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Twotype multiagent game for egress congestion

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HICSS 2017, Hawaii, Jan. 4-7, 2017

Systems Analysis Laboratory

Evacuation simulations

- Crowd evacuating through narrow bottlenecks creates clogging and jams that slow down the egress flow.
- Pushing towards the exit creates faster-is-slower effect.
- We present a spatial game to model the interaction of agents in such situations.
- Our model explains the origin of panic.
- We apply the game model to a continuous time egress simulation FDS+Evac (http://virtual.vtt.fi/virtual/proj6/fdsevac/documents/FDS+Evac_textbased_homepage.txt).

Previous research

- Evacuation experiments and computer simulations: S. P. Hoogendorn et al., 2005; Heliövaara et al., 2012; D. Helbing et al., 2000; A. Kirchner et al. 2003.
- Social psychology of panic: A. Mintz, 1951.
- Prisoner's Dilemma (PD) game: R. Brown, 1965; J. S. Coleman, 1990.
- Spatial games and computation: M. A. Nowak et al., 1992; M. Sysi-Aho et al., 2005; Heliövaara et al., 2013; von Schantz et al., 2015.
- Biological evolution and games: J. Maynard Smith, 1982.

Game matrix for agent-agent interaction

- Estimated evacuation time of agent i:

  $T_i = \frac{\lambda_i}{\beta}$. Denote $T_{ij} = (T_i + T_j)/2$.

  Available safe egress time (ASET): T_{ASET}

  Cost function: $u(T_i;\ T_{ASET})$

  Players' strategies: Patient, Impatient

  The rules of the game:

  (i) An impatient agent i can overtake its patient neighbor $j \Rightarrow$ the cost of agent i decreases by $\Delta u(T_{ij}) \simeq u'(T_{ij})\Delta T$.

  (ii) Two patient agents do not interact with each other $\Rightarrow$ their costs do not change.

  (iii) Two impatient agents, neither can overtake the other. Instead they will face a conflict with equal chance of getting injured $\Rightarrow$ Cost of conflict $C\triangle T$.

Game matrix to be minimized:

		Player 2	
		Impatient	**Patient**
Player 1	**Impatient**	$\frac{C}{\Delta u(T_{ij})}, \frac{C}{\Delta u(T_{ij})}$	$-1, 1$
	Patient	$1, -1$	$0, 0$

- The game to be played:

(i) prisoner's dilemma (PD) if $0 < \frac{C}{\Delta u(T_{ij})} \leq 1$,

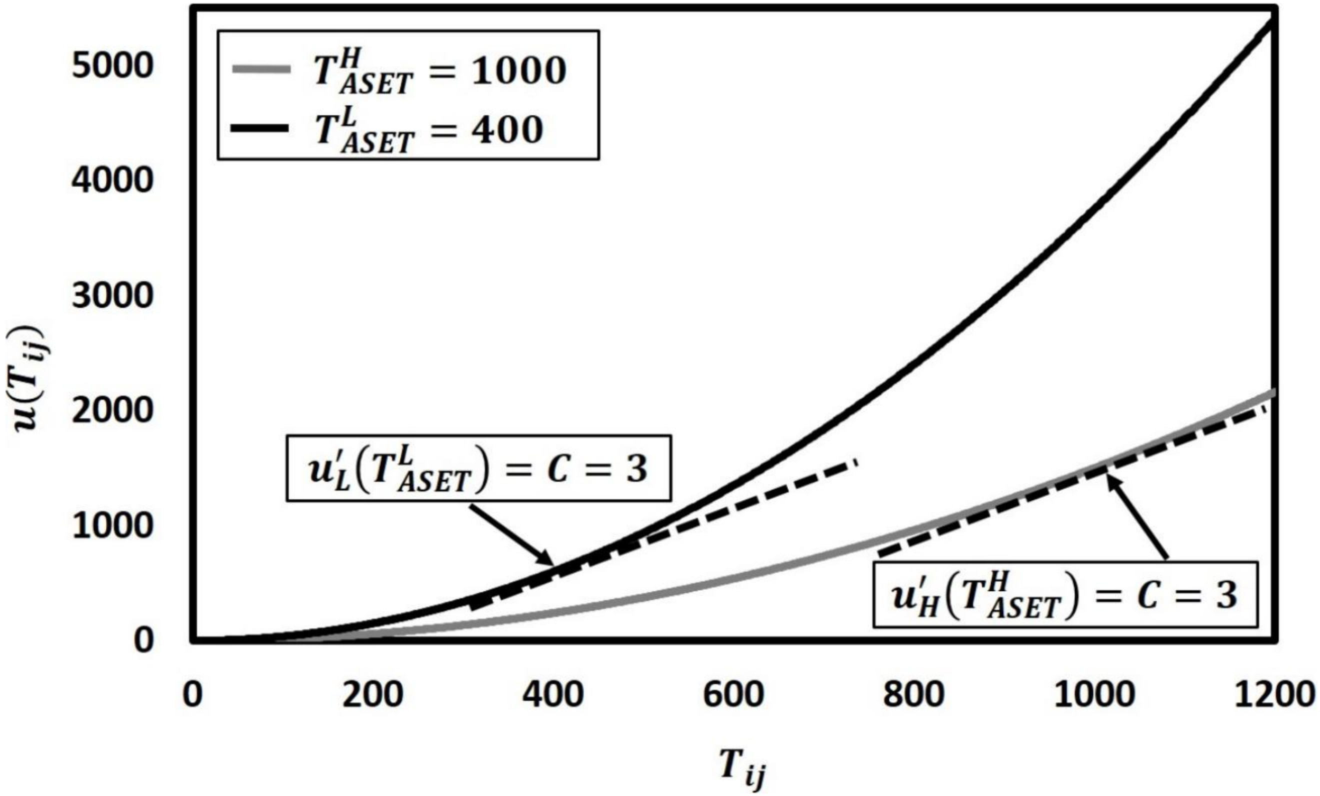
(ii) hawk-dove (HD) if $\frac{C}{\Delta u(T_{ij})} > 1$.

Convex cost function:

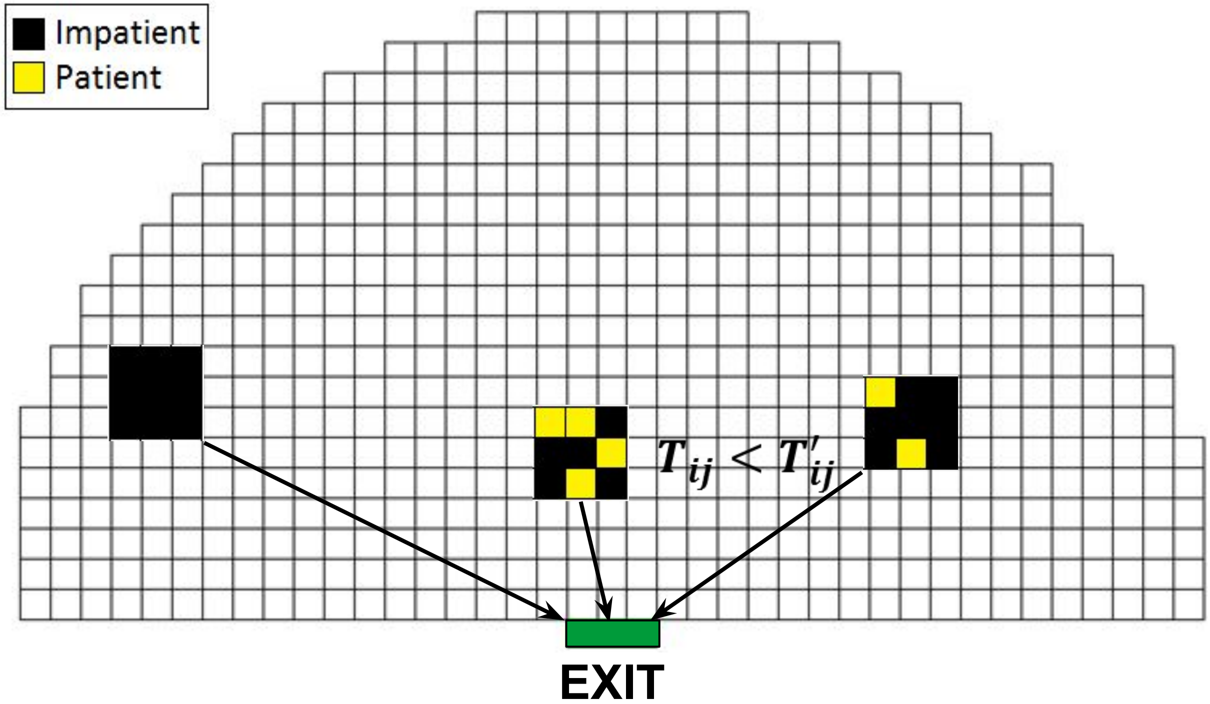
		Player 2	
		Impatient	Patient
Player 1	Impatient	$\frac{T_{ASET}}{T_{ij}}, \frac{T_{ASET}}{T_{ij}}$	$-1, 1$
	Patient	$1, -1$	$0, 0$

