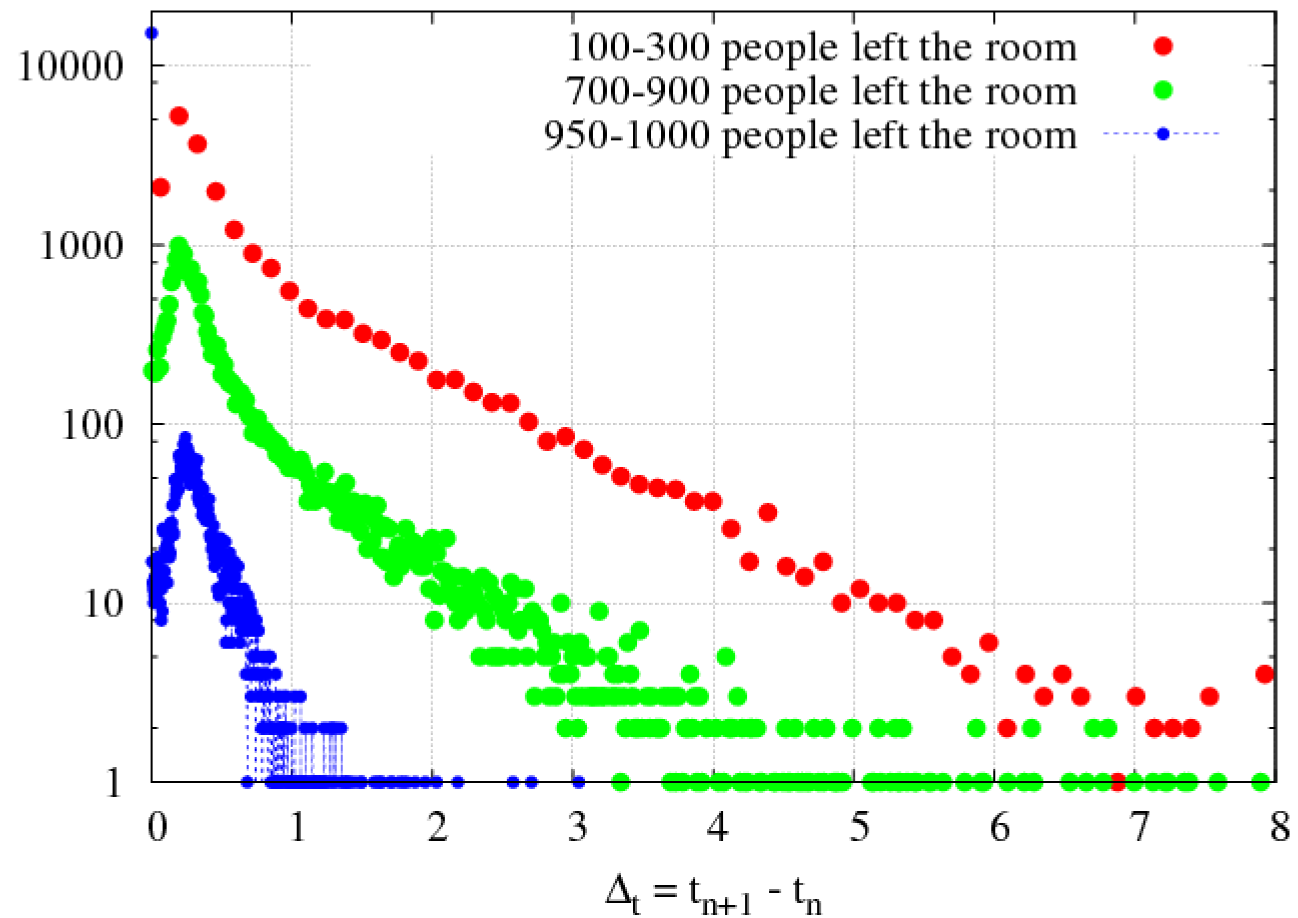
•Initially the mean length of the time lags decreases with the number of people in the room, then increases.

A closed door scenario: two characteristic times



I. Mean time interval between the exit events in a group of people leaving the room: *0.2s*.

A closed door scenario: two characteristic times



II. Clogging time $\propto$ $\mathbf{e^{-const\ t}}$

The events of clogging of the group of people are independent.

Conclusions

•Our numerical results indicate that once the crowd size N exceeds *150-200* pedestrians, it is unlikely that a single individual can withdraw under one's own steam.

•The only way then is to mobilize a group of pedestrians nearby who are willing to help. Still, the necessary number of helpers increases with the size of the crowd.

• The analysis of the time intervals between the persons leaving the room shows the correlation within a group of people leaving the room and no correlation between separate groups leaving the room.

Thank you for your attention.