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Analysis of Symmetry-Breaking in Evacuation Exit Choices during the Tangshan Earthquake

Keywords: Herd Behavior, Evacuation Decision, Earthquake, Multi-agent simulation, Video Analysis

Extended Abstract

Herd behavior during evacuation is a controversial topic today, despite being extensively studied by the research community. Symmetry-breaking in the choice of evacuation exit is a well-known phenomenon that is considered a result of evacuees' irrational decision-making due to herd behavior among them [1]. Some empirical studies have shown that herding was not observed in human evacuation situations; instead, people tended to follow minorities [2]. Furthermore, the researchers in [2] mentioned that the symmetry-breaking phenomenon observed in different species, such as ants and mice, should not be generalized to human evacuation.

Real-life disaster data are hard to obtain; as a result, researchers rely on data obtained through surveys and laboratory experiments, albeit with limitations such as survivorship bias and the impractical experimental settings. Objective data that allow quantitative analysis possible are valuable even if they are somewhat inprecise. Recent studies have utilized video clips of real-life evacuations to overcome these limitations [1, 3]. [3] conducted a video clip analysis of students' evacuation behaviors during the Tangshan earthquake of 28 May 2012. In this video, there were 35 students in the classroom when the earthquake started and they all used two exits: 12 students chose the front exit (Exit 1) and 23 chose the back exit (Exit 2). These output choices appear to be asymmetrical, suggesting positive evidence of symmetry breaking. The study also shows students' positions in the classroom and exit choices (Figure 1) as well as each student's evacuation time (Figure 2).

In the current study, we attempted to reproduce the evacuation behaviors of the students considered in [3] through multi-agent simulation using the evacuation decision model [1] that represents the herd behavior of evacuees during evacuation. In this model, an agent can only perform two actions: random selection of exits and herd behavior.

First, we analyze whether the data are suitable for representing a symmetry-breaking phenomenon. Initially, we conducted the Bernoulli trial assuming that each student (agent) chooses exits randomly, and we let the number of students choosing Exit 1 be a random variable following a binominal distribution $X \sim B(n = 35, p = 0.5)$. The probability that 12 or fewer students choose Exit 1 is $F(12) = P(X \leq 12) = 0.045$. We also assume that an agent may choose an exit depending on a probability based on distances, e.g. if the distances to Exit 1 and Exit 2 are 1 and 3 m, respectively, the agent will choose Exit 1 with $p = 0.75$ and Exit 2 with $p = 0.25$. The result of 100,000 Monte Carlo simulations yields $F(12) = P(X \leq 12) = 0.060$. Given these results, it is reasonable to conclude that the students' choices regarding exits in the video are not random events.

Figure 3 shows the initial simulation setup. Light grey areas indicate walls and desks that restrict the agents' movements where there are 35 agents positioned like in the video clip. Figure 4 shows the temporal dynamics of the number of agents through Exits 1 and 2 in 100 simulations; the former is shown in blue, and the latter in red with standard deviations represented by colored regions. The means for Exit 1 and 2 calculated using the simulation are 13.7 and 21.1, respectively, while the calculated using the video data are 12 and 23.

Figure 5 shows the evacuation results regarding the video on the left and the simulations on the right, respectively. We assigned values of 1 to the students who chose Exit 1 and 2 to the students who chose Exit 2; the right figure also shows the means of these values in 100 simulations. The simulation results indicate that the agents in the first two rows tend to choose Exit 1, and those in the last four rows tend to choose Exit 2. The agents in the third row chose these two exits randomly, suggesting that these results reproduced the students' exit choices reasonably well.

Figure 6 shows the evacuation time, the elapsed time between the start of an evacuation and the instant when the agent arrives at one of the exits. The left figure shows the evacuation times of each student in the video, and the right figure shows the mean evacuation times of each agent in the simulations. The longest evacuation time in the video is 8.5, and the shortest is 0.9; the simulation times in the right figure were adjusted between these two values. Longer evacuation times are shown in purple and shorter in green. These figures also show the broad similarity of the results with the video, although there are some differences, i.e., students in the front of the second column have a longer evacuation time; in contrast, agents in the middle of the second column have a longer evacuation time.

These results revealed that our simulations reproduced not only the number of evacuees choosing each exit, but also the positions of choosing each exit and the evacuation times of these evacuees. Interestingly, none of the agents were found to have a concept of distance; none of them knew which exit was closer, suggesting that random choice and herd behavior are sufficient to reproduce symmetry-breaking. This could be because of the initial setting, where all the evacuees had to face forward (top of the figures). Under this setting, because the evacuee at the front can be seen by those behind him/her, his/her decision-making influences the decision-making of those behind him/her; whereas, an evacuee at the back can only influence a few standing near him/her. If an agent at the front chooses Exit 1, the time spent by that agent affecting others is short because the distance to Exit 1 is short. Conversely, if the evacuee chooses Exit 2, the time spent is long because the distance to Exit 2 is long. As a result, the number of agents following the agents who chose Exit 2 increases.