- Assume $u(T_{ij}) = \frac{CT_{ij}^2}{2T_{ASET}}$, if $T_{ij} \geq 0$; $u(T_{ij}) = 0$; if $T_{ij} < 0$, and $u'(T_{ASET}) = C$.

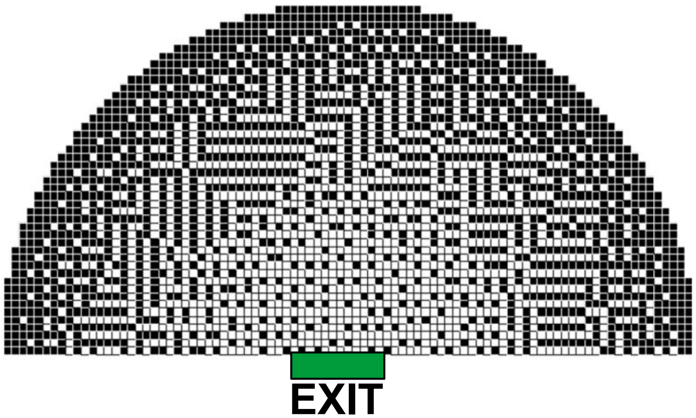
Convex cost function:



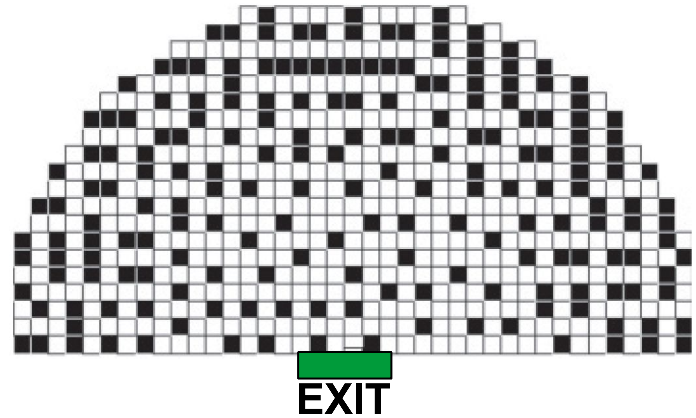
Spatial setting, BR-dynamics, and shuffle update rule