We have studied evacuation behavior during the Tangshan earthquake, found positive evidence of symmetry-breaking, and shown that herd behavior can reproduce this phenomenon. One limitation of our study is that only the data from [3][1] was used. Further quantitative studies on this topic will be desirable.

References

[1] A. Tsurushima, "Reproducing evacuation behaviors of evacuees during the Great East Japan Earthquake using the evacuation decision model with realistic settings," in *Proceedings of the 13th International Conference on Agents and Artificial Intelligence - Volume 1: ICAART,*, pp. 17–27, INSTICC, SciTePress, 2021.

[2] M. Haghani and M. Sarvi, "'Herding' in direction choice-making during collective escape of crowds: How likely is it and what moderates it?," *Safety Science*, vol. 115, pp. 362 – 375, 2019.

[3] J. Zhou, S. Li, G. Nie, X. Fan, J. Tan, H. Li, and X. Pang, "Developing a database for pedestrians' eqrthquake emergency evacuation in indoor scenarios," *PLoS ONE*, vol. 13, no. 6, 2018.

[1] In this study, we used the data from Figs. 17 and 18 in [3] because these are the most specific and detailed, whereas the authors only included 30 students in their analysis. They also provide a supplementary file at `https://doi.org/10.7910/DVN/YGATYB`, but this data only covers one student from the Tangshan earthquake case.

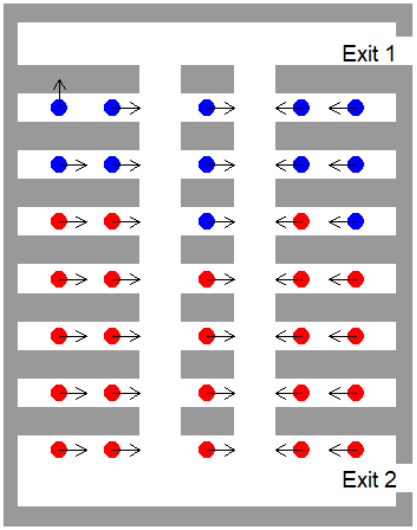

Figure 1: Fig. 17 in [3]. Blue circles indicate the students who selected Exit 1; red circles, Exit 2. Arrows indicate directions of evacuation.

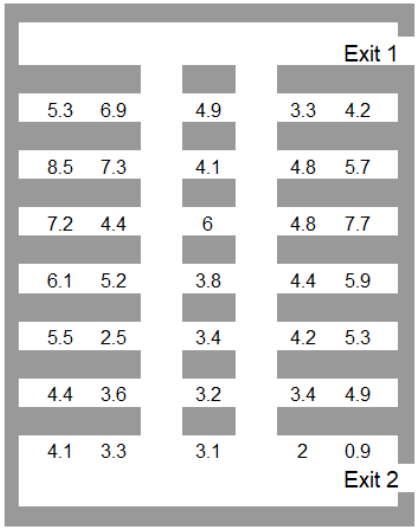

Figure 2: Fig. 18 in [3]. Numbers indicate the evacuation time of each student. Light grey regions indicate walls and desks.

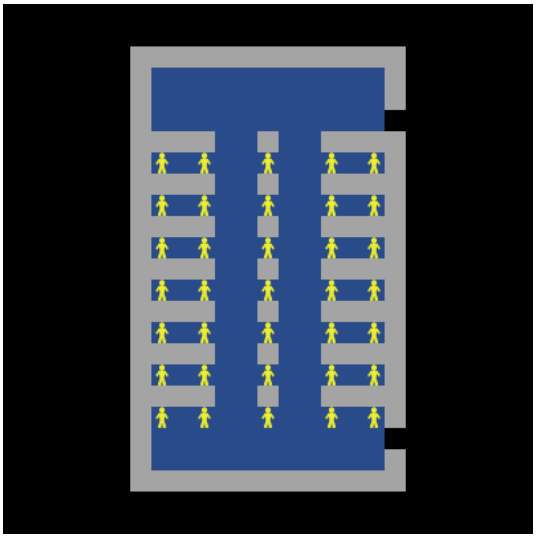

Figure 3: Initial setup of the simulation.