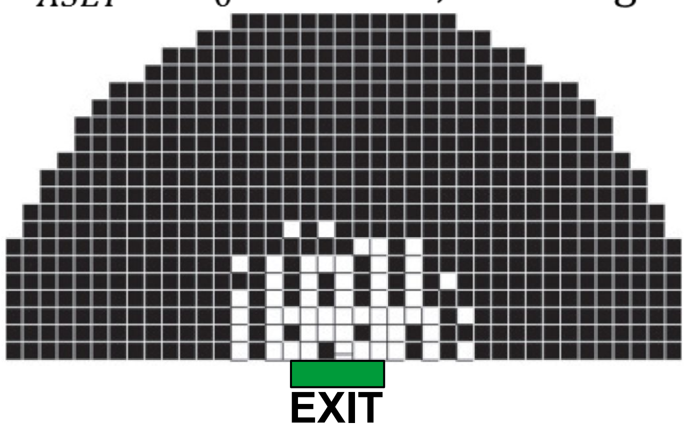
Equilibria in discrete grid



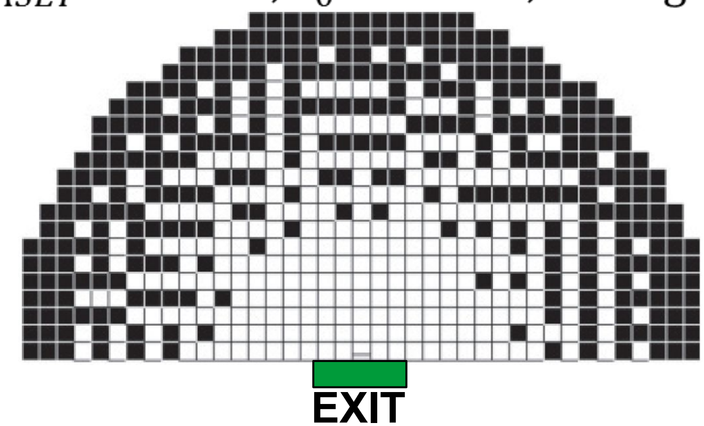
$T_{ASET} = T_0 = 2800\ s,\ \ 3180$ agents



$T_{ASET} = 1500s, T_0 = 1500s$, 628 agents



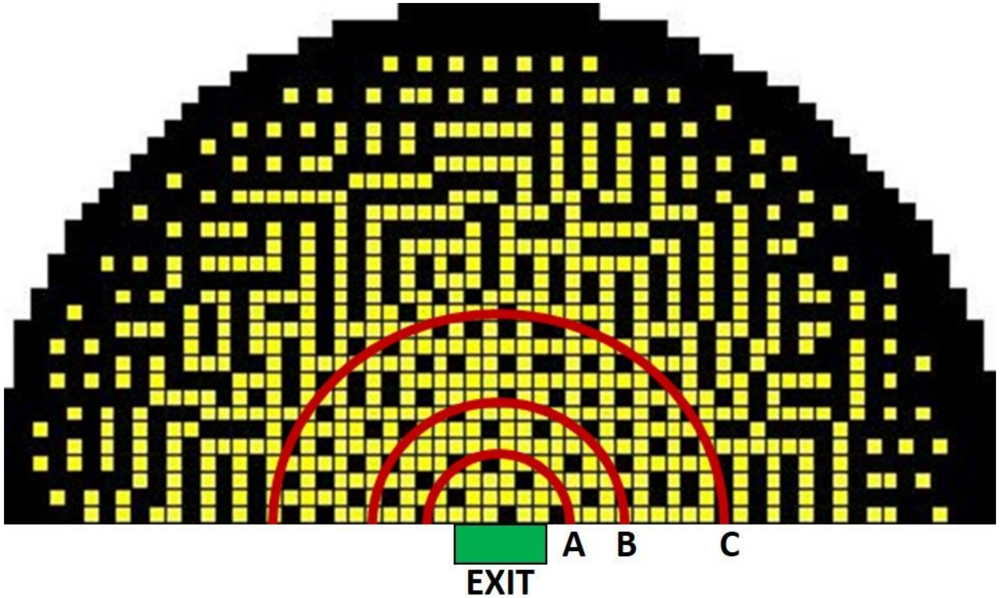
$T_{ASET} = 100s, T_0 = 100s$, 628 agents



$T_{ASET} = 500s, T_0 = 400s$, 628 agents

Evolutionary Stable Strategy, ESS

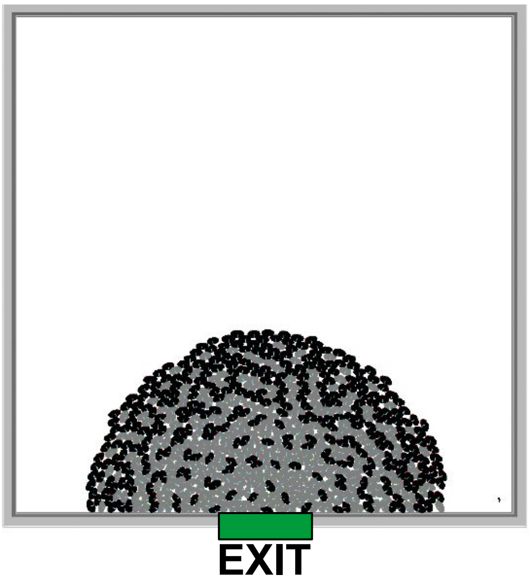
- Among the semicircles A, B, C, the number of impatient agents in the Moore neighborhood of agents are at most 1,2,4, respectively.
- The proportion of impatient agents along a semicircle approximates the ESS of the game at that distance.



$T_{ASET} = T_0 = 1000\ s,\ 1413\ \text{agents}$

- For the proportion of impatient agents in the Moore neighborhood of agent i it holds, $\frac{|N_i^{Imp}|}{|N_i|} \leq \frac{T_i}{T_{ASET}}$.

Equilibria in continuous space: FDS+Evac simulations

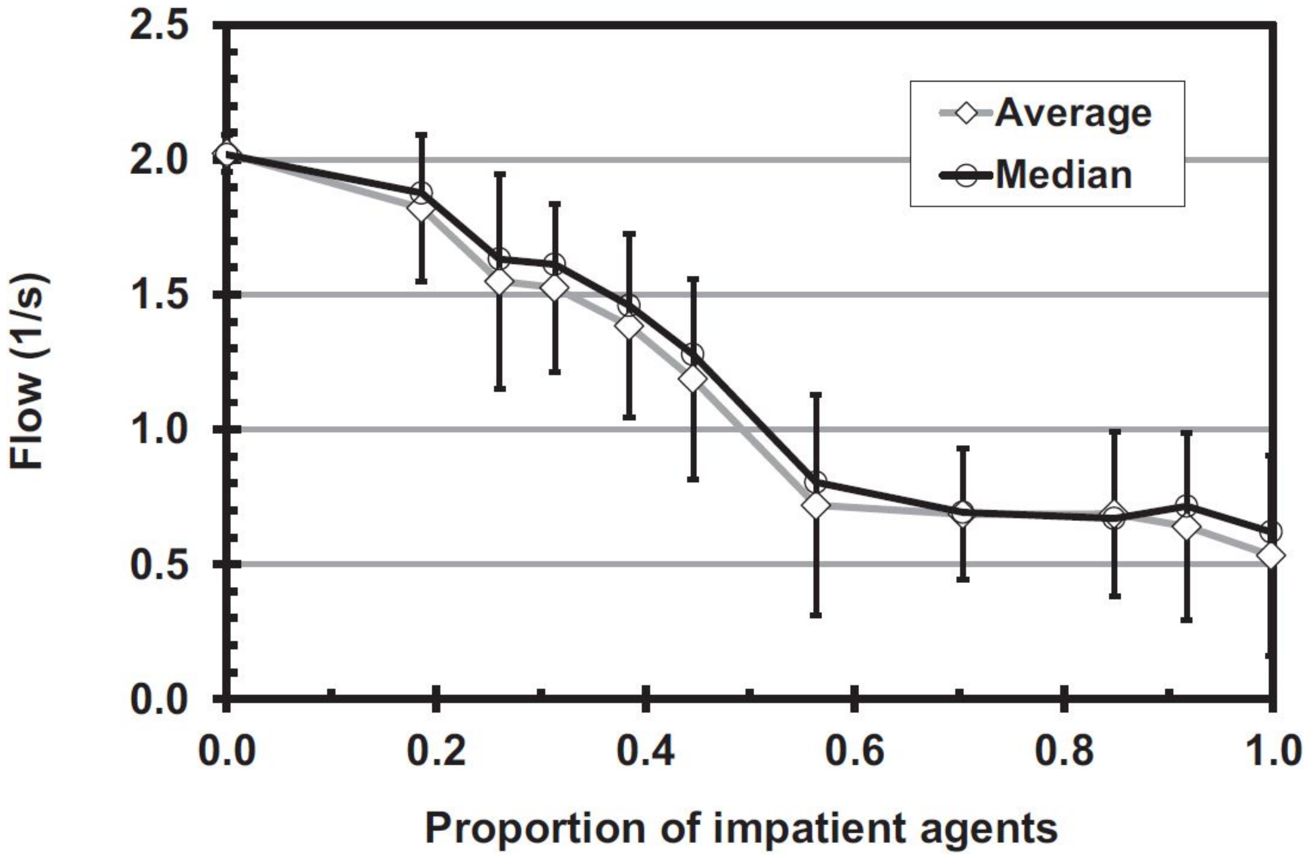


$T_{ASET} = 500s, T_0 = 500s$, 628 agents

$T_{ASET} = 1500s, T_0 = 1500s$, 628 agents

- Impatient agents: do not avoid contacts with other agents; accelerate faster to their target velocity; move more nervously.