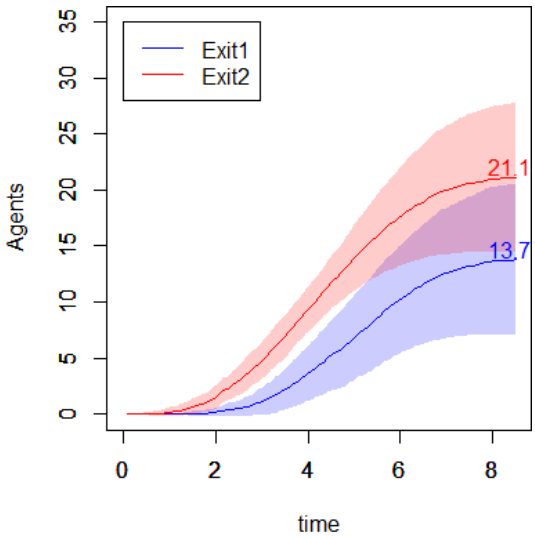

Figure 4: Temporal dynamics of the simulation.

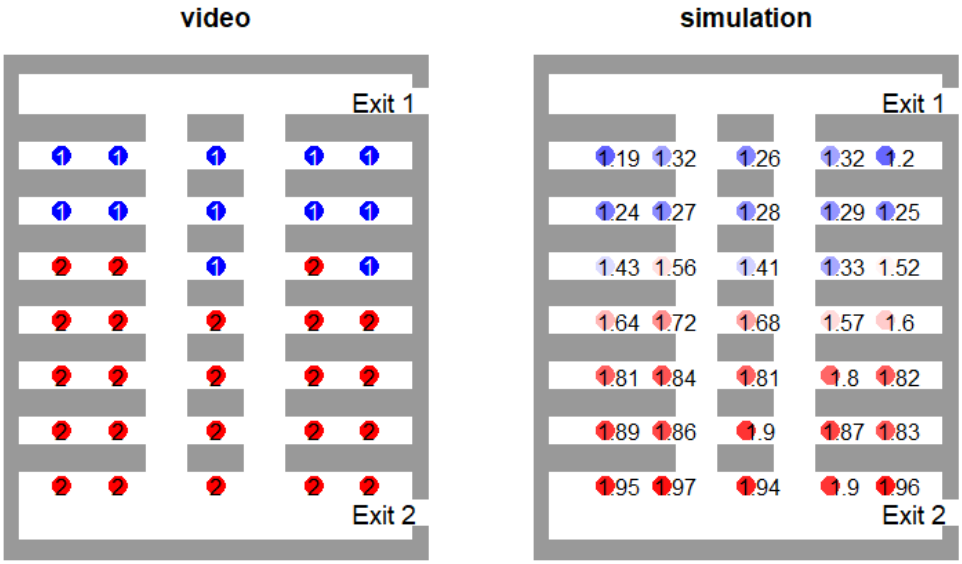

Figure 5: Positions of evacuees concerning their selected exits and evacuation results regarding the video on the left and the simulations on the right.

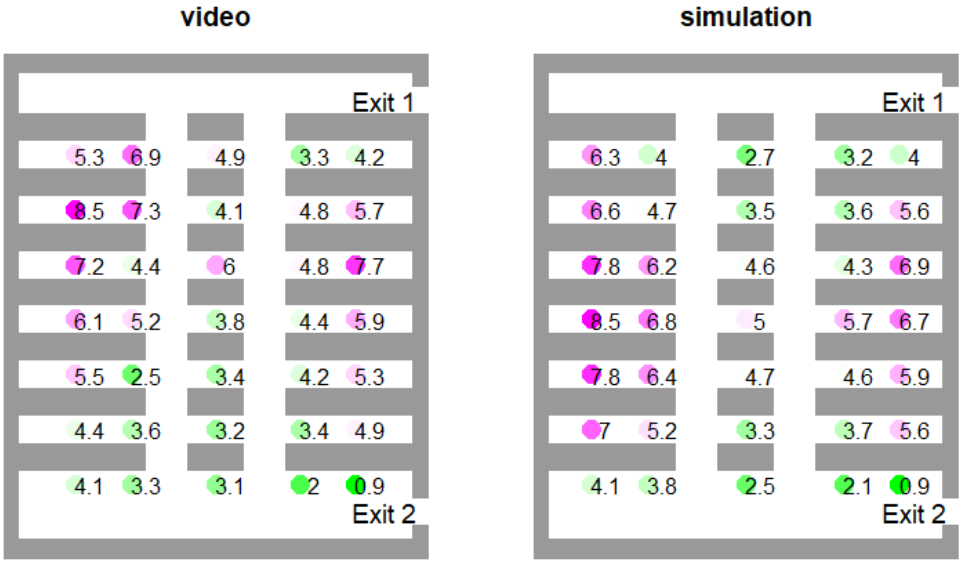

Figure 6: Positions of agents and respective evacuation times.