Faster-is-slower effect

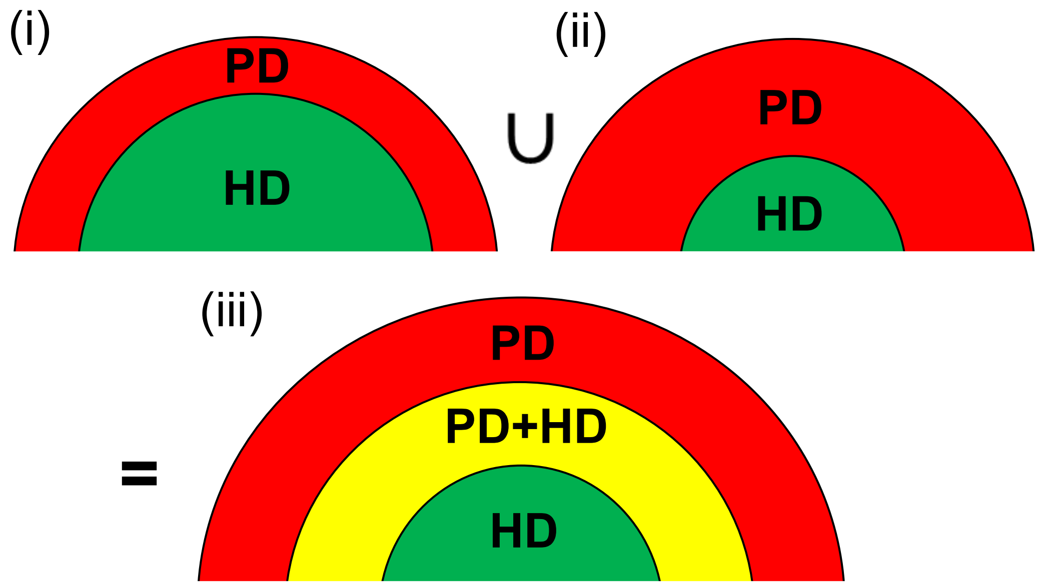


Cellular automaton model, CA (A. Kirchner et al., 2003)

- Agents are located in the cells of a discrete square grid, and they move according to transition probabilities that depend on static and dynamic floor fields.
- If several agents try to move simultaneously to the same cell, the agent allowed to move is determined randomly.
- The spatial game is coupled to the CA by setting the agents to play against the agents in their Moore neighborhood.
- Various strategies correspond to different movement in the grid. Impatient agents rush to the exit, patient agents don’t rush.
- Produces qualitatively similar results as FDS+Evac, however is computationally lighter ($O(N)$ vs. $O(N^2)$)

Equilibrium of the twotype game

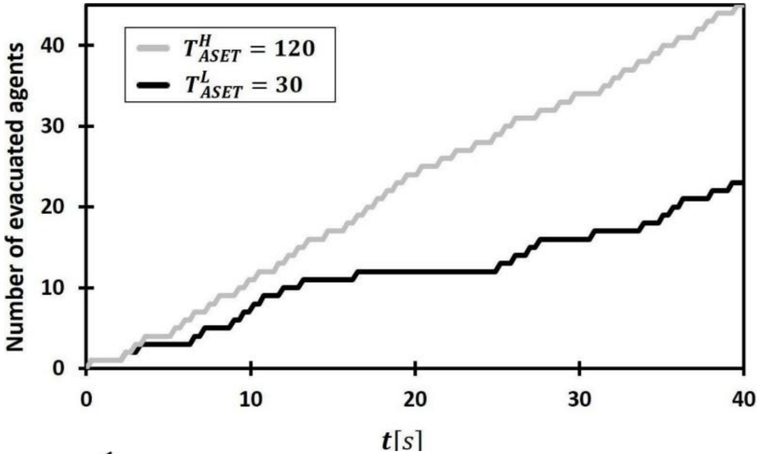
- Equilibrium configuration for a crowd with only high T_{ASET} agents (i), a crowd with only low T_{ASET} agents (ii), and a crowd with 50% high T_{ASET} agents and 50% low T_{ASET} agents (iii).

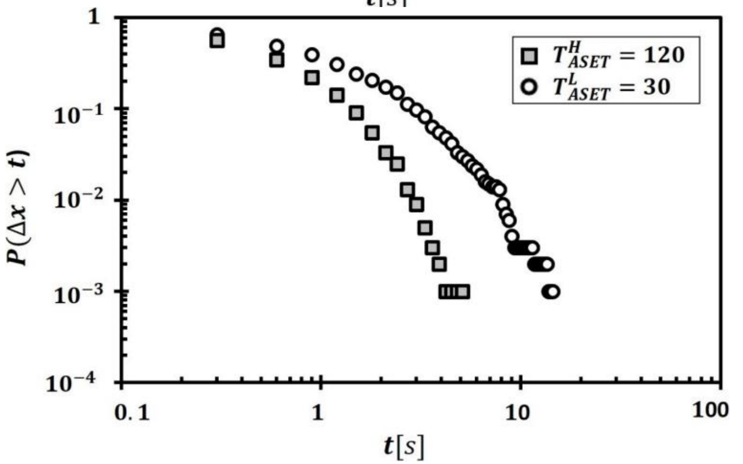


- Merging low T_{ASET} agents in the crowd forces high T_{ASET} agents to play Patient (the yellow area of (iii)).

Irregular succession of evacuated agents

- The number of evacuated agents increase in an irregular stepwise manner in time.
- Typical for real crowds. It's a result of human arches forming and breaking down.
- The complementary cumulative frequency distribution shows that time lapses Δx between consecutive evacuated agents are longer for low T_{ASET} agents than for high T_{ASET} agents.

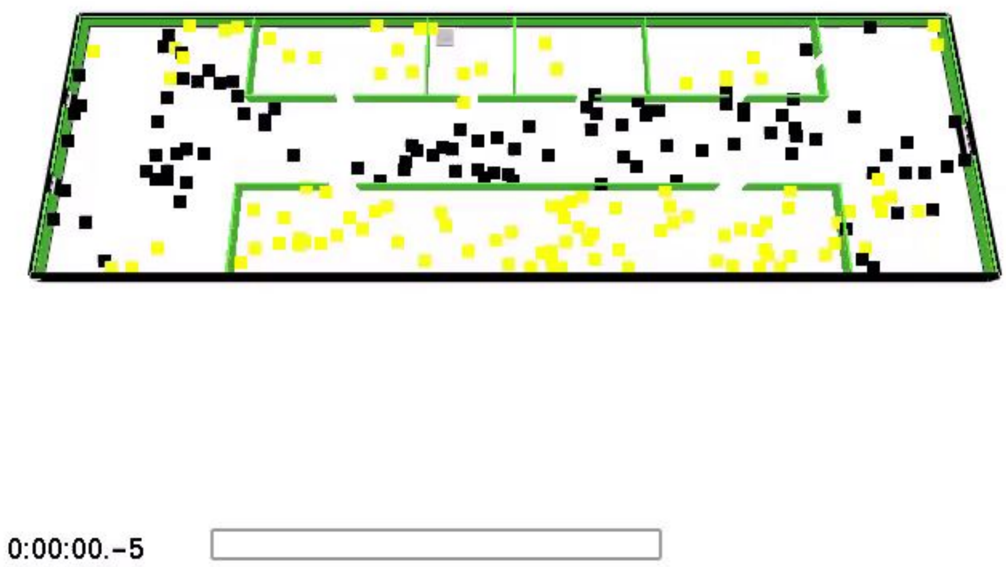




Conclusions

- Spatial game model describes when, why and how the crowd members adopt impatient pushing behavior.
- FDS+Evac simulation software is based on physics ⇒ simulations too heavy.
- We study the embedding of our spatial game model to the CA-model developed by A. Kirchner et al., 2003 ⇒ simulation of agent flow is easy, A. von Schantz and H. Ehtamo, 2014.
- Then the incident commander could give timely and accurate instructions with a real-time model.

Crowd evacuating from a department store



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Our research

